# THE KUWAIT OIL FIRES:

# AIR QUALITY DATA AND REPORTS

THE GULF PROGRAM OFFICE - N.O.A.A.
U.S. DEPARTMENT OF COMMERCE
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# The Kuwait Oil Fires:
# Air Quality Data and Reports


Gulf Program Office
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# FOREWORD

The reports in this collection are a cross section of the international research effort on the atmospheric effects of the Kuwait oil fires. All of the research has been undertaken since February 1991, when over 600 oil wells in Kuwait were ignited by Iraqi forces. Although some of the selections are final reports by government agencies, others are still in draft form. Many of the selections are sets of unpublished statistical tables that summarize the results of laboratory analysis of smoke plume and ambient air samples. Articles already published in the scientific literature are not included.

The Gulf Program Office of the National Oceanic and Atmospheric Administration (NOAA) has helped coordinate the US research effort on atmospheric aspects of the oil fires in Kuwait. This collection is an extension of that effort, and is in keeping with NOAA's commitment to ensuring that all data are shared with all concerned parties. The Office thanks all those who have forwarded copies of their reports and unpublished data for inclusion in this collection.

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23. "Overview of the EPA/NASA In Plume and Ground Level Measurements Made in Kuwait July 28 to August 8, 1991," Robert K. Stevens and Joseph P. Pinto, Environmental Protection Agency (EPA), Research Triangle Park, North Carolina, 10 September 1991.

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## SOURCES OF INFORMATION

W. Sources

# WORLD METEOROLOGICAL ORGANIZATION

REPORT OF THE

WMO MEETING OF EXPERTS ON THE ATMOSPHERIC PART OF THE

JOINT U.N. RESPONSE TO THE KUWAIT OILFIELD FIRES

Geneva, 27-30 April 1991

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# EXECUTIVE SUMMARY

The world is facing a unique, man-caused environmental pollution on an order never before experienced. The 500 or more burning oil wells in the Kuwaiti oilfields and the oil released on land and in the Gulf represent unprecedented threat to the environment and possible severe short- as well as long-term damage to the health and ambient conditions of humans and animals. The oil release began in January 1991 and the oilfield fires began in late February. It is estimated that extinguishing the oilfield fires will take about two years and that the effects of the oil spills will last a similarly long time.

This report represents the views of a group of experts, originating from 14 countries, brought together by the World Meteorological Organization, on how to access the effects and coordinate an international response for the atmospheric part of the joint U.N. response to the Kuwait oilfield fires, as a component of the joint U.N. Inter-Agency Action Plan (March 1991). A list of participating organizations and contact persons is summarized in Appendix I. The WMO Meeting of Experts report addresses:

(a) the need for augmenting surface, upper-air including aircraft, and satellite monitoring of meteorological and air quality variables (especially of trace gases and particles);

(b) the data and information flow, both operational and special, from real-time, delayed, and research sources;

(c) relevant meteorological and air pollution numerical models for local, regional, and global predictions.

The atmospheric part of the response to the Kuwait oilfield fires is based largely on existing structures of the WMO including the World Weather Watch and the Global Atmosphere Watch. The World Weather Watch, which includes meteorological surface, upper-air and satellite data and a global network for exchange of data and information, will need augmentation especially near the source and where observing stations are not functioning. The Global Atmosphere Watch, which is a system for measuring the chemical composition and physical characteristics of the atmosphere, must be enhanced in the region of the fires and fully activated and augmented in downwind areas. The improvements to the WWW and the GAW can be assisted by dedicated contributions by interested Members.

Health problems could result from gases such as sulfur dioxide, sulfuric acid, hydrogen sulfides, carbon monoxide, nitrogen oxides; from suspended particles containing partially burned hydrocarbons and metals; and from carcinogens such as benzo-a-pyrene. The extent and severity of potential health impacts are the concerns of the World Health Organization which has its own special needs for air quality data specifically related to population areas. The WHO air quality measurements will be coordinated with the WMO monitoring activity.

As for the effects of the fires thus far, the local atmospheric radiation balance has been disturbed, but no global effect has been detected. Although, at present, the effect of the fires on the southwest monsoon is unknown, the actual difference is expected to be difficult to distinguish from natural fluctuations. Global precipitation patterns are not expected to be impacted by the fires, but regionally, incidences of precipitation containing pollutants, including oil and soot scavenged from the fire plume, and highly acidic rain have occurred. Near the source, the lower level winds vary throughout the year (most recently coming from the north), but the upper winds which effect global distribution of the plume are generally from the west throughout the year. Increased concentrations of soot particles are being detected in Global Atmosphere Watch monitoring sites as far away as Mauna Loa observatory.

Several numerical models have produced predictions of the location and concentration of various pollutants from the fires on local, regional and global scales. Nevertheless, without proper data on source characteristics and the meteorological environment, and without data to evaluate the model predictions, it is not possible to select any specific model or set of models suitable to provide routine predictions or accurate long-term assessments. Modellers made known their data needs for monitoring and were encouraged to continue their modelling activities until such time as comparisons are possible to determine which models are more appropriate for operational purposes. Modellers were asked to continue their work including development and improvement of models specifically to address the fires problem. WMO was asked to assist with arranging for timely transmission of model results to the region as soon as proper communications can be established.

The U.K. presented the preliminary results from their recent aircraft flights in the region. The U.S.S.R. also presented aircraft data collected 2-3000 km downwind. Germany, the U.S.A., and the U.S.S.R. presented plans for aircraft monitoring flights in the region. Other countries (e.g. Canada) have aircraft programmes under consideration. The meeting identified the most important aircraft data requirements and urged WMO to co-ordinate among the measurement flights in order to establish a sequence of monitoring flights covering the next several months, with some overlap for intercomparison purposes. The WMO also was asked to assist with logistical support for the aircraft programmes including developing focal points and in-country contacts, and also to assist with data and information flow.

A number of governments and groups of scientists are ready to assist in carrying out additional measurements programmes and to help develop forecasting capabilities. However, no individual group or country is in a position to plan, organize and coordinate such actions. The meeting strongly recommended that, as part of the international efforts, the WMO establish a coordination office for atmospheric monitoring and modelling in Geneva as soon as possible and consider the need to have WMO experts join the U.N. Interagency Coordination Office in Kuwait City which opened on 26 April 1991. There, an operational data and a modelling center to support the atmospheric and environment efforts contributing also to health-related studies, could be included. Since WMO activities will require funding, which is not provided in the regular budget, countries were encouraged to contribute directly to a WMO Trust Fund for these purposes. Depending on the availability of funding, the WMO was asked to establish an operational data and modelling centre to support the atmospheric and environment efforts which would contribute also to health-related studies.

The most immediate needs for atmospheric monitoring include the re-establishment of Kuwait's surface and upper-air meteorological stations; the placement of mobile air monitoring stations, especially air chemistry measurements, at locations near the source and in population centres; enhancement of downwind meteorological and air chemistry observations including special observations important for modelling, such as carbon soot, atmospheric transparency, and components of the radiation balance. Of special importance is the continuation of monitoring activities along with the expected changes in the meteorological regimes and of the characteristics of the source.

WMO was asked to convene several task groups and expert meetings over the next few months (i) to consider further implementation of monitoring (immediate area, regional, global), (ii) to examine modelling efforts, thus far, and related data needs, (iii) to compare aircraft data and coordinate further programmes, if needed, and (iv) to evaluate overall results and recommend further actions.

The meeting noted both the Gulf Regional Air Monitoring Programme that was presented by experts from Saudi Arabia and the Work Plan for the Rehabilitation of an Environmental Monitoring Programme for Kuwait that was made available to the meeting by the Secretary-General of WMO by the courtesy of the Environmental Protection Council of Kuwait. These two plans, which have many common elements, will serve as basis for WMO coordination activities in the immediate area of the fires while the programme in the downwind region is being developed.

1. OPENING OF MEETING, ELECTION OF CHAIRMEN AND APPROVAL OF THE AGENDA

1.1 The meeting was opened on Saturday, 27 April 1991 at 09:30 a.m. by the Secretary-General of the World Meteorological Organization, Professor G.O.P. Obasi, who welcomed the participants and thanked them for responding upon such short notice (for list of participants see Appendix II). He expressed WMO's appreciation to the Governments who made possible the attendance of their experts, noting the concern felt by governments and scientists over the serious environmental problems confronting the Gulf region.

1.2 Professor Obasi stated that, within the U.N. system, the WMO is charged with the responsibilities for providing the authoritative scientific information and advice on the condition and behaviour of the global atmosphere and the climate, and the factors affecting them. Accordingly, WMO has convened this meeting with the aim of developing a project to monitor and assess the atmospheric pollution resulting from the Gulf fires. This action is carried out in the context of the joint U.N. Inter-Agency Action Plan for response to the consequences of the fires.

1.3 Professor Obasi emphasized that the main task of this meeting is to consider and make proposals for, the rehabilitation and enhancement of the monitoring systems in the region, for modelling and assessing, both on the short- and long-term basis, the severity of the pollution within and downwind from the region. He asked the meeting to recommend establishing predictive capabilities on a semi-operational basis for estimating the adverse effects of the fires in the Gulf region and other parts of the globe. In conclusion, Professor Obasi said that WMO stands ready to provide the forum to coordinate this effort.

1.4 The meeting unanimously elected Dr. F.B. Smith (U.K.) and Mr. B.B. Hicks (U.S.A.)as co-chairmen. The provisional agenda (Appendix III) was adopted with the understanding that it could be amended as necessary during the meeting.

2. INTRODUCTION TO THE PROBLEM

2.1 International Involvement

2.1.1 Dr. R. Bojkov, Chief of the Environment Division in the WMO Research and Development Programme Department informed the meeting that apart from its operational system - the World Weather Watch (WWW) - which provides for real-time, world-wide monitoring of standardized meteorological parameters and data communication, the WMO has also the Global Atmosphere Watch (GAW) system which is a potential source of continuous information on the chemical composition and physical characteristics of the atmosphere necessary for detecting changes in the atmosphere. He then explained that the UN Inter-Agency Action Plan on the Kuwait oil fires has identified four main areas of concern and that WMO was the lead agency to develop the atmospheric component. WMO is willing to assist coordination for its implementation which will include:

- air and precipitation sampling in the immediate vicinity of the fires and in downwind regions up to 3-5000 km;
- rehabilitation and enhancement of the meteorological networks of the WWW and GAW, including provision of equipment and training;
- establishment of near real time data collection necessary for modelling of air pollution dispersion and deposition;
- scientific assessments of the atmospheric effect of pollution updated periodically to serve as advice to decision makers.

2.1.2 Dr. Bojkov further informed the meeting that although there are a number of GAW stations in the Red Sea region and further downwind in Pakistan, India, the southern U.S.S.R. and western China reporting ozone data, only incidentally precipitation chemistry or atmospheric turbidity is reported. Therefore, there is an urgent need to reactivate, augment and extend GAW stations in the affected region in order to monitor anomalous tropospheric chemistry and physical characteristics. The cooperation with potentially affected countries and timely contributions by interested Members would be essential.

2.1.3 Finally, Dr. Bojkov asked the experts to identify ways to provide answers to the following questions:

- What is the composition and amount of gaseous and particles by-products being produced from the burning oil wells?
- What is the magnitude of the exposure to toxic substances in the Gulf region in relation to human health risks?
- What are the expected effects in areas more remote from the source as regards additional air pollution and deposition?
- Are there any global effects to be expected and what would be the magnitude and duration?

2.1.4 Mr. S. Mildner, Director of Basic Systems in the WMO World Weather Watch Department provided an overview of the existing WWW operational structures in the Middle East. The WWW has about 180 surface observing stations and about 40 upper air stations in the countries concerned (See Figure 1). Recent monitoring at WMO shows that the data regularly available from these stations for international exchange varies between 0% and 90%. Meteorological satellites, both geostationary (METEOSAT 4 and 5) and polar-orbiting (NOAA 10 and 11), are providing regular coverage . He noted that Jeddah (Saudi Arabia) has the role of the Regional Telecommunications Hub (RTH) and maintains high capacity links to various major meteorological centres. It also functions as a Regional Specialized Meteorological Centre (RSMC) providing analysis and forecast products on a regular basis. The Jeddah RSMC might also be used for establishing a specialized environmental data base and the exchange of relevant products for the Kuwaiti oilfield fires emergency. He also noted that the WWW offers the infrastructure needed for the successful implementation of data flow for the emergency response to this environmental disaster.

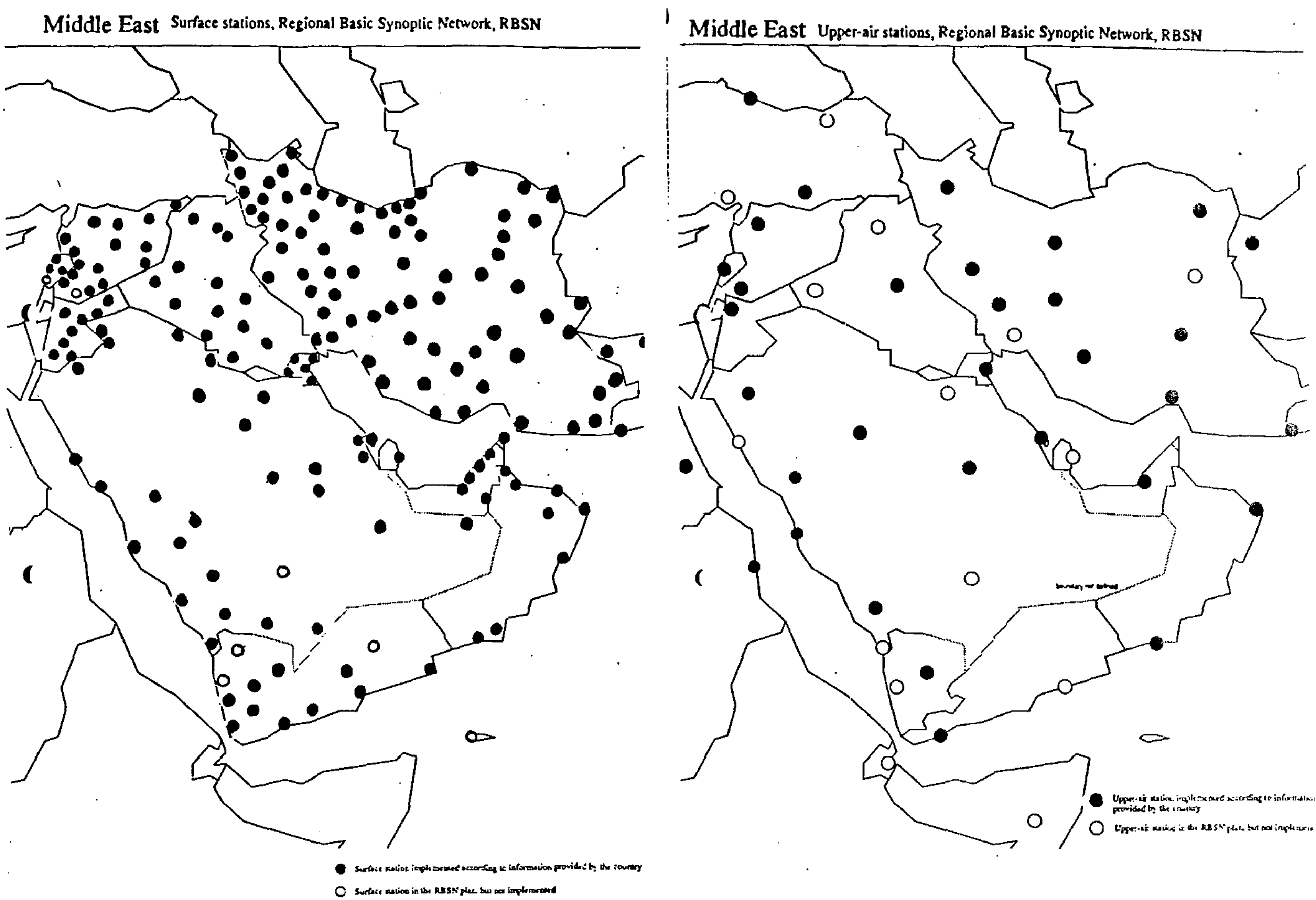



Fig. 1. Locations of surface (left) and upper air (right) stations in the Regional Basic Synoptic Network of the WMO World Weather Watch.

2.1.5 Mr. G. Ozolins from the World Health Organization discussed the activities and plans of WHO with respect to air quality monitoring needed for responding to the health needs of Kuwait. A WHO air quality specialist, Dr. D. Mage, was recently in Kuwait, assisting the Kuwaiti Ministry of Public Health and the Environment Protection Council in preparing a Workplan for the Rehabilitation of an Environmental Monitoring Programme for Kuwait. The Secretary General of the Environment Protection Council (Kuwait) sent the Workplan by telefax to the Secretary-General of WMO and this was made available to the meeting (see Appendix IV).

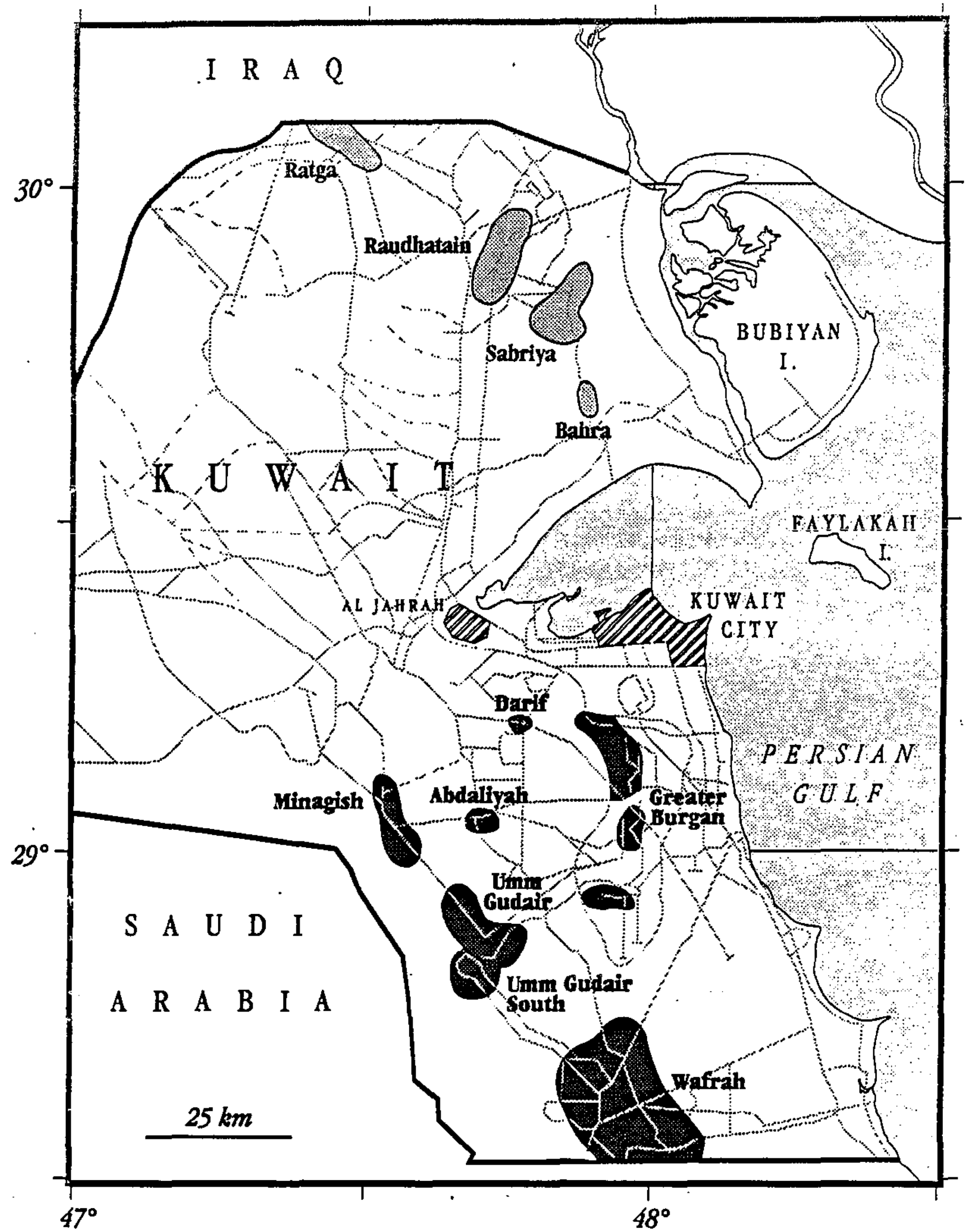
2.1.6 The representative from the Commission of the European Communities (CEC), Dr. A. Ghazi, informed the meeting that CEC has already allocated several million ECUs as funds dealing with different aspects of pollution in the Gulf. He pledged close cooperation between the CEC programme and the WMO and WHO efforts.

2.1.7 Dr. C.C. Wallen, representing the United Nations Environment Programme, announced that UNEP had been instrumental in establishing the U.N. Interagency Office in Kuwait City which was opened on 26 April 1991.

2.1.8 The Saudi Arabia Monitoring Action Plan covering the Gulf regional air monitoring programme (Appendix V) was presented by experts from Saudi Arabia. The programme was developed in consultation with other countries and represents the basis for work currently underway in part of the affected region.

2.1.9 Dr. R. Sartorius, the representative of the German Federal Environmental Agency informed the meeting that an action was prepared to send a mobile container for monitoring air pollutants to Kuwait City. The Federal Government is ready to integrate this project into the internationally coordinated action by WMO as a contribution of Germany. Any suggestions and proposals are welcome and will be thoroughly considered. The German Government has been informed that there is an urgent demand by the Kuwaiti authorities to have these measurement devices available as soon as possible. Providing that this meeting supports this initiative and that the WMO as the international organization involved agrees, Germany would expedite shipment in the beginning of May. Another project having a more bilateral character, consists of an airplane measuring programme to investigate the extension, behaviour and chemical composition of the (visible and invisible) plume of the burning oil wells. Coordination with other airplane measurements would be very useful in order to achieve mutual supplementation and comparability of results. Furthermore, groundbased mobile measurements are planned in Iran.

2.1.10 The Kuwaiti representative, Mr. M. Behbehani, said that the situation in Kuwait at the present time is desperate and remedial action is urgent. He noted that the international aspects to the problem and the need for international cooperation to address it. Mr. Behbehani pledged the cooperation of the Government of Kuwait to a coordinated monitoring and modelling effort which would benefit both local and regional population.




## *Oilfields of Kuwait*

*Oilfield*

*Oilfield with $H_2S$ gas production*

Fig. 2.

## 2.2 Local Effects: The Human Health Concern

2.2.1 The focus of this meeting was on the meteorological factors that influence the fires and the plume from them, not on the health effects or their causes. Nevertheless, considerable time was spent on discussion of matters related to exposure and human health, largely to help the audience of meteorologists gain an improved understanding of the severe problems presently confronting the Kuwaiti population. Other meetings and other organizations are addressing the health impact issue more directly.

2.2.2 The meeting was informed that about 500 oil wells are currently burning in Kuwait, consuming approximately three to five million barrels of crude oil and 70 million cubic meters of associated gases daily. The fires originate in seven oilfields, located both north and south of Kuwait City (see Figure 2). Based on measurements to date and the known composition of Kuwaiti crude oil, emissions from the burning wells will include airborne particles, carbon dioxide, sulfur dioxide formed from the combustion of hydrogen sulfide, and oxides of nitrogen, as well as considerable quantities of water vapour. Incomplete combustion products include hydrogen sulfide, carbon monoxide, polycyclic aromatic hydrocarbons (PAHs) and other volatile organic hydrocarbons, and heavy metals. Other secondary pollutants will include ozone and acidic aerosols, such as sulfuric acid.

2.2.3 The urgent question faced by the countries in the Gulf region, and in particular by Kuwait, is the extent and severity of potential health impacts on their populations. Informed answers must be obtained so that the affected countries can act to protect their populations and plan for future health needs. A concerted, coordinated effort on the part of experts in (i) air monitoring (ii) local, regional, and global scale modelling (iii) atmospheric chemistry and (iv) health and risk assessment will be necessary.

2.2.4 Emissions from the oilfield fires have the potential of causing both acute and chronic health effects, although there is considerable uncertainty as to the magnitude of the risk. Prolonged exposure to lower concentration levels of soot and chemical components of the plume may decrease lung function, and increase the incidence of chronic bronchitis and lung cancer. Special health concern is focused on individuals working close to the fires, pregnant women, children, the elderly, and those with pre-existing respiratory and cardiac diseases.

2.2.5 A U.S.A. Inter-Agency scientific team obtained some limited real-time data in Kuwait and in Saudi Arabia on the smoke emissions. The sampling did not reveal the existence of high concentrations at ground level of sulfur dioxide or hydrogen sulfide close to the burning wells. Also, no large-scale acute human health impacts have yet been observed although reports of respiratory difficulties among local population are increasingly frequent. It was stressed that the report of the findings, however, were only preliminary and that considerable follow-up will be necessary to evaluate definitely the nature and magnitude of the human health, ecological, and atmospheric effects of the smoke problem.

2.2.6 The pollutants of primary concern to people are likely to be particles and sulfur dioxide. According to the U.S.A. preliminary measurements, hydrogen sulfide concentrations have been found to be very low, thus far, as were PAHs attached to particles, and volatile organic compounds. Not surprisingly, a wide variability of the measurements was noted according to distance from the source and wind direction. The extremes of the Total Suspended Particulates (TSP) measurements range from a low of 10 $\mu g/m^3$ at the U.S.A. Embassy in Kuwait City on a day when the wind was out of the north, to a high of 5400 $\mu g/m^3$ within a plume in the Al Maqwa oilfield. It should be emphasized that the space and time sampling of the measurements is insufficient and their results should be viewed and interpreted with great caution.

2.2.7 Physicians in Kuwait feel that they are observing exacerbation of asthma and non-reversible chronic obstructive lung disease. Furthermore, they perceive an increase in complaints of upper airway irritation and eye irritation sometimes associated with conjunctivitis (inflammation of the eye). All of these phemonena appear to be treatable by standard medical practice.

## 2.3 Regional-scale Effects

2.3.1 The local meteorological conditions over the past two months have tended to transport the smoke plume in the atmospheric boundary layer toward the southeast, with periodic excursions toward the northeast. At altitudes above 600 m, the pollutants were transported mainly eastward. In the region, March through July are relatively windy months; there are on average 30 days of very strong winds from the northwest in this period. Frequent sandstorms are expected to rapidly ventilate the smoke in the immediate surroundings of the fires and to spread the pollutants further downwind. As summer advances, solar-induced convective mixing will increase the maximum height of the plume into the upper half of the troposphere, perhaps to above 7 km which is not yet experienced. It is in these situations that the stage will be set for extensive long-distance transport of the plume in the middle and possibly upper troposphere, with associated long-range effects. In August to October, the incidence of strong winds should drop sharply, and local conditions may worsen.

2.3.2 Upper-level winds tend to be more consistently from the southwest and west causing a marked vertical wind shear which has had, as seen from satellite photos, and will continue to have a profound effect on plume behaviour.

## 2.4 Global Effects

2.4.1 The experts felt that, although "self-lofting" may occur (due to the heating of the particles in the plume by solar radiation), the top of the plume should not often rise above 5 km. Large convective cells in the summer could easily transport material into the upper half of the troposphere. However, this would rarely happen. It was felt that there is little fear of a stratospheric injection of plume pollutants, as would be required for severe global environmental effects.

2.4.2 In the troposphere, the pollutants should have a residence time from ten to perhaps as many as 20 days (depending on the prevailing meteorology). This is enough time for the pollutants to be distributed widely over the Northern Hemisphere. Thus, the pollutants are expected to be detected at great distances, although their effects on the temperature or precipitation distribution will likely be small and difficult to distinguish from natural variability.

2.4.3 While the above arguments rule out major effects on the global radiation balance, reduced surface temperatures by low degrees C under the plume have indeed been observed at localities near the fires themselves.

2.4.4 The reported "black rain" or "black snow," precipitation falling from clouds affected by the plume, are due to pollutants scavenged from the plume, including oil and soot. It remains to be seen how frequently such events will occur and, therefore, there is a necessity for a rapid expansion of of Global Atmosphere Watch measurements of carbon soot content precipitation chemistry, $SO_2$ and surface ozone from the area of the Red Sea through the Gulf, downwind (eastward) as far as Iran, Pakistan, northern India, Afghanistan, the U.S.S.R. and western China.

2.4.5 It is projected that soot deposition over the snow covered mountains of the Himalayas and northward may cause some faster melting in the spring season (March-May). The projected slight increase in the temperature contrast with the Indian Ocean might somewhat intensify the monsoon rain (as in an anomalous year); however, the natural variability is so large that the detection of a significant change would be difficult.

## 3. THE SOURCE

### 3.1 Meteorology

3.1.1 Near-source exposure regimes will be dominated by local meteorological factors, such as the presence of a land-sea breeze circulation and the strength of any drainage flow from higher elevations inland. In addition, the local wind velocity will be affected considerably by the presence of the fires themselves. Forecasts of periods of high concentration must take such factors into account. Figure 3 defines the generic source term in the broader context of local, regional and global meteorological perspectives and the need for local warning/alerting and forecasting systems.

3.1.2 The area is generally arid with rainfall varying from 50-500 mm/year (Kuwait has about 115 mm/year). Most of this rain falls from November to May, with the summer months being particularly dry. Somewhat further afield, and especially over much of the Indian sub-continent, the annual rainfall is dominated by the summer monsoons. The shift in rainfall pattern will be reflected in shifts in the deposition pattern of the fire-plume's constituents.

3.2 Output

3.2.1 Current estimates of the amount of oil burning vary from 3 to 5 Mbl/day. Combustion product formation is highly dependent on fuel characteristics which vary across the Kuwaiti oilfields, fire size, and fire dynamics. In particular, soot is often in the form of complex agglomerates. The products will include a spectrum of particles sizes and types, sulfur dioxide, carbon monoxide, carbon dioxide, polycyclic aromatic hydrocarbons (PAHs), volatile hydrocarbons and heavy metals including vanadium. Hydrogen sulfide will also be present, but will be rapidly oxidized to sulfur dioxide if the plume is burning.

3.3 Combustion Products

3.3.1 Preliminary results in the near-field have shown peak concentrations as follows (see also Appendix VI):

| | | |
|---|---|---|
| $SO_2$ | : | 2 ppm (instrument detection limit of 1 ppm) |
| $H_2S$ | : | 42 ppb (close to a pool of oil) |
| VOC | : | 2.5 ppm |
| Particulates | : | 5.4 $mg/m^3$ (during plume touchdown in the Al Maqwa oilfield) |

Long-term averages of $SO_2$ and particulate matter - "fumées noires" (FN) were measured by the mobile air monitoring laboratory of AIRPARIF, Paris, France. $SO_2$ was recorded at 500 $\mu g/m^3$ for 8- and 12-hour measuring periods with peaks ranging up to 2900 $\mu g/m^3$. FN reached 700 $\mu g/m^3$ for a 6-hour average and the maximum hourly average was 1600 $\mu g/m^3$. The Kuwait Oil Company also measured an 18-hour average of 5000 $\mu g/m^3$ of $SO_2$ at Ahmadi Hospital (See Appendix IV, Section 2.2).

While somewhat further away in Saudi Arabia, high levels observed were 600 $\mu g/m^3$ for $SO_2$ and 300 $\mu g/m^3$ for TSP.

3.3.2 P. Foster (France) carried out various simulations of oil burning for different $O_2$/oil ratios to simulate incomplete burning. Previous analyses of the exhaust gases where done for CO, $CO_2$, NO, $NO_x$, $SO_2$ and PAH. Interactions with aerosols can be studied using a special smog chamber.

3.4 Particle Size Distribution

3.4.1 Particulate aerosols resulting from oil fires, in addition to gases, pose a health problem to exposed populations. Particles with small aerodynamic sizes (on the order of one micron) penetrate deeper into the human respiratory system than do larger particles. Combustion processes can produce a large number of small particles and thus the size distribution of airborne particles in addition to the total suspended mass, must be characterized to determine the level of health threat. Chemical reactions, particles scavenging, agglomeration, and deposition are a function of the particles size distribution.

3.4.2 Soot particles formed from the source have irregular shapes and their size distribution depends upon the oil fuel composition and resulting temperature of combustion. In order to determine the evaluation and fate of the resulting pollution, size and composition distribution of the aerosols at the source and along the plume paths must be measured and modelled.

3.4.3 There are a large number of scientific particles measurement capabilities which can determine the quantity of Total Suspended Particles (TSP), Particle Mass below 10 microns ($PM_{10}$) and the quantity of the varying chemical composition and mass accross the spectrum of particle sizes (using a so-called diffusion battery). Such measurements, when compared with upstream values, are invaluable for analysis and modelling of source processes and plume evolution.

3.5 Heat Output

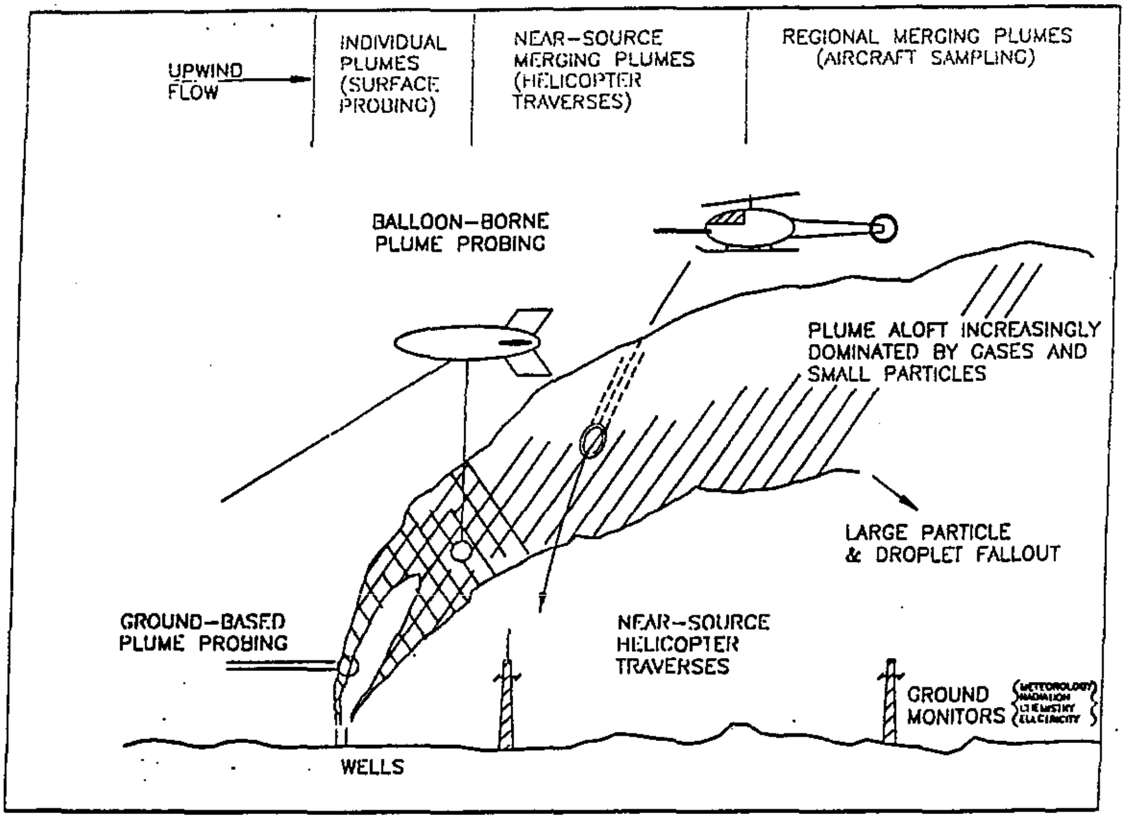
3.5.1 As the emitted oil burns, heat is released into the environment. The resulting heat is responsible for the initial buoyancy driven plume rise although additional rise or fall may occur due to the absorption of solar radiation (self-lofting), and the effect of fire-induced wind circulations. Super or aggregate plumes result from the contributions of many smaller fires. While combustion temperatures can be modelled from fuel composition and mixing approximations, these models are not accurate enough and uncertainty surrounds such calculations. Combustion, temperature and plume rise measurements can be made by remote and in situ techniques.

3.6 Near-source Monitoring

3.6.1 Figure 3 defines a framework for source term measurements from individual well fires and total oilfield including the gaseous and particulate emissions into individual plumes which subsequently merge into the super plumes.

3.6.2 The near-source measurements needed for establishing credible assessments, models, or forecasts include the following:

- collection of background air samples for particle and gas analysis, both at ground level and at plume levels,
- characterization of the Kuwait crude oil in terms of its chemical composition and its product when burned in the conditions of the fires,
- characterization of soot - both organic and black carbon - from an appropriate range of combustion conditions, including geometrical and optical properties, and
- a survey of burning wells in which each well is classified by the character of its fire (to be updated periodically as the fires are extinguished).



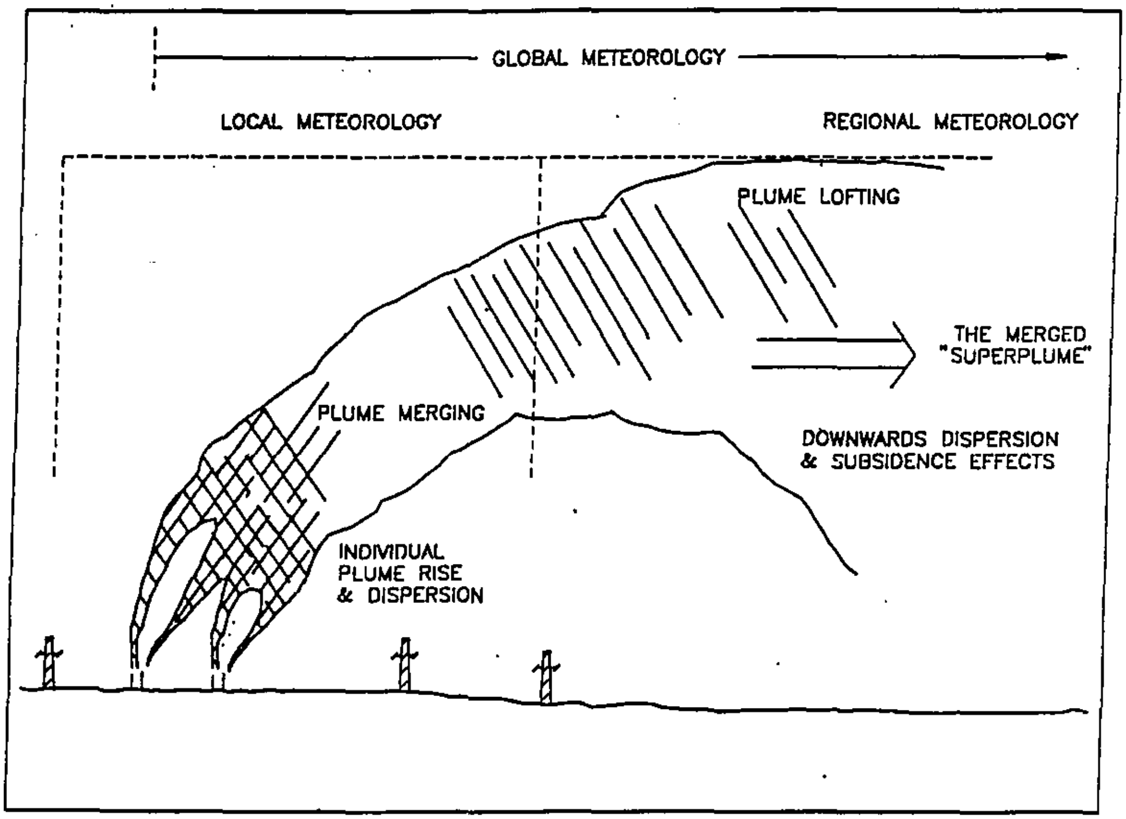




**Fig. 3.** (top) A sampling of the various levels of experimental activity, necessary to provide data to test components of models; (bottom) A schematic representation showing the different scales associated with the individual plumes from separate well-fires.

These data then can be used to:

- estimate fuel flows,
- estimate heat release rates of individual burning wells and of total oilfields,
- estimate detailed well smoke, gaseous and particulate emissions,
- coordinate emission estimates resulting from the above source analyses and from measurements within the super plumes, using aircraft and surface-based instrumentation,
- develop local induced flow field models in combination with ground data for local warning system forecasts, and
- develop super plume effective source prediction model to provide input to regional and global models.

3.6.3 Near the source, the effect on population centres and sensitive ecosystems on land and in the Gulf waters will be influenced by local meteorological conditions -- the presence of strong vertical mixing, subsidence due to local effects (for example the presence of a closed circulation due to land-sea differences) or subsidence due to large-scale synoptic conditions. None of these conditions can be accurately forecast without extensive information on local wind fields, primarily in the region between the sources and the impact areas of concern. Such wind field information can be provided by an array of meteorological instruments and by a numerical model that is designed to account for the local surface variability and is verified against data.

# 4 REVIEW OF PRESENT MONITORING AND ESTIMATED EFFECTS OF THE FIRES

## 4.1 Structure of the Plume

4.1.1 Where they exist, data on the composition of the source oil taken prior to the fires need to be made available to the modellers. Other data on flows rates, heat, smoke, gas or particulate emissions are not available. Consequently modellers have based their calculations on either assumed values for source term parameters or literature values derived from other, presumably similar cases. This makes modelling the Kuwaiti plume very uncertain.

4.1.2 Photographs of the burning wells, show a variety of conditions: some wells have high pressure jet flames shooting straight up, others appear to be a combination of tilted jets with or without substantial surrounding burning pools of oil on the ground; some wells are spewing out large quantities of thick black smoke, other have whitish plumes that look more like steam than burning oil. The meeting was informed that with the creation of a local heat-island, a distinct inflow of near surface air has been observed within the lower 150 to 300 m above ground level. At times that inflow wind was estimated to be 5 to 15 m/s.

## 4.2 Current Meteorological and Air Sampling Surface Monitoring

4.2.1 Surface monitoring programmes are critical to any evaluation of potential health impacts of the pollutants generated by the Kuwaiti oilfield fires. Concentrations of these pollutants are governed by emissions and by a wide range of meteorological variables. Surface based and upper air meteorological measurements are essential and currently missing in Kuwait. Therefore, an improved knowledge of the local and regional meteorological regime is urgently required.

4.2.2 Saudi Arabia has a long-standing monitoring capability which is presently being enhanced to provide more information related to questions about potential human health effects (see Appendix VI).

4.2.3 There are at present only two operational air quality stations. In Kuwait City, however, these currently do not measure soot or other particles fractions likely to be of concern to health physicists. The locations and coverage of samples are inadequate to cover what is needed for assessment of the environmental damage and the impact on health.

4.2.4 The reports on Kuwaiti and French measurements of $SO_2$ (5000 $\mu g/m^3$) are alarming and exceed the WHO standards. Measurements done in Saudi Arabia show maximum levels of $SO_2$ (6000 $\mu g/m^3$, TSP (3000 $\mu g/m^3$), and PAH when within the plume. Already topsoil (0-5 cm) analyses show higher nickel and vanadium concentrations than lower soil layers (15-25 cm).

4.2.5 On the regional scale, outside Saudi Arabia and Kuwait, no data are available as yet. At WMO GAW global baseline stations no significant atmospheric disturbances have been reported yet, but if trends or anomalies in e.g. atmospheric turbidity would be detected, it is expected that immediate reports will be available.

## 4.3 Aircraft Measurements

4.3.1 Observations, taken in late March/early April 1991 by the U.K. aircraft , are still being analyzed (See Appendix VII). However, preliminary results at a height of 2000 m, at a distance of 100 km downwind of the fires, indicate peak values as follows:

| $SO_2$ (ppb) | $NO_x$ (ppb) | $PM_{10}$ ($cm^{-3}$) | Ozone (ppb) | Sunlight | Plume-top (km) | Plume-base (km) |
|---|---|---|---|---|---|---|
| 1000 | 50 | 30,000 | Reduced levels except at at plume-top (80 ppb) | Reduced to essentially zero | 3-4 | 1-1.5 |

At 1000 km downwind, $PM_{10}$ counts reduced to 1,000 per cc.

4.3.2 The results taken by the U.S.S.R. aircraft at distances more than 2000 km from the fires in the region of the Caucasus and the Crimea at a height of 1500 - 3000 m indicate soot values of 0.12-0.32 $\mu g/m^3$ amd a benzo-a-pyrene concentration of 0.02 - 0.16 $ng/m^3$

4.3.3 The U.S.A. presented a national plan (summarized in Appendix VIII) for research aircraft flights involving several agencies which is about to be implemented in the Gulf region. The existence of plans in various stages of development for activities in the region (for example, Germany and U.S.S.R.) was noted by the experts. The interested parties were urged to coordinate their plans and flights with the existing Kuwaiti and Saudi Arabian plans through the use of the recommended WMO coordination mechanism for this project.

4.3.4 The U.S.S.R. proposed an aircraft campaign in order to determine the geographical distribution of the combustion on the regional scale over a range up to 3000 km from the source. Details of the plan are given in the Appendix IX).

## 4.4 Satellite Observations

4.4.1 Satellites and the space shuttle observations clearly show the Kuwait oilfield fire signatures and downwind gas/aerosol plumes spreading out and merging over hundreds of kilometers. Conventional meteorological, LANDSAT, SPOT, and other satellites provide a range of spectral and areal resolutions which can be used to identify well and surface fires as well as track the plumes. Image processing and analysis of satellite data is proceeding to quantify the character and extent of plume coverage and will provide a means of verifying predictions. In addition, future satellites and shuttle missions should be considered for new observational tasks.

# 5. USE OF MODELS TO ASSESS CONTINUING EFFECTS

The meeting heard presentations on the results of several modelling efforts already performed based on the available data and information. A review of the models presented is given in Appendix X.

## 5.1 Near-field Models

5.1.1 At the present time, near-field results depend on data from limited information about the source, local meteorology, and atmospheric composition characteristics. Photographs from the oilfields show significant variations in plumes from nearby fires.

5.1.2 Relatively brief attention was given to the problem of near-field modelling, regardless of the recognized importance of this topic. In practice, the purpose of near-field modelling is largely to warn of the likelihood of occasions of unusually high exposures, for which application it is not necessary to have detailed information on emission rates. However, if it is desired to forecast actual exposure regimes as well as their likelihood of occurrence, then detailed source data are required. For proper prediction of downwind concentrations, it is necessary to have reliable input data on the following parameters:

a. Source emission rates with time for individual wells and their locations;
b. Heat release for each fire and combustion efficiency;
c. Chemical composition of gases and particles;
d. Oil-water mixing ratio;
e. Exit velocity and exit temperature;
f. Effective diameter of the ruptured pipe;
g. Effective plume rise;
h. Variation of transport layer depth with time;
i. Wind-field data at various locations;
j. Stability conditions in time and space.

5.1.3 Dr. U. Schumann presented results from a non-hydrostatic three-dimensional mesoscale model. The heat release from burning 1.3 Mbl/day of oil within an area of 10 km x 10 km causes a fire-wind of about 10 m/s inward and upward. This wind carries the soot from the fire upward up to the level of increasing tropospheric stratification (about 3 km). The plume penetrates about 500 m into the stable troposphere but is then transported downwind with the mean wind which was about 7.5 m/s at that level. The soot concentration is of the order of 1 mg/kg within a layer from 2 to 3 km in altitude. Satellite observations of 24 February 1991 confirmed that the plume stays below about 3 kms.

5.1.4 The King Fahd University attempted to apply "RAM" near-field software package in order to estimate concentration of pollutants within 100-150km radius from the burning oil wells. This model when applied in the Gulf area showed high concentrations of pollutants on 1-hour time scale, atmospheric chemistry development on an 8-hourly time-scale and wet and dry deposition processes (also see Appendix VI).

5.2 Medium- and Long-range Models

5.2.1 Operational models, both Eulerian and Lagrangian exist for simulating dispersion on medium-range scales. They simulate transport, dispersion, wet and dry deposition. Urban and regional scale air pollution models which treat the atmospheric chemistry, wet and dry deposition processes are available for application in the Gulf region. Use of models on this scale is hampered by lack of meteorological and pollution concentration observations, particularly precipitation fields.

5.2.2 Some models concentrate on climatological aspects of the problem on this scale. Other models attempt to give fields (short period or long-term) of concentration; dosage and deposition; as well as statistics of episodes of highly acidic rain. For their verification, there is an acute need of atmospheric composition and precipitation measurements in the downwind regions.

5.2.3 The Air Resources Laboratory (ARL) of National Oceanic and Atmospheric Administration (NOAA) produces operational forecasts of trajectories in the 850-700 mb height range for 36 to 72 hours. These forecasts can be produced routinely for use in assessments of the movement of emissions from the Kuwaiti oilfield fires. Trajectories are integrated from NOAA meteorological forecast and analysis products. The NOAA "ATDL" model has been prepared for operation in the Gulf region and beyond, and can give operationally daily information as well as estimates of climatology.

5.2.4 Both the Lawrence Livermore National Laboratory (LLNL) and the Dutch National Meteorological Service (KNMI) are able to produce operationally and routinely patterns of air pollution dispersion in the region. Due to the uncertainty of the source term and the meteorological input data, these patterns have a highly qualitative nature.

5.2.5 More detailed mesoscale meteorological models such as the "Pielke" model have also been applied to the oilfield fires. The model has been used to assess the likelihood of land-sea breeze effects as they might influence the transport of the plume. NOAA is already supporting and will continue to support operations in the larger Kuwait area with its modelling tools.

5.3 Global Models

5.3.1 Only a few general circulation models modified to cope with pollutant transfer are available. They have been used to assess the large-scale increase in atmospheric dust load and the impact this may have on the strength of the Indian monsoon, on "black snow", and the effect of this on overall albedo.

5.3.2 J.P. Blanchet informed the meeting on some preliminary results obtained with the Canadian Atmospheric Environment Service - Climate Centre model (see Appendix X).

5.3.3 Dr. H. Graf from the Max Planck Institute for Meteorology showed results of similar calculations and announced that the investigations will be published in "Nature" (30 May 1991) (see also Appendix X for a summary).

5.3.4 Dr. J. Penner from the Lawrence Livermore National Laboratory presented results (Appendix X) from the application of the LLNL global climate/chemistry model.

5.3.5 Preliminary results from these modelling activities are summarized here. They showed that the soot, estimated to be fully two-thirds of the total world-wide emissions, will certainly have regional implications for climate, but its global consequences are projected to be negligible although they need to be further investigated. As it is known, the smoke could either warm the climate or cool it, depending on its altitude in the atmosphere and on whether it is thermally coupled or decoupled from the surface. Enhancements to existing Global Atmosphere Watch stations throughout the region and downwind on the order of 3000 to 5000 km should be pursued in order to quantify the amount and spread of the soot as well as the changes in radiation parameters and atmospheric composition. It has been estimated that the total mass release of fine particles (less that 2.5 microns) from the burning oilfields will be on the order of $18x10^{12}$ g/y, which is similar or in excess of the annual world-wide emissions of such particles through car exhausts. After one year, the emissions of carbon soot from the fires will double the present concentration of these particles in the global atmosphere. For more detailed results of these studies is referred to Appendix X.

## 6. RECOMMENDATIONS

### 6.1 General

6.1.1 The experts agreed that plans for activities in relation to the atmospheric environmental effects of the Kuwait oil fires should focus on:

a. the fires themselves - their dynamics and products,

b. the plumes - their dispersion and trajectories and their chemistry,

c. improvement of the meteorological and atmospheric composition monitoring,

d. deposition and effects, such as those related to acid rain and other chronic environmental impacts,

e. effects on weather, especially concerning the monsoon, and

f. effects on climate, including the effect on the global radiation balance.

g. the provision of effective daily risk asseesments to the Kuwaiti authorities to help minimize the impact of the pollution on local centres of population.

6.1.2 The Workplan for the Rehabilitation of an Environmental Monitoring Programme for Kuwait (Appendix IV) was noted by the meeting. In this respect, the meeting also recommended that close cooperation be established between the monitoring activities of WHO and those of WMO.

6.1.3 The Gulf Regional Air Monitoring Programme (Appendix V) was also endorsed by the meeting, with the following suggestions:

a. The possibility that evaporating light fraction from oil spills could contribute to the dosage of noxious pollutants experienced in major population centres was noted.

b. The plan focuses on $PM_{10}$ monitoring. The WMO experts group suggest an additional central monitoring station where many air pollutant components are measured as well as the standard $PM_{10}$.

c. Surface ozone measurements were suggested for key monitoring stations, with $SO_2$ at the source, in order to provide data related to possible synergistic reactions.

d. Black carbon measurements in both air and precipitation are desirable at key locations. There is a need to analyze total carbon aerosols since black carbon is likely to constitute a minor fraction of the carbonaceous material.

e. Some monitoring sites near the coast are suggested in order to assess deposition fluxes to the water surface and possible accumulation and effects in marine organisms.

f. An emphasis on the source term is needed. Presently, estimates vary across a range of more than a factor of two on amounts of oil consumed per day and a factor of ten on chemical and particulate emissions per unit of oil consumed.

g. The extension of the plan to wider areas and the global scale was deemed desirable.

h. Measurements of optical depth of the atmosphere are needed, with a few sites arranged around the sources, a few others distributed globally.

i. Up to 3-4000 km downwind, the GAW/BAPMoN (Background Air Pollution Monitoring Network) precipitation collection protocols should be expanded to include measurements of Ni, V, and soot, as well as of the normal chemical species including pH of the samples. Collections should be weekly. New stations should be set up in the immediate as well as downwind region, to augment the existing GAW/BAPMoN stations.

j. In addition, a major GAW baseline background monitoring station should be set up in the southwest part of Saudi Arabia at 3000 m above msl (Abha region) as soon as possible. This station is essential to the air monitoring part of this project.

6.1.4 The meeting suggested that in order to assist in determining the chronic exposure to $SO_2$, diffusion batteries might be used. These are entirely passive devices and large numbers of them can be deployed. Only one central analysis facility would be required. Exposure times for the batteries could be on the order of a few days to a week in duration. In addition to using the batteries in populated areas, arrays of batteries could be used over a larger area to assist in determining the ground level concentration field of $SO_2$ for comparison with the numerical model predictions of the long-term average concentrations of $SO_2$.

6.1.5 For an assessment of the acute effects of Total Suspended Particles (TSP) on human health, a continuous method would be preferred. The meeting suggested using quartz microbalances which can provide a "continuous" TSP signal. This can then be used directly with the continuous measurements of $SO_2$ concentrations. In addition to the improvement to human exposure estimates, such measurements can be used to help in assessing the flux of particles from the source. The ratio of TSP to $SO_2$ would be obtained on a continuous basis and it is probably easier to estimate the $H_2S$ and $SO_2$ source strengths than it is to make estimates of the particles source. It is essential that scanning electron microscope images be taken to reveal partial morphology.

6.1.6 The meeting noted that measurement programmes should continue for at least two years after the last fires are extinguished, to show the complete recovery of the atmospheric environment to its unperturbed state.

6.1.7 In view of the Kuwait Workplan, the Saudi Arabian Programme and subsequent discussion as summarized above, the meeting strongly recommended that an international project be organized under the leadership of WMO, in close cooperation with WHO and UNEP, with the following components:

a. Establish, in cooperation with the meteorological services of countries in the region, a network of upper-air and surface meteorological and background air pollution stations to provide data required for analysis, forecasts, and advisory purposes, and to provide input for transport and dispersion models;

b. Establish a network of surface layer wind and other meteorological observations required near the source of the fires, including relevant air chemistry;

c. Establish and/or augment existing GAW network of surface meteorological stations on a regional scale including the solar radiation measurements (diffuse, global and optical depth), precipitation chemistry, and essential atmospheric composition measurements (eg. $SO_2$, soot, surface ozone);

d. Undertake a co-ordinated programme of aircraft measurements and develop a coordination mechanism for aircraft operations and other experimental activities (e.g., tethered balloon operations);

e. Promote the expansion of on-going air monitoring programme within the Global Atmosphere Watch on a global scale;

f. Develop formats and procedures to facilitate the international exchange of data ensuring that these data required in real time are exchanged through the WMO/WWW mechanisms;

g. Arrange for operational forecasting capabilities and international exchange of forecast information using model output on all scales including determination of the source term, the prediction of the plume, and the long-range transport of the pollutants. The objective will be to predict high concentrations, deposition and optical characteristics in space, time, and content;

h. Promote observational and analysis activities to test the validity of models on all scales;

i. Provide required atmospheric data and analysis to support WHO programmes for human health assessment activities; and

j. Arrange for workshops and expert meetings as required for comparison of measurements and assessing progress.

6.1.8 The meeting recommended that the WMO provide the interface between the various national efforts participating in this project and also provide a focus for proposals by all groups seeking to participate.

6.1.9 The meeting noted that the activities envisaged above would require substantial funds which are not available under the regular WMO budget. In addition to the work of the WMO constituent bodies and their working groups, a considerable amount would have to be covered by external funds and assistance in kind. This might include support for field operations, provision of instruments, expert missions, central analysis laboratory, as well as the establishment of a central coordinating office (providing logistic support) and a coordinating body involving the Organization and interested countries.

6.1.10 Based on availability of funds, WMO will seek to organize a centre for data acquisition, archiving, and regional environmental assessment in the Gulf region which will facilitate the archival of all observed data within the existing system of the World Data Centres.

6.1.11 Based on availability of funds, WMO will seek to organize a centre for observations and operational support in Kuwait City in conjunction with WHO activities and with the U.N. Inter-Agency Action Plan. This centre would also provide in-country logistic support for aircraft studies and other field activities.

6.1.12 Based on availability of funds, the meeting recommended that an operational modelling centre be established for support of health efforts, environmental efforts, and real-time operational support of measurements and tactical decisions.

## 6.2 Aircraft Monitoring Strategy

6.2.1 The meeting recommended that, where possible, aircraft should give priority to the measurement of source strength and characterization of soot, the wind and concentration field in near to medium distances (up to 200 kms), the evolution of plume chemistry at long distances downwind (greater than 200 kms) and the temporal variation of source strength, as above, as fires are put out.

6.2.2 Since for determination of the amount of soot released per time unit, the mass-flux is required, it was therefore recommended to measure (i) the mean wind field by aircraft and sondes, (ii) the extent and relative concentration field within the total plume, (iii) in-situ measurements of soot concentration at approximately the same time and at least one flight level within the plume, (iv) total sulfur concentration by probes and (v) increase in water vapour within the plume. Considered flight patterns were: vertical profiles near the source (30 to 80 km)and along the main plume axis at distances from 30 km to 300 km and, in addition vertical cross-sections at large distances from the sources (up to 1000 km).

6.2.3 The meeting considered the following items as important for immediate consideration:

a. The WMO aircraft coordinator should contact UNEP and appropriate officials within Kuwait immediately to coordinate establishment within Kuwait of a focal point for coordination and logistical support of personnel and projects involved in the implementation of the aircraft operations,

b. Funding for provision of logistical support for field projects, especially aspects of the aircraft programme, must be provided to WMO by participants either directly or through the U.N. Interagency Fund (through UNEP),

c. All data collected by parties to this programme, particularly in the region, should be made available to all parties through WMO, in a timely manner, in view of the multiple uses for the data and the urgency of the matter,

d. A very high priority needs to be placed on the re-establishment of capabilities in Kuwait for collection of source and local meteorological data,

e. In view of the continuing critical importance of accurate source term data, it is essential that efforts be implemented immediately and provision be made for continuing updates and dissemination of data.

6.2.4 The coordination of aircraft flights should proceed as follows:

a. A sequence of aircraft flights should be made covering each month with some overlap, where possible, for intercomparison of measurements,

b. WMO should assist in arranging the coordination of aircraft activities through national focal points,

c. WMO should assist aircraft teams to obtain access to national air space in the region,

d. Local support for aircraft teams in the Gulf area is essential,

e. Assistance is needed in providing aircraft teams with model forecasts for flight campaigns,

f. The WMO should assist in the distribution of flight data. Wide distribution of flight data will assist in the planning of subsequent aircraft activities and provide test data for model evaluation,

g. The WMO should assist, within the next few months, in the organization of at least one workshop to compare and discuss aircraft results,

h. The experts noted that the U.K., U.S.A. and German airplane measuring programmes were bilateral in character. While recognizing the need for urgent measurements, the meeting urged these programmes and future aircraft monitoring programmes to be structured under the framework of the WMO project.

(More details on the aircraft monitoring strategy are given in Appendix XI)

6.3 Surface Monitoring Strategy

6.3.1 The meeting listed the following important considerations in developing a coordinated monitoring strategy:

a. Dispersion of the plumes including upper and lower heights, and lateral spreading,

b. Particle size spectrum of soot,

c. Upward and downward short-wave and long-wave radiation fluxes in order to estimate the heating rate within the plume and the cooling below the plume,

d. Turbulence generated by solar radiation heating within the plume which should be observable by pilot reports and measureable by turbulence probes (the turbulent motions on the order of much less that 10 Hz are important),

e. Particle sedimentation measurements at various distances from source,

f. Observations of the deposition of soot by precipitation,

g. Boundary conditions for microscale/mesoscale modelling (including horizontal wind-field, vertical temperature-profile, vertical humidity-profile, accurate information on distribution and intensity of the single fire sources, cloud cover, background concentrations of ozone, nitrogen oxides, sulfur, etc., up to altitudes well above the plume),

h. Air-chemistry measurements including surface ozone, NO, $NO_x$, particles, sulfate, nitrate, etc. These measurements would be essential in determining detrimental interactions between existing air pollutants (chlorinated pesticides) and the soot component of the oil fire plumes.

i. Surface albedo, atmospheric transparency, components of radiation balance.

6.3.2 There is an urgent need for a small meeting of experts on atmospheric monitoring to determine the most desirable measurements as a factor of distance from the fires (immediate, regional, global) and to recommend specific actions for WMO to take for implementation, funding, and expert missions to make these data available.

6.4 Modelling Strategy

6.4.1 The meeting recommended the following strategy for the modelling community:

a. Emergency response and hazard assessment models should be used immediately to provide information on possible health implications and close and downwind guidance for necessary measurements,

b. Regional and global models must be tested using the available enhanced data which must be archived and made available,

c. WMO should designate a task force of modelling experts to meet shortly to examine results of modelling and data gathering efforts in order to determine how to use these in the larger scale models and to plan for later aircraft intercomparisons and comparisons with other data, and

d. Research efforts should be made to improve these models and to transfer advanced technology into operational and assessment models (the task force may be used to coordinate this technology transfer).

6.4.2 The meeting concluded that the models discussed in Appendix X have important capabilities for multiple situations. However, for improved specific application, research efforts are still needed for regional atmospheric modelling in the areas of transport and diffusion, terrain influences, surface boundary layer parameterization, air-land-sea interaction, oil fire impacts, radiation balance, chemical reactions, deposition, model formulation, solution technology, and coupled verification and development measures. Appendix X also contains a detailed list of modelling recommendations endorsed by the meeting.

6.4.3 For source-term characterization, a phased approach will be necessary to include:

a. conducting preliminary exploratory studies of the feasibility of characterizing individual fire plumes, their heat release, and their combustion products,

b. conducting full scale programmes including both dynamic and chemical aspects,

c. establishing a micrometeorological network to provide local wind field data and to verify local flow field models, and

d. implement multi-fire local flow field models.

6.5 Data Collection, Assessment, and Management

6.5.1 Near field data from Kuwait should be routinely collected and analyzed in Kuwait City and made available to the authorities concerned. The WMO office on site in cooperation with these authorities would also serve to provide local background wind field data for field studies as well as to effect exchanges of data and analyses with aircraft and modellers.

6.5.2 The collection of data and exchange of information on an international scale would be organized by WMO in accordance with agreed WWW procedures using WWW structures, where appropriate. In particular, use would be made of the GTS as far as possible for the real-time exchange of data and products and of the capabilities of the Regional Specialized Meteorological Centre (RSMC) and Regional Telecommunication Hub (RTH) in Jeddah to provide data base services.

6.5.3 Relevant data collected downwind and globally should be copied to the RSMC in Jeddah in addition to their normal submission procedures to the World Data Centres.

7. REPORT AND CLOSURE OF THE MEETING

7.1 The Co-chairmen thanked the experts for their hard work and active participation during the past four days. They noted that despite the short time available for preparation and the short meeting time which included a weekend, a number of important steps had already been taken.

7.2 The meeting reviewed the main parts of the draft report and the Chairmen promised to assist the WMO Secretariat to produce the final report in the shortest time possible so that it could be used to meet the urgent needs in Kuwait and the entire affected region by WMO, by WHO, by other international agencies, and by countries involved with further contributions, coordination, and planning.

7.3 The Kuwaiti representative thanked the chairmen and the experts for their efforts. He reiterated the urgency of the current situation and appealed to interested countries to make timely contributions and thus facilitate WMO's effort to proceed with implementation of the meeting recommendations as quickly as possible.

7.4 The meeting was declared closed at 3:00 PM on Tuesday, 30 April 1991.

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# INTERNATIONAL ORGANIZATIONS INVOLVED IN THE UN INTER-AGENCY PLAN OF ACTION IN THE ROPME REGION

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WMO MEETING OF EXPERTS ON THE ATMOSPHERIC PART OF THE JOINT U.N. RESPONSE TO THE KUWAIT OILFIELD FIRES

(Geneva, 27-30 April 1991)

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APPENDIX III

WMO MEETING OF EXPERTS ON THE ATMOSPHERIC PART OF THE JOINT U.N. RESPONSE TO THE KUWAIT OILFIELD FIRES

(Geneva, 27-30 April 1991)

AGENDA

1. OPENING OF THE MEETING, ELECTION OF CHAIRMEN AND APPROVAL OF THE AGENDA
2. INTRODUCTION TO THE PROBLEM
3. THE SOURCE
4. REVIEW OF PRESENT MONITORING AND ESTIMATED EFFECTS OF THE FIRES
5. USE OF MODELS TO ASSESS CONTINUING EFFECTS
6. RECOMMENDATIONS
7. REPORT AND CLOSURE OF THE MEETING

بسم الله الرحمن الرحيم

مجلس حماية البيئة

**ENVIRONMENT PROTECTION COUNCIL**

Reference EPC/90/1600
Date 26 APRIL 1991

الرقم : م ع ب/٩٠/١٦٠٠
التاريخ : ٢٦ أبريل ١٩٩١

Dr. Obasi
Secretary General W M O

Dear Sir:

Thank you and the World Meteorological Organization for hosting this meeting and for your kind invitation to attend. We are very sorry we could not come because of the short notice and the unavailability of flights from Kuwait.

Attached please find a copy of a plan for the rehabilitation of the environmental monitoring facilities of Kuwait. The plan was discussed with Dr. David Mage of the World Health Organization (WHO) who kindly agreed to present it in our behalf and express our points of view. We regret that he will not be able to return to Geneva until Sunday 28 April 1991. Many other experts, some of them attending this meeting, have first hand information of the situation in Kuwait. If Dr. Will Pendergraf (NOAA) and Mr. Andy Bond (US EPA) are attending they can explain to you how desperate our situation is and how much help we need.

I would like to take this opportunity to thank WMO and all the organizations represented at the meeting for their interest and desire to help us. Many organizations and governments have already provided help. The French Ministry of the Environment helped with the air pollution measurements and the US EPA provided us some badly needed equipment and promised more. Many other organizations showed real concern and willingness to help, which we would like to acknowledge.

Thank you again for your kind assistance.

I remain sincerely yours,

Ibrahim M. Hadi

IBRAHIM M. HADI
Secretary General,
Environment Protection Council (KUWAIT)
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Attachment: Plan for Rehabilitation of Environmental Monitoring

cc: Dr. Hiroshi Nakajima, Director General WHO
Attention Dr. D. Tarantola, ERO and Dr. W. Kreisel, EHE
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# WORK PLAN FOR THE REHABILITATION OF AN ENVIRONMENTAL MONITORING PROGRAMME FOR KUWAIT

## A. AIR POLLUTION MONITORING

### 1. Background

1.1 The air pollution problem coming from the burning of approximately 6 million barrels per day of crude oil plus natural gas from the oilfields is probably the most serious incident of this kind ever recorded. This burning began in earnest on 22 February 1991 and many people have been exposed to the resulting fumes since then. The environmental impact of crude oil smoke is probably unique and previous experience with coal smoke or diesel particulates is not going to help very much. To our knowledge there is no information on the composition and toxicity of the chemicals being emitted and no computer models are available to handle the complex plume behaviour from the burning oilfields.

1.2 The urban area in Kuwait extends as an inverted L. The short limb runs from east to west along the coast of the Gulf of Kuwait. The longer limb extends north to south down towards Saudi Arabia (see Figure 2).

1.3 The oilfields on fire are to the southeast and to the northwest of Kuwait City. The coastal strip will be mostly affected by the oilfields to the south. These oilfields are quite close to the coastal strip and extend for almost 80 km on its periphery.

1.4 The meteorological department is not operating at the time, as all equipment was looted and the facilities destroyed. Based on the previous records (1957-1982), during the period April-June the synoptic wind is mostly north or northwest. In the absence of the oil fire heat island effects the wind would be blowing from the southeast for 18% of the time. Further day and night differences were recorded and land and sea breeze data had to be taken into account for the coastal area when the wind speed is low. Ground based inversions were generally prevalent at night when the sky was clear and radiation from the surface unobstructed.

1.5 The existing pattern of the surface wind is now probably significantly different from what it was before the oil fires. The burning wells are creating strong "heat islands" and strong incoming winds towards the fires are reported at the periphery of the fields no matter what the direction of the prevailing wind in the upper air might be.

1.6 The monitoring facilities for air quality included three fixed stations measuring the principle pollutants and meteorology. Four high volume samplers and several dustfall buckets were available. Two of the stations are operating now but the third station is being cannibalized and used up as spare parts to keep the other two stations operating.

### 2.1 Air Quality Data

Air quality measurements have been made by several agencies during the first two months of this oil fire crisis. Preliminary data show that peak levels of $SO_2$ are exceeding WHO guidelines with an increase in mortality among elderly and chronically ill people when accompanied by an equal concentration of (coal) smoke type particulate matter. Because the crude oil smoke particles have a different chemical composition, their relative toxicity compared to coal smoke particles is an unknown. For example, to our knowledge, the rate of catalytic conversion of $SO_2$ to $H_2SO_4$ on the surface of these oil smoke particles has not been measured. These plumes are so opaque over the EPD monitoring stations that incident solar radiation is being reduced to one-tenth of the normal values measured on the same dates in the past.

2.2 Measurements of $SO_2$

2.2.1 The government of France, through the Department of Police, Paris, kindly provided the services of a mobile air monitoring laboratory to EPD in late March and early April 1991. Measurements made on $SO_2$ at several locations in Kuwait found concentrations of $SO_2$ reaching high levels.

High values of 470 $\mu g/m^3$ for a 12-hour average, with a maximum five-minute value of 2900 $\mu g/m^3$ and a 3-second peak of 3400 $\mu g/m^3$ were obtained. During this period of peak pollution the thermometer recorded a significant rise of temperature indicating the touchdown of direct plume. These data were measured during the evening from 3 to 4 April 1991 at the English school at the 5th ring road of Kuwait City.

On 3 April 1991 at the 7th ring road nearer to the oilfield fires an 8-hour average of 500 $\mu g/m^3$ was measured with a maximum 5-minute average of 1200 $\mu g/m^3$ and a 3-second peak of 1450 $\mu g/m^3$ with no accompanying fluctations of temperature.

2.2.2 The government of the U.S.A. through the courtesy of EPA provided measurements of $SO_2$ made at several locations in Kuwait from instantaneous and 20-minute grab samples. Although the measurement technique used had a high limit of detection, their results on $SO_2$ in the Kuwait area indicated a range of instantaneous values up 0 to 1 ppm (2860 $\mu g/m^3$) at the U.S. Embassy and up to 0.2 ppm $SO_2$ (Summa data) in the oilfields directly in the plumes. The U.S. Air Team report states "the $SO_2$ levels of 1 - 2 ppm should be used with caution".

2.2.3 The Kuwait Oil Company medical facility of Ahmadi Hospital has recorded $SO_2$ by the $H_2O_2$ bubbler method. On 22 April 1991 an 18-hour average of 1.65 ppm (4700 $\mu g/mg^3$) was measured during a period of direct fumigation from the Ahmadi oilfield plumes which produced a blackout. During this period a Professor of environmental studies reported that stinging droplets of oil fell on his skin and that two of his female students fainted while out taking part in a survey of symptoms in the neighborhood.

2.2.4 The Kuwait MOPH/EPD has also measured 24-hour average $SO_2$ by the $H_2O_2$ bubbler method at 4 hospitals in Kuwait City since 13 March 1991. Maximum daily $SO_2$ levels of 200 to 250 $\mu g/m^3$ have been measured.

2.3 Comparison to WHO Guidelines for $SO_2$ and Particulate

WHO has recommended that susceptible individuals be protected from 10-minute peak values of 1000 $\mu g/m^3$ of $SO_2$ by use of a safety factor of 2 resulting in a guideline value of 500 $\mu g/m^3$. This value is consistent with a one-hour value of 350 $\mu g/m^3$ under typical urban air pollution conditions which was therefore chosen as the 1-hour average guideline value.

For longer term 24-hour averages of $SO_2$ exposures combined with particles arising from urban sources such as coal, fuel oil and gasoline combustion, the health effects associated with these combinations are shown in Table 1. It is necessary to note again that the chemistry of the particulate phase resulting from the Kuwait crude oil fires can vary between the oilfields as some are sweet (low S) and others are sour (high S) and both will be different from the winter urban particle mix on which Table 1 is based.

WHO does not provide guidelines for exposures based on carcinogenicity since no safe threshold may exist. Until the organic constituents of the plumes are measured and understood prudence requires avoiding unnecessary outdoor exposures during blackout periods.

2.4 Potential for Health Effects from the Oil Fire Plumes

The measurements described above and their relationship to the WHO guidelines indicate that a serious air pollution situation exists for the people residing in Kuwait. At the present time, the combination of synoptic meteorology, the heat island effect and the emission source distribution has lead to rapidly fluctuating positions of maximal impact of the oil fire plumes. Measurements at fixed station locations show the presence of high concentrations for short periods of time (6 to 18 hours), after which the plume cloud appears to shift to another location where measurements are not available and the concentrations decrease at the station.

At the present time, it is impossible to predict accurately what the seasonal changes in weather patterns will do to the oil fire plumes. As the pressure in the oilfields decreases and oil fires are extinguished the thermal plume rise and heat island effect will become smaller and much higher ground levels of $SO_2$ and $PM_{10}$ can be expected nearer to the population centres. In the event of atmospheric stagnation the $SO_2$ and $PM_{10}$ concentrations could build up to the levels shown in Table 1 which would constitute an acute air pollution emergency.

It is therefore necessary that an air quality monitoring system capable of measuring the overall spatial pollution distribution and meteorological variables be developed to provide real time information and predictive capabilities so that public health authorities can issue warnings and take protective actions to protect the people living in Kuwait.

The sections that follow describe the components of the overall plan that the MOPH/EPD sees as necessary to put in place. There is a need for funding, supplies, equipment, personnel, consultants and advisors to help the MOPH and EPD in this period of need until our country can stand on its own as it did before the war. It is hoped that this outline will show areas of need so that the international community can provide assistance to Kuwait that is an element of our plan and not a duplication or superfluous effort.

3. <u>Air Quality Monitoring</u>

The system was designed to look after the air quality resulting from traffic, industry and power plants. Of course the problem of the pollution from the burning oil wells was not anticipated or accounted for so major changes may need to be introduced to the system to get them in line with the existing (or future) plume directions and impact locations. Examination of the $SO_2$ data from the fixed stations shows significantly lower concentrations than measured by the mobile lab and grab samples taken nearer to the plume axes.

A number of facilities including three mobile stations were looted and other equipment was badly damaged. This loss of equipment combined with the loss of technical personnel and the existing magnitude of the new air pollution sources makes it imperative for the complete system to be expanded and updated as soon as possible.

The following sections describe the integrated elements that will be required for an air quality monitoring system that is proposed by the EPD for managing the overall programme:

3.1 Fixed Monitoring Station Requirements

The area to the west of Kuwait City, Jahra (150,000 before the crisis) is not covered in the existing system now. The area is rural but it is now in the plume shadow of the northern fields. No monitoring stations are now in the area to the south near the border with Saudi Arabia. Information from this area will help estimate the transboundary flux. A means for transmitting the information directly to the central computer in the EPC is needed. An alarm system should be installed to alert us if and when the levels of pollutants exceed our warning levels (still to be established by EPD). The computer capabilities should be upgraded and special software developed for this system.

3.2 Mobile Air Monitoring Laboratories

All the mobile laboratories were taken away to Iraq. At least two vans provided with pollutant analyzers and meteorology sensors are needed. The wind direction in the vicinity of the oilfields is changing very rapidly and vans are needed to measure the levels up and down the wind axes and to trace the plumes. The system could determine the probable contribution of the different sources. The vans are intended to be used in the field and a power supply (220 V/50 Hz) would provide the necessary flexibility.

The Federal Republic of Germany has kindly promised to provide one van to the EPD and the People's Republic of China has offered the services of a similar van and crew, if transportation and crew expenses can be provided. A mobile gas chromatograph would be a very valuable complement to this system.

3.3 Monitoring for Particulate Matter

The U.S.A. EPA has kindly loaned us 9 portable $PM_{10}$ samplers. The equipment will be installed at sites to be agreed on. Three fixed $PM_{10}$ monitors are available now (2 provided by U.S. EPA) and will be installed at the fixed stations. The filter papers will be weighed and extracted locally. Certain heavy metals will be looked for in an attempt at "finger printing" and the composition of the hydrocarbon fractions will be determined by the HPLC and GCMS in the EPC laboratory.

3.4 Personal and Indoor/Outdoor Monitoring

Because people will spend most of their time indoors, preferentially in air conditioned homes especially during times of plume impact and blackout, their exposures may not be accurately characterized by ambient air quality data. It is therefore necessary to run some personal monitoring of exposures to $SO_2$ and $PM_{10}$ in areas of expected maximal concentrations in order to evaluate exposures and protection factors. For certain volunteer subjects

$SO_2$ and $PM_{10}$ will also be monitored both indoors and outdoors to measure the protection factors for the various types of homes and activity diaries will be kept. Equipment required will be passive personal exposure monitors (PEMS) for $SO_2$ and pump/cyclone cartridge combinations for particles. Personal samplers for PAH such as those designed by ORNL can be used to get the vapour phase PAH exposures. (See section 4.2 for discussion of the HEAL project this will be a part of).

3.5 Meteorology Network

The only available (non-military) data now for meteorology and modelling are those provided by the two EPC fixed stations in the built up areas. No predictive capabilities are available from the Kuwait weather service which was destroyed during the war. The U.S. NOAA was kind enough to provide a system of 15 weather stations together with transmitter/receiver capabilities that can operate remotely using solar powered batteries. This will cover the problem of the surface data. However, upper air data are not available and they are needed for tracing the large scale plume transport. The alarm system will require this information. A doppler sodar system with 3 km range is needed to replace the one destroyed.

3.6 Quality Assurance

Some grave decisions may need to be based on the information generated by this system and the quality of the data must be looked into critically. There are many protocols available and the appropriate ones should be selected. The U.S. EPA has promised QA/QC help in extracting and analyzing the $PM_{10}$ filters. Before the war EPD used to run duplicate samples with Kuwait University and Kuwait Institute of Scientific Research (KISR). Now this must be done through other institutions abroad. The IAEA marine laboratory (ILMR) in Monaco was used as a reference lab before the war and contacts will be established through the UN coordinated plan to reinstate this service.

3.7 Laboratory Requirements

The EPD laboratory will need the ability to measure the inorganic and organic gas phase constituents which are sampled in special studies using Summa containers or equivalent. The particulate fractions to be collected will need to be weighted, extracted and analyzed in Kuwait in order to minimize turn around time and reduce the possibility of sample loss or transformation during transport. Microbalances and extraction equipment are required for weighing and sample preparation. The equipment for analytical procedures, GCFID, GCMS and HPLC are available in Kuwait but new standards for the crude oil combustion constituents and spare parts are required.

The toxicology testing of collected fractions of the particle mix and semi-volatiles (PUF) will be performed by the Harvard School of Public Health and another laboratory (perhaps at EPA) and will be needed for an independent verification or QA/QC control.

3.8 Repair Facility

In order to assure continuous operation of equipment a repair facility with modern test kits and diagnostic tools is required. An inventory of spare parts most likely to fail must be established and communications arranged with suppliers so that expensive units not stocked can be supplied immediately on demand. Although it is planned to have a spare one of each type of monitoring instrument in the repair/calibration facility the ability to immediately repair equipment is needed. The EPD repair facility was looted and a list of equipment required will be made available for donor support.

3.9 Data Base Management

The most urgent requirement is for real time data transmission from remote stations to the central location for emergency warning capabilities. There will be a continuous flow of data into the data base from monitoring stations, meteorlogical stations, chemistry laboratories and other participating institutes (e.g. QC results). A data base manager will have to organize sample identification, tracking, storage and retrieval and arrange priorities for special reports to MOPH along with routine processing.

3.10 Coordination Centre (CC)

The MOPH/EPD will provide a project director (PD) who will be responsible for overall management of the entire programme. The PD will establish priorities and maintain oversight of all activities. The coordinating centre will hold a daily briefing in the morning to review the forecast for daily pollution and weather, to review the previous 24-hour conditions and to discuss non-routine projects such as special studies. There will be 24 hour per day coverage at the coordination centre so emergencies during nighttime and holidays are responded to, and to provide communications to and from other time zones where collaborators are located. The CC will also have a finance/budget officer to keep track of spending and maintain records of the expenditures.

3.11 Data Analysis and Interpretation

In the short-term the inflow of data on air quality and meteorology needs to be analyzed with the aid of predictive models that can reliably forecast where pollution maxima will occur in the next 6 to 24 hours. Summary reports on pollution extent and possible health impacts (e.g. relation to WHO guidelines) need to be prepared on a fixed schedule. These data reports will need to be interfaced with the health monitoring project (see section 4 below).

3.12 Logistics

A basic need for any complex international project is for logistical support. There will be a need for planning and coordination of transport/vehicles, ordering of parts, supplies and consumables, keeping a secure storeroom and inventory, plus typewriters, fax, computers, phones, copiers to keep operational. There will be a need to organize visas, tickets, customs clearances, mail, shipments, etc.

3.13 Public Relations (PR)

A PR officer (PRO) should be assigned as the contact point to keep the news media informed of progress and of the general situation. The PRO would arrange for visits and tours by government officials and others, and would handle press releases.

3.14 Public Awareness (PA)

The PA officer (PAO) would be the official contact to the media and emergency authorities to provide forecasts of critical situations on a daily basis. The PAO would also be responsible for discussing the health implications of the situation in consultation with the medical specialists assigned by MOPH.

## 4. Requirements for the Study of Health Impacts

The impact on the health of the people residing close to the oil plume sources is causing due concern. A large proportion of the population is still outside the country and needs assurance that the situation is quite safe and that predictive and preventive measures are planned in case the situation changes. The question of the need to evacuate certain areas was discussed and although the need didn't arise, and it is hoped that it will not, public health is our first concern and all precautions must be taken to assure that appropriate measures are in place.

4.1 Health Status of Populations

The short term impact mostly related to particulates and $SO_2$ (and to a lesser extent $NO_2$ and $O_3$) are of immediate concern. An epidemiological study showing the health status of people in relation to the environment and the various factors that influence their exposure and resulting test outcomes is needed. Until the carcinogenic potential of the oil smoke plume is established, the longer term possible effects will have to take second priority. The investigation should address the selection of a representative random sample and/or specially targeted populations, designing questionnaires for the local conditions, clinical examinations, pulmonary function tests, the taking of blood, urine and sputum samples and other investigations.

The following sections address the other elements that must be considered in the design of the appropriate health studies for our population.

4.2 Personal Exposures

In June 1990 before the present disaster, Kuwait joined the WHO/UNEP Global Environment Monitoring System (GEMS) Human Exposure Assessment Locations (HEAL) programme. Exposure to particulates was suggested as a priority because of the wind blown dust problem. Even before the war, Kuwait had the highest TSP levels reported to the GEMS/Air system and now the particulates due to the oil fire plumes will be added to them. In addition, the wind blown dust will now probably have a high organic content adhering to it from the crude oil residues contaminating the top soil.

The U.S.A. EPA has offered to provide the needed technical support for this aspect of the study if funding can be provided. Personal exposures to $SO_2$ may be added to the particulate studies. A stratified random sample of the population living in different areas of Kuwait with different age groups would be selected as part of the health study.

The HEAL protocols used for the exposure portion of this health study could provide better knowledge about the short term ($SO_2$) and long term (PAH) exposure risks of the populations of the subjects under study so that their total exposures to PAHs from possibly contaminated food or water can be considered, if they are found to be significant in relation to the air route exposures.

Assistance will be required for the food sampling and analysis portion of this study. Because of the possible dermal exposures from the droplets of oil falling out of the plume clouds, some measures of the effects of these droplets on total exposure will need to included.

4.3 Quality Assurance

A quality assurance (QA) protocol needs to be established to cover each type of measurement in the studies. There needs to be duplicate sampling and replicate analyses on measurements of exposure variables, biological media and physiological data. Questionnaire and diary response need to be validated and the digitized responses should be checked. A QA officer needs to be appointed with responsibility for carrying out the QA protocol.

4.4 Data Management

There will need to be a person assigned to manage and coordinate the data flow. There will be physiological and exposure data to be associated with each subject along with their medical history, questionnaire and diary responses. General medical records (admissions) from hospitals and clinics need to be entered.

4.5 Coordination Centre (CC)

The project manager (PM) from MOPH should be established at the CC where overall direction for the project can be maintained. The PM would maintain oversight of all project aspects and hold regular meetings with medical, exposure, data and record retrieval staff. The CC would handle all international contacts and interface with the air quality monitoring project director on a regular basis.

4.6 Data Analysis

The data sets obtained in this study need to be examined on a continuing basis. Whereas a classical epidemiology study might analyze these data after the fact, in this case it may be possible to discover health effects associated with the oil smoke now so that prophylaxis can be considered and susceptible groups can be identified and warned. Epidemiologists will need to screen these data for early warning signs in susceptible populations. When the oil fires are extinguished and air quality returns to the previous regime dominated by wind blown dust, the analyses of the overall effects can be performed. However, the wind blown dust may then have a high residual oil component bound to it which could present another problem. Population data will need to be gathered so that the denominator can be estimated for use in incidence rate computations.

4.7 Hospital records:

The national recording system was interrupted on the second of August 1990. The data of the previous years could be retrieved and used as background for comparative studies. The recording at Ahmadi hospital started from the first of April 1991 and some data will be available soon. The records from the local clinics and regional polyclinics are more difficult to use and they may not be of the needed quality. Some polyclinics could be selected and the physicians in charge asked to start the recording of their diagnoses for a predetermined period. This will give an overall bird's-eye view of the situation and the expenses and labor involved would be within the existing limitations.

4.8 Logistics

With many institutions participating in the investigation, a local group with the MOH or EPC should be appointed and given the task of looking after the visas, travel, accommodations, transport, mail, etc. This is usually done as a matter of routine by EPD, but with the present situation, a special group would be given that responsibility.

4.9 Emergency Response and Warning

Special risk groups (elderly, asthmatics, bronchitics, etc.) may need prior warning of the worsening air quality conditions. The hospital emergency rooms at the general hospital should be alerted to the situation of the possibility of the plume impacting their catchment areas. The hospitals should prepare their own protocols for handling the inflow of cases that are suffering due to the air pollution episode.

4.10 Long Term Follow Up Studies

There should be consideration for the development of a tracking system for long term follow up studies of the exposed populations. Records that show development of pulmonary conditions, cancer incidence and other disease data will need to be established, pending the results of toxicity and mutagenicity testing.

B. Water Quality Monitoring

5.1 Drinking Water Supplies

The programme for monitoring the drinking water quality was completely interrupted by the occupation. Basic water quality parameters will be overlooked for the time being. Analyses of the residual chlorine shows very low concentrations owing to the stagnation of the water in the reservoirs. Samples for bacteriological examinations will be collected from the residential areas on a weekly basis. Positive faecal coliform will be reported to the Ministry of Electricity and Water (MEW) for examination of the network for possible sewage intrusion. Examination for bacteriophages for indication of viral contamination will be resumed after the technical staff is recruited.

The programme needs the following support:

a) Four (4) total and faecal coliform field testing kits (about 120 samples per month will be analyzed)

b) Four (4) chlorine test kits

c) Two (2) digital pH meters

5.2 Coastal and Marine Environmental Monitoring

The Kuwait Gulf has been exposed to the biggest oil slick in history. However, in the past it was chronically impacted, and a monitoring programme was established many years ago. The EPD had a large research vessel and several speed boats for taking samples. The vessels were lost during the occupation and the sampling programme was suspended.

Samples of the surface film, water, sediment and biota will be collected for PAH and trace metal analyses (Ni, V, Hg, Pb) in order to determine the impact of the oil well spills and oil fire fallout on the marine environment. Sulfated PAH species may be used to differentiate between the two possible sources. Baseline data on trace metals and PAHs are available through the EPC national monitoring programme records as well as through the ROPME regional monitoring projects, carried out in cooperation with the IAEA Monaco ILMR laboratory.

Such a study should be a part of an ecological assessment of the marine environment with the objective of assessing the impact of the war activities, oil spills, well fires and the presence of mines on the marine environment, with special emphasis on sensitive populations and systems (i.e. coral reefs, oyster beds, tidal flats, marine turtles, mammals and birds). The impact on avoidance of mined areas on fishing activities and fishery resources could also be incorporated in such a study.

The equipment needed for running the programme includes the following items:

a) Two (2) four-man inflatable rubber boats and engines (Zodiac)

b) Two (2) sediment grab samplers (Vanweer)

c) Three (3) sets of diving equipment (Scuba)

d) Two (2) sea water quality analyzers (salinity range 10 - 50 ppt, temperature 0 - 45°C)

e) Two (2) hand held low speed current meters with recorders

f) One (1) meteorological station (wind speed and direction, temperature and humidity, solar radiation and atmospheric pressure)

g) One (1) 100 foot shallow draft research vessel (cruising speed to 14 knots, accommodations for 3 crew and 4 researchers, navigational and positional fixing aides, echosounder, sea bed profile scanner, current meter, temperature probes 0 to 40°C, salinity probes up to 50 ppt, DO, turbidity, water samplers for water quality, trace metals and bacteriology, PC, refrigerators and freezers).

C. Soil, Flora and Fauna Monitoring Needs

6.1 The desert flora of Kuwait used to suffer from overgrazing, off-road vehicles and quarrying. Now they are facing new problems. The military vehicles with their treads probably caused greater harm to the soil surface than the passenger cars. Abandoned mine fields are a threat that will take years to eliminate by clearance, if this can ever truly be completely accomplished. The disturbance to the top soil by mine sweeping operations will last for decades.

In the vicinity of the burning oilfields, the chemical properties of the soil and its capacity to retain water have probably changed due to its contamination by oil. Vegetation is suffering from the deposition of soot and the intensive heat generated by the fires. All the trees and shrubs in the city of Kuwait were not irrigated during the period of occupation. Water is not yet available in sufficient quantity to allow normal watering. The dry hot summer months are coming, and it is not known whether our plants and trees will survive.

Little is known about the effects of the war on wildlife. Sheep, goats and camels grazing in the areas impacted by the burning wells have turned black from the falling drops of oil and have started to lose their fur and die. Many birds observed flying through the plumes are overcome by heat and fumes and fall to the ground. Many other birds have died as a result of the oil pollution when they landed in the oil pools (mistaken for water) caused by the freely gushing wells.

The home gardens were a rest place for migrating birds, and the lack of water has destroyed this habitat. The farms at Abdally and Wafra to the northwest and south of Kuwait City have been destroyed and abandoned which will add to the suffering of the domestic and migrating birds.

6.2 Monitoring Needs

The needs to assess the impact on the top soil would include an aerial survey to determine the magnitude of the top soil damage and the extent of the mine fields in coordination with the military authorities. A survey of the vegetative cover and wildlife should be organized. The background information on the prewar conditions is available from surveys sponsored by the EPC. FAO and non-governmental organizations can provide advice on replanting of new species, rehabilitation of the soil and the combat of desertification.

D. Environmental Awareness Campaign

7.1 The problems of water supply, waste and sanitation, air pollution, and the presence of mines and other unexploded ordinance should be the focus for a vigorous public awareness campaign. The production of posters, booklets, TV short films and radio messages by medical staff, military officers, and religious leaders should be started immediately. A special short weekly or biweekly TV programme on public safety should be centered around interviews with specialists on mines, mine field clearance operations, and mine victim treatment specialists from the casualty wards to impress upon the population the seriousness of this impending danger.

7.2 Equipment Needs

a) Two (2) video cameras compatible with the national system

b) Two (2) video sets

c) Two (2) portable tape recorders

d) Film (100 hours)

TABLE I. SUMMARY OF HEALTH EFFECTS KNOWN TO BE ASSOCIATED WITH WINTER TYPE SMOG - LEVELS OF 24-HOUR AVERAGE CONCENTRATIONS OF AIR-POLLUTANT MIXTURES CONTAINING $SO_2$ AND PARTICULATE MATTER ABOVE WHICH SPECIFIC ACUTE EFFECTS ON HUMAN HEALTH ARE EXPECTED ON THE BASIS OF OBSERVATIONS MADE IN EPIDEMIOLOGICAL STUDIES

| $SO_2$ | Particles ($\mu g/m^3$) | Health effects | Overall classification of effects |
|---|---|---|---|
| 200 | 200 (gravimetric) | Small, transient decrements in lung function (FVC, $FEV_1$) in children and adults, which may last for 2-4 weeks. The magnitude of the effect is in the order of 2-4% of the group mean. | Moderate |
| 250 | 250 (black smoke) | Increase in respiratory morbidity among susceptible adults (chronic bronchitis) and possibly children. | Moderate |
| 500 | 500 (black smoke) | Increase in mortality among elderly and chronically ill people. | Severe |

Note: Effects on human health are thought to become severe at levels of 400 $\mu g/m^3$ for both sulfur dioxide and particulate matter.

مصلحة الأرصاد وحماية البيئة

METEOROLOGY & ENVIRONMENTAL PROTECTION ADMINISTRATION

(MEPA)

# Saudi Arabia Monitoring Programme

# Action Plan

# SAUDI ARABIA AIR MONITORING PROGRAMME ACTION PLAN

## GULF REGIONAL AIR MONITORING PROGRAMME

## 1. INTRODUCTION

The U.S. Interagency Air Monitoring Team is working with the Saudi Arabian Meteorology and Environmental Protection Agency (MEPA) to develop an air monitoring plan for the Gulf region that will provide information to assess the impact of the fires in Saudi Arabia. This plan is being discussed and developed with the King Fahd University of Petroleum and Minerals/Research Institute (K.F.U.P.M./R.I./R.I.) in Dhahran, the Cooperation Council for the Arab States of the Gulf (GCC), and the Saudi Arabian Oil Company (ARAMCO). The plan is being developed at the request of Dr. Tawfiq, Vice President of the Saudi Arabian MEPA. Meetings have been held with officials from all of the above mentioned organizations.

### 1.1 Approach

The Team is gathering information on the existing air monitoring networks in the region operated by MEPA, Saudi ARAMCO, Kuwait, Bahrain, and the Royal Commission of Jubayl and Yunbo. The spatial distribution of the existing network in the Region is being reviewed as to the location of sites, the air pollutants and meteorological variables that are monitored at each of these sites and the quality of existing data. That review is to determine if the existing network needs to be expanded in terms of the air pollutants and meteorological variables monitored and additional air monitoring stations to determine the impact from the oil fires. The capabilities of the existing agencies and governments to deal with a more complete network is also being investigated.

### 1.2 Objectives of Air Monitoring in the Gulf Region

Air monitoring data is needed for the following reasons:

a. To provide an Early Warning Health Advisory System for the Gulf Region to respond to the air pollution resulting from the Kuwaiti oil fires. The proposed Early Warning System could be based on an adaptation of the U.S. Air Quality Index, the Pollutant Standards Index (PSI), which can be modified to use Saudi air quality standards. The index would provide for health advisories to the affected populations so they can minimize their exposure to high pollution levels.

b. To track the air pollution from the Kuwaiti oilfield fires over time to assess the potential long term health and ecological effects. The air monitoring network proposal being developed is being coordinated with a parallel effort to develop a health monitoring information system.

c. To collect samples of airborne particles to perform toxicity testing and dose response assessment utilizing in-vivo animal models.

d. To facilitate evaluations of models which are use to predict the local and regional scale behaviour of the oilfield emissions. Data from the expanded GULF REGIONAL AIR MONITORING NETWORK of ambient air quality and meteorological data will be important for those evaluations.

2. BACKGROUND

There are currently 516 oils wells burning in Kuwait, consuming approximately five million barrels of crude oil and 70 million $m^3$ of associated gases daily. The fires originate in seven oilfields (Figure 1), located both north and south of the Kuwait City airport. The fires may represent one of the greatest manmade environmental disasters in recorded history.

Based on the composition of Kuwaiti crude oil, emissions from the burning wells are likely to include airborne particles, sulfur dioxide formed from the combustion of hydrogen sulfide, and oxides of nitrogen. Incomplete combustion products include hydrogen sulfide, carbon monoxide, polycyclic aromatic and other volatile organic hydrocarbons, and heavy metals. Other pollutants, including ozone and acid aerosols, such as sulfuric acid, would be formed secondarily in the atmosphere.

Meteorological conditions over the past two months have tended to transport the smoke plume toward the southeast, with periodic excursions toward the northeast. March through July are relatively windy months; there are normally 30 days of very strong winds from the northwest in this period, which produce sandstorms and rapidly ventilate the smoke. August to October, the incidence of strong winds should drop sharply, and local conditions will likely worsen.

As summer advances, solar induced convective mixing will increase the maximum height or pollutants to levels not yet experienced, perhaps to above 6 km. It is in these situations that the stage will be set for long-distance transport of the plume in the upper atmosphere, with associated long-range effects.

Emissions from the well fires have the potential of causing both acute and chronic health effects, although there is considerable uncertainty as to the magnitude of the risk. Thermal damage and poisoning from the chemical components of the plume are the two major mechanisms of acute pulmonary injury. Prolonged exposure to lower concentration levels of smoke may decrease lung function, and increase the incidence of chronic bronchitis and lung cancer. Special health concern is focussed on individuals working close to the fires, pregnant women, children, the elderly, and those with pre-existing respiratory and cardiac diseases.

The U.S. interagency scientific team has been conducting a reconnaissance survey of the fire plumes and their effects in Kuwait and Saudi Arabia since 10 March 1991. The Team obtained limited real-time data on the smoke emissions, assessed the existing air pollution monitoring infrastructure in the region, and conducted a number of interviews with health officials to evaluate the extent of acute respiratory problems related to smoke exposure. While only a cursory assessment is possible at this point, some data obtained by the Team were encouraging. Large-scale acute human health impacts, for example, have not been observed. Nor did limited sampling reveal the existence of high concentrations of sulfur dioxide or hydrogen sulfide close to the burning wells. The Team has stressed, however, that their observations represent only a preliminary assessment and that considerable follow-up will be necessary to definitely evaluate the nature and magnitude of the human health, ecological, and atmospheric effects of the smoke problem.

## 2.1 Preliminary Investigation of the Existing Monitoring Networks

The air quality monitoring sites listed in Table 1 have been identified for each of the Gulf nations that could contribute monitoring information within the sphere of influence of airborne effluents from the Kuwait oil fires.

Based upon our review of the existing networks, the principal pollutants which are missing are in the Saudi network and in the present Kuwaiti network are $PM_{10}$, which represents particulate matter with particles less than 10 microns in diameter, polycyclic aromatic hydrocarbons (PAH) and volatile organic compounds (VOC). With respect to $PM_{10}$, these are the particles which are most likely to penetrate deeply into the lung. It should be noted that Kuwait has collected particulate data using an Anderson Cascade Impactor, with limited size distributions below seven microns within a TSP sample. Because of the importance of this particular pollutant and the large amount of TSP resulting from the oil fires, the Team is recommending that special efforts be initiated to gather $PM_{10}$ data and if possible to determine its constituents - trace metals and hydrocarbons. The $PM_{10}$ data collection effort should be supplemented with the collections of PAH samples and if possible, grab samples for VOC analysis.

An ongoing effort is being conducted to examine the analytical laboratory support for air monitoring in Kuwait, MEPA, King Fahd U.P.M., and Saudi ARAMCO. The Kuwaiti laboratory capability to analyze air and TSP samples has been left largely intact. As of 27 March 1991, two of the three continuous monitoring stations have been activated and are collecting data. The remaining site has its continuous sampling equipment however, like the analytical laboratory, is without electrical power. There is no projected date for power at these locations. The analytical laboratory has had experience with polyurethane foam (PUF) extractions for PAH measurements (PS-1 sampler) and has done pesticide extraction and analysis research. The most critical need for the laboratory is obviously power to provide the basis of future support to the sampling plan. Additional training must be provided with documented procedures for these new sampling and analytical procedures, and lastly they are in need of a complete set of standards to support instrument calibrations for their existing continuous monitors and the new proposed technologies. Quality control and quality assurance samples and support for the network should be developed within the available laboratories but, should be supplemented from an external source.

TABLE I - The Distribution of Air Pollutant and Meteorological Monitoring Sites by Gulf Nation

| Nation | Organization | Number of Air and Meteorological Sites |
|---|---|---|
| SAUDI ARABIA | MEPA | 3 fixed sites - meteorology and air pollution at different locations of the same city<br>1 mobile site - meteorology and air pollution<br>1 fixed meteorology site |
| | Saudi ARAMCO | 8 air quality sites with meteorology<br>6 additional meteorology sites |
| | Royal Commission for Jubayl & Yunbo | Cluster of Five Stations in Jubayl |
| KUWAIT | | 3 sites with continuous monitors (2 with power, 1 without power).<br>4 sites with Anderson samplers, high vols. and dustfall buckets. (no power)<br>1 additional TSP site (no power)<br>6 additional dustfall sites<br>4 temporary $SO_2$ bubbler sites located at 4 hospitals (some power) |
| BAHRAIN | | 2 sites |
| QATAR | | 3 mobile monitoring sites |
| IRAN | | unknown |
| IRAQ | | unknown |

The analytical laboratory at King Fahd U.P.M. has recently been provided the above procedures to permit a self assessment of their equipment availability to conduct these detailed analyses. Currently, the K.F.U.P.M. is conducting experiments on PAH's analysis of high volume filters as a first step in this programme. K.F.U.P.M. has not had any experience with PUF, VOC canister analysis, or $PM_{10}$ sampling and analysis. They can expand their current analytical capability to provide support to the proposed network.

The analytical laboratory of Saudi ARAMCO as with MEPA has had no experience in collecting and analyzing $PM_{10}$ samples, PUF, and canister samples for VOC speciation and PAHs.

In summary, the current level of technical competence within all of the facilities visited, MEPA, King Fahd U.P.M., Saudi ARAMCO, and Kuwait, indicates that upon the procurement of additional equipment, standards, and training, they all could support the sampling and analysis required for this programme.

A substantial number of meteorological measurement sites exist within the eastern province of Saudi Arabia and the nations of the Gulf Region. Most of those sites are along the shoreline of the Gulf. ARAMCO operates 14 sites with meteorological data. Eight of those sites have collocated air quality measurements. Three of those sites are over the Gulf waters on platforms or on an island. MEPA (Saudi Arabia) has five sites with collocated air quality measurements. In addition, there are surface observations collected at many of the airports throughout the Kingdom. Surface meteorological data are being collected at other Gulf region locations. Their locations may be identified through the WMO publications. Previously, there were other surface measurement sites within Kuwait but their operational status remain unknown at this time.

Two upper air balloon sounding sites are operating within Saudi Arabia. One site is at Dhahran and the other is about 115 miles to the southwest of Kuwait City at Al Qaysumah. Twice daily soundings are collected at those locations, at 0000 and 1200 GMT. Prior to the war in Kuwait, twice daily upper air soundings were made at the Kuwait International Airport. The resumption of those soundings could be of substantial benefit to describing the airflow across the areas of Kuwaiti oil fires.

## 2.2 Meteorological Observations

The following summarizations are based upon first hand observations of the smoke plumes and fires. Those observations were made during overflights and during vehicle traverses both within the oilfields and along roads outside of the burning oilfields.

For any given day, the prevailing large-scale meteorological pattern will be the main driving feature which determines where the smoke plumes will be located and how dense they will be.

Individual smoke plumes appear to act in manners typical of buoyant plumes from ground level sources or plumes from short chimneys. Plume rise, the development of a bent-over plume geometry, etc., seem to apply to the individual well-head fires; some have jets of fire and others are nearly surface based burnings of the more combustible fractions of crude oil spread across the ground in the vicinity of the well. Most of the fire plumes rise to between 150 to 300 feet above ground level before becoming mostly bent over, although some plumes have a significant amount of smoke remaining within a few hundred feet of the ground.

Collectively, as groups of multiple fires within oilfields with a high density of burning wells (particularly Greater Burgan), they assert a meteorological influence of their own. It is suggested that the grouping of fires with a horizontal diameter of 25 to 40 km provides enough of an intense "heat-island" that significant additional vertical rise of the smoke occurs inside the area. That additional plume rise lifts smoke to elevations often 1000, 1200, to 1500 m above ground within the initial few miles downwind. Eventually, portions of the smoke rise even more, with multiple layers often forming at heights up to 2400, 2700, 3600, to 3900 m. Between such layers and at the tops of layers many tens of miles downwind, a generally diffuse and homogenous zone of smoke has been observed. The eventual smoke height limits are bounded by the regional vertical temperature structure and synoptic weather characteristics. Information reviewed to date suggest that those maximum heights are mostly 2400 to 3600 m within the initial 150 to 300 km downwind from the Kuwaiti oilfield fires.

With the creation of a local heat-island, a distinct inflow of near surface air has been observed within the initial 500 to 1000 feet above ground level. At times, that inflow of wind is estimated to be 5 to 15 m/s in strength. Smoke plumes at the peripheral bounds of the burn area tend to slant inward toward the centre of the burning field instead of pointing downwind with direction of the expected ambient wind.

Local variations in daily wind flow, along with the fire-storm like winds, are likely to produce preferred locations and times of day at which more concentrated smoke plume exposures reach ground level. Prevailing winds are from the northwest throughout the year. During the daytime a sea breeze can be expected to develop at the Gulf shoreline and progress inland as the day progresses. That inflow of air can readily clear out the smoke plumes and yield substantially cleaner air at ground level on the Gulf side. Along the leading edge of the sea breeze front there likely may be a zone of extended and elevated exposures to fire effluent. That zone may well extend down the shoreline from Kuwait City some 100 km. The area of greatest susceptibility appears to be to the southeast of fires in the Al Ahmadi oilfield (part of the greater Burgan field).

## 2.3 Data Base Management

In addition to evaluating the existing air monitoring networks, the Team made an initial review of existing data systems to handle the air monitoring data. The previous meteorological, air quality, and visual observations of the oilfield fire plumes should be archived, along with data to be obtained during the period of on-going Kuwaiti fires. A dedicated facility for the performance of that archiving does not appear to exist. The data management task is likely to be a sizeable task and extend a period of a year and more.

Some of the general functional needs of the data management system include the following. The data which will need to be assembled into the data base will likely come from many different sources and exist in diverse formats and media. One role of the data base management activity will be to assemble all information into a common, uniform structure. The second and equally important part of the data archiving is the provision of a uniform and consistent mechanism for the retrieval of data by participating agencies. The degree to which that data base is well formulated, will significantly affect the efforts of users of the data as they attempt to study and interpret the measurements.

A number of possible methods exist for the set-up of a computerized data base. Commercial software and hardware of various degrees and complexity and cost exist which would satisfy the data management needs. Before the choices of system software and hardware are made, the functionality of the overall system and the manners in which users work with the data sets should be considered. For example, it may be required that the data base be a "relational" data base. Other sources of software that might be used to handle a large volume of data would be the U.S. Environmental Agency's (USEPA) Aerometric Information and Retrieval System. That system can handle hourly data and has considerable software available to both summarize and analyze the ambient air data.

MEPA has asked the Team to recommend the type of computer and associated software needed to manage the data collected in order to implement the monitoring plan. For now, it is more appropriate to defer specific recommendations. A number of general performance characteristics may be stated but specific details should be formulated in conjunction with data base specialists at a later date.

## 3. RECOMMENDATIONS

While preliminary, the Team believes that the following recommendations should be implemented based on our initial data gathering exercise. A general objective is listed as a recommended goal and below that objective are listed several needed items or activities to facilitate the achievement of the overall goal.

Objective 1

Provide a framework for an early warning advisory capability for areas expected to be impacted by effluents from Kuwaiti oilfield fires.

Needs:

a. Meteorological data observations and forecasts;
b. Visual observations from key receptor areas;
c. Review existing monitoring data;
d. Calculate smoke trajectories and concentrations.

Objective 2

Provide a cursory wide-area indication of the distribution and composition of the Kuwaiti oilfield fire effluents.

Needs:

a. Establish 15 to 20 $PM_{10}$ monitoring locations using portable monitors;
b. Train personnel in the operation of the portable $PM_{10}$ monitors and develop the analytical support capability within Saudi Arabia and Kuwait;
c. Define the $PM_{10}$ to TSP ratios;
d. Define the composition of the plume by XRF analysis for metals, and GC-MS analysis for limited organic identification;
e. Establish a central media preparation and analysis location;
f. Define the baseline contribution of the ambient aerosol from the surrounding desert.

Objective 3

Characterize the aerial smoke plume.

Needs:

a. Collect by fixed or rotary winged aircraft many of the same plume measurements recommended for the ground monitoring array;
b. Correct descriptions of the width and vertical extent of the smoke plume at several downwind distances;
c. Characterize the regional background by samples outside of the smoke plumes.

Objective 4

Develop a more complete profile of the smoke plume constituents

Needs:

a. Procure equipment for a limited number of comprehensive air quality monitoring stations to collect: TSP, $PM_{10}$, organic, and inorganic constituents;
b. Establish a limited number of comprehensive air quality monitoring stations to collect: TSP, $PM_{10}$, organic, and inorganic constituents. These should be collocated with the continuous monitors wherever possible;
c. Train individuals to operate and maintain the sampling instrumentation in support of the monitoring programme;
d. Procure the necessary analytical laboratory equipment required for analyses of the samples collected under this objective;
e. Train laboratory personnel in the preparation of the sampling media, QA/QC procedures required and the subsequent sample analytical procedures.

Objective 5

Determine the need for expansion of the monitoring network to a wider regional coverage.

Needs:

a. Review the data developed from the limited network;
b. Assess the current and projected status of control of the oilfield fires and emissions;
c. Review the population health survey statistics;
d. Review the suitability of the sampling strategy, and modify where needed;
e. Expand the limited network as the situation requires, data analysis indicates an additional need for data.

Many of the same considerations listed for air quality above also apply to meteorological considerations.

Objective 6

Provide a meteorological data stream to facilitate the modelling and prediction of areas expected to be impacted by effluents from Kuwaiti oilfield fires.

Needs:

a. Upper air balloon sounding data representative of the Kuwaiti oilfield fire area and Gulf region plume transport;
b. Supplemental surface based measurements of wind speed and direction, temperature, moisture content of the air (dew point, relative humidity, etc.), solar radiation, atmospheric pressure, precipitation.

Objective 7

Provide a meteorological data set to investigate the areas of climate modifications occurring due to effluents from Kuwaiti oilfield fires.

Needs:

a. Supplemental surface based measurements diffuse and direct solar radiation;
b. Special collections of precipitation throughout the region to examine the pH and chemistry of the rains;
c. Aircraft soundings and profiles of smoke, winds and temperatures, air quality related measurements of plume compositions and concentrations representative of the Kuwaiti oilfield fire area and Gulf region transported plumes.

4. PHASED AIR MONITORING PLAN

This section of the report discusses a prioritized plan of stepwise incremental actions for the phased implementation of the recommendations discussed above. Five phases for implementing the plan follow.

4.1 Phase 1. Provide a Framework for an Early Warning Advisory

In order to accomplish this task, the following action items need to be initiated or incorporated into the task framework.

1. Gather daily weather forecasts to predict meteorological conditions which would effect pollution potential in both Saudi Arabia and Kuwait;

2. Use visual observations from key receptor sites to determine possible pollution levels;

3. Gather existing air monitoring data from fixed and mobile sites operated by MEPA, Saudi ARAMCO, and the governments of Kuwait and Bahrain to develop a data base of existing data;

4. Establish a daily briefing for representatives of the many entities concerned with behaviours and fate of the aerial effluents from the oilfield fires in Kuwait;

5. Develop a daily map depiction of the aerial distribution of the smoke plumes across the region using satellite imagery, for each day since initiation of the oilfield fires;

6. Issue a daily general statement about the expected behaviour(s) of the oil fire plumes. Areas of potentially adverse conditions could be treated as locations for which advisories would be issued;

7. Provide forecast meteorological conditions across the region for the next 2 to 3 day period, including the expected location(s) of the smoke;

8. Obtain data from the MEPA network throughout the eastern province;

9. Direct the crews of the SLAR aircraft (USCG Falcon Jet) to continue on a regular basis the present visual observation and mapped notations concerning the horizontal extent of the smoke plumes and the estimations of altitudes of layer bases and tops;

10. The above information could be compiled initially in hard copy form. Later it should be stored on electronic media in a way that an existing PC data management system could readily incorporate it.

4.2 Phase 2. Establish a $PM_{10}$ Monitoring Network Using Portable $PM_{10}$ Monitors

Working in conjunction with the Saudi Arabian Meteorology and Environmental Protection Agency (MEPA), the proposed plan has been developed to collect information on $PM_{10}$, which represents particulate matter with particles less than 10 microns in diameter. At the present time there is no $PM_{10}$ monitoring in the Gulf region.

OBJECTIVES

The objectives for this effort are as follows:

1) Determine the magnitude or the health threat to residents of population centres and field-based military personnel impacted by the oilfield fires and typical sources (windblown desert soils);

2) Establish a scientifically based capability to alert these affected populations prior to the onset of the potential health threats from real-time measurements;

3) Establish a technical basis for executing predictive air quality dispersion models which simulate the oil well fire emissions, background sources, and consequent impacts over space and time;

4) Establish a regional network of $PM_{10}$ stations using a consistent monitoring methodology across the countries of Saudi Arabia, Kuwait, and Bahrain;

5) Train personnel to operate and analyze the media produced by the network from each of the participating countries;

6) Develop a regional data base and encourage the sharing of data developed from the network with all participants;

The above objectives convert the foregoing goals into discrete actions:

1) Determine the spatial temporal frequency, and severity of the impact to the resident populations and military centres affected through the application of saturation sampling techniques with portable $PM_{10}$ samplers;

2) Establish the correlation of real-time surrogate monitoring data to data generated from direct sampling methods through the collocation and simultaneous operation of both methods over time;

3) Where possible use impact data collected from samplers as an input to the dispersion model, run the model "backwards" to develop a better estimate of the emission rates of the fires and produce a higher level of confidence in the predictive modelling results;

4) Obtain from the literature and/or develop from source sampling analysis chemical profiles of all major pollutant sources in order to:

a) Identify those contaminants that pose the greatest health concerns and to develop an estimate of acceptable ambient levels (AALs) prior to the conduct of field work,

b) identify the chemical "signature" of the major contaminants and other tracers characteristic of the primary sources,

c) enable apportionment of these contaminants and other tracers compounds from a simple total mass concentration measured by the ambient samples, and

d) attempt to relate these levels in turn to the surrogate real-time monitoring methods for use in issuing timely health risk alerts;

5) Ensure that the data generated by the network are of a demonstrably high quality (precision & accuracy), completeness, representativeness, and comparability.

APPROACH

Conduct a $PM_{10}$ saturation sampling study to determine the temporal and spatial features of the impact of the oil well fires and attempt to reconcile the data with existing model estimates. $PM_{10}$ mass concentrations would be available within 24-48 hours following sampling. No on-site meteorological, gas, or aerosol monitoring or chemical analysis is required (chemistry could be attempted later on the preserved media). One or more portable nephelometers would be collocated at several sampling sites to develop correlations between manual and continuous (real-time) methods for alert advisories.

A total of 15-20 portable $PM_{10}$ samplers equipped with quartz filters would be run simultaneously on a daily basis or "triggered" (impact forecast) basis throughout the study area. Network design would involve a "nested" approach to address the objectives:

1) samplers sited at background locations (not impacted) by the smoke plume and samplers in populated areas;

2) samplers in populated areas impacted by smoke.

Samplers could be "ganged" (2 or more) and programmed to run consecutively at individual sites if filter clogging problems occur because of high loading. Further, multiple samplers could be collocated at certain sites to collect fine particles (less than 2.5 microns) and coarse particles (2.5-10 microns) on teflon sample filters (facilitating XRF elemental analysis). One of the 10-12 sampling sites would be equipped with duplicate samplers in an effort to develop sampling precision estimates.

This comprehensive programme will yield the following:

1) short turnaround $PM_{10}$ concentrations;

2) gross estimates of the fire-specific contributions to total mass could be derived by subtracting background concentrations from the impact site concentrations;

3) applying assumptions on the source profiles to pollutant loading attributable to the well fires, estimates of individual target compound loadings could be computed and a comparison to AALs made;

4) correlations factors can be determined between real-time surrogate methods and manual methods, and

5) impacted sampling media would be available for subsequent intensive chemical analysis in an attempt to reconcile assumed source signatures and extracts can be used to perform any other analytical tests (mutagenicity). Special precautions may be needed to preserve the sample integrity during storage and transfer.

Limitations: potentially, no on-site meteorological data to calculate emissions rates, no on-site chemistry (unless developed) to confirm critical assumptions, and no concurrent gas or acid aerosol measurements to evaluate or correlate with the particulate data.

Resources: 1-2 professionals, 1 field technician per site, if it must be operated individually (actual number contingent upon the network logistics and potential "clogging" implications), portable $PM_{10}$ saturation samplers, portable nephelometers, lap-top computer, microbalance, expendables and sundry support gear.

In summary, this approach is $PM_{10}$ mass data- and assumption-rich which must be reconciled with a poor and broad pollutant characterization.

SAMPLING AND ANALYTICAL METHODS

The alternate approaches identified above involve the use of a variety of sampling and analytical methods summarized below:

Portable $PM_{10}$ Saturation Samplers

- segregate and capture of filter, particles of 10 micron size (respirable particles) and smaller;
- battery-operated, lightweight, rugged, inexpensive, small, and quiet;
- easily deployed and operated;
- programmable timer for unattended on and off;
- rechargeable battery packs;
- continuous operation up to 30 hours on a single charge;
- precise and accurate;
- low detection limit of approximately 5 $\mu g/m^3$
- sustained operation under high particulate loadings, e.g. 1000 $\mu g/m^3$ or more;
- electronic sample flow regulation;
- electronic sample flow totalizer;
- low flow shutoff/warning;
- can accept a variety of other pollutant sampling media (e.g. PUF, DNPH, charcoal, denuders, etc.) or take whole air samples (Tedlar bags) with little or no modification.

Portable Nephelometers

- many of the same attributes of the $PM_{10}$ saturation sampler;
- battery operated;
- effectively measure particles of 1 micron diameter or smaller;
- continuous reading, storing five minute averages;
- rechargeable;
- continuous operation from 24-48 hours on a single battery charge;
- internal storage for up to nine days of sampling data;
- data download to a portable lap-top computer through RS232 serial port;
- operationally equivalent to standard nephelometers.

Microbalance

- five to six place balance;
- rugged, transportable while precise and accurate.

Field XRF Unit

- similar MQLS with in-situ laboratory units;
- rugged.

Support Gear

- calibration and audit gear, tools and diagnostic equipment, etc.

PROPOSED NETWORK DESIGN

The recommendation for siting of the portable $PM_{10}$ samplers is predicated on providing a large area of coverage for developing a better estimate of the areas impacted by the plume, a cross-sampling of population and troop centres, and to provide the opportunity to transfer this technology to Saudi Arabia, Kuwait, and Bahrain.

SAUDI ARABIA

- collocated site at K.F.U.P.M. (2 sites);
- two sites in Riyadh (1 U.S. Embassy & 1 MEPA location);
- one site collocated with one of the Royal Commission for Jubayl and Yunbo sites;
- one site Saudi ARAMCO at Tanajib;
- one site MEPA at Khafji.

Total of seven (7) sites.

KUWAIT

- three sites (3) located at the two operational continuous monitoring sites within Kuwait City (one site collocated);
- one site at Camp Freedom;
- One site U.S. Embassy;
- One site Al-Ahmadi (Kuwait Oil Company Hospital).

Total of six (6) sites.

CENTCOM

- two sites at selected troop locations.

Total of two (2) sites.

BAHRAIN

- one site to be determined.

Total of one (1) site.

A total of sixteen samplers are committed to field sampling with the remainder as spares or as changes to the sampling plan dictate.

DATA MANAGEMENT

The data base created by this special $PM_{10}$ network could be stored and analyzed using existing PC software.

4.3 Phase 3. Characterize the Aerial Plume.

This phase should follow closely with Phase 2, in order to characterize the 3-dimensional nature of the smoke plumes from the fires in Kuwaiti oilfields. To achieve that goal, many of the same plume measurements collected by the existing and proposed ground level measurement locations should be provided by the aerial sampling platform. Obviously, the longer time integrated samples (e.g., 24 hour total values, averages, etc.) cannot be reproduced by aircraft borne devices. Short-term and across plume integrated measurement descriptions may be obtained to characterize the spatial extent and details of actual constituents of the elevated portions of the oil fire plumes.

The aerial sampling activities may be separated into measurements which address the three general zones of plume characteristics, from a meteorological sense. Those zones are the 1) close-in zone, 2) intermediate or transition zone and 3) extended or distant zone. Measurements very near the wellhead are difficult to impossible to obtain due to excessive heat and great levels of turbulence. Measurements at intermediate distances will be difficult and many locations within the clustered groups of burning wells may be unsafe for aerial traverses due to the extremely dense smoke and hidden turbulent plumes. Measurements at the longer distances, a few miles downwind of the last burning wells, should be possible. Measurements from a few to several hundred miles downwind of the fire area should be feasible. Within that distance range the approximate concentrations, plume dimensions, and estimated mass flux in the downwind directions may be approximated. The aerial sampling strategies should concentrate on the obtaining of those types of information.

4.4 Phase 4. Develop a Complete Profile of the Smoke Plume Constituents.

Obtain additional equipment to expand existing continuous monitoring high priority sites in Kuwait and Saudi Arabia

The survey conducted by the Team during Phase 1 of this plan indicated that within the region, respirable particulate sampling technology, aerosol and total particulate sampling and analysis for volatile organic compounds (VOC), semi-volatile organic compounds (SVOC), and PAHs were either not available or insufficient to properly characterize the effects of the oil well fires on the population centres and the troop concentrations within the region.

This phase of the plan proposes to bring into the region several new technologies and to train personnel within the region to operate samplers, to condition, and analyze the several new media necessary to support this expanded network. The objective of this process is to develop a stand-along capability within each participating country for aerosol and particulate monitoring which will support the Gulf regional air quality characterization and index plan outlined in Phase V.

During this phase of the plan the Team proposes to expand the continuous air and meteorological monitoring currently being conducted within the region at six sites. These sites are recommended based on the need to jointly develop the sampling and analytical capability within the region to ensure that it becomes self-sufficient and sustainable. The particular technologies outlined below are not currently operated within the region nor are the analytical procedures required to support them currently being utilized. However, the Phase I survey indicates that with sufficient training, additional equipment, and some experience with actual field samples the transfer should be relatively smooth.

Initially, the Team's recommendation of six strategically placed sites along the axis of the area of greatest impact by the oil well fire plume will generate sufficient samples for the required training, while also providing critical data not currently being collected by the existing networks or available through the portable $PM_{10}$ network proposed in Phase II. As this data base develops it can be used to better define the constituents of the plume and thus permit a more accurate assessment of the potential long-term health risk.

The equipment listed below should be collocated with the full compliment of continuous air and meteorological monitors described in Phase V at these six proposed sites. A brief description of the equipment is provided below:

- TSP High Volume Sampler - used to collect a 24-hour sample of the total suspended particles, operated nominally at 50 CFM, and typically uses 8x10 inch glass fiber or quartz filter media;

- $PM_{10}$ High Volume Sampler - used to collect a 24-hour sample of the 10 micron and smaller sized fraction of the TSP sample collected by the TSP sampler above, sampler is typically operated at 40 CFM, and utilizes an 8x10 inch Quartz or teflon filter media. Note: glass fiber media should not be used if there is concern for a known sulfate artifact formation problem;

- $PM_{10}$ Manual Dichotomous Sampler - used to collect a 24-hour sample of the 10 micron particle size fraction of the TSP, sampler operates at 16.7 liters/minute, and utilizes two (2) 37 mm diameter Teflon filters to collect a fractionated sample with a cut point of 0-2.5 micron (fine fraction) and 2.5 - 10 micron (coarse fraction);

- VOC Canister Sampler - used to collect up to a 24-hour integrated whole air sample in six-liter evacuated stainless steel canisters, interior walls are passivated to minimize sample degradation, samples volume can be regulated by either limiting the volume to ambient pressure or pumping in addition sample to an approximate volume of 16 liters, these samples can be used for the determination of total hydrocarbons or analyzed for specific hydrocarbons, multiple analysis are available from a single pressurized canister sample. Note: An extensive canister cleanup process is required prior to the collection of additional air samples;

- Polyurethane Foam (PUF) Low Volume Sampler - used to collect 24-hour aerosol samples utilizing small AC or battery operated pumps at flow rates less than five liters per minute on relatively small glass cartridges containing a PUF plug, these samples can be extracted and analyzed for PAHs, or other SVOCs. Note: Both the glass cartridge and PUF plug require an extensive cleanup procedure prior to re-use;

- Optional Tenex/Charcoal/XAD-2 tubes - these media can be used with same type of low volume pumps described above to collect additional samples for further definition of the constituents of the plume for SVOCs.

Organic compounds will be present in all three phase distributions (particle bound, SVOC, and VOC) and each phase will have to be sampled and then a determination will have made as to importance of each.

The particle bound phase can be collected for extractible organic analysis from both quartz, teflon impregnated glass fiber filters, or teflon.

The SVOC phase can be collected on PUF and within the canister. The VOC phase can be collected with canisters and charcoal tubes. Employment of Tenex and XAD-2 sampling tubes in conjunction with PUF, charcoal tubes, and canisters in an overlapping sampling matrix, can be used to confirm of the presence or absence of compounds which could be missed by a less complex sampling matrix.

PROPOSED LOCATIONS FOR THE INITIAL SIX EXPANDED SITES

The Team recommends that the six locations follow the general axis of plume drift from Kuwait City south into Saudi Arabia. It is further suggested that the operation of these sites be divided amongst the key network managers within the two countries: Kuwait, MEPA, and Saudi ARAMCO. This division of responsibility supports the philosophy to jointly develop both the sampling and analytical capability within all three entities.

Kuwaiti Locations

The Team recommends that two (2) of the sites be located at the existing operational continuous monitoring stations located in Kuwait City. A third site should be established in Al-Ahmadi at the Kuwaiti Oil Company Hospital. This location is situated within 300 - 400 m of several burning wells and is adjacent to the closest residential area associated with any of the oilfields.

Saudia Arabian Locations

The Team recommends that a site be established at King Fahd University of Petroleum and Miners (K.F.U.P.M.) in Dhahran, one site to be collocated with Saudi ARAMCO site in Tanajib and the last site should be established by MEPA in Khafji.

4.5 Phase 5. Develop Regional Air Monitoring Network to Track the Impact of the Kuwaiti Oil Fires on the Gulf Region.

This phase of the proposal will be developed in series of stages. The network is directed at long term fixed site monitoring, which will collect a battery of both air quality and meteorological data that would satisfy the objectives identified in this report. Particular attention will be given to providing an early warning system advising the effected public on what cautionary steps should be taken to minimize the impact of air pollution on health. It is proposed that the early warning system will be modelled after the air quality index used in the U.S.A.. The second focus will be directed at tracking the air pollution problem over time to be used in determining both long term health and ecological impacts due to the Kuwaiti oil fires. The data base will provide information to develop key policy decisions which could minimize the possible health and ecological impacts.

RECOMMENDED MEASUREMENT PARAMETERS AT EACH SITE

The basic plan is for each site within the regional monitoring network to consist of the same types of measurement devices. Deviations for that general consistency will be addressed on an individual basis. Two general categories of information are proposed for every location. Data measurement are grouped into either meteorological or air quality categories.

a. Meteorological variables

The nominal set of meteorological measurements to be collected at each site are the following:

Wind speed and direction (at 10 m);
Temperature;
Moisture content of the air;
Dew point, relative humidity, or wet bulb;
Solar radiation;
Precipitation (saved for chemical analyses, pH, etc.).

b. Air quality variables

The nominal set of air quality measurements to be collected at each site are the following. Two general categories of collection needs exist. The first set of needs relate to the onset of episodic levels of airborne concentrations. In those situations a need may be developing for an early warning advisory for downwind population centres. The second set of needs relate to the need to monitor for longer term, more subtle risks.

| Episodic/EARLY WARNING measurements | | Longer term monitoring |
|---|---|---|
| $PM_{10}$ | (continuous) | Acid aerosols |
| TSP | | VOCs |
| $SO_2$ | (continuous) | Aldehydes |
| $O_3$ | (continuous) | BaP, other PAHs |
| NOx, NO | (continuous) | Trace elements |
| CO | (continuous) | Fine particles |
| $H_2S$ | (continuous) | |

c. Health Monitoring Survey

Air monitoring data collected through the proposed air monitoring network will provide basis for interpreting the results of health surveys of the populations and ecosystems potentially effected by the effluents from the oil fires in Kuwait. The kinds of health data that could be collected include:

TABLE 2 - Location of existing air meteorology monitoring stations

| NATION | ORGANIZATION | LOCATION | STAGE OF IMPLEMENTATION |
|---|---|---|---|
| SAUDI ARABIA | MEPA | Damman | 1 |
| | | Hofuf | 2 |
| | | Tanagib (Mobile Site) | 1 |
| | | Riyadh | 1 |
| | Saudi ARAMCO | Udhailiyah | 3 |
| | | Shedgum | 3 |
| | | Abqaiq | 3 |
| | | Dhahran | 2 |
| | | Tartut | 2 |
| | | Rahimah | 2 |
| | | Juaymah | 1 |
| | | Tanajib | 1 |
| | | Safaniyah Oilfield (met. only) | 3 |
| | | Marjan Oilfield (met. only) | 3 |
| | | Abusafahs Field (met. only) | 2 |
| | The Royal Commission for Jubyayl and Yunbo | Cluster of 5 stations in Jubyayl | 1 |
| KUWAIT | | Mansoria | 1 |
| | | Rabia | 1 |
| | | Rega | 1 |
| QATAR | | 3 mobile units, unknown locations | 2 |

Health questionnaires;
Blood samples;
Urine samples;
Hair samples;
In-vivo animal studies;
Forced expiratory volumes;
Other morbidity parameters.

Distribution of Proposed and Existing Air Monitoring Sites

Table 2 lists the location of the existing and proposed air monitoring sites, while Table 3 lists the locations of the proposed air monitoring sites. In order to complete the network in an orderly manner, it is proposed that the network be developed in several stages. The first order of business would be to upgrade key existing monitoring locations so that there exist a full complement of air and meteorological monitoring equipment, as well as add new critical air monitoring sites (Stage 1). The second stage would be to establish those sites that would satisfy the minimum requirements for tracking the plume caused by the oil fire and to provide an early warning system for Saudi Arabia, Kuwait, and Bahrain (Stage 2). The third and final stage would be to complete the final network following a review of the quality and quantity of findings to date (Stage 3).

5. SUMMARY

The initial measurements made by the Team suggest that there is not an imminent threat from $SO_2$ and $H_2S$ to the urban populations, while short-term measurements of particles are frequently high. Historically, this region has high particulate levels due to wind blown dust. The particulate measurements that were collected by the Team reflect total particles, as opposed to respirable particles, that is $PM_{10}$. There has not been a principal focus in the Region on total particles, $PM_{10}$, and organics up to now. Therefore, the Team developed the five phased monitoring plan with an emphasis on better understanding particulates and the aerosol organics associated with the oil fires in Kuwait. Particulates and organics could be a source of concern for both health and ecological effects.

The air monitoring proposals presented in this report represent the Team's collective judgement on what needs to be done. Those judgements are based upon an on-site evaluation of the situation in Kuwait, discussions with officials from the Saudi Arabian MEPA, Kuwait, Saudi ARAMCO, and the King Fahd University of Petroleum and Minerals. Needless to say more work is needed regarding data management, statistical design, data analysis and quality assurance. Because of the complexity and immediacy of this problem, an extended time commitment will be needed on the part of all Gulf nation agencies to achieve the objectives outlined here.

TABLE 3 - Location of proposed air meteorology monitoring stations

| NATION | ORGANIZATION | LOCATION | STAGE OF IMPLEMENTATION |
|---|---|---|---|
| SAUDI ARABIA | MEPA | Awiyah | 3 |
| | | Shumlul | 2 |
| | | Sarrar | 2 |
| | | Nuayriyah | 2 |
| | | Lisafah | 3 |
| | | Hafar al Batin | 1 |
| | | 28°6' N 47°51' E | 2 |
| | | 28°30' N 48°1' E | 1 |
| | | 28°55' N 47°32' E | 1 |
| | | 29°7' N 46°39' E | 1 |
| KUWAIT | | Mina Saud | 1 |
| | | U.S. Embassy | 1 |
| | | Al Ahmadi (Hospital) | 1 |
| | | International Airport | 1 |
| | | 29°23' N 46°55' E | 2 |
| | | 29°50' N 47°15' E | 2 |
| | | 30°4' N 47°42' E | 2 |
| | | 29°33' N 47°50' E | 2 |
| BAHRAIN | | Mina Manama | 2 |
| | | Bahrain University | 2 |
| QATAR | | Doha | 3 |
| UNITED ARAB EMIRATES | | Abu Dhabi | 3 |
| | | Dubai | 3 |
| OMAN | | Muscat | 3 |

# ENVIRONMENTAL IMPACT OF OIL BURNING IN THE KUWAITI OILFIELDS - A PRELIMINARY EVALUATION

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## SUMMARY

It was reported in the second week of February 1991 that about 200 oil wells were put on fire in Wafra, Umm Gudair, Minagesh Burgan, and Romeilla oil fields in Kuwait. These numbers increased to above 600 by February 24 with the addition of more wells on fire in Raudhatain, Sabriya, and a large area of Burgan oil-fields. It is estimated that approximately 2.5 million barrels of crude oil and 35 million cubic meters of associated gases are on fire emitting approximately 20,000 tons of sulfur dioxide ($SO_2$), 1500 tons of particulates, 250 tons of carbon monoxide (CO) and 500 tons of oxides of nitrogen (NOx) to the atmosphere on daily basis. In addition to these, tons of toxic metals and carcinogenic elements are also being released into the atmosphere.

The above pollutants in high concentration may cause serious health problems. So far the measured concentration of these pollutants in major cities in Saudi Arabia have been found within the permissible limits as recommended by MEPA. However, simulation study shows very high concentration of these pollutants, particularly $SO_2$ in Kuwait City, Mina al Saud, Mina al Ahmadi, and Bubayan and Faylakah islands. Depending upon wind direction and wind speed, high concentration of $SO_2$ has been estimated few times in cities such as Khafji, Safaniyah, and Basrah. Since it may take several months to extinguish these wells, it is important to understand the impact of these pollutants on human health.

In order to assess the environmental impact of burning of oil wells, both modelling and monitoring programs have been initiated by the Research Institute at King Fahd University of Petroleum and Minerals (KFUPM/RI). The Institute, in addition to its own monitoring program, has also been compiling ambient air pollution data from various sources such as Saudi ARAMCO, Royal Commission for Jubail and Yanbu, and the Meteorology and Environmental Protection Administration (MEPA).

This report summarizes various activities being conducted by KFUPM/RI in collaboration with the Meteorology and Environmental Protection Administration (MEPA), US Air Team, Ministry of Health, and Saudi Arabian American Oil Company (ARAMCO).

## INTRODUCTION

Burning wells in Kuwait are producing large amount of gases such as sulfur dioxide, carbon monoxide, hydrogen sulfide, carbon dioxide, and oxides of nitrogen as well as particulates containing partially burned hydrocarbons and metals, all of which have a potential for affecting human health and vegetation growth. Particularly harmful gases are sulfur dioxide and the nitrogen oxides. Photochemical reactions between the nitrogen oxides and hydrocarbons produce oxidants of secondary pollutants which may also affect vegetation.

The chronic effects of the air pollutants increase the death rate among the elderly and chronically ill people. The moderate effects may cause increase of prevalence of eyes and respiratory irritation. Epidemiological data suggests an association between increased concentration of $SO_2$ and particulate matters. Sulfur dioxide, being a very soluble gas, is absorbed in the nose and upper airway while breathing which, in turn, produces increased airway resistance in the lung. High doses of $SO_2$ i. e. 2 to 5 ppm (5200 to 13,000 micrgram/cum) may cause severe impairment of lung functions. In some cases, a healthy person without any previous history of asthma may develop a moderately severe attack of the disease. Chronic cough and mucus secretion may result from repeated exposures.

Of several oxides of nitrogen present in the ambient air, only two are known to affect human health. These are nitric oxide and nitrogen dioxide. These oxides, if transferred across the lung-blood barrier, can produce inactive forms of hemoglobin. It is estimated that eye and nasal irritation will develop after exposure to about 15 ppm nitrogen dioxide and pulmonary discomfort will commence after brief exposure to 25 ppm.

Upon entering the respiratory system, carbon monoxide (CO) combines in the lung with hemoglobin in the bloodstream to form carboxyhemoglobin (COHb). This reduces the capability of hemoglobin to carry oxygen to the body tissue.

Sulfur dioxide concentration above 0.5 ppm for a maximum exposure time of three hours may cause visible injury in most temperate crops. Atmospheric sulfur dioxide can enter leaves and can be absorbed by the roots. Prolonged exposure to high concentrations of sulfur dioxide can be lethal to some plants depending upon a variety of environmental conditions. Oil burning in Kuwait may cause an increase in atmospheric acidity. Photo-oxidation of sulfur dioxide is enhanced by the presence of moisture and results in the formation of sulfuric acid. Similarly nitrogen oxides may also contribute to acid rain. Should burning of the oil wells in Kuwait continues unabated for some time, adverse impacts on regional vegetation may occur.

Oil burning will release metals in the smoke. High concentrations of some of these metals, such as nickel and vanadium, are toxic to both plants and animals. The availability of toxic elements to crop plant may increase due to acidification of the soils through acid rain.

The release of huge amount of toxic gases and other oil hydrocarbon compounds into the atmosphere as a result of burning of the Kuwaiti oil wells, may result an adverse health hazard if the level of polynuclear aromatic compounds (PAHs) in the atmosphere increases. These compounds have both mutagenic and carcinogenic properties.

This paper summarizes various monitoring and modeling activities to assess the impact of the pollutants due to burning of well in the Kuwait oil fields.

## REMOTE SENSING APPLICATION IN IDENTIFYING BURNING OIL WELLS

The image processing facilities at KFUPM/RI has been used in identifying the locations and number of burning oil wells in the Kuwaiti oil fields. Among the various oil fields, the Burgan is the largest one with more than 600 wells. The average daily production rate of each well is approximately 4,000 barrels. The National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (A VHRR) computer compatible tapes were received from NOAA/NESDIS, USA. These tapes were digitally processed at the Image Processing Center using the thermal infrared band 3 which is designed to record intense heat sources such as volcanoes and fires.

The fire at Greater Burgan increased slightly by January 29, 1991. On February 4, 1991, number of fires in Kuwait increased while on February 7, 1991, the fires at the Greater Burgan and Umm Gudair oil fields increased substantially. Fires reached peak on February 24 Landsat TM band 6 of February 23, 1991 showed more than 300 wells on fire in the Greater Burgan field.

Based on the information through satellite imagery processing and other sources, the number of wells on fire in different oil fields with their capacities were estimated about 600. Their locations, capacities, and distributions are listed in Table 1. Using US EPA emission factors for crude oil and associated gases (Ref. 1), the total emission of $SO_2$, $NO_x$, CO, and particulates were compiled and listed in Table 2.

The total suspended air particulates collected in March 1991 using high volume samplers on three locations in the Eastern Province of Saudi Arabia (i.e. Dhahran, Tanajib, and Nuayriyah) were analyzed for toxic metal concentration and oil hydrocarbons including some carcinogenic organic compounds. The metals covered in this study were arsenic, cadmium, cobalt, barium, chromium, copper, manganese, lead, and titanium while the organic analysis was conducted mainly for the aliphatic hydrocarbons and polynuclear aromatic compounds. Metal concentrations were determined using Inductively Coupled Argon Plasma Analyzer (ICAP). The concentrations of arsenic were determined using hydride generation technique. The aliphatic hydrocarbons were analyzed using a Varian 6000 Gas Chromatograph (GC) equipped with FID detector while the polynuclear aromatic compounds were analyzed using HPLC system equipped with UV and fluorescence detectors.

The findings, although preliminary due to limited number of samples, are summarized below:

1. Samples collected from Nuariyah, a bordering city near Kuwait, contained relatively high concentration of most of the metals. Barium zinc, lead, and copper were found high in Dhahran samples.

2. The analysis showed that all of the air particulate filters were contaminated with the aliphatic and polynuclear hydrocarbons. Analysis carried out previously on particulate samples collected from the same locations showed significantly low concentration of PAHs compounds. It is worth mentioning that the levels of PAHs found on March 5, 1991 was much higher than those found on other dates.

The concentration of the total suspended particulates in March on 24-hour basis was found in the range of 50 microgram/cum to about 300 microgram/cum in Dhahran area.

Soil samples were also collected from different locations in March and April and were analyzed for nickel and Vanadium. The concentration of metals decreased with an increase in the distance from the border. Kuwaiti crude oil contains 10 mg/kg and 30 mg/kg of nickel and vanadium respectively. Atmospheric fallout from Kuwait oil fields seem responsible for distance - metal concentration correlation.

Real time measurements of various pollutants in the ambient air are being carried out on continuous basis in Dhahran, Abqaiq, Rahimah, Jubail, and Tanajib. By analyzing the measured values at these locations, no significant impact of the burning of oil wells in these areas has been observed. Other pollutants although not reported here, were much lower than their respective limits as specified by MEPA. The standard specified by MEPA are listed in Table 3.

Short-duration measurements were also carried out by the US EPA and British scientific team in Kuwait area and also in the plume. The highest SO2 concentration reported by these team was less than 2 ppm. MEPA has moved one of its mobile laboratories to the bordering Saudi cities for continuous monitoring.

## MODELING ACTIVITIES

In order to assess the impact of burning of oil wells, the modeling activity has also been initiated. A number of available air pollution modelling packages were reviewed. The following two types of air pollution modeling packages are currently being used by the Research Institute:

### 1. UNAMAP's RAM Model

The institute has initiated the application of RAM (a multiple-point and area-source algorithm), a software within Users' Network for Applied Modeling (UNAMAP) to assess the impact of burning of oil wells in the Kuwaiti oil-fields. This package requires surface meteorological data on wind speed and direction, temperature, mixing height, and stability classes on hourly basis (Ref. 2-3).

The estimated concentration of $SO_2$ on 1-hourly and 24-hourly basis at the selected receptor points (cities) for the same period is listed in Table 4. These concentration values are compared with the standard specified by MEPA as listed in Table 3. Similar analysis is conducted on daily basis and the periodic status report is prepared and submitted th MEPA on regular basis.

### 2. ARL-ATAD Model

$SO_2$, once released to the atmosphere, is dispersed vertically in the mixing layer. Once $SO_2$ is completely mixed within the transport layer depth or mixing depth, further dilution in the concentration is due to horizontal dispersion, subsidence of clean air into the mixing depth, and removal and transformation processes (Ref. 4). The removal of $SO_2$ due to dry deposition on the ground is related to the deposition velocity. The processes by which the removal of $SO_2$ under wet conditions occur are rainout and washout. Rainout is the absorption of airborne material within a cloud, followed by removal in rain. Washout is the removal of rain falling below the cloud base. Transformation of $SO_2$ to $SO_4$ take place during transport and due to dry and wet removal processes.

The methods of calculating the dispersion of $SO_2$ are, therefore, basically dependent on the factors such as the decay rate of $SO_2$ in dry and wet conditions, the rate of transformation of $SO_2$ to sulfates, and depth of mixing layer. These factors are usually not considered in a short-range steady-state modeling while the long-range transport models take into account some of these factors.

To trace the movement of plume from burning sites on long range basis, and also to estimate concentration and deposition of pollutants on regional basis (within and outside the Kingdom), we are planning to use another package called Air Resources Laboratory, Air Transport and Dispersion Model (ARL - ATAD) (Ref. 5). This model plots trajectories of the plume for a long duration originating from a number of sources. Each trajectory is calculated using transport winds averaged in a vertical layer. Dispersion calculations are also made from these trajectories. The trajectory position can be mapped. Time averaged surface air concentration and deposition amounts can also be calculated and mapped.

To run this model effectively, upper air data on wind speed, wind direction, temperature, and pressure are required on a number of locations at 6-hour interval. In the eastern part of Saudi Arabia, upper air data, at present, is collected only at Dhahran meteorological station at 00 and 12z. An other station in the northern part is Qaisumah where two launches a day are made. Based on the limited data on these two stations, it was not possible to use the model to draw trajectories and estimate concentration and deposition of the pollutants. It was, therefore, decided to retrieve information on upper air data from weather charts available for synoptic, 850 mb, and 700 mb pressure levels. These weather charts are prepared by the Meteorology and Environmental Protection Administration (MEPA) twice a day. MEPA office in Dhahran supplies these charts on daily basis. KFUPM/RI personnel have been trained by MEPA on how to read these charts and retrieve the desired meteorological information. Eight locations in the Arabian Gulf region and in the Eastern Kingdom have been selected on which the information on wind speed and direction, temperature, pressure, and height are retrieved.

The use of ARL-ATAD model is demonstrated in Figs. 13 to 16 for a typical day in March, 1991 by tracing (a) the movement of smoke from the Kuwaiti oil burning sources in the form of trajectories originating at 00, 06, 12, and 18z, (b) estimating the transport layer depth with time for each trajectory, and (c) calculating the concentration of $SO_2$ at different locations with and without deposition option on daily basis, and (d) calculating the average deposition on the surface for a specific period.

## CONCLUSIONS AND RECOMMENDATIONS

In this paper, the activities being conducted by KFUPM/RI in collaboration with MEPA, US Air Team, Ministry of Health, and Saudi ARAMCO are summarized to assess the impact of pollutants due to burning of oil wells in the Kuwaiti oil fields. The preliminary results presented in this report demonstrate the need of such research plan to study the behavior of the plume, its movement, decay of the pollutants with time, dispersion, and deposition with the distance and time. and long-term impact on human health and surrounding environment.

The results presented in this report are based on uncertainties in the source input data and climatological variables. For the effective use of the model, it is important to have reliable information on the chemistry of the source, burning efficiency, amount of oil being burnt from each oil well, and exact number of wells and their locations. In order to study the dispersion and deposition characteristics and to validate the model, it is equally important to intensify air quality and meteorological network in the gulf region. US Air Team has prepared a detailed plan on the intensification and the expansion of the Gulf regional air monitoring and meteorological network with emphasis on the collection of particulate sampling and development of database.

For more reliable prediction of the plume movement, plume rise, and the concentration estimates, the boundary layer variables should be estimated reliably. To accomplish this, ARL-ATAD model should be coupled with the planetary boundary layer model. Model should also be integrated with the general circulation model applicable in the desert conditions with the sea-breeze conditions in the coastal region.

## ACKNOWLEDGEMENT

We are grateful to Saudi ARAMCO and Royal Commission for Jubail and Yanbu for supplying air quality and metrological monitoring data on regular basis. The technical support provided by the US Air Team is highly acknowledged.

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**Table 1: Data on Oil Fields, Well Capacity, and Associated Gases (based on February 24, 1991)**

| Oil Fields | No. of Wells Under Fire | Production Capacity of each Well in bbls/day | Associated Gas/Barrel in cubic meter | Total Oil Burnt in bbls/day | Total Gas Burnt in million cubic meter/ day |
|---|---|---|---|---|---|
| Wafra (P1) | 25 | 350 | 14.14 | 8750 | 0.124 |
| Romeilla (P2) | 75 | 4000 | 14.14 | 300,000 | 4.242 |
| Raudhatain (P3) | 50 | 4000 | 14.14 | 200,000 | 2.828 |
| Umm Gudair (P4) | 50 | 4000 | 14.14 | 200,000 | 2.828 |
| Bahrah (P5) | 25 | 4000 | 14.14 | 100,000 | 1.414 |
| Mina Gesh (P6) | 50 | 4000 | 14.14 | 200,000 | 2.828 |
| Burgan (P7) | 350 | 4000 | 14.14 | 1,400,000 | 19.796 |
| TOTAL | 625 | | | 2,408,750 | 34.060 |

**Table 2: Total Emission of Gases in Tons/day (based on February 24, 1991)**

| | $SO_2$ | CO | $NO_X$ | Particulates |
|---|---|---|---|---|
| Due to Oil Burning | 21,197 | 241 | 60 | 169 |
| Due to Burning of Associated Gases | 1,213 | 11 | 486 | 2.7 |
| TOTAL | 22,410 | 252 | 546 | 171.7 |

Table 3. MEPA air quality standards.*

| Averaging Time | Maximum Concentration | Exceedances |
|---|---|---|
| **Sulfur Dioxide ($SO_2$)** | | |
| 1 hour | 730 µg/m³ (0.28 ppm) | twice a month |
| 24 hours | 365 µg/m³ (0.14 ppm) | once a year |
| 1 year | 80 µg/m³ (0.03 ppm) | (none) |
| **Inhalable Particulates (IP)** | | |
| 24 hours | 340 µg/m³ | once a year |
| 1 year | 80 µg/m³ | (none) |
| **Photochemical Oxidants (Defined as Ozone, $O_3$)** | | |
| 1 hour | 295 µg/m³ (0.15 ppm) | twice a month |
| **Nitrogen Oxides (Defined as Nitrogen Dioxide, $NO_2$)** | | |
| 1 hour | 660 µg/m³ (0.35 ppm) | twice a month |
| 1 year | 100 µg/m³ (0.05 ppm) | (none) |
| **Carbon Monoxide (CO)** | | |
| 1 hour | 40 mg/m³ (35 ppm) | twice a month |
| 8 hours | 10 mg/m³ (9 ppm) | twice a month |
| **Hydrogen Sulfide ($H_2S$)** | | |
| 1 hour | 195 µg/m³ (0.14 ppm) | twice a month |
| 24 hours | 40 µg/m³ (0.03 ppm) | once a year |
| **Fluorides ($F^-$)** | | |
| 30 days | 1 µg/m³ (0.001 ppm) | (none) |

*Source: MEPA 1402 H

**Table 4: Simulated Values of $SO_2$ Concentration Using RAM Model (US EPA) (March 22; Hourly Met. Data - Jubail)**

| Name of City/ Town | Highest 1-Hourly (microgram/cum) | Time | Highest 24-Hourly (microgram/cum) |
|---|---|---|---|
| Dhahran | 3 | 0900 | 0 |
| Jubail | 9 | 0900 | 0 |
| Hofuf | 4 | 0900 | 0 |
| Riyadh | 10 | 1100 | 1 |
| Nariyah | 27 | 0900 | 1 |
| Manifa | 19 | 0900 | 1 |
| Safaniya | 40 | 0900 | 2 |
| Khafji | 170 | 0900 | 14 |
| Shedgum | 12 | 0900 | 1 |
| Juraibiya | 0 | - | 0 |
| Bakr | 0 | - | 0 |
| Jaladi | 39 | 0900 | 2 |
| Fadhili | 112 | 0900 | 5 |
| Jaham | 3 | 1100 | 0 |
| Khurais | 0 | - | 0 |
| Abu Jifan | 0 | - | 0 |
| M. Ahmadi | 1770* | 0500 | 242 |
| Kuwait City | 203 | 0900 | 8 |
| Basrah | 0 | - | 0 |
| Luhais | 369 | 2400 | 20 |
| Zuluf | 865* | 0600 | 77 |
| Bubyan | 1220* | 0400 | 101 |
| Falaykah | 306 | 0100 | 13 |
| Mina Saud | 2691* | 0800 | 176 |
| Marjan | 705 | 0600 | 68 |
| Tanajib | 70 | 0900 | 3 |
| Rastanura | 0 | - | 0 |
| Abqaiq | 22 | 0900 | 1 |
| Sarrar | 55 | 0900 | 2 |
| Nita | 10 | 0900 | 0 |
| Mulayjah | 10 | 0900 | 0 |
| Jararah | 12 | 0900 | 1 |
| Al Ula | 11 | 0900 | 0 |

* The concentration exceeded MEPA limit of 730 microgram/cum.
** The concentration exceeded MEPA limit of 365 microgram/cum.

REPORT ON U.K. AIRCRAFT MEASUREMENTS IN THE GULF

The MRF C-130 aircraft, based at Bahrain, arrived on 22 March 1991 and departed on 2 April. Seven successful flights were made into the oil plume, totalling 55 hours airborne, at a wide range of altitudes and different distances from Kuwait.

From helicopter flights into the middle of the burning oil wells, different modes of burning were observed; mostly thick black smoke, others white, and a few (presumably only gas) were clean.

C-130 measurements through the plume at about 100 km from Kuwait showed maximum concentrations (about 200 m altitude) of about 1000 ppb of $SO_2$; 50 ppb of nitrogen oxides, and nearly 30,000 particles of aerosol (0.1-10.0 microns diameter) per cubic centimeter. Ozone concentration is generally reduced close to source. Levels of sunlight are reduced to essentially zero; night-time lighting was required on the aircraft flight deck.

Filters of teflon or quartz were exposed on long booms wound out from the aircraft, and stainless steel bottles were filled with outside air; these await analysis in the U.K.

Further downwind, strong windshear often carries the top of the plume away to the northwest, with the remainder typically blowing down the west Gulf coast. At 100 km from source, the plume top is typically 3-4000 m high, with a base at 1000-1500 m. Here, enhanced levels of ozone are seen, but only up to about 80 ppb.

At distances of about 1000 km from Kuwait, aerosol particle concentrations were reduced to less than 1000 counts per cc, and only the very smallest particles remain suspended.

The mission was very successful in fulfilling its objectives, thanks in particular to the skill of the RAF air crew and the excellent co-operation from the authorities in Bahrain and other Gulf states.

# SUMMARY OF THE U.S.A. INTER-AGENCY SCIENCE PLAN

## PHASE I

The Phase I experimental goals for two research aircraft and their auxiliary support from satellite observations, forecasting and plume trajectory analysis are, in brief, as follows:

- To characterize the regional emission rates of smoke particles and trace gases.
- To measure radiative properties of the smoke particles, and the net radiative effects of the plumes, with attention to how radiation affects the altitudes of the plumes and the stability of the atmosphere.
- To measure characteristics of the smoke particles and determine if the particles have a hygroscopic component (or acquire such a component through chemical transformations) that would accelerate their removal from the atmosphere.
- To search for direct evidence that the smoke particles are scavenged in clouds, and to determine the effects of the smoke on the composition and radiative properties of clouds.
- To measure the chemical composition of the plume and determine how that composition changes with time. Such measurements will aid in developing estimates of the smoke's atmospheric residence time.
- To study regional weather anomalies associated with these smoke emissions.

The primary tools used to meet these goals are the research aircraft of the National Center for Atmospheric Research (Lockheed Electra) and the University of Washington (Convair C-131A):

- The Electra will be extensively equipped to provide smoke aerosol characterization, to study aerosol/cloud interactions, to measure (by a combination of in-situ and remote sensing) the regional mass flux of aerosols and trace gases, to detail the chemistry of the smoke and its alterations with time, and to examine the dynamical interactions of solar heating on the plume. With more than twice the range of the Convair and a superior service ceiling the Electra will devote extra effort to the aged plume and Eulerian experiments along great lengths of the plume.

- The Convair, with a long history of studying large fires, is similarly equipped with special strengths in characterization of the smoke's optical properties, and the plume's spectral albedo. The use of grab samplers makes the aircraft especially valuable in the characterization of individual sources and in measuring specialized emission factors with the carbon balance method.

PHASE II

In Phase II, U.S. scientists will focus on longer term issues and will emphasize surface based monitoring, though at some point the programme would allow the airborne team to return to revisit issues which remain unresolved. Tentatively, the surface stations would focus on radiation balance, optical depth, and precipitation chemistry and would include at least one precipitation formation over the heat sources, in the smoke downwind and in unaffected areas to look for acute meteorological anomalies. Some elements of Phase II would be of sufficient duration so that the results of the decay of the sources, as fires are extinguished can be observed. This may be especially important if weather anomalies are observed that may have comparatively low initiation thresholds.

An issue of some importance in both Phase I and II studies is the monitoring of changes in surface albedo associated with wet and dry deposition of the soot. While redistribution and covering of the sooted soil may occur rather rapidly, it is easy to see that, given the high insolation and already high surface temperatures, a large change in surface albedo could dramatically raise the already high surface temperatures.

Research Goals

The research goals are:

a. Regional emission rates of smoke particles and trace gases,
b. Radiative properties of the smoke particles and smoke plume,
c. Smoke particle characteristics,
d. Smoke plume/cloud interactions,
e. Effects of plume aging, and
f. Regional weather anomalies.

Programme Schedule

The Phase I airborne experiment is scheduled to depart the United States on approximately 1 May, 1991 for a field experiement of roughly 30 days duration. Both research aircraft plan to fly about 100 hours devoted to their research missions basing either Bahraín or Dhahran, Saudi Arabia. The month of May is the soonest the airborne teams can reasonably depart. It is at the crucial-meteorological transition to a dry season allowing observations of the fate of the smoke under both cloudy and cloud free conditions. Climatological modelling of the plume trajectories show that more than 80% of the time the plumes will remain in airspace accessible to our aircrafts out to plume travel times of 5 days or more.

The Phase II schedule has not been determined at this time, although the aircraft should take samples during the period with the highest precipitation probability.

# U.S.S.R. AIRCRAFT PROGRAMME FOR THE GULF

## 1. U.S.S.R. AIRCRAFT MEASUREMENTS OF THE GEOGRAPHICAL DISTRIBUTION AND CHARACTERISTICS OF POLLUTANTS RESULTING FROM THE OILFIELD FIRES IN THE GULF

### 1.1 Introduction

Timely and objective information on the characteristics and geographical distribution of various combustion products is required. The existing observational network in this region has no possibility to get the information.

The first objective is to get experimental data on the physical characteristics of the fire products and of their geographical distribution using an aircraft-meteorological laboratory IL-18 "Cyclone" (four-engine turboprop).

Onboard instrumentation of this special aircraft-meteolab allows to measure a wide range of parameters including:

- characteristics of aerosols (optical depth, vertical profile and spectral distribution);
- gaseous contaminants (CO, $CO_2$, $CH_4$, ethane, ethylene, benzo(a)pyrene);
- solar radiation (incident and reflected);
- thermodynamics (temperature, wind, pressure, dew point);
- remote sensing (IR-temperature of the surface, oil spills).

The second objective is to analyze experimental data in terms of potential influence on the ecology of the particular country.

The third objective is to get this information to the interested countries, their institutions and to international bodies for further analysis and consideration.

### 1.2 Flight plan

Some ideas on the possible flight routes are shown on the map of the area. Total flight time required goes up to 95 flight hours which takes about 30 days to fulfill (see Figure IX for tentative flight plan).

### 1.3 Cost of the project

The preliminary estimate of project's cost is U.S.$ 600,000. This includes: jet fuel, air traffic control, insurance, aircraft service, hotel, per diem, etc. A list of Parameters measured by on board equipment of IL-18 aircraft meteolab is given in the next table

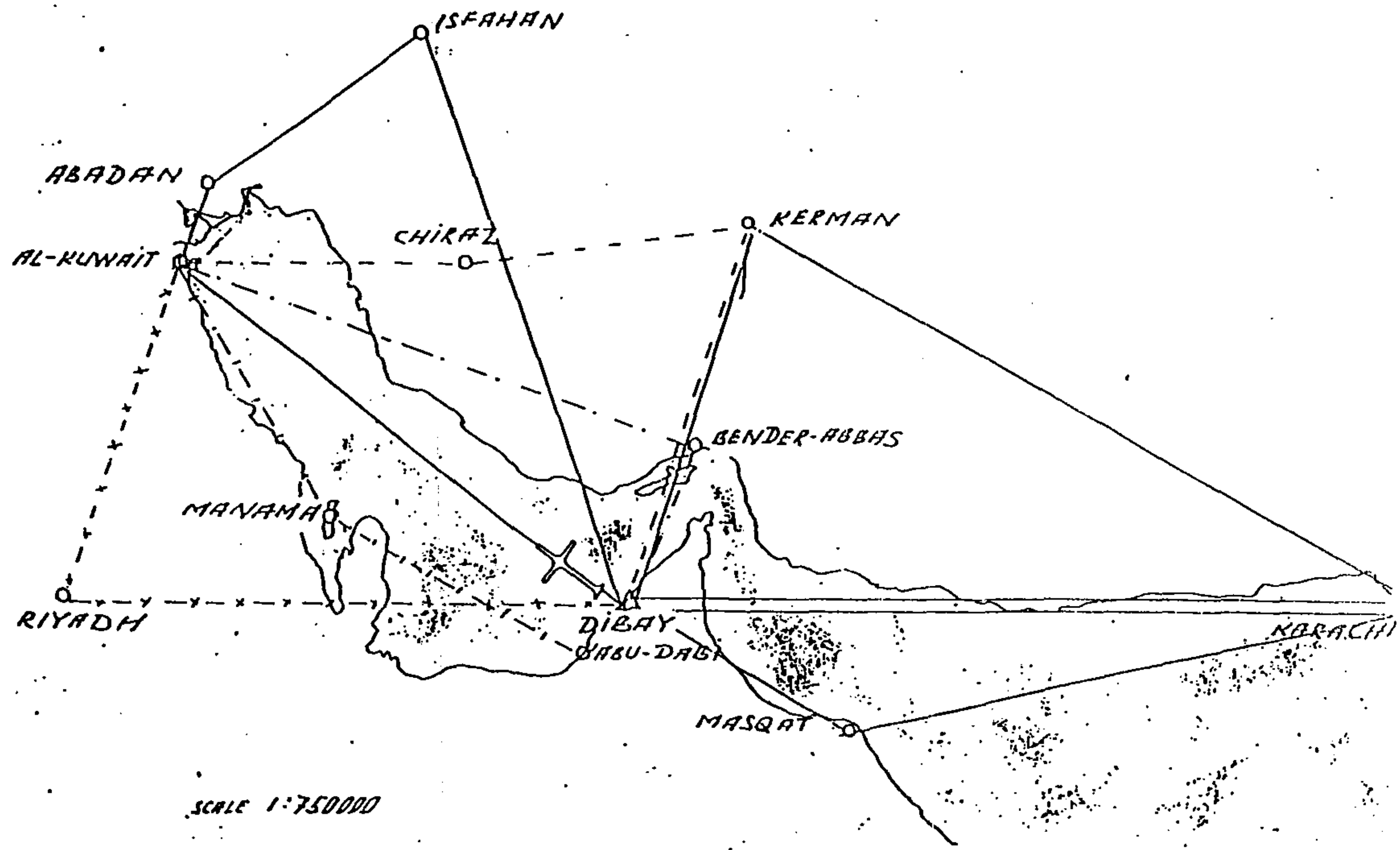



Fig. IX.1. Projected flightroutes in the USSR aircraft measurement plan.

| | | | |
|---|---|---|---|
| A. | CHARACTERISTICS OF AEROSOL | | |
| | 1. | Optical depth of the atmosphere | Sun spectrometer |
| | 2. | Vertical profile of aerosol concentration | Lidar-polarimeter |
| | 3. | Modal size of aerosol particles | Lidar-polarimeter |
| | 4. | Spectra of aerosol particles | Particle size polarimeter |
| B. | AIR CONCENTRATIONS | | |
| | 5. | CO, $CO_2$, $CH_4$, ethane, ethylene, benzo(a)pyrene | Sampling of gas probes aboard followed by chromatography analysis on the ground |
| C. | SOLAR RADIATION | | |
| | 6. | Incident solar radiation | Pyranometer |
| | 7. | Reflected solar radiation | Pyranometer |
| D. | THERMODYNAMIC PARAMETERS | | |
| | 8. | Air Temperature | Resistance thermometer |
| | 9. | Dew point | Condensation hydrometer |
| | 10. | Wind velocity | Inertial navigation |
| | 11. | Pressure | Barometric sensor |
| E. | SURFACE DATA | | |
| | 12. | Radiation temperature of surface | Infrared radiometer |
| | 13. | Oil spill detection on water surface | Lidar-polarimeter |

Remarks:

1. Real-time geographic position of the aircraft and other supporting parameters are measured and registered.

2. Scientific data are registered using IBM PC compatible formats.

## 2. PROGRAMME ON AIRCRAFT INVESTIGATIONS INTO THE ATMOSPHERE POLLUTION

### 2.1 Introduction

The main measurement objectives are to detect the atmospheric pollution level, pollutant emissions, fluxes, spatial distribution, and transformation and removal of the atmospheric pollutants from the oilfield fires.

The main pollutants are sulfur dioxide and sulfates, nitrogen oxides and nitrates, ozone, benz(a)pyrene, petroleum hydrocarbons, mercury vapour and heavy metals.

### 2.2 Outline of flight plan

The way of investigation can be schematized as follows: the emitted pollutants are scanned by aircraft in various sections at distances $R_1$, $R_2$ ..., $R_n$ from the source at heights $h_1$, $h_2$, ..., $h_n$. The maximum section height is selected to be above or equal to the plume height. The pollution concentration is measured at each section. The ambient concentrations in the plume at various distances $Q(R_1)$, $Q(R_2)$, ..., $Q(R_n)$ are found from the result of aircraft observations in the various sections through integration. The function $Q = Q(R)$ is determined by $Q(R_i)$ values.

The emission value $Q_o$ is found through the function $Q(R)$ at $R = 0$. The mean time residence of the pollutant in the plume or (t) is calculated from the above function relative to the distance and wind velocity, where $t = R/V$ and V the mean wind velocity. Concentrations measured at various distances and heights $C(R_i, h_j)$ make it possible to estimate possible maximum concentrations at the ground level $C(R_i, h_i = 0)$ and their threat to human health and environment. The values $Q_o$ and ™(t) are the major parameters required to provide a reliable estimate of the dispersion of pollutants from the oil well fires. The experience gained in the U.S.S.R. with the airborne studies demonstrates that not less than 200 flight hours are needed to get reliable values of $C(R_i, O_o)$ and the parameters $Q_o$ and ™(t) under available fire scales. 100 flight hours are sufficient to estimate roughly the characteristics of the dispersion.

### 2.3 Additional information

A detailed theory of the environmental pollution assessments from aircraft measurement data is given in Yu. A. Izrael, I.M. Nazarov and Sh. D. Fridman's monograph "Air pollutant transboundary transport modelling", Leningrad, Hydrometeoizdat, 1987, 303 p.

The Institute of Global Climate Ecology under Goskomhydromet and the U.S.S.R. Academy of Sciences can provide the aircraft operations on the condition that the expenditures are paid in hard currency.

## 3. THE AIRCRAFT LABORATORY AN-30R

An aircraft laboratory was designed in the U.S.S.R. on the basis of a two-engine aircraft AN-30, to measure atmospheric and surface radioactive and chemical pollution. It has been operated on a routine basis since 1984. In 1987, the aircraft laboratory was used in the international experiment on the study of long-range pollutant transport in Czecho-Slovakia. The laboratory includes gas analyzers, sampling systems, a gamma spectrometer and a dismountable small-size remote-controlled vehicle.

### 3.1 Aircraft specifications:

- flight speed 300 to 450 km/hr;
- flight altitude 200 to 7000 m;
- range 2000 km;
- load-carrying capacity 3 tons;
- flight time 5 hours;
- fuel consumption 1 t/hr;
- crew 5 persons;
- number of flight operators 4 persons;
- ground servicing of the aircraft 2 persons.

### 3.2 Laboratory equipment specifications

A. Gas measurements

Gases are measured with gas analyzers during the flight (see Table 1).

Table 1

| Pollutant | Detection limit | Measurement regime and technique |
|---|---|---|
| Hydrogen sulfide | 2 $\mu g/m^3$ | continuous, plasma photometry |
| Nitrogen oxides | 4 $\mu g/m^3$ | continous, chemiluminescence |
| Ozone | 3 $\mu g/m^3$ | UV-absorption |
| Mercury vapour | $10^{-5}$ $\mu g/m^3$ | discrete, atom absorption with gold sorbent for collection |

B. Aerosol measurements

Aerosol sampling is performed on special filters using two types of samplers. Samples are analyzed at the laboratory.

Sampling of the first type ensures simultaneous collection of one to three samples. The collection filter diameter for single sampling is 120 mm and the air flow rate through the filter is 20 $m^3$/hr. In case of a three sample collection filter, the diameter is 50 mm and air flow rate through each filter is 6.5 $m^3$/hr. Filters are changed during the flight. The sampling period in the plumes of industrial sources equals to several minutes. At background pollution levels the period normally makes up about 30 minutes. Table 2 presents the most typical pollutants measured. Detection limits are given as a pollutant amount per sample.

| Pollutant | Detection limit | Measurement technique |
|---|---|---|
| Sulfate | 3 µg | Turbidimetry with barium chloride |
| Nitrate | 6 µg | Colorimetry |
| Ammonium | 6 µg | Colorimetry |
| Benz(a)pyrene | $10^{-4}$ µg | Linear spectra |
| Petroleum hydrocarbons | 10 µg | Gas chromatography |
| Soot carbon | 20 µg | Optical IR spectrometry |
| Heavy metals | $10^{-3}$–$10^{-2}$ µg | Plasma spectrometry, atom absorption |
| Radon decay products | 0.3 Bq | γ-ray flight measurements |

Second type sample provides collection of two large volume (up to $1510^3$ $m^3$/hr) samples during a flight. Filters are changed only at the ground.

C. Measurements of the Surface Radioactive Contaminiation

Measurements are performed by γ-ray detection using a dosimeter and a semi-conductor gamma spectrometer.

D. Small-Size Remote Controlled Vehicle (SRCV)

The aircraft laboratory AN-30R includes a dismountable miniature remote controlled vehicle equipped with a sampling device. SRCV is serviced by two operators and transported by a motor car. SRCV is dedicated to aerosol and gas sampling near emission sources, e.g. plant stacks, where aircraft laboratory flights are inhibited for safety requirements.

Main specifications of SRCV:

- maximum mass 6.8 kg;
- payload 1.4 kg;
- wing span 2.3 m;
- length 2 m;
- flight speed 50 to 120 km/hr;
- flight altitude up to 2000 m;
- flight time up to 1.5 hours;
- maximum distance from the operator 3 km;
- air rate through the filter up to 10 $m^3$/hr.

3.3 Tentative estimate of aircraft operation costs

According to sanitation standards, the crew is allowed to perform flights with a total duration of 100 hours (20 5-hour flights) per month.

The approximate cost of 100 flight hours are:

1. Aircraft lease - 160,000 rubles which may be paid by the Institute of Global Climate and Ecology, Goscomhydromet/U.S.S.R. Academy of Sciences.

2. Operation costs in Kuwait (fuel, airfield maintenance, wages, hotel expenditures, per diem expenses of the crew and operators) - 150,000 U.S. dollars. The cost of fuel and airfield maintenance - 75,000 U.S.

It would be expedient to urge the countries concerned to provide fuel free of charge (60,000 U.S. dollars). In this case the cost would equal to 90,000 U.S. dollars.

# REGIONAL ATMOSPHERIC MODELLING RECOMMENDATIONS AND REVIEW

## RECOMMENDATIONS

The following material was presented to the meeting R.E. Meyers, and endorsed as a recommendation from the experts:

The range of important regional atmospheric modelling capabilities presented to the meeting included both real-time and research meteorological and air quality models. There is no single model which is sufficient for the accurate characterization and mitigation of the oil fire problem. However, there are relevant research and operational modelling capabilities.

a. On a priority basis near real-time operational models should be used in the near term to provide forecasting of meteorology, concentrations, dose, and visibility. Both forecast and diagnostic models can be used to advantage for health, research operations, placement of sensors, and tactical decisions.

b. Because the problem is likely to continue for more than a year, it is prudent to upgrade modelling capabilities as improved models, modules, and scientific formulations become available.

Since unique modelling capabilities are spread over many scientists and institutions, it is necessary that several modelling capabilities be developed, both for real-time and research, and that these efforts be coordinated. Expertise should be drawn from the widest possible circle.

The oil fires produce effects interrelated on many scales (micro, local, regional, and global) and it is recommended that multi-scale models be developed which incorporate high resolution source, chemistry, transport and diffusion, deposition, heat, and complex terrain modules.

The following enhancements to the models were discussed:

a. Surface boundary layer (sbl) parameterization throughout the diurnal cycle,

b. Improved flux relations of heat, moisture, momentum, energy, and chemical species,

c. Influences of complex terrain on sbl,

d. Influences of oil fires on sbl and entire atmospheric boundary layer,

e. A better coupling of fire modelling and meteorological modelling whereby fires affect the meteorology and vice versa,

f. Improvement in numerical methods which allow solution of the model equation on multiple scales, including development of adaptive grids, moving grids, nesting, and mixed eulerian and lagrangian numerical modelling capabilities to solve the Navier-Stokes Equations efficiently and with high accuracy,

g. Major emphasis should be placed on solving the Navier-Stokes equations in as detailed and systematic a manner as is possible for the multi-scale problem,

h. Improved closures must be made in the turbulence terms of the Navier-Stokes equation (the lessons learned from Large Eddy Simulations and Direct Simulations of the atmosphere must be brought to bear on the oil fire-atmospheric problem),

i. Improved deposition, both dry and wet:

   1. Dry deposition - better gas/aerosol interaction with the turbulence and surface,
   2. Wet deposition - better cloud/rain interaction models,

j. Better chemistry modules which more closely represent the heterogeneous and homogeneous chemical reactions in the oil, combustion, and atmospheric chemicals,

k. The technology from regional and urban air pollution models, such as those used in the Los Angeles area, must be adapted to the oil fire-atmospheric problem,

l. Because a large portion of the Kuwait oil fire affected region involves coastal zones, it is important to model the effects of land-sea interfaces in the models,

m. Models should be tested against combined sets of air quality and meteorological data in the Kuwait-Gulf area,

n. The oil fire plumes can themselves be used in verifying mesoscale models, and

o. The electromagnetic radiation interaction with the oil fire pollution should be measured and modelled in detail.

Improvements are also needed in the characterization and modelling of atmospheric transport and diffusion. To aid in this, safe tracers such as $SF_6$, which are non-reactive and conservative, should be used in field experiments to characterize plume growth rates under different conditions. Comparisons should be made with ambient chemicals available in the smoke plume which are subject to deposition and chemical reaction.

REVIEW

The following are summaries of the regional models discussed at the meeting. The presenter and affiliation are also listed.

1. (DLR) Institute for Atmospheric Physics, Federal Republic of Germany
Presented by: U. Schumann

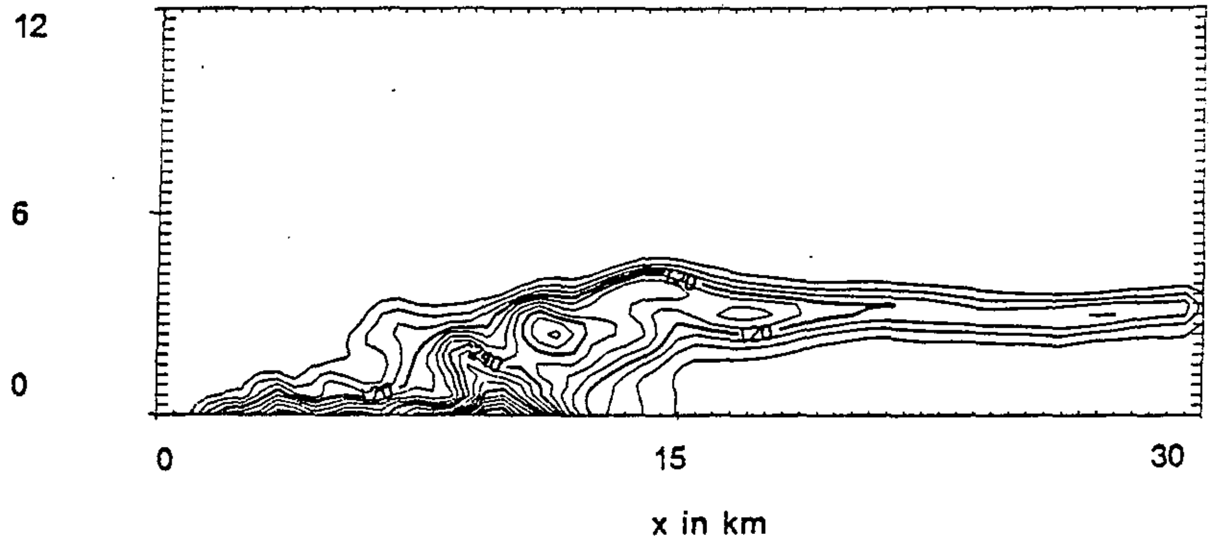
The modelling effort here employed non-hydrostatic solutions of the Navier-Stokes Equation (MESOSCOP) over a 30 x 30 x 12 km domain for oil fire meteorology and air pollution (see Fig. X.1). The model can be enhanced in resolution and domain coverage as more computer resources are applied. The modelling effort employed meteorological and source terms estimated to be representative of the Kuwait oil fire problem. The methodology is based on first principles and would be appropriate for nesting in larger scale models.

2. Building and Fire Research Laboratory, NIST, U.S.A.
Presented by: H. Baum

NIST has developed advanced fire modelling capabilities. Individual fires and ensemble of fires have been modelled. Detailed fire plume models allow calculation of some of the effects of the fires on the surrounding meteorology and of the meteorological effects on the fires. The presenter argues persuasively for integrated meteorological and fire models. The presenter also reviewed verification of NIST fire models and indicates field measurement capabilities of NIST which can be implemented to provide key source information and for model verfication.

3. TASC, Reading, Massachusetts, U.S.A.
Presented by: R.Chase and A. Bass

TASC has developed and has been using operationally a near realtime meteorological and air pollution impact assessment models using in-house and government (U.S.) support. These are tied together in an integrated interactive modelling capability. Starting from a detailed and updated source database TASC computes the downwind concentration, dose, and deposition from their dispersion model (see Fig. X.2). The dispersion and transport model gets its meteorology from a spectral global circulation model and can run from historical analyses or model forecasts. An improved plume model is included to represent the oil fire effects, as is a chemical reaction simulation. Detailed concentration, dose, and deposition fields can be graphically displayed as computer and hardcopy color images. TASC has begun comparisons of its model output with satellite visualizations of oil fire plumes and general agreement is found. TASC intends to continue developing its capabilities to include more detailed diffusion, transport, chemistry and meteorology.



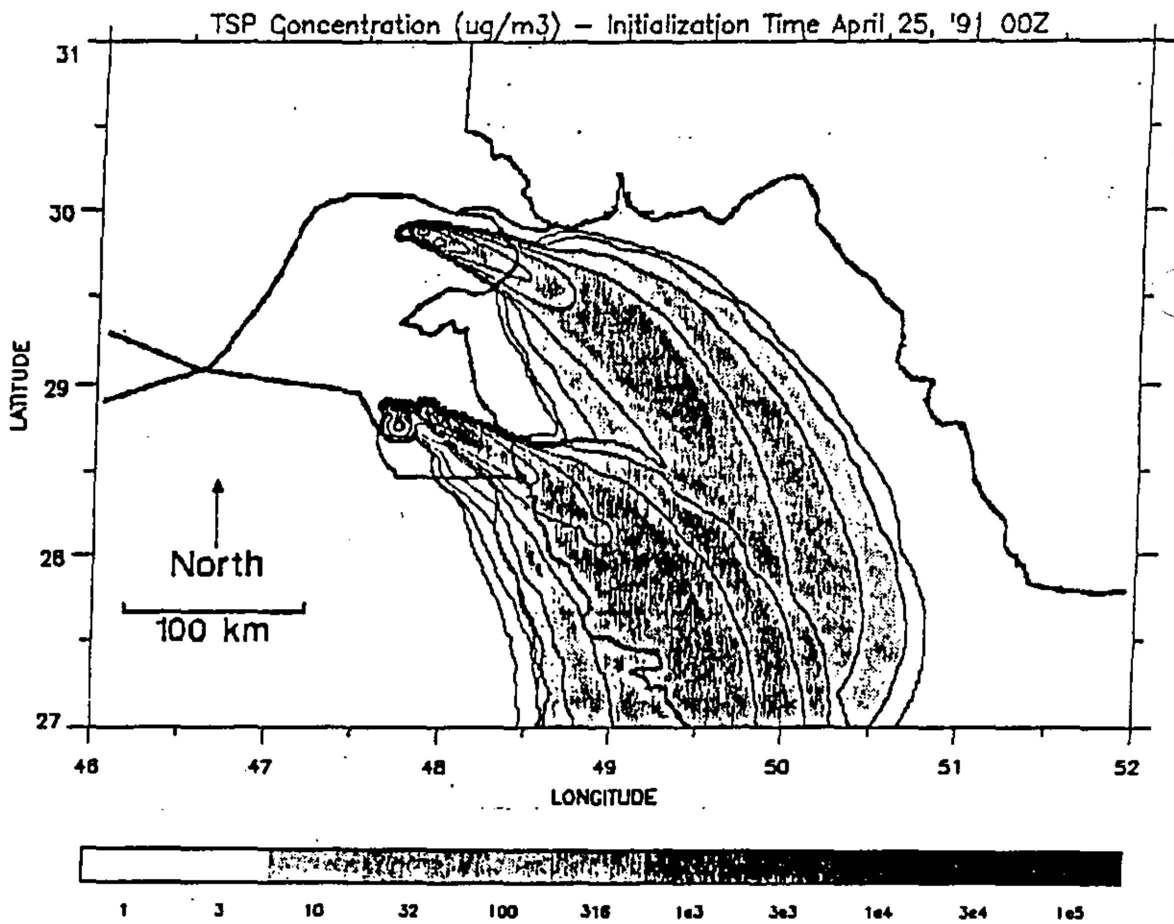




Fig. X.1. (top) Contours of soot concentration afters 2 hours of simulation (mg/kg). The contour interval spacing is 0.3 mg/kg).

Fig. X.2. (bottom) TSP concentration (micr. g./$m^3$). The initialization time was 25 April 1991, 00Z.

4. Lawrence Livermore National Laboratory, U.S.A.
Presented by: T. Sullivan

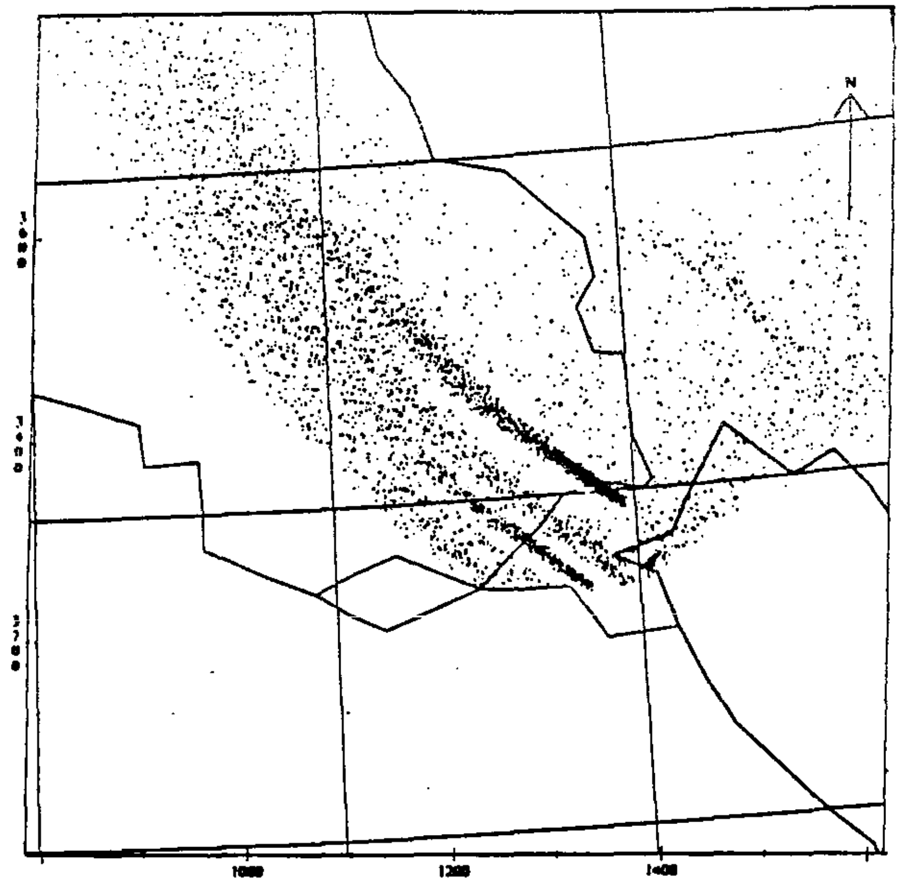
The Atmospheric Release Advisory Capability (ARAC) which has been used as an essential tool in mitigating atmospheric hazards (particularly nuclear ones) has been applied to model optical density in the larger Kuwait area. The capability provides near-real-time assessments of concentrations, dose, and deposition, and employs a diagnostic meteorological model (MATHEW) to add physical constraints such as complex terrain influences to the Air Force Global Weather Control forecasts and analyses (see Figure X.3). Concentration, dosage, and deposition are included in the analyses. Improved plume rise modelling has been included in the ARAC models. Dispersion is calculated by second generation particle-in-cell methods. The presenter recommends use of ARAC capabilities for Kuwait oil fire operations.

5. ARL (NOAA) U.S.A.
Presented by: J. Heffter

ARL produces operational forecasts of tajectories in the 850-700 mb height range of 36 to 72 hours after Z time (see Figs. X.4-X.6). These forecasts can be made available around the world. Trajectories are integrated from NOAA meteorological forecast and analysis products. The ARL trajectory capability has been developed, tested, and utilized over many years. ARL is also investigating the use of more detailed mesoscale meteorological models such as the CSO-RAMS model (R. Pielke). NOAA is looking toward implementing a full capability real-time hazard assessment and forecast capability in the near future using advanced computers and communications technology. NOAA is already supporting and will continue to support operations in the Kuwait area with its modelling tools.

6. Météorologie Nationale, France
Presented by: F. Bompay

Two main numerical weather models are currently in operation: Emeraude, a global model, and Peridot, a limited area model. During the Gulf war, Peridot was applied to Kuwait and used its forecasts operationally. The model has a 40 x 40 km resolution. A Eulerian model of atmospheric dispersion was developed (MEDIA). It can use input data from Emeraude or Peridot and yield an operational survey of the pollution in Kuwait after some changes. It may be considered to implement it in its operational system of the French weather service so that it can provide daily outputs (of air concentration, cumulative deposition, etc.) models, starting in October.



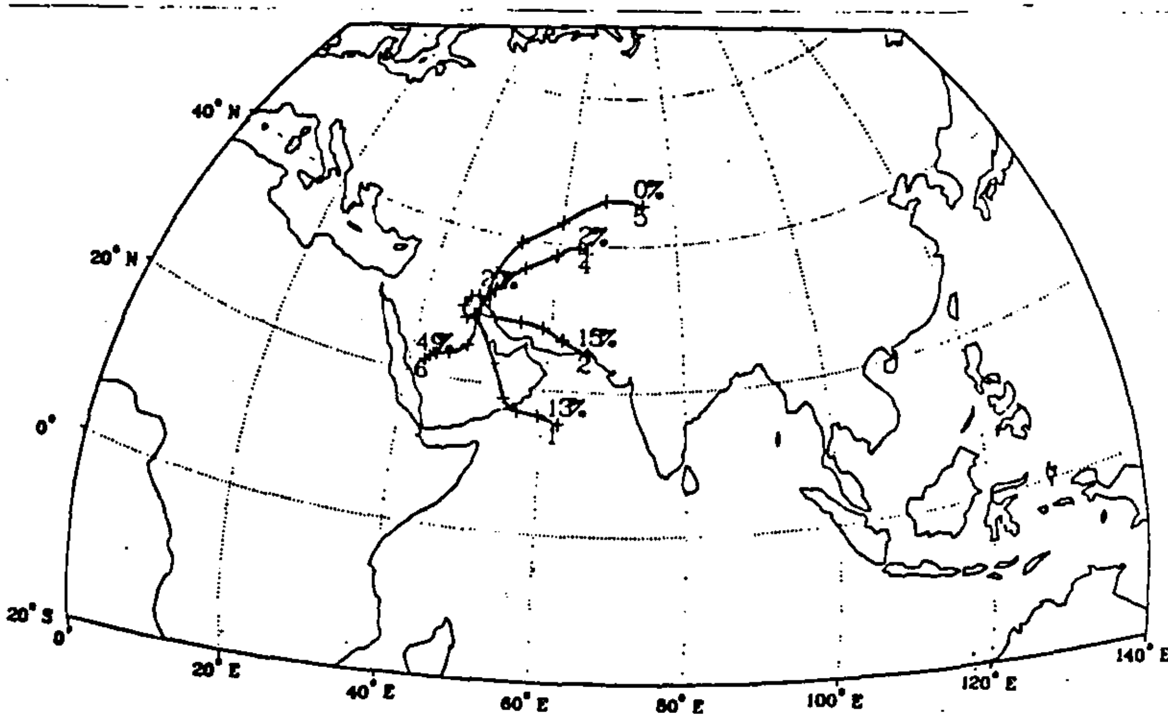




Fig. X.3. (top) Dispersion simulation with the LLNL ARAC particle disperion model, after a 24 hr. simulation. The initialization date was 2 February 1991, 00Z; (These data are currently provided on an experimental basis)

Fig. X.4. (bottom) 850 mb trajectory clusters originating in Kuwait. The numbers refer to the relative frequency of occurrence. For the clusters, over 300 trajectories were used.

7. Meteorological Office, U.K.
Presented by: F.B. Smith

A 3-D Monte Carlo model has been used to simulate the transport of the plume and to assess dry and wet deposition, surface layer time-integrated concentrations, and episodes of highly acidic rain likely to be damaging to crops (see Figure X.7). The model plume is compared with a subjectively analyzed meteosat visible plume picture.

8. Max Planck Institute für Chemie, Federal Republic of Germany
Presented by: G. Carmichael

Two models could be applied to the Gulf region. Both are eulerian transport/chemistry/deposition models designed for analysis of air quality on an event basis.

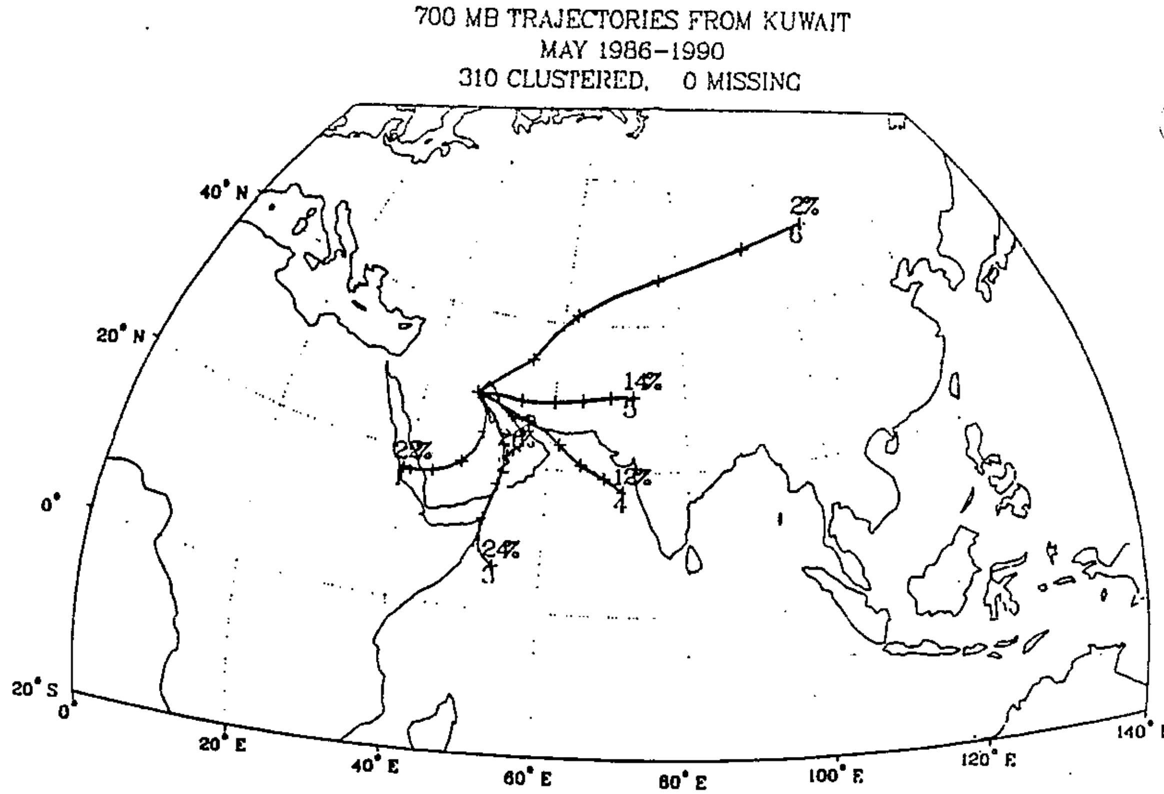
The Local Scale Model (CALGRID) is an urban-scale air pollution model designed for California Air Resources Board. It covers spatial scale up to 300x300 $km^2$, with a grid resolution of 2-5 km. This "system" contains a model to prepare meteorological fields from observations, or hydrostatic meteorological model, and a transport/chemistry/dry deposition model. It calculates 3-D distribution of $SO_2$, sulfate, VOCs, $NO_x$, ozone for events for a few days.

The Regional Scale Model (STEM-II) covers spatial domains up to 4000 x 4000 $km^2$, with horizontal resolution of 20 to 80 km. It calculates 3-D distributions of $SO_2$, sulfate, CO, VOCs, $NO_x$, ozone for events for days to weeks and includes dry and wet deposition, and size resolved aerosols (dust and inorganic, but can easily add soot).

9. Cologne University, Federal Republic of Germany
Presented by: H.J. Jakobs

A regional scale numerical model, EURAD (European Acid Deposition Model) may be used for episodic case studies during the burning. The model is described by Hass et al. (1990), it is a eulerian model, which calculates the transport, chemical transformation and deposition of atmospheric pollutants. It was designed for case studies of high pollution events over the European region (Hass et al., 1990 and Ebel et al., 1991). Although EURAD runs for European applications it can easily be transformed to other regions of the world like the Middle East. Besides soot (5-10% of the burning oil) the main atmospheric pollutants like $SO_2$ and $NO_x$ are emitted. EURAD is able to calculate not only the transport but also the chemical transformation and the dry and wet deposition of these constituents.

In the first phase it is planned to prepare the meteorological fields for several episodes in March - May 1991. Typical weather situations are selected for the case studies with the EURAD Model (including frontal passages for the assessment of the wet deposition). An



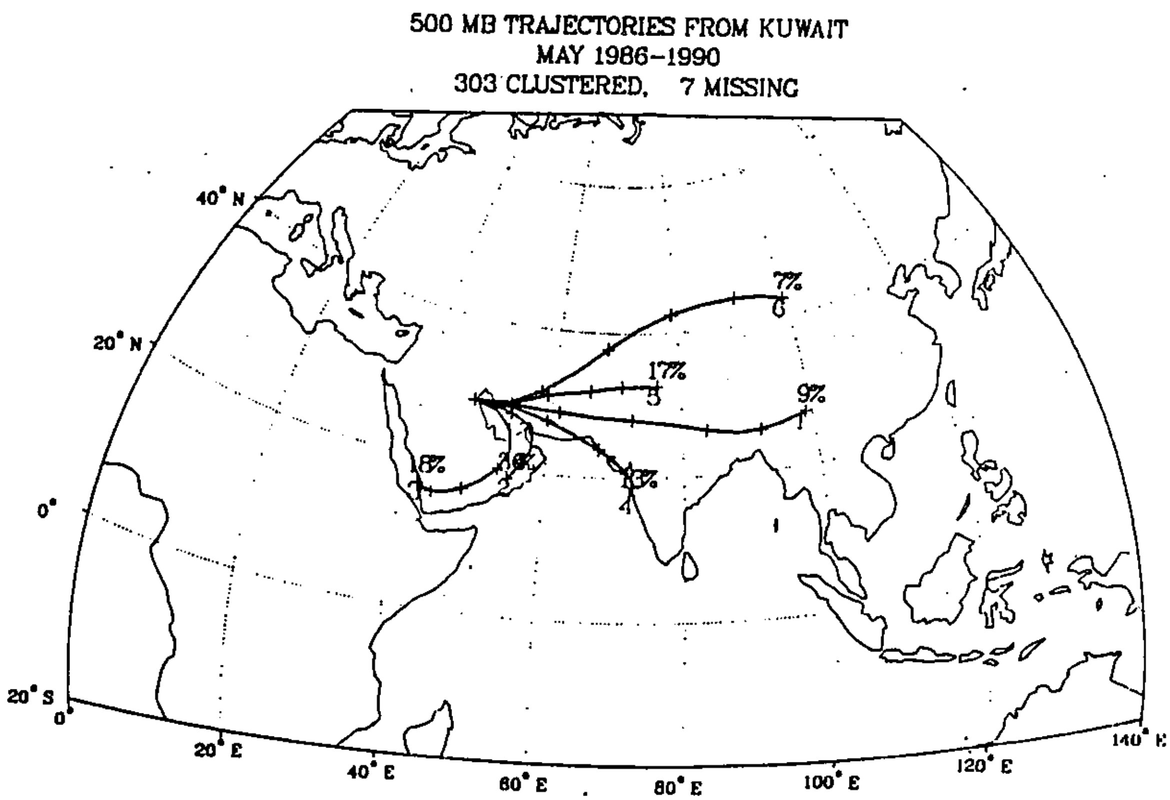




Fig. X.5. (see Fig. X.4) 700 mb level.

Fig. X.6. (see Fig. X.4) 500 mb level.

appropriate emission scenario must be developed for this EURAD application, neglecting in the first step the backgound emissions, because this information is difficult to incorporate in a short time period. When the simulation experiments are conducted, the results have to be compared and validated with measurements (satellite, aircraft and surface observations).

Ebel A., Hass H., Jakobs H. J., Memmesheimer M., Laube M., Oberreuter A., Geiss H. and Kuo Y. H., Simulation of Oxone Intrusion caused by a Tropopaus Fold and Cut-Off Row, Atmospheric Environment,in press, 1991.

Hass H., Memmesheimer M., Geiss H., Jakobs H.J., Laube M., and Ebel A., Simulation of the Chernobyl Radioactive Cloud over Europe using the EURAD Model, Atmospheric Environment, 24A, 673-692, 1990.

10. Royal Netherlands Meteorological Institute (KNMI)
Presented by: G. Verver

The Royal Netherlands Meteorological Institute and collaborating scientists developed and validated with good results a real-time puff dispersion model for application to emergency situations. The model has a two layer boundary layer structure plus one "reservoir layer" aloft. Puffs, nominally released every hour, are transported by winds, and split to resolve wind shear. A grid is also used to resolve larger pollution patterns. The model calculates deposition, concentrations, and total column values. It uses meteorology and atmospheric boundary layer information from the European ECMWF prognostic model. The model can be run against archived meteorological data or can produce forecasts. Research to improve the atmospheric boundary layer formulation is underway. The model is operational both in forecast and analysis mode (see Figure X.8).

11. U.S. Army Atmospheric Sciences Laboratory, U.S.A.
Presented by: R.E. Meyers

The U.S. Army Atmospheric Sciences Laboratory (ASL) has developed the Model of Atmospheric Chemical Hazards (MACH) which is a real-time interactive modelling-computer system which calculates downwind chemical hazards. This modelling capability predicts downwind concentrations, doses, and deposition over complex terrain including the Kuwait and greater Gulf region. The model reconstructs or forecasts wind flows and resulting pollution fields using mesoscale prognostic and diagnostic models, and advanced transport, diffusion air chemistry modules. The model and computer system are available for technology transfer.

Additional related research at ASL includes mesoscale modelling, Large Eddy Simulation modelling and gas and aersol flow modelling over complex terrain and complex structures (including dense, neutral, and buoyant gases and aerosols). ASL has a large number of unique research resources which can be brought to bear on the Kuwait oil fires problem including:

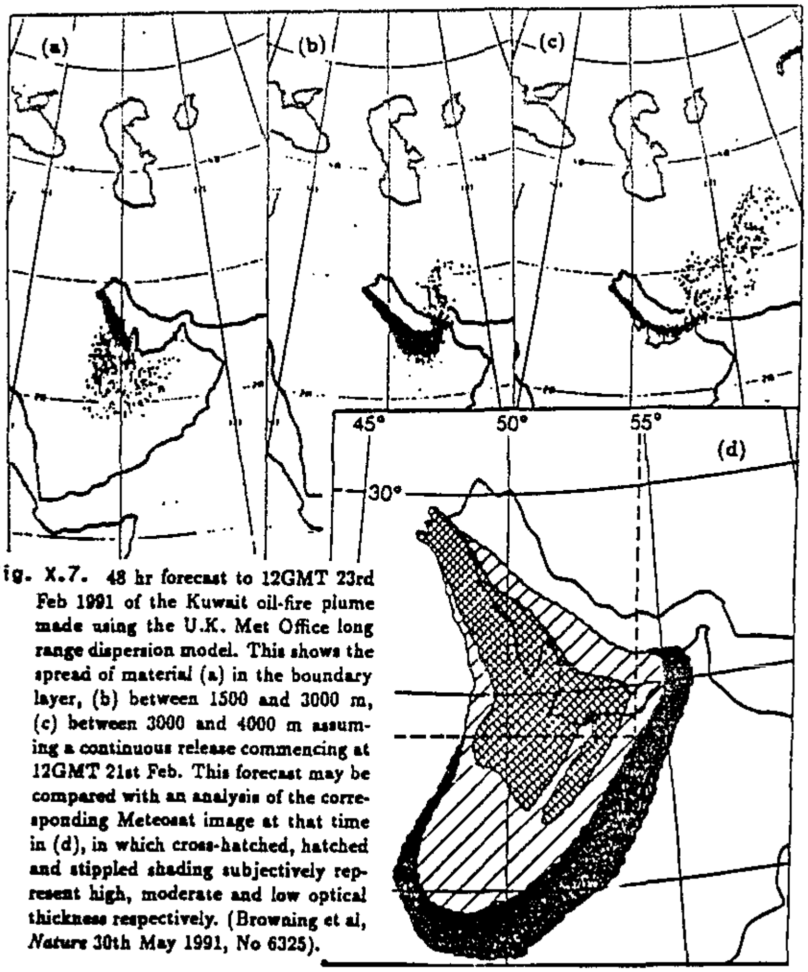



Fig. X.7. 48 hr forecast to 12GMT 23rd Feb 1991 of the Kuwait oil-fire plume made using the U.K. Met Office long range dispersion model. This shows the spread of material (a) in the boundary layer, (b) between 1500 and 3000 m, (c) between 3000 and 4000 m assuming a continuous release commencing at 12GMT 21st Feb. This forecast may be compared with an analysis of the corresponding Meteosat image at that time in (d), in which cross-hatched, hatched and stippled shading subjectively represent high, moderate and low optical thickness respectively. (Browning et al, *Nature* 30th May 1991, No 6325).

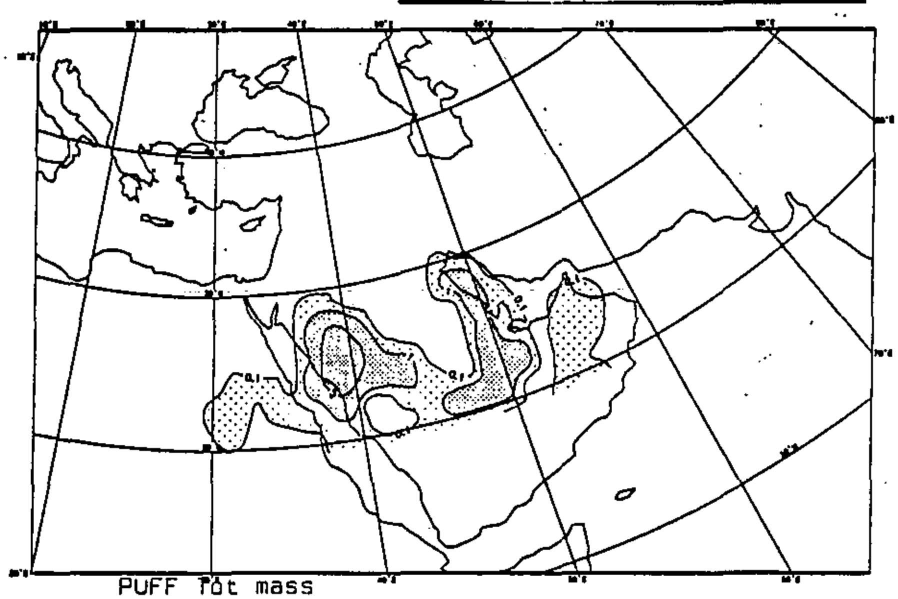
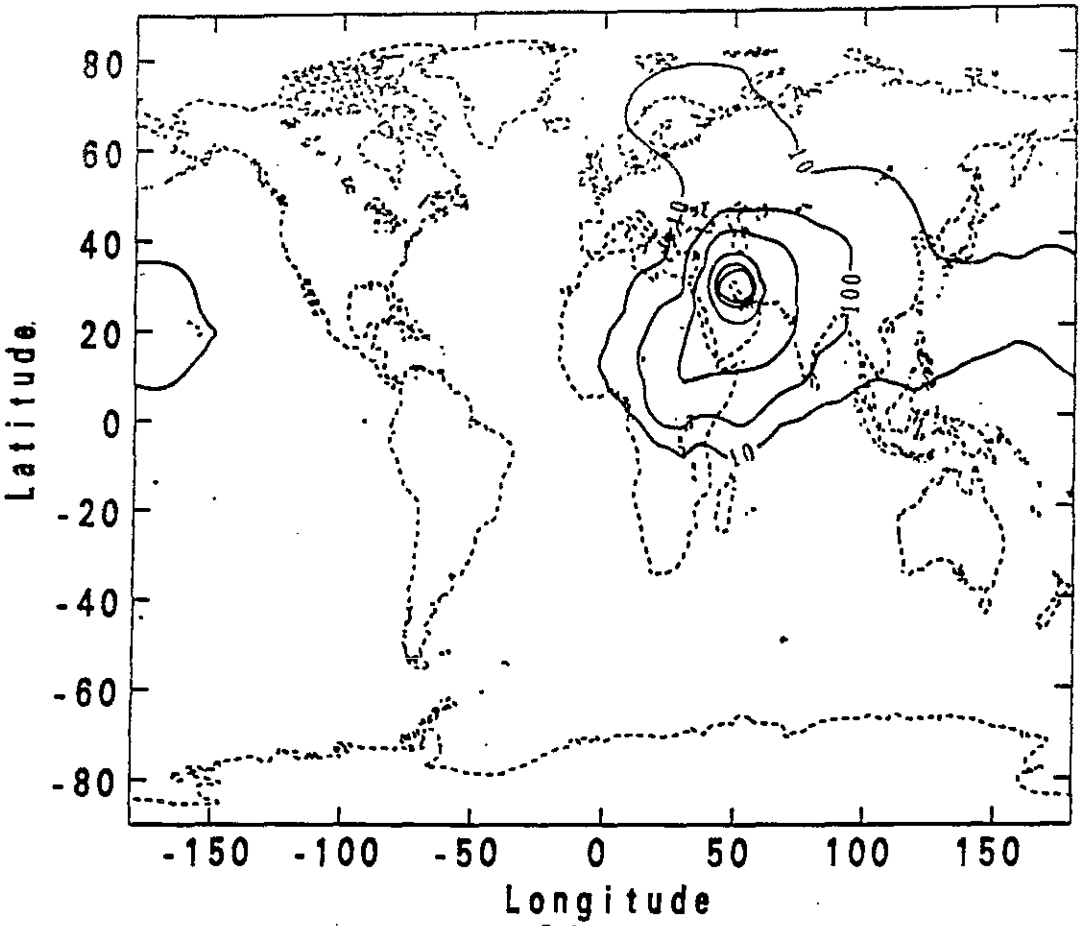



Fig. X.8. Total column $SO_2$ mass ($mg/m^2$) for Sunday 28 April 1991, based on a forecast made on 25 April 1991 by the Dutch operational dispersion model.

(a) multi-scale field data for verification of models (project WIND)
(b) aerosol, gas, and high resolution optical-spectrographic sensing equipment
(c) mesoscale modelling verification capabilities
(d) automated meteorological sensing equipment

12. U.S. Department of Defense
Presented by: R.E. Meyers

The US Department of Defense (DOD) is coordinating, via Defense Nuclear Agency, a large number of research and operational efforts in support of mitigating the adverse effects of the Kuwait oil fires. These effort utilized not only DOD resources, but also those of other agencies such as the National Science Foundation (NSF) and NCAR. Research is underway or has been proposed in the following areas: meteorology upwind of fire site; chemical analysis of raw oil and gas; oil, gas, water expulsion rate from well; fire structure; photographic records of plume; flame temperatures; combustion chemistry; physics of smoke production; smoke yield based on carbon balance; sulfur dioxide gas concentrations; carbonyl sulfide gas concentration; hydrogen sulfide gas concentration; trace gas chemistry ($SO_2$, NO, $NO_x$, $NO_y$, $H_2O_2$, $O_3$); organic fraction of smoke; fire effects on close-in meteorology; chemical analysis of effluent gases in plume and at numerous ranges downwind; smoke physical parameters in plume and at numerous ranges downwind (particle morphology, mass density, particle size distribution, optical indicies of smoke particles); aerosol chemistry; aerosol particulate carbon fraction, aerosol size distribution, aerosol morphology, size-fractionalized particulate matter; smoke particulate constituent concentrations (CO, $CO_2$, PAN); meteorology downwind of fire size (temp., relative humidity, winds, position); transport/diffusion of smoke and gases (regional and global scales); smoke buoyancy due to solar absorption; smoke and cloud track and dimensions; agglomerate structure, primary sphere size; cloud nucleation activity; cloud droplet size distribution; prompt/late-time scavenging (particle attachment, agglomeration, sedimentation); effect of atmospheric moisture on scavenging; rain chemistry/precipitation scavenging; interaction of smoke with dust; effects of cloud seeding; light extinction, IR scattering, absorption, single scatter albedo; optical depth, plume spectral emission profiles; plume radiation map; solar radiation flux; bulk effects of smoke on solar radiation, visible light, IR transmission, photon attenuation, loss of contrast for imaging; ozone parameters; settled particulate matter, mass, and conductivity; analysis of material settled on ground (effect on target appearance, effects on biological systems); rate of contamination and clogging of air filters; corrosive films on electronic equipment; rate of corrosion and contamination of electrical equipment; organic trace elements in precipitation; rate of degradation of historic artifacts (both outdoors and within museums); flame extinction during blowout; high speed photography of flame suppression.



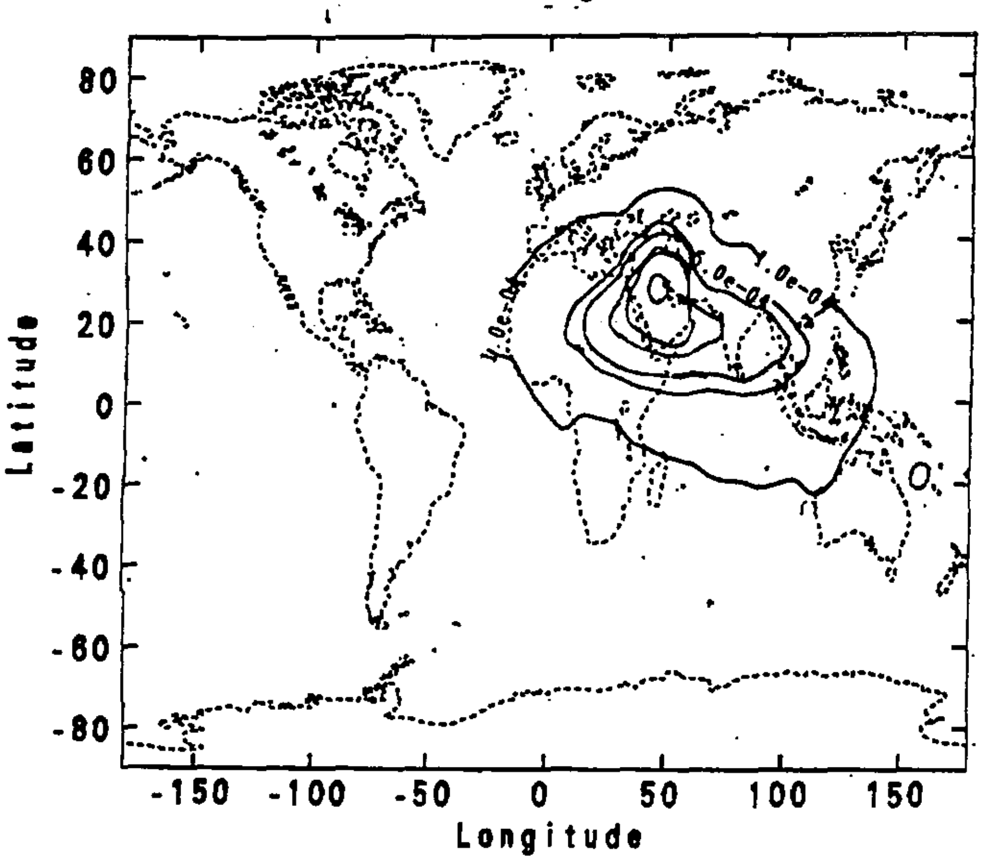




Fig. X.9. (top) Soot surface concentration ($ng/m_3$) due to estimated Kuwait emissions.

Fig. X.10. (bottom) Total column soot ($g/m^2$) for July, due to Kuwait emissions.

Further proposals for research related to the oil fires can be sent to:

Dr. Mohammud Owais
Technical Manager, Radiation Policy Div.
Defense Nuclear Agency
6801 Telegraph Rd.
Alexandria, Virginia 22310-3398
U.S.A.

or

Dr. David Auton
Chief Radiation Policy Div., DNA
6801 Telegraph Rd.
Alexandria, Virginia 22310-3398
U.S.A.

Additional information can be obtained from:

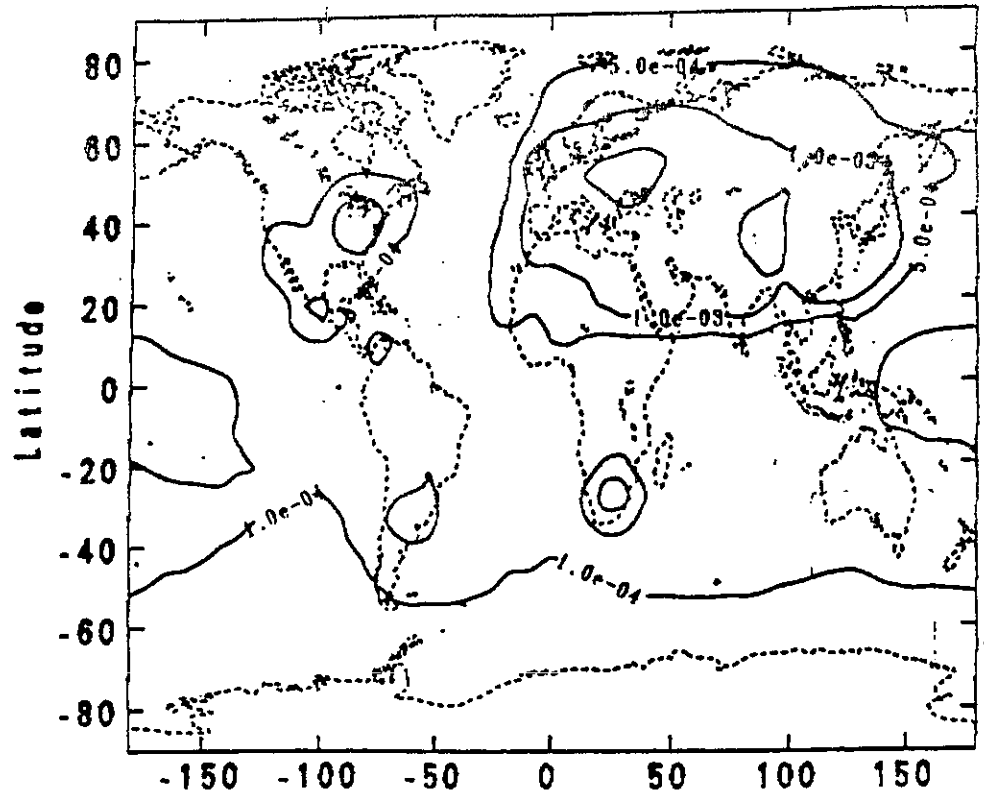
Ronald E. Meyers, Physicist
U.S. Army Atmospheric Sciences Laboratory
White Sands Missile Range
New Mexico, 88002
U.S.A.
Telephone #: 505-678-4037

13. Lawrence Livermore National Lab., U.S.A.
Presented by J. Penner

The estimated soot emissions from Kuwait are fully two-third of the total world-wide emissions and represent the largest contributor of soot within the regions. The source rate from Kuwait (spread over a 5 degree by 5 degree zone) would equal almost 15,000 $kg/km^2/yr$.

The source of sulfur from the Kuwait fires may also be estimated to be $2.5 \times 10^{10}$ gS/d. This is 10-15% of the total sulfur emissions in the latitude band between 20 to 35°N.

The sources of soot and sulfur from Kuwait fires were input into the LLNL global climate/chemistry model (c.f. Penner et al. 1991b). It uses the winds and precipitation fields from the National Center for Atmospheric Research (NCAR) Community Climate Model (version CCM1) with an resolution of approximately 4.5° latitude by 7.5° longitude. The model also assumed a 6-day e-folding lifetime for conversion of $SO_2$ to $SO_4^=$ to simulate aqueous conversion processes. Each species in the model may experience deposition if parcels are in the lowest 100 mb. Soot, $SO_2$, and $SO_4^=$ were also scavenged by precipitation and rates proportional to the rate of precipitation in the model. The scavenging coefficients were set to 2.5 $cm^{-1}$, 2.5 $cm^{-1}$ and 1.0 $cm^{-1}$, respectively.



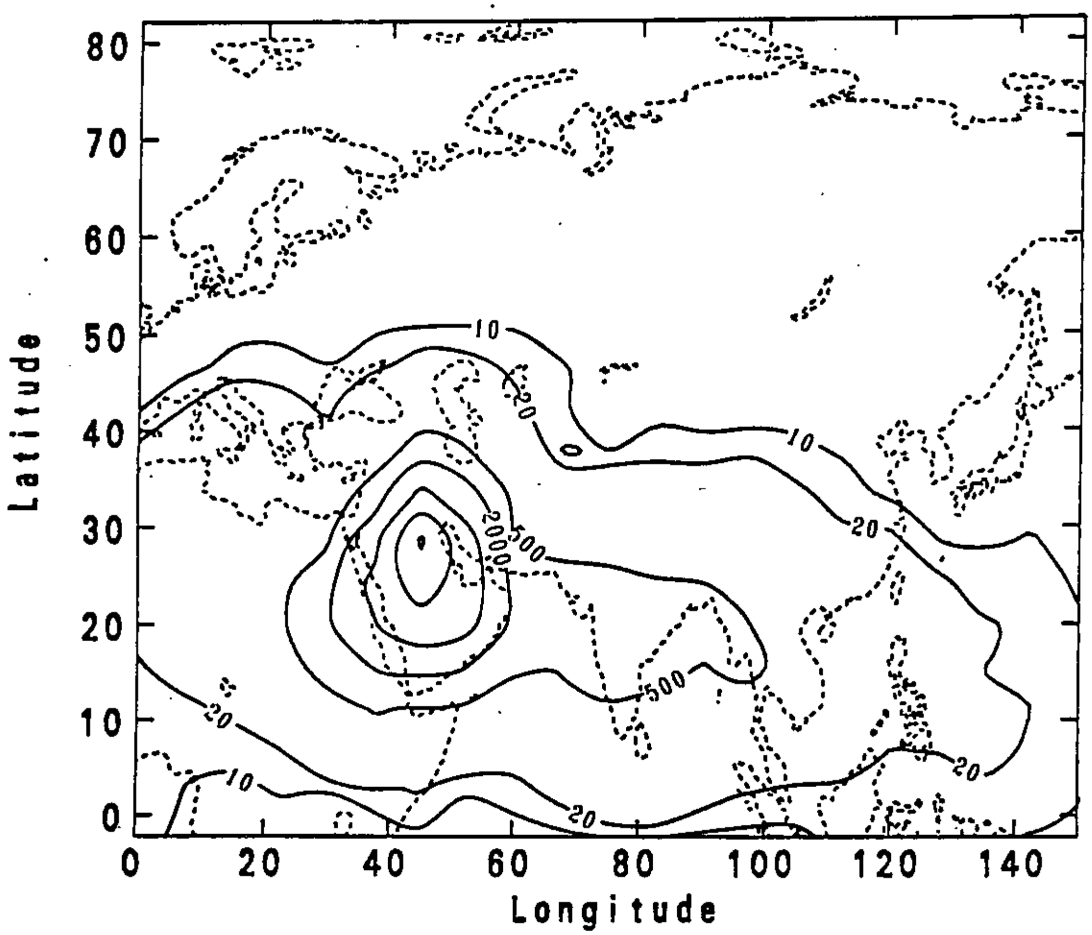




Fig. X.11. The same as Fig. X.10, for the global total fuel consumption.

Fig. X.12. Sulfate concentrations due to Kuwait emissions (pptv).

The monthly averaged surface concentrations for soot (in ng/$m^3$) for March is shown in Figure X.9. In March, high winds carry soot as far east as Mauna Loa. This is particularly interesting in view of the recent tentative identification of soot at Mauna Loa from the Kuwait fires (R. Schnell, private communication, 1991). The soot emissions are retained closer to the source in July, but average concentrations of more than 100 ng/$m^3$ are experienced throughout the Indian subcontinent and parts of southwest Asia. This concentration contour also encompasses much of northeast Africa and extends northward to the Black Sea. Much of this region will experience a doubling of the concentration of soot as a result of the fires. Figures X.10 and X.11 show the column abundance of soot from the oil fires in July and from the ambient fossil fuel calculations for July, respectively. These figures may be approximately converted to absorption optical depth by multiplying by a factor of 10. In Figure X.10, there is a column abundance of up to 0.05 $gm^{-2}$ centered over Kuwait. A large region, extending from the middle of Africa to southwest Asia experiences column abundances of more than 0.001 $gm^{-2}$. These column abundances for soot may be compared to the abundances calculated for the ambient fossil fuel scenario. These are shown in Figure X.11. The 0.001 $gm^{-2}$ contour interval in this case extends over much of Europe, northwest Africa, Saudi Arabia, and to eastern Asia. Two areas, over eastern Europe and China, experience column abundances of 0.005 $gm^{-2}$. The Kuwait fires appear to be capable of increasing the optical depths from soot by at least a factor of two over a large area surrounding the source region.

Contour intervals of the predicted monthly averaged surface concentrations of $SO_4^=$ (in ppt) for July are shown in Figure X.12. $SO_4^=$ is widely spread and covers much of India and parts of southeast Asia. This is due to the several days time required to form $SO_4^=$ from $SO_2$ in the model and the slower rate of removal.

Most of the $H_2S$ is confined to the local region, although concentrations as high as 10 ppt reach out towards India in the east, towards northeast Africa in the west, up to the Black Sea in the north and to Saudi Arabia in the south.

The potential emissions of soot from the Kuwait oil fires are large relative to the global emissions of this substance. The spread of soot may reach as far as Mauna Loa in some seasons. In other seasons, the loading of soot within a large area centered about the fires may more than double. This soot will certainly have regional implications for climate, but its global consequences should be investigated. The smoke could either warm the climate or cool it, depending on its altitude in the atmosphere and on whether it is thermally coupled or

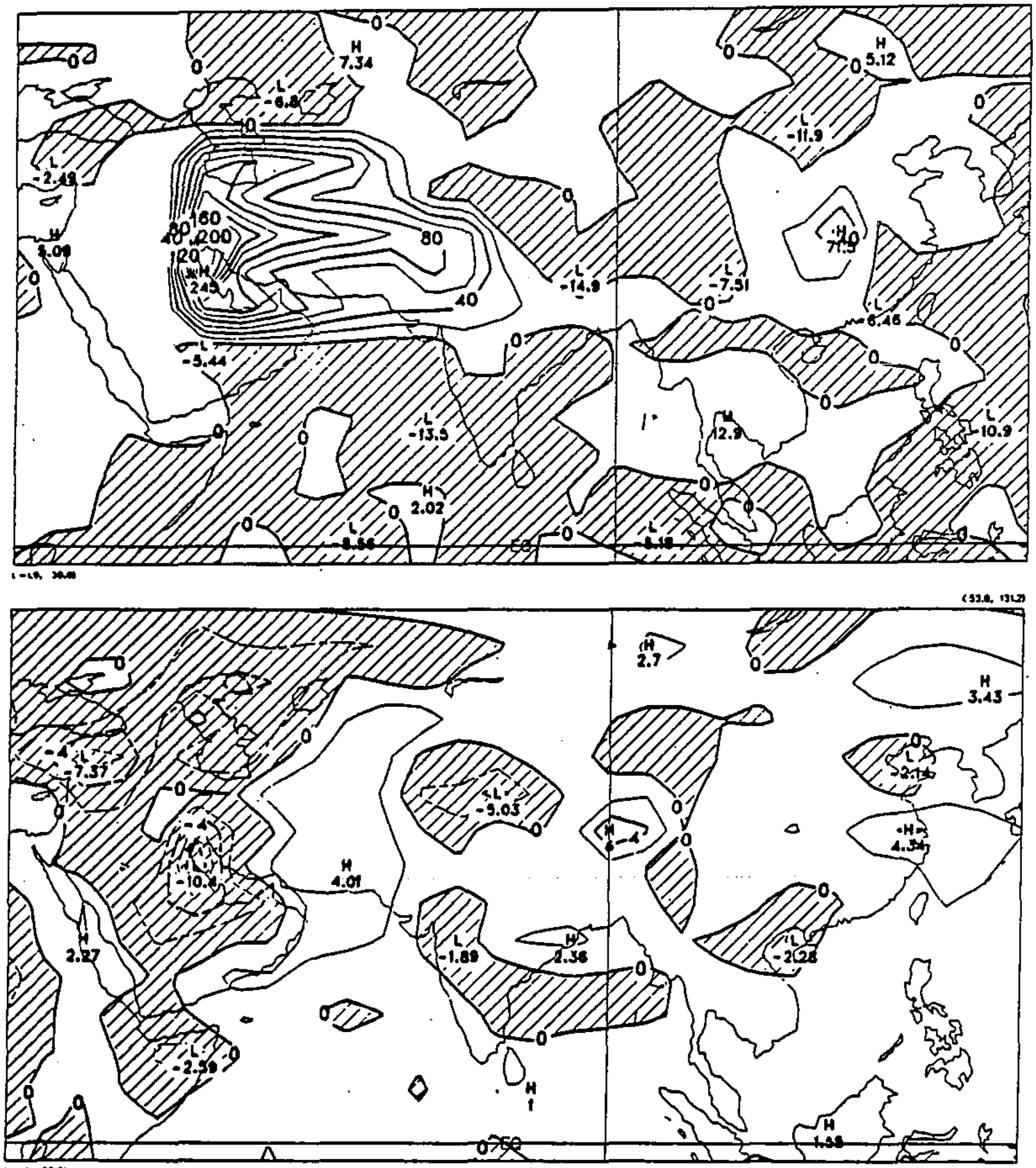



Fig. X.13. (top) Estimated change in solar heating due to soot in the lower atmosphere ($W/m^2$).

Fig. X.14. (bottom) The corresponding change of the ground temperature (K) for July.

decoupled from the surface (Ghan and Penner, 1991). Enhancements to existing monitoring stations throughout the region should be pursued in order to quantify the amount and spread of the soot.

The sulfur emissions from the fires are a large source relative to other sources in the area. The monitoring of $SO_2$ and $SO_4^=$ throughout the region could help quantify the spread of this pollutant as well.

Ghan, S.J. and J.E. Penner, "The effects of smoke on climate," Encyclopedia of Earth System Science, in press, 1991.

Novakov, T., J.E. Penner, and H. Eddleman, "An inventory for global soot emissions from fossil fuel combustion," presented at the 4th International Conference on Carbonaceous Aerosols in the Atmosphere, Vienna, Austra, April 3-5, 1991.

Penner, J.E., S.J. Ghan and J.J. Walton, "The role of biomass burning in the budget and cycle of carbonaceous soot aerosols and their climate impact," in Global Biomass Burning: Atmospheric, Climatic, and Biospheric Impolications, J. Levine, Ed., in press, MIT Press, Cambridge MA 1991a.

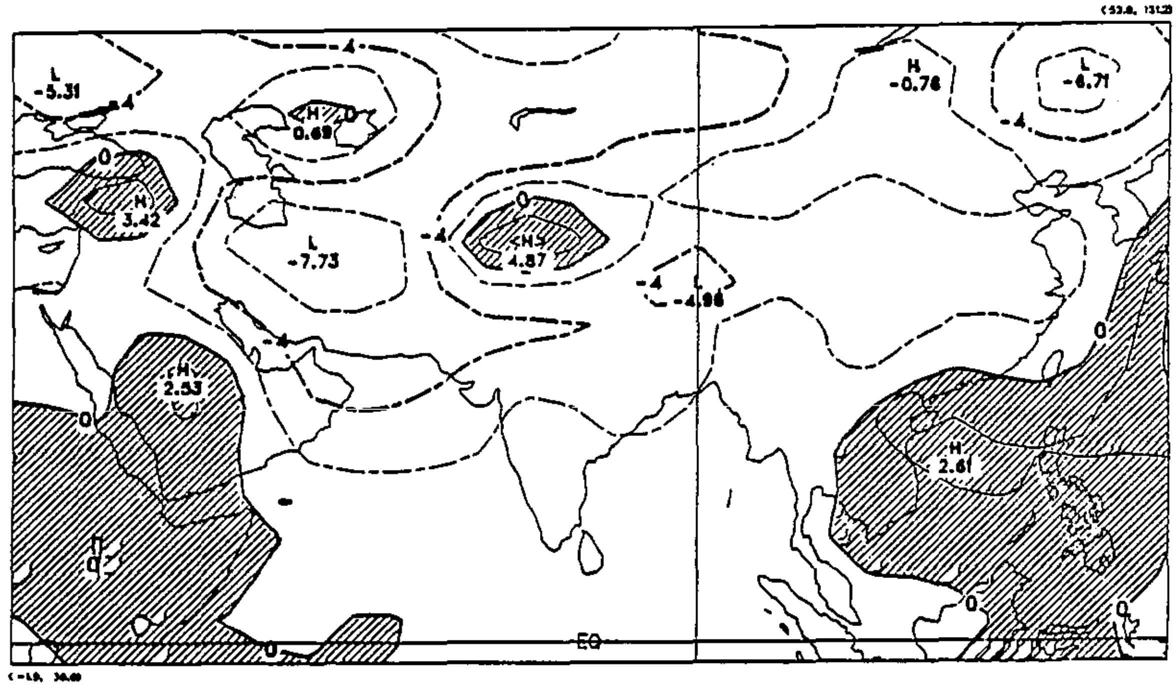
Penner, J.E., C.S. Atherton, J. Dignon, S.J. Ghan, J.J. Walton, and S. Hameed, "Tropospheric nitrogen: A Three-dimensional study of sources, distributions, and deposition," J. Geophys. Res., 96 959-990, 1991b.

Walton, J.J., M.C. MacCracken and S.J. Ghan, "A global scale Lagrangian trace species model of transport, transformation, and removal processes, J. Geophys. Res., 93, 8339-9354, 1988.

14. Atmospheric Environment Service, Canada
Presented by J.P. Blanchet

The effects of smoke on the local and regional meteorological conditions and short-term climate perturbations has been investigated. The concentration of soot in the smoke cloud is evaluated assuming steady state between a constant injection rate and a prescribed removal rate. An "e-folding time" of 5-10 days is assumed to account for removal processes from the volume by dry and wet deposition as well as advection. Soot concentration depends only on the volume of atmosphere being filled. This approach is a gross simplification of the actual situation.

The Canadian Climate Centre General Circulation Model (CCC/GCM) with a spectral resolution of T32 wavenumbers is used together with a 1-D radiative convective photochemical model (RCPM). The 1-D RCPM evaluates "static" solutions for equilibrium surface temperature and the corresponding radiative forcing. There is a broad agreement between the 1-D and GCM for the surface temperature versus optical



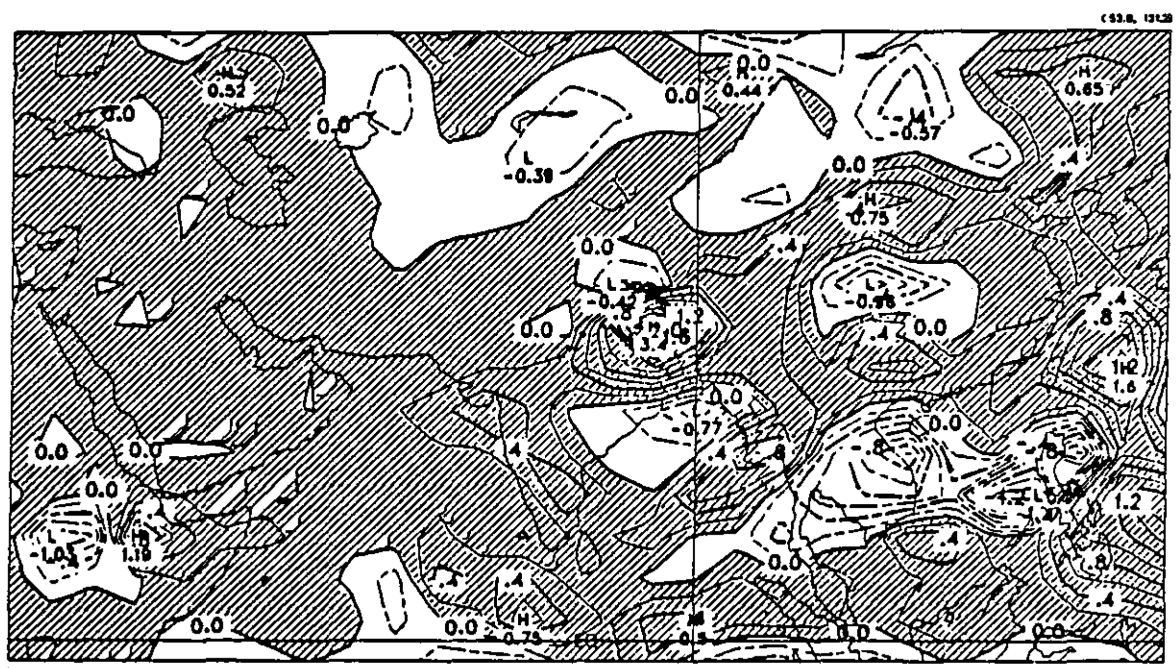


Fig. X.15. (top) Changes in surface pressure (mb) for July.

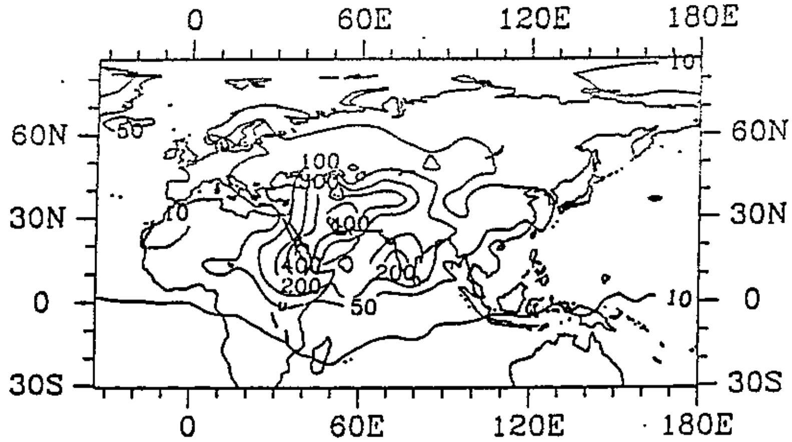
Fig. X.16. (bottom) Changes in monsoon precipitation ($10^{-5}$ $kgm^{-2}s^{-1}$). The same area as in Fig. X.15 is shown.

depth at most scales. Only on small scales, near the source, smoke produces surface cooling due to reduced insolation. The large coolings reflect large optical depths. At regional scale and above, and for soot located in the lower troposphere, the effects on temperature change to warming. This is mostly due to relative increase of the long-wave atmospheric radiation. The magnitude is particularly sensitive to the height of the smoke layer.

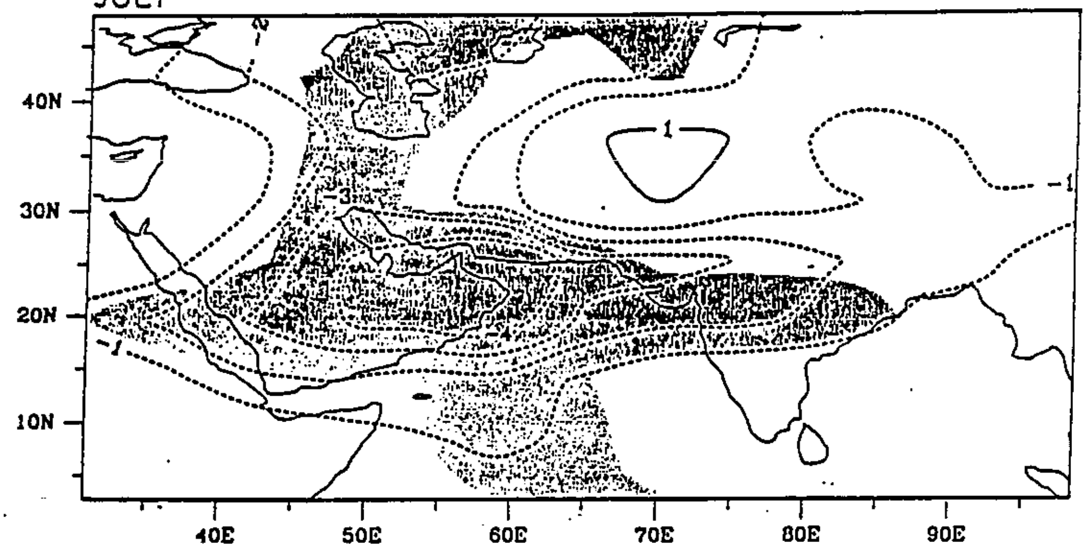
Secondly, the GCM is used for a seven month simulation (January-July) with the intention of investigating the links between smoke concentration, radiation and heat budgets, surface and air temperatures, snow melt, and eventually monsoon activity. In this experiment, smoke is restricted to the 700-900 mb layers of the GCM. The maximum optical depth is reduced to about 2 over Kuwait and decreases with volume extending eastward from the source. Figure X.13 shows mostly solar heating due to soot in the lower atmosphere. It is also a good indicator of the smoke distribution in this model run. Figure X.14 shows the corresponding change of ground temperature for July. In the Kuwait area, the model produces cooling of the order of 5-10 degrees centigrade. Downwind from the source, warming around 2 degrees are obtained. Beyond 1000 km downwind from Kuwait, natural variability dominates and nothing can be inferred from this short run. It is important to note that those temperature changes are larger than actually expected due to the assumed large optical depths. This experiment is not a forecast of the actual situation but a means to investigate the relationships between smoke and meteorological parameters. It also indicates a trend and provides a scale for assessment purposes. Figure X.15 shows the corresponding change of surface pressure in July. With warming east of Kuwait, a relative thermal low is formed. Figure X.16 shows increases in monsoon precipitation over India due to increased convection and moist flow in low levels. Figures X.13-X.16 illustrate potential links between oil fire smoke and meteorological parameters. Those results are very preliminary and need to be extended and fully diagnosed before drawing final conclusions. A substantial amount of soot is being deposited on the snow surface. It is also a concern that the snow reflectivity would be altered by black carbon. Even a minute amount of soot increases considerably the amount of solar energy absorbed by the surface. We stress the need for monitoring large-scale background soot concentration, particles, size distribution, and smoke optical properties for the evaluation of short-term climate and environmental changes.

15. Max PLanck Institute for Meteorology, Federal Republic of Germany
Presented by H. Graf

Model calculations have been carried out with a global circulation model (T21). It was assumed that present emissions continued during a year. Two different scenarios were taken for the wave length dependence of the radiation absorption cross sections. Results obtained pertain to changes in net surface solar radiation, surface temperature and precipitation in different months. (Some examples are given in Figs. X.17, X.18).




JULY




MAY

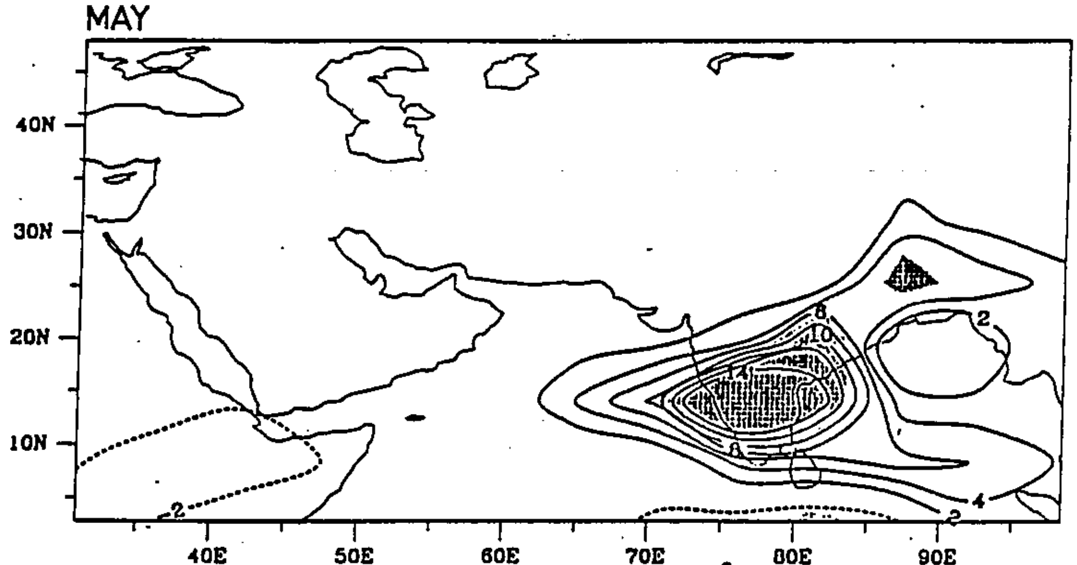



Fig. X.17. (top) Total deposition of soot ($mg/m^2$) during the 12 month simulation. Contour of 10, 50, 100, 200, 300 and 400 $mg/m^2$ are depicted.

Fig. X.18. Climate response in summer. Anomalous 2 m temperature for July (middle); the contour interval is 1 $^oC$. Anomalous precipitation for May (bottom); the contour interval is 2 mm/day. The zero contours have been suppressed. Shading indicates regions with local significance levels larger than 95 %.

A significant cooling of about 4°C was computed for the summer over the Gulf region (≈500 x 500 $km^2$). On a global scale non-significant changes were predicted. Due to the relatively short residence time of the soot, it is expected that soon after the extinction of the fires, effects, if any, will disappear. A significant weakening of the Indian summer monsoon was estimated to be unlikely.

# AN AIRCRAFT MONITORING STRATEGY

Aircraft should give priority to the following measurements:

a. Source strength and characterization of soot including characterization of particles size, shape and composition which will affect lifetime, optical properties and effects.

i) Source strength (for individual oilfields and total emissions) using, where possible, all four methods (integral of mass, lidar backscatter, measurement of optical thickness, and comparison of observed and predicted) used in combination. Flights should be coordinated with ground-based observations as well as lidar and satellite measurements.

ii) Characterisation of particles including PAH measurements (chronic health hazard), organic carbon/black carbon ratio in particles, trace elements, size spectrum, and morphology.

b. Wind and concentration field in near to medium distances (up to 200 kms) of $SO_2$ $NO_x$, $O_3$, particles mass and characterization, optical density, VOC's, HCHO, CO, $CO_2$.

c. Evolution of plume chemistry at long distances downwind (greater than 200 km) of $SO_2$, $SO_4$ aerosol, $NO_x$, $NO_y$, $NO_3$ aerosol, VOC's, $O_3$, optical density, particle mass and characterization. For such measurements a local based station will be needed for grab sample analysis.

d. Temporal variation of source strength, as above, as fires are put out.

The coordination of aircraft flights should proceed as follows:

a. A sequence of aircraft flights should be made covering each month with some overlap, where possible, for intercomparison of measurements.

b. WMO should assist in arranging the coordination of aircraft activities through national focal points.

c. WMO should assist aircraft teams to obtain access to national air space in the region.

d. Local support for aircraft teams in the Gulf area is essential. The meeting recommended that WMO maintain information on the appropriate contacts in the area throughout the observational period.

e. Assistance is needed in providing aircraft teams with model forecasts for flight campaigns. These forecasts should cover a variety of timescales.

f. The WMO should assist in the distribution of flight data as it becomes available, recognizing that some data need processing at national facilities. Wide distribution of flight data will assist in the planning of subsequent aircraft activities and provide test data for model evaluation.

g. The WMO should assist, within the next few months, in the organization of at least one workshop to compare and discuss aircraft results.

h. The experts noted that the U.K., U.S.A. and German airplane measuring programmes were bilateral in character. While recognizing the need for urgent measurements, the meeting urged these programmes and future aircraft monitoring programmes to be structured under the framework of the WMO project.

i. The list of planned measurement campaigns is not complete and because all relevant data are highly useful, further campaigns (aircraft and otherwise) at later dates are encouraged.

The status of plans for aircraft monitoring identified at meeting is summarized in the Table:

Status of Aircraft Plans, 30 April 1991

| Number | Country | Organization | Period | Duration | Funding | Meeting Contact |
|---|---|---|---|---|---|---|
| 1 | U.K. | U.K. Meteorological Office | March/April | 2 weeks | Done | Smith |
| 2 | U.S.A. | NCAR | mid-May | 3 weeks | Available | Baumgardner |
| | | University of Washington | mid-May | 3 weeks | Available | Hobbs* |
| 1 | Germany | Umwelt Bundesamt | May/June | 2 weeks | Available | Sartorius |
| 2 | U.S.S.R. | State Committee for Hydrometeorology | Unknown | 50 hours | Partial | Tsaturov |
| | | Institute of Global Climate and Ecology | 10 July 91 | 100 to 200 hours | Partial | Nazarov |
| | | Central Aerological Observatory | 20 June 91 | 100 to 150 hours | Partial | |
| 2 | Germany | DLR | June, July, August | 2-3 weeks | Partial | Schumann |
| 1 | U.S.A. | Pac.NW Labs | July, August | 4 weeks | Unknown | Hales* |

* Not present at the meeting

Collaborative work in association with the aircraft programme is necessary:

a. Field measurements and laboratory studies associated with source characterizations should commence as soon as possible.

b. Near-field modelling of individual plumes is important for the aircraft programme. Attendant to this, a micro-network of meteorological field monitoring stations is needed in addition to those already planned or in place for other purposes. These should include precipitation and dry deposition sampling.

c. Collaborative laboratory studies between atmospheric fire scientists and aerosol chemists are needed to expand understanding of critical carbonaceous aerosols including formation, chemistry, characterization, and aerodynamic properties.

The following items require immediate consideration:

a. The WMO aircraft coordinator should contact UNEP and appropriate officials within Kuwait immediately to coordinate establishment within Kuwait of a focal point for coordination and logistical support of personnel and projects involved in the implementation of the aircraft operations.

b. Funding for provision of logistical support for field projects, especially aspects of the aircraft programme, must be provided to WMO by participants either directly or through the U.N. Interagency Fund (through UNEP),

c. All data collected by parties to this programme, particularly in the region, should be made available to all parties through WMO, in a timely manner, in view of the multiple uses for the data and the urgency of the matter.

d. A very high priority needs to be placed on the re-establishment of capabilities in Kuwait for collection of source and local meteorological data.

e. In view of the continuing critical importance of accurate source term data, it is essential that efforts be implemented immediately and provision be made for continuing updates and dissemination of data.

For determination of the amount of soot released per time unit, the mass-flux is required. It was therefore recommended measuring:

a. The mean wind field across the plume by aircraft and sondes,

b. The extent and relative concentration field within the total plume. (These can be obtained by Lidar measurements from, for example, the German Falcon by flying across the plume's cross-section at altitude above the plume (about 5 km) at a distance from Kuwait where the optical depth is small enough to get signals from the ground),

c. In-situ measurements of soot concentration at approximately the same time and at least one flight level within the plume,

d. Total sulfur concentration by probes,

e. Increase in water vapour within the plume. (The German aircraft proposes to try DIAL measurements. However, it was noted that the increase in water vapour may be too small to be detected.)

<u>The following possibilities were considered for flight patterns</u>:

a. vertical profiles near the source (30 to 80 km),

b. vertical cross-sections along main plume axis at distances from 30 km to 300 km and

c. vertical cross-sections at large distances from the sources (up to at least 1000 km). (This measurement has high priority because of its importance for global modelling).

# Gulf Regional
# Air Monitoring Plan
# (GRAMP)

**Andrew E. Bond**

**Atmospheric Research
and Exposure Assessment Laboratory
Office of Research and Development
U.S. Environmental Protection Agency**

# Phased Air Monitoring Plan

| | |
|---|---|
| Phase I. | Provide a Framework for an Early Warning Advisory |
| Phase II. | Establish a $PM^{10}$ Monitoring Network |
| Phase III. | Characterize the Aerial Plume |
| Phase IV. | Develop a More Complete Profile of the Smoke Plume Constituents |
| Phase V. | Develop a Gulf Regional Air Monitoring Network to Track the Impact of the Plume |

# Phase I.
# Provide a Framework for an Early Warning Advisory

- Gather Daily Weather Forecasts to Predict Meteorological Conditions
- Use Visual Observations
- Gather Existing Air Monitoring Data from Fixed and Mobile Sites Operated by Saudi MEPA, Saudi ARAMCO, and the Governments of Kuwait and Bahrain

# Phase I.
# Provide a Framework for an Early Warning Advisory

(continued)

- Establish a Daily Briefing
- Develop a Daily Map Depiction of the Aerial Distribution of the Smoke Plumes
- Issue a Daily General Statement about the Expected Behavior(s) of the Oil Fire Plumes

# Phase II.
# Establish a PM$^{10}$ Monitoring Network Using Portable PM$^{10}$ Monitors

- Working in Conjunction with the Saudi Arabian Meteorology and Environmental Protection Agency (MEPA), the Proposed Plan Has Been Developed to Collect Information on PM$^{10}$, Which Represents Particulate Matter with Particles Less Than 10 Microns in Diameter (at the present time there is little or no PM$^{10}$ monitoring in the Gulf Region)

# Phase II.
# Establish a PM10 Monitoring Network Using Portable PM10 Monitors

(continued)

- Conduct a PM10 Saturation Sampling Study to Determine the Temporal and Spatial Features of the Impact of the Oil Well Fires and Attempt to Reconcile the Data with Existing Model Estimates
- Total of 15–20 Portable PM10 Samplers Equipped with Quartz Filters Would Be Run Simultaneously on a Daily Basis

# Phase II.
# Establish a PM10 Monitoring Network Using Portable PM10 Monitors

(continued)

- The Recommendation for Siting of the Portable PM10 Samplers is Predicated on Providing a Large Area of Coverage for Developing a Better Estimate of the Areas Impacted by the Plume, a Cross-Sampling of Population Centers, and to Provide the Opportunity to Transfer this Technology to Saudi Arabia, Kuwait, and Bahrain

# Phase III.
# Characterize the Aerial Plume

- To Achieve This Goal, Many of the Same Plume Measurements Collected by the Existing and Proposed Ground Level Measurement Locations Should Be Provided by the Aerial Sampling Platform
- The Aerial Sampling Activities May Be Separated into Measurements Which Address the Three General Zones of Plume Characteristics, from a Meteorological Sense
  - Close-In Zone
  - Intermediate of Transition Zone
  - Extended or Distant Zone

# Phase IV.
# Develop a Complete Profile of the Smoke Plume Constituents

- Obtain Additional Equipment to Expand Existing Continuous Monitoring High Priority Sites in Kuwait and Saudi Arabia
- The Survey Conducted by the Team During Phase I of This Plan Indicated That within the Region, Respirable Particulate Sampling Technology, Aerosol and Total Particulate Sampling and Analysis for Volatile Organic Compounds (VOC), Semi-Volatile Organic Compounds (SVOC), and PAHs Were Either Not Available or Insufficient to Properly Characterize the Effects of the Oil Well Fires on the Population Centers and the Troop Concentrations within the Region

# Phase IV.
# Develop a Complete Profile of the Smoke Plume Constituents

**(continued)**

- **The Plan Proposes to Expand the Continuous Air and Meteorological Monitoring Currently Being Conducted within the Region at Six Sites**

# Phase IV.
# Proposed Monitoring Equipment

- TSP High Volume Sampler
- $PM^{10}$ High Volume Sampler
- $PM^{10}$ Dichotomous Sampler
- VOC Canister Sampler
- Polyurethane Foam (PUF) Low Volume Sampler
- Optional Tenax/Charcoal/XAD-2 Tubes

# Phase V.
# Develop Regional Air Monitoring Network to Track the Impact of the Kuwait Oil Fires on the Gulf Region

- This Phase of the Proposal Will Be Developed in Series of Stages
- The Network is Directed at Long Term Fixed Site Monitoring, Which Will Collect a Battery of Both Air Quality and Meteorological Data
- Particular Attention Will Be Given to Providing an Early Warning System Advising the Effected Public on What Cautionary Steps Should Be Taken to Minimize the Impact of Air Pollution on Health

# Phase V.
# Develop Regional Air Monitoring Network to Track the Impact of the Kuwait Oil Fires on the Gulf Region

(continued)

- Recommended Measurement Parameters at Each Site
  - Meteorological Variables
    - Wind Speed and Direction
    - Temperature
    - Moisture Content of the Air
    - Dew Point, Relative Humidity
    - Solar Radiation
    - Precipitation
  - Air Quality Variables

# Phase V.
# Develop Regional Air Monitoring Network to Track the Impact of the Kuwait Oil Fires on the Gulf Region

(continued)

| Episodic/Early Warning Measurements | Longer Term Monitoring |
|---|---|
| PM[10] (continuous) | Acid Aerosols |
| TSP | VOCs |
| $SO_2$ (continuous) | Aldehydes |
| $O_3$ (continuous) | B[a]P, Other PAHs |
| $NO_x$, NO (continuous) | Trace Elements |
| CO (continuous) | Fine Particulates |
| $H_2S$ (continuous) | |

# Phase V.
# Develop Regional Air Monitoring Network to Track the Impact of the Kuwait Oil Fires on the Gulf Region

(continued)

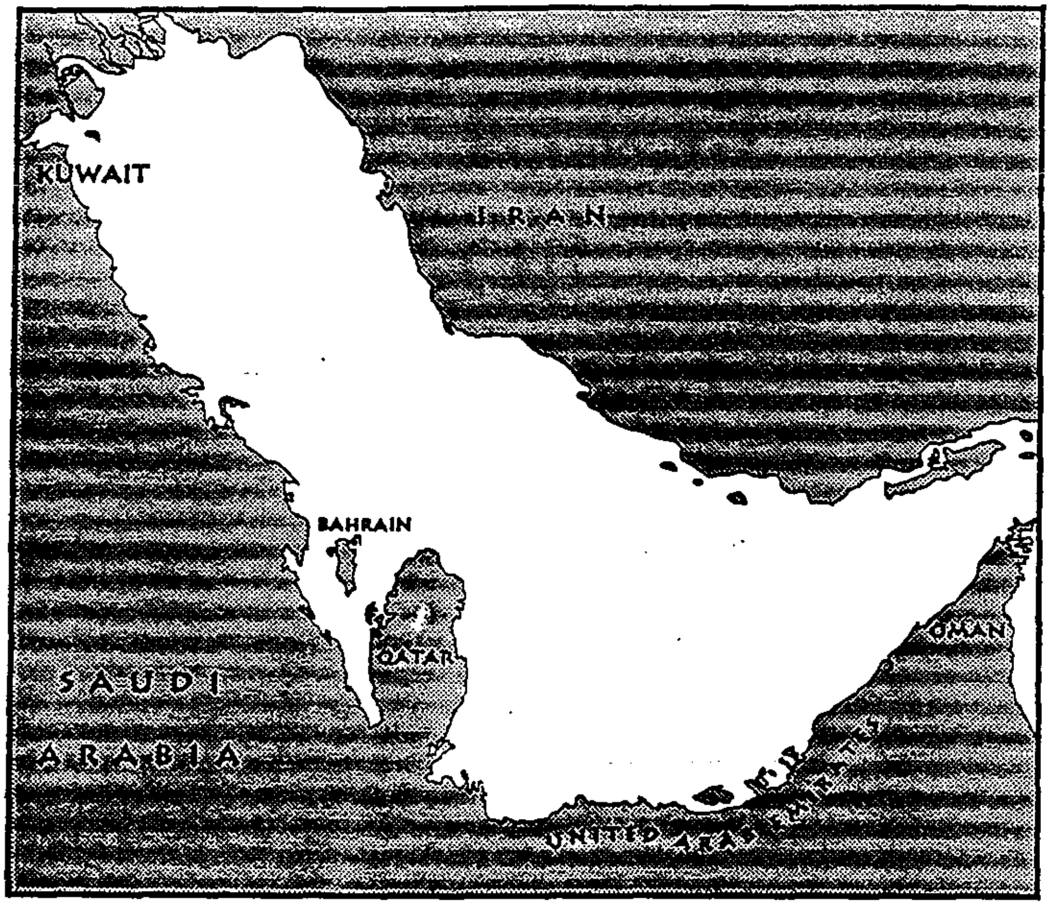
- Health Monitoring Survey
  - Health Questionnaires
  - Blood Samples
  - Urine Samples
  - Hair Samples
  - *In Vivo* Animal Studies
  - Forced Expiratory Volumes
  - Other Morbidity Parameters

# Phase V.
# Develop Regional Air Monitoring Network to Track the Impact of the Kuwait Oil Fires on the Gulf Region

(continued)

- **Distribution of Existing and New Sites Air Monitoring Sites**

| Locations | Existing | New Sites |
|---|---|---|
| Saudi MEPA | 4 | 10 |
| Saudi ARAMCO | 11 | 0 |
| Kuwait | 3 | 8 |
| Bahrain | 0 | 2 |
| Other Locations | 8 | 4 |




# Kuwait Oil Fires:

## Interagency Interim Report

*April 3, 1991*

KUWAIT OIL FIRES
INTERAGENCY INTERIM REPORT

## I. SUMMARY

More than 500 oil well, storage tank and refinery, and facility fires are currently raging in Kuwait and each day produce an enormous amount of smoke and other pollutants. The quantity and character of the smoke plumes are not yet certain, and the fires are expected to continue for some period. The fires originate in seven oil fields, located both north and south of Kuwait City, with the majority centered in the Al Burgan oil field south of the Kuwait City airport. The fires may represent one of the most extraordinary manmade environmental disasters in recorded history.

In response to this situation, the Saudi Government requested U.S. technical assistance on the public health and environmental impact of the fires. The U.S. Embassy in Saudi Arabia concurred in this request, and voiced its additional concerns about the health effects of the fires on the hundreds of thousands of U.S. troops in the region as well as the thousands of American citizens residing in Saudi Arabia and the other Gulf countries. Similar concerns were also expressed in Kuwait. An Interagency Air Assessment Team consisting of representatives from the Environmental Protection Agency, the National Oceanic and Atmospheric Administration, and the Department of Health and Human Services was formed and deployed to the Persian Gulf area. In country, this team was supplemented by representatives of the United States Coast Guard, the Department of Defense, and the Department of Energy.

The specific mission of the team was to assess the conditions through air sampling and monitoring in oil fields and other areas to determine the effect on public health; to review the health infrastructure; to determine the capability of the region to deal with the health threat through air monitoring and appropriate corrective action; to provide technical assistance; and to consider appropriate follow-up action.

Meteorological conditions over the past two months have tended to transport the smoke plume toward the southeast, with periodic excursions toward the northeast. March through July are relatively windy months; there are normally 30 days of very strong winds from the northwest in this period, which produce sandstorms and rapidly ventilate the smoke. From August to October, the incidence of strong winds should drop sharply. The plume is generally below about 12,000 feet. As the summer progresses, it is possible that the height of the plume will increase and that it will then be evident to greater distances.

Emissions from oil fires may have the potential of causing health effects of both an acute and chronic nature, although there is considerable uncertainty as to the extent of the threat. Chemicals such as sulfur dioxide and hydrogen sulfide as well as carbon monoxide and polycyclic aromatic hydrocarbons are often found along with particulate matter in oil fires. While only a limited assessment is possible at this time, the Team did not detect such chemicals in any significant quantity; also, preliminary analysis of the substantial amount of particulate matter did not reveal any chemicals at levels of concern. Additional testing is needed to better define if other toxic materials may be associated with the high levels of particulates found.

The host nation governments also provided the Team with an abundance of preexisting air monitoring information covering the past several years in Saudi Arabia, Kuwait, and Bahrain. These data provide

a useful baseline on limited parameters for comparing the conditions that exist and may evolve during the next several months. The Team concurred with the Saudi Government's view that the considerable Saudi public and private sector competence in air monitoring would need to be supplemented with support and technical assistance. This situation is even more acute in Kuwait City due to the lack of power and to the disruption of the governmental and scientific infrastructure. The Team considered it of critical importance that additional technical assistance be made available to the countries, if requested.

There is need to consider the overall problem from several perspectives so as to ensure economy as well as success. First, because high levels of particulates were found in the air, and prolonged exposure to particulate matter may contribute to respiratory discomfort and perhaps long-term or permanent respiratory disorder, it will be necessary to find out what is in the plume and how it varies over time and distance. Second, we should assess the immediate and long-term human health risk. Third, we should quantify effects on the environment, especially on crops and climate.

## II. TEAM'S ACTIVITIES AND FINDINGS

With the assistance of the Saudi and Kuwaiti Governments, the U.S. Interagency Air Assessment Team has been conducting a reconnaissance survey of the fire plumes and their effects in Kuwait and Saudi Arabia since March 10, 1991. The primary objective of the Team was to obtain preliminary, short-term data on the emissions from the smoke emanating from the oil well fires at a variety of locations, in order to:

1. Determine if there is an acute health threat associated with the Hydrogen Sulfide ($H_2S$) and Sulfur Dioxide ($SO_2$) and particulates, three pollutants that might be emitted from burning oil wells;

2. Identify and quantify the gaseous and particulate byproducts being produced from the burning oil wells; and

3. Determine if the materials associated with these fires are affecting areas where American citizens are located.

4. Assess the potential extent of the health effects related to the emissions from the fires and the status of the Kuwaiti and Saudi health infrastructure.

Based on these objectives, limited, real-time data was obtained directly from the Kuwait oil fields, as well as from Kuwait and Saudi Arabia locations where embassy officials, troops, and citizens work and reside. Additionally, the Team conducted a number of interviews with health officials to evaluate the extent of acute respiratory problems related to smoke exposure. While only a cursory assessment is possible at this point, some data obtained by the team were encouraging. The preliminary findings are as follows:

1. Limited sampling did not reveal the existence of high concentrations of sulfur dioxide or hydrogen sulfide near the burning wells or in population areas in the path of the oil well emissions;

2. High levels of particulate were found in the air;

3. The results of the current monitoring findings and health interviews with medical personnel in the affected areas suggest that at the present time susceptible subpopulations, such as individuals with asthma and chronic obstructive lung disease, may experience exacerbation of their symptoms. Special health concerns, warnings, advisories, and precautions are clearly warranted for these individuals. This situation does not appear to be life threatening under current exposure conditions but, if meteorological conditions change, i.e., poor air mixing or plume touchdown, there could be adverse health effects for these susceptible individuals; and,

4. The long-term effects on health are not readily ascertainable at this time due to insufficient data on the populations exposed, the composition of the smoke plume, the impact of oil pools, and long-term meteorological patterns. Both the Kuwaiti and Saudi health communities have expressed great interest in obtaining training and support from the US medical community that can be continued by themselves in future years. Aggravating the problem is the severe damage done to the scientific infrastructure of Kuwait thus limiting the current in-country analytic capabilities. Any response by the US would have to include both training and equipment.

The Team has stressed, however, that their observations represent only a preliminary assessment and that considerable follow-up will be necessary to evaluate definitively the nature and magnitude of the human health, ecological, and atmospheric effects of the oil fires. Such follow-up activities will need to be carefully coordinated with the governments in the region as well as with other governments and international organizations, such as WMO, WHO, and UNEP, which are seeking to assist in evaluating the situation.

## III. PROPOSED PROGRAM

The local populations are being exposed to an increased health risk, the magnitude of which cannot be estimated with any degree of certainty without further measurements and surveys. The extent to which conditions may worsen needs to be understood and a forecast capability developed. Without such measurements and assessment, and development of a predictive capability, the regional population remains exposed to an uncertain risk, and reconstruction of the area may be impeded. Moreover, without such input, an accurate and defensible quantification of environmental effects will not be possible.

In addition to providing direct answers to questions regarding the effects of the smoke plumes on the atmospheric environment, intensive studies of the plumes will accelerate progress in understanding manmade effects on regional and global air quality, meteorology, and climate. Because the expected changes in air chemistry, solar radiation, and cloud microstructure are so large, observations of these processes could circumvent the need for many years of study directed at much lesser phenomena.

The program proposed below is comprised of three primary elements: human health surveillance and risk assessment, air monitoring, and development of a forecast capability. These elements will be closely linked to achieve the goals of understanding and predicting the degree of human health risk and the effects on atmospheric processes.

## 1. *Air Monitoring*

The objective of the air monitoring program is to collect the necessary data to determine the nature and concentration of pollutants associated with the fires, and demonstrate the recovery of the environment as the fires are extinguished.

The development and deployment of an integrated monitoring network will serve several interrelated purposes. It will assure data consistency throughout the region. It will provide better data to assess the immediate health risk and potential for long term risks. It will be used to initiate, test, and refine forecast models discussed later in this plan, and thus greatly assist in the development of location and condition specific alerts -- assisting in issuing special advisories for populations at risk under unique conditions. Lastly, it will provide a better basis for scientific understanding and knowledge of the important regional and international issues and will assist in assessing possible extended consequences of the fires.

The U.S. Interagency Air Assessment Team is working with the Saudi Arabian Meteorology and Environmental Protection Agency (MEPA), Saudi ARAMCO, and King Fahd University of Petroleum and Minerals to develop an air monitoring plan for the Gulf Region that will provide the air monitoring data to assess the impact of the Kuwaiti fires in Saudi Arabia. While focused primarily on the needs of Saudi Arabia, the plan forms the general basis for a regional network that should meet the needs of other Gulf nations as well.

The following activities are proposed in cooperation with and support of the host governments:

- Immediate steps would be taken to collect and analyze meteorological observations and forecasts, record visual observations of the smoke plume, and review existing monitoring data. Plume observations via satellite would be obtained daily, supplemented by periodic on-scene aerial transects designed to characterize the overall geometry of the plume.

- A ground-based sampling network of portable equipment would be installed by EPA and others at approximately 15-20 locations to measure particulate matter less than 10 microns in diameter (the particle size most likely to penetrate deeply into the lungs). The ratio of the less than 10 micron particles to total particulate load would be established. Limited organic analysis would be undertaken.

- Measurements of carbon monoxide, carbon dioxide, methane, hydrogen sulfide, sulfur dioxide, particle size distribution, elemental and organic carbon, metals, polycyclic aromatic hydrocarbons, and acid aerosols would be obtained close to the fires by NASA and NIST. These measurements should attempt to characterize and categorize emissions from several specific wells.

- Specially equipped aircraft from the University of Washington (April 15 to May 15), NCAR (May 1 to June 1), and NOAA (July 1 to August 1) would be deployed to measure downwind plume composition and dispersion, radiative properties and climatic effects, and effects on clouds and precipitation. On the basis of the initial aircraft results, a longer-term sampling program would be designed to monitor the relaxation of the atmospheric environment as the fires are extinguished.

- Six additional comprehensive air quality monitoring stations would be established along the general axis of the plume from Kuwait City to Saudi Arabia to collect data on particulates, as well as on the organic and inorganic constituents of the plume.

- Meteorological stations would be co-located at as many as possible of the selected monitoring sites. Data would be collected on wind, temperature, humidity, direct and diffuse radiation, soil temperature, and precipitation. Ten precipitation monitoring stations operated by WMO would be upgraded to measure departures in precipitation chemistry and restabilization to normal levels.

- A data and information system would be designed to provide world-wide access to data of all types related to the fires. High speed data transmission capability would be established to enable image, graphics, and text exchange among participants in the monitoring, forecast, and health elements of the program. In the short-term a temporary archive would be developed to avoid loss of key data sets.

### 2. *Development of a Forecast Capability*

The objective of this activity is to develop an early warning advisory system for the Gulf and downwind regions. The system would forecast the trajectory of plumes created by the fires and compute the atmospheric concentrations of several constituents of known human health and potential environmental impact.

Mathematical models of the fires and their effects are being developed by institutions in Saudi Arabia and the United States to assess the impact of the fires. The models detail the combustion process associated with each well, and predict plume rise, chemical transformations, transport and dispersion, and particle deposition. These models are in turn linked to other algorithms and databases to predict the impact of the plume on human health, and the local and distant environment (including effects on crops).

A number of activities would be undertaken to complete the development of a forecast system:

- Short-term meteorological forecasts would be used immediately to predict the orientation and general concentration of the smoke plume throughout the region.

- Existing models in the U.S., Saudi Arabia, and elsewhere would be tested through air quality measurements obtained through the monitoring program described in the preceding section. As testing is completed, the models would be used to adjust the location of portable monitoring stations for optimal sampling and provide improved forecasts of plume characteristics.

- Selected models, when tested, would be assembled into a single computer system linked to weather forecast models available through NOAA's National Climatic Data Center. The system would form the basis of an early warning system with terminals into the system available both in the United States as well as from the Gulf region.

- At the conclusion of model development and testing, training and equipment would be provided to allow the modeling capability to be fully operated by appropriate agencies in the Gulf region.

### 3. *Human Health Surveillance and Risk Assessment*

The objectives of this activity are to assess initial data obtained by the U.S. Interagency Air Assessment Team, to set up the needed infrastructure, and to conduct medical surveillance, epidemiological studies, and clinical field studies for the purpose of examining specific health endpoints in order to ascertain whether there are short-term and/or long-term trends in morbidity and mortality associated with exposure to the oil smoke plumes and deposition.

Developing plans for and conducting a cross-disciplinary approach to human health risk assessment and health advisories is a difficult, complex and time-consuming task. The plan presented below can proceed only after accomplishing a coordinated interagency evaluation and assessment of the EPA monitoring data and other information. At that time, additional monitoring and modeling may be required. On that basis, the scope of effort, the type and number of health personnel both here and abroad, equipment, and other items cannot be identified in any detail. However, continued coordination and collaboration with the DOD and the Kuwaiti and Saudi health authorities is necessary to maintain established information sharing. Continued information sharing will aid in the development of baseline data for a complete human health risk assessment. In addition, this can help provide Kuwait with some important needed assistance in reestablishing their medical and health care infrastructure.

The following tasks need immediate attention:

- Health advisories should be reviewed and updated for use by military and non-military personnel based on an assessment of the U. S. Interagency Air Assessment Team data and observations.
- Interim preventive measures should be identified and initiated including, but not limited to, the use of dust masks and limiting exercise during periods of severe smoke.
- Medical facilities should be alerted to the potential increased frequency of asthma attacks and eye irritations and ensure adequate supplies of appropriate medications. Protocol should be established to alert military, indigenous, and other non-military transient populations of potential health risks, particularly for high risk populations such as asthmatics, people with heart disease or chronic obstructive pulmonary disease, children, and pregnant women.
- A plan should be developed to collect needed medical and demographic information on affected populations including health examinations and a permanent archive of service records for all U.S. personnel stationed in the Gulf. These records will be vital in order to answer future questions on the health impact of U.S. personnel serving in the Gulf.
- Host governments should be assisted, as requested, in baseline studies of affected populations.
- Develop plans for conducting medium- and long-term epidemiological and clinical studies, and establishing medical surveillance systems.
- Establish criteria for assessing the effectiveness of an early warning system to protect the U.S. and civilian personnel. Based on the monitoring system established by the host countries, an early warning health advisory system should be established.

These efforts should promptly follow:

- Non-plume and plume samples for short-term in-vitro and in-vivo toxicity and mutagenicity testing and dose response assessment should be collected.

- Acute and chronic health risks based on integrating information from exposure assessments, epidemiological/clinical studies, and in-vitro and in-vivo toxicity studies must be assessed.

- Assess the impact of oil pooling and combustion deposition on potential exposure pathways.

## IV. INTERNATIONAL COORDINATION

The U.S. Interagency Air Assessment Team currently working in the Gulf region has undertaken several first steps to coordinate planning with the governments of Saudi Arabia, Kuwait, and Bahrain. To achieve the objectives of this plan, several further steps toward international coordination are necessary:

- Arrangements should be made with the government of Kuwait to complete the reactivation of the three air monitoring stations which were operating before the war. These stations will be critical to obtaining key observations near the source of the fires.

- The British Meteorological Office is currently conducting long-range sampling of the fire plume by aircraft. Coordination of data exchange and research plans between programs should be arranged through WMO.

- WMO should also be requested to arrange for collaboration of modeling efforts with Canadian and British scientists who work on similar programs.

- Collaboration is needed with Kuwaiti and Saudi health authorities to assess the effectiveness of an early warning system to limit or reduce air pollution-related mortality and morbidity, and to monitor trends in respiratory disease.

- The design and conduct of short-and long-term epidemiological and clinical studies must be integrated between Kuwaiti, WHO, and other countries providing assistance.

- To the extent feasible, and, when requested, U.S. agencies should work with multinational organizations to rebuild the public health infrastructure in Kuwait.

## APPENDIX A

## AIR SAMPLING AND MONITORING

The initial air sampling and monitoring program conducted by the U.S. Interagency Air Assessment Team in Kuwait and Saudi Arabia had the following objectives:

1. Determine if there is an acute health threat associated with the Hydrogen Sulfide (H2S) and Sulfur Dioxide (SO2) gases being emitted from the burning oil wells.

This objective was accomplished by collecting Real Time Measurements (i.e. instantaneous readings) using portable instruments for the following parameters: H2S, SO2, oxygen, and total particulate. These measurements were collected at 13 locations in Kuwait and Saudi Arabia, U.S. Embassies in Kuwait and Riyadh, MEPA Dhahran, at five oil well fields, and at various locations near the oil fields in Kuwait. The results from the March 13-20 monitoring are summarized in Table 2.

The highest readings were recorded from measurements taken in the smoke plumes in the oil fields. The results from this monitoring did not indicate an acute health threat. However, if conditions change, (i.e., fires are extinguished without capping, allowing high levels of gases) an acute threat near the wells may occur.

The highest levels observed were: particulate 5.4 mg/m3, VOCs 2.5 ppm (adjacent to large pools of oil), H2S 42 ppb, and SO2 2 ppm. It should be noted that the detection limit for the SO2 monitor is 1-2 ppm. A different SO2 monitor with a detection limit 0.1 ppm did not indicate SO2. Also, the field personnel wer, unable to detect any sulfur odors at any of the locations. Therefore, the SO2 levels of 1-2 ppm should be used with caution.

The only elevated levels observed in the monitoring conducted in the population areas were for particulates. A reading of 480 $ug/m^3$ was obtained at MEPA in Dhahran, Saudi Arabia. Based on field observation this reading was probably a combination of smoke from the fires and sand. Baseline particulate levels due to blowing sand in Saudi Arabia and Kuwait range from 200-3000 $ug/m^3$.

Further sampling and monitoring occurred from 3/24 - 3/27. These results are also attached. The results from this monitoring are similar the previous monitoring results. In general, the particulate concentrations at ground level in the oil fields were lower than in the downwind areas outside the fields, except when in the direct path of a ground level plume. The downwind locations most heavily affected vary, depending on wind speed, temperature, humidity, and other diurnal factors.

The real time particulate readings during this phase are 15 and 20 minute averages. The highest reading occurred at the Ahmadi Hospital, with a 20 minute average reading of 0.935 $mg/m^3$ with a single highest reading of 1.16 $mg/m^3$. Other successive 20 minute averages taken at this location display the variation in particulate levels at the same location, as conditions such as wind direction change.

2. The second objective was to identify and quantify the gaseous and particulate byproducts that are associated with the burning oil wells.

This objective has partially been accomplished. Samples from 10 locations have been analyzed by ERT's laboratory in the U.S. The air samples were collected for the following parameters at all locations: volatile organic (VOCs), polycyclic aromatic hydrocarbons (PAHs i.e naphthalene, benzo[a]pyrene), heavy metals, SO2, and inorganic acids (i.e. sulfuric, nitric, etc.). A limited number of samples were collected for H2S, formaldehyde, CO, and total nuisance dust. For specific findings relevant to these samples see the section entitled "Air Sampling Results."

3.The third objective was to determine if the materials associated with the fire were effecting areas where American citizens were located.

This objective will partially be accomplished by reviewing the data from the samples taken at MEPA Dhahran, Saudi Arabia, U.S. Embassies in Kuwait and Riyadh, Camp Freedom Kuwait, and Port Shuaybah, Kuwait, and reviewing the air monitoring data being collected by MEPA and ARAMCO in Saudi Arabia air monitoring stations and sulfur dioxide data taken at temporary hospital locations in Kuwait City.

In order to complete this objective in a sound scientific manner, sampling for $PM_{10}$ particulate (i.e. particulate less than 10 microns in size), which are the respirable particulate, and samples from the plume above ground level should be taken. Also, the air monitoring network proposed by the U.S. Interagency Air Assessment Team should be implemented.

AIR SAMPLING RESULTS:

The results from the air samples collected for sulfur dioxide, volatile organics, and inorganic acids from 3/13 - 3/20 in Kuwait and Saudi Arabia confirmed the real time measurements and sampling and analysis performed by the Kuwaitis and the Saudis. These results confirmed the conclusion of the U.S. Interagency Air Assessment Team that the primary hazards from the oil well fire is with the particulate matter.

The highest level of sulfur dioxide (0.68 ppm) was detected in th smoke plume of the Burgan Oil Field. This level is above the EPA 24 hour (0.14 ppm) and 3 hour (0.5 ppm) limit. None of the sulfur dioxide samples collected in populated areas exceeded the EPA air quality limits.

The organic vapor analysis showed that compounds associated with petroleum (i.e. benzene, toluene, and aliphatic hydrocarbons such as n-heptane (n-C7)) were detected. The highest levels (i.e. 10-20 ppb level) were detected in the smoke plume in the oil fields and a grab (SUMMA) sample collected at ground level near a pool of oil in the Sabiriyah well field. The inorganic acid analysis showed low ppb levels for both sulfuric and nitric acid. Based on this limited data, the sulfur dioxide and nitrous oxide that may be byproducts from the burning of the oil are not being formed in large amounts.

The results from the particulate analysis for polycyclic aromatic hydrocarbons (PAHs) and heavy metals showed very low levels of both parameters in the samples collected in the populated areas and in the oil fields. The only metals detected were those associated with materials found in the sand particles (i.e. sodium, aluminum, magnesium, etc.).

Based on these limited number of samples, the major hazard associated with the oil well fires seems to be the particulate matter being emitted. The monitoring and sampling program discussed in the Air Monitoring Strategy Plan should help further define the hazards associated with the particulates.

The complete results from the sampling are summarized in the attached exhibits. Only the compounds detected are listed.

PARAMETERS:

The air samples collected at the oil well fields, Camp Freedom, MEPA Dhahran, Saudi Arabia, and U.S. Embassies in Kuwait and Riyadh, Saudi Arabia were analyzed for the following parameters:

PAHs: (NIOSH Method 5515)

Naphthalene, 2-Methylnaphthalene, 1-Methylnapthlalene, Biphenyl, 2,6-Dimethylnaphthalene, Acenaphthylene, Acenapthene, Dibenzofuran, Fluorene, Phenanthrene, Anthracene, Carbazole, Fluoranthene, Pyrene, Benzo[a]anthracene, Chrysene, Benzo[b]fluoranthene, Benzo[k]flouranthene, Benzo[e]pyrene, Benzo[a]pyrene,Indeno(1,2,3-cd)pyrene,Dibenzo[a,h]anthracene,Benzo[g,h,i]perylene.

**Inorganic Acids: (NIOSH Methods 7903)**

Hydrochloric, Phosphoric, Sulfuric, Nitric, Hydrofluoric.

Metals: (NIOSH Methods 7300)

Platinum, Titanium, Molybdenum, Zirconium, Silver, Aluminum, Beryllium, Cadmium, Calcium, Chromium, Cobalt, Copper, Iron, Magnesium, Manganese, Sodium, Nickel, Lead, Tin, Vanadium, Zinc.

Volatile organics: (Modified Method 1500, 1501, 1003)

1,1,1-Trichloroethane, Cyclohexane, Carbon Tetrachloride, Benzene, Cyclohexene, n-Heptane (n-C7), 1,2-Dichlorpropane, Trichloroethane, 1,4-Dioxane, Methylcyclohexane, Methylisobutylketone, Toluene, n-Octane (n-C8), Tetrachloroethane, Chlorobenzene, Ethylbenzene, para-Xylene, Bromoform, Styrene, o-Xylene, n-Nonene, n-Nonane (n-C9), 1,1,2,2-Tetrachloroethane, Cumene, Mesitylene, Alpha-methylstyrene, 1,3-Dichlorobenzene, 1,4-Dichlorobenzene, 1,2-Dichlorobenzene, Benzyl Chloride, alpha-Terpine, D-Limonene, 4-tert-Butyltoluene, 1,2,4-Trichlorobenzene, Naphthalene, 4-Phenylcyclohexene, n-Decane (n-C10), n-Decene, n-Undecene, n-Undecane (n-C11), n-Nonanal, n-Dodecane (n-C12), n-Tridecane (n-C13), n-Tetradecane (n-C14), n-Pentane (n-C15), n-Hexadecane (n-C16).

Others:

Formaldehyde and Sulfur Dioxide.

EXHIBT 1: Air Sampling Results

## U.S. EMBASSY, KUWAIT

Results for 3/16

PAHs:

none detected — detection limit: 2 - 4.6 ppb

Sulfur Dioxide:

**none detected** — **detection limit: 0.04 mg/m3**

Inorganic Acids:

$HNO_3$ 5ppb — detection limit: 1 - 6 ppb

VOCs:

Benzene 0.4 ppb, n-Heptane 0.13 ppb, Toluene 0.61 ppb, Ethylbenzene 0.1 ppb, para-Xylene 0.29 ppb, o-Xylene 0.12 ppb.

Metals:

Na < 1.0 ug/m3, Mg 2 ug/m3, Fe 2 ug/m3, Ca 8 ug/m3, Al 2 ug/m3.

Results for 3/17

PAHs:

Naphthalene 0.31 ppb

Sulfur Dioxide:

< 0.02 mg/m3

Inorganic Acids:

HCl 3.0 ppb, H2SO4 1.0 ppb, HNO3 2.0 ppb

VOCs:

Cyclohexane 1.31 ppb, Benzene 4.0 ppb, n-Heptane 6.0 ppb, TCE 0.7 ppb, Methylcyclohexane 2.0 ppb, Toluene 7.7 ppb, n-Octane 3.0 ppb, Ethylbenzene 1.7 ppb, p-Xylene 5.4 ppb, Styrene 0.4 ppb, o-Xylene 2.4 ppb, n-Nonane 1.9 ppb, Cumene 0.2 ppb, Mesitylene 0.6 ppb, D-Limonene 0.1 ppb, n-Decane 1.5 ppb, n-Undecane 1.0 ppb, n-C12 0.7 ppb, n-C13 0.4 ppb.

Metals:

Na 10 ug/m3, Mg 2 ug/m3, Fe 3 ug/m3, Ca 10 ug/m3, Al 2 ug/m3.

**U.S. EMBASSY, KUWAIT, continued**

Results for 3/18

PAHs:

Naphthalene 0.16 ppb

Sulfur Dioxide:

< 0.05 mg/m3

Inorganic Acids:

HCl 6 ppb, HNO3 2 ppb, H2SO4 1.0 ppb.

VOCs:

Cyclohexane 1.2 ppb, Benzene 5.2 ppb, n-C7 8.1 ppb, Methylcyclohexane 3.0 ppb, Toluene 14.6 ppb, n-C8 4.7 ppb, Ethylbenzene 3.2 ppb, p-Xylene 9.3 ppb, o-Xylene 4.7 ppb, n-C9 2.7 ppb, Cumene 0.3 ppb, Mesitylene 1.3 ppb, Naphthalene 0.18 ppb, n-C10 1.7 ppb, n-C11 1.0 ppb, n-C12 0.7 ppb, n-C13 0.3 ppb.

Metals:

Na 5 ug/m3, Mg 1 ug/m3, Fe 1 ug/m3, Ca 7 ug/m3, Al 1 ug/m3.

## CAMP FREEDOM

Results For 3/17

PAHs:
Naphthalene 0.09 ppb, 2-Methylnaphthalene 0.06 ppb, 1-Methylnaphthalene 0.04 ppb.

**Sulfur Dioxide:**
0.12 mg/m3  0.045 ppm

Inorganic Acids:
HCl 16 ppb, HF 23 ppb, H2SO4 31 ppb

VOCs:
Cyclohexane 7 ppb, Benzene 4.6 ppb, n-C7 25.6 ppb, Methylcyclohexane 9.5 ppb, Toluene 13 ppb, n-C8 18 ppb, Ethylbenzene 2.7 ppb, p-Xylene 8 ppb, o-Xylene 4.5 ppb, n-C9 10.9 ppb, Cumene 0.5 ppb, Mesitylene 1 ppb, Naphthalene 0.18 ppb, n-C10 6.3 ppb, n-C11 4.1 ppb, n-C12 2.3 ppb, n-C13 0.9 ppb, n-C14 0.5 ppb. These levels may also include emissions from vehicles in the area.

Metals:
No Data.

Results for 3/18

PAHs:
Naphthalene 0.28 ppb

Sulfur Dioxide:
<0.04 mg/m3 , < 0.015 ppm

Inorganic Acids:
HNO3 4.0 ppb, H2SO4 4 ppb.

VOCs:
Cyclohexane 2.8 ppb, Benzene 6.9 ppb, n-C7 9.7 ppb, Methylcyclohexane 3.9 ppb, Toluene 16 ppb, n-C8 5.4 ppb, Ethylbenzene 3.1 ppb, p-Xylene 9.5 ppb, Styrene 0.3 ppb, o-Xylene 4.5 ppb, n-C9 3 ppb, Cumene 0.3 ppb, Mesitylene 1.1 ppb, n-C10 1.5 ppb, n-C11 0.8 ppb, n-C14 0.2 ppb.

Metals:
Al 2 ug/m3, Ca 8 ug/m3, Fe 2 ug/m3, Mg 2 ug/m3, Na 3 ug/m3.

EXHIBT 1: Air Sampling Results

**MEPA DHAHRAN, SAUDI ARABIA**

Results For 3/13

PAHs:
none detected

Sulfur Dioxide:
<0.1 mg/m3, <0.037 ppm

Inorganic Acids:
$H_2SO_4$ 5 ppb.

VOCs:
Benzene 0.3 ppb, Cyclohexane 0.1 ppb, Toluene 0.5 ppb, Ethylbenzene 0.1 ppb, p-Xylene 0.2 ppb, o-Xylene 0.1 ppb, Mesitylene 0.04 ppb.

Metals:
Al 2 ug/m3, Ca 5 ug/m3, Fe 2 ug/m3, Mg 2 ug/m3, Na 1 ug/m3.
Cd o.o1 ug/m3

Results For 3/14

PAHs:
none detected

Sulfur Dioxide:
<0.08 mg/m3 , < 30 ppb.

Inorganic Acids:
$HNO_3$ 2 ppb, $H_2SO_4$ 6 ppb.

VOCs:
Cyclohexane 0.2 ppb, Benzene 0.5 ppb, n-C7 0.8 ppb, Methylcyclohexane 0.3 ppb, Toluene 0.7 ppb, n-C8 0.4 ppb, Ethylbenzene 0.1 ppb, p-Xylene 0.3 ppb, o-Xylene 0.1 ppb, n-C9 0.3 ppb.

Metals:
Al 3 ug/m3, Ca 14 ug/m3, Fe 3 ug/m3, Mg 4 ug/m3, Na 8 ug/m3.

## U.S. EMBASSY RIYADH, SAUDI ARABIA

Results For 3/28

PAHs:
none detected

Sulfur Dioxide:
< 0.08 mg/m3 , < 30 ppb

Inorganic Acids:
NO3 3 ppb, H2SO4 < 2 ppb.

VOCs:
Benzene 0.3 ppb, Toluene 0.6 ppb, Ethylbenzene 1.0 ppb, p-Xylene 0.3 ppb.

Metals:
Al 8 ug/m3, Ca 4 ug/m3, Fe 1 ug/m3.

## PORT SHUAYBAH

Results For 3/17

PAHs:
no data

Sulfur Dioxide:
< 0.05 mg/m3, , 19 ppb

Inorganic Acids:
H2SO4 19 ppb.

VOCs:
Benzene 4.2 ppb, n-C7 13 ppb, Methylcyclohexane 5.3 ppb, Toluene 15 ppb, n-C8 5.6 ppb, p-Xylene 6.9 ppb, Ethylbenzene 2.2 ppb, o-Xylene 2.9 ppb, n-C9 3.8 ppb, Cumene 0.2 ppb, n-C10 2.9 ppb, n-C11 1.9 ppb, n-C12 1.4 ppb, n-C13 0.8 ppb.

Metals:
Ca 4 ug/m3, Na 7 ug/m3, AL 2 ug/m3.

EXHIBT 1: Air Sampling Results

## Al MAQUA OIL FIELD

<u>Results for 3/15</u>

PAHs:

no data

Sulfur Dioxide:

<0.3 mg/m3 , <0.1 ppm

Inorganic Acids:

no data

VOCs:

Cyclohexane 0.6 ppb, Benzene 1.8 ppb, n-C7 3.2 ppb, Methylcyclohexane 1.1 ppb, Toluene 2 ppb, Ethylbenzene 0.4 ppb, p-Xylene 1.4 ppb, o-Xylene 0.8 ppb, n-C9 2.8 ppb, Mestilylene 0.3 ppb, n-C10 3.3 ppb, n-C11 3.5 ppb, n-C12 3.3 ppb, n-C13 1.8 ppb, n-C16 1.1 ppb.

Metals:

Al 8 ug/m3, Ca 6 ug/m3, Fe 6 ug/m3.

EXHIBT 1: Air Sampling Results

## Al AHMADI OIL FIELD

Results For 3/16

PAHs:
none detected

Sulfur Dioxide:
0.45 mg/m3 , 0.17 ppm

Inorganic Acids:
$H_2SO_4$ 27 ppb, $HNO_3$ 10 ppb, HCl 9 ppb.

VOCs:
Cyclohexane 0.4 ppb, Benzene 3.9 ppb, n-C7 2.5 ppb, Methylcyclohexane 1 ppb, Toluene 2 ppb, n-C8 2.3 ppb, Ethylbenzene 0.5 ppb, p-Xylene 1.5 ppb, o-Xylene 0.9 ppb, n-C9 2.9 ppb, Mesitylene 0.4 ppb, Naphthalene 0.5 ppb, n-C10 3.4 ppb, n-C11 3.8 ppb, n-C12 4 ppb, n-C13 2.9 ppb, n-C14 2.9 ppb, n-C15 2 ppb, n-C16 1.7 ppb.

Metals:
Al 7 ug/m3, Ca 4 ug/m3, Fe 20 ug/m3.

Formaldehyde:
8 ppb.

Hydrogen Sulfide: ND 0.3 ppm - detection limited .

SUMMA Data:
$SO_2$ 0.2 ppm; CO 1.9 ppm

EXHIBT 1: Air Sampling Results

## Al BURGAN OIL FIELD

Results For 3/17

PAHs:
none detected; detection limit 50 ppb

Sulfur Dioxide:
1.8 mg/m3 , 0.67 ppm

Inorganic Acids:
$H_2SO_4$ 30 ppb, $HNO_3$ 32 ppb, HCl 15 ppb.

VOCs:
Benzene 8.7 ppb, n-C7 4.6 ppb, Methylcyclohexane 2.5 ppb, Toluene 4.31 ppb, n-C8 5.1 ppb, Ethylbenzene 1.3 ppb, p-Xylene 4.2 ppb, o-Xylene 2.4 ppb, n-C9 7.1 ppb, Naphthalene 1.6 ppb, n-C10 9.1 ppb, n-C11 10.4 ppb, n-C12 11.3 ppb, n-C13 7.8 ppb, n-C14 7.4 ppb, n-C15 5.4 ppb, n-C16 4.6 ppb.

Metals:
Al 20 ug/m3, Ca 120 ug/m3, Fe 20 ug/m3, Mg 30 ug/m3.

Formaldehyde:
20 ppb;

SUMMA Data:
$SO_2$ 0.23 ppm, CO 1.6 ppm, $H_2S$ none detected (0.1 ppm detection limit.)

EXHIBT 1: Air Sampling Results

## Al WAFRA OIL FIELD

Results for 3/19

PAHs:
no data

Sulfur Dioxide:
none detected 0.3 mg/m3 , 0.11 ppm.

Inorganic Acids:
none detected 10 ppb detection limit

VOCs:
Benzene 2.3 ppb, n-C7 0.6 ppb, Methylcyclohexane 1.6 ppb, Ethylbenzene 0.3 ppb, o-Xylene 0.4 ppb, Mesitylene 0.4 ppb

Metals:
no data

Hydrogen Sulfide:
ND 0.16 ppm dection limited.

## SABIRIYAH OIL FIELD

Results For 3/17

SUMMA DATA:

Ground Level Sample:
H2S none detected (0.1 ppm); SO2 0.13 ppm; CO 1.1 ppm; NO and NO2 none detected

VOCs:
Benzene 9.8 ppb, Toluene 8.7 ppb, Ethylbenzene 10 ppb, m&p-Xylene 27.8 ppb o-Xylene 24 ppb, m-Ethyltoluene 15.8 ppb, n-C6 83 ppb, n-C7 60 ppb, n-C8 91 ppb, n-C9 91 ppb, n-C10 89 ppb, n-C11 65 ppb.

3000 ft Sample:
H2S none detected; SO2 0.08 ppm, CO none detected; NO and NO2 none detected 0.5 ppm.

1000 ft Sample:
H2S, SO2, CO, NO, and NO2 none detected.

Table 1
Kuwait Oil Well Fires Real Time Monitoring
March 13-20, 1991

| Site, Date, Time | Total Particulate $mg/m^3$ | Sulfur Dioxide ppm | Hydrogen Sulfide ppm | Volatile Organics ppm |
|---|---|---|---|---|
| 1) MEPA Faciltiy, Dhahran, SA 3/13 1100 hrs | .170 | 0.0 | 0.0 | 0.0 |
| MEPA Facility 3/14 1300 hrs | .480 | 0.0 | 0.0 | 0.0 |
| 2) Al Dhuba 3/15 1430 hrs | .420 | 0.0 | 0.0 | 0.0 |
| 3) Umn Al Haiman 3/15 1500 hrs | .320 | 0.0 | 0.0 | 0.0 |
| 4) Mina Abdulla 3/15 1530 hrs | .250 | 0.0 | 0.01 | 0.6 |
| 5) Near Al Maqwa Oil Field 3/15 1630 hrs | .010 | 0.0 | 0.024 | 0.8 |
| 6) In Al Maqwa Well Plume 3/15 1700 hrs | 5.4 | 0.0 | 0.006 | 0.8 |
| 7) U.S. Embassy 3/06 0900 hrs | .01 | 0.0 | 0.001 | 0.0 |
| U.S. Embassy 3/18 1230 hrs | .055 | 1.0 | 0.005 | 0.2 |
| 8) In Al Ahmadi Well Plume 3/16 1230 hrs | --- | 0.0 | 0.032 | 0.0 |
| In Al Ahmadi Oil Field 3/16 1300 hrs | .120 | 1.0 | 0.009 | 0.0 |
| 9) In Al Burgan Well Plume 3/17 1100 hrs | — | 1.0 | 0.015 | 0.0 |
| 10) In Sabiriyan Well Plume, Pooled Oil 3/18 1530 hrs | --- | 1.0 | 0.042 | 2.5 |
| 11) In Al Wafra Well Plume 3/19 1200 hrs | .050 | 2.0 | 0.015 | 0.0 |
| 12) Freedom City | --- | --- | --- | --- |
| 13) U.S. Embassy Riyadh, SA 3/20 1300 hrs | .032 | 0.0 | 0.0 | 0.0 |

Table 2
Kuwait Oil Well Fires Real Time Monitoring
March 24-27, 1991

| Site, Date, Time | Total Particulate mg/m³ | Sulfur Dioxide ppm | Hydrogen Sulfide ppm | Volatile Organics ppm |
|---|---|---|---|---|
| 1) Al Safer Motorway and Wafra Road 3/24 1440 hrs | .825 (15 min. avg.) | 2.0 | 0.0 | 0.3 |
| 2) Al Ahmadi Gathering Center #22 3/24 1530 hrs | .359 (15 min. avg.) | 0.0 | 0.0 | 0.0 |
| 3) Al Ahmadi Hospital 3/24 1530 hrs | .222 (32 min. avg.) | 0.0 | 0.0 | 0.0 |
| 4) 1 mi. NW of Station 2 in Ahmadi Oil Field 3/24 1730 hrs | .256 (10 min. avg.) | 0.0 | 0.0 | 0.0 |
| 5) Al Maga Oil Field, .5 mi south of 7th Ring Road near oil pool 3/25 1400 hrs | .034 (17 min. avg.) | 1.0 | 0.0 | 0.6 |
| 6) Al Ahmadi Oil field (same as Station 4) 3/25 1500 hrs | .561 (13 min. avg.) | 0.0 | 0.003 | 0.6 |
| 7) Al Ahmadi Hospital (same as Station 3) 3/25 1545 hrs | .295 (15 min. avg. | 0.0 | 0.0 | 0.0 |
| 8) Al Safer and Wafra Road 3/25 1615 hrs | .065 (16 min. avg.) | 0.0 | 0.002 | 0.0 |
| 9) Al Ahmadi Hospital (same as Station 3 and 7) 3/27 1020 hrs | .935 (20 min. avg.) | 0.0 | 0.0 | 0.2 |
| 10) Al Ahmadi Hospital (same as Stations 3, 7, and 9) 3/27 1040 hrs | .457 (20 min. avg.) | --- | --- | --- |
| 11) Al Ahmadi Hospital (same as Stations 3, 7, 9, and 10) 3/27 1100 hrs | .457 (20 min. avg.) | --- | --- | --- |
| 12) Shuaiba Port 3/27 1215 hrs | .468 (15 min. avg.) | 0.0 | 0.0 | 0.0 |

| Site, Date, Time | Total Particulate mg/m³ | Sulfur Dioxide ppm | Hydrogen Sulfide ppm | Volatile Organics ppm |
|---|---|---|---|---|
| 13) Al Safer Motorway and Wafra Road 3/27 1300 hrs | .119 (12 min. avg.) | 0.0 | 0.0 | 0.0 |
| 14) 16 Kilo-meters SE of Al Safer and Wafra Roads 3/27 1330 hrs | .257 (12 min. avg.) | 0.0 | 0.0 | 0.0 |
| 15) 27 Kilo-meters SE of Al Safer and Wafra Roads 3/27 1350 hrs | .227 (15 min. avg.) | --- | --- | --- |
| 16) 5 Kilometers South of Khafji, Saudi Arabia 3/27 1510 hrs | .072 (14 min. avg.) | --- | --- | --- |

Table 3
Sulfur Dioxide Bubbler Measurements
(Acidimetric Method)
Temporary Hospital Locations in Kuwait City
March 13-24

| Hospital | Date | Concentration (ug/m$^3$) |
|---|---|---|
| Adan | 3/14/91 | 40.31 |
| | 3/17/91 | 43.88 |
| | 3/18/91 | 39.34 |
| | 3/19/91 | 26.18 |
| | 3/20/91 | 27.68 |
| | 3/23/91 | 28.16 |
| | 3/24/91 | 15.99 |
| Mubarek Al Kabeer | 3/13/91 | 193.66 |
| | 3/18/91 | 56.48 |
| | 3/19/91 | 58.11 |
| | 3/20/91 | 42.34 |
| | 3/23/91 | 43.43 |
| | 3/24/91 | 23.72 |
| Al Farwaniya | 3/13/91 | 81.32 |
| | 3/16/91 | 19.21 |
| | 3/17/91 | 29.56 |
| | 3/18/91 | 134.81 |
| | 3/19/91 | 218.65 |
| | 3/20/91 | 27.57 |
| | 3/23/91 | 26.66 |
| | 3/24/91 | 10.54 |
| Al Jahra | 3/16/91 | 32.03 |
| | 3/18/91 | 66.59 |
| | 3/19/91 | 32.54 |
| | 3/23/91 | 13.92 |
| | 3/24/91 | 9.90 |

## APPENDIX B

## A REGIONAL GULF AIR MONITORING PLAN IN RESPONSE TO THE 1991 KUWAITI OIL FIELD FIRES

I. INTRODUCTION
- Purpose of the Plan
- Team Membership
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II. BACKGROUND
- Nature of the Fires and Oil Field Locations
- Qualitative Meteorological Observations
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ATTACHMENTS

List of existing and proposed air monitoring sites
Locations of existing and proposed air monitoring sites

APPENDIX B

# A REGIONAL GULF AIR MONITORING PLAN IN RESPONSE TO THE 1991 KUWAITI OIL FIELD FIRES

## 1. INTRODUCTION

The U.S. Interagency Air Monitoring Team is working with the Saudi Arabian Meteorology and Environmental Protection Agency (MEPA) to develop an air monitoring plan for the Gulf region that will provide information to assess the impact of the [Kuwaiti] fires in Saudi Arabia. This plan is being discussed and developed with the King Faud University of Petroleum and Minerals in Dhahran, the Cooperation Council for the Arab States of the Gulf (CCG), and the Saudi Arabian Oil Company (ARAMCO). The plan is being developed at the request of Dr. Tawfiq, Vice President of the Saudi Arabian MEPA. Meetings have been held with officials from all of the above mentioned organizations.

### 1.1 Approach

The Team is gathering information on the existing air monitoring networks in the region operated by MEPA, ARAMCO, Kuwait, Bahrain, and the Royal Commission of Jubayl and Yunbo. The spatial distribution of the existing network in the Region is being reviewed as to the location of sites, the air pollutants and meteorological variables that are monitored at each of these sites and the quality of existing data. That review is to determine if the existing network needs to be expanded in terms of the air pollutants and meteorological variables monitored and additional air monitoring stations to determine the impact from the oil fires. The capabilities of the existing agencies and governments to deal with a more complete network is also being investigated.

### 1.2 Objectives of Air Monitoring in the Gulf Region

Air monitoring data is needed for the following reasons:

a. To provide an Early Warning Health Advisory System for the Gulf Region to respond to the air pollution resulting from the Kuwaiti oil fires. The proposed Early Warning System could be based on an adaptation of the U.S. Air Quality Index, the Pollutant Standards Index (PSI), which can be modified to use Saudi air quality standards. The index would provide for health advisories to the affected populations so they can minimize their exposure to high pollution levels.

b. To track the air pollution from the Kuwaiti oil field fires over time to asses the potential long term health and ecological effects. The air monitoring network proposal being developed is being coordinated with a parallel effort to develop a health monitoring information system.

c. To collect samples of airborne particles to perform toxicity testing and dose response assessment utilizing in-vivo animal models.

d. To facilitate evaluations of models which are use to predict the local and regional scale behavior of the oil field emissions. Data from the expanded GULF REGIONAL AIR MONITORING NETWORK of ambient air quality and meteorological data will be important for those evaluations.

## 2. BACKGROUND

### 2.1 Preliminary Investigation of the Existing Monitoring Networks

The air quality monitoring sites listed in Table 1 have been identified for each of the Gulf nations that could contribute monitoring information within the sphere of influence of airborne effluents from the Kuwait oil fires.

Based upon our review of the existing networks, the principal pollutants which are missing are in the Saudi network and in the present Kuwaiti network are $PM_{10}$, which represents particulate matter with particles less than 10 microns in diameter, polycyclic aromatic hydrocarbons (PAH) and volatile organic compounds (VOC). With respect to $PM_{10}$, these are the particles which are most likely to penetrate deeply into the lung. It should be noted that Kuwait has collected particulate data using an Anderson Cascade Impactor, with limited size distributions below seven microns within a total suspended particulate sample. Because of the importance of this particular pollutant and the extensive particulate resulting from the oil fires, the Team is recommending that special efforts be initiated to gather $PM_{10}$ data and if possible to determine its constituents - trace metals and hydrocarbons. The $PM_{10}$ data collection effort should be supplemented with the collections of PAH samples and if possible, grab samples for VOC analysis.

An ongoing effort is being conducted to examine the analytical laboratory support for air monitoring in Kuwait, MEPA, KFUPM, and Saudi ARAMCO. The Kuwaiti laboratory capability to analyze air and particulate samples has been left largely intact. As of March 27, 1991, two of the three continuous monitoring stations have been activated and are collecting data. The remaining site has its continuous sampling equipment however, like the analytical laboratory, is without electrical power. There is no projected date for power at these locations. The analytical laboratory has had experience with polyurathane foam (PUF) extractions for PAH measurements (PS-1 sampler) and has done pesticide extraction and analysis research. The most critical need for the laboratory is obviously power to provide the basis of future support to the sampling plan. Additionally training must be provided with documented procedures for these new sampling and analytical procedures, and lastly they are in need of a complete set of standards to support instrument calibrations for their existing continuous monitors and the new proposed technologies. Quality control and quality assurance samples and support for the network should be developed within the available laboratories but, should be supplemented from an external source.

The analytical laboratory at King Faud U.P.M. has recently been provided the above procedures to permit a self assessment of their equipment availability to conduct these detailed analyses. Currently, the K.F.U.P.M. is conducting experiments on PAH's analysis of high volume filters as a first step in this program. K.F.U.P.M. has not had any experience with PUF, VOC canister analysis, or $PM_{10}$ sampling and analysis. They have on hand the capability to expand their current analytical capability to provide support to the proposed network.

The analytical laboratory of Saudi ARAMCO as with MEPA has had no experience in collecting and analyzing particulate $PM_{10}$ samples, PUF, and canister samples for VOC speciation and PAHs.

In summary, the current level of technical competence within all of the facilities visited, MEPA, King Faud U.P.M., Saudi ARAMCO, and Kuwait, indicates that upon the procurement of adequate equipment, standards, and training, they all could support the sampling and analysis required for this program.

TABLE B-1. The Distribution of Air Pollutant and Meteorological Monitoring Sites by Gulf Nation.

| Nation | Organization | Number of Air and Met Sites |
|---|---|---|
| SAUDI ARABIA | MEPA | 3 fixed sites - meteorology and air pollution at different locations of the same city |
| | | 1 mobile site - meteorology and air pollution |
| | | 1 fixed meteorology site |
| | Saudi ARAMCO | 8 air quality sites with meteorology |
| | | 6 additional meteorology sites |
| | Royal Comm. for Jubayl & Yunbo | Cluster of Five Stations in Jubayl |
| KUWAIT | | 3 sites with continuous monitors (2 with power, 1 without power). |
| | | 4 sites with Anderson samplers, high vols. and dustfall buckets. (no power) |
| | | 1 additional TSP site (no power) |
| | | 6 additional dustfall sites |
| | | 4 temporary S02 bubbler sites located at 4 hospitals (some power) |
| BAHRAIN | | 2 sites |
| QATAR | | 3 mobile monitoring sites |
| IRAN | | unknown |
| IRAQ | | unknown |

A substantial number of meteorological measurement sites exist within the eastern provence of Saudi Arabia and the nations of the Gulf Region. Most of those sites are along the shoreline of the Gulf. ARAMCO operates 14 sites with meteorological data. Eight of those sites have collocated air quality measurements. Three of those sites are over the Gulf waters on platforms or on an island. MEPA (Saudi Arabia) has five sites with collocated air quality measurements. In addition, there are surface observations collected at many of the airports throughout the kingdom. Surface meteorological data are being collected at other Gulf region locations. Their locations may be identified through the WMO publications. Previously, there were other surface measurement sites within Kuwait but their operational status remain unknown at this time.

Two upper air balloon sounding sites are operating within Saudi Arabia. One site is at Dhahran and the other is about 115 miles to the SW of Kuwait City at Al Qaysumah. Twice daily soundings are collected at those locations, at 0000 and 1200 GMT. Prior to the war in Kuwait, twice daily upper air soundings were made at the Kuwait International Airport. the resumption of those soundings could be of substantial benefit to describing the airflow across the areas of Kuwaiti oil fires.

### 2.2 Meteorological Observations

The following summarizations are based upon first hand observations of the smoke plumes and fires. Those observations were made during overflights and during vehicle traverses both within the oil fields and along roads outside of the burning oil fields.

For any given day, the prevailing large-scale meteorological pattern will be the main driving feature which determines where the smoke plumes will be located and how dense they will be.

Individual smoke plumes appear to act in manners typical of buoyant plumes from ground level sources or plumes from short chimneys. Plume rise, the development of a bent-over plume geometry, etc., seem to apply to the individual well-head fires; some have jets of fire and others are nearly surface based burnings of the more combustible fractions of crude oil spread across the ground in the vicinity of the well. Most of the fire plumes rise to between 500 to 1000 feet above ground level before becoming mostly bent over, although some plumes have a significant amount of smoke remaining within a few hundred feet of the ground.

Collectively, as groups of multiple fires within oil fields with a high density of burning wells (particularly Greater Burgan), they assert a meteorological influence of their own. It is suggested that the grouping of fires with a horizontal diameter of 15 to 25 miles provides enough of an intense "heat-island" that significant additional vertical rise of the smoke occurs inside the area. That additional plume rise lifts smoke to elevations often 3000, 4000, to 5000 feet above ground within the initial few miles downwind. Eventually, portions of the smoke rise even more, with multiple layers often forming at heights up to 8000, 9000, even 12000 to 13000 feet. Between such layers and at the tops of layers many tens of miles downwind, a generally diffuse and homogenous zone of smoke has been observed. The eventual smoke height limits are bounded by the regional vertical temperature structure and synoptic weather characteristics. Information reviewed to date suggest that those maximum heights are mostly 8000 to 12000 feet within the initial 100 to 200 miles downwind from the Kuwaiti oil field fires.

With the creation of a local heat-island, a distinct inflow of near surface air has been observed within the initial 500 to 1000 feet above ground level. At times, that inflow of wind is estimated to be 5 to 15 m/sec in strength. Smoke plumes at the peripheral bounds of the burn area tend to slant inward toward the center of the burning field instead of pointing downwind with direction of the expected ambient wind.

Local variations in daily wind flow, along with the fire-storm like winds, are likely to produce preferred locations and times of day at which more concentrated smoke plume exposures reach ground level. Prevailing winds are from the northwest throughout the year. During the daytime a sea breeze can be expected to develop at the Gulf shoreline and progress inland as the day progresses. That inflow of air can readily clear out the smoke plumes and yield substantially cleaner air at ground level on the Gulf side. Along the leading edge of the sea breeze front there likely may be a zone of extended and elevated exposures to fire effluent. That zone may well extend down the shoreline from Kuwait City some 100 km. The area of greatest susceptibility appears to be to the southeast of fires in the Al Ahmadi oil field (part of the greater Burgan field).

### 2.3 Data Base Management

In addition to evaluating the existing air monitoring networks, the Team made an initial review of existing data systems to handle the air monitoring data. The previous meteorological, air quality, and visual observations of the oil field fire plumes should be archived, along with data to be obtained during the period of on-going Kuwaiti fires. A dedicated facility for the performance of that archiving does not appear to exist. The data management task is likely to be a sizeable task and extended of a period of a year and more.

Some of the general functional needs of the data management system include the following. The data which will need to be assembled into the data base will likely come from many different sources and exist in diverse formats and media. One role of the data base management activity will be to assemble all information into a common, uniform structure. The second and equally important part of the data archiving is the provisions of a uniform and consistent mechanism for the retrieval of data by participating agencies. The degree to which that data base is well formulated, will significantly affect the efforts of users of the data as they attempt to study and interpret the measurements.

A number of possible methods exist for the set-up of a computerized data base. Commercial software and hardware of various degrees and complexity and cost exist which would satisfy the data management needs. Before the choices of system software and hardware are made, the functionality of the overall system and the manners in which users work with the data sets should be considered. For example, it may be required that the data base be a "relational" data base. Other sources of software that might be used to handle a large volume of data would be the U.S. Environmental Agency's (USEPA) Aerometric Information and Retrieval System. That system can handle hourly data and has considerable software available to both summarize and analyze the ambient air data.

MEPA has asked the Team to recommend the type of computer and associated software needed to manage the data collected in order to implement the monitoring plan. For now, it is more appropriate to defer specific recommendations. A number of general performance characteristics may be stated but specific details should be formulated in conjunction with data base specialists at a later date.

## RECOMMENDATIONS

While preliminary, the Team believes that the following recommendations should be implemented based on our initial data gathering exercise. A general objective is listed as a recommended goal and below that objective are listed several needed items or activities to facilitate the achievement of the overall goal.

1. Objective: Provide a framework for an early warning advisory capability for areas expected to be impacted by effluents from Kuwaiti oil field fires.

Needs:
- a. Meteorological data observations and forecasts
- b. Visual observations from key receptor areas
- c. Review existing monitoring data
- d. Calculate smoke trajectories and concentrations

2. Objective: Provide a cursory wide-area indication of the distribution and composition of the Kuwaiti oil field fire effluents.

Needs:
- a. Establish 10 to 15 $PM_{10}$ monitoring locations using portable monitors.
- b. Train personnel in the operation of the portable PM-10 monitors and develop the analytical support capability within Saudi Arabia and Kuwait.
- c. Define the $PM_{10}$ to TSP ratios.
- d. Define the composition of the plume by XRF analysis for limited organic identification.
- e. Establish a central media preparation and analysis location.
- f. Define the baseline contribution of the ambient aerosol from the surrounding desert.

3. Objective: Characterize the aerial smoke plume.

Needs:
- a. Collect many of the same plume measurements recommended for the ground monitoring array
- b. Collect descriptions of the width and vertical extent of the smoke plume at several downwind distances
- c. Characterize the regional background by samples outside of the smoke plumes

4. Objective: Develop a more complete profile of the smoke plume constituents

Needs:
- a. Procure equipment for a limited number of comprehensive air quality monitoring stations to collect: TSP, $PM_{10}$; organic, and inorganic constituents
- b. Establish a limited number of comprehensive air quality monitoring stations to collect: TSP, $PM_{10}$, organic, and inorganic constituents. These should be collocated with the continuous monitors wherever possible.
- c. Train individuals to operate and maintain the sampling instrumentation in support of the monitoring program
- d. Procure the necessary analytical laboratory equipment required for analyses of the samples collected under this objective
- e. Train laboratory personnel in the preparation of the sampling media, QA/QC procedures required and the subsequent sample analytical procedures.

5. Objective: Determine the need for expansion of the monitoring network to a wider regional coverage.

Needs:
- a. Review the data developed from the limited network.
- b. Assess the current and projected status of control of the oil field fires and emissions.
- c. Review the population health survey statistics.
- d. Review the suitability of the sampling strategy, and modify where needed

e. Expand the limited network as the situation requires, data analysis indicates an additional need for data, the response of the affected populations indicate, or the model requires additional parameters.

Many of the same considerations listed for air quality above also apply to meteorological considerations.

6. Objective: Provide a meteorological data stream to facilitate the modeling and prediction of areas expected to be impacted by effluents from Kuwaiti oil field fires.

Needs:

a. Upper air balloon sounding data representative of the Kuwaiti oil field fire area and Gulf region plume transport.

b. Supplemental surface based measurements of wind speed and direction, temperature, moisture content of the air (dew point, relative humidity, etc.), solar radiation, atmospheric pressure, precipitation.

7. Objective: Provide a meteorological data set to investigate the areas of climate modifications occurring due to effluents from Kuwaiti oil field fires.

Needs:

a. Supplemental surface based measurements diffuse and direct solar radiation.

b. Special collections of precipitation throughout the region to examine the pH and chemistry of the rains.

c. Aircraft soundings and profiles of smoke, winds and temperatures, air quality related measurements of plume compositions and concentrations representative of the Kuwaiti oil field fire area and Gulf region transported plumes.

## 4. PHASED AIR MONITORING PLAN

This section of the report discusses a prioritized plan of stepwise incremental actions for the phased implementation of the recommendations discussed above. Five phases for implementing the plan follow.

### 4.1 Phase 1. Provide a Framework for an Early Warning Advisory

In order to accomplish this task, the following action items need to be initiated or incorporated into the task framework.

1. Gather daily weather forecasts to predict meteorological conditions which would effect pollution potential in both Saudi Arabia and Kuwait.
2. Use visual observations from key receptor sites to determine possible pollution levels.
3. Gather existing air monitoring data from fixed and mobile sites operated by MEPA, Saudi ARAMCO, and the governments of Kuwait and Bahrain to develop a data base of existing data.
4. Establish a daily briefing for representatives of the many entities concerned with behaviors and fate of the aerial effluents from the oil field fires in Kuwait.
5. Develop a daily map depiction of the aerial distribution of the smoke plumes across the region using satellite imagery, for each day since initiation of the oil field fires.
6. Issue a daily general statement about the expected behavior(s) of the oil fire plumes. Areas of potentially adverse conditions could be treated as locations for which advisories would be issued.
7. Provide forecast meteorological conditions across the region for the next 2 to 3 day period, including the expected location(s) of the smoke.
8. Obtain data from the MEPA network throughout the eastern province.
9. Direct the crews of the SLAR aircraft, (USCG Falcon Jet), to continue on a regular basis the present visual observation and mapped notations concerning the horizontal extent of the smoke plumes and the estimations of altitudes of layer bases and tops.
10. The above information could be compiled initially in hard copy form. Later it should be stored on electronic media in a way that an existing PC data management system could readily incorporate it.

### 4.2 Phase 2. Establish a $PM_{10}$ Monitoring Network Using Portable $PM_{10}$ Monitors.

Working in conjunction with the Saudi Arabian Meteorology and Environmental Protection Agency (MEPA), the proposed plan has been developed to collect information on $PM_{10}$, which represents particulate matter with particulates less than 10 microns in diameter. At the present time there is no $PM_{10}$ monitoring in the Gulf region.

OBJECTIVES

The objectives for this effort are as follows:

1) Determine the magnitude or the health threat to residents of population centers and field-based military personnel impacted by the oil field fires and typical sources (windblown desert soils).

2) Establish a scientifically based capability to alert these affected populations prior to the onset of the potential health threats from real-time measurements.

3) Establish a technical basis for executing predictive air quality dispersion models which simulate the oil well fire emissions, background sources, and consequent impacts over space and time.

4) Establish a regional network of $PM_{10}$ stations using a consistent monitoring methodology across the countries of Saudi Arabia, Kuwait, and Bahrain.

5) Train personnel to operate and analyze the media produced by the network from each of the participating countries.

6) Develop a regional data base and encourage the sharing of data developed from the network with all participants.

The above objectives convert the foregoing goals into discrete actions:

1) Determine the spatial temporal frequency, and severity of the impact to the resident populations and military centers affected through the application of saturation sampling techniques with portable $PM_{10}$ samplers.

2) Establish the correlation of real-time surrogate monitoring data to date generated from direct sampling methods through the collocation and simultaneous operation of both methods over time.

3) Where possible use impact data collected from samplers as an input to the dispersion model, run the model "backwards" to develop a better estimate of the emission rates of the fires and produce a higher level of confidence in the predictive modeling results.

4) Obtain from the literature and/or develop from source sampling analysis chemical profiles of all major pollutant sources in order to:

a) identify those contaminants that pose the greatest health concerns and to develop an estimate of acceptable ambient levels (AALs) prior to the conduct of field work,

b) identify the chemical "signature" of the major contaminants and other tracers characteristic of the primary sources,

c) enable apportionment of these contaminants and other tracer compounds from a simple total mass concentration measured by the ambient samples, and

d) attempt to relate these levels in turn to the surrogate real-time monitoring methods for use in issuing timely health risk alerts.

5) Ensure that the data generated by the network are of a demonstrably high quality (precision & accuracy), completeness, representativeness, and comparability.

| TIME | POSITION (LAT/LONG) | BASE/TOP | WIND (DIR/SPD) |
|---|---|---|---|
| 0545 | N2623E50-31 | CLR VIS 15 M | 332/23 |
| 0600 | N2700E4958 | CLR | 321/19 |
| 0615 | N2744E4916 | CLR | 300/20 |
| 0630 | N2822E4839 | TOPS 070/030 | 331/008 |
| 0645 | N2918E4819 | SMOKE 060/030 | 335/10 |
| 0700 | N2932E4810 | SMOKE 070/030 | 344/10 |
| 0715 | N29344830 | SMOKE 070/030 | 265/7 |
| 0730 | N29354857 | THIN SMOKE 050/030 | 215/6 |
| 0745 | N2925E4920 | VERY THIN SMOKE 090 | 133/003 |
| 0800 | N2833E4945 | THICKER SMOKE 090/ 080 | 326/006 |
| 0815 | N2738E5035 | THIN SMOKE 090/080 | 280/005 |
| 0830 | N2702E5111 | SMOKE 090/060 | 192/010 |
| 0845 | N2625E5148 | SMOKE/HAZE 080/060 | 215/12 |
| 0900 | N2618E5118 | SMOKE/HAZE 070/SURF | 230/009 |

**APPROACH**

Conduct a $PM_{10}$ saturation sampling study for the determination of the temporal and spatial features of the impact of the oil well fires and attempt to reconcile the data with existing model estimates. $PM_{10}$ mass concentrations would be available within 24-48 hours following sampling. No on-site meteorological, gas, or aerosol monitoring or chemical analysis is required (chemistry could be attempted later on the preserved media). One or more portable nephelometers would be collocated at several sampling sites to develop correlations between manual and continuous (real-time) methods for alert advisories.

A total of 15-20 portable $PM_{10}$ samplers equipped with quartz filters would be run simultaneously on a daily basis or "triggered" (impact forecast) basis throughout the study area. Network design would involve a "nested" approach to address the objectives:

1) samplers sited at background locations (not impacted) by the smoke plume and samplers in populated areas.

2) samplers in populated areas impacted by smoke.

Samplers could be "ganged" (2 or more) and programmed to run consecutively at individual sites if filter clogging problems occur because of high loading. Further, multiple samplers could be collocated at certain sites to collect fine particulates (less than 2.5 microns) and coarse particulates (2.5-10 microns) on teflon sample filters (facilitating XRF elemental analysis). One of the 10-12 sampling sites would be equipped with duplicate samplers in an effort to develop sampling precision estimates.

This comprehensive program will yield the following:

1) short turnaround $PM_{10}$ concentrations,

2) gross estimates of the fire-specific contributions to total mass could be derived by subtracting background concentrations from the impact site concentrations,

3) applying assumptions on the source profiles to pollutant loading attributable to the well fires, estimates of individual target compound loadings could be computed and a comparison to AALs made,

4) correlations factors can be determined between real-time surrogate methods and manual methods, and

5) impacted sampling media would be available for subsequent intensive chemical analysis in an attempt to reconcile assumed source signatures and extracts can be used to perform any other analytical tests (mutagenicity). Special precautions may be needed to preserve the sample integrity during storage and transfer.

Limitations: no on-site meteorological data to calculate emissions rates, no on-site chemistry (unless developed) to confirm critical assumptions, and no concurrent gas or acid aerosol measurements to evaluate or correlate with the particulate data.

Resources: 1-2 professionals, 1 field technician per site, if it must be operated individually (actual number contingent upon the network logistics and potential "clogging" implications), portable $PM_{10}$ saturation samplers, portable nephelometers, lap-top computer, microbalance, expendables and sundry support gear.

In summary, this approach is $PM_{10}$ mass data-rich, and assumption rich and in contrast to being reconciliation and broad pollutant characterization-poor.

## SAMPLING AND ANALYTICAL METHODS

The alternate approaches identified above involve the use of a variety of sampling and analytical methods summarized below:

Portable $PM_{10}$ Saturation Samplers

- segregate and capture of filter, particulates of 10 micron size (respirable particles) and smaller.
- battery-operated, lightweight, rugged, inexpensive, small, and quiet.
- easily deployed and operated.
- programmable timer for unattended on and off.

- rechargeable battery packs.
- continuous operation up to 30 hours on a single charge.
- precise and accurate.
- low detection limit of approximately 5 ug/m3
- sustained operation under high particulate loadings, e.g. 100 ug/m3 or more.
- electronic sample flow regulation.
- electronic sample flow totalizer.
- low flow shutoff/warning.
- can accept a variety of other pollutant sampling media (e.g. PUF, DNPH, charcoal, denuders, etc.) or take whole air samples (Tedlar bags) with little or no modification.

Portable nephelometers
- many of the same attributes of the $PM_{10}$
- battery operated
- effectively measure particulates of 1 micron diameter or smaller.
- continuous reading, storing five minute averages.
- rechargeable.
- continuous operation from 2-48 hours on a single battery charge.
- internal storage for up to nine days of sampling data.
- data download to a portable lap-top computer through RS232 serial port.
- operationally equivalent to standard nephelometers.

Microbalance
- five to six place balance.
- rugged, transportable while precise and accurate.

Field XRF Unit
- similar MQLS with situ laboratory units.
- rugged.

Support Gear
- calibration and audit gear, tools and diagnostic equipment, etc.

**PROPOSED NETWORK DESIGN**

The recommendation for siting of the portable $PM_{10}$ samplers is predicated on providing a large area of coverage for developing a better estimate of the areas impacted by the plume, a cross-sampling of population and troop centers, and to a capability to provide a technology transfer to Saudi Arabia, Kuwait, and Bahrain.

SAUDI ARABIA
- collocated site at K.F.U.P.M. (2 sites)
- two sites in Riyadh (1 U.S. Embassy & 1 MEPA location)
- one site Royal Commission at Jubayl
- one site Saudi ARAMCO at Tanajib
- one site MEPA at Khafji

Total of seven (7) sites.

KUWAIT

- three sites (3) located at the two operational continuous monitoring sites within Kuwait City (one site collocated)
- one site at Camp Freedom
- One site U.S. Embassy
- One site Al Hamadi (Kuwait Oil Company Hospital)

Total of six (6) sites.

CENTCOM

- two sites at selected troop locations

Total of two (2) sites.

BAHRAIN

- one site to be determined

Total of one (1) site.

A total of sixteen samplers are committed to field sampling with the remainder as spares or as changes to the sampling plan requires.

Phase 3. Characterize the Aerial Plume.

This phase should follow closely with Phase 2, in order to characterize the 3-dimensional nature of the smoke plumes from the fires in Kuwaiti oil fields. To achieve that goal, many of the same plume measurements collected by the existing and proposed ground level measurement locations should be provided by the aerial sampling platform. Obviously, the longer time integrated samples (e.g., 24 hour total values, averages, etc.) cannot be reproduced by aircraft borne devices. Short-term and across plume integrated measurement descriptions may be obtained to characterize the special extent and details of actual constituents of the elevated portions of the oil fire plumes.

The aerial sampling activities may be separated into measurements which address the three general zones of plume characteristics, from an a meteorological sense. Those zones are the 1) close-in zone, 2)intermediate or transition zone and 3)extended or distant zone. Measurements very near the wellhead are difficult to impossible to obtain due to excessive heat and great levels of turbulence. Measurements at intermediate distances will be difficult and many locations within the clustered groups of burning wells may be unsafe for aerial traverses due to the extremely dense smoke and hidden turbulent plumes. Measurements at the longer distances, a few miles downwind of the burning wells, should be possible. Measurements from a few to several hundred miles downwind of the fire area should be feasible. Within that distance range the approximate concentrations, plume dimensions, and estimated mass flux in the downwind directions may be approximated. The aerial sampling strategies should concentrate on the obtaining of those types of information.

4.4 Phase 4. Develop a Complete Profile of the Smoke Plume Constituents.

Obtain additional equipment to expand existing continuous monitoring high priority sites in Kuwait and Saudi Arabia

The survey conducted by the Team during Phase 1 of this plan indicated that within the region, respirable particulate sampling technology, aerosol and total particulate sampling and analysis for volatile organic compounds (VOC), semi-volatile organic compounds (SVOC), and PAHs were either not available or insufficient to properly characterize the effects of the oil well fires on the population centers and the troop concentrations within the region.

This phase of the plan proposes to bring into the region several new technologies and to train personnel withn the region to operate samplers, to condition, and analyze the several new media necessry to support this expanded network. The objective of this process is to develop a stand-along capability within each participating country for aerosol and particulate monitoring which will support the Gulf regional air quality characterization and index plan outlined in Phase V.

During this phase of the plan the Team proposes to expand the continuous air and meteorological monitoring currently being conducted within the region at six sites. These sites are recommended based on the need to jointly develop the sampling and analytical capability within the region to ensure that it becomes self-sufficient and sustainable. The particular technologies outlined below are not currently operated within the rgion nor are the analytical procedures required to support them currently being utilized. However, the Phase I survey indicates that with sufficient training, additional equipment, and some experience with actual field samples the transfer should be relatively smooth.

Initially, the Team's recommendation of six sites strategically placed along the axis of the area of greatest impact by the oil well fire plume will generate sufficiaent samples for the required training, while also providing critical data not currently being collected by the existing networks or available through the portable $PM_{10}$ network proposed in Phase II. As this data base develops it can be used to better define the constituents of the plume and thus permit a more accurate assessment of the potential long-term health risk.

The equipment listed below should be collocated with the full compliment of continuous air and meteorological monitors described in Phase V at these six proposed sites. A brief description of the equipment is provided below:

TSP High Volume Sample - used to collect a 24-hour sample of the total suspended particulates, operated nominally at 50 OFM, and typically uses 8x10 inch glass fiber, quartz, or teflon filter media.

$PM_{10}$ High Volume Sampler - used to collect a 24-hour sample of the 10 micron and smaller sized fraction of the total suspended particulate sample collected by the TSP sampler above, sampler is typically operated at 40 CFM, and utilizes an 8x10 inch Quartz or teflon filter media. Note: glass fiber media should not be used if there is concern for a known sulfate artifact formation problem.

$PM_{10}$ Manual Dichotomous Sampler - used to collect a 24-hour sample of the 10 micron particulate size fraction of the TSP, sampler operates at 16.7 liters/minute, and utilzes two (2) 37 mm diameter Teflon filters to collect a fractionated sample with a cut point of 0-2.5 micron (fine fraction) and 2.5 - 10 micron (coarse fraction).

VOC Canister Sampler - used to collect up to a 24- hour integrated whole air sample in six-liter evacuated stainless steel canisters, interior walls are passivated to minimize sample degradation. samples volume can be rgulated by either limiting the volume to ambient pressure or pumping in addition sample to an approximate volume of 16 liters, these samples can be used for the determination of total hydrocarbons or analyzed for specific hydrocarbons, multiple analysis are available from a single pressurized canister sample. Note: An extensive canister cleanup process is required prior to the collection of additional air samples.

Polyurethane Foam (PUF) Low Volume Sampler - used to collect 24-hour aerosol samples utilizing small AC or battery operated pumps at flow rates less than five liters per minute on relatively small glass cartridges containing a PUF plug, these samples can be extracted and analyzed for PAHs, or other SVOCs. Note: Both the glass cartridge and PUG plug require an extensive cleanup procedure prior to re-use.

Optional Tenex/Charcoal/XAD-2 tubes - these media can be used with same type of low volume pumps described above to collect additional samples for further definition of the constituents of the plume for SVOCs.

Organic compounds will be present in all three phase distributions (particle bound, SVOC, and VOC) and each phase will have to be sampled and then a determination will have made as to importance of each.

The particle bound is phase can be collected for extractible organic analysis from both quartz, teflon impregnated glass fiber gilters, or teflon.

The SVOC phase can be collected on PUF and within the canister. The VOC phase can be collected with canisters and charcoal tubes. Employment of Tenex and SAD-2 sampling tubes in conjunction with PUF, charcoal tubes, and canisters in an overlapping sampling matrix, can be used to confirm of the presence or absence of compounds which could be missed by a less complex sampling matrix.

Proposed locations for the initial six expanded sites:

The Team recommends that the six locations follow the general axis of plume drift from Kuwait City south into Saudi Arabia. It is further suggested that the operation of these sites be divided amongst the key network managers within the two countries: Kuwait, MEPA, and Saudi ARAMCO. This division of respnsibility supports the philosophy to jointly develop both the sampling and analytical capability within all three entities.

Kuwaiti Locations

The Team recommends that two (2) of the sites be located at the existing operational continuous monitoring stations located in Kuwait City. A third site should be established in Al-Abmadj at the Kuwaiti Oil Company Hospital. This location is situated within 300 - 400 meters of several burning wells and is adjacent to the closest residential area associated with any of the oil fields.

Saudia Arabian Locations

The Team recommends that a site be established at King Fahd University of Petroleum and Miners (K.F.U.P.M.) in Dharhran, one site to be collocated with Saudi ARAMCO site in Tanajib and the last site should be collocated with the MEPA sie in Khafji which currently is only collecting meteorology data.

| Episodic/EARLY WARNING measurements | | Longer term monitoring |
|---|---|---|
| $PM_{10}$ | (continuous) | Acid aerosols |
| TSP | | VOCs |
| SO2 | (continuous) | Aldehydes |
| O3 | (continuous) | BaP, other PAHs |
| NOx, NO | (continuous) | Trace elements |
| CO | (continuous) | Fine particles |
| H2S | (continuous) | |

3. Health Monitoring Survey

Air monitoring data collected through the proposed air monitoring network will provide basis for interpreting the results of health surveys of the populations and ecosystems potentially effected by the effluents from the oil fires in Kuwait. The kinds of health data that could be collected include:

- Health questionnaires
- Blood samples
- Hair samples
- In-vivo animal studies
- Forced expiratory volumes
- Other morbidity parameters

Distribution of Proposed and Existing Air Monitoring Sites

Table 2 shows the location of the existing and proposed air monitoring sites, while Table 3 lists the locations of the proposed air monitoring sites. In order to complete the network in an orderly manner, it is proposed that the network be developed in several stages. The first order of business would be to upgrade the existing monitoring locations so that there exist a full complement of air and meteorological monitoring equipment, as well as add new critical air monitoring stages (Stage 1). The second stage would be to establish those sites that would satisfy the minimum requirements for tracking the plume caused by the oil fire and to provide an early warning system for Saudi Arabia, Kuwait, and Bahrain (Stage 2). The third and final stage would be to complete the final network following a review of the quality and quantity of findings to date (Stage).

5. SUMMARY

The initial measurements made by the Team suggest that there is not an imminent threat from SO2 and H2S to the urban populations, while short term measurements of particulate are frequently high. Historically, this region has high particulate levels due to wind blown dust. The particulate measurements that were collected by the Team reflect total particulate, as opposed to respirable particulates, that is $PM_{10}$. There has not been a principal focus in the Region on total particulate, $PM10_{10}$, and organics up to now. Therefore, the Team developed the five phased monitoring plan with an emphasis on better understanding particulates and the aerosol organics associated with the oil fires in Kuwait. Particulates and organics could be a source of concern for both health and ecological effects.

The air monitoring proposals presented in this report represent the Team's collective judgement on what needs to be done. Those judgements are based upon an on-site evaluation of the situation in Kuwait, discussions with officials from the Saudi Arabian MEPA, Kuwait, Saudi ARAMCO, and the King Faud University of Petroleum and Minerals. Needless to say more work is needed regarding data management, statistical design, data analysis and quality assurance. Because of the complexity and immediacy of this problem, an extended time commitment will be needed on the part of all Gulf nation agencies to achieve the objectives outlined in this report.

Cost estimates for the various tuypes of air and meteorological monitors are attached to this plan, along with documentation on the U.S. Environmental Protection Agency's Pollutant Standards Index (PSI).

TABLE 2. Location of existing air and meteorology monitoring stations

| NATION | ORGANIZATION | LOCATION | STAGE OF IMPLEMENTATION |
|---|---|---|---|
| EXISTING SITES | | | |
| Saudi Arabia | MEPA | Damman | 1 |
| | | Hofuf | 2 |
| | | Tanagib (Mobile Site) | 1 |
| | | Riyadh | 1 |
| | | Khafji (Met Only) | 1 |
| | | Udayliyah | 3 |
| | | Shedgum | 3 |
| | | Abqaiq | 3 |
| | | Dhahran | 2 |
| | | Tartut | 2 |
| | | Rahimah | 2 |
| | | Juaymah | 1 |
| | | Tanajib | 1 |
| | | Saffaniyah Oil Field (met only) | 3 |
| | | Marjan Oil Field (met only) | 3 |
| | | Farisiyah Island (met only) | 2 |
| | The Royal Comm. for Jubyayl and Yunbo | Cluster of 5 stations in Jubyayl | 1 |
| Existing Sites: Kuwait | | SITE 1 | 1 |
| | | SITE 2 | 1 |
| | | SITE 3 | 1 |
| Existing Sites: Qatar | | 3 mobile units, unknown locations | 2 |

TABLE 3. Location of proposed air and meteorology monitoring stations

| NATION | ORGANIZATION | LOCATION | STAGE |
|---|---|---|---|
| Proposed Sites: Saudi Arabia | MEPA | Awiyah | 3 |
| | | Shumlul | 2 |
| | | Sarrar | 2 |
| | | Nuayriyah | 2 |
| | | Lisafah | 3 |
| | | Uafar al Batin | 1 |
| | | 28 deg 6 min latitude, 47 deg 51 min longitude | 2 |
| | | 28 deg 30 min latitude 48 deg 1 min longitude | 1 |
| | | 28 deg 55 min latitude 47 deg 32 min longitude | 2 |
| | | 29 deg 7 min latitude 46 deg 39 min longitude | 2 |
| Kuwait | | Mina Saud | 1 |
| | | U.S. Embassy | 1 |
| | | Al Ahmadi (Hospital) | 1 |
| | | International Airport | 1 |
| | | 29 deg 23 min latitude 46 deg 55 min longitude | 2 |
| | | 29 deg 50 min latitude 47 deg 15 min longitude | 2 |
| | | 30 deg 4 min latitude 47 deg 42 min longitude | 2 |
| | | 29 deg 33 min latitude 47 deg 50 min longitude | 2 |
| Bahrain | | Manamah | 2 |
| Qatar | | Dawhah | 2 |
| United Arab Emirates | | Aub Dhabi | 3 |
| | | Dubai | 3 |
| Oman | | Muscat | 3 |

APPENDIX B

# A REGIONAL GULF AIR MONITORING PLAN IN RESPONSE TO THE 1991 KUWAITI OIL FIELD FIRES

APPENDIX B

# A REGIONAL GULF AIR MONITORING PLAN IN RESPONSE TO THE 1991 KUWAITI OIL FIELD FIRES

## 1. INTRODUCTION

The U.S. Interagency Air Monitoring Team is working with the Saudi Arabian Meteorology and Environmental Protection Agency (MEPA) to develop an air monitoring plan for the Gulf region that will provide information to assess the impact of the [Kuwaiti] fires in Saudi Arabia. This plan is being discussed and developed with the King Faud University of Petroleum and Minerals in Dhahran, the Cooperation Council for the Arab States of the Gulf (CCG), and the Saudi Arabian Oil Company (ARAMCO). The plan is being developed at the request of Dr. Tawfiq, Vice President of the Saudi Arabian MEPA. Meetings have been held with officials from all of the above mentioned organizations.

### 1.1 Approach

The Team is gathering information on the existing air monitoring networks in the region operated by MEPA, ARAMCO, Kuwait, Bahrain, and the Royal Commission of Jubayl and Yunbo. The spatial distribution of the existing network in the Region is being reviewed as to the location of sites, the air pollutants and meteorological variables that are monitored at each of these sites and the quality of existing data. That review is to determine if the existing network needs to be expanded in terms of the air pollutants and meteorological variables monitored and additional air monitoring stations to determine the impact from the oil fires. The capabilities of the existing agencies and governments to deal with a more complete network is also being investigated.

### 1.2 Objectives of Air Monitoring in the Gulf Region

Air monitoring data is needed for the following reasons:

a. To provide an Early Warning Health Advisory System for the Gulf Region to respond to the air pollution resulting from the Kuwaiti oil fires. The proposed Early Warning System could be based on an adaptation of the U.S. Air Quality Index, the Pollutant Standards Index (PSI), which can be modified to use Saudi air quality standards. The index would provide for health advisories to the affected populations so they can minimize their exposure to high pollution levels.

b. To track the air pollution from the Kuwaiti oil field fires over time to asses the potential long term health and ecological effects. The air monitoring network proposal being developed is being coordinated with a parallel effort to develop a health monitoring information system.

c. To collect samples of airborne particles to perform toxicity testing and dose response assessment utilizing in-vivo animal models.

d. To facilitate evaluations of models which are use to predict the local and regional scale behavior of the oil field emissions. Data from the expanded GULF REGIONAL AIR MONITORING NETWORK of ambient air quality and meteorological data will be important for those evaluations.

## 2. BACKGROUND

### 2.1 Preliminary Investigation of the Existing Monitoring Networks

The air quality monitoring sites listed in Table 1 have been identified for each of the Gulf nations that could contribute monitoring information within the sphere of influence of airborne effluents from the Kuwait oil fires.

Based upon our review of the existing networks, the principal pollutants which are missing are in the Saudi network and in the present Kuwaiti network are $PM_{10}$ which represents particulate matter with particles less than 10 microns in diameter, polycyclic aromatic hydrocarbons (PAH) and volatile organic compounds (VOC). With respect to $PM_{10}$, these are the particles which are most likely to penetrate deeply into the lung. It should be noted that Kuwait has collected particulate data using an Anderson Cascade Impactor, with limited size distributions below seven microns within a total suspended particulate sample. Because of the importance of this particular pollutant and the extensive particulate resulting from the oil fires, the Team is recommending that special efforts be initiated to gather $PM_{10}$ data and if possible to determine its constituents - trace metals and hydrocarbons. The $PM_{10}$ data collection effort should be supplemented with the collections of PAH samples and if possible, grab samples for VOC analysis.

An ongoing effort is being conducted to examine the analytical laboratory support for air monitoring in Kuwait, MEPA, KFUPM, and Saudi ARAMCO. The Kuwaiti laboratory capability to analyze air and particulate samples has been left largely intact. As of March 27, 1991, two of the three continuous monitoring stations have been activated and are collecting data. The remaining site has its continuous sampling equipment however, like the analytical laboratory, is without electrical power. There is no projected date for power at these locations. The analytical laboratory has had experience with polyurathane foam (PUF) extractions for PAH measurements (PS-1 sampler) and has done pesticide extraction and analysis research. The most critical need for the laboratory is obviously power to provide the basis of future support to the sampling plan. Additionally training must be provided with documented procedures for these new sampling and analytical procedures, and lastly they are in need of a complete set of standards to support instrument calibrations for their existing continuous monitors and the new proposed technologies. Quality control and quality assurance samples and support for the network should be developed within the available laboratories but, should be supplemented from an external source.

The analytical laboratory at King Faud U.P.M. has recently been provided the above procedures to permit a self assessment of their equipment availability to conduct these detailed analyses. Currently, the K.F.U.P.M. is conducting experiments on PAH's analysis of high volume filters as a first step in this program. K.F.U.P.M. has not had any experience with PUF, VOC canister analysis, or $PM_{10}$ sampling and analysis. They have on hand the capability to expand their current analytical capability to provide support to the proposed network.

The analytical laboratory of Saudi ARAMCO as with MEPA has had no experience in collecting and analyzing particulate $PM_{10}$ samples, PUF, and canister samples for VOC speciation and PAHs.

In summary, the current level of technical competence within all of the facilities visited, MEPA, King Faud U.P.M., Saudi ARAMCO, and Kuwait, indicates that upon the procurement of adequate equipment, standards, and training, they all could support the sampling and analysis required for this program.

TABLE B-1. The Distribution of Air Pollutant and Meteorological Monitoring Sites by Gulf Nation.

| Nation | Organization | Number of Air and Met Sites |
|---|---|---|
| SAUDI ARABIA | MEPA | 3 fixed sites - meteorology and air pollution at different locations of the same city |
| | | 1 mobile site - meteorology and air pollution |
| | | 1 fixed meteorology site |
| | Saudi ARAMCO | 8 air quality sites with meteorology |
| | | 6 additional meteorology sites |
| | Royal Comm. for Jubayl & Yunbo | Cluster of Five Stations in Jubayl |
| KUWAIT | | 3 sites with continuous monitors (2 with power, 1 without power). |
| | | 4 sites with Anderson samplers, high vols. and dustfall buckets. (no power) |
| | | 1 additional TSP site (no power) |
| | | 6 additional dustfall sites |
| | | 4 temporary S02 bubbler sites located at 4 hospitals (some power) |
| BAHRAIN | | 2 sites |
| QATAR | | 3 mobile monitoring sites |
| IRAN | | unknown |
| IRAQ | | unknown |

A substantial number of meteorological measurement sites exist within the eastern provence of Saudi Arabia and the nations of the Gulf Region. Most of those sites are along the shoreline of the Gulf. ARAMCO operates 14 sites with meteorological data. Eight of those sites have collocated air quality measurements. Three of those sites are over the Gulf waters on platforms or on an island. MEPA (Saudi Arabia) has five sites with collocated air quality measurements. In addition, there are surface observations collected at many of the airports throughout the kingdom. Surface meteorological data are being collected at other Gulf region locations. Their locations may be identified through the WMO publications. Previously, there were other surface measurement sites within Kuwait but their operational status remain unknown at this time.

Two upper air balloon sounding sites are operating within Saudi Arabia. One site is at Dhahran and the other is about 115 miles to the SW of Kuwait City at Al Qaysumah. Twice daily soundings are collected at those locations, at 0000 and 1200 GMT. Prior to the war in Kuwait, twice daily upper air soundings were made at the Kuwait International Airport. the resumption of those soundings could be of substantial benefit to describing the airflow across the areas of Kuwaiti oil fires.

## 2.2 Meteorological Observations

The following summarizations are based upon first hand observations of the smoke plumes and fires. Those observations were made during overflights and during vehicle traverses both within the oil fields and along roads outside of the burning oil fields.

For any given day, the prevailing large-scale meteorological pattern will be the main driving feature which determines where the smoke plumes will be located and how dense they will be.

Individual smoke plumes appear to act in manners typical of buoyant plumes from ground level sources or plumes from short chimneys. Plume rise, the development of a bent-over plume geometry, etc., seem to apply to the individual well-head fires; some have jets of fire and others are nearly surface based burnings of the more combustible fractions of crude oil spread across the ground in the vicinity of the well. Most of the fire plumes rise to between 500 to 1000 feet above ground level before becoming mostly bent over, although some plumes have a significant amount of smoke remaining within a few hundred feet of the ground.

Collectively, as groups of multiple fires within oil fields with a high density of burning wells (particularly Greater Burgan), they assert a meteorological influence of their own. It is suggested that the grouping of fires with a horizontal diameter of 15 to 25 miles provides enough of an intense "heat-island" that significant additional vertical rise of the smoke occurs inside the area. That additional plume rise lifts smoke to elevations often 3000, 4000, to 5000 feet above ground within the initial few miles downwind. Eventually, portions of the smoke rise even more, with multiple layers often forming at heights up to 8000, 9000, even 12000 to 13000 feet. Between such layers and at the tops of layers many tens of miles downwind, a generally diffuse and homogenous zone of smoke has been observed. The eventual smoke height limits are bounded by the regional vertical temperature structure and synoptic weather characteristics. Information reviewed to date suggest that those maximum heights are mostly 8000 to 12000 feet within the initial 100 to 200 miles downwind from the Kuwaiti oil field fires.

With the creation of a local heat-island, a distinct inflow of near surface air has been observed within the initial 500 to 1000 feet above ground level. At times, that inflow of wind is estimated to be 5 to 15 m/sec in strength. Smoke plumes at the peripheral bounds of the burn area tend to slant inward toward the center of the burning field instead of pointing downwind with direction of the expected ambient wind.

Local variations in daily wind flow, along with the fire-storm like winds, are likely to produce preferred locations and times of day at which more concentrated smoke plume exposures reach ground level. Prevailing winds are from the northwest throughout the year. During the daytime a sea breeze can be expected to develop at the Gulf shoreline and progress inland as the day progresses. That inflow of air can readily clear out the smoke plumes and yield substantially cleaner air at ground level on the Gulf side. Along the leading edge of the sea breeze front there likely may be a zone of extended and elevated exposures to fire effluent. That zone may well extend down the shoreline from Kuwait City some 100 km. The area of greatest susceptibility appears to be to the southeast of fires in the Al Ahmadi oil field (part of the greater Burgan field).

2.3 Data Base Management

In addition to evaluating the existing air monitoring networks, the Team made an initial review of existing data systems to handle the air monitoring data. The previous meteorological, air quality, and visual observations of the oil field fire plumes should be archived, along with data to be obtained during the period of on-going Kuwaiti fires. A dedicated facility for the performance of that archiving does not appear to exist. The data management task is likely to be a sizeable task and extended of a period of a year and more.

Some of the general functional needs of the data management system include the following. The data which will need to be assembled into the data base will likely come from many different sources and exist in diverse formats and media. One role of the data base management activity will be to assemble all information into a common, uniform structure. The second and equally important part of the data archiving is the provisions of a uniform and consistent mechanism for the retrieval of data by participating agencies. The degree to which that data base is well formulated, will significantly affect the efforts of users of the data as they attempt to study and interpret the measurements.

A number of possible methods exist for the set-up of a computerized data base. Commercial software and hardware of various degrees and complexity and cost exist which would satisfy the data management needs. Before the choices of system software and hardware are made, the functionality of the overall system and the manners in which users work with the data sets should be considered. For example, it may be required that the data base be a "relational" data base. Other sources of software that might be used to handle a large volume of data would be the U.S. Environmental Agency's (USEPA) Aerometric Information and Retrieval System. That system can handle hourly data and has considerable software available to both summarize and analyze the ambient air data.

MEPA has asked the Team to recommend the type of computer and associated software needed to manage the data collected in order to implement the monitoring plan. For now, it is more appropriate to defer specific recommendations. A number of general performance characteristics may be stated but specific details should be formulated in conjunction with data base specialists at a later date.

RECOMMENDATIONS

While preliminary, the Team believes that the following recommendations should be implemented based on our initial data gathering exercise. A general objective is listed as a recommended goal and below that objective are listed several needed items or activities to facilitate the achievement of the overall goal.

1. Objective: Provide a framework for an early warning advisory capability for areas expected to be impacted by effluents from Kuwaiti oil field fires.

Needs:
a. Meteorological data observations and forecasts
b. Visual observations from key receptor areas
c. Review existing monitoring data
d. Calculate smoke trajectories and concentrations

2. Objective: Provide a cursory wide-area indication of the distribution and composition of the Kuwaiti oil field fire effluents.

Needs:
a. Establish 10 to 15 $PM_{10}$ monitoring locations using portable monitors.
b. Train personnel in the operation of the portable PM-10 monitors and develop the analytical support capability within Saudi Arabia and Kuwait.
c. Define the $PM_{10}$ to TSP ratios.
d. Define the composition of the plume by XRF analysis for limited organic identification.
e. Establish a central media preparation and analysis location.
f. Define the baseline contribution of the ambient aerosol from the surrounding desert.

3. Objective: Characterize the aerial smoke plume.

Needs:
a. Collect many of the same plume measurements recommended for the ground monitoring array
b. Collect descriptions of the width and vertical extent of the smoke plume at several downwind distances
c. Characterize the regional background by samples outside of the smoke plumes

4. Objective: Develop a more complete profile of the smoke plume constituents

Needs:
a. Procure equipment for a limited number of comprehensive air quality monitoring stations to collect: TSP, $PM_{10}$, organic, and inorganic constituents
b. Establish a limited number of comprehensive air quality monitoring stations to collect: TSP, $PM_{10}$, organic, and inorganic constituents. These should be collocated with the continuous monitors wherever possible.
c. Train individuals to operate and maintain the sampling instrumentation in support of the monitoring program
d. Procure the necessary analytical laboratory equipment required for analyses of the samples collected under this objective
e. Train laboratory personnel in the preparation of the sampling media, QA/QC procedures required and the subsequent sample analytical procedures.

5. Objective: Determine the need for expansion of the monitoring network to a wider regional coverage.

Needs:
a. Review the data developed from the limited network.
b. Assess the current and projected status of control of the oil field fires and emissions.
c. Review the population health survey statistics.
d. Review the suitability of the sampling strategy, and modify where needed

e. Expand the limited network as the situation requires, data analysis indicates an additional need for data, the response of the affected populations indicate, or the model requires additional parameters.

Many of the same considerations listed for air quality above also apply to meteorological considerations.

6. Objective: Provide a meteorological data stream to facilitate the modeling and prediction of areas expected to be impacted by effluents from Kuwaiti oil field fires.

Needs:

a. Upper air balloon sounding data representative of the Kuwaiti oil field fire area and Gulf region plume transport.

b. Supplemental surface based measurements of wind speed and direction, temperature, moisture content of the air (dew point, relative humidity, etc.), solar radiation, atmospheric pressure, precipitation.

7. Objective: Provide a meteorological data set to investigate the areas of climate modifications occurring due to effluents from Kuwaiti oil field fires.

Needs:

a. Supplemental surface based measurements diffuse and direct solar radiation.

b. Special collections of precipitation throughout the region to examine the pH and chemistry of the rains.

c. Aircraft soundings and profiles of smoke, winds and temperatures, air quality related measurements of plume compositions and concentrations representative of the Kuwaiti oil field fire area and Gulf region transported plumes.

## 4. PHASED AIR MONITORING PLAN

This section of the report discusses a prioritized plan of stepwise incremental actions for the phased implementation of the recommendations discussed above. Five phases for implementing the plan follow.

### 4.1 Phase 1. Provide a Framework for an Early Warning Advisory

In order to accomplish this task, the following action items need to be initiated or incorporated into the task framework.

1. Gather daily weather forecasts to predict meteorological conditions which would effect pollution potential in both Saudi Arabia and Kuwait.

2. Use visual observations from key receptor sites to determine possible pollution levels.

3. Gather existing air monitoring data from fixed and mobile sites operated by MEPA, Saudi ARAMCO, and the governments of Kuwait and Bahrain to develop a data base of existing data.

4. Establish a daily briefing for representatives of the many entities concerned with behaviors and fate of the aerial effluents from the oil field fires in Kuwait.

5. Develop a daily map depiction of the aerial distribution of the smoke plumes across the region using satellite imagery, for each day since initiation of the oil field fires.

6. Issue a daily general statement about the expected behavior(s) of the oil fire plumes. Areas of potentially adverse conditions could be treated as locations for which advisories would be issued.

7. Provide forecast meteorological conditions across the region for the next 2 to 3 day period, including the expected location(s) of the smoke.

8. Obtain data from the MEPA network throughout the eastern province.

9. Direct the crews of the SLAR aircraft, (USCG Falcon Jet), to continue on a regular basis the present visual observation and mapped notations concerning the horizontal extent of the smoke plumes and the estimations of altitudes of layer bases and tops.

10. The above information could be compiled initially in hard copy form. Later it should be stored on electronic media in a way that an existing PC data management system could readily incorporate it.

### 4.2 Phase 2. Establish a $PM_{10}$ Monitoring Network Using Portable $PM_{10}$ Monitors.

Working in conjunction with the Saudi Arabian Meteorology and Environmental Protection Agency (MEPA), the proposed plan has been developed to collect information on $PM_{10}$, which represents particulate matter with particulates less than 10 microns in diameter. At the present time there is no $PM_{10}$ monitoring in the Gulf region.

OBJECTIVES

The objectives for this effort are as follows:

1) Determine the magnitude or the health threat to residents of population centers and field-based military personnel impacted by the oil field fires and typical sources (windblown desert soils).

2) Establish a scientifically based capability to alert these affected populations prior to the onset of the potential health threats from real-time measurements.

3) Establish a technical basis for executing predictive air quality dispersion models which simulate the oil well fire emissions, background sources, and consequent impacts over space and time.

4) Establish a regional network of $PM_{10}$ stations using a consistent monitoring methodology across the countries of Saudi Arabia, Kuwait, and Bahrain.

5) Train personnel to operate and analyze the media produced by the network from each of the participating countries.

6) Develop a regional data base and encourage the sharing of data developed from the network with all participants.

The above objectives convert the foregoing goals into discrete actions:

1) Determine the spatial temporal frequency, and severity of the impact to the resident populations and military centers affected through the application of saturation sampling techniques with portable $PM_{10}$ samplers.

2) Establish the correlation of real-time surrogate monitoring data to date generated from direct sampling methods through the collocation and simultaneous operation of both methods over time.

3) Where possible use impact data collected from samplers as an input to the dispersion model, run the model "backwards" to develop a better estimate of the emission rates of the fires and produce a higher level of confidence in the predictive modeling results.

4) Obtain from the literature and/or develop from source sampling analysis chemical profiles of all major pollutant sources in order to:

a) identify those contaminants that pose the greatest health concerns and to develop an estimate of acceptable ambient levels (AALs) prior to the conduct of field work,

b) identify the chemical "signature" of the major contaminants and other tracers characteristic of the primary sources,

c) enable apportionment of these contaminants and other tracer compounds from a simple total mass concentration measured by the ambient samples, and

d) attempt to relate these levels in turn to the surrogate real-time monitoring methods for use in issuing timely health risk alerts.

5) Ensure that the data generated by the network are of a demonstrably high quality (precision & accuracy), completeness, representativeness, and comparability.

| TIME | POSITION (LAT/LONG) | BASE/TOP | WIND (DIR/SPD) |
|---|---|---|---|
| 0545 | N2623E50-31 | CLR VIS 15 M | 332/23 |
| 0600 | N2700E4958 | CLR | 321/19 |
| 0615 | N2744E4916 | CLR | 300/20 |
| 0630 | N2822E4839 | TOPS 070/030 | 331/008 |
| 0645 | N2918E4819 | SMOKE 060/030 | 335/10 |
| 0700 | N2932E4810 | SMOKE 070/030 | 344/10 |
| 0715 | N29344830 | SMOKE 070/030 | 265/7 |
| 0730 | N29354857 | THIN SMOKE 050/030 | 215/6 |
| 0745 | N2925E4920 | VERY THIN SMOKE 090 | 133/003 |
| 0800 | N2833E4945 | THICKER SMOKE 090/ 080 | 326/006 |
| 0815 | N2738E5035 | THIN SMOKE 090/080 | 280/005 |
| 0830 | N2702E5111 | SMOKE 090/060 | 192/010 |
| 0845 | N2625E5148 | SMOKE/HAZE 080/060 | 215/12 |
| 0900 | N2618E5118 | SMOKE/HAZE 070/SURF | 230/009 |

## APPROACH

Conduct a $PM_{10}$ saturation sampling study for the determination of the temporal and spatial features of the impact of the oil well fires and attempt to reconcile the data with existing model estimates. $PM_{10}$ mass concentrations would be available within 24-48 hours following sampling. No on-site meteorological, gas, or aerosol monitoring or chemical analysis is required (chemistry could be attempted later on the preserved media). One or more portable nephelometers would be collocated at several sampling sites to develop correlations between manual and continuous (real-time) methods for alert advisories.

A total of 15-20 portable $PM_{10}$ samplers equipped with quartz filters would be run simultaneously on a daily basis or "triggered" (impact forecast) basis throughout the study area. Network design would involve a "nested" approach to address the objectives:

1) samplers sited at background locations (not impacted) by the smoke plume and samplers in populated areas.

2) samplers in populated areas impacted by smoke.

Samplers could be "ganged" (2 or more) and programmed to run consecutively at individual sites if filter clogging problems occur because of high loading. Further, multiple samplers could be collocated at certain sites to collect fine particulates (less than 2.5 microns) and coarse particulates (2.5-10 microns) on teflon sample filters (facilitating XRF elemental analysis). One of the 10-12 sampling sites would be equipped with duplicate samplers in an effort to develop sampling precision estimates.

This comprehensive program will yield the following:

1) short turnaround $PM_{10}$ concentrations,

2) gross estimates of the fire-specific contributions to total mass could be derived by subtracting background concentrations from the impact site concentrations,

3) applying assumptions on the source profiles to pollutant loading attributable to the well fires, estimates of individual target compound loadings could be computed and a comparison to AALs made,

4) correlations factors can be determined between real-time surrogate methods and manual methods, and

5) impacted sampling media would be available for subsequent intensive chemical analysis in an attempt to reconcile assumed source signatures and extracts can be used to perform any other analytical tests (mutagenicity). Special precautions may be needed to preserve the sample integrity during storage and transfer.

Limitations: no on-site meteorological data to calculate emissions rates, no on-site chemistry (unless developed) to confirm critical assumptions, and no concurrent gas or acid aerosol measurements to evaluate or correlate with the particulate data.

Resources: 1-2 professionals, 1 field technician per site, if it must be operated individually (actual number contingent upon the network logistics and potential "clogging" implications), portable $PM_{10}$ saturation samplers, portable nephelometers, lap-top computer, microbalance, expendables and sundry support gear.

In summary, this approach is $PM_{10}$ mass data-rich, and assumption rich and in contrast to being reconciliation and broad pollutant characterization-poor.

## SAMPLING AND ANALYTICAL METHODS

The alternate approaches identified above involve the use of a variety of sampling and analytical methods summarized below:

Portable $PM_{10}$ Saturation Samplers

- segregate and capture of filter, particulates of 10 micron size (respirable particles) and smaller.
- battery-operated, lightweight, rugged, inexpensive, small, and quiet.
- easily deployed and operated.
- programmable timer for unattended on and off.

- rechargeable battery packs.
- continuous operation up to 30 hours on a single charge.
- precise and accurate.
- low detection limit of approximately 5 ug/m3
- sustained operation under high particulate loadings, e.g. 100 ug/m3 or more.
- electronic sample flow regulation.
- electronic sample flow totalizer.
- low flow shutoff/warning.
- can accept a variety of other pollutant sampling media (e.g. PUF, DNPH, charcoal, denuders, etc.) or take whole air samples (Tedlar bags) with little or no modification.

Portable nephelometers
- many of the same attributes of the $PM_{10}$
- battery operated
- effectively measure particulates of 1 micron diameter or smaller.
- continuous reading, storing five minute averages.
- rechargeable.
- continuous operation from 2-48 hours on a single battery charge.
- internal storage for up to nine days of sampling data.
- data download to a portable lap-top computer through RS232 serial port.
- operationally equivalent to standard nephelometers.

Microbalance
- five to six place balance.
- rugged, transportable while precise and accurate.

Field XRF Unit
- similar MQLS with situ laboratory units.
- rugged.

Support Gear
- calibration and audit gear, tools and diagnostic equipment, etc.

## PROPOSED NETWORK DESIGN

The recommendation for siting of the portable $PM_{10}$ samplers is predicated on providing a large area of coverage for developing a better estimate of the areas impacted by the plume, a cross-sampling of population and troop centers, and to a capability to provide a technology transfer to Saudi Arabia, Kuwait, and Bahrain.

SAUDI ARABIA
- collocated site at K.F.U.P.M. (2 sites)
- two sites in Riyadh (1 U.S. Embassy & 1 MEPA location)
- one site Royal Commission at Jubayl
- one site Saudi ARAMCO at Tanajib
- one site MEPA at Khafji

Total of seven (7) sites.

KUWAIT

- three sites (3) located at the two operational continuous monitoring sites within Kuwait City (one site collocated)
- one site at Camp Freedom
- One site U.S. Embassy
- One site Al Hamadi (Kuwait Oil Company Hospital)

Total of six (6) sites.

CENTCOM

- two sites at selected troop locations.

Total of two (2) sites.

BAHRAIN

- one site to be determined

Total of one (1) site.

A total of sixteen samplers are committed to field sampling with the remainder as spares or as changes to the sampling plan requires.

Phase 3. Characterize the Aerial Plume.

This phase should follow closely with Phase 2, in order to characterize the 3-dimensional nature of the smoke plumes from the fires in Kuwaiti oil fields. To achieve that goal, many of the same plume measurements collected by the existing and proposed ground level measurement locations should be provided by the aerial sampling platform. Obviously, the longer time integrated samples (e.g., 24 hour total values, averages, etc.) cannot be reproduced by aircraft borne devices. Short-term and across plume integrated measurement descriptions may be obtained to characterize the special extent and details of actual constituents of the elevated portions of the oil fire plumes.

The aerial sampling activities may be separated into measurements which address the three general zones of plume characteristics, from an a meteorological sense. Those zones are the 1) close-in zone, 2)intermediate or transition zone and 3)extended or distant zone. Measurements very near the wellhead are difficult to impossible to obtain due to excessive heat and great levels of turbulence. Measurements at intermediate distances will be difficult and many locations within the clustered groups of burning wells may be unsafe for aerial traverses due to the extremely dense smoke and hidden turbulent plumes. Measurements at the longer distances, a few miles downwind of the burning wells, should be possible. Measurements from a few to several hundred miles downwind of the fire area should be feasible. Within that distance range the approximate concentrations, plume dimensions, and estimated mass flux in the downwind directions may be approximated. The aerial sampling strategies should concentrate on the obtaining of those types of information.

4.4 Phase 4. Develop a Complete Profile of the Smoke Plume Constituents.

Obtain additional equipment to expand existing continuous monitoring high priority sites in Kuwait and Saudi Arabia

The survey conducted by the Team during Phase 1 of this plan indicated that within the region, respirable particulate sampling technology, aerosol and total particulate sampling and analysis for volatile organic compounds (VOC), semi-volatile organic compounds (SVOC), and PAHs were either not available or insufficient to properly characterize the effects of the oil well fires on the population centers and the troop concentrations within the region.

This phase of the plan proposes to bring into the region several new technologies and to train personnel withn the region to operate samplers, to condition, and analyze the several new media necessry to support this expanded network. The objective of this process is to develop a stand-along capability within each participating country for aerosol and particulate monitoring which will support the Gulf regional air quality characterization and index plan outlined in Phase V.

During this phase of the plan the Team proposes to expand the continuous air and meteorological monitoring currently being conducted within the region at six sites. These sites are recommended based on the need to jointly develop the sampling and analytical capability within the region to ensure that it becomes self-sufficient and sustainable. The particular technologies outlined below are not currently operated within the rgion nor are the analytical procedures required to support them currently being utilized. However, the Phase I survey indicates that with sufficient training, additional equipment, and some experience with actual field samples the transfer should be relatively smooth.

Initially, the Team's recommendation of six sites strategically placed along the axis of the area of greatest impact by the oil well fire plume will generate sufficiaent samples for the required training, while also providing critical data not currently being collected by the existing networks or available through the portable $PM_{10}$ network proposed in Phase II. As this data base develops it can be used to better define the constituents of the plume and thus permit a more accurate assessment of the potential long-term health risk.

The equipment listed below should be collocated with the full compliment of continuous air and meteorological monitors described in Phase V at these six proposed sites. A brief description of the equipment is provided below:

TSP High Volume Sample - used to collect a 24-hour sample of the total suspended particulates, operated nominally at 50 OFM, and typically uses 8x10 inch glass fiber, quartz, or teflon filter media.

$PM_{10}$ High Volume Sampler - used to collect a 24-hour sample of the 10 micron and smaller sized fraction of the total suspended particulate sample collected by the TSP, sampler above, sampler is typically operated at 40 CFM, and utilizes an 8x10 inch Quartz or teflon filter media. Note: glass fiber media should not be used if there is concern for a known sulfate artifact formation problem.

$PM_{10}$ Manual Dichotomous Sampler - used to collect a 24-hour sample of the 10 micron particulate size fraction of the TSP, sampler operates at 16.7 liters/minute, and utilizes two (2) 37 mm diameter Teflon filters to collect a fractionated sample with a cut point of 0-2.5 micron (fine fraction) and 2.5 - 10 micron (coarse fraction).

VOC Canister Sampler - used to collect up to a 24- hour integrated whole air sample in six-liter evacuated stainless steel canisters, interior walls are passivated to minimize sample degradation, samples volume can be rguiated by either limiting the volume to ambient pressure or pumping in addition sample to an approximate volume of 16 liters, these samples can be used for the determination of total hydrocarbons or analyzed for specific hydrocarbons, multiple analysis are available from a single pressurized canister sample. Note: An extensive canister cleanup process is required prior to the collection of additional air samples.

Polyurethane Foam (PUF) Low Volume Sampler - used to collect 24-hour aerosol samples utilizing small AC or battery operated pumps at flow rates less than five liters per minute on relatively small glass cartridges containing a PUF plug, these samples can be extracted and analyzed for PAHs, or other SVOCs. Note: Both the glass cartridge and PUG plug require an extensive cleanup procedure prior to re-use.

Optional Tenex/Charcoal/XAD-2 tubes - these media can be used with same type of low volume pumps described above to collect additional samples for further definition of the constituents of the plume for SVOCs.

Organic compounds will be present in all three phase distributions (particle bound, SVOC, and VOC) and each phase will have to be sampled and then a determination will have made as to importance of each.

The particle bound is phase can be collected for extractible organic analysis from both quartz, teflon impregnated glass fiber gilters, or teflon.

The SVOC phase can be collected on PUF and within the canister. The VOC phase can be collected with canisters and charcoal tubes. Employment of Tenex and SAD-2 sampling tubes in conjunction with PUF, charcoal tubes, and canisters in an overlapping sampling matrix, can be used to confirm of the presence or absence of compounds which could be missed by a less complex sampling matrix.

Proposed locations for the initial six expanded sites:

The Team recommends that the six locations follow the general axis of plume drift from Kuwait City south into Saudi Arabia. It is further suggested that the operation of these sites be divided amongst the key network managers within the two countries: Kuwait, MEPA, and Saudi ARAMCO. This division of respnsibility supports the philosophy to jointly develop both the sampling and analytical capability within all three entities.

Kuwaiti Locations

The Team recommends that two (2) of the sites be located at the existing operational continuous monitoring stations located in Kuwait City. A third site should be established in Al-Abmadj at the Kuwaiti Oil Company Hospital. This location is situated within 300 - 400 meters of several burning wells and is adjacent to the closest residential area associated with any of the oil fields.

Saudia Arabian Locations

The Team recommends that a site be established at King Fahd University of Petroleum and Miners (K.F.U.P.M.) in Dharhran, one site to be collocated with Saudi ARAMCO site in Tanajib and the

last site should be collocated with the MEPA sie in Khafji which currently is
data.

Episodic/EARLY WARNING measurements

| | |
|---|---|
| $PM_{10}$ | (continuous) |
| TSP | |
| SO2 | (continuous) |
| O3 | (continuous) |
| NOx, NO | (continuous) |
| CO | (continuous) |
| H2S | (continuous) |

Longer term mc

Acid aeros
VOCs
Aldehydes
BaP, other PAH.
Trace elements
Fine particles

3. Health Monitoring Survey

Air monitoring data collected through the proposed air monitoring network will provide bas interpreting the results of health surveys of the populations and ecosystems potentially effected by t effluents from the oil fires in Kuwait. The kinds of health data that could be collected include:

- Health questionnaires
- Blood samples
- Hair samples
- In-vivo animal studies
- Forced expiratory volumes
- Other morbidity parameters

Distribution of Proposed and Existing Air Monitoring Sites

Table 2 shows the location of the existing and proposed air monitoring sites, while Table 3 lists the locations of the proposed air monitoring sites. In order to complete the network in an orderly manner, it is proposed that the network be developed in several stages. The first order of business would be to upgrade the existing monitoring locations so that there exist a full complement of air and meteorological monitoring equipment, as well as add new critical air monitoring stages (Stage 1). The second stage would be to establish those sites that would satisfy the minimum requirements for tracking the plume caused by the oil fire and to provide an early warning system for Saudi Arabia, Kuwait, and Bahrain (Stage 2). The third and final stage would be to complete the final network following a review of the quality and quantity of findings to date (Stage).

5. SUMMARY

The initial measurements made by the Team suggest that there is not an imminent threat from SO2 and H2S to the urban populations, while short term measurements of particulate are frequently high. Historically, this region has high particulate levels due to wind blown dust. The particulate measurements that were collected by the Team reflect total particulate, as opposed to respirable particulates, that is $PM_{10}$. There has not been a principal focus in the Region on total particulate, $PM10_{10}$, and organics up to now. Therefore, the Team developed the five phased monitoring plan with an emphasis on better understanding particulates and the aerosol organics associated with the oil fires in Kuwait. Particulates and organics could be a source of concern for both health and ecological effects.

The air monitoring proposals presented in this report represent the Team's collective judgement on what needs to be done. Those judgements are based upon an on-site evaluation of the situation in Kuwait, discussions with officials from the Saudi Arabian MEPA, Kuwait, Saudi ARAMCO, and the King Faud University of Petroleum and Minerals. Needless to say more work is needed regarding data management, statistical design, data analysis and quality assurance. Because of the complexity and immediacy of this problem, an extended time commitment will be needed on the part of all Gulf nation agencies to achieve the objectives outlined in this report.

Cost estimates for the various tuypes of air and meteorological monitors are attached to this plan, along with documentation on the U.S. Environmental Protection Agency's Pollutant Standards Index (PSI).

TABLE 2. Location of existing air and meteorology monitoring stations

| NATION | ORGANIZATION | LOCATION | STAGE OF IMPLEMENTATION |
|---|---|---|---|
| EXISTING SITES | | | |
| Saudi Arabia | MEPA | Damman | 1 |
| | | Hofuf | 2 |
| | | Tanagib (Mobile Site) | 1 |
| | | Riyadh | 1 |
| | | Khafji (Met Only) | 1 |
| | | Udayliyah | 3 |
| | | Shedgum | 3 |
| | | Abqaiq | 3 |
| | | Dhahran | 2 |
| | | Tartut | 2 |
| | | Rahimah | 2 |
| | | Juaymah | 1 |
| | | Tanajib | 1 |
| | | Saffaniyah Oil Field (met only) | 3 |
| | | Marjan Oil Field (met only) | 3 |
| | | Fariaiyah Island (met only) | 2 |
| | The Royal Comm. for Jubyayl and Yunbo | Cluster of 5 stations in Jubyayl | 1 |
| Existing Sites: Kuwait | | SITE 1 | 1 |
| | | SITE 2 | 1 |
| | | SITE 3 | 1 |
| Existing Sites: Qatar | | 3 mobile units, unknown locations | 2 |

TABLE 3. Location of proposed air and meteorology monitoring stations

| NATION | ORGANIZATION | LOCATION | STAGE |
|---|---|---|---|
| Proposed Sites: Saudi Arabia | MEPA | Awiyah | 3 |
| | | Shumlul | 2 |
| | | Sarrar | 2 |
| | | Nuayriyah | 2 |
| | | Lisafah | 3 |
| | | Uafar al Batin | 1 |
| | | 28 deg 6 min latitude, 47 deg 51 min longitude | 2 |
| | | 28 deg 30 min latitude 48 deg 1 min longitude | 1 |
| | | 28 deg 55 min latitude 47 deg 32 min longitude | 2 |
| | | 29 deg 7 min latitude 46 deg 39 min longitude | 2 |
| Kuwait | | Mina Saud | 1 |
| | | U.S. Embassy | 1 |
| | | Al Ahmadi (Hospital) | 1 |
| | | International Airport | 1 |
| | | 29 deg 23 min latitude 46 deg 55 min longitude | 2 |
| | | 29 deg 50 min latitude 47 deg 15 min longitude | 2 |
| | | 30 deg 4 min latitude 47 deg 42 min longitude | 2 |
| | | 29 deg 33 min latitude 47 deg 50 min longitude | 2 |
| Bahrain | | Manamah | 2 |
| Qatar | | Dawhah | 2 |
| United Arab Emirates | | Aub Dhabi | 3 |
| | | Dubai | 3 |
| Oman | | Muscat | 3 |

# UN
# INTERAGENCY ACTION PLAN
# ON THE KUWAIT OIL FIRES

## AREAS OF CONCERN

- MARINE AND COASTAL ENVIRONMENT
- ATMOSPHERIC POLLUTION
- INLAND TERRESTRIAL CONTAMINATION
- HAZARDOUS WASTE MANAGEMENT

# UN
# INTERAGENCY ACTION PLAN ON THE KUWAIT OIL FIRES

## APPROACH

- MULTIDISCIPLINARY SURVEYS AND ASSESSMENTS
- DEFINING REQUIREMENTS FOR EXPERTISE, EQUIPMENT AND FUNDS
- FORMULATION OF A PLAN OF OPERATION
- FIELD IMPLEMENTATION

# WMO COORDINATION OF THE ATMOSPHERIC COMPONENT

- ATMOSPHERIC COMPOSITION AND AIR QUALITY

- LONG-RANGE TRANSPORT

- ASSESSMENT OF GLOBAL SCALE EFFECTS

- PROVISION OF ATMOSPHERIC DATA FOR IMPACT STUDIES ON TERRESTRIAL AND AQUATIC ECOSYSTEMS

# WMO COORDINATION OF THE ATMOSPHERIC COMPONENT

- AIR AND PRECIPITATION SAMPLING (100-3000 KM)
- REHABILITATION AND ENHANCEMENT OF THE METEOROLOGICAL NETWORK (WWW AND GAW) INCLUDING EQUOIPMENT AND TRAINING
- DATA AND COMMUNICATION FOR MODELLING AIR POLLUTION DISPERSION AND DEPOSITION
- ADVICE TO DECISION MAKERS
- SCIENTIFIC ASSESSMENTS

# WMO assessment of the atmospheric consequences of the KUWAIT OIL FIELD FIRES

## o QUESTIONS

- WHAT IS THE COMPOSITION AND AMOUNT OF GASEOUS AND PARTICULATE BYPRODUCTS BEING PRODUCED

- WHAT IS THE MAGNITUDE OF THE EXPOSURE IN THE IMMEDIATE VICINITY (TO SERVE WHO HUMAN HEALTH RELATED STUDIES)

- WHAT ARE THE POSSIBLE CONSEQUENCES AS REGARDS LONG-RANGE TRANSPORT AND ENHANCED BACKGROUND AIR POLLUTION AND DEPOSITION

- WILL THERE BE SIGNIFICANT GLOBAL EFFECTS

## o TOOLS

- MONITORING

- MODELLING

# MONITORING OBJECTIVES

## TO ESTABLISH A DATA BASE FOR

- **AIR AND PRECIPITATION COMPOSITION AND THEIR TRENDS**
- **MONITORING ANOMALOUS TROPOSPHERIC CHEMISTRY AND RELATED EFFECTS**
- **AIR POLLUTION TRANSPORT MODELLING**
- **ASSESSING CLIMATE EFFECTS**
- **MONITORING ATMOSPHERIC COMPOSITION CHANGES IN THE FIRE EXTINGUISHING PROCESS**

# GROUND BASED MONITORING

- METEOROLOGICAL PARAMETERS
- PRECIPITATION CHEMISTRY
- RADIATION (INCLUDING OPTICAL DEPTH)
- TOTAL CARBON AND SOOT
- GASEOUS COMPONENTS ($CO_2$, CO, $CH_4$, $SO_2$, $H_2S$, $O_3$, VOC's INCLUDING PAH)
- AEROSOL

# MONITORING LOCATIONS

- NEAR THE SOURCES (DETERMINATION OF EMISSIONS, LOCAL IMPACT)

- MEDIUM RANGE (REGIONAL EFFECTS)

- LONG RANGE (GLOBAL EFFECTS)

# GLOBAL ATMOSPHERE WATCH

(A SYSTEM FOR ENVIRONMENTAL POLLUTION MONITORING AND RESEARCH)

## main long term objectives (1)

- To provide authoritative scientific information and advice on the composition and behaviour of the global atmosphere

## main long term objectives (2)

- TO ESTABLISH AND CO-ORDINATE AN OPERATIONAL SYSTEM TO DETERMINE GLOBAL AND REGIONAL LEVELS AND TRENDS OF NATURAL AND MAN-MADE ATMOSPHERIC CONSTITUENTS (INCLUDING THOSE WITH A POSSIBLE IMPACT ON CLIMATE)
  - TO FORECAST FUTURE STATES OF, AND STRESSES ON, THE ENVIRONMENT
  - TO ENABLE GOVERNMENTS TO TAKE PROMPT ACTIONS TO REDUCE POLLUTION

# main long term objectives (3)

- To further the understanding of the chemistry and physics of the environment
  - to apply this in the field of meteorology and climatology (atmospheric modelling)

- To promote studies of the interaction of the atmosphere with the marine and terrestrial biosphere

- To meet the responsibilities of WMO to provide leadership and guidance for the protection and management of the atmospheric environment

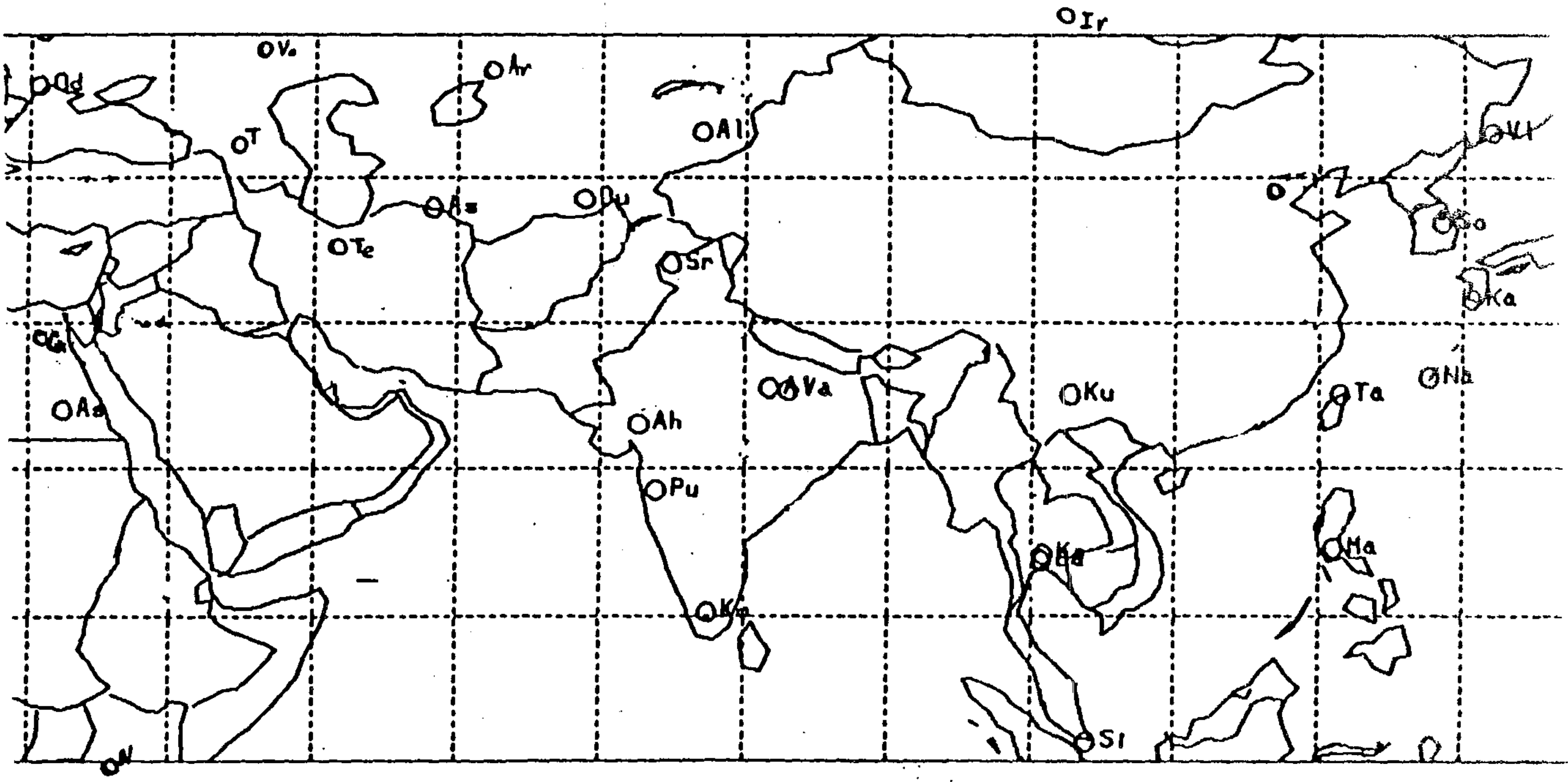
# GLOBAL ATMOSPHERE WATCH

## ESSENTIALS

- RELATIONSHIP ATMOSPHERIC COMPOSITION AND CLIMATE CHANGE
- IMPACT OF CLIMATE CHANGE ON ATMOSPHERIC CHEMICAL COMPOSITION
- LONG RANGE TRANSPORT AND DEPOSITION OF POTENTIALLY HARMFUL SUBSTANCES
- ATMOSPHERE/OCEAN/BIOSPHERE CHEMICAL CYCLES AND ANTHROPOGENIC IMPACT

# ELEMENTS OF GAW

- o GLOBAL OZONE OBSERVING SYSTEM ($GO_3OS$)
- o BACKGROUND AIR POLLUTION MONITORING NETWORK (BAPMoN)
- o DISPERSION, TRANSPORT, CHEMICAL TRANSFORMATION AND DEPOSITION OF ATMOSPHERIC POLLUTANTS OVER LAND AND SEA ON DIFFERENT TIME AND SPACE SCALES
- o EXCHANGE OF POLLUTANTS BETWEEN THE ATMOSPHERE AND OTHER ENVIRONMENTAL COMPARTMENTS AND INTEGRATED MONITORING



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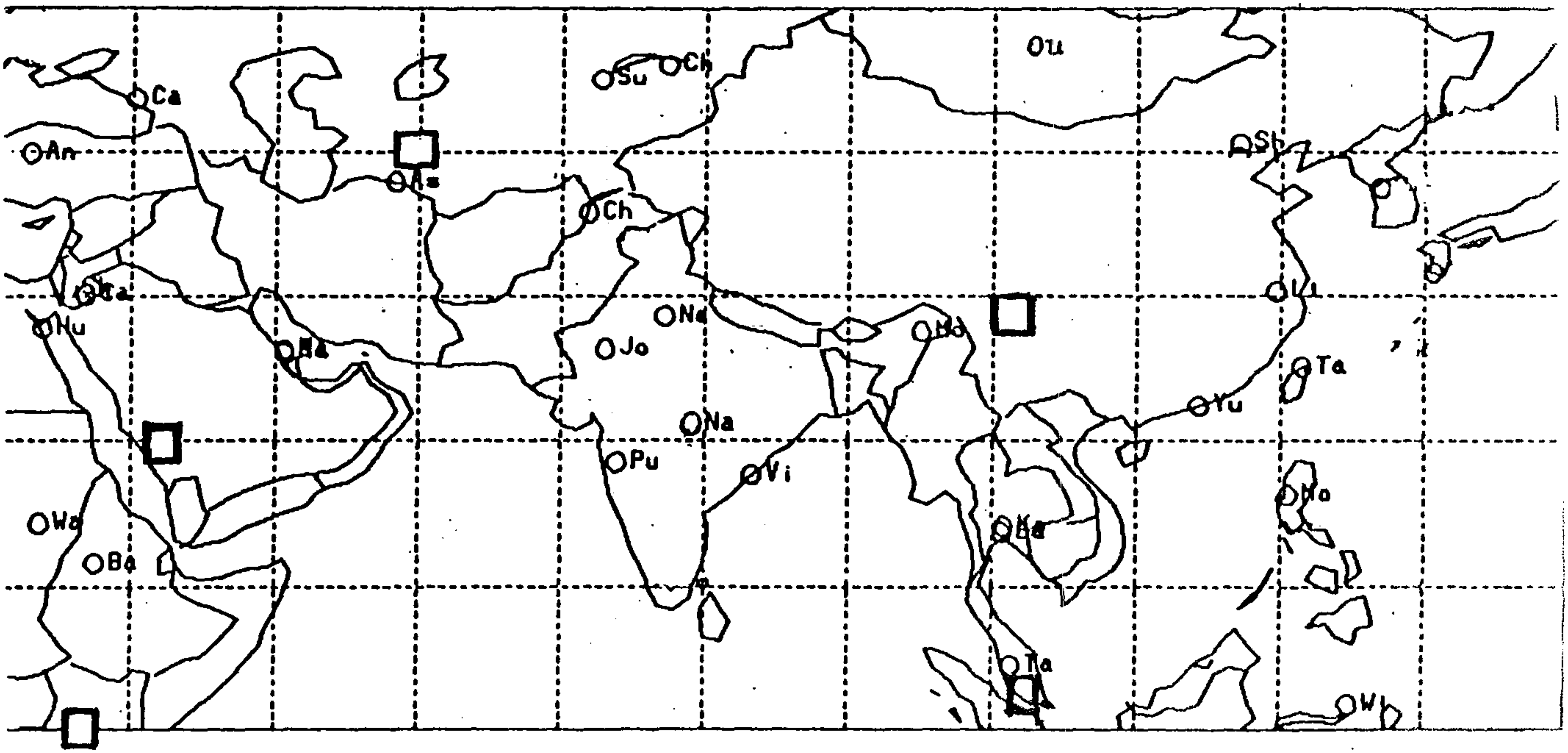
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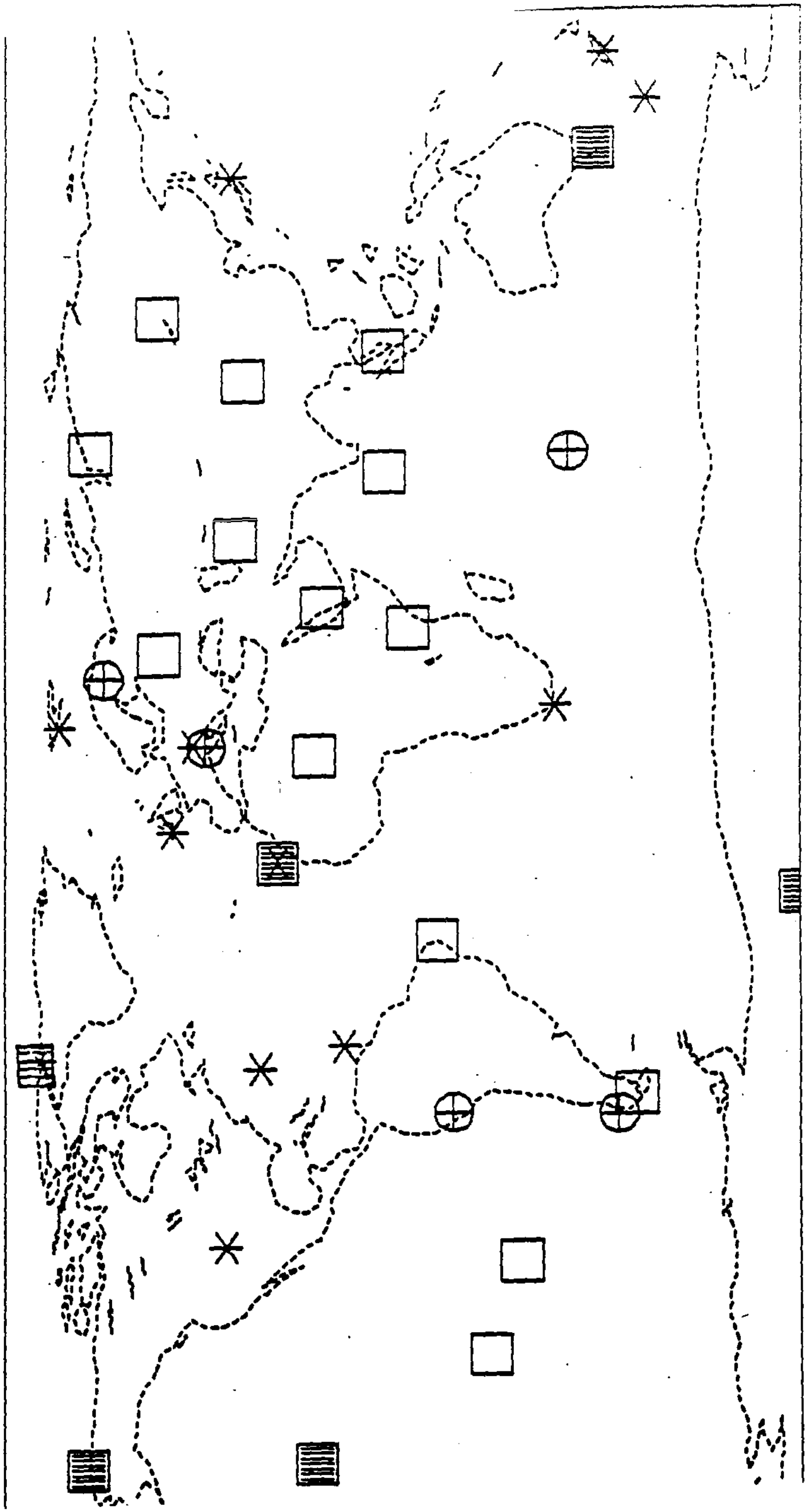

# AIRBORNE MEASUREMENTS

- EMISSION RATES OF SMOKE PARTICLES AND TRACE GASES
- THE VERTICAL AND HORIZONTAL EXTENT OF THE SMOKE "PLUME"
- THE CHANGES IN CHEMICAL COMPOSITION DURING THE EVOLUTION OF THE "PLUME"
- VERTICAL PROFILES OF ATMOSPHERIC SHORT AND LONG-WAVE RADIATION
- PHYSICAL AND CHEMICAL PROPERTIES OF THE SOOT (HYGROSCOPY, SCAVENGING POTENTIAL, CHEMICAL TRANSFORMATION, COAGULATION, CONDENSATION NUCLEI POTENTIAL)

# MODELLING REQUIREMENTS

- EMISSIONS AND SOURCE CHARACTERISTICS
- CLIMATOLOGICAL DATA IN THE GULF REGION
- ANALYSED 6 HOURLY WINDFIELDS FROM 1 FEBRUARY 1991 ONWARDS
- SYNOPTIC METEOROLOGICAL DATA (INCLUDING PRECIPITATION AND UPPER AIR DATA) OF THE REGION

# MODELLING STRATEGY

- URBAN AIR QUALITY CLIMATOLOGICAL MODELS
- TRAJECTORY CALCULATIONS WITH PREDICTIVE CAPACITY
- REAL TIME OPERATIONAL REGIONAL SCALE TRANSPORT AND DEPOSITION MODELS (FOR MONITORING ASSISTANCE AND REGIONAL IMPACTS)
- GLOBAL CIRCULATION MODELLING (CLIMATE EFFECTS, SCIENTIFIC ASSESSMENTS)

CHECK AGAINST DELIVERY

19 Nov 91

**STATEMENT BY MISS MARGARET J. ANSTEE**
**DIRECTOR-GENERAL, UNITED NATIONS OFFICE AT VIENNA, AND**
**PERSONAL REPRESENTATIVE OF THE SECRETARY-GENERAL**
**TO COORDINATE UNITED NATIONS EFFORTS**
**TO COUNTER THE IMPACT OF THE BURNING OIL WELLS**
**AND OTHER ENVIRONMENTAL CONSEQUENCES OF THE GULF CONFLICT**
**IN KUWAIT AND IN THE REGION**

**Mr. Chairman,**
**Distinguished delegates,**

By a strange twist of fate I have had the unique - and, I may add, unenviable - experience: to behold, within the space of a few months, the devastation caused by the two greatest man-made environmental disasters humanity has known: Chernobyl in April; and then, in early October, the burning oil wells in Kuwait and the war-ravished desert, air and marine environment of the Gulf.

In both cases the Secretary-General has given me special responsibilities to coordinate activities and seek the best means of mobilizing international cooperation to counteract their cataclysmic effects.

The causes of these two sombre reminders of the fragility of the world in which we live were very different. Yet there are striking similarities. Both were unprecendented in their scope and nature. Both were insidiously pervasive in their compass, disdaining man-made frontiers, spreading their evil harvest indiscriminately in regions far from the original site, and sowing fear and anxiety in their wake. In a world where the words "international" and "interdependence" have become commonplace, these events gave them a new and sinister meaning.

Even more strikingly, both happenings will stretch over time as well as space. Some of their consequences are immediately and hideously visible. Others are not, and cannot be measured accurately, or counteracted, except with the passage of years and careful and sustained monitoring. The costs in either case are thus incalculable with any degree of precision but inevitably very high. That means the even more difficult task of ensuring sustained international interest and support over many years during which new disasters will predictably capture the headlines.

I have already addressed this Committee on the subject of Chernobyl on 17 October. But in the context of your broader discussion on environment, it seemed to me important to bring out the affinities between these two phenomena, each in its own way so peculiarly characteristic of the hazards faced by - indeed, caused by - humanity at the end of the twentieth century.

It was no doubt with these kind of analogies in mind that the Government of Kuwait requested the Secretary-General to make similar arrangements to those for Chernobyl in respect of coordinating efforts to counter the impact, in Kuwait and the region, of the burning oil wells and other environmental consequences of the Gulf conflict. In response the Secretary- General appointed me as his Personal Representative on 19 September.

It was in this capacity that I made a first visit to Kuwait in early October. While there, I had discussions at the highest level of government, meeting with His Highness, the Emir, His Highness, the Crown Prince and Prime Minister, and His Excellency, the Deputy Prime Minister and Minister of Foreign Affairs. I also had extensive talks on technical aspects of the problem, notably with Dr. Abdul Rahman Al-Awadi, Head of the Emergency Environmental Committee and Executive Secretary of the Regional Organization for the Protection of the Marine Environment (who I am delighted to see will be giving this Committee the benefit of his extensive and first-hand experience) and with the Kuwait Environmental Protection Council. On my mission I was accompanied by representatives of UNEP and UNDP to ensure consistency with work already in hand.

Most memorably of all, I was taken to see the burning oil wells themselves, by land, and flown by helicopter over the waters and lands laid waste by war. It has left an indelible impression.

So much has been written, and so many voluminous studies are available, that it would be superfluous for me to add to them here. I would only say that, whatever one has read, or even seen portrayed in photographs or films of the disaster, pales into insignificance compared to the reality. At the end of the road, as far as it was safe to go, we found our way barred by an impenetrable wall of billowing black smoke, hundreds of metres high, interspersed with great bursts of flame, generating intolerable heat. The thundering roar of gas expelled from the wells made speech virtually impossible. All around us, the desert surface itself was a blackened crust of burnt oil, flecked with charred vegetation and interspersed with large lakes of oil.

Dante's Inferno was the immediate comparison that came to mind - his words "All hope abandon, ye who enter here" never rang more true.

And yet, if humanity has shown a deplorable capacity to heap disasters on itself, it has also shown a remarkable resilience in dealing with them. When the full extent of the oil well fires was first known, estimates of the time needed to quell them extended into years. I was much struck by the remark of a senior official of the Kuwaiti Oil Company, that when contingency planning for an eventuality of this sort was undertaken in the United States while the conflict was still raging, the "worst scenario" was 100 wells. The verdict was that, beyond that number, it would be impossible to cope.

Notwithstanding, on 6 November the last oil well, of a staggering total of 732 originally on fire, was capped, barely seven months after the end of the war. It was particularly fitting that this should be done by a Kuwaiti team, and I would like to draw attention to the fact that that team was headed by a Kuwaiti woman engineer, Miss Sarah Salah.

The capping of the oil wells was a remarkable achievement by any standard. It was made possible by an unprecedented demonstration of international cooperation, involving twenty-seven teams from nine countries, applying many different, and often ingeniously inventive methods to quench the flames, and all working in almost intolerable conditions of heat, noise and daily danger.

Yet, while we applaud this outcome we must beware of the dangers of concluding that the worst is now over. It would be tragic indeed if the act of extinguishing the last flames, whose apocalyptic images have captured the attention of media and public alike over these months, were to signify also the extinction of international concern and interest.

The effects, as I said before, are likely to be with us for many years to come. Nor are the problems confined to the consequences of the burning oil wells: there is also the effect of oil spills into the waters of the Gulf; the omnipresence of mines; the problem of hazardous waste; the depredations caused to the fragile ecology of a desert by modern warfare.

The resulting environmental problems can be divided into three main areas of concern:

- air pollution, and its effects on the health of the population (especially for particularly vulnerable groups - the elderly, children, asthmatics, people with chronic bronchitis or cardiac diseases)

- land pollution, and its implications for grazing and agriculture, and the dangers to the delicate ecology, flora and fauna of the desert

- marine pollution, and its effects on the marine environment, fisheries and wild life

The latter two inevitably also pose an additional health risk for the population, through the consumption of polluted agricultural produce, and through their dependence on the marine environment as a source of drinking water and food such as fish and shrimp.

In approaching my task, I have been conscious of the need to avoid duplicating anything that has been done before, or that is already underway. This is harder than one might think because the sheer enormity of the disaster has brought forth a multiplicity of responses from innumerable and diverse sources - governmental, non-governmental, UN system, academic and scientific institutions, private sector and individuals.

It also seemed very clear to me from the outset that, in coordinating the actions and mobilizing sustained international support for the very long process of rehabilitation that lies ahead, three main aspects must be addressed:

First and foremost, the technical aspect, embracing initial survey, the assessment of impact, the identification of requirements and the design of the actions needing to be taken;

Second, the international aspect and the need to give prominence to the dimensions of the problem and its worldwide significance on a sustained basis;

Third, the provision of adequate funding and other resources to ensure implementation of the agreed Plan of Action.

Technical aspect

The technical aspect is, understandably, the one in which work is most advanced, especially as regards assessment of impact and preliminary identification of needs. Considering the short lapse of time since the cessation of hostilities and the almost insuperable obstacles faced, I would go so far as to say spectacular progress has been made.

I was particularly impressed by what has been achieved by the Kuwaiti authorities themselves, under the able leadership of Dr. Al-Awadi, despite the fact that their scientific research capability, including equipment and records, has been decimated. Many other countries in the Gulf region are, of course, also very active, and the work of the Regional Organization for the Protection of the Marine Environment (ROPME), now expanded to other areas as well, has also been of key importance. So has the contribution of the Saudi Arabian Meteorology and Environmental Protection Agency, especially in assessing and cleaning up the damage done to coastal areas and the marine environment by oil spills in the Gulf.

Nor has the international community stood idly by. An early assessment was made by the UN mission led by Mr. Abdulrahim Abbe Farah which visited Kuwait from 16 March to 4 April, and I would particularly refer you to sections IV and V (paras. 136 - 225) of that mission's report to the Security Council (S/22535) of 29 April 1991.

In the ensuing weeks all the relevant agencies of the UN system worked energetically on the problem under the leadership of UNEP, and in close cooperation with ROPME. I have had the benefit of a personal briefing on these activities from Dr. Mostafa Tolba, the Executive Director of UNEP, as well as from Dr. Al-Awadi.

This has been a situation in which the smaller technical agencies, particularly IMO and WMO, have been able to demonstrate their value. Other UN agencies and organizations involved have been UNDP, WHO, FAO, IAEA, UNCHS (Habitat), IOC/UNESCO, UNIDO and UNDRO. In addition, non-governmental organizations such as the World Conservation Union (IUCN), the World Wide Fund for Nature (WWF), Earthtrust, Friends of Earth, and Green Peace, and a host of research institutions contributed to this collective effort. Many of these activities were financed by Member States on a bilateral basis or through the UN system.

As a result, a report on the first phase of an Inter-Agency Plan of Action, comprising initial surveys and preliminary assessments, was presented by UNEP to a ministerial meeting of ROPME on 16 - 17 October and accepted as a framework for future work. The immediate future work consists of drawing up detailed and costed programmes and projects to address the problems identified in the first phase document.

It is hoped that this will provide the basis for a document to be presented, among others relating to countries outside the Gulf area, at the Funding Strategy Meeting for the Proposed Programme for the Socio-Economic and Environmental Revival of Countries Affected by the Gulf Crisis, being convened in New York on 16 December by the United Nations Development Programme, in response to a decision by its Governing Council.

I am sure that Dr. Al-Awadi and Mr. Mansfield (the representative of UNEP) will be addressing the technical aspects in their statements to this Committee, so I will not dwell on them here, except to stress once again the essentially open-ended and long-term nature of the phenomenon which makes immediate definitive assessments impossible.

Let me illustrate this as regards the effects on health. All of the monitoring studies carried out, whether by the Government, the UN system or other outside technical groups, seem to concur that, so far as Kuwait is concerned, by a fortunate chance of meteorological conditions, the unexpected evaporation of some of the toxic elements in the smoke plume, and the rapid actions in putting out the oil fires before seasonal wind directions veered consistently in the direction of Kuwait City, the impact has not been as severe as could have been feared.

I must stress, however, that these observations refer only to the immediate, short-term, effects on health caused by the smoke and other pollutants now no longer being ejected into the atmosphere. No one knows what the longer-term effects on health can be, since no population has ever previously been exposed to this particular phenomenon, and it will require a very long period of monitoring before these consequences can be reliably determined. There is also the incalculable psychological effect inflicted on the population which has been subjected to the unnerving experience of an apparently permanent eclipse of the sun, of day turned into night, and the anxiety and stress of not knowing what form the ultimate effects will take - another characteristic in common with the victims of Chernobyl.

<u>International aspect</u>

As I have intimated, in addition to the ongoing technical work, a major challenge will be to maintain international concern and support. We must be very clear that this is not just a problem - however deplorable - affecting a limited number of member states in a particular region.

It is an <u>international</u> problem: the fall-out (if I may use that term) has already been experienced in many places much farther afield.

More importantly, it is of concern to governments and peoples everywhere. A vital part of our common and universal heritage is at stake. And the lessons that science and societies everywhere can derive from this tragedy are countless. The initial favourable response from countries in the first months of the tragedy must be continued.

I am therefore particularly pleased that the issue is being given the prominence it deserves in this Committee and hope that this will lead to conclusions that will ensure that it is kept squarely in the sights of the General Assembly and of the international community in the future.

I believe it is also very important that it should receive special attention at the United Nations Conference on Environment and Development in Rio de Janeiro in June next year.

Resources and Funding

Sustained understanding of the importance and international nature of the issue is of course also vital to the assurance of adequate funding from a wide variety of sources.

I have no illusions that fund-raising will be easy. At the present time, given the imponderables I have mentioned, it is impossible, and would be rash, to attempt to give a global figure of the likely cost. All one can say with some certainty, is that it will be in the range of several billions of dollars. A more precise estimate can be made, I hope relatively soon, as the work of preparing costed programmes and projects evolves.

Then there is the question of where the resources will come from.

UNEP has managed to raise a fund of US $ 2.6 million but this is already either spent or committed for initial technical work.

It should also be noted that international cooperation is required not only in the form of money, but also in kind, through the provision of services and equipment, loan of scientific personnel, etc. One very important first requirement is to restore the shattered research capability of Kuwait itself.

The quest for funding should also be varied and wide-ranging, embracing non-governmental organizations and scientific institutions, universities, etc., as well as governments.

Three main sources spring to mind:

- the UN Compensation Fund
- Kuwait and the governments of the region
- the international community

As to the first of these, UN Security Council resolution 687 includes damage to the environment and to natural resources among the areas for which claims may be made on the Compensation Fund. I have had preliminary conversations in Geneva with the Chairman of the Fund's Governing Council and its Executive Secretary about the best way of proceeding in this regard. While there is agreement that this avenue must certainly be pursued, there is recognition that the process is likely to be lengthy.

The needs, however, are immediate.

As a result - and here I pass to the second on my list of categories - Kuwait, Saudi Arabia, Iran and other countries in the region have already spent considerable sums in clean-up and assessment operations.

I have been assured that this will continue, but there is an understandable feeling that the full burden of payments for an international problem with implications for many other countries and peoples should not fall on the region alone.

Moreover, the oil well fires have had a severe economic impact on Kuwait in addition to the environmental consequences. Fighting the fires is estimated to have cost the country US$2 billion. Assessments of the damage to the wells themselves are still not complete but the Government estimates that 2% of the country's 100 billion barrels of reserves has been lost and that up to 30% of the wells will have to be abandoned. Barely 45% will be able to return to production with only minor repairs and overall production is not expected to return to its former levels before 1994.

Aside, therefore, from the international character of the disaster, the financial impact on Kuwait is very great.

For all of the reasons just cited, it is therefore my hope, and that of the Secretary-General, that the international community, drawing, as I suggested earlier, not only on the resources of member governments but many others as well, will also respond generously. What we hope to do, through a concerted effort of the UN system, is to assist the governments of the region and ROPME in their efforts to draw up a detailed plan of action which will provide a valid framework for all assistance provided, in whatever form and through whatever channel. Only in this way can the optimal use of contributions be ensured for priority areas of action.

In speaking of resources, I have also to mention that such work as I have done so far has been accomplished "within available resources". My own office is tiny and as the work gathers momentum will be unable to cope without some modest strengthening. I hope this can be borne in mind when the Committee decides on future actions.

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Mr. Chairman, distinguished delegates, my appointment as the Secretary-General's Personal Representative took effect only a few weeks ago. So far, I have, as I said, visited Kuwait at the invitation of the Government, made personal contact with all the UN organizations involved or likely to become involved, and consulted with the UN Compensation Fund.

Time and limited resources have not made it possible for me to visit the other countries in the region that are immediately affected and to have the indispensable consultations on the ground required to complement the many reports I have read. That is why my statement today may seem to focus more narrowly. I want to make clear that it is my intention, early in 1992, to make a wider visit to the area, providing, naturally, that this is the wish of each government concerned.

Mr. Chairman, a very long and difficult task - of rehabilitating one of nature's most precious preserves, and of protecting and monitoring the human beings whose health has been placed in jeopardy - lies ahead of the international community. I do believe, however, that, thanks to the efforts already deployed on so many sides, we have a sound basis to move forward. What we need now are those all too rare qualities of sustained commitment and perseverance.

## Preliminary Scientific Report - Kuwait Oil Fires

### INTRODUCTION

On June 4, 1991, scientists from Bahrain, Oman, the Federal Republic of Germany, the United Kingdom, and the United Sates met in Manama, Bahrain, to discuss preliminary observations related to the smoke plumes from the oil fires in Kuwait. The meeting was convened by the Environmental Protection Committee of Bahrain. The following is a summary of the meeting prepared by the National Oceanic and Atmospheric Administration (NOAA).

### GROUND-BASED OBSERVATIONS

The Manama scientific meeting was opened with a discussion of ground-based data obtained in Saudi Arabia and Bahrain since the onset of the fires in Kuwait.

Saudi Arabia representatives discussed the Gulf Regional Air Monitoring Program, and indicated that several aspects of the program were proceeding toward full implementation. Gaseous pollutants of concern in Saudi Arabia have remained within allowable limits at all air monitoring stations. Concentrations of total suspended particulates (TSP) have also been within the allowable range, however peaks in TSP have approached safe limits on two occasions. Values for nickel and vanadium in the atmosphere appear to drop sharply from the Kuwait border south into Saudi Arabia. Only low levels of polynuclear aromatic hydrocarbons (PAH) have been observed. Temperature depressions of up to 10 degrees C have been noted in northern Saudi Arabia in areas influenced by the plume.

Bahrain representatives indicated that levels of all gaseous pollutants have similarly been low at local ground monitoring stations, however particulate levels have been above normal. Especially high levels of PM10 (respirable particles below 10 microns in diameter) were observed in May. High levels of sulfuric acid have been recorded, however no baseline on this substance exists for comparison with the levels observed.

### AIRCRAFT MEASUREMENTS

As of 9 June 1991, there have been four aircraft involved in the smoke plume investigation. The following table summarizes operational details regarding the four programs:

| Flight Organization | Dates | Aircraft | Flights | Flight Hours |
|---|---|---|---|---|
| British Meteorological Office - UK | 23 Mar - 31 Mar | C-130 | 8 | 57 |
| University of Washington - USA | 16 May - 15 Jun | C-131 | 12 | 77 |
| National Center for Atmospheric Research - USA | 19 May - 4 Jun | Electra | 15 | 97 |
| Goethe University - FRG | 18 May - ? | Piper | 16 | 55 |

## Flight Program Objectives

The objectives of all of the above programs have generally been to:

- To characterize the physical, chemical and optical properties of the plume and determine changes in the plume's characteristics over time.

- To determine the effects of the plume on atmospheric conditions.

## Smoke Distribution

The distribution of the plume varies form day to day depending on meteorological conditions. In stable conditions, with low wind speeds, the plume is shaped in the form of a large cumulus cloud, extending from a base of 1 to 2,000 feet to a height of 8 to 10,000 feet or more. Excursions as high as 22,000 feet have been noted on some occasions. In most instances, the plume initially rises rapidly due to the heat of combustion. A further rise, termed "self lofting", has been noted to occur due to solar heating of the predominantly black plume.

When the atmosphere exhibits a more complex structure with the presence of one or more inversion layers, the plume may separate into segments with relatively clean areas between layers. If the lower thermal barrier is at low altitude, smoke may occur close to the ground, even at long distances from the source.

There is no indication the plume will reach into the stratosphere, a key factor in limiting the area of effect of the plume. Aircraft and satellites have tracked the plume to distances of 1000 kilometers, however at this distance the plume is generally only barely detectable. While it is possible that some very small fraction of the particulate material may travel large distances, reports of the plume reaching Hawaii and Wyoming are generally discounted.

## Particulate Concentration and Form

The size distribution of particulates in the plume tends to be bimodal, with the peaks centered around about 0.2 and 2 micrometer diameter. Maximum concentrations of approximately 100,000 particles per cc have been observed near the source (the ambient level of particulates in clean air in the region is only a few hundred particles per cc). The smaller particles encountered near the source tend to form chain aggregates early in the life of the plume; these aggregates may tend to either fall out of breakup at later stages in the lifetime of the plume.

The plume is diverse in color and optical properties. The occasional white smoke tends to scatter sunlight effectively, while the blacker smoke tends to be highly absorbing of visible light. The black smoke, however, absorbs less in the near-infrared than the white smoke. The plume exhibits no backscattering in the visible spectrum, but substantial backscattering in the near infrared.

Most of the particles appear to be effective cloud condensation nuclei (CCN), another factor which will limit the lifetime of the plume. Such particles, as they encounter ambient moisture clouds along their trajectory, will readily be removed from the atmosphere by precipitation.

## Chemical Composition

The following typical and maximum values were reported for the various chemical constituents of the plume. (Because these were measured in the densiest portions of the plume aloft, they should represent maximum values that might, under certain conditions, be reached at the surface.)

| Species | near Field ~ 100 km | Mid-Field ~ 450 km | Far Field ~ 1000 km |
|---|---|---|---|
| Hydrogen sulfide | Very low (specific values not yet available) | | |
| Sulfur dioxide* | 100 to 500 ppbv | 5 to 20 ppbv | 1 to 3 ppbv |
| Carbon monoxide** | 0.1 to 0.5 ppmv | <0.1 ppmv | undetectable |
| Ozone*** | 20 to 45 ppbv | 35 to 55 ppbv | background |
| Nitrogen oxides | 10 to 30 ppbv | 2 ppbv | undetectable |
| Carbon dioxide**** | 400 to 460 ppmv | 375 ppbv | 365 ppbv |

* Maximum value of 1 ppmv observed 15 km south of Burgan field
** Values are generally about 100 x concentrations of sulfur dioxide
*** Ozone depletion in the near field appears due to formation of nitrogen oxides
**** Background carbon dioxide is about 360 ppbv

## Future Plans for Aircraft Observations

Flights remaining for the University of Washington will primarily be directed to the characterization of individual plumes to allow the uniqueness of the chemical composition associated with various wells to be determined, and flux measurements in the composite plume. Thus far individual plumes have shown no striking difference in chemical composition based on real-time readings for the above chemical compounds. Detailed, post-flight chemical analysis will be directed at this question.

Three additional aircraft programs are currently under development for continued investigation of the plumes under varying meteorological conditions:

- A helicopter-based series of investigation of various individual plumes is planned for two weeks in late June. This investigation will be undertaken by NASA and EPA in cooperation with regional scientists.
- A fixed-wing aircraft program in the summer season (July 15 - August 30) is planned by the Department of Energy (Battelle Laboratories). This program will be undertaken aboard a Gulfstream I aircraft.
- NOAA plans a winter study for the month of December aboard a P-3 aircraft.

Detailed plans for the above programs are currently being prepared for the approval of the host governments.

## DATA MANAGEMENT

Two to three years will be required to fully analyze the data collected form the variety of aircraft and ground-based programs undertaken thus far. In order that scientists in other nations may participate effectively in the data analysis process, agreement was reached among the investigators to rapidly make raw data available in a form that lends itself to independent interpretation.

Agreement was reached among the investigators to share raw data from ground-based, aircraft, and satellite obsevations, under the auspices of WMO. The US National Center for Atmospheric Research (NCAR) agreed to adapt specialized software programs developed at the Center for archival, display, and analysis of the combined data set. in general the NCAR data management program allows the analysis of data obtained from a variety of sources at a specified time and location. This would enable, for example, the correlation of ground-based measurements with aircraft observations taken near the same location at the same time. A subsequent meeting was scheduled to refine this concept.

## FOLLOW-UP BRIEFINGS

On June 5, NOAA and the University of Washington briefed the American Embassy in Kuwait and the Kuwait Environmental Protection Council on the outcome of the June 4 meeting. The Kuwait EPC offered considerable background data obtained within the country that will contribute to a fuller understanding of the scope of the problem.

On June 6, NOAA briefed the American embassy in Riyadh on the findings of the meeting, followed by a briefing on the American Embassy in Manama on June 8. Further briefings in UAE are scheduled later this week. Briefings for the WMO staff are planned for June 10.

# An Updated Briefing on the Kuwaiti Oil Fire Smoke Experiment (KOFSE)

## A part of Gulf Regional Air Monitoring Program (GRAMP)

Lawrence F. Radke
National Center for Atmospheric Research
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**Research Sponsors:**

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Chevon Corporation
Defense Nuclear Agency
Department of Energy

July, 1991

# Why are the Kuwaiti Oil Fires an Important Research Topic?

- Resulting black smokes were forecast to have a host of disastrous environmental effects, including:
  - Global cooling via the nuclear winter hypothesis
  - Modification of global and regional weather patterns, including interruption of the Indian monsoon
  - Regional cooling and heating
  - Regional precipitation modifications, including precipitation amounts, acid rain and black rain
  - Release of greenhouse gases

file NCAR

# Why are the Kuwaiti Oil Fires an Important Research Topic? (cont.)

- Concern about toxicity hazards to humans and marine life, as well as other threats to both. These threats included:

  - Emissions of highly toxic hydrogen sulfide

  - Emissions of other toxic trace gases, including those trace hydrocarbons considered potential carcinogens.

  - Respiratory threat from high concentrations of submicron particles

  - Deposition on land and sea of large soot particles and unburned oil droplets coating and possibly killing food chain elements.

# Why are the Kuwaiti Oil Fires an Important Research Topic? (cont.)

- Finally, and perhaps in the long term most importantly, the fires provide an exaggerated example of anthropogenic pollution. Given the difficulties of establishing cause and effect for more benign examples of pollution, exaggerated examples are often keys to understanding.

## The Kuwait Oil-Fire Smoke Experiment

### Primary Objectives

- To characterize the regional emission rates of smoke particles and trace gases.
- To measure radiative properties of the smoke particles and the radiative effects of the plumes with attention to how radiation affects the altitudes of the plumes and the stability of the atmosphere.
- To measure characteristics of the smoke particles, i.e. size, shape, composition, and optical properties.
- To evaluate the degree to which smoke particles are scavenged in clouds their subsequent effects on composition and radiative properties of clouds.
- To measure how the properties of the plume change with time.
- To study regional weather anomalies associated with these smoke emissions.

## The Kuwait Oil-Fire Smoke Experiment Box Score on Primary Objectives

- Successful characterization of emission rates of pollutants.
- Excellent multi-spectral radiometric data on the plumes and dynamic measures of solar forcing of stability of the atmosphere.
- Excellent full characterization of the smoke particles.
- Limited data on smoke/cloud interactions and scavenging due to a lack of clouds. Important finding that most of the mass of the smoke particles are cloud condensation nuclei
- Successful characterization of plume transformation out to ranges of 1600km (48 hrs) downwind.
- Limited observations of "weather anomalies" beyond observed dynamics, radiative, and stability changes.

**Participants on Electra**

**NCAR**

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***Bahrain Environmental Protection Committee***

# KUWAITI SMOKE

## HIGHLIGHTS AND SURPRISES

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- Smoke was optically far whiter than expected....$\tilde{\omega}$ = 0.5 - 0.6 (JP-4 pool fires $\tilde{\omega}$ = 0.3, forest fires 0.4 - 0.9, water clouds 0.99).

- Solar self-lofting was observed, but dilution makes it self limiting. Most smoke remained below 3km. A small fraction lofted as high as 6km in 24 hrs, but no smoke was seen to go higher after 48 hours.

- $SO_2$ flux smaller than expected based on fraction of S thought in fuel.

- Contrary to some predictions smoke particles were found to be very effective Cloud Condensation Nuclei. CN/CCN ratio approached 1.0! Obviously acts to reduce the smokes tropospheric lifetime.

- Oil precipitation was found up to 100km downwind. Directly emitted? Condensation and coagulation?

- At smoke ages of ~48 hrs and distances down wind of ~1600km concentrations were approaching "normal" levels of urban pollution.

# Atmospheric Residence Time of Kuwaiti Smoke Particles

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*Scientists from the National Center for Atmospheric Research, British Meteorological Service, and the University of Washington concur:*

- Early suggestions that the smokes would be "hydrophobic" and thus resistant to atmospheric removal processes have been shown to be WRONG.

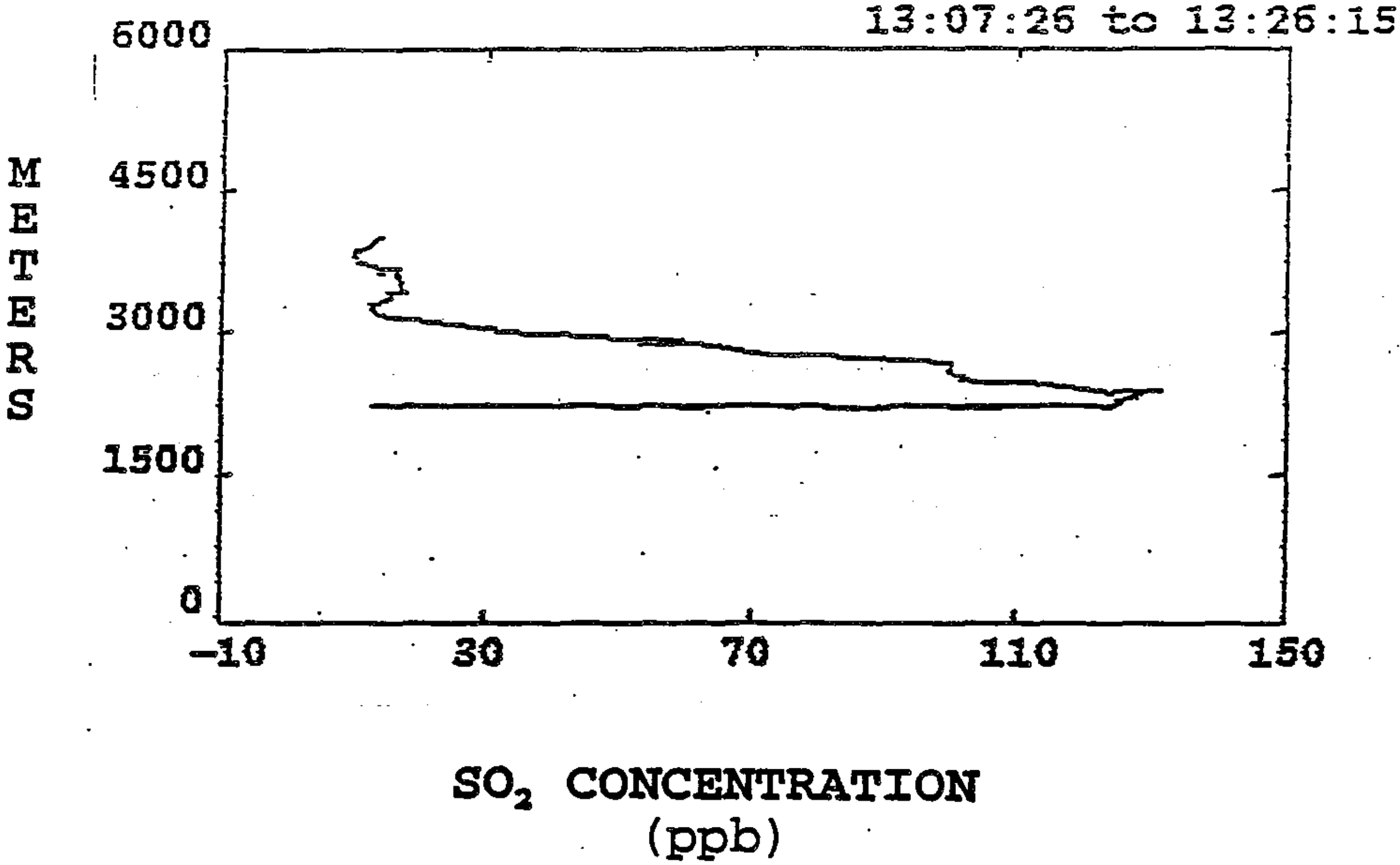
- The smokes have proven to be largely "hydrophilic" acting as the nuclei for cloud droplet formation. This places them in the class of particles most easily cleansed from the atmosphere.

# Atmospheric Residence Time of Kuwaiti Smoke Particles (cont.)

- Early suggestions that the smokes would rise rapidly in the atmosphere by solar self-lofting and thus escape many particle scavenging mechanisms has been shown to be largely INCORRECT.

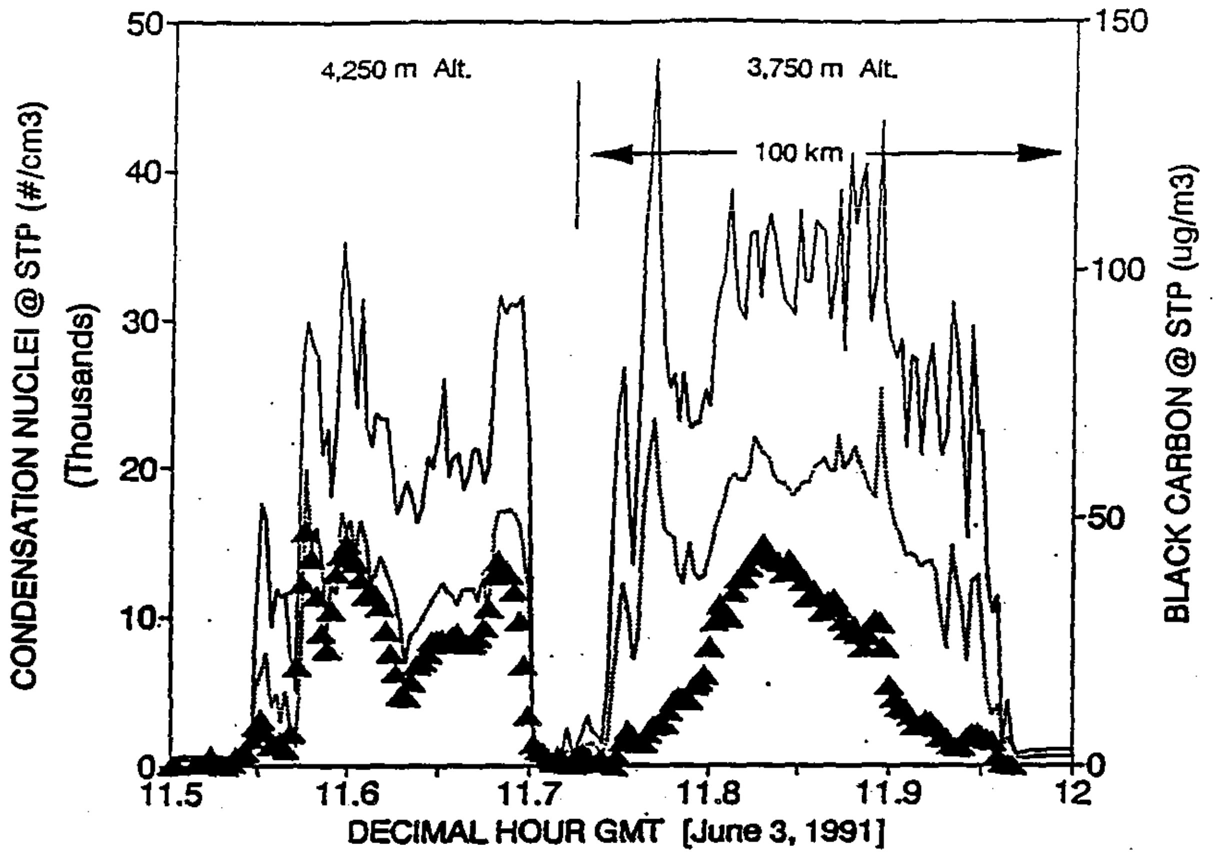
- Solar self-lofting was observed, but the combination of a rather low initial stabilization height for the plume, larger than expected smoke albedo, and dilution have acted to LIMIT self-lofting and render it an interesting, but inefficient mechanism.

# Sounding of $SO_2$ by the NCAR Electra




On June 1, 1991, the Kuwaiti smoke plume was over Bahrain (≈350 Km downwind) producing a bright hazy sky and dark horizons. The aircraft climbed to the top of the smoke plume.

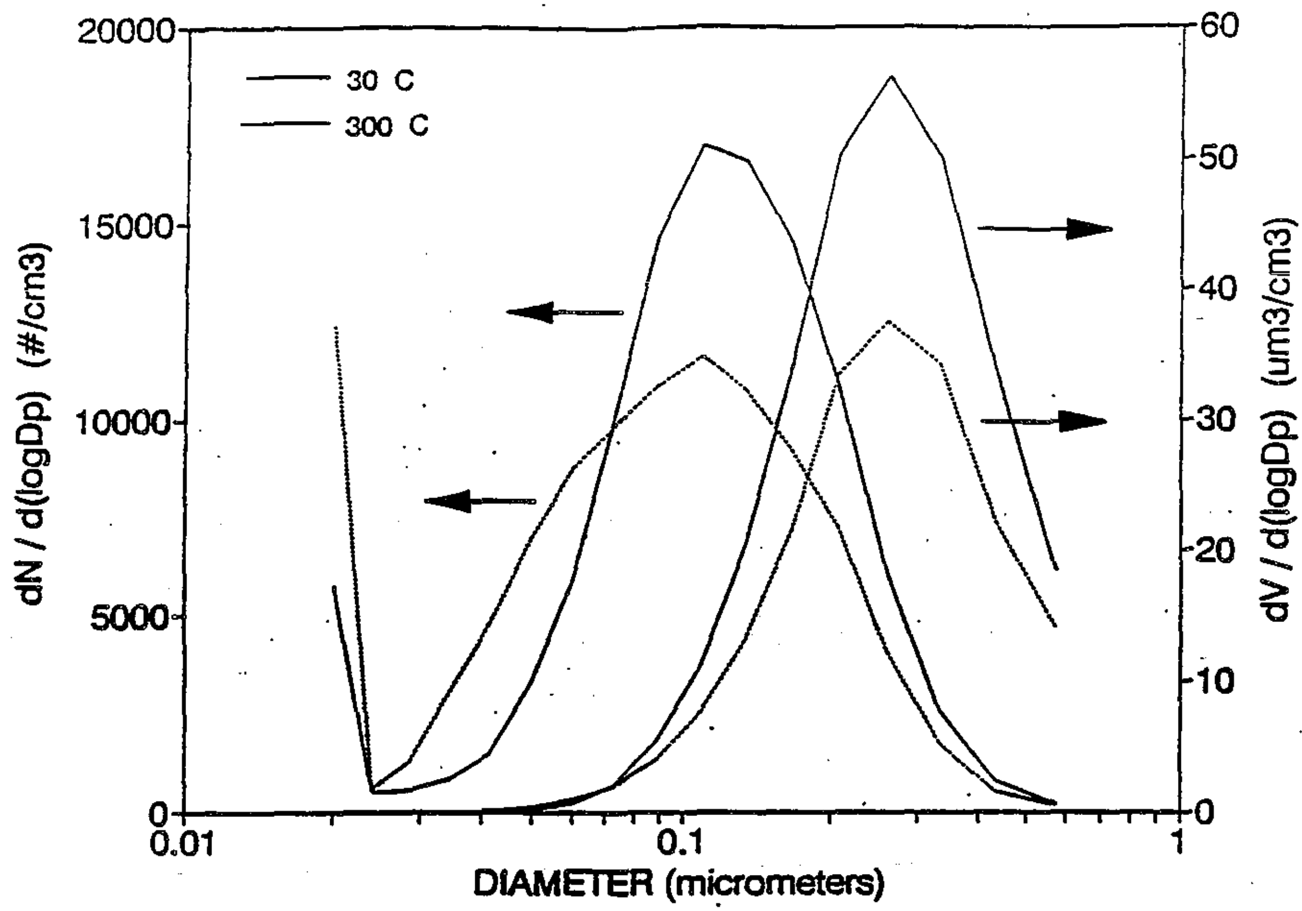
Two transects of the Kuwaiti smoke plume on May 27, 1991, 200 km downwind of the fire. The first was at 4,250m near plume top, and the second at 3750m.




Time series of total particle concentrations larger than 0.003$\mu$m ( — ), larger than 0.015 $\mu$m diameter ( ------ ) and the mass concentration of elemental (black) carbon ( △ ). The data suggests photochemical production of nuclei mode particles near the edges of the plume.

# Kuwaiti oil fire smoke particle size distributions

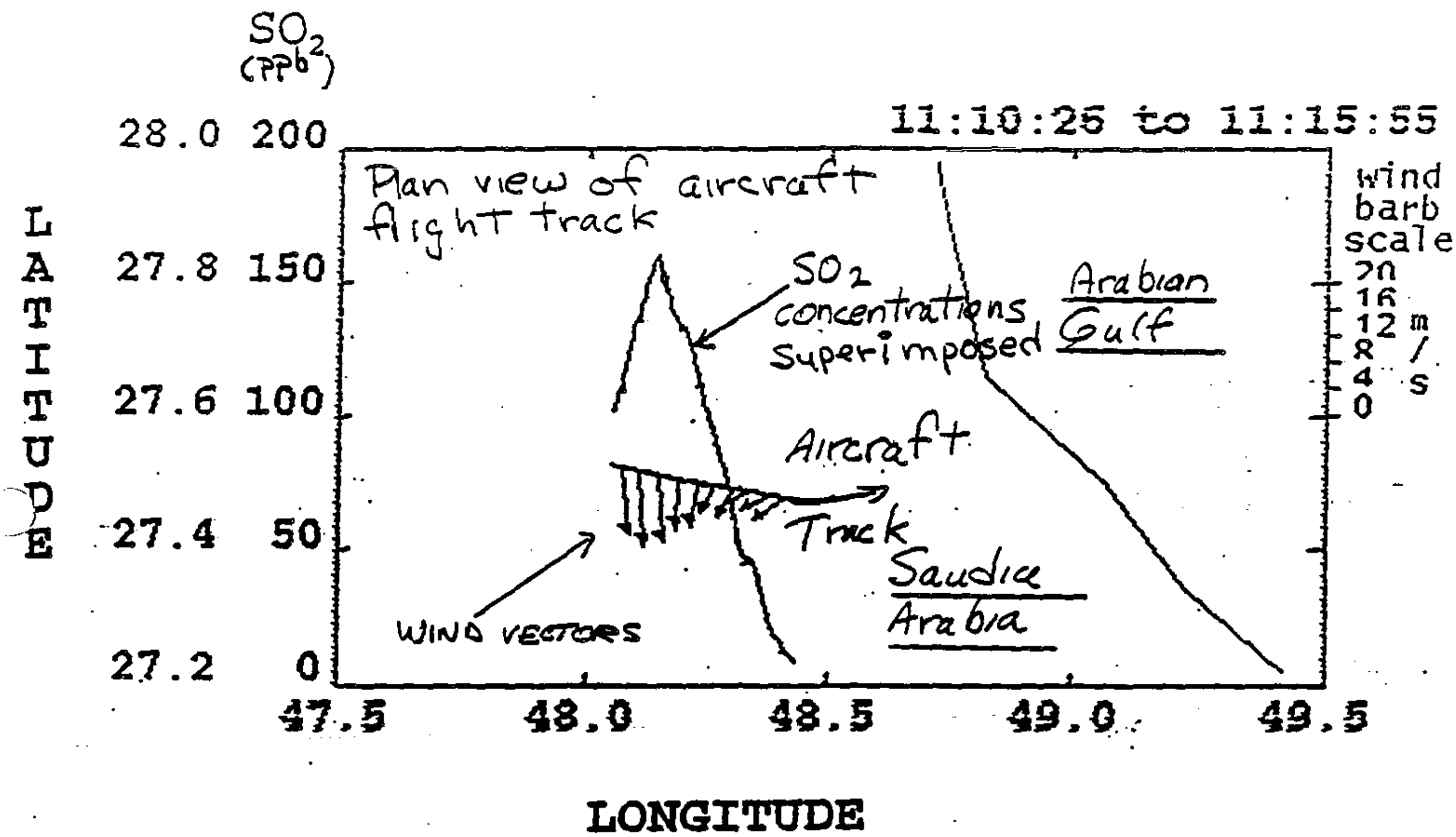
(differential mobility analysis by
T. Clarke, University of Hawaii)




**Number and volume distributions of the smoke on June 3, 1991.**

Samples are heated to 30°C to remove water and then 300°C to remove remaining volatile fractions. Roughly 30% of the total particle volume (mass) was removed at 300°C. Data shows that the number mode was internally mixed, while the volume mode was externally mixed.

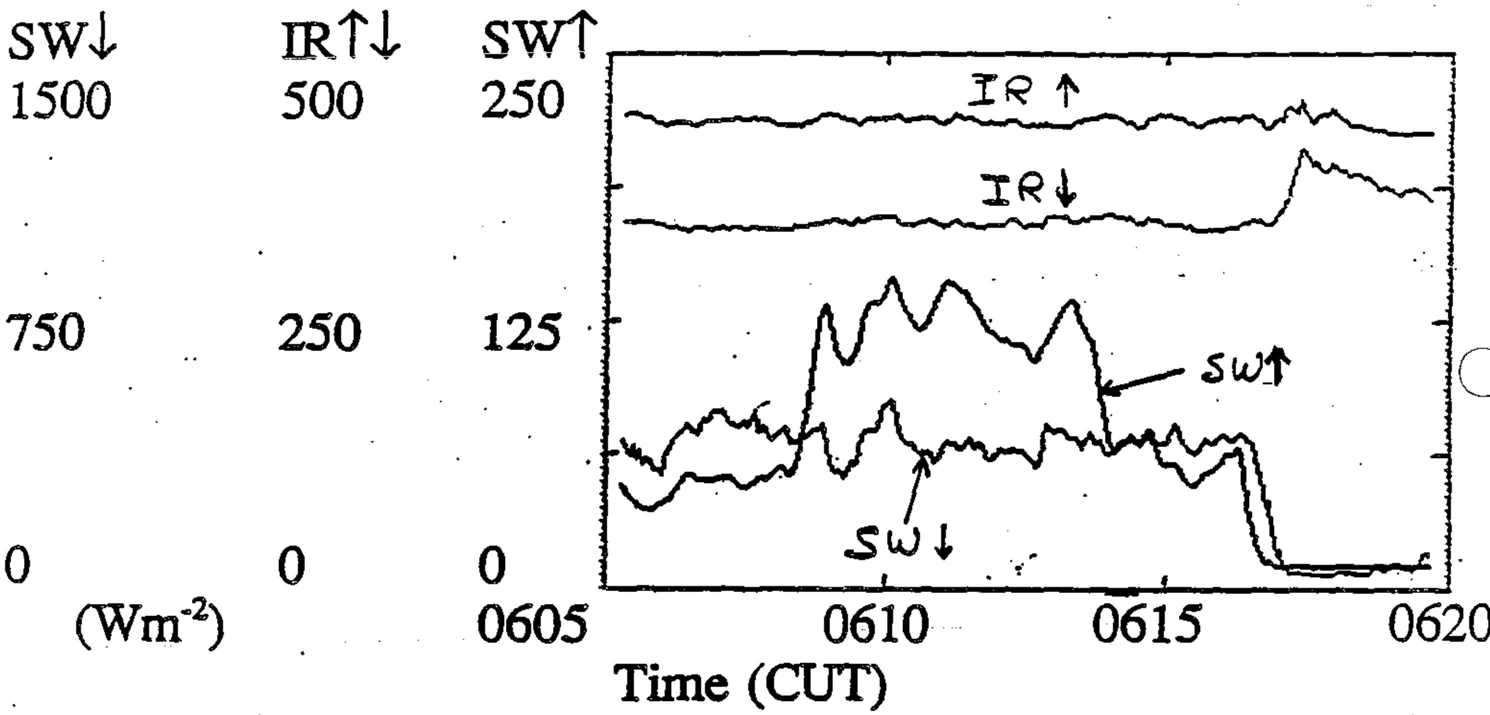
# Smoke Plume Convergence




Marked convergence in the horizontal wind field was a frequent observation during penetrations of plume perpendicular to its axis.

# A Passage from Day to Night

## a transect of the center of the Burgan oil field (350 wells ablaze) at 500m (MSL)




Approaching the oil field we note a steady SW↓ and the changes in surface albedo causes marked variation in SW↑. Both visible (SW) went to zero inside of the plume. VERY DARK!

# Observations of $CO_2$, CO and $CH_3$

(Communication from T.J. Conway, NOAA CMDL and G. Kok, NCAR)

- Emission of $CH_3$ (methane) and other light hydrocarbons are surprisingly low.

♦ This indicates that these gases (like $H_2S$) are efficiently combusted and that there are probably no gas-rich wells which are not burning.

- $CO_2$ emissions are rather large but have no global significance since roughly equivalent amounts would be released if this oil was used (as in normal times) as fuel.

- CO emissions are rather low, roughly 1% of $CO_2$, indicating unexpectedly efficient combustion in what visually appears to be a rather inefficient one.

♦ Therefore, the fires' are a minor contribution to the global CO budget.

# Trace gas concentrations: A Local Impact?

(W. Luke, G. Kok and R. Schillawski, NCAR)

- Peak concentrations of carbon monoxide (CO), ozone ($O_3$), nitrogen oxides ($NO_x$) and sulfur dioxide ($SO_2$) in the smoke plume at 130 km from the fires was everywhere less than the U.S. National Ambient Air Quality Standards with the exception of $SO_2$ which occasionally exceeded the standards.

- While these observations are dependent on meteorological conditions (primarily wind speed and mixing) they clearly provide an indication that beyond the local region, these pollutants do not constitute a hazard even if the elevated smoke plume were lowered to the surface.

# Observations of Kuwaiti Smoke at Great Distance

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- There are reports from Hawaii and Wyoming that specialized sampling has detected Kuwaiti smoke high in the troposphere.

- Do these observations contradict the contentions that the smoke will be efficiently scavenged and inefficiently self-lofted?

## Observations of Kuwaiti Smoke at Great Distance (cont.)

- At this time I see no contradiction. The concentrations of smoke particles observed over Wyoming are highest during those periods of rapid meteorological transport (jet stream). At the highest concentrations observed, Hofman states them to be <u>without climatological significance</u> - an interesting remnant only.

- Similarly, if the smoke wasn't self-lofted, how did they get to the upper troposphere? Clouds provide a useful (if high loss) mechanism for lofting smoke as does frontal meteorological activity. These mechanisms are the <u>normal</u> "lofters" of all pollution into the upper troposphere and lower stratosphere. Our interest in self-lofting was as an additional and efficient mechanism for raising the altitude of the smoke.

# Sulfur Dioxide

## Emissions of ($SO_2$) from the Kuwaiti fires and other sources of interest (preliminary results)

| Source | Time Interval | Amount (million tons) | |
|---|---|---|---|
| Kuwait | 1 year | 3.2 | (1) |
| | | 4.0 | (2) |
| | | 6.0 | (3) |
| US Electric Utilities (1988) | 1 year | 14 | (2) |
| Mt. Pinatubo | 2 weeks | 15-20 | (4) |

1) P. Hobbs, 11 July, 1991
2) B. Hicks, NAPAP Newsletter (to be published)
3) A. Bandy, 26 July, 1991
4) Global Environmental Change Report, 3 July, 1991

## Summary of Preliminary Observational Review and Data Analysis

- Global impact of "black carbon" particulate emissions continues to be small.
- Global impact of trace gases is small.
- Regional climate and weather change remains and open question. Primary impact seems likely to be limited to less than 1000 km.
- Local impact on climate and ecology continues to be large with some effects being accumulative.

# Just How Big ARE the Fires in Kuwait?

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- Based on estimated oil and gas combustion rates and mindful of some uncertainties in combustion efficiency, I calculate a heat release rate of about $5x10^{14}$ Joules per hour.

- Modest test fires I have studied where about 1000 acres of logging debris is burned in about an hour have heat release rates of roughly $10x10^{14}$ Joules per hour.

- The Yellowstone wildfire of a few years ago sustained a similar heat release rate (twice Kuwait) for more than 30 days.

# Just How Big ARE the Fires in Kuwait? (cont.)

- The National Academy of Science estimates that about $1.2x10^{10}$ $m^2$ of the earth's surface is burned over each day by deliberate and wild biomass fire. This yields a heat release of $5x10^{15}$ Joules per hour or about the equivalent of 50 Kuwait fires.

- While biomass fires and the Kuwaiti oil fires are not entirely comparable, both yield similar (biomass somewhat more) amounts of smoke per unit of heat released. Such scaling helps us retain our sense of perspective for large scale fire phenomena.

- Clearly, the Kuwaiti fires are large, but hardly without precedent and small compared to global biomass burning.

مجلس حماية البيئة

# ENVIRONMENT PROTECTION COUNCIL

STATEMENT BY

DR. ABDULRAHMAN A. AL AWADI

CHAIRMAN OF EMERGENCY COMMITTEE,

ENVIRONMENT PROTECTION COUNCIL (EPC)

OF KUWAIT TO THE SECOND COMMITTEE,

UNITED NATIONS GENERAL ASSEMBLY

NOVEMBER 20, 1991

Mr. Chairman

Ladies and Gentlemen

I am honoured to address this august body and express my country's appreciation for the essential role the United Nations have played in securing the liberation of Kuwait.

I beg your indulgence in presenting an overview of the extent of the environmental damage inflicted upon my country and the region by the Iraqi regime and the efforts that have been exerted to assess the state of the environment and the associated risks to human health. I will also address the challenges ahead and the need for an internationally supported programme for the rehabilitation of the environment and follow up of the long term health and ecological damage sustained by the people and the natural environment of Kuwait.

Kuwait and the Gulf region in general suffered the largest air, water and soil pollution episodes ever recorded. This incident is different from any other reported in history by the fact that this was premeditated. The Iraqi troops discharged millions of barrels of oil into the Gulf and put explosives on the oil wells and detonated all the producing and experimental wells. Out of 943 wells only 155 were intact, 613 were on fire, 76 were gushing and 99 were badly damaged. This resulted in the ignition of 6m barrels/day of oil and 100 $mm^3$/day of gas and discharge of 743 thousand barrels from the gushing oil into the soil.

The air was polluted by thousands of tons of soot, sulfur and nitrogen oxides, carbon monoxide and carbon dioxides. The estimates about the quantities were staggering; 60,000 tons of $SO_2$, 3000 tons of $NO_2$ and 45,000 tons of soot. The quantity of $CO_2$ added to the air ranged from 1-2 m tons. These pollutants are not new to the environment, they are known by-products from heat generation and industrial activities. What is new is that they are burnt for no useful purpose. What happened in Kuwait is irrational and unforgivable.

The pollutants are discharged in a very vulnerable environment. The ground based inversion is found almost every night, elevated inversion is also very common. The background dust load is quite high and can reach very high levels with dust storms. The role of dust as carrier for the pollutants and hence as a health hazard is well recognized. The other air pollution problem is the high level of hydrocarbons mostly of geogenic source. The solar radiation and the probability of oxidants come with the scorching heat. This is the background to what is added to the pollutants emitting from the well fires.

The real picture of the air pollution in Kuwait will never be fully appreciated. The air quality monitoring system was designed to verify the problems arising from traffic, power plants and industry. The problem of the well fires was not anticipated or accounted for. No monitoring facilities have been stationed in the townships to the west of the urban area or to the south on the coastal strip. The air pollution mobile laboratories that were used to support the existing system were looted by the Iraqis. Many of the equipment were also either stolen or damaged.

Two more serious handicaps had to be faced. The Iraqi regime destroyed the basic infrastructure of the whole State and we had to cope with the lack of power for weeks before starting up the monitoring. The other problem was the severe shortage of trained manpower. Many of our technicians were out of the country at the time of the invasion and did not come back, many of those who were in the country were forced to leave. This included the operators and the maintenance crew.

All the information we have about the first weeks of the pollution episode is that from one site, Mansoria, in the urban area away from the wake of the plume. With the other station Reqa in the coastal strip, the electric power was connected late and it relied on generators and the voltage was unstable and this interrupted the recording very much. The levels of soot, sulfur dioxide and nitrogen oxides in the period April-July 1991 was comparable to those seen in the same months in 1990. The usual sources of these pollutants, power plants, industry and traffic were not back to normal. The wind was most of the time taking the plume away from the measuring site and the plume was rising to high levels during the day times and the established ground based inversions were obstructing the fall back of pollutants to the ground at night.

The mean level of methane and non-methane hydrocarbons were appreciably high in 1991 compared to 1990. The maximum was seen up to 11 ppm for methane and 20 ppm for non-methane. The most likely source was the oil pools in the oilfield. The hydrocarbons by the natural environment or under the influence of the intense heat generated by the well fires are emitted at ground level and do not go up with the plume. With calm winds and with stagnant condition the levels would give the air the the characteristic smell of oil. The level of CO were mostly lower in 1991 compared to 1990. This could be attributed to the much lower traffic movement. The lower level of CO which is a component of the plume will show that the plume was passing over the monitoring site.

The need for mobilization of resources and manpower delayed the active participation of UN specialized agencies in the monitoring and assessment efforts. Scientific teams from many countries moved in to help with the monitoring. The US EPA started as early as 13 of March by taking measurements from the air at several points in the burning fields, to the south of Kuwait City and within the US Embassy. The measurements were made by hand held equipment. Levels of $SO_2$ reaching 20 ppm were detected inside the oil fields in one of the cases and from 0-1 ppm and 2 ppm on two other occasions. The levels of particulates were quite high (.01-.933 $mg/m^3$) and levels of up to 5.4 $mg/m^3$ were detected in the oil well plumes.

More comprehensive information was provided with the help from the French Ministry of Environment who kindly loaned Kuwait a well equipped mobile laboratory. Unfortunately the laboratory was made available only for two weeks. $SO_2$ levels measured in Ahmadi township was in the region of 3-268 ppb, levels of CO were between .4-2.6 ppm and $O_3$ 7-36 ppb. All are associated with health risks particularly to the children, the elderly and those in critical health. Ahmadi is an inhabited area and before the invasion had 30,000 people. The levels are in line with the measurements taken by the staff of Ahmadi Hospital using hand held equipment. The 16 hour mean was 1.65 ppm. This is a level that exceeds the WHO health criteria.

The increase of particulates and smoke in the air has resulted in a significant decrease in solar radiation and air temperatures. The air temperature decreased by 3-4°C in the mid day during the first few months. The level of particulates was measured during March at the sites of the general hospitals due to the availability of electricity and only total suspended particulated could be measured. However, by May nine portable PM10 instruments designed to measure particles of 10 microns or less which fall within the inhalable fraction were provided on loan basis to Kuwait from the US EPA. The values during the period from May to July were in the range of 250-338 micrograms/$m^3$. PM10 levels at Ahmadi (338) and Fahaheel (309), two residential areas in the vicinity of the Burgan oil fields, were higher than those found in the other areas. It was also interesting to note that the levels fluctuated widely and that with calm winds the levels were higher.

The levels of polycyclic aromatic hydrocarbons (PAH) and volatile organic compounds (VOC) were determined by several teams. The measurements taken in summer should be assessed with caution. The heat reduces the efficiency of trapping of these compounds as they remain in the vapour phase. The levels in Ahmadi were measured by the French team and results were generally in line with the results by Kuwait EPD which show maximum levels of benzo(a)pyrene (30 $ng/m^3$). This is a compound representative of the PAHs having carcinogenic properties. The Norwegian Institute for Air Research (NILU) team took 4 air samples from the area of Umm Quasr to the north near the Iraqi borders. The total PAH varied between 207-412 $ng/m^3$. The average total PAH contribution was 296 $ng/m^3$.

Control of Air Pollution:

The State gave top priority to extinguishing of the oil well fires. Estimates of the time needed to overcome the problem was in the range of 2-5 years. The first oil well was controlled on 20th March 1991, less than 3 weeks after liberation. The number of wells successfully capped during each week in the period April to October showed a very sharp rise in the number of wells with the increase in the number of teams. An average of nearly 3 wells/day was achieved with a peak of 13/day. The record number of wells controlled on a single week was 52.

The Health Alert:

The prediction done by NOAA for the period July-December for the level of $SO_2$ between the ground and up to 1 km showed that the level of $SO_2$ may reach 1000 ug/m$^3$. The prediction was based on the meteorological data for the last two years. The prediction agrees well with those done by KEPD though a worse situation was anticipated in October followed by November and December. The prediction was based on historical data between 1957-1982.

The Health Alert System was established to handle the worst probability. Three air quality monitoring stations were connected by telephone lines. The hospitals and the organisations participating in the contingency plan would be alerted. The general hospitals and some designated polyclinics were asked to prepare clean rooms where the air is filtered.

The health plan have been elaborated and discussed with the WHO and other interested organisations. The plan included informing the physicians and nursing staff of their role in providing needed care during pollution episodes. Several health studies were initiated. At the Adan hospital, asthma accounted for 6% of the visits and chest problems for 29% more. These figures are higher than the percentage of the complaints received by the hospital in the same period in 1986 for which data are available. A more extensive survey of the visits to 7 health centres distributed among the different regions is running since the beginning of September 1991. A survey of the asthmatics attending the Allergy Centre has been carried out since June 1991. All the asthmatics were called to join the study. A questionnaire about their exposure, lung function testing and physical examination is given to each patient. The peak flow is measured twice daily and a diary is kept.

A cohort study of 1600 families residing in the area impacted by the oil fires and 400 control households in the City of Kuwait of the same socio-economic level was planned. The health exposure assessment location study (HEAL) is running with the help of, WHO, US EPA and Harvard School of Public Health. Personal samplers are used to determine the exposure of a random sample of 400 Kuwaiti citizens above 10 years to particles 10 microns or less. A diary of the different activities is kept. The level of PM10 and PM2.5 are measured indoor and outdoors of the houses in half of the cases. Exposure to PAH using a personal sampler will be determined for another family member.

Certain investigations including biological monitoring was done by US and German teams. The American study was based on taking blood from 14 volunteers mostly from the troops serving in Kuwait. A large number of volatile compounds were detected in the blood. The German study covered both the enviromental and biological monitoring. The biological monitoring was done by examining samples of blood or urine for volatile organic compounds or other substances taken from 32 persons working in Shuaiba industrial complex. Relatively high levels of benzene and other aromatic hydrocarbons, toluene and m-xylene were detected in the blood of a group of non-smokers that cannot be explained by the low levels detected in the environment which were generally lower than the concentrations found in German cities.

Psychological impacts resulting from oppression during the occupation and the social impact of forced immigration of the Kuwaiti population outside the country are probably substantial. The familial separation and the lack of communication is an example of the problems that should be addressed. The psychological impacts experienced by the prisoners of war and by those who suffered from the torture by the Iraqis have been investigated. Preliminary results show that among a number of male prisoners of war who were subjected to psychological torture, 69% had depression, 24% had anxiety and 37% suffered from sleep disturbances. The prevalence of night mares (21%), lack of concentration (39%) and nervousness (34%) were very common. A large proportion suffered from agitation (39%) and social withdrawal was seen in 9% of the cases.

Another study addressing the heavioural abnormalities in Kuwaiti children who stayed all the time in Kuwait during the occupation and those who suffered from familial separation out of the country was done. The results will be released soon. Investigation of the post traumatic stress disorders (PTSD) have been planned for the first degree relative of the martyrs, missing prisoners of war and victims of injuries during the invasion and post liberation due to the mines implanted by the Iraqis.

The Marine Environment:

The Arabian Gulf has experienced the largest oil pollution episode in the recent history. The Arabian Gulf constitutes an almost closed body of shallow water, 1000 km long by 300 km wide, with an average depth of 35 m. It is a highly productive plankton water body, but it is also regarded as being one of the most fragile and vulnerable marine ecosystems. Its low tidal displacement means that it has little discharge of its water into the Indian Ocean and thus little opportunity to flush out pollutants.

The oil spills started on January 19 when Iraq started pumping oil from five tankers moored near the Mina Al Ahmadi oil terminal. The quantity is estimated to be up to 500,000 tons. On 30th January, this was reported to cause a slick some 50 x 15 miles in extent coverng an area of about 750 square miles. It has not come ashore, its impact was mostly on marine birds. A second spill started around January 20, when the pipelines on the Sea Island terminals about 12 km off-shore from Mina Al Ahmadi oil terminal were opened. Oil continued to spill into the sea from these pipelines until January 26, when U.S. aircraft destroyed the manifolds that controlled the oil flow to the terminal from storage tanks located 5 miles inland. The quantity of oil released ranged from 100,000 to 1 million tons. Between 24 April and 8 May oil was observed stranded on shorelines in both Kuwait and Saudi Arabia. In early May the entire coastline of Saudi Arabia from the Kuwaiti border to Jabail was to varying degrees affected by the spills.

The monitoring programme run by EPD was resumed in September 1991. The level of heavy metals in October 1991 compared to 1989 showed much higher means for copper, iron and lead in 1991. The mean for nickel in 1991 was slightly higher. The mean petroleum hydrocarbons was higher inside the Kuwait Bay where war wrecks were found and in the points near the destroyed South Pier or near the marine base. However, no oil deposits were found around the coral reefs, but evidence of damage by explosives was seen.

The effects of the crisis on fisheries of Kuwait is most obvious in the direct devastation of the fishing industry. The United Fisheries of Kuwait lost all 15 of its well-equipped, 26 m shrimp trawlers which were taken by the Iraqi authorities.

The problem of sunken ships needs concerted international efforts. Preliminary survey of the ships that were sunk in the Gulf War is about 80, added to the ships that were sunk in the Iraqi-Iranian war and were not salvaged.

The sewage system suffered heavily from disrepair during the occupation. Raw sewage was being discharged into the Gulf through a number of emergency outfalls that opened directly on the beach. Pollution by sewage-related bacteria in the coastal area extending to hundreds of meters on both sides of the outfall was detected during most of the summer months.

The plan to cope with the problem of pollution by oil and the marine environment in general covers several areas. The contingency plan for combating oil pollution was revised. The plan include setting up the prediction model on a personal computer. Air surveillance using remote sensing is needed. Oil Skimmers, booms, pumps and dispersants were ordered to replenish the stores that were taken away by the Iraqis. Calling in the trained manpower or training other people if these were not available is an integral part of the plan.

The Terrestrial Ecosystem:

The impact of oil from the estimated 70 gushing wells has resulted in the formation of a large number of pools covering several kilometers in area both to the north and south of the country. Estimates of the amount of oil in these pools is as high as 80 million barrels. Trenches filled with oil by the Iraqis, and overflow from wells just before capping, also resulted in extensive damage to the soil and vegetation.

The soot has covered large areas, polluting the soil and coating the vegetation. KEPD soil samples in June and July 1991 from the surface amd 10cm deep were taken from Mina Abdalla in the middle of the coastal strip, Wafra Road to the south of the country and from Doha to the west of the urban area. Two small uninhabited islands Auha and Qaroh were also included in the investigation. The mean extractable organic matter (EOM) was appreciably higher in the surface samples. The difference was persistent. However, it was much higher in Mina Abdalla and Wafra Road which had the maximum mean. A similar picture is seen for the petroleum hydrocarbon (PHC) equivalents. The effect on the fragile ecosystem of the desert is likely to be substantial. The reflectivity of the sand will drop appreciably, the scorching heat in mid-summer will disturb the heat balance and raise the temperature of the soil and subsoil water. The microflora of the surface soil and the role of the chemical reaction may also be altered. The air exchange potential and the porosity of the soil as a result of cloggging the pores should be investigated.

Dealing with oil pools fall into two components, recovery of the oil and treatment of contaminated soils. Another problem related to the oil well fires is the extensive amount of saline water used for fire fighting. A total of 361 water lagoons the size of small lakes were prepared to support fire fighting operations. War bombings and shellings have considerable direct and indirect effects on Kuwait's fauna. Landmines still pose a threat to animal life. Bunkers and ditches will inevitably cause the disappearance of proper habitats for some animals and the appearance of others. The impacts of the war on the agricultural development is far reaching. The invasion forced most of the workers to leave the country. The Iraqi troops looted all that was left in the abandoned farms. The lack of irrigation during the period of occupation caused the soil to suffer. The fertile top soil was blown out and it will take a long time for the soil to recover.

The Hazardous and Domestic Wastes:

Inside the Shuaiba Area, the damage to the small- and medium-scale industries located in the Shuaiba Central and Western Mina Abdulla were looted and set afire. Raw and auxiliary materials, and various chemicals have been mishandled, poured from their containers and spread on the ground.

The dumping of garbage presents an immediate threat to public health and safety. Hazardous wastes at abandoned or damaged industrial and commercial sites needs to be located, identified, and moved to safe interim storage or disposal facilities. Another issue is the release of PCB's from power transformers deliberately burned by the Iraqis. Some of the transformers are in residential areas which require immediate attention.

The extent of the problem of mines and unexploded ordnance is substantial. The area that had the highest density of mines was the shores, where about 11,000 mines were removed from an 8 Km strech of the Kuwait water front. The safety problem is quite serious. Between March and June 1991, the general hospitals received 1257 victims, mostly males (74.7%). Children under 13 years accounted for 27% of the total. The mortality rate was quite high (10.5%) for ammunition and 5% for explosives burn injuries.

The problem of the depleted uranium and the risk of exposure to the radiation emitted thereof is being investigated by the Radiation Protection Department. The source of DU is the antitank munition used by the allied troops during the war and this may constitute a health problem.

The Challenges:

The immediate impact of the crisis is over. The well fires are extinguished. I am quite confident that the oil pools will be dealt with properly with the same enthusiasm. The question of mines is more difficult to handle. However, clearing the mines is an example of the international cooperation. Presently many teams belonging to 6 States are helping the local staff in dealing with the problem.

We are now entering a new phase, where we can plan ahead and act instead of reacting to the acute problems. Before the invasion, the KEPC prepared a plan of action for the period 1991-1996. The plan was addressing specific topics. Now the plan has to be revised and priorities allocated. The monitoring systems should be revised and the location of the existing stations and the parameters being monitored should be looked into. The system needs renovation and better facilities are required. The training of new technicians to replace those who left the country is another challenge which will take years to overcome.

With air pollution, we are faced by a unique situation where the total population of a country has been exposed to massive levels of pollution resulting from the burning of oil. The pollutants produced are not entirely different from those emitted from most power plants, automobile exhaust and industrial installations. However, the rate of release and the burning efficiency are different. The problem of inhalable and respirable particulates which was quite significant has acquired a new dimension. The sand and dust storms will not be the same. The soil in large areas of Kuwait is polluted by the fall out of petroleum droplets. This will be blown up by the winds and the health impacts will not be limited to the acute forms we are familiar with.

Pollution by hydrocarbons is likely to be much more intense. With the program of drilling new wells instead of the damaged ones will pollute the air with large quantities of non-methane and volatile organic compounds. It is anticipated to live with the problem for at least a number of years. The reaction of the hydrocarbons with the nitrogen oxides generated by the industrial activities, power plans and traffic and the generation of oxidants is likely in view of the intense UV that is characteristic of the clear skies and intense solar flux in the region.

With the health impacts, many challenges should be faced. A higher proportion of complaints of chest and asthma was reported by the emergency room visits in the general hospital close to the areas impacted by the plume. How far this is real will need more intensive investigation. The change in the pattern of mortality in the period the fires were blazing will be compared with similar period in the last years to confirm the validity of emergency room visits.

The chronic impacts is quite challenging. The cohort study of the presumably more exposed population is designed. A matched control group living in the north was selected. However the total area of the urban area of Kuwait is quite small. The farthest point is only 50 km from the burning oil fields and the wind direction is variable. Comparing the results with similar population elsewhere may be sought.

The study by itself is quite challenging and the attrition rate should be kept to a minimum. Out of the 1600 households, probably half will be lost before the end of the period. The same is expected with the control group which is much smaller to begin with and statistical significance may be a problem. The motivation is waining with the extinguishing of the fires and the memory of the horrible days is likely to be suppressed.

The assessment of the exposure to particulates and PAHs is likely to address the problem of the risk involved. However, it started only one month before the fires were extinguished and so it missed the period where the exposure was more intense. The use of the data collected to assess the risk to the population to the PAH is likely to be difficult. Extrapolating the results to cover the acute episode is not an easy job. Thp expertise is not available locally and use of models developed in other regions of the world may be difficult.

The psychological impacts is also demanding. The people of Kuwait have been subjected to a horrifying and tragic experience by a brutal inhuman invasion carried out by the Iraqi regime. The seven-month occupation has severely impacted every aspect of life in

Kuwait and the over 800,000 Kuwaitis and another million people belonging to over 70 nationalities who came to earn a decent living in a peaceful country. The destruction of property, looting, detention, rape, torture and killing of people was compounded by the worst premeditated manmade environmental disaster ever carried out by an occupying force.

The shock encountered by the occupation, the insecurity, fear and humiliation was an experience that will never be forgotten by the people who lived in Kuwait. The worries and home sickness of the Kuwaiti people outside Kuwait is the sigma of those who were abroad or were forced to leave the country. The loss of identity of the two groups is another experience. The grief and misery of the families that lost a family member is well known. The missing of imprisoned Kuwaitis reached 7455, out of which 110 were less than 12 years old. There are still over 2000 POWs in Iraq. For a small population and the family size, probably every family has lost one or two members. The psychological impacts experienced by the pressure of war and by those who suffered from the torture by the Iraqis are grave. The time needed for these people to recover is not known. A long term follow up study is needed and the resources should be made available. The behavioural abnormality of the children that lived in Kuwait under the oppression of the occupation and those who have been stranded abroad need to be addressed.

The long term impact on the marine environment is being addressed on both the national and regional levels. Studies to assess the extent of damage to the marine environment are being organized through the Regional Organization for the Protection of the Marine Environment (ROPME) in cooperation with IOC, UNEP, IAEA, and US NOAA as well as National Focal Points and research institutions of the ROPME Member States. A short term and a more extensive oceanic cruises are being organized now for this purpose. The long term impacts on mangroves and tidal flats and the rate of recovery should be monitored.

The problem of the sunken ships is quite demanding. Based on the experience gained from the Iraq-Iran war, this problem need a concerted international effort. The ships by themselves are a chronic source of pollution of metals and petroleum. The type of cargo should also be considered. The floating mines have almost been cleared from the navigation channels. However, the security is never complete and accidents may be expected.

The impact of the plume on the marine environment is a sltudy topic that have not been frequently encountered in other regions. This needs to be investigated as an added stress to the marine environment. The organisms that are living and the extent of their tolerance and the new impacts is likely to cause unfavourable reactions.

The terrestrial environment is more challenging. The oil lakes have covered a relatively small area (30-40 $km^2$). With the intense scorching heat, the volatiles will evaporate. The bacteria will eat up some and the asphalt will be left as permanent scars disfiguring the desert. Thousands of kilometers are covered by the soot and the fall out of the oil droplets from the plume. The effect of the black soot on the reflectivity of the desert is anticipated. The rise in the temperature and the effect on the ecobalance should be monitored.

The impacts of the salt water lagoons on the surface water and the probability of their impact on the survival of the desert plants is anticipated. The probability of the plants in the oil field to complete their life cycle is not likely. Transport of the seeds from the other areas need to be investigated in view of the hostile environment. The impacts of the machinery on the earth crust is likely to be intense in the areas that have been used by the military vehicles. The equipment and vehicles used for fire fighting is not more friendly. The anticipated increase in dust and sand storms is likely to be substantial in the next few years.

Mr. Chairman, it is obvious that these challenges cannot be met by Kuwait alone, or by its sister countries in the region. With a crippled economy, tremendous rebuilding effort of infrastructures devastated by the Iraqis, Kuwait can only look towards the world community for assistance. The undertakings of the above challenges is expected to be technically complicated and costly. With the priority for reparations from war damages to be paid by Iraq in accordance with the Security Council Resolution No. 687, the share for the environment is expected to be slight and the procedure to be lengthy. However, the establishment of a more solid and continuous source of funding may ensure the continuity of the studies and rehabilitation programmes. In this respect we fully trust the UN system to develop the arrangements that allow for action to begin. A resolution from your distinguished committee calling for placing a higher priority to the environmental and health studies and the rehabilitation of the environment programmes and to establish a funding mechanism to ensure their implementation would be most appreciated by the Kuwaiti people. Should such a resoltion be passed and endorsed by the General Assembly, then a meeting of the contributing parties could be held to review their various programmes proposed for the region including the national plans of action, the regional plan of action (ROPME) and that being developed by the UNDP. A joint fund management committee could be established involving donor as well as recipient countries and the UN special organizations concerned (e.g. UNDP, UNEP and others).

Thank you.

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# Kuwaiti Oil Well Fires Updated

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**SUMMARY**

Before being driven from the country, the Iraqis sabotaged all of Kuwait's oil wells. At present, some 500 are burning and dozens are flowing uncontrollably, creating huge lakes of crude oil. More than 70 of the wells have been shut-in by well control crews, at least ten of which were on fire. Well fire fighting has been hampered because sufficient water is not yet available. The loss in crude oil due to the damaged wells is estimated at about 4 million barrels per day.

## Kuwaiti Oil Well Fires

At the time of the Iraqi invasion, about 858 of Kuwait's 1,386 wells were producing oil. This includes the wells in the Kuwaiti administered Neutral Zone. The Iraqi occupation troops, supervised by petroleum engineers, packed each wellhead with 30 to 40 pounds of Russian-made C-4 plastic explosives shortly after the invasion. It was an enormous undertaking, carried out with an extensive bureaucracy. The electric detonation systems were backed up by non-electric detonators. In December, six wells were ignited as experiments to determine the most efficient method of destruction. When the air war began, 60 wells were blown up by the Iraqis and as many as 34 more wells may have been destroyed by allied bombing. The explosives packed around the remaining wellheads were detonated by the Iraqi troops about a week before the beginning of the ground war and the subsequent liberation of Kuwait. Most of the wellheads were blown open at the base, with some of the surface casing also damaged. Maximum destruction was achieved by packing down the explosive charges with sandbags. About two-thirds of the wellheads were completely blown off, while others were badly damaged with above ground valves and pipes destroyed.

About seven wells survived because of malfunctions in the detonation devices, but until the plastic explosives are removed, remain susceptible to accidental detonation. Not all of the successfully sabotaged wells are burning. Oil is flowing uncontrollably from dozens of these wells, creating huge, flammable lakes of petroleum that are spreading toward highways and threatening residential areas and groundwater. Some of the flowing wells also release hydrogen sulfide, which can be lethal, into the atmosphere. For health reasons, two of these wells were ignited so that, in burning, they produce sulfur dioxide instead, which is less toxic. Other flowing wells also may have to be ignited for the same reason. There remain about 500 sabotaged producing wells that are burning uncontrollably.

The wells burn at about 3,000 degrees Fahrenheit and can be under pressures as high as 7,000 pounds per square inch. Uncontrolled oil flow from a well could range up to 90,000 barrels per day, with a typical well flowing 10,000 to 15,000 barrels per day. Such wells would normally be choked back to a regulated flow between 3,000 and 12,000 barrels per day under usual production practices. The burning is extremely destructive, consuming an estimated 4 million barrels of oil per day (about $80 million worth of oil). By way of comparison, the United States is now importing from all sources about 5.6 million barrels of crude oil per day.

Also, severe underground reservoir damage can be caused by long-term uncontrolled flow, whether or not the well is on fire. If the blowouts are not contained, water coning, gas migration, relative permeability reduction, and other irreversible petrophysical effects within the reservoir will further reduce ultimate petroleum recovery. Steam has been observed escaping from some of the wells, suggesting that formation and/or ground water is mixing with the oil in some locations. Some wells have burned themselves out as water flow increased in proportion to that of oil. As formation water encroaches into the fields along the edges and from below, natural gas (dissolved gas-to-oil ratios = 500-15,000:1) escapes and some of the heavier oil is left behind. The pressures in the oil fields then become uneven, with higher water levels in some parts and lower gas pressures in others. This adversely affects ultimate oil recovery, as up to 20 percent of proved reserves may become unrecoverable.

About 60 flowing wells that were not burning have been capped by well control crews that pumped thousands of pounds of mud and cement into the damaged wellheads. Thus far, the wells that have been plugged have been those that offered the fewest problems. In general, they were smaller producers that are close to roads and free of land mines and unexploded bombs. The super-giant *Burgan* field is still an inferno, with slow moving rivers of oil pouring across the dessert. The smoke and soot from the burning wells is not considered a global threat. The warmer air above 18,000 feet is holding it down and dispersing it into a 1,000 mile-long plume across the Persian Gulf region, locally causing acid rainfall and lower than normal temperatures. Some may have entered the jet stream, as an increase in black carbon soot has been observed in Hawaii. However, it is not certain that the soot originated in Kuwait. British meteorologists have estimated from satellite monitors that the well fires are burning about 1.5 million barrels of oil per day, substantially less oil than the 4 million barrels per day estimated by the petroleum engineers on the ground. The two amounts can be considered as defining a range, with the actual amount of oil being burned fluctuating somewhere in between. The fluctuations, however, are generally downward as less oil is consumed over time. This reduction occurs as flowing wells are shut-in, associated gas burned off, and field pressures decrease.

The burning wells will have to be extinguished. Some 25 well firefighting crews are currently available. These are from four Houston companies: Cudd Pressure Control Inc. (7 crews), Wild Well Control, Inc. (6 crews), Boots and Coots, Inc. (5 crews), and Red Adair Co., Inc. (5 crews), plus Safety Boss, Ltd of Calgary (2 crews). These companies are working together in Kuwait for the first time. Kuwait also is negotiating with additional firefighting companies from Britain, France, China, Iran, Germany, and the Soviet Union to reduce the time required to extinguish all of the well fires from years to months. This would save billions of dollars of crude oil as well as greatly ease the environmental damage. There are questions, however, whether the additional firefighting companies have comparable expertise to the five already in Kuwait.

There are several methods of fighting oil well fires. The availability of enormous amounts of water is a basic requirement. Kuwait's water supply was sabotaged by the retreating Iraqis who blew up distillation and desalination plants. The Kuwait Oil Company is fashioning a 30 mile water pipeline from the Persian Gulf to the *Burgan* and *Magwa* oil fields to provide cooling water. When the system is in place it will produce great volumes of water, up to 15,000 gallons per minute, to fill plastic-bottomed ponds in the dessert. Each pond will be dug to a depth of 20 feet and will cover an area in excess of one-half square mile. Initially, a curtain of water will be sprayed from the ponds onto a burning well by a series of pumps, each with a capacity of 5,000 gallons per minute. The water alone will put out some of the well fires. In other cases, liquid nitrogen is effective. It is pumped into a large diameter venturi tube positioned over the burning wellhead, depriving the flames of oxygen as water is sprayed on the fire. Two small well fires have been put out by this method, but it does not appear to work on the larger fires. For such fires, a curtain of water will be employed to allow the damaged well equipment to be removed by cranes and what remains of the wellhead to be packed with 300 to 400 pounds of dynamite or an equivalent amount of C-4 plastic explosive. When the explosives are detonated, the explosion will often consume enough of the surrounding oxygen to snuff out the fire.

Past oil well fires have been rare and singular accidents. In Kuwait, with so many fires burning in close proximity, for the first time it will be possible to organize a coordinated oil well firefighting effort, moving from well to well. Also, it will be economic to fabricate large structures that may be used to fight the numerous fires. One device that is been considered is a 30-foot steel dome with a ten-foot diameter base that can be lowered over a burning oil wells from a heavy-lift crane. The weight of the dome would press its bottom edge into the oil soaked sand forming a fairly tight seal. As the oil fills the dome and the oxygen is consumed, the fire could continue burning only at the top of the dome where the gas is vented. Curved fins within the dome swirl the gushing oil toward the wall of the vessel where it would run down into a collection trough at ground level. From there it could be pumped out to collection pipes that lead to a production system. The oil flow rates would still be uncontrolled, but the oil resource would no longer be lost and the burning gas would be less polluting than the previously burning gas/oil mixture.

The most difficult fires, that cannot be "blown out" by explosives, eventually can be extinguished with the assistance of directional drilling. A new well is drilled nearby and positioned to intercept the uncontrolled well near the top of the reservoir, far below the fire. Cement and mud is then pumped into the intercept well to stop the uncontrolled flow of oil to the surface. With its fuel cut off, the fire is extinguished. Directional drilling takes much more time than the use of water, liquid nitrogen, or explosives to put out well fires. Over one hundred of the burning wells in Kuwait may require this method of treatment. The most dangerous work comes after a fire has been extinguished. Gas can erupt from the well and oil sprays over the entire area. As the firefighters, drenched in oil, attempt to cap the blowout, any static electricity or flames from a nearby well could reset the fire. A major hazzard is the presence of Iraqi land mines and unexploded bombs buried in the oil fields. These weapons will have to be removed to allow the firefighters to work efficiently.

The final plugging of an uncontrolled well is accomplished by pumping in heavy mud (weighted with barium sulfide) and cement. If the well damage is considerable, hundreds of barrels of cement must be used. While a small plug of concrete easily can be drilled out when the well is put back into production, it is more economic to drill a new well near-by than to drill through a massive amount of concrete. This is especially true in Kuwait's fields, which are well known and rarely deeper than 5,000 feet. As the old wells are redrilled, new methods, such as horizontal drilling, could be used which could add to the efficiency of recovery.

In addition to the damaged and burning wellheads, the Iraqis destroyed more than 20 of the 26 gathering centers that separate the oil, gas, and water recovered from the reservoirs. Each of the gathering centers served 30 to 40 wells, and must be rebuilt before production can begin again. It is expected that it will take at least one year to put out all of the well fires, but it could take as long as from two to five years. [Even at four million barrels per day, Kuwait would lose less than two percent of its 97 billion barrel oil reserves in a year. However, the reservoir damage caused by the uncontrolled flow of many wells could cause additional significant losses in ultimate oil recovery and, in spite of better engineering in the new wells, the pressure losses in the reservoirs will make future oil recovery generally more expensive, as more pumping will be required. Depending upon reservoir mechanics, there will be certain critical wells that should be controlled first to minimize reservoir damage. In spite of the damage, Kuwait may have 50,000 barrels per day of oil production on stream within two months, enough to run the local power plants. The next priority, after power restoration, is an additional 50,000 barrels per day of crude oil production to refine for domestic gasoline.

# Kuwait Oil Fire Extinguishing Chronology

Gulf Program Office
Office of the Chief Scientist
National Oceanic and Atmospheric Administration

November 1991

Department of Commerce
14th and Constitution
Washington, DC 20230

Sources:

Well numbers and dates: Kuwait Oil Company, Production Operations Department, "Oil Wells Survey Data," Kuwait, 1991 (unpublished).

Flow rates: calculated by The Analytic Sciences Corporation (TASC), Reading, Massachusetts pursuant to NOAA Contract No. 50-DGNA-1-00139. October 1991.

# Kuwait Oil-Fire Extinguishing Chronology

Prepared by
The Gulf Program Office

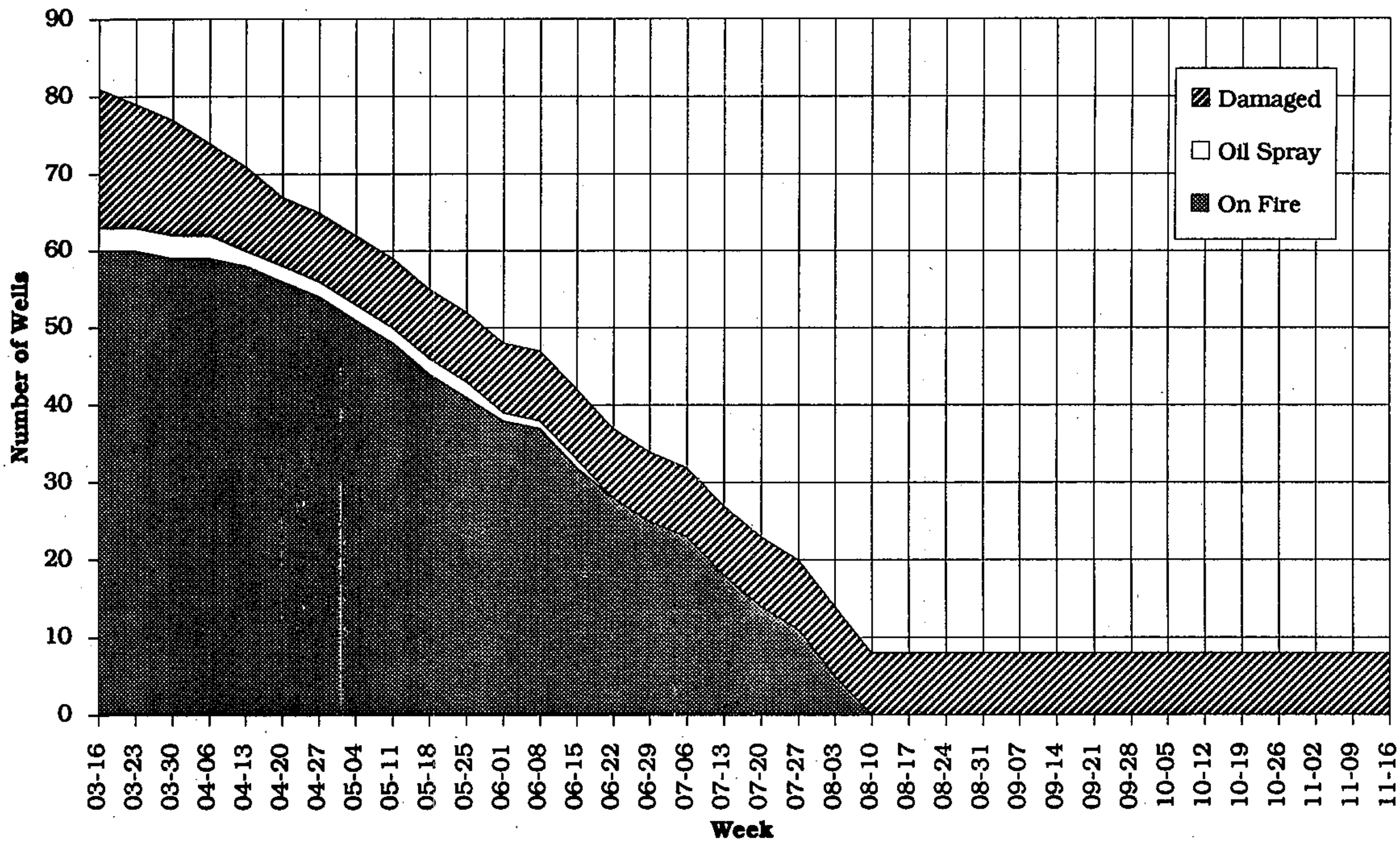
| Abdullyah Field History | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| Well Number | Gathering Center | On Fire | Oil Spray | Damaged | Intact | Date Capped |
| 1 | 16 | | | | 1 | |
| 2 | 16 | | | | 1 | |
| 3 | 16 | | | | 1 | |
| 4 | 16 | | | | 1 | |
| 5 | 16 | | | | 1 | |
| | | | | | | |
| Wells | | 0 | 0 | 0 | | |
| Wells Controlled | | 0 | 0 | 0 | | |
| | | | | | | |
| Remaining | | 0 | 0 | 0 | | |

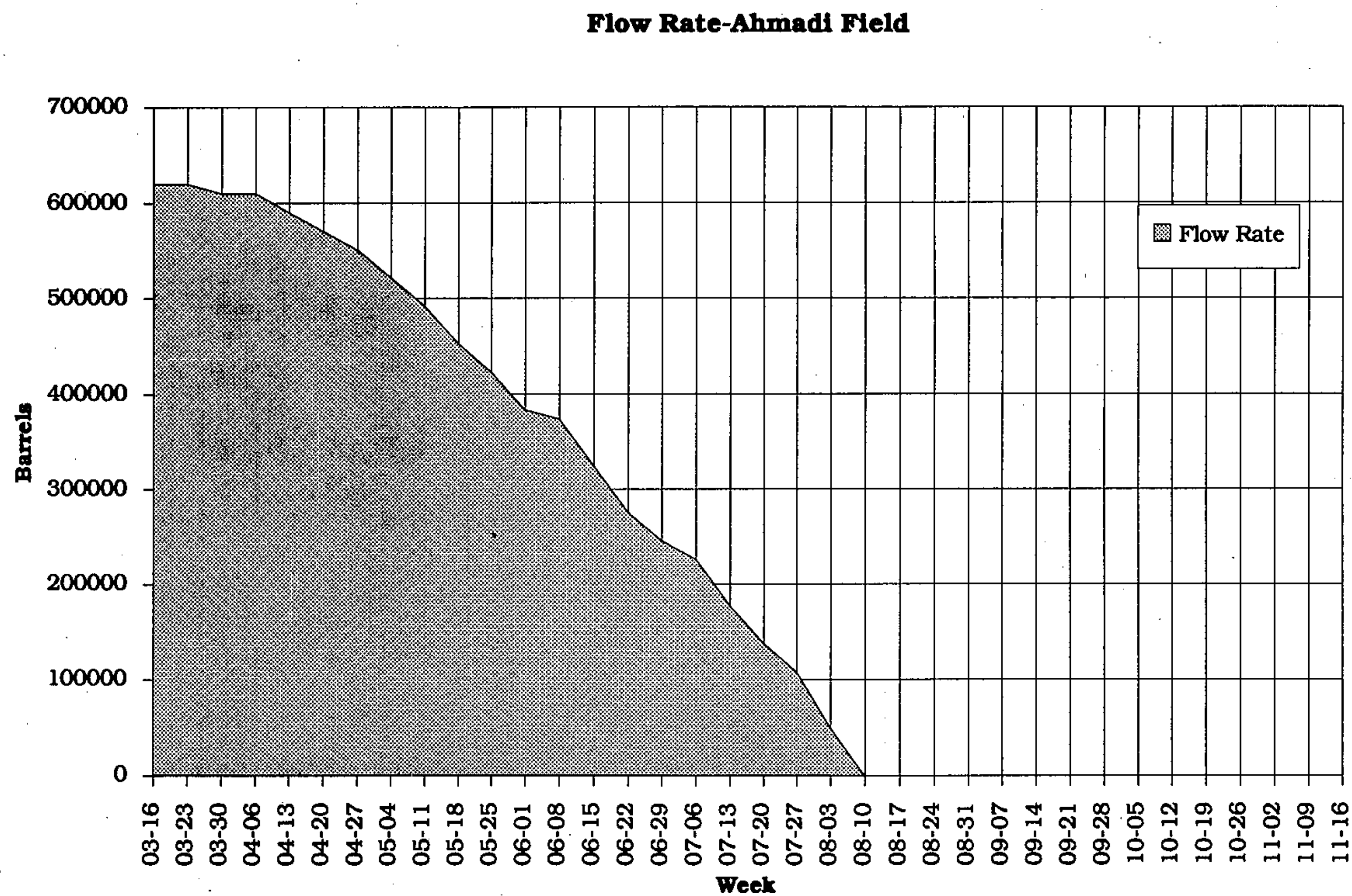
| Ahmadi Field History | | | | | | |
|---|---|---|---|---|---|---|
| **Well Number** | **Gathering Center** | **On Fire** | **Oil Spray** | **Damaged** | **Intact** | **Date Capped** |
| 1 | 22 | | | 1 | | Abandoned |
| 3 | 20 | 1 | | | | 5/29/91 |
| 4 | 20 | 1 | | | | 5/24/91 |
| 5 | 22 | | | 1 | | |
| 6 | 20 | 1 | | | | 6/23/91 |
| 7 | 22 | 1 | | | | 6/3/91 |
| 8 | 20 | 1 | | | | 4/17/91 |
| 9 | 22 | 1 | | | | 7/8/91 |
| 10 | 22 | 1 | | | | 5/20/91 |
| 11 | 22 | 1 | | | | 7/17/91 |
| 12 | 22 | 1 | | | | 7/7/91 |
| 13 | 19 | 1 | | | | 6/10/91 |
| 14 | 22 | | | 1 | | |
| 15 | 22 | 1 | | | | 8/5/91 |
| 16 | 20 | 1 | | | | 4/22/91 |
| 17 | 22 | 1 | | | | 6/10/91 |
| 18 | 22 | 1 | | | | 7/9/91 |
| 19 | 22 | 1 | | | | 7/9/91 |
| 20 | 22 | 1 | | | | 7/14/91 |
| 21 | 22 | 1 | | | | 6/1/91 |
| 22 | 22 | 1 | | | | 5/18/91 |
| 23 | 22 | 1 | | | | 6/1/91 |
| 24 | 20 | 1 | | | | 3/30/91 |
| 25 | 20 | 1 | | | | 4/29/91 |
| 26 | 20 | | | | 1 | |
| 27 | 20 | 1 | | | | 6/17/91 |
| 28 | 20 | 1 | | | | 6/20/91 |
| 29 | 20 | 1 | | | | 5/13/91 |
| 30 | 20 | 1 | | | | 6/13/91 |
| 31 | 22 | 1 | | | | 7/31/91 |
| 32 | 19 | 1 | | | | 6/24/91 |
| 33 | 19 | | | 1 | | |
| 34 | 19 | 1 | | | | 7/15/91 |
| 35 | 22 | 1 | | | | 7/12/91 |
| 36 | 19 | 1 | | | | 4/12/91 |
| 38 | 20 | | 1 | | | 6/18/91 |
| 39 | 22 | 1 | | | | 5/18/91 |
| 40 | 22 | 1 | | | | 7/3/91 |
| 41 | 22 | 1 | | | | 8/5/91 |
| 42 | 19 | 1 | | | | 6/20/91 |
| 43 | 19 | 1 | | | | 8/4/91 |
| 44 | 20 | | | 1 | | 4/16/91 |
| 46 | 20 | 1 | | | | 6/18/91 |
| 47 | 20 | 1 | | | | 5/10/91 |
| 48 | 20 | | 1 | | | 4/11/91 |
| 49 | 20 | | | 1 | | 3/20/91 |
| 50 | 20 | 1 | | | | 5/19/91 |
| 52 | 20 | | | 1 | | 8/5/91 |
| 53 | 20 | | | | 1 | |
| 54 | 19 | | | 1 | | |

| Ahmadi Field History (Continued) | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| **Well Number** | **Gathering Center** | **On Fire** | **Oil Spray** | **Damaged** | **Intact** | **Date Capped** |
| 55 | 22 | 1 | | | | 7/23/91 |
| 56 | 22 | | | 1 | | |
| 57 | 20 | 1 | | | | 5/3/91 |
| 58 | 20 | | | 1 | | 3/26/91 |
| 59 | 20 | | | | 1 | |
| 60 | 20 | 1 | | | | 7/31/91 |
| 61 | 20 | 1 | | | | 4/21/91 |
| 62 | 20 | | | 1 | | |
| 63 | 20 | 1 | | | | 5/9/91 |
| 64 | 20 | 1 | | | | 5/3/91 |
| 65 | 20 | | | 1 | | 3/20/91 |
| 66 | 20 | | | 1 | | 4/19/91 |
| 67 | 20 | 1 | | | | 4/20/91 |
| 68 | 20 | 1 | | | | 6/26/91 |
| 69 | 19 | | | | 1 | |
| 70 | 19 | | | 1 | | |
| 71 | 22 | 1 | | | | 6/13/91 |
| 72 | 22 | | | 1 | | 3/31/91 |
| 73 | 22 | 1 | | | | 6/9/91 |
| 74 | 22 | 1 | | | | 8/10/91 |
| 75 | 22 | 1 | | | | 8/2/91 |
| 76 | 22 | 1 | | | | 7/21/91 |
| 77 | 22 | 1 | | | | 7/22/91 |
| 78 | 22 | 1 | | | | 7/30/91 |
| 79 | 19 | | | 1 | | 3/31/91 |
| 80 | 19 | 1 | | | | 8/8/91 |
| 81 | 19 | | 1 | | | 5/29/91 |
| 82 | 22 | 1 | | | | 7/16/91 |
| 83 | 22 | | | 1 | | 4/9/91 |
| 84 | 22 | 1 | | | | 8/1/91 |
| 85 | 22 | 1 | | | | 7/29/91 |
| 86 | 20 | 1 | | | | 5/12/91 |
| 87 | 22 | 1 | | | | 5/5/91 |
| 88 | 22 | 1 | | | | 7/5/91 |
| 89 | 20 | | | 1 | | 4/4/91 |
| | | | | | | |
| **Wells** | | **60** | **3** | **18** | | |
| **Wells Controlled** | | **60** | **3** | **10** | | |
| | | | | | | |
| **Remaining** | | **0** | **0** | **8** | | |

| Ahmadi Field Summary | | | | | |
|---|---|---|---|---|---|
| Week | On Fire | Oil Spray | Damaged | Flow (bbs/day) | Flow (kgs/sec) |
| 03-16 | 60 | 3 | 18 | 620000 | 1004.40 |
| 03-23 | 60 | 3 | 16 | 620000 | 1004.40 |
| 03-30 | 59 | 3 | 15 | 610159 | 988.46 |
| 04-06 | 59 | 3 | 12 | 610159 | 988.46 |
| 04-13 | 58 | 2 | 11 | 590476 | 956.57 |
| 04-20 | 56 | 2 | 9 | 570794 | 924.69 |
| 04-27 | 54 | 2 | 9 | 551111 | 892.80 |
| 05-04 | 51 | 2 | 9 | 521587 | 844.97 |
| 05-11 | 48 | 2 | 9 | 492064 | 797.14 |
| 05-18 | 44 | 2 | 9 | 452698 | 733.37 |
| 05-25 | 41 | 2 | 9 | 423175 | 685.54 |
| 06-01 | 38 | 1 | 9 | 383810 | 621.77 |
| 06-08 | 37 | 1 | 9 | 373968 | 605.83 |
| 06-15 | 32 | 1 | 9 | 324762 | 526.11 |
| 06-22 | 28 | 0 | 9 | 275556 | 446.40 |
| 06-29 | 25 | 0 | 9 | 246032 | 398.57 |
| 07-06 | 23 | 0 | 9 | 226349 | 366.69 |
| 07-13 | 18 | 0 | 9 | 177143 | 286.97 |
| 07-20 | 14 | 0 | 9 | 137778 | 223.20 |
| 07-27 | 11 | 0 | 9 | 108254 | 175.37 |
| 08-03 | 5 | 0 | 9 | 49206 | 79.71 |
| 08-10 | 0 | 0 | 8 | 0 | 0.00 |
| 08-17 | 0 | 0 | 8 | 0 | 0.00 |
| 08-24 | 0 | 0 | 8 | 0 | 0.00 |
| 08-31 | 0 | 0 | 8 | 0 | 0.00 |
| 09-07 | 0 | 0 | 8 | 0 | 0.00 |
| 09-14 | 0 | 0 | 8 | 0 | 0.00 |
| 09-21 | 0 | 0 | 8 | 0 | 0.00 |
| 09-28 | 0 | 0 | 8 | 0 | 0.00 |
| 10-05 | 0 | 0 | 8 | 0 | 0.00 |
| 10-12 | 0 | 0 | 8 | 0 | 0.00 |
| 10-19 | 0 | 0 | 8 | 0 | 0.00 |
| 10-26 | 0 | 0 | 8 | 0 | 0.00 |
| 11-02 | 0 | 0 | 8 | 0 | 0.00 |
| 11-09 | 0 | 0 | 8 | 0 | 0.00 |
| 11-16 | 0 | 0 | 8 | 0 | 0.00 |

## Ahmadi Field-Oil Well Status

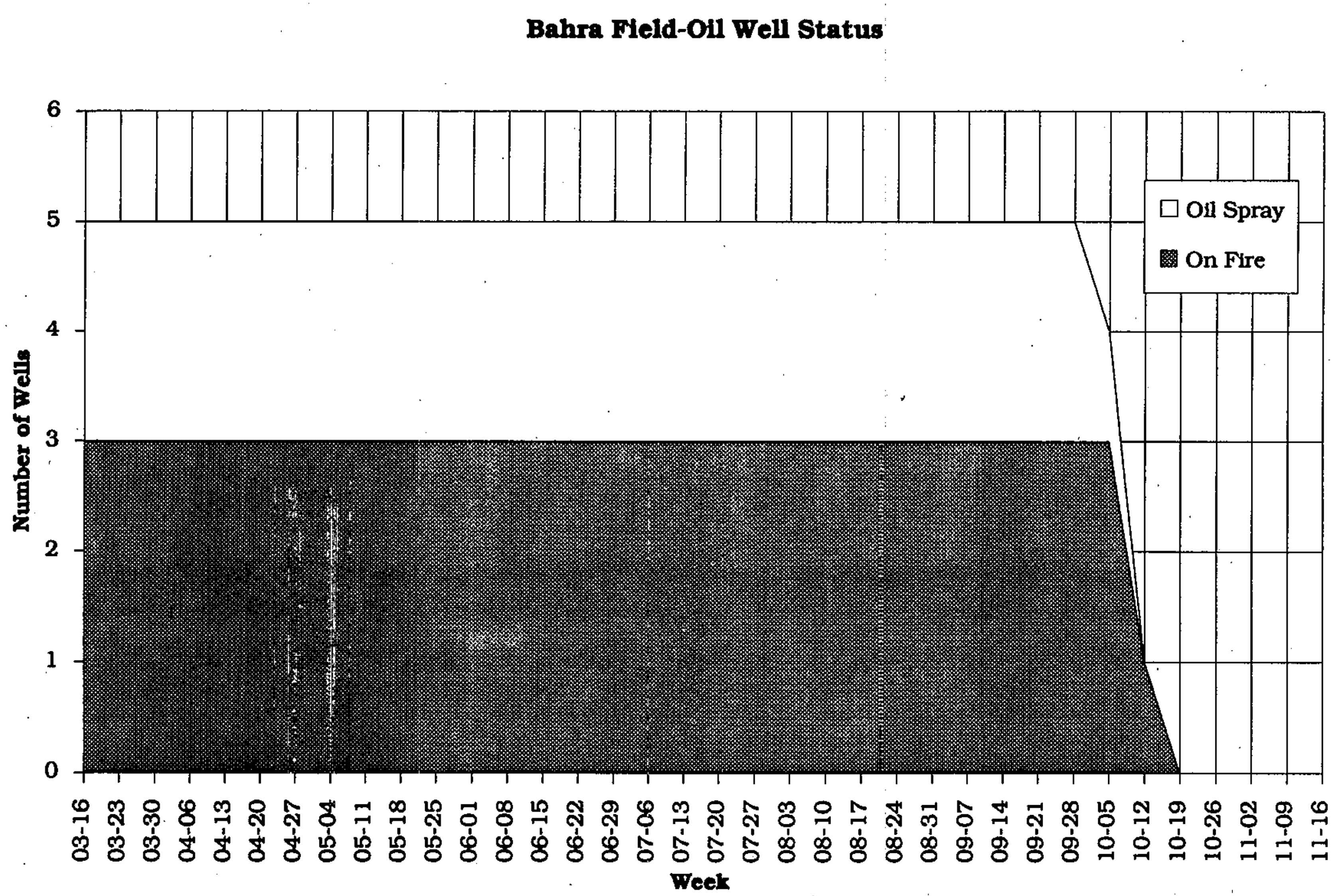


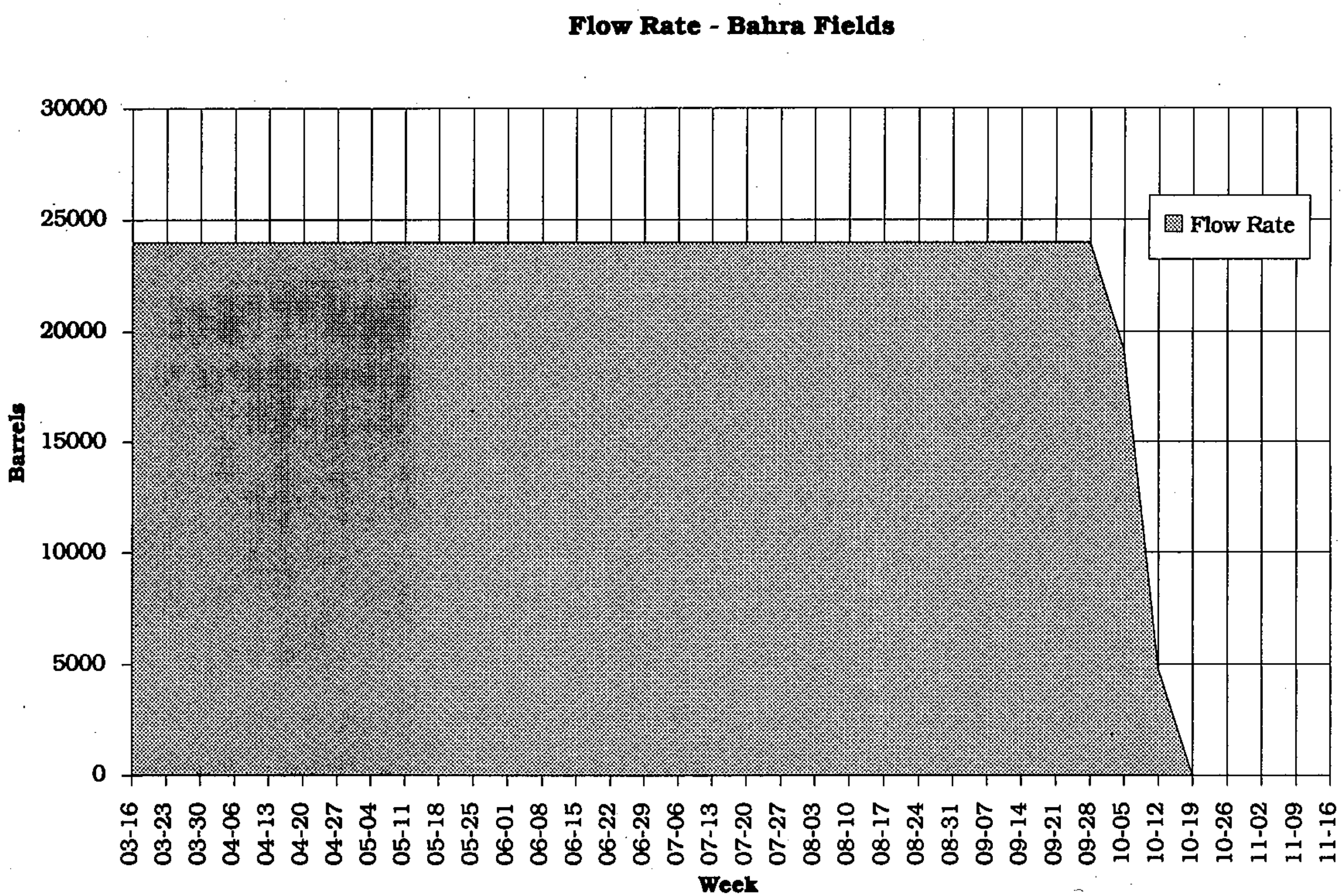


Flow Rate-Ahmadi Field
700000
600000
500000
400000
300000
200000
100000
0
Barrels
03-16 03-23 03-30 04-06 04-13 04-20 04-27 05-04 05-11 05-18 05-25 06-01 06-08 06-15 06-22 06-29 07-06 07-13 07-20 07-27 08-03 08-10 08-17 08-24 08-31 09-07 09-14 09-21 09-28 10-05 10-12 10-19 10-26 11-02 11-09 11-16
Week
Flow Rate

| **Bahra Field History** | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| **Well Number** | **Gathering Center** | **On Fire** | **Oil Spray** | **Damaged** | **Intact** | **Date Capped** |
| 2 | 24 | 1 | | | | 10/10/91 |
| 4 | 24 | 1 | | | | 10/12/91 |
| 6 | 24 | | 1 | | | 10/3/91 |
| 8 | 24 | | 1 | | | 10/11/91 |
| 9 | 24 | 1 | | | | 10/13/91 |
| | | | | | | |
| **Wells** | | **3** | **2** | **0** | **0** | |
| **Controlled** | | **3** | **2** | **0** | | |
| | | | | | | |
| **Remaining** | | **0** | **0** | **0** | | |

| Bahra Field Summary | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| Week | On Fire | Oil Spray | Damaged | Flow (bbs/day) | Flow (kgs/sec) | |
| 03-16 | 3 | 2 | 0 | 24000 | 38.88 | |
| 03-23 | 3 | 2 | 0 | 24000 | 38.88 | |
| 03-30 | 3 | 2 | 0 | 24000 | 38.88 | |
| 04-06 | 3 | 2 | 0 | 24000 | 38.88 | |
| 04-13 | 3 | 2 | 0 | 24000 | 38.88 | |
| 04-20 | 3 | 2 | 0 | 24000 | 38.88 | |
| 04-27 | 3 | 2 | 0 | 24000 | 38.88 | |
| 05-04 | 3 | 2 | 0 | 24000 | 38.88 | |
| 05-11 | 3 | 2 | 0 | 24000 | 38.88 | |
| 05-18 | 3 | 2 | 0 | 24000 | 38.88 | |
| 05-25 | 3 | 2 | 0 | 24000 | 38.88 | |
| 06-01 | 3 | 2 | 0 | 24000 | 38.88 | |
| 06-08 | 3 | 2 | 0 | 24000 | 38.88 | |
| 06-15 | 3 | 2 | 0 | 24000 | 38.88 | |
| 06-22 | 3 | 2 | 0 | 24000 | 38.88 | |
| 06-29 | 3 | 2 | 0 | 24000 | 38.88 | |
| 07-06 | 3 | 2 | 0 | 24000 | 38.88 | |
| 07-13 | 3 | 2 | 0 | 24000 | 38.88 | |
| 07-20 | 3 | 2 | 0 | 24000 | 38.88 | |
| 07-27 | 3 | 2 | 0 | 24000 | 38.88 | |
| 08-03 | 3 | 2 | 0 | 24000 | 38.88 | |
| 08-10 | 3 | 2 | 0 | 24000 | 38.88 | |
| 08-17 | 3 | 2 | 0 | 24000 | 38.88 | |
| 08-24 | 3 | 2 | 0 | 24000 | 38.88 | |
| 08-31 | 3 | 2 | 0 | 24000 | 38.88 | |
| 09-07 | 3 | 2 | 0 | 24000 | 38.88 | |
| 09-14 | 3 | 2 | 0 | 24000 | 38.88 | |
| 09-21 | 3 | 2 | 0 | 24000 | 38.88 | |
| 09-28 | 3 | 2 | 0 | 24000 | 38.88 | |
| 10-05 | 3 | 1 | 0 | 19200 | 31.10 | |
| 10-12 | 1 | 0 | 0 | 4800 | 7.78 | |
| 10-19 | 0 | 0 | 0 | 0 | 0.00 | |
| 10-26 | 0 | 0 | 0 | 0 | 0.00 | |
| 11-02 | 0 | 0 | 0 | 0 | 0.00 | |
| 11-09 | 0 | 0 | 0 | 0 | 0.00 | |
| 11-16 | 0 | 0 | 0 | 0 | 0.00 | |
| | | | | | | |


Bahra Field-Oil Well Status
Number of Wells
0
1
2
3
4
5
6
03-16
03-23
03-30
04-06
04-13
04-20
04-27
05-04
05-11
05-18
05-25
06-01
06-08
06-15
06-22
06-29
07-06
07-13
07-20
07-27
08-03
08-10
08-17
08-24
08-31
09-07
09-14
09-21
09-28
10-05
10-12
10-19
10-26
11-02
11-09
11-16
Week
Oil Spray
On Fire


Flow Rate - Bahra Fields
Barrels
30000
25000
20000
15000
10000
5000
0
Flow Rate
03-16
03-23
03-30
04-06
04-13
04-20
04-27
05-04
05-11
05-18
05-25
06-01
06-08
06-15
06-22
06-29
07-06
07-13
07-20
07-27
08-03
08-10
08-17
08-24
08-31
09-07
09-14
09-21
09-28
10-05
10-12
10-19
10-26
11-02
11-09
11-16
Week

| Burgan Field History | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| Well Number | Gathering Center | On Fire | Oil Spray | Damaged | Intact | Date Capped |
| 1 | 6 | 1 | | | | 9/12/91 |
| 2 | 11 | | | | 1 | |
| 3 | 11 | | | | 1 | |
| 4 | 2 | 1 | | | | 9/9/91 |
| 5 | 1 | 1 | | | | 6/13/91 |
| 6 | 14 | | | 1 | | 4/30/91 |
| 7 | 14 | 1 | | | | 4/20/91 |
| 9 | 11 | | | | 1 | |
| 10 | 6 | 1 | | | | 10/6/91 |
| 11 | 1 | 1 | | | | 9/20/91 |
| 12 | 1 | 1 | | | | 9/4/91 |
| 13 | 1 | 1 | | | | 9/4/91 |
| 14 | 14 | | 1 | | | 8/13/91 |
| 15 | 6 | 1 | | | | 9/29/91 |
| 16 | 1 | 1 | | | | 8/10/91 |
| 17 | 2 | 1 | | | | 9/11/91 |
| 18 | 11 | | 1 | | | 5/17/91 |
| 19 | 14 | | | | 1 | |
| 20 | 2 | | | 1 | | 6/5/91 |
| 21 | 1 | 1 | | | | 9/13/91 |
| 22 | 2 | 1 | | | | 9/6/91 |
| 23 | 14 | 1 | | | | 8/26/91 |
| 24 | 11 | 1 | | | | 7/7/91 |
| 25 | 2 | | | 1 | | 5/27/91 |
| 26 | 2 | | | | 1 | |
| 27 | 11 | | | | 1 | |
| 28 | 11 | 1 | | | | 8/17/91 |
| 29 | 2 | | | | 1 | |
| 30 | 2 | 1 | | | | 10/4/91 |
| 31 | 2 | | 1 | | | 5/8/91 |
| 32 | 8 | 1 | | | | 9/23/91 |
| 33 | 5 | 1 | | | | 9/14/91 |
| 34 | 8 | 1 | | | | 8/31/91 |
| 35 | 5 and 11 | | | | 1 | |
| 36 | 12 | 1 | | | | 10/23/91 |
| 37 | 3 and 21 | 1 | | | | 10/20/91 |
| 38 | 2 | 1 | | | | 9/7/91 |
| 39 | 1 | 1 | | | | 9/12/91 |
| 40 | 7 | 1 | | | | 10/22/91 |
| 41 | 3 | 1 | | | | 9/11/91 |
| 42 | 8 | 1 | | | | 10/12/91 |
| 43 | 5 | 1 | | | | 10/10/91 |
| 44 | 13 | 1 | | | | 8/14/91 |
| 45 | 5 | | | 1 | | 7/16/91 |
| 46 | 13 | 1 | | | | 10/21/91 |
| 47 | 7 | 1 | | | | 10/3/91 |
| 48 | 7 | 1 | | | | 10/26/91 |
| 49 | 12 | 1 | | | | 10/20/91 |
| 50 | 4 | 1 | | | | 8/22/91 |
| 51 | 13 | 1 | | | | 9/1/91 |

| Burgan Field History (Continued) | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| Well Number | Gathering Center | On Fire | Oil Spray | Damaged | Intact | Date Capped |
| 52 | 13 | 1 | | | | 7/25/91 |
| 53 | 12 | 1 | | | | 10/15/91 |
| 54 | 12 | 1 | | | | 10/12/91 |
| 55 | 4 | 1 | | | | 8/24/91 |
| 56 | 4 | | 1 | | | 8/7/91 |
| 57 | 11 | 1 | | | | 7/3/91 |
| 58 | 8 | 1 | | | | 9/18/91 |
| 59 | 5 | | 1 | | | 7/20/91 |
| 60 | 4 | 1 | | | | 8/4/91 |
| 61 | 5 | 1 | | | | 7/22/91 |
| 62 | 14 | 1 | | | | 8/19/91 |
| 63 | 4 | | | | 1 | |
| 64 | 13 | 1 | | | | 8/10/91 |
| 65 | 4 | 1 | | | | 8/27/91 |
| 66 | 13 | 1 | | | | 7/18/91 |
| 67 | 7 | 1 | | | | 6/10/91 |
| 68 | 4 | 1 | | | | 8/5/91 |
| 69 | 4 | | | | 1 | |
| 70 | 5 | 1 | | | | 7/29/91 |
| 71 | 4 | 1 | | | | 10/4/91 |
| 72 | 12 | 1 | | | | 10/9/91 |
| 73 | 5 | | 1 | | | 7/9/91 |
| 74 | 14 | | | | 1 | |
| 75 | 4 | 1 | | | | 7/10/91 |
| 76 | 11 | 1 | | | | 7/2/91 |
| 77 | 13 | 1 | | | | 7/13/91 |
| 78 | 4 | | 1 | | | 8/8/91 |
| 79 | 8 | | 1 | | | 6/7/91 |
| 80 | 7 | 1 | | | | 10/4/91 |
| 81 | 4 | | 1 | | | 7/8/91 |
| 82 | 2 | 1 | | | | 9/1/91 |
| 83 | 4 | | | | 1 | |
| 84 | 5 | | | | 1 | |
| 85 | 14 | 1 | | | | 8/14/91 |
| 86 | 19 | 1 | | | | 5/24/91 |
| 87 | 12 | 1 | | | | 10/11/91 |
| 88 | 11 | | | | 1 | |
| 89 | 14 | 1 | | | | 5/15/91 |
| 90 | 11 | | | | 1 | |
| 91 | 2 | | 1 | | | 6/5/91 |
| 92 | 11 | 1 | | | | 6/18/91 |
| 93 | 2 | 1 | | | | 8/22/91 |
| 94 | 2 | 1 | | | | 5/13/91 |
| 95 | 14 | 1 | | | | 8/20/91 |
| 96 | 19 | 1 | | | | 8/14/91 |
| 97 | 14 | 1 | | | | 9/3/91 |
| 98 | 3 and 21 | 1 | | | | 10/5/91 |
| 99 | 5 | 1 | | | | 9/8/91 |
| 100 | 3 | 1 | | | | 9/13/91 |
| 101 | 5 | 1 | | | | 9/6/91 |

| Burgan Field History (Continued) | | | | | | |
|---|---|---|---|---|---|---|
| Well Number | Gathering Center | On Fire | Oil Spray | Damaged | Intact | Date Capped |
| 102 | 5 | 1 | | | | 9/10/91 |
| 103 | 6 | 1 | | | | 9/27/91 |
| 104 | 6 | 1 | | | | 10/4/91 |
| 105 | 2 and 6 | | | | 1 | |
| 106 | 6 | 1 | | | | 9/19/91 |
| 107 | 1 | 1 | | | | 8/23/91 |
| 108 | 1 | 1 | | | | 9/24/91 |
| 109 | 1 | 1 | | | | 9/23/91 |
| 110 | 1 | 1 | | | | 9/18/91 |
| 111 | 8 | 1 | | | | 10/6/91 |
| 112 | 21 | 1 | | | | 9/24/91 |
| 113 | 1 | 1 | | | | 9/26/91 |
| 114 | 13 | 1 | | | | 10/20/91 |
| 115 | 7 | 1 | | | | 10/12/91 |
| 116 | 13 | 1 | | | | 10/22/91 |
| 117 | 7 | 1 | | | | 10/6/91 |
| 118 | 12 | 1 | | | | 11/2/91 |
| 119 | 21 | 1 | | | | 10/24/91 |
| 120 | 13 | 1 | | | | 8/18/91 |
| 121 | 12 | 1 | | | | 10/23/91 |
| 122 | 13 | 1 | | | | 10/16/91 |
| 123 | 13 | 1 | | | | 10/15/91 |
| 124 | 3 | | | | 1 | |
| 125 | 8 | 1 | | | | 10/7/91 |
| 126 | 12 | 1 | | 1 | | 10/14/91 |
| 127 | 8 | 1 | | | | 9/23/91 |
| 128 | 8 | | 1 | | | 6/9/91 |
| 129 | 8 | 1 | | | | 9/10/91 |
| 130 | 8 | 1 | | | | 9/7/91 |
| 131 | 11 | | | | 1 | |
| 132 | 2 | 1 | | | | 8/28/91 |
| 134 | 14 | | | | 1 | |
| 136 | 1 | 1 | | | | 9/27/91 |
| 137 | 13 | 1 | | | | 11/1/91 |
| 138 | 3 and 5 | 1 | | | | 9/23/91 |
| 139 | 8 | 1 | | | | 8/26/91 |
| 140 | 21 | 1 | | | | 10/21/91 |
| 141 | 12 | 1 | | | | 10/20/91 |
| 142 | 12 | 1 | | | | 10/7/91 |
| 143 | 5 | 1 | | | | 9/5/91 |
| 144 | 13 | 1 | | | | 8/5/91 |
| 145 | 12 | 1 | | | | 10/15/91 |
| 146 | 4 | 1 | | | | 9/3/91 |
| 147 | 7 | 1 | | | | 10/2/91 |
| 148 | 4 | 1 | | | | 8/15/91 |
| 149 | 7 | 1 | | | | 10/5/91 |
| 150 | 13 | 1 | | | | 7/18/91 |
| 151 | 7 | 1 | | | | 6/14/91 |
| 152 | 5 | 1 | | | | 10/10/91 |

| Burgan Field History (Continued) | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| **Well Number** | **Gathering Center** | **On Fire** | **Oil Spray** | **Damaged** | **Intact** | **Date Capped** |
| 153 | 2 | 1 | | | | 9/13/91 |
| 154 | 7 | | 1 | | | 6/8/91 |
| 155 | 4 | 1 | | | | 8/22/91 |
| 156 | 2 | 1 | | | | 9/10/91 |
| 157 | 11 | | | | 1 | |
| 158 | 21 | 1 | | | | 10/12/91 |
| 159 | 11 | | | | 1 | |
| 160 | 13 | 1 | | | | 10/27/91 |
| 161 | 11 | | | | 1 | |
| 162 | 1 | 1 | | | | 9/11/91 |
| 163 | 11 | 1 | | | | 5/20/91 |
| 164 | 2 | 1 | | | | 9/5/91 |
| 165 | 11 | | | | 1 | |
| 166 | 2 | 1 | | | | 9/10/91 |
| 167 | 11 | | | | 1 | |
| 168 | 8 | 1 | | | | 9/18/91 |
| 169 | 2 | 1 | | | | 9/12/91 |
| 170 | 11 | | | | 1 | |
| 172 | 21 | 1 | | | | 11/2/91 |
| 173 | 5 | 1 | | | | 10/12/91 |
| 174 | 11 | | | | 1 | |
| 175 | 13 | 1 | | | | 10/17/91 |
| 176 | 12 | 1 | | | | 10/24/91 |
| 177 | 11 | | | | 1 | |
| 178 | 12 | 1 | | | | 10/17/91 |
| 179 | 12 | 1 | | | | 10/1/91 |
| 180 | 8 | 1 | | | | 8/17/91 |
| 181 | 4 | 1 | | | | 9/30/91 |
| 182 | 12 | 1 | | | | 10/5/91 |
| 183 | 4 | 1 | | | | 8/31/91 |
| 184 | 8 | 1 | | | | 5/28/91 |
| 185 | 12 | 1 | | 1 | | 10/14/91 |
| 186 | 4 | 1 | | | | 9/1/91 |
| 187 | 7 | 1 | | | | 10/29/91 |
| 188 | 8 | 1 | | | | 9/13/91 |
| 189 | 7 | 1 | | | | 10/9/91 |
| 190 | 4 | | | 1 | | 7/23/91 |
| 191 | 7 | 1 | | | | 10/3/91 |
| 192 | 4 | 1 | | | | 8/2/91 |
| 193 | 8 | 1 | | | | 9/26/91 |
| 194 | 8 | 1 | | | | 10/8/91 |
| 195 | 4 | 1 | | | | 8/19/91 |
| 196 | 5 | 1 | | | | 10/13/91 |
| 197 | 4 | 1 | | | | 8/13/91 |
| 198 | 5 | 1 | | | | 9/12/91 |
| 199 | 4 | 1 | | | | 7/10/91 |
| 200 | 6 | 1 | | | | 9/22/91 |
| 201 | 13 | | | 1 | | 8/1/91 |
| 202 | 5 | 1 | | | | 9/11/91 |
| 203 | 13 | 1 | | | | 8/11/91 |

| Burgan Field History (Continued) | | | | | | |
|---|---|---|---|---|---|---|
| Well Number | Gathering Center | On Fire | Oil Spray | Damaged | Intact | Date Capped |
| 204 | 2 | 1 | | | | 5/31/91 |
| 205 | 13 | 1 | | | | 8/17/91 |
| 206 | 13 | 1 | | | | 6/1/91 |
| 207 | 2 | 1 | | | | 7/12/91 |
| 208 | 13 | 1 | | | | 7/15/91 |
| 209 | 2 | | 1 | | | 6/4/91 |
| 210 | 12 | | 1 | | | 6/25/91 |
| 211 | 14 | | | | 1 | |
| 212 | 5 | 1 | | | | 9/7/91 |
| 213 | 6 | 1 | | | | 10/7/91 |
| 214 | 5 | 1 | | | | 9/12/91 |
| 215 | 19 | 1 | | | | 8/25/91 |
| 216 | 6 | 1 | | | | 10/2/91 |
| 217 | 2 | | | | 1 | |
| 218 | 19 | | | 1 | | 6/18/91 |
| 219 | 5 | 1 | | | | 7/20/91 |
| 220 | 19 | 1 | | | | 8/8/91 |
| 221 | 5 | 1 | | | | 9/1/91 |
| 222 | 19 | 1 | | | | 8/11/91 |
| 223 | 5 | 1 | | | | 7/30/91 |
| 224 | 3 | 1 | | | | 10/5/91 |
| 225 | 19 | 1 | | | | 6/29/91 |
| 226 | 2 | | 1 | | | 6/3/91 |
| 227 | 21 | 1 | | | | 10/12/91 |
| 228 | 2 | 1 | | | | 7/13/91 |
| 229 | 21 | 1 | | | | 10/22/91 |
| 230 | 2 | 1 | | | | 8/27/91 |
| 231 | 3 | 1 | | | | 10/18/91 |
| 232 | 1 | 1 | | | | 8/18/91 |
| 233 | 21 | 1 | | | | 10/15/91 |
| 234 | 13 | 1 | | | | 7/22/91 |
| 235 | 2 | | | 1 | | 4/28/91 |
| 236 | 13 | 1 | | | | 7/20/91 |
| 237 | 4 | 1 | | | | 10/20/91 |
| 238 | 2 | 1 | | | | 9/3/91 |
| 239 | 4 | | 1 | | | 4/29/91 |
| 240 | 4 | 1 | | | | 8/7/91 |
| 241 | 4 | | | | 1 | |
| 242 | 4 | 1 | | | | 8/25/91 |
| 243 | 4 | 1 | | | | 8/26/91 |
| 244 | 4 | 1 | | | | 8/11/91 |
| 245 | 4 | 1 | | | | 9/22/91 |
| 246 | 4 | 1 | | | | 10/17/91 |
| 247 | 12 | 1 | | | | 10/12/91 |
| 248 | 12 | 1 | | | | 10/7/91 |
| 249 | 12 | | 1 | | | 6/26/91 |
| 250 | 7 | 1 | | | | 10/1/91 |
| 251 | 7 | 1 | | | | 4/18/91 |
| 252 | 7 | 1 | | | | 9/28/91 |

| Burgan Field History (Continued) | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| Well Number | Gathering Center | On Fire | Oil Spray | Damaged | Intact | Date Capped |
| 253 | 8 | | | 1 | | 6/12/91 |
| 254 | 14 | | | | 1 | |
| 255 | 14 | | | | 1 | |
| 256 | 14 | 1 | | | | 8/25/91 |
| 257 | 14 | 1 | | | | 8/24/91 |
| 258 | 14 | 1 | | | | 8/29/91 |
| 259 | 14 | | | | 1 | |
| 260 | 2 | 1 | | | | 5/11/91 |
| 261 | 2 | 1 | | | | 8/31/91 |
| 262 | 1 | | | | 1 | |
| 263 | 1 | 1 | | | | 9/7/91 |
| 264 | 1 | 1 | | | | 9/13/91 |
| 265 | 1 | 1 | | | | 8/30/91 |
| 266 | 5 | 1 | | | | 9/8/91 |
| 267 | 13 | 1 | | | | 7/17/91 |
| 268 | 13 | 1 | | | | 8/11/91 |
| 269 | 12 and 4 | 1 | | | | 10/17/91 |
| 270 | 7 | 1 | | | | 10/4/91 |
| 271 | 8 | 1 | | | | 10/9/91 |
| 272 | 8 | 1 | | | | 9/26/91 |
| 273 | 2 | | | | 1 | |
| 275 | 14 | 1 | | | | 9/6/91 |
| 276 | 14 | | | | 1 | |
| 277 | 19 | 1 | | | | 8/14/91 |
| 278 | 19 | | | | 1 | |
| 279 | 19 | 1 | | | | 7/4/91 |
| 280 | 19 | 1 | | | | 7/5/91 |
| 281 | 19 | 1 | | | | 8/19/91 |
| 282 | 14 | 1 | | | | 8/12/91 |
| 283 | 13 | 1 | | | | 10/22/91 |
| 284 | 1 | 1 | | | | 8/15/91 |
| 285 | 21 | 1 | | | | 10/8/91 |
| 286 | 14 | 1 | | | | 9/3/91 |
| 287 | 6 | 1 | | | | 10/4/91 |
| 288 | 12 | 1 | | | | 10/20/91 |
| 289 | 1 | 1 | | | | 9/17/91 |
| 290 | 12 | 1 | | | | 10/18/91 |
| 291 | 6 | 1 | | | | 10/9/91 |
| 292 | 14 | | | | 1 | |
| 293 | 14 | 1 | | | | 9/8/91 |
| 294 | 14 and 3 | | 1 | | | 4/7/91 |
| 295 | 7 | 1 | | | | 10/15/91 |
| 296 | 7 | 1 | | | | 11/2/91 |
| 297 | 8 | 1 | | | | 10/17/91 |
| 298 | 11 | 1 | | | | 5/25/91 |
| 299 | 11 | 1 | | | | 6/23/91 |
| 300 | 11 | 1 | | | | 6/17/91 |
| 301 | 11 | 1 | | | | 6/23/91 |
| 302 | 19 | 1 | | | | 8/10/91 |
| 303 | 3 | 1 | | | | 9/27/91 |

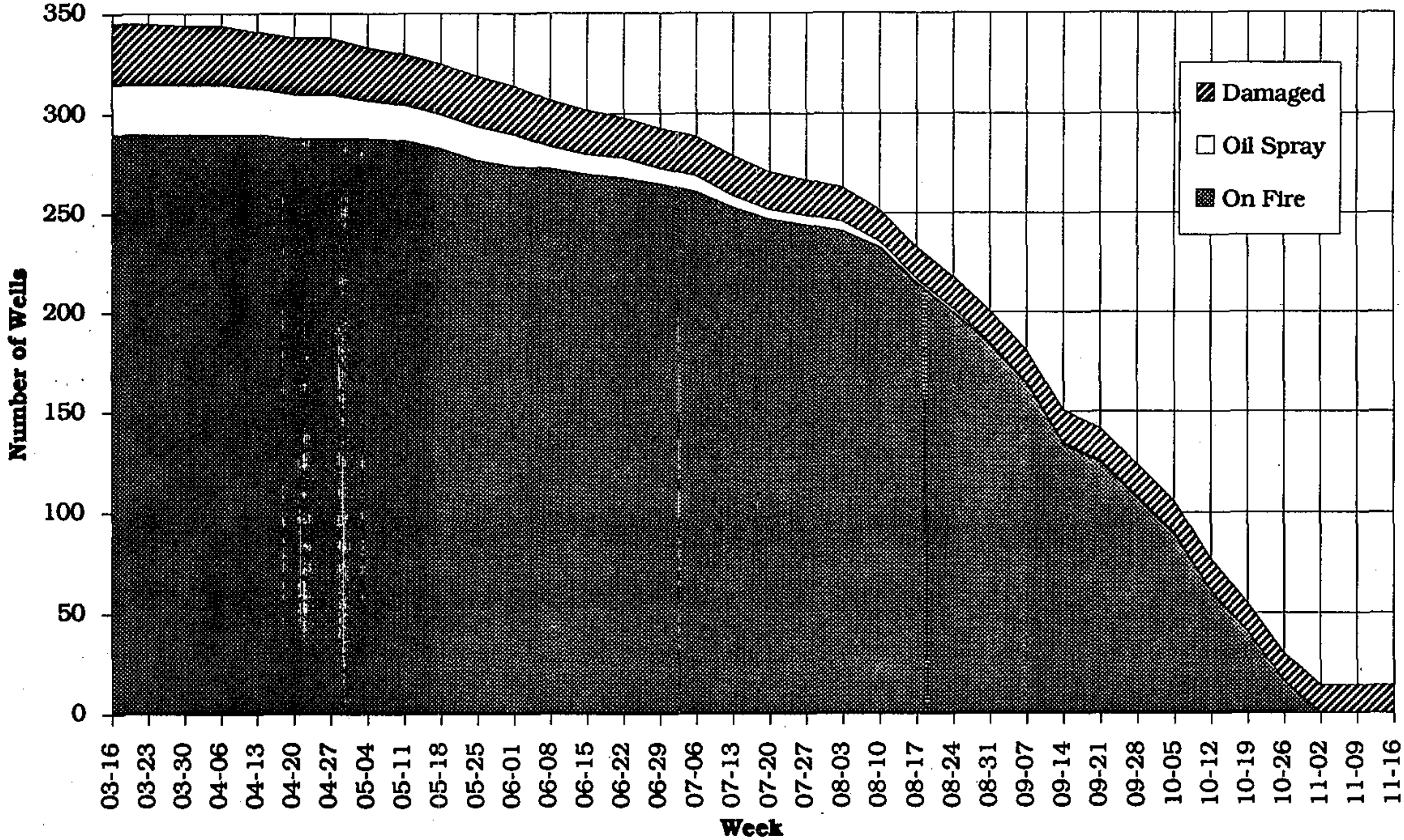
| Burgan Field History (Continued) | | | | | | |
|---|---|---|---|---|---|---|
| **Well Number** | **Gathering Center** | **On Fire** | **Oil Spray** | **Damaged** | **Intact** | **Date Capped** |
| 304 | 19 | | | 1 | | |
| 305 | 11 | | | | 1 | |
| 306 | 11 | | | | 1 | |
| 307 | 11 | | | | 1 | |
| 308 | 1 | 1 | | | | 8/30/91 |
| 309 | 1 | 1 | | | | 5/23/91 |
| 310 | 1 | 1 | | | | 5/15/91 |
| 311 | 1 | 1 | | | | 8/20/91 |
| 312 | 1 | 1 | | | | 9/10/91 |
| 313 | 1 | 1 | | | | 9/13/91 |
| 314 | 2 | 1 | | | | 9/11/91 |
| 315 | 2 | 1 | | | | 9/10/91 |
| 316 | 2 | 1 | | | | 9/8/91 |
| 317 | 5 | 1 | | | | 9/9/91 |
| 318 | 5 | 1 | | | | 10/7/91 |
| 319 | 13 | 1 | | | | 10/15/91 |
| 320 | 13 | 1 | | | | 10/30/91 |
| 321 | 12 | 1 | | | | 10/29/91 |
| 322 | 12 | 1 | | | | 10/22/91 |
| 323 | 14 | 1 | | | | 8/20/91 |
| 324 | 14 | | | 1 | | |
| 325 | 14 | | | | 1 | |
| 326 | 2 | 1 | | | | 7/8/91 |
| 327 | 1 | 1 | | | | 8/25/91 |
| 328 | 2 | 1 | | | | 9/8/91 |
| 329 | 2 | | | | 1 | |
| 330 | 6 | 1 | | | | 9/21/91 |
| 331 | 3 | 1 | | | | 10/15/91 |
| 332 | 13 | 1 | | | | 10/30/91 |
| 333 | 13 | 1 | | | | 10/29/91 |
| 334 | 13 | 1 | | | | 10/29/91 |
| 335 | 12 | | 1 | | | 10/11/91 |
| 336 | 12 | 1 | | | | 10/10/91 |
| 337 | 12 | 1 | | | | 10/20/91 |
| 338 | 7 | 1 | | | | 11/1/91 |
| 339 | 7 | 1 | | | | 10/24/91 |
| 340 | 12 | 1 | | | | 10/24/91 |
| 341 | 12 | 1 | | | | 10/20/91 |
| 343 | 13 | 1 | | | | 10/29/91 |
| 344 | 5 | | | | 1 | |
| 345 | 4 | 1 | | | | 10/13/91 |
| 348 | 4 | | | 1 | | |
| 349 | 5 | | | 1 | | |
| 351 | 8 | 1 | | | | 10/9/91 |
| 352 | 11 | | | | 1 | |
| 353 | 6 | 1 | | | | 9/24/91 |
| 354 | 11 | 1 | | | | 5/23/91 |
| 355 | 19 | | | | 1 | |
| 356 | 6 | 1 | | | | 9/25/91 |
| 357 | 14 | | | | 1 | |

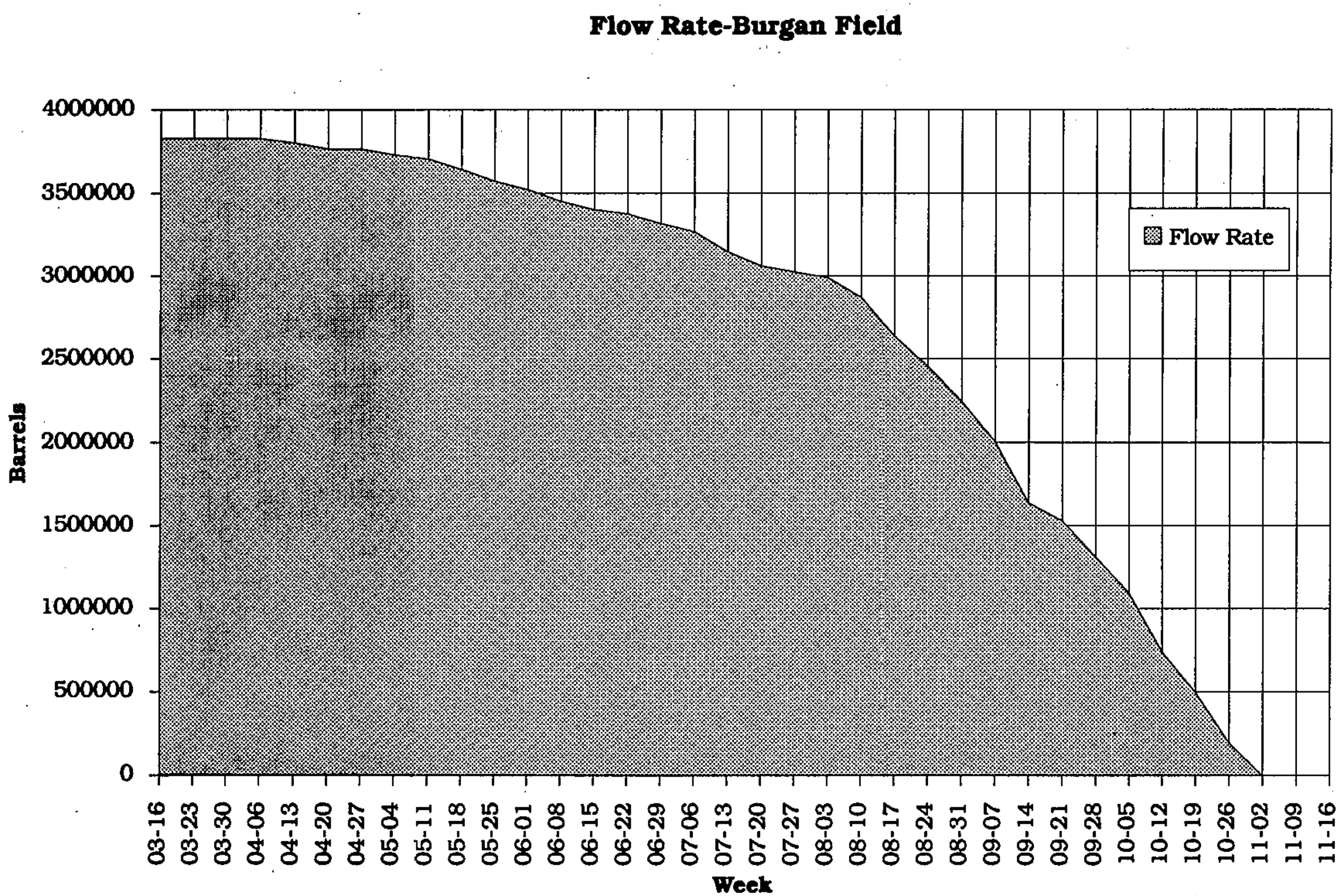
| Burgan Field History (Continued) | | | | | | |
|---|---|---|---|---|---|---|
| Well Number | Gathering Center | On Fire | Oil Spray | Damaged | Intact | Date Capped |
| 358 | 19 | 1 | | | | 8/18/91 |
| 359 | 21 | 1 | | | | 10/7/91 |
| 360 | 11 | 1 | | | | 8/11/91 |
| 361 | 11 | | | 1 | | 6/19/91 |
| 362 | 11 | | | | 1 | |
| 363 | 3 | | | 1 | | |
| 364 | 14 | | | | 1 | |
| 365 | 14 | | | | 1 | |
| 366 | 13 | 1 | | | | 7/12/91 |
| 367 | 13 | | | | 1 | |
| 368 | 3 | 1 | | | | 10/29/91 |
| 369 | 13 | | | | 1 | |
| 370 | 21 | 1 | | | | 10/17/91 |
| 372 | 6 | 1 | | | | 10/9/91 |
| 373 | 6 | | | | 1 | |
| 374 | 21 | | | 1 | | |
| 375 | 21 | 1 | | | | 10/23/91 |
| 376 | 21 | 1 | | | | 10/31/91 |
| 377 | 21 | 1 | | | | 10/27/91 |
| 378 | 21 | 1 | | | | 10/25/91 |
| 379 | 5 | 1 | | | | 9/21/91 |
| 380 | 7 | 1 | | | | 10/23/91 |
| 381 | 14 | | 1 | | | 5/4/91 |
| 382 | 14 | | 1 | | | 4/18/91 |
| 383 | 2 | | 1 | | | 4/9/91 |
| 384 | 19 | | | 1 | | |
| 385 | 19 | | | 1 | | 4/8/91 |
| 386 | 14 | 1 | | | | 8/13/91 |
| 387 | 14 | | | 1 | | 8/9/91 |
| 388 | 1 | 1 | | | | 9/22/91 |
| 389 | 11 | | | 1 | | 5/8/91 |
| 390 | 11 | | | | 1 | |
| 391 | 11 | | 1 | | | 8/27/91 |
| 392 | 19 | | | 1 | | 3/25/91 |
| 393 | 11 | | | | 1 | |
| 396 | 4 | | | | 1 | |
| 397 | 2 | 1 | | | | 9/2/91 |
| 398 | 8 | | | | 1 | |
| 399 | 5 | 1 | | | | 9/16/91 |
| 399B | 5 | | | | 1 | |
| 400 | 14 | | | | 1 | |
| 401 | 14 | | | | 1 | |
| 402 | 14 | | | | 1 | |
| 403 | 19 | 1 | | | | 5/21/91 |
| 404 | 14 | | | | 1 | |
| 405 | 14 | | | | 1 | |
| 406 | 14 | | | | 1 | |
| 407 | 19 | | | 1 | | |
| 408 | 19 | 1 | | | | 8/14/91 |
| 409 | 14 | 1 | | | | 5/17/91 |

| Burgan Field History (Continued) | | | | | | |
|---|---|---|---|---|---|---|
| **Well Number** | **Gathering Center** | **On Fire** | **Oil Spray** | **Damaged** | **Intact** | **Date Capped** |
| 411 | 19 | | | | 1 | |
| 412 | 14 | | 1 | | | 5/4/91 |
| 413 | 7 | | 1 | | | 5/27/91 |
| 415 | 14 | | | | 1 | |
| 416 | 11 | | | 1 | | |
| 418 | 13 | | | 1 | | |
| 419 | 1 | | | 1 | | |
| 420 | 1 | 1 | | | | 6/5/91 |
| 421 | 7 | | | 1 | | |
| 422 | 7 | | | 1 | | |
| 423 | 11 | | | 1 | | |
| | | | | | | |
| **Wells** | | **290** | **25** | **30** | | |
| **Controlled** | | **290** | **25** | **16** | | |
| | | | | | | |
| **Remaining** | | **0** | **0** | **14** | | |

| Burgan Field Summary | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| | On | Oil | | Flow | Flow | |
| Week | Fire | Spray | Damaged | (bbs/day) | (kgs/sec) | |
| 03-16 | 290 | 25 | 30 | 3829218.75 | 6203.33 | |
| 03-23 | 290 | 25 | 30 | 3829219 | 6203.33 | |
| 03-30 | 290 | 25 | 29 | 3829219 | 6203.33 | |
| 04-06 | 290 | 25 | 29 | 3829219 | 6203.33 | |
| 04-13 | 290 | 23 | 28 | 3804906 | 6163.95 | |
| 04-20 | 288 | 22 | 28 | 3768438 | 6104.87 | |
| 04-27 | 288 | 22 | 28 | 3768438 | 6104.87 | |
| 05-04 | 288 | 19 | 26 | 3731969 | 6045.79 | |
| 05-11 | 287 | 18 | 25 | 3707656 | 6006.40 | |
| 05-18 | 283 | 17 | 25 | 3646875 | 5907.94 | |
| 05-25 | 277 | 17 | 25 | 3573938 | 5789.78 | |
| 06-01 | 274 | 16 | 24 | 3525313 | 5711.01 | |
| 06-08 | 273 | 11 | 23 | 3452375 | 5592.85 | |
| 06-15 | 270 | 10 | 22 | 3403750 | 5514.08 | |
| 06-22 | 268 | 10 | 20 | 3379438 | 5474.69 | |
| 06-29 | 265 | 8 | 20 | 3318656 | 5376.22 | |
| 07-06 | 261 | 8 | 20 | 3270031 | 5297.45 | |
| 07-13 | 253 | 6 | 20 | 3148469 | 5100.52 | |
| 07-20 | 247 | 5 | 19 | 3063375 | 4962.67 | |
| 07-27 | 244 | 5 | 18 | 3026906 | 4903.59 | |
| 08-03 | 241 | 5 | 17 | 2990438 | 4844.51 | |
| 08-10 | 233 | 3 | 16 | 2868875 | 4647.58 | |
| 08-17 | 215 | 2 | 16 | 2637906 | 4273.41 | |
| 08-24 | 200 | 2 | 16 | 2455563 | 3978.01 | |
| 08-31 | 184 | 1 | 16 | 2248906 | 3643.23 | |
| 09-07 | 164 | 1 | 16 | 2005781 | 3249.37 | |
| 09-14 | 134 | 1 | 16 | 1641094 | 2658.57 | |
| 09-21 | 125 | 1 | 16 | 1531688 | 2481.33 | |
| 09-28 | 107 | 1 | 16 | 1312875 | 2126.86 | |
| 10-05 | 89 | 1 | 16 | 1094063 | 1772.38 | |
| 10-12 | 61 | 0 | 16 | 741531 | 1201.28 | |
| 10-19 | 41 | 0 | 14 | 498406 | 807.42 | |
| 10-26 | 16 | 0 | 14 | 194500 | 315.09 | |
| 11-02 | 0 | 0 | 14 | 0 | 0.00 | |
| 11-09 | 0 | 0 | 14 | 0 | 0.00 | |
| 11-16 | 0 | 0 | 14 | 0 | 0.00 | |
| | | | | | | |

## Burgan Field-Oil Well Status



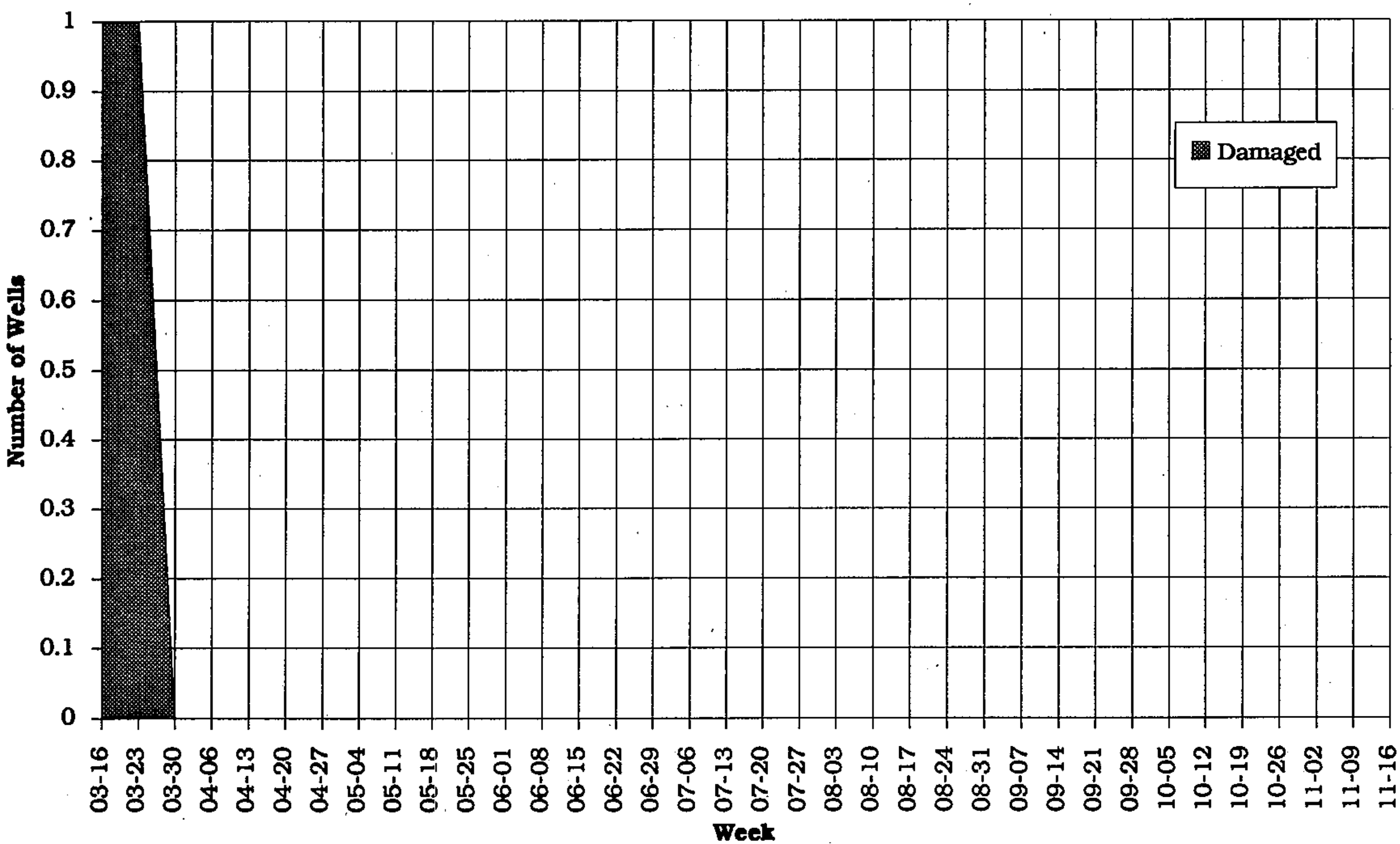

Flow Rate-Burgan Field
Barrels
4000000
3500000
3000000
2500000
2000000
1500000
1000000
500000
0
Flow Rate
Week
03-16
03-23
03-30
04-06
04-13
04-20
04-27
05-04
05-11
05-18
05-25
06-01
06-08
06-15
06-22
06-29
07-06
07-13
07-20
07-27
08-03
08-10
08-17
08-24
08-31
09-07
09-14
09-21
09-28
10-05
10-12
10-19
10-26
11-02
11-09
11-16

| Dharif Field History | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| Well Number | Gathering Center | On Fire | Oil Spray | Damaged | Intact | Date Capped |
| 1 | 10 | | | | 1 | |
| 3 | 10 | | | | 1 | |
| 4 | 10 | | | | 1 | |
| | | | | | | |
| Wells | | 0 | 0 | 0 | | |
| Controlled | | 0 | 0 | 0 | | |
| | | | | | | |
| Remaining | | 0 | 0 | 0 | | |

| Khashman Field History | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| Well Number | Gathering Center | On Fire | Oil Spray | Damaged | Intact | Date Capped |
| 5 | 9 | | | 1 | | 3/28/91 |
| 6 | 9 | | | | 1 | |
| | | | | | | |
| **Wells** | | **0** | **0** | **1** | | |
| **Controlled** | | **0** | **0** | **1** | | |
| | | | | | | |
| **Remaining** | | **0** | **0** | **0** | | |

| Khashman Field Summary | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| | On | Oil | | Flow | Flow | |
| Week | Fire | Spray | Damaged | (bbs/day) | (kgs/sec) | |
| 03-16 | 0 | 0 | 1 | 0 | 0.00 | |
| 03-23 | 0 | 0 | 1 | 0 | 0.00 | |
| 03-30 | 0 | 0 | 0 | 0 | 0.00 | |
| 04-06 | 0 | 0 | 0 | 0 | 0.00 | |
| 04-13 | 0 | 0 | 0 | 0 | 0.00 | |
| 04-20 | 0 | 0 | 0 | 0 | 0.00 | |
| 04-27 | 0 | 0 | 0 | 0 | 0.00 | |
| 05-04 | 0 | 0 | 0 | 0 | 0.00 | |
| 05-11 | 0 | 0 | 0 | 0 | 0.00 | |
| 05-18 | 0 | 0 | 0 | 0 | 0.00 | |
| 05-25 | 0 | 0 | 0 | 0 | 0.00 | |
| 06-01 | 0 | 0 | 0 | 0 | 0.00 | |
| 06-08 | 0 | 0 | 0 | 0 | 0.00 | |
| 06-15 | 0 | 0 | 0 | 0 | 0.00 | |
| 06-22 | 0 | 0 | 0 | 0 | 0.00 | |
| 06-29 | 0 | 0 | 0 | 0 | 0.00 | |
| 07-06 | 0 | 0 | 0 | 0 | 0.00 | |
| 07-13 | 0 | 0 | 0 | 0 | 0.00 | |
| 07-20 | 0 | 0 | 0 | 0 | 0.00 | |
| 07-27 | 0 | 0 | 0 | 0 | 0.00 | |
| 08-03 | 0 | 0 | 0 | 0 | 0.00 | |
| 08-10 | 0 | 0 | 0 | 0 | 0.00 | |
| 08-17 | 0 | 0 | 0 | 0 | 0.00 | |
| 08-24 | 0 | 0 | 0 | 0 | 0.00 | |
| 08-31 | 0 | 0 | 0 | 0 | 0.00 | |
| 09-07 | 0 | 0 | 0 | 0 | 0.00 | |
| 09-14 | 0 | 0 | 0 | 0 | 0.00 | |
| 09-21 | 0 | 0 | 0 | 0 | 0.00 | |
| 09-28 | 0 | 0 | 0 | 0 | 0.00 | |
| 10-05 | 0 | 0 | 0 | 0 | 0.00 | |
| 10-12 | 0 | 0 | 0 | 0 | 0.00 | |
| 10-19 | 0 | 0 | 0 | 0 | 0.00 | |
| 10-26 | 0 | 0 | 0 | 0 | 0.00 | |
| 11-02 | 0 | 0 | 0 | 0 | 0.00 | |
| 11-09 | 0 | 0 | 0 | 0 | 0.00 | |
| 11-16 | 0 | 0 | 0 | 0 | 0.00 | |
| | | | | | | |

## Khashman Field-Oil Well Status



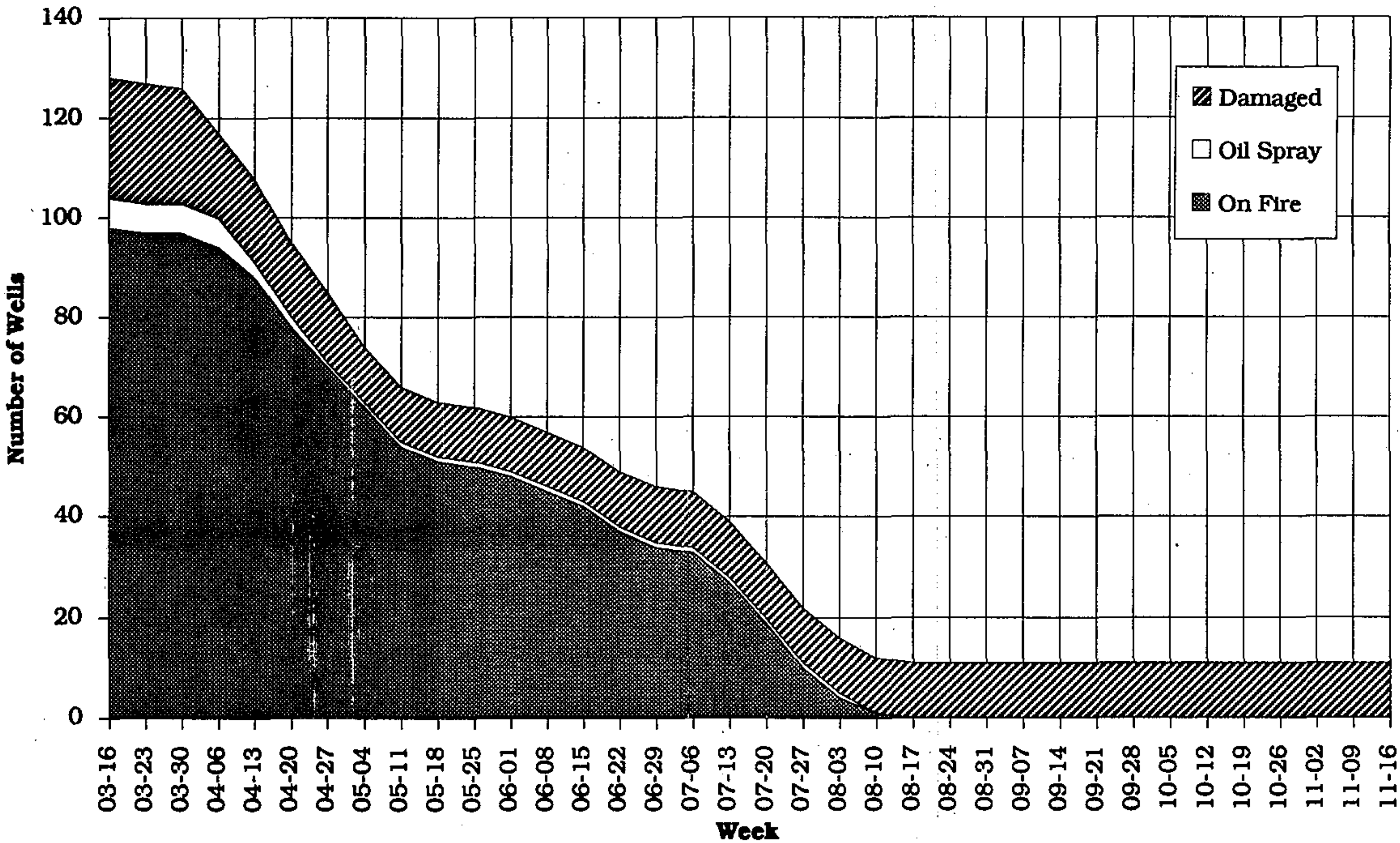
| Magwa Field History | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| Well Number | Gathering Center | On Fire | Oil Spray | Damaged | Intact | Date Capped |
| 1 | 9 | 1 | | | | 5/17/91 |
| 2 | 9 | | 1 | | | 4/25/91 |
| 3 | 10 | 1 | | | | 7/25/91 |
| 4 | 9 | | | 1 | | 4/2/91 |
| 5 | 10 | 1 | | | | 7/11/91 |
| 6 | 9 | 1 | | | | 5/22/91 |
| 7 | 10 | 1 | | | | 4/28/91 |
| 8 | 9 | 1 | | | | 5/2/91 |
| 9 | 10 | 1 | | | | 4/27/91 |
| 10 | 10 | | | | 1 | |
| 11 | 9 | 1 | | | | 7/15/91 |
| 12 | 10 | 1 | | | | 4/10/91 |
| 13 | 9 | | | 1 | | 4/22/91 |
| 14 | 10 | 1 | | | | 7/16/91 |
| 15 | 9 | 1 | | | | 5/10/91 |
| 16 | 10 | 1 | | | | 4/25/91 |
| 17 | 10 | 1 | | | | 4/29/91 |
| 18 | 9 | | | 1 | | 4/3/91 |
| 19 | 20 | | | | 1 | |
| 20 | 9 | | | 1 | | 4/5/91 |
| 21 | 20 | 1 | | | | 7/22/91 |
| 22 | 10 | 1 | | | | 4/21/91 |
| 23 | 10 | 1 | | | | 6/29/91 |
| 24 | 9 | 1 | | | | 5/5/91 |
| 25 | 10 | 1 | | | | 5/28/91 |
| 26 | 10 | 1 | | | | 7/22/91 |
| 27 | 20 | 1 | | | | 4/9/91 |
| 28 | 10 | | | | 1 | |
| 29 | 10 | 1 | | | | 8/9/91 |
| 30 | 22 | 1 | | | | 7/18/91 |
| 31 | 22 | 1 | | | | 7/11/91 |
| 32 | 10 | 1 | | | | 7/13/91 |
| 33 | 10 | 1 | | | | 4/20/91 |
| 34 | 10 | 1 | | | | 4/15/91 |
| 35 | 9 | 1 | | | | 7/24/91 |
| 37 | 10 | 1 | | | | 4/26/91 |
| 38 | 9 | 1 | | | | 7/26/91 |
| 39 | 9 | 1 | | | | 7/11/91 |
| 40 | 9 | 1 | | | | 6/7/91 |
| 42 | 9 | 1 | | | | 4/30/91 |
| 43 | 9 | 1 | | | | 7/20/91 |
| 44 | 9 | 1 | | | | 4/6/91 |
| 45 | 20 | | 1 | | | 4/10/91 |
| 46 | 10 | 1 | | | | 8/14/91 |
| 47 | 19 | 1 | | | | 8/5/91 |
| 48 | 9 | 1 | | | | 5/11/91 |
| 49 | 10 | 1 | | | | 7/10/91 |
| 50 | 10 | 1 | | | | 7/8/91 |
| 51 | 10 | | | 1 | | 4/16/91 |
| 52 | 9 | 1 | | | | 8/3/91 |

| Magwa Field History (Continued) | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| Well Number | Gathering Center | On Fire | Oil Spray | Damaged | Intact | Date Capped |
| 53 | 9 | 1 | | | | 8/3/91 |
| 54 | 9 | | | 1 | | 4/3/91 |
| 55 | 9 | 1 | | | | 5/26/91 |
| 56 | 9 | 1 | | | | 4/19/91 |
| 57 | 9 | 1 | | | | 6/14/91 |
| 58 | 9 | 1 | | | | 4/21/91 |
| 59 | 9 | 1 | | | | 4/8/91 |
| 60 | 9 | 1 | | | | 6/28/91 |
| 61 | 9 | | 1 | | | 4/12/91 |
| 62 | 9 | 1 | | | | 7/30/91 |
| 63 | 10 | 1 | | | | 7/14/91 |
| 65 | 9 | | | 1 | | Abandoned |
| 67 | 9 | | | 1 | | |
| 68 | 9 | | | 1 | | |
| 69 | 9 | 1 | | | | 4/28/91 |
| 70 | 20 | | | 1 | | 4/29/91 |
| 71 | 20 | | | 1 | | 3/26/91 |
| 72 | 9 | | | | 1 | |
| 73 | 20 | | | | 1 | |
| 74 | 20 | | | | 1 | |
| 75 | 10 | 1 | | | | 5/10/91 |
| 76 | 20 | 1 | | | | 4/15/91 |
| 77 | 20 | 1 | | | | 3/23/91 |
| 78 | 10 | 1 | | | | 5/6/91 |
| 79 | 10 | 1 | | | | 4/19/91 |
| 80 | 10 | | | | 1 | |
| 81 | 10 | 1 | | | | 4/17/91 |
| 82 | 10 | 1 | | | | 6/20/91 |
| 83 | 10 | | | 1 | | |
| 84 | 10 | 1 | | | | 7/4/91 |
| 85 | 10 | 1 | | | | 4/14/91 |
| 86 | 9 | 1 | | | | 5/6/91 |
| 87 | 9 | 1 | | | | 4/13/91 |
| 88 | 9 | 1 | | | | 5/4/91 |
| 89 | 9 | 1 | | | | 4/26/91 |
| 90 | 9 | 1 | | | | 4/27/91 |
| 91 | 9 | | | 1 | | 4/29/91 |
| 92 | 10 | 1 | | | | 8/1/91 |
| 93 | 10 | | | | 1 | |
| 94 | 10 | 1 | | | | 4/14/91 |
| 95 | 22 | 1 | | | | 7/21/91 |
| 96 | 22 | 1 | | | | 7/16/91 |
| 97 | 22 | 1 | | | | 6/20/91 |
| 98 | 10 | 1 | | | | 4/16/91 |
| 99 | 10 | 1 | | | | 4/13/91 |
| 100 | 10 | 1 | | | | 4/17/91 |
| 101 | 10 | | | | 1 | |
| 102 | 10 | 1 | | | | 5/5/91 |
| 103 | 10 | | 1 | | | 8/6/91 |
| 104 | 10 | 1 | | | | 4/12/91 |

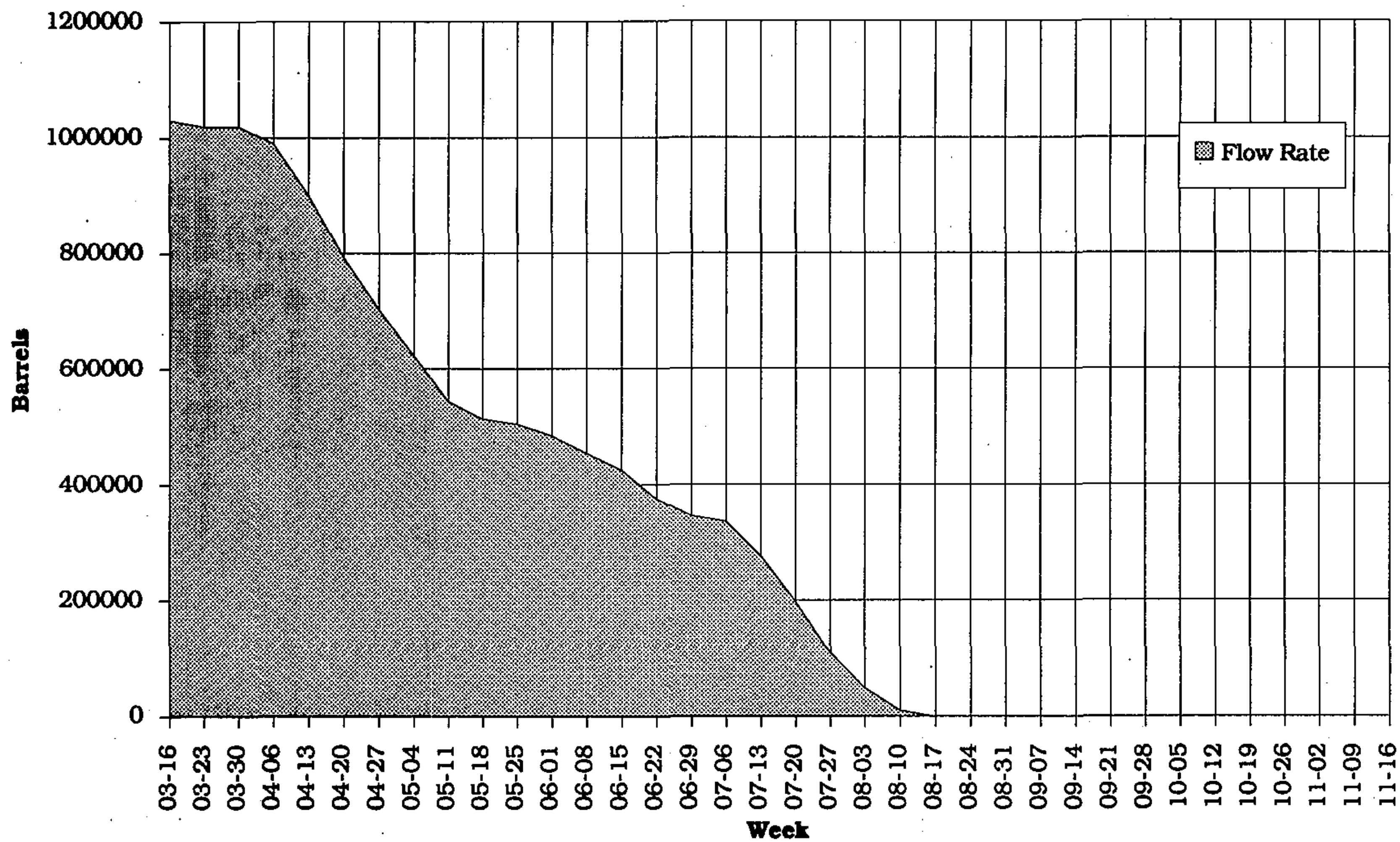
| Magwa Field History (Continued) | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| **Well Number** | **Gathering Center** | **On Fire** | **Oil Spray** | **Damaged** | **Intact** | **Date Capped** |
| 105 | 10 | | | | 1 | |
| 106 | 10 | | | | 1 | |
| 107 | 22 | 1 | | | | 7/19/91 |
| 108 | 9 | 1 | | | | 4/2/91 |
| 109 | 9 | 1 | | | | 4/23/91 |
| 111 | 10 | 1 | | | | 6/19/91 |
| 112 | 10 | 1 | | | | 6/6/91 |
| 113 | 10 | | | 1 | | 4/18/91 |
| 114 | 19 | 1 | | | | 8/2/91 |
| 115 | 10 | 1 | | | | 7/26/91 |
| 116 | 9 | 1 | | | | 5/12/91 |
| 117 | 9 | 1 | | | | 6/6/91 |
| 118 | 9 | 1 | | | | 4/4/91 |
| 119 | 10 | | | 1 | | 4/2/91 |
| 120 | 20 | 1 | | | | 6/13/91 |
| 121 | 9 | | 1 | | | 4/17/91 |
| 123 | 9 | 1 | | | | 6/21/91 |
| 124 | 10 | 1 | | | | 5/12/91 |
| 125 | 10 | 1 | | | | 6/20/91 |
| 126 | 10 | 1 | | | | 8/6/91 |
| 127 | 10 | | | 1 | | |
| 128 | 10 | | | 1 | | |
| 129 | 10 | 1 | | | | 7/27/91 |
| 130 | 10 | 1 | | | | 4/28/91 |
| 131 | 10 | 1 | | | | 5/3/91 |
| 132 | 10 | | | | 1 | |
| 133 | 10 | 1 | | | | 5/6/91 |
| 134 | 10 | 1 | | | | 8/3/91 |
| 135 | 10 | 1 | | | | 7/21/91 |
| 136 | 10 | | 1 | | | 4/11/91 |
| 137 | 10 | | | 1 | | |
| 138 | 10 | | | 1 | | |
| 139 | 10 | | | 1 | | |
| 141 | 10 | | | 1 | | |
| 142 | 10 | 1 | | | | 6/23/91 |
| 143 | 10 | | | 1 | | |
| 144 | 10 | 1 | | | | 7/18/91 |
| 145 | 10 | 1 | | | | 6/10/91 |
| 147 | 10 | | | 1 | | 5/2/91 |
| 148 | 9 | | | 1 | | 4/2/91 |
| | | | | | | |
| **Wells** | | **98** | **6** | **24** | | |
| **Controlled** | | **98** | **6** | **13** | | |
| | | | | | | |
| **Remaining** | | **0** | **0** | **11** | | |

| Magwa Field Summary | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| | On | Oil | | Flow | Flow | |
| **Week** | **Fire** | **Spray** | **Damaged** | **[bbs/day]** | **[kgs/sec]** | |
| 03-16 | 98 | 6 | 24 | 1030000 | 1668.60 | |
| 03-23 | 97 | 6 | 24 | 1020097 | 1652.56 | |
| 03-30 | 97 | 6 | 23 | 1020097 | 1652.56 | |
| 04-06 | 94 | 6 | 17 | 990385 | 1604.42 | |
| 04-13 | 88 | 3 | 17 | 901250 | 1460.03 | |
| 04-20 | 78 | 2 | 15 | 792308 | 1283.54 | |
| 04-27 | 70 | 1 | 14 | 703173 | 1139.14 | |
| 05-04 | 62 | 1 | 11 | 623943 | 1010.79 | |
| 05-11 | 54 | 1 | 11 | 544712 | 882.43 | |
| 05-18 | 51 | 1 | 11 | 515000 | 834.30 | |
| 05-25 | 50 | 1 | 11 | 505096 | 818.26 | |
| 06-01 | 48 | 1 | 11 | 485289 | 786.17 | |
| 06-08 | 45 | 1 | 11 | 455577 | 738.03 | |
| 06-15 | 42 | 1 | 11 | 425866 | 689.90 | |
| 06-22 | 37 | 1 | 11 | 376346 | 609.68 | |
| 06-29 | 34 | 1 | 11 | 346635 | 561.55 | |
| 07-06 | 33 | 1 | 11 | 336731 | 545.50 | |
| 07-13 | 27 | 1 | 11 | 277308 | 449.24 | |
| 07-20 | 19 | 1 | 11 | 198077 | 320.88 | |
| 07-27 | 10 | 1 | 11 | 108942 | 176.49 | |
| 08-03 | 4 | 1 | 11 | 49519 | 80.22 | |
| 08-10 | 1 | 0 | 11 | 9904 | 16.04 | |
| 08-17 | 0 | 0 | 11 | 0 | 0.00 | |
| 08-24 | 0 | 0 | 11 | 0 | 0.00 | |
| 08-31 | 0 | 0 | 11 | 0 | 0.00 | |
| 09-07 | 0 | 0 | 11 | 0 | 0.00 | |
| 09-14 | 0 | 0 | 11 | 0 | 0.00 | |
| 09-21 | 0 | 0 | 11 | 0 | 0.00 | |
| 09-28 | 0 | 0 | 11 | 0 | 0.00 | |
| 10-05 | 0 | 0 | 11 | 0 | 0.00 | |
| 10-12 | 0 | 0 | 11 | 0 | 0.00 | |
| 10-19 | 0 | 0 | 11 | 0 | 0.00 | |
| 10-26 | 0 | 0 | 11 | 0 | 0.00 | |
| 11-02 | 0 | 0 | 11 | 0 | 0.00 | |
| 11-09 | 0 | 0 | 11 | 0 | 0.00 | |
| 11-16 | 0 | 0 | 11 | 0 | 0.00 | |
| | | | | | | |

## Magwa Field-Oil Well Status



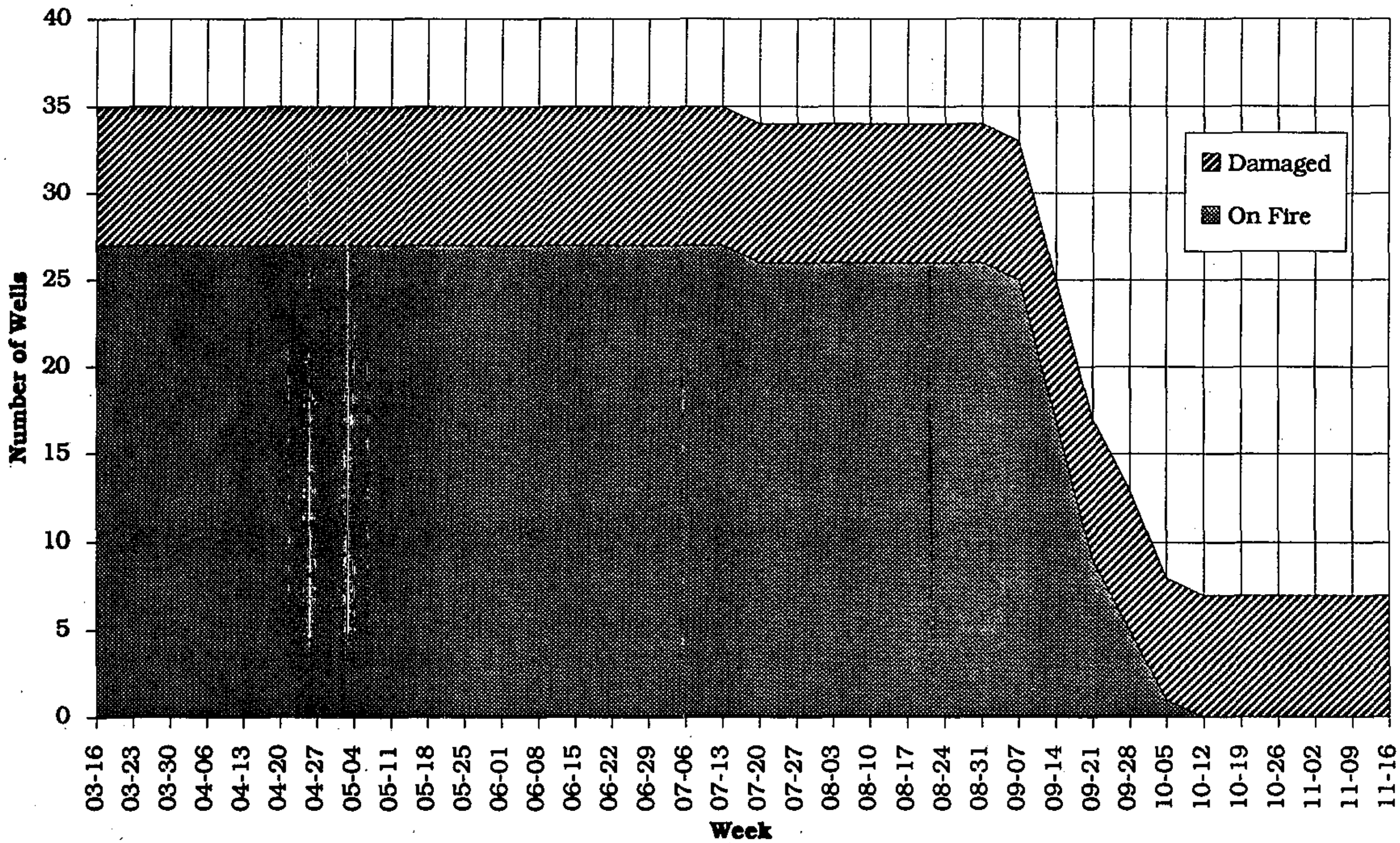
Flow Rate - Magwa Fields



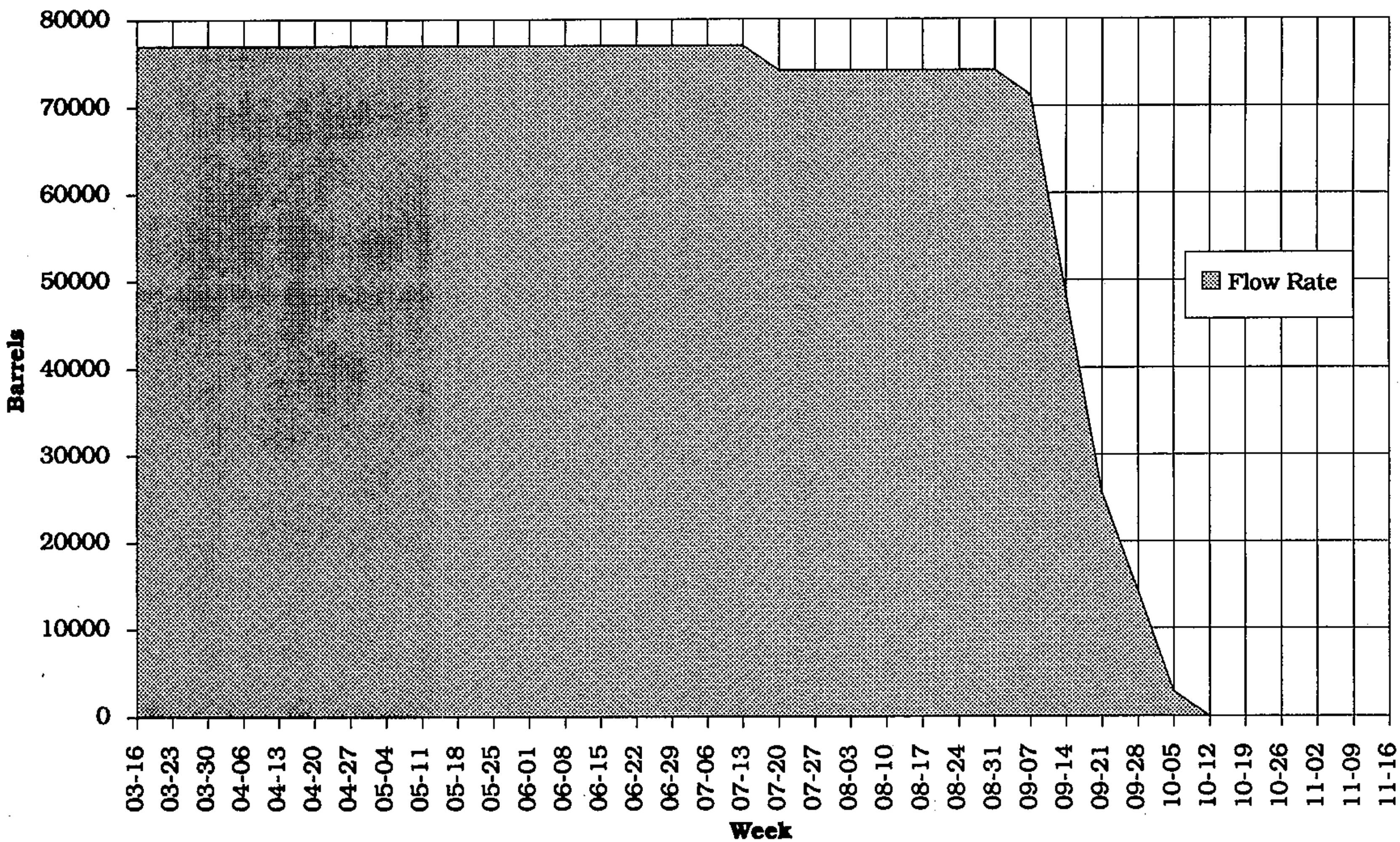
| Minagish Field History | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| **Well Number** | **Gathering Center** | **On Fire** | **Oil Spray** | **Damaged** | **Intact** | **Date Capped** |
| 1 | 16 | 1 | | | | 9/18/91 |
| 2 | 16 | 1 | | | | 9/21/91 |
| 3 | 16 | 1 | | | | 9/16/91 |
| 4 | 16 | 1 | | | | 9/11/91 |
| 6 | 16 | 1 | | | | 9/26/91 |
| 7 | 16 | 1 | | | | 9/19/91 |
| 8 | 16 | 1 | | | | 10/4/91 |
| 9 | 16 | 1 | | | | 9/28/91 |
| 10 | 16 | 1 | | | | 10/9/91 |
| 11 | 16 | 1 | | | | 9/29/91 |
| 12 | 16 | 1 | | | | 9/29/91 |
| 13 | 16 | | | 1 | | |
| 14 | 16 | | | 1 | | 9/30/91 |
| 18 | 16 | | | 1 | | |
| 19 | 16 | 1 | | | | 9/24/91 |
| 20 | 16 | | | 1 | | |
| 21 | 16 | 1 | | | | 10/5/91 |
| 22 | 16 | | | 1 | | |
| 23 | 16 | 1 | | | | 9/9/91 |
| 25 | 16 | | | 1 | | |
| 26 | 16 | | | 1 | | |
| 27 | 16 | 1 | | | | 9/17/91 |
| 28 | 16 | 1 | | | | 9/18/91 |
| 29 | 16 | 1 | | | | 9/26/91 |
| 30 | 16 | 1 | | | | 9/12/91 |
| 31 | 16 | | | 1 | | |
| 32 | 16 | 1 | | | | 9/19/91 |
| 33 | 16 | 1 | | | | 9/19/91 |
| 34 | 16 | 1 | | | | 9/10/91 |
| 35 | 16 | 1 | | | | 9/8/91 |
| 36 | 16 | 1 | | | | 9/8/91 |
| 37 | 16 | 1 | | | | 9/12/91 |
| 38 | 16 | 1 | | | | 9/13/91 |
| 39 | 16 | 1 | | | | 7/19/91 |
| 40 | 16 | 1 | | | | 9/7/91 |
| | | | | | | |
| **Wells** | | **27** | **0** | **8** | | |
| **Controlled** | | **27** | **0** | **1** | | |
| | | | | | | |
| **Remaining** | | **0** | **0** | **7** | | |

| Minagish Field Summary | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| Week | On Fire | Oil Spray | Damaged | Flow (bbs/day) | Flow (kgs/sec) | |
| 03-16 | 27 | 0 | 8 | 77000 | 124.74 | |
| 03-23 | 27 | 0 | 8 | 77000 | 124.74 | |
| 03-30 | 27 | 0 | 8 | 77000 | 124.74 | |
| 04-06 | 27 | 0 | 8 | 77000 | 124.74 | |
| 04-13 | 27 | 0 | 8 | 77000 | 124.74 | |
| 04-20 | 27 | 0 | 8 | 77000 | 124.74 | |
| 04-27 | 27 | 0 | 8 | 77000 | 124.74 | |
| 05-04 | 27 | 0 | 8 | 77000 | 124.74 | |
| 05-11 | 27 | 0 | 8 | 77000 | 124.74 | |
| 05-18 | 27 | 0 | 8 | 77000 | 124.74 | |
| 05-25 | 27 | 0 | 8 | 77000 | 124.74 | |
| 06-01 | 27 | 0 | 8 | 77000 | 124.74 | |
| 06-08 | 27 | 0 | 8 | 77000 | 124.74 | |
| 06-15 | 27 | 0 | 8 | 77000 | 124.74 | |
| 06-22 | 27 | 0 | 8 | 77000 | 124.74 | |
| 06-29 | 27 | 0 | 8 | 77000 | 124.74 | |
| 07-06 | 27 | 0 | 8 | 77000 | 124.74 | |
| 07-13 | 27 | 0 | 8 | 77000 | 124.74 | |
| 07-20 | 26 | 0 | 8 | 74148 | 120.12 | |
| 07-27 | 26 | 0 | 8 | 74148 | 120.12 | |
| 08-03 | 26 | 0 | 8 | 74148 | 120.12 | |
| 08-10 | 26 | 0 | 8 | 74148 | 120.12 | |
| 08-17 | 26 | 0 | 8 | 74148 | 120.12 | |
| 08-24 | 26 | 0 | 8 | 74148 | 120.12 | |
| 08-31 | 26 | 0 | 8 | 74148 | 120.12 | |
| 09-07 | 25 | 0 | 8 | 71296 | 115.50 | |
| 09-14 | 17 | 0 | 8 | 48481 | 78.54 | |
| 09-21 | 9 | 0 | 8 | 25667 | 41.58 | |
| 09-28 | 5 | 0 | 8 | 14259 | 23.10 | |
| 10-05 | 1 | 0 | 7 | 2852 | 4.62 | |
| 10-12 | 0 | 0 | 7 | 0 | 0.00 | |
| 10-19 | 0 | 0 | 7 | 0 | 0.00 | |
| 10-26 | 0 | 0 | 7 | 0 | 0.00 | |
| 11-02 | 0 | 0 | 7 | 0 | 0.00 | |
| 11-09 | 0 | 0 | 7 | 0 | 0.00 | |
| 11-16 | 0 | 0 | 7 | 0 | 0.00 | |
| | | | | | | |

## Minagish Field-Oil Well Status



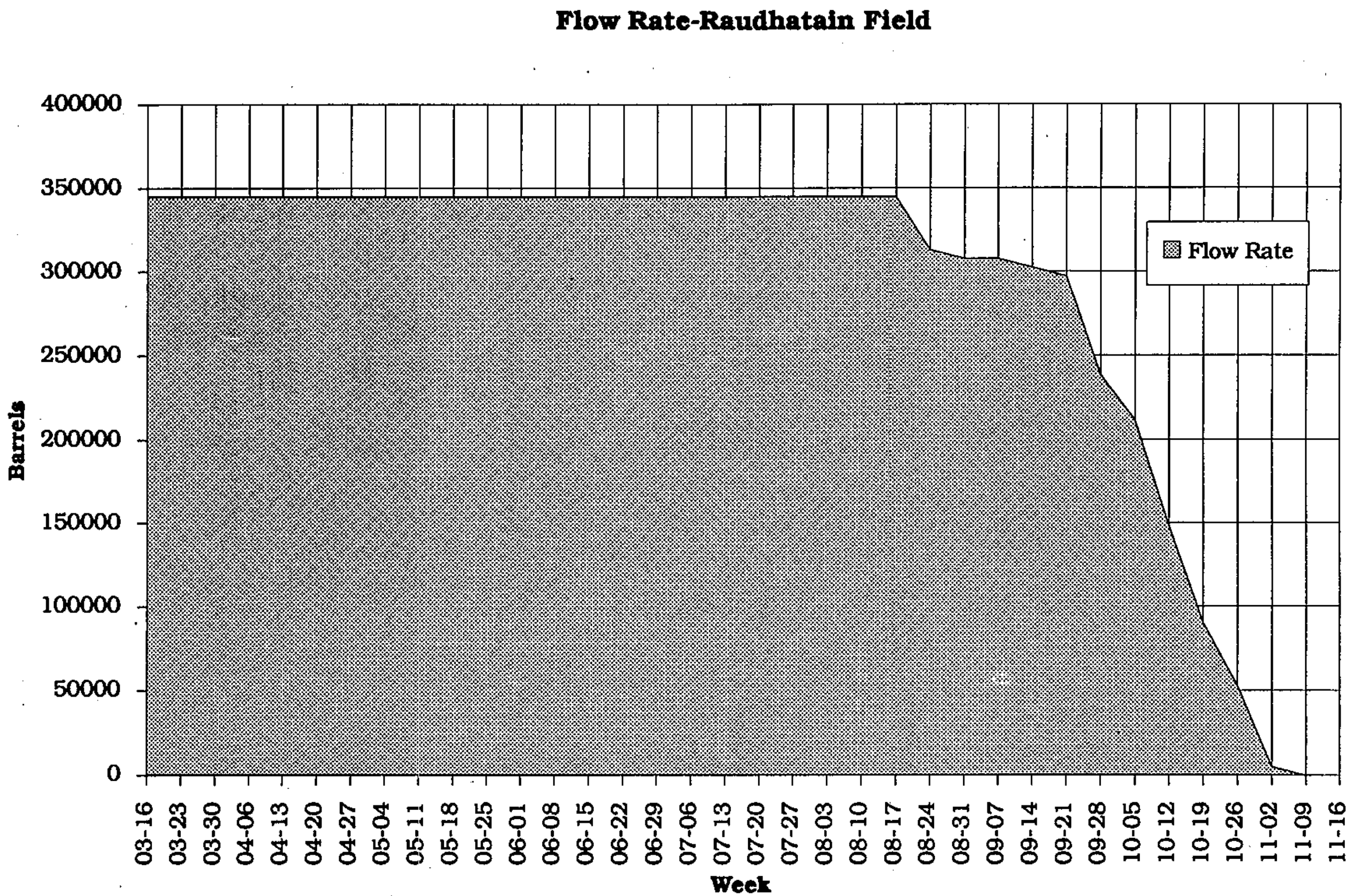
## Flow Rate - Minagish Fields



| Raudhatian Field History | | | | | | |
|---|---|---|---|---|---|---|
| **Well Number** | **Gathering Center** | **On Fire** | **Oil Spray** | **Damaged** | **Intact** | **Date Capped** |
| 1 | 15 | 1 | | | | 9/24/91 |
| 2 | 15 | | 1 | | | 8/23/91 |
| 3 | 25 | 1 | | | | 9/25/91 |
| 4 | 25 | 1 | | | | 10/6/91 |
| 5 | 25 | 1 | | | | 10/11/91 |
| 6 | 15 | 1 | | | | 8/21/91 |
| 7 | 15 | 1 | | | | 10/22/91 |
| 8 | 25 | 1 | | | | 9/30/91 |
| 9 | 25 | 1 | | | | 10/23/91 |
| 10 | 15 | 1 | | | | 9/26/91 |
| 11 | 15 | 1 | | | | 8/26/91 |
| 12 | 25 | 1 | | | | 9/27/91 |
| 13 | 25 | 1 | | | | 10/31/91 |
| 14 | 15 | 1 | | | | 10/31/91 |
| 15 | 25 | 1 | | | | 9/24/91 |
| 16 | 15 | 1 | | | | 10/9/91 |
| 17 | 25 | 1 | | | | 10/18/91 |
| 18 | 15 | 1 | | | | 10/7/91 |
| 19 | 25 | 1 | | | | 9/22/91 |
| 20 | 15 | 1 | | | | 10/30/91 |
| 21 | 15 | 1 | | | | 10/30/91 |
| 22 | 25 | 1 | | | | 10/2/91 |
| 23 | 25 | 1 | | | | 10/6/91 |
| 24 | 15 | 1 | 1 | | | 10/13/91 |
| 25 | 25 | 1 | | | | 10/6/91 |
| 26 | 15 | 1 | | | | 10/25/91 |
| 27 | 15 | 1 | | | | 9/17/91 |
| 30 | 15 | 1 | | | | 10/30/91 |
| 33 | 25 | 1 | | | | 10/15/91 |
| 34 | 15 | 1 | | | | 11/1/91 |
| 35 | 15 | 1 | | | | 10/19/91 |
| 36 | 15 | 1 | | | | 9/23/91 |
| 37 | 25 | 1 | | | | 10/3/91 |
| 38 | 15 | 1 | | | | 10/9/91 |
| 43 | 15 | | | | 1 | |
| 44 | 15 | | 1 | | | 8/18/91 |
| 45 | 15 | 1 | | | | 10/23/91 |
| 46 | 15 | 1 | | | | 11/6/91 |
| 47 | 15 | 1 | | | | 10/25/91 |
| 48 | 15 | 1 | | | | 10/10/91 |
| 49 | 15 | 1 | | | | 10/29/91 |
| 50 | 15 | 1 | | | | 10/17/91 |
| 51 | 15 | 1 | | | | 10/18/91 |
| 52 | 25 | 1 | | | | 10/4/91 |
| 53 | 25 | 1 | | | | 9/13/91 |
| 54 | 25 | 1 | | | | 9/27/91 |
| 55 | 15 | 1 | | | | 10/15/91 |
| 56 | 15 | 1 | | | | 9/25/91 |
| 57 | 15 | 1 | | | | 10/9/91 |
| 58 | 25 | 1 | | | | 10/21/91 |

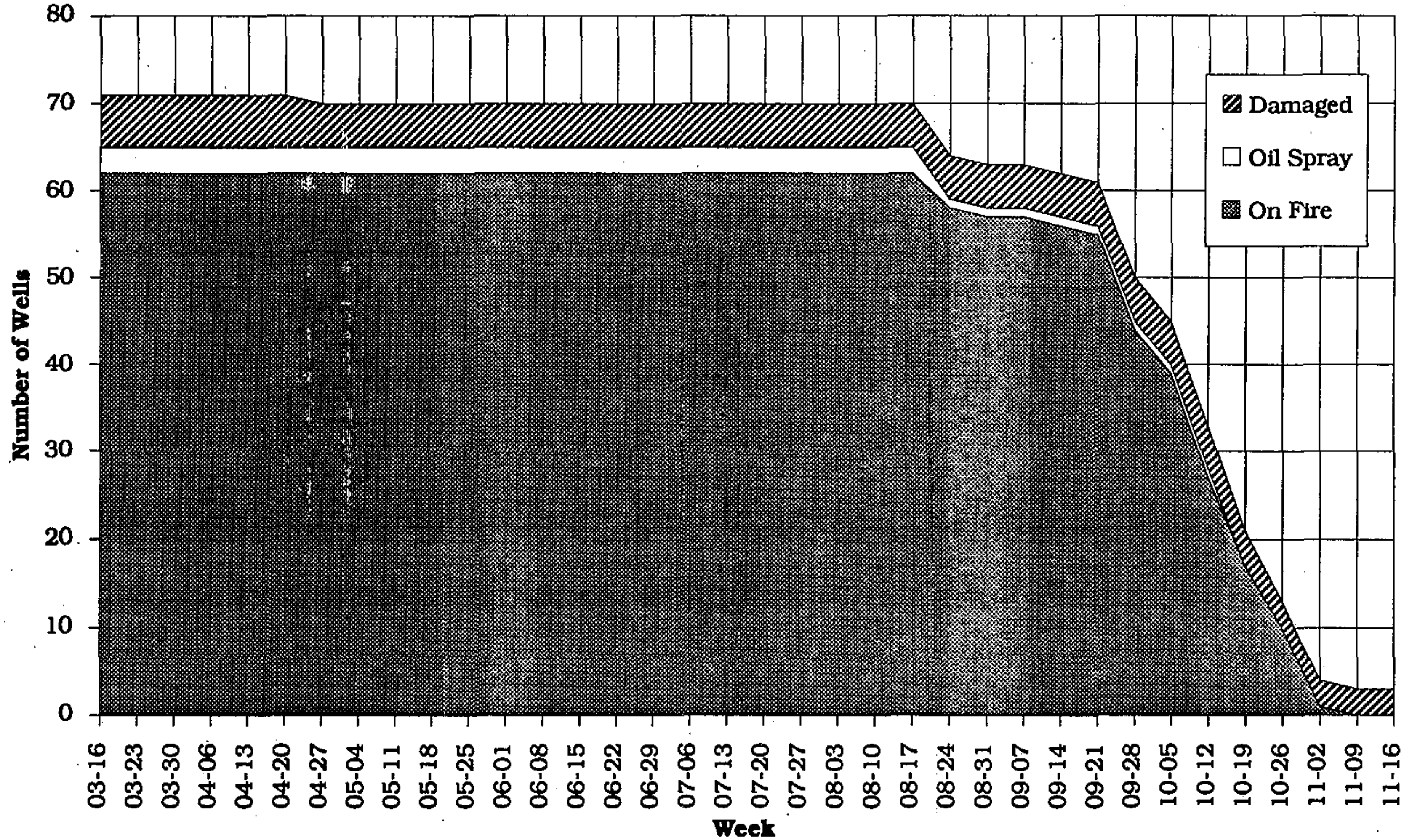
| Raudhatian Field History (Continued) | | | | | | |
|---|---|---|---|---|---|---|
| Well Number | Gathering Center | On Fire | Oil Spray | Damaged | Intact | Date Capped |
| 59 | 15 | | | | 1 | |
| 61 | 25 | | | | 1 | |
| 62 | 15 | 1 | | | | 10/24/91 |
| 63 | 25 | 1 | | | | 10/17/91 |
| 64 | 15 | | | 1 | | 10/26/91 |
| 65 | 15 | | | 1 | | |
| 66 | 15 | 1 | | | | 10/15/91 |
| 67 | 15 | 1 | | | | 10/18/91 |
| 68 | 25 | 1 | | | | 8/24/91 |
| 69 | 25 | 1 | | | | 9/23/91 |
| 70 | 15 | | | 1 | | |
| 71 | 15 | | | 1 | | 10/15/91 |
| 72 | 15 | | | 1 | | |
| 73 | 15 | 1 | | | | 10/31/91 |
| 74 | 15 | 1 | | | | 10/4/91 |
| 75 | 15 | 1 | | | | 8/19/91 |
| 76 | 25 | 1 | | | | 10/28/91 |
| 77 | 25 | 1 | | | | 8/21/91 |
| 78 | 25 | 1 | | | | 10/10/91 |
| 79 | 25 | 1 | | | | 10/10/91 |
| 80 | 15 | 1 | | | | 10/12/91 |
| 83 | 25 | | | 1 | | 4/23/91 |
| 84 | 25 | 1 | | | | 9/23/91 |
| 85 | 15 | | | | 1 | |
| | | | | | | |
| **Wells** | | 62 | 3 | 6 | | |
| **Controlled** | | 62 | 3 | 3 | | |
| | | | | | | |
| **Remaining** | | 0 | 0 | 3 | | |

| Raudhatian Field Summary | | | | | | |
|---|---|---|---|---|---|---|
| Week | On Fire | Oil Spray | Damaged | Flow (bbs/day) | Flow (kgs/sec) | |
| 03-16 | 62 | 3 | 6 | 345000 | 558.90 | |
| 03-23 | 62 | 3 | 6 | 345000 | 558.90 | |
| 03-30 | 62 | 3 | 6 | 345000 | 558.90 | |
| 04-06 | 62 | 3 | 6 | 345000 | 558.90 | |
| 04-13 | 62 | 3 | 6 | 345000 | 558.90 | |
| 04-20 | 62 | 3 | 6 | 345000 | 558.90 | |
| 04-27 | 62 | 3 | 5 | 345000 | 558.90 | |
| 05-04 | 62 | 3 | 5 | 345000 | 558.90 | |
| 05-11 | 62 | 3 | 5 | 345000 | 558.90 | |
| 05-18 | 62 | 3 | 5 | 345000 | 558.90 | |
| 05-25 | 62 | 3 | 5 | 345000 | 558.90 | |
| 06-01 | 62 | 3 | 5 | 345000 | 558.90 | |
| 06-08 | 62 | 3 | 5 | 345000 | 558.90 | |
| 06-15 | 62 | 3 | 5 | 345000 | 558.90 | |
| 06-22 | 62 | 3 | 5 | 345000 | 558.90 | |
| 06-29 | 62 | 3 | 5 | 345000 | 558.90 | |
| 07-06 | 62 | 3 | 5 | 345000 | 558.90 | |
| 07-13 | 62 | 3 | 5 | 345000 | 558.90 | |
| 07-20 | 62 | 3 | 5 | 345000 | 558.90 | |
| 07-27 | 62 | 3 | 5 | 345000 | 558.90 | |
| 08-03 | 62 | 3 | 5 | 345000 | 558.90 | |
| 08-10 | 62 | 3 | 5 | 345000 | 558.90 | |
| 08-17 | 62 | 3 | 5 | 345000 | 558.90 | |
| 08-24 | 58 | 1 | 5 | 313154 | 507.31 | |
| 08-31 | 57 | 1 | 5 | 307846 | 498.71 | |
| 09-07 | 57 | 1 | 5 | 307846 | 498.71 | |
| 09-14 | 56 | 1 | 5 | 302538 | 490.11 | |
| 09-21 | 55 | 1 | 5 | 297231 | 481.51 | |
| 09-28 | 44 | 1 | 5 | 238846 | 386.93 | |
| 10-05 | 39 | 1 | 5 | 212308 | 343.94 | |
| 10-12 | 27 | 1 | 5 | 148615 | 240.76 | |
| 10-19 | 17 | 0 | 4 | 90231 | 146.17 | |
| 10-26 | 10 | 0 | 3 | 53077 | 85.98 | |
| 11-02 | 1 | 0 | 3 | 5308 | 8.60 | |
| 11-09 | 0 | 0 | 3 | 0 | 0.00 | |
| 11-16 | 0 | 0 | 3 | 0 | 0.00 | |



Flow Rate-Raudhatain Field
Barrels
400000
350000
300000
250000
200000
150000
100000
50000
0
Flow Rate
03-16
03-23
03-30
04-06
04-13
04-20
04-27
05-04
05-11
05-18
05-25
06-01
06-08
06-15
06-22
06-29
07-06
07-13
07-20
07-27
08-03
08-10
08-17
08-24
08-31
09-07
09-14
09-21
09-28
10-05
10-12
10-19
10-26
11-02
11-09
11-16
Week

## Raudhatain Field-Oil Well Status



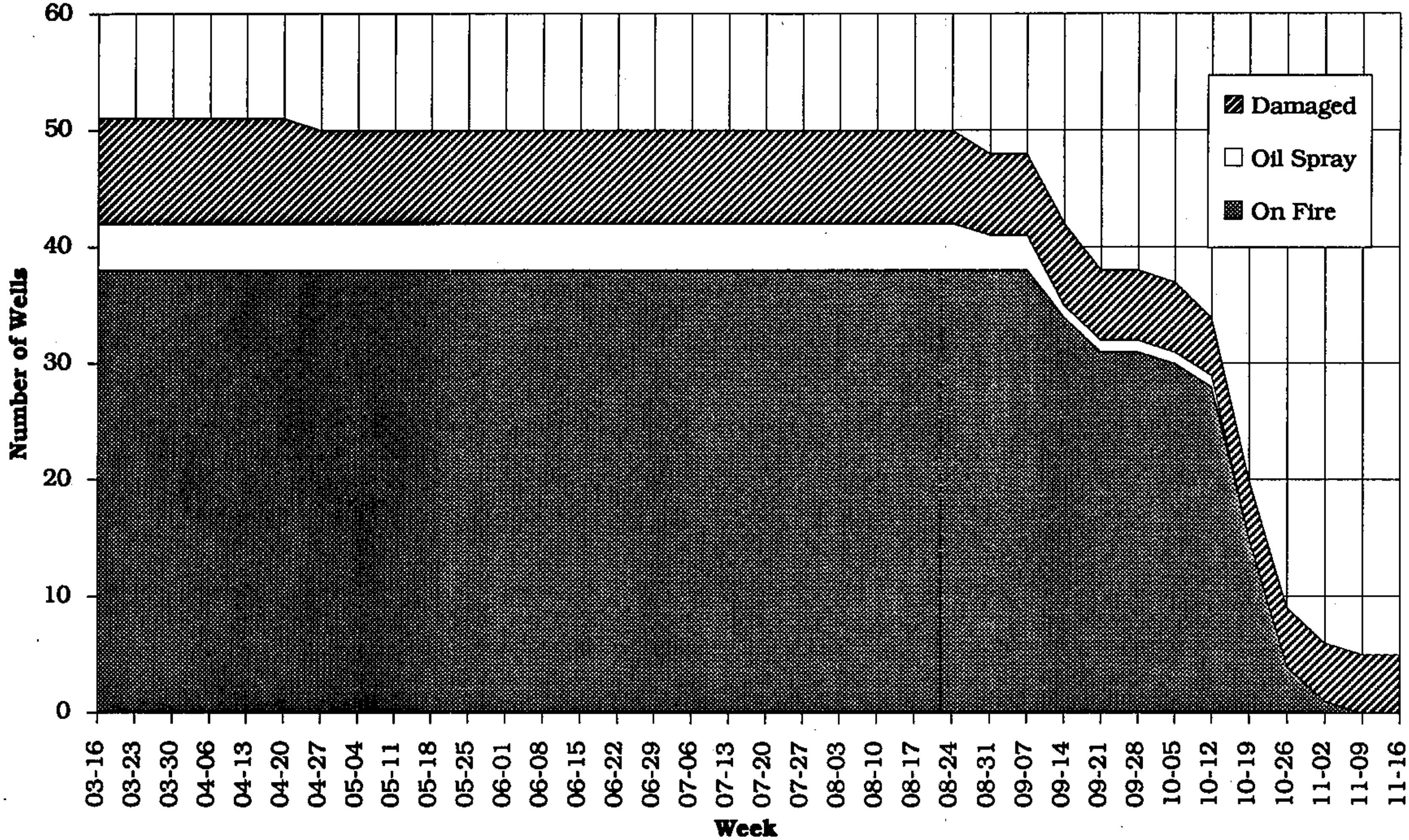
| Raqua Field History | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| **Well Number** | **Gathering Center** | **On Fire** | **Oil Spray** | **Damaged** | **Intact** | **Date Capped** |
| | | | | | | |
| | **INDIVIDUAL WELL HISTORIES ARE NOT AVAILABLE FOR THIS FIELD** | | | | | |
| | | | | | | |
| **Wells** | | 0 | 0 | 0 | | |
| **Controlled** | | 0 | 0 | 0 | | |
| | | | | | | |
| **Remaining** | | 0 | 0 | 0 | | |
| | | | | | | |

| Sabriyah Field History | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| Well<br>Number | Gathering<br>Center | On<br>Fire | Oil<br>Spray | Damaged | Intact | Date<br>Capped |
| 1 | 23 | 1 | | | | 10/23/91 |
| 2 | 23 | 1 | | | | 10/25/91 |
| 3 | 23 | | | 1 | | |
| 4 | 24 | | 1 | | | 9/11/91 |
| 5 | 24 | 1 | | | | 9/19/91 |
| 6 | 24 | | | 1 | | 9/18/91 |
| 7 | 23 | 1 | | | | 10/15/91 |
| 8 | 24 | 1 | | | | 10/25/91 |
| 9 | 23 | | | 1 | | 10/12/91 |
| 10 | 23 | | | 1 | | |
| 11 | 23 | | | | 1 | |
| 13 | 24 | | | 1 | | |
| 14 | 24 | | | | 1 | |
| 17 | 24 | 1 | | | | 10/17/91 |
| 18 | 23 | 1 | | | | 11/1/91 |
| 19 | 23 | 1 | | | | 10/29/91 |
| 20 | 23 | | 1 | | | 10/16/91 |
| 21 | 24 | 1 | | | | 10/20/91 |
| 22 | 24 | 1 | | | | 10/15/91 |
| 23 | 24 | 1 | | | | 9/21/91 |
| 24 | 24 | 1 | | | | 9/12/91 |
| 26 | 23 | 1 | | | | 10/19/91 |
| 27 | 24 | 1 | | | | 10/20/91 |
| 28 | 23 | 1 | | | | 10/17/91 |
| 29 | 23 | 1 | | | | 10/1/91 |
| 30 | 23 | 1 | | | | 10/18/91 |
| 31 | 24 | 1 | | | | 10/21/91 |
| 32 | 24 | 1 | | | | 9/15/91 |
| 33 | 24 | 1 | | | | 10/14/91 |
| 34 | 23 | 1 | | | | 10/26/91 |
| 35 | 23 | | | 1 | | 4/23/91 |
| 36 | 23 | 1 | | | | 10/19/91 |
| 37 | 23 | 1 | | | | 10/26/91 |
| 38 | 24 | 1 | | | | 9/11/91 |
| 39 | 23 and 24 | 1 | | | | 10/19/91 |
| 40 | 23 | 1 | | | | 9/13/91 |
| 41 | 23 | 1 | | | | 10/28/91 |
| 42 | 23 | | 1 | | | 8/27/91 |
| 43 | 24 | 1 | | | | 10/20/91 |
| 44 | 24 | 1 | | | | 10/18/91 |
| 45 | 24 | | 1 | | | 9/11/91 |
| 46 | 24 | 1 | | | | 10/15/91 |
| 47 | 24 | 1 | | | | 10/19/91 |
| 48 | 23 | 1 | | | | 11/6/91 |
| 49 | 24 | 1 | | | | 9/13/91 |
| 50 | 24 | 1 | | | | 10/22/91 |
| 51 | 24 | 1 | | | | 10/21/91 |
| 59 | 23 | | | 1 | | |
| 60 | 23 | | | 1 | | |
| 61 | 23 | 1 | | | | 10/12/91 |

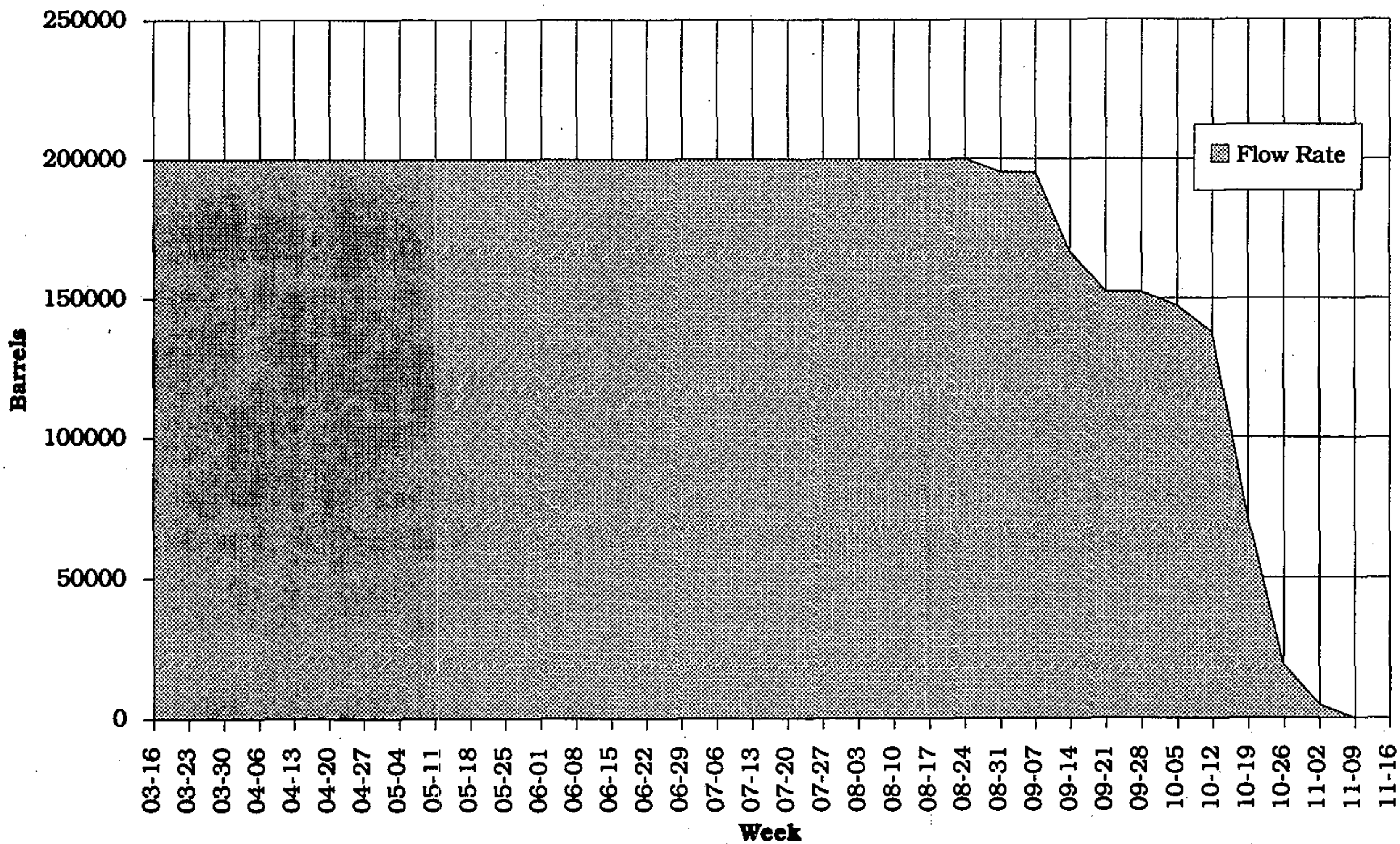
| Sabriyah Field History (Continued) | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| **Well Number** | **Gathering Center** | **On Fire** | **Oil Spray** | **Damaged** | **Intact** | **Date Capped** |
| 62 | 23 | | | 1 | | 8/27/91 |
| 63 | 23 | 1 | | | | 10/12/91 |
| 64 | 23 | 1 | | | | 10/13/91 |
| | | | | | | |
| **Wells** | | **38** | **4** | **9** | | |
| **Controlled** | | **38** | **4** | **4** | | |
| | | | | | | |
| **Remaining** | | **0** | **0** | **5** | | |

| Sabriyah Field Summary | | | | | | |
|---|---|---|---|---|---|---|
| **Week** | **On Fire** | **Oil Spray** | **Damaged** | **Flow (bbs/day)** | **Flow (kgs/sec)** | |
| 03-16 | 38 | 4 | 9 | 200000 | 324.00 | |
| 03-23 | 38 | 4 | 9 | 200000 | 324.00 | |
| 03-30 | 38 | 4 | 9 | 200000 | 324.00 | |
| 04-06 | 38 | 4 | 9 | 200000 | 324.00 | |
| 04-13 | 38 | 4 | 9 | 200000 | 324.00 | |
| 04-20 | 38 | 4 | 9 | 200000 | 324.00 | |
| 04-27 | 38 | 4 | 8 | 200000 | 324.00 | |
| 05-04 | 38 | 4 | 8 | 200000 | 324.00 | |
| 05-11 | 38 | 4 | 8 | 200000 | 324.00 | |
| 05-18 | 38 | 4 | 8 | 200000 | 324.00 | |
| 05-25 | 38 | 4 | 8 | 200000 | 324.00 | |
| 06-01 | 38 | 4 | 8 | 200000 | 324.00 | |
| 06-08 | 38 | 4 | 8 | 200000 | 324.00 | |
| 06-15 | 38 | 4 | 8 | 200000 | 324.00 | |
| 06-22 | 38 | 4 | 8 | 200000 | 324.00 | |
| 06-29 | 38 | 4 | 8 | 200000 | 324.00 | |
| 07-06 | 38 | 4 | 8 | 200000 | 324.00 | |
| 07-13 | 38 | 4 | 8 | 200000 | 324.00 | |
| 07-20 | 38 | 4 | 8 | 200000 | 324.00 | |
| 07-27 | 38 | 4 | 8 | 200000 | 324.00 | |
| 08-03 | 38 | 4 | 8 | 200000 | 324.00 | |
| 08-10 | 38 | 4 | 8 | 200000 | 324.00 | |
| 08-17 | 38 | 4 | 8 | 200000 | 324.00 | |
| 08-24 | 38 | 4 | 8 | 200000 | 324.00 | |
| 08-31 | 38 | 3 | 7 | 195238 | 316.29 | |
| 09-07 | 38 | 3 | 7 | 195238 | 316.29 | |
| 09-14 | 34 | 1 | 7 | 166667 | 270.00 | |
| 09-21 | 31 | 1 | 6 | 152381 | 246.86 | |
| 09-28 | 31 | 1 | 6 | 152381 | 246.86 | |
| 10-05 | 30 | 1 | 6 | 147619 | 239.14 | |
| 10-12 | 28 | 1 | 5 | 138095 | 223.71 | |
| 10-19 | 15 | 0 | 5 | 71429 | 115.71 | |
| 10-26 | 4 | 0 | 5 | 19048 | 30.86 | |
| 11-02 | 1 | 0 | 5 | 4762 | 7.71 | |
| 11-09 | 0 | 0 | 5 | 0 | 0.00 | |
| 11-16 | 0 | 0 | 5 | 0 | 0.00 | |

## Sabriya Field-Oil Well Status



## Flow Rate - Sabriyah Fields



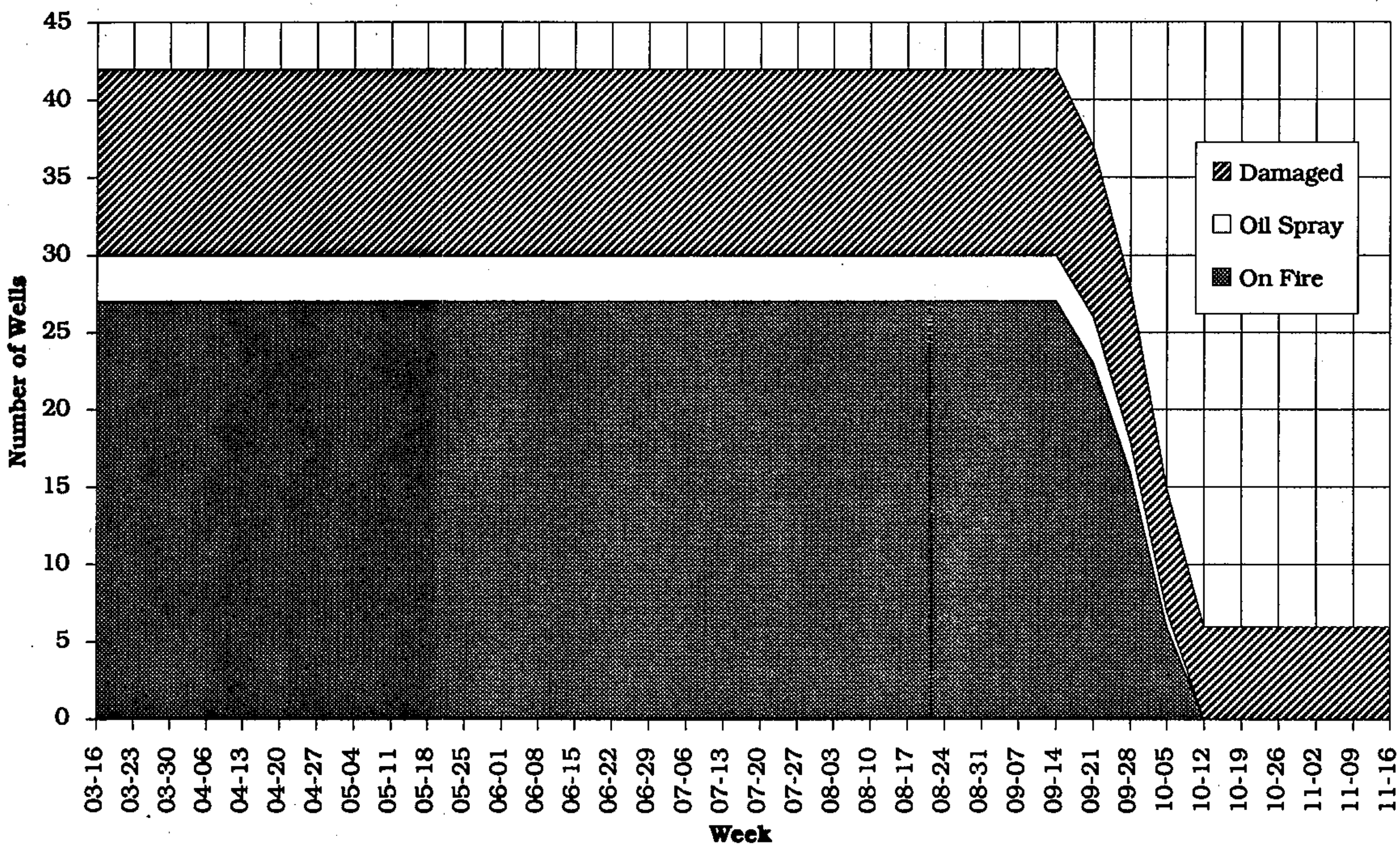
| South Fuwaris Field History | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| Well Number | Gathering Center | On Fire | Oil Spray | Damaged | Intact | Date Capped |
| | | | | | | |
| | **INDIVIDUAL WELL HISTORIES ARE NOT AVAILABLE FOR THIS FIELD** | | | | | |
| | | | | | | |
| **Wells** | | 0 | 0 | 0 | | |
| **Controlled** | | 0 | 0 | 0 | | |
| | | | | | | |
| **Remaining** | | 0 | 0 | 0 | | |
| | | | | | | |

| South Umm Gudair Field History | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| Well Number | Gathering Center | On Fire | Oil Spray | Damaged | Intact | Date Capped |
| | | | | | | |
| | **INDIVIDUAL WELL HISTORIES ARE NOT AVAILABLE FOR THIS FIELD** | | | | | |
| | | | | | | |
| **Wells** | | 0 | 0 | 0 | | |
| **Controlled** | | 0 | 0 | 0 | | |
| | | | | | | |
| **Remaining** | | 0 | 0 | 0 | | |
| | | | | | | |

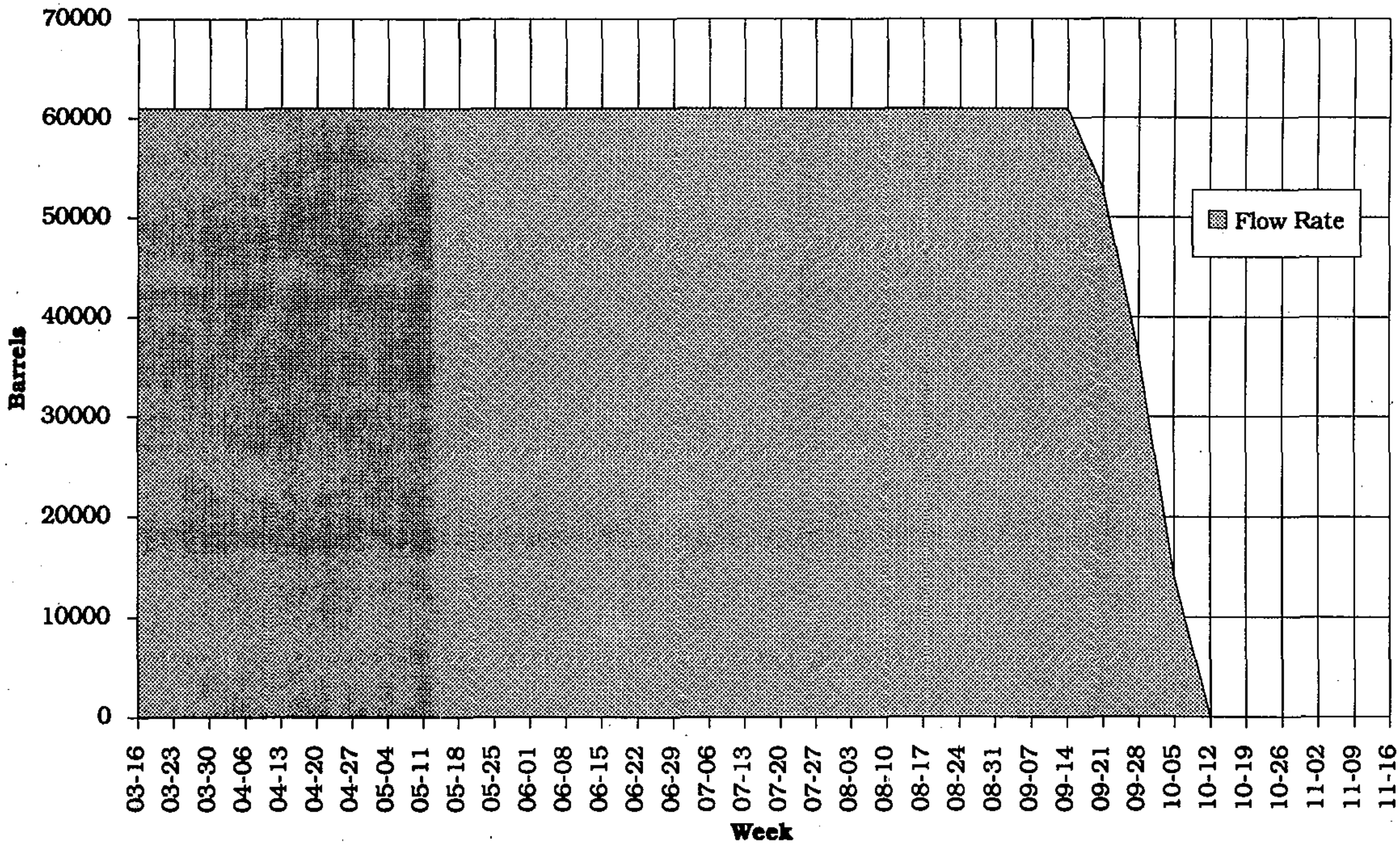
| Umm Gudair Field History | | | | | | |
|---|---|---|---|---|---|---|
| **Well Number** | **Gathering Center** | **On Fire** | **Oil Spray** | **Damaged** | **Intact** | **Date Capped** |
| 2 | 18 | 1 | | | | 9/17/91 |
| 3 | 17 | 1 | | | | 10/3/91 |
| 4 | 17 | 1 | | | | 9/26/91 |
| 5 | 18 | 1 | | | | 9/15/91 |
| 6 | 17 | 1 | | | | 10/7/91 |
| 7 | 18 | 1 | | | | 9/18/91 |
| 8 | 17 | 1 | | | | 10/8/91 |
| 9 | 17 | 1 | | | | 10/5/91 |
| 10 | 17 | 1 | | | | 9/26/91 |
| 11 | 18 | | | 1 | | |
| 12 | 17 | | 1 | | | 9/26/91 |
| 13 | 17 | 1 | | | | 10/1/91 |
| 14 | 18 | | | 1 | | 9/20/91 |
| 15 | 17 | | | 1 | | 9/28/91 |
| 16 | 18 | 1 | | | | 9/25/91 |
| 17 | 17 | 1 | | | | 9/30/91 |
| 18 | 18 | 1 | | | | 9/22/91 |
| 19 | 17 | 1 | | | | 10/2/91 |
| 20 | 18 | | | 1 | | |
| 21 | 17 | 1 | | | | 10/5/91 |
| 22 | 17 | 1 | | | | 10/4/91 |
| 23 | 18 | | | 1 | | |
| 24 | 17 | | | | 1 | |
| 25 | 17 | 1 | | | | 10/6/91 |
| 26 | 18 | | | 1 | | |
| 27 | 17 | | 1 | | | 9/30/91 |
| 28* | 17 | | 1 | 1 | | 10/6/91 |
| 29 | 18 | 1 | | | | 9/25/91 |
| 30 | 17 | 1 | | | | 10/2/91 |
| 31 | 17 | | | 1 | | |
| 32 | 17 | | | 1 | | 10/8/91 |
| 33 | 18 | 1 | | | | 9/26/91 |
| 34 | 17 | 1 | | | | 10/7/91 |
| 35 | 17 | 1 | | | | 10/10/91 |
| 36 | 17 | | | 1 | | 10/4/91 |
| 37 | 17 | | | | 1 | |
| 38 | 17 | 1 | | | | 10/1/91 |
| 39 | 17 | 1 | | | | 10/7/91 |
| 40 | 17 | | | 1 | | 9/30/91 |
| 41 | 17 | 1 | | | | 9/27/91 |
| 42 | 16 | 1 | | | | 9/21/91 |
| 43 | 16 | 1 | | | | 9/29/91 |
| 44 | 16 | | | 1 | | |
| | | | | | | |
| **Wells** | | **27** | **3** | **12** | | |
| **Controlled** | | **27** | **3** | **6** | | |
| | | | | | | |
| **Remaining** | | **0** | **0** | **6** | | |

| Umm Gudair Field Summary | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| **Week** | **On Fire** | **Oil Spray** | **Damaged** | **Flow (bbs/day)** | **Flow (kgs/sec)** | |
| 03-16 | 27 | 3 | 12 | 61000 | 98.82 | |
| 03-23 | 27 | 3 | 12 | 61000 | 98.82 | |
| 03-30 | 27 | 3 | 12 | 61000 | 98.82 | |
| 04-06 | 27 | 3 | 12 | 61000 | 98.82 | |
| 04-13 | 27 | 3 | 12 | 61000 | 98.82 | |
| 04-20 | 27 | 3 | 12 | 61000 | 98.82 | |
| 04-27 | 27 | 3 | 12 | 61000 | 98.82 | |
| 05-04 | 27 | 3 | 12 | 61000 | 98.82 | |
| 05-11 | 27 | 3 | 12 | 61000 | 98.82 | |
| 05-18 | 27 | 3 | 12 | 61000 | 98.82 | |
| 05-25 | 27 | 3 | 12 | 61000 | 98.82 | |
| 06-01 | 27 | 3 | 12 | 61000 | 98.82 | |
| 06-08 | 27 | 3 | 12 | 61000 | 98.82 | |
| 06-15 | 27 | 3 | 12 | 61000 | 98.82 | |
| 06-22 | 27 | 3 | 12 | 61000 | 98.82 | |
| 06-29 | 27 | 3 | 12 | 61000 | 98.82 | |
| 07-06 | 27 | 3 | 12 | 61000 | 98.82 | |
| 07-13 | 27 | 3 | 12 | 61000 | 98.82 | |
| 07-20 | 27 | 3 | 12 | 61000 | 98.82 | |
| 07-27 | 27 | 3 | 12 | 61000 | 98.82 | |
| 08-03 | 27 | 3 | 12 | 61000 | 98.82 | |
| 08-10 | 27 | 3 | 12 | 61000 | 98.82 | |
| 08-17 | 27 | 3 | 12 | 61000 | 98.82 | |
| 08-24 | 27 | 3 | 12 | 61000 | 98.82 | |
| 08-31 | 27 | 3 | 12 | 61000 | 98.82 | |
| 09-07 | 27 | 3 | 12 | 61000 | 98.82 | |
| 09-14 | 27 | 3 | 12 | 61000 | 98.82 | |
| 09-21 | 23 | 3 | 11 | 52867 | 85.64 | |
| 09-28 | 16 | 2 | 10 | 36600 | 59.29 | |
| 10-05 | 6 | 1 | 8 | 14233 | 23.06 | |
| 10-12 | 0 | 0 | 6 | 0 | 0.00 | |
| 10-19 | 0 | 0 | 6 | 0 | 0.00 | |
| 10-26 | 0 | 0 | 6 | 0 | 0.00 | |
| 11-02 | 0 | 0 | 6 | 0 | 0.00 | |
| 11-09 | 0 | 0 | 6 | 0 | 0.00 | |
| 11-16 | 0 | 0 | 6 | 0 | 0.00 | |
| | | | | | | |

## Umm Gudair Field-Oil Well Status



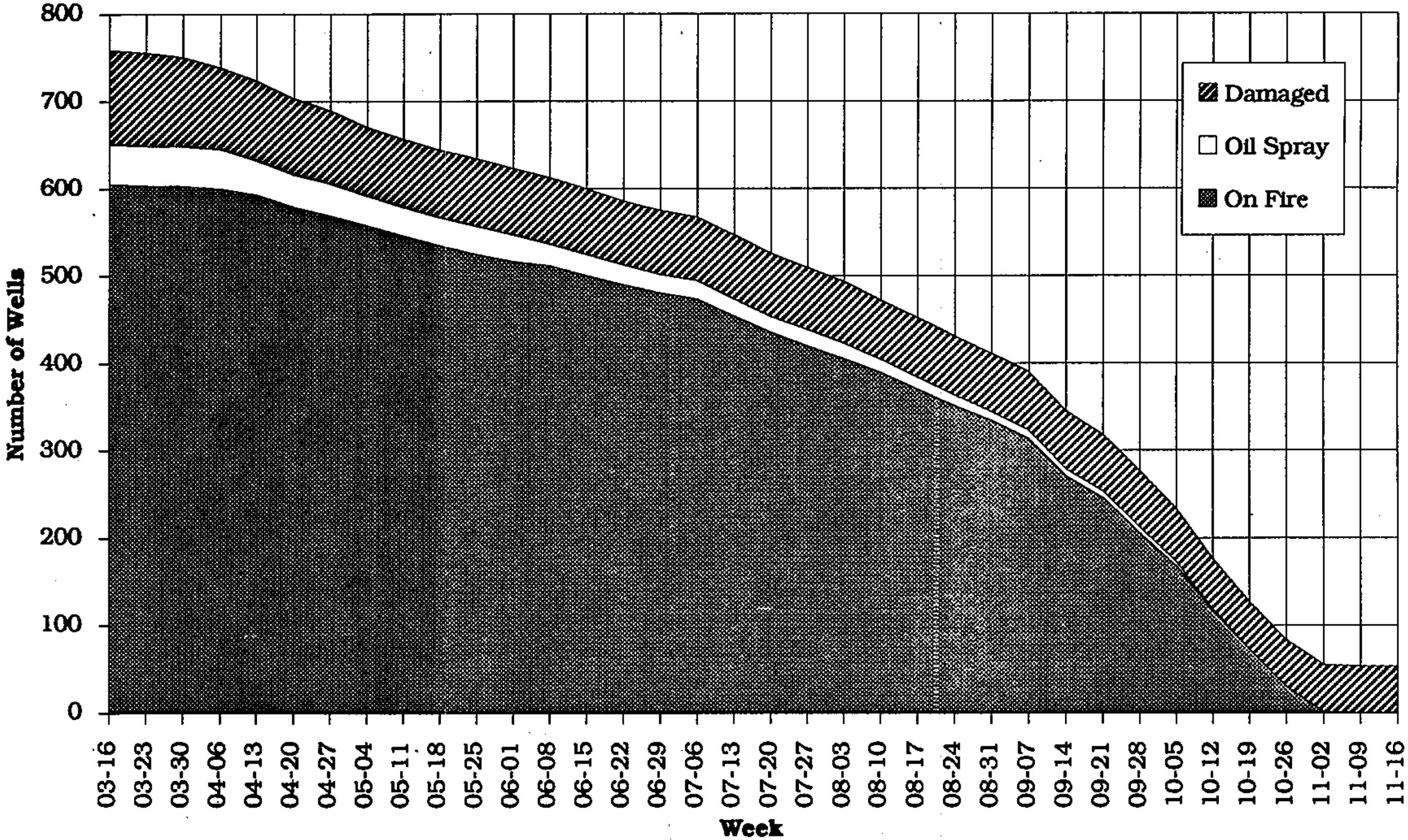
Flow Rate-Umm Gudair Field



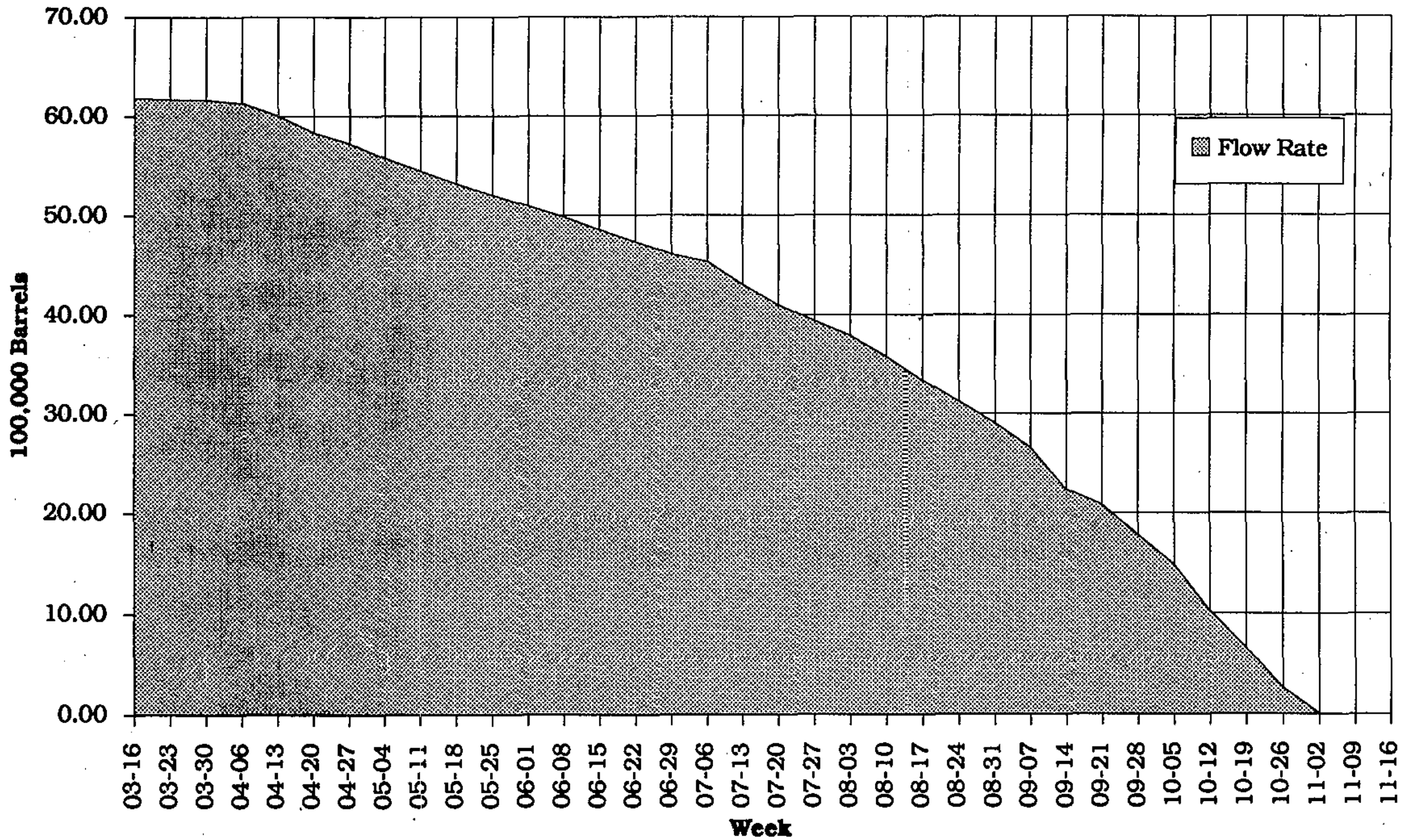
| Wafra Field History | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| **Well Number** | **Gathering Center** | **On Fire** | **Oil Spray** | **Damaged** | **Intact** | **Date Capped** |
| | | | | | | |
| | **INDIVIDUAL WELL HISTORIES ARE NOT AVAILABLE FOR THIS FIELD** | | | | | |
| | | | | | | |
| **Wells** | | 6 | 33 | N/A | | |
| **Controlled** | | 6 | 33 | N/A | | |
| | | | | | | |
| **Remaining** | | 0 | 0 | N/A | | |
| | | | | | | |

| Summary - All Fields (Not Including Wafra Field) | | | | | | |
|---|---|---|---|---|---|---|
| Week | On Fire | Oil Spray | Damaged | Flow (100,000 bbs/day) | Flow (kgs/sec) | |
| 03-16 | 605 | 46 | 108 | 61.86 | 10021.67 | |
| 03-23 | 604 | 46 | 106 | 61.76 | 10005.63 | |
| 03-30 | 603 | 46 | 102 | 61.66 | 9989.69 | |
| 04-06 | 600 | 46 | 93 | 61.37 | 9941.55 | |
| 04-13 | 593 | 40 | 91 | 60.04 | 9725.88 | |
| 04-20 | 579 | 38 | 87 | 58.39 | 9458.43 | |
| 04-27 | 569 | 37 | 84 | 57.30 | 9282.15 | |
| 05-04 | 558 | 34 | 79 | 55.84 | 9046.89 | |
| 05-11 | 546 | 33 | 78 | 54.51 | 8831.32 | |
| 05-18 | 535 | 32 | 78 | 53.22 | 8620.95 | |
| 05-25 | 525 | 32 | 78 | 52.09 | 8438.92 | |
| 06-01 | 517 | 30 | 77 | 51.01 | 8264.28 | |
| 06-08 | 512 | 25 | 76 | 49.89 | 8082.05 | |
| 06-15 | 501 | 24 | 75 | 48.61 | 7875.43 | |
| 06-22 | 490 | 23 | 73 | 47.38 | 7676.11 | |
| 06-29 | 481 | 21 | 73 | 46.18 | 7481.68 | |
| 07-06 | 474 | 21 | 73 | 45.40 | 7354.98 | |
| 07-13 | 455 | 19 | 73 | 43.10 | 6982.07 | |
| 07-20 | 436 | 18 | 72 | 41.03 | 6647.47 | |
| 07-27 | 421 | 18 | 71 | 39.48 | 6396.17 | |
| 08-03 | 406 | 18 | 70 | 37.93 | 6145.16 | |
| 08-10 | 390 | 15 | 68 | 35.83 | 5804.34 | |
| 08-17 | 371 | 14 | 68 | 33.42 | 5414.13 | |
| 08-24 | 352 | 12 | 68 | 31.28 | 5067.14 | |
| 08-31 | 335 | 10 | 67 | 29.11 | 4716.04 | |
| 09-07 | 314 | 10 | 67 | 26.65 | 4317.56 | |
| 09-14 | 271 | 8 | 67 | 22.44 | 3634.92 | |
| 09-21 | 246 | 8 | 65 | 20.84 | 3375.81 | |
| 09-28 | 206 | 7 | 64 | 17.79 | 2881.92 | |
| 10-05 | 168 | 5 | 61 | 14.90 | 2414.24 | |
| 10-12 | 117 | 2 | 58 | 10.33 | 1673.53 | |
| 10-19 | 73 | 0 | 55 | 6.60 | 1069.31 | |
| 10-26 | 30 | 0 | 54 | 2.67 | 431.93 | |
| 11-02 | 2 | 0 | 54 | 0.10 | 16.31 | |
| 11-09 | 0 | 0 | 54 | 0.00 | 0.00 | |
| 11-16 | 0 | 0 | 54 | 0.00 | 0.00 | |

## All Fields-Oil Well Status



## Flow Rate - All Fields



# Summary of the GULFEX flights.

## 23rd - 31st March 1991

by

**M.A.Gibbs, D.W.Johnson,**

**C.G.Kilsby and D.S.McKenna.**

**Meteorological Research Flight**

**Y46 Building**

**Royal Aerospace Establishment**

**Farnborough**

**Hants GU14 6TD**

**May 1991**

# CONTENTS

## 1. INTRODUCTION.

Between the 22nd March and the 2nd April 1991 the C-130 aircraft of the Meteorological Research Flight (MRF) was detached to the Gulf to assess the environmental effects of the smoke from the Kuwaiti oil well fires resulting from the Kuwait - Iraq war. The aircraft was based throughout the measurement phase of GULFEX (Gulf Experiment) in Bahrain.
The major objective of the experiment was

> To characterise the oil smoke plume at a number of downwind distances in terms of its dynamics, its particulate density, its chemical composition, its effect on solar and infra-red radiation and its interaction with water cloud in order to improve our assessments of the impact of the plume on the local, regional and global environment.

Secondary aims were to validate the predictions of the mesoscale and nuclear accident numerical models, to investigate the morphology of the smoke particulates and to study the microwave characteristics of the oil slicks on the sea .

## 2. C-130 MEASUREMENTS.

Eight scientific sorties were flown over a nine day period (totalling 57 hours flying time) from Bahrain over the Gulf, Kuwait, Saudi Arabia and Qatar. The measurements made can be split up into four categories.

(a) Standard meteorological parameters

- (i) temperature,
- (ii) dew point,
- (iii) wind speed and direction,
- (iv) vertical velocity,
- (v) liquid water,
- (vi) total water,
- (vii) position and
- (viii) forward and downward facing video.

(b) Radiation measurements

- (i) broad band radiation fluxes made with the pyranometers and pyrgeometers in the solar, near infra red (0.3 - 3$\mu m$) and infra red wavelengths (4.0 - 50$\mu m$),
- (ii) narrow band radiances made with the multi channel radiometer (MCR) at both visible/near infra red (0.55 - 2.3$\mu m$) and infra red wavelengths (10 - 14$\mu m$),
- (iii) the total scattering coefficient was measured with the nephelometer,
- (iv) a PRT 4 radiometer was used to measure the cloud top temperature and sea surface temperature and
- (v) microwave measurements were made with the MARSS radiometer (89 and 157GHz).

(c) Chemistry measurements

- (i) Ozone - chemi-luminescent detector,
- (ii) NO - chemi-luminescent detector,
- (iii) NOx - chemi-luminescent detector,

(iv) SO2 - hydrogen flame photometric detector,

(v) electron capture gas chromatographs were used to measure trace chemicals such as PAN and

(vi) bottle samples.

(d) Cloud physics and aerosol measurements

(i) the passive cavity aerosol spectrometer probe (PCASP) was used to measure particles in the size range 0.1 - 3.0μm,

(ii) the forward scattering spectrometer probe (FSSP) was used to measure particles in the size range 1.0 - 45μm,

(iii) the 2D cloud probe was used to measure particles in the size range 25 - 800μm

(iv) some holograms were exposed (these can resolve particles larger than 10μm) and

(v) filter samples.

Table 1 summarizes the instruments used on each flight and gives some idea of how they performed.

| INSTRUMENT | A074 | A075 | A076 | A077 | A078 | A079 | A080 | A081 |
|---|---|---|---|---|---|---|---|---|
| Static Head | O | O | O | O | O | O | O | O |
| Pitot-static | O | O | O | O | O | O | O | O |
| Gust probes | O | O | O | O | O | O | O | O |
| ICTP | O | O | O | O | O | O | O | O |
| De-iced therm | O | O | O | O | O | O | O | O |
| Non de-iced therm | O | O | O | O | O | O | O | O |
| General Eastern hygro | O | O | O | O | O | O | X | X |
| CCN | X | O | O | O | O | O | O | O |
| Nephelometer | O | O | O | O | O | O | O | O |
| Filter boom | O | O | O | O | O | O | O | O |
| Bendix Ozone | O | O | O | O | O | O | O | O |
| Desibi Ozone | O | X | X | X | X | X | X | X |
| SO2 | O | O | O | O | O | O | O | O |
| NOx | O | O | O | O | O | O | O | O |
| Bottle samples | X | O | O | O | O | O | O | O |
| ECGCs | O | O | O | O | O | O | O | O |
| 2D cloud probe | O | O | O | O | 3 | 3 | 3 | 2 |
| PCASP | O | O | O | O | O | O | O | O |
| FSSP | O | O | O | O | O | O | O | O |
| Holography | X | X | X | X | X | X | O | X |
| JW liquid water | O | O | O | O | O | O | O | O |
| Total water | O | O | O | O | O | O | O | O |
| BBR | O | O | O | O | O | O | O | O |
| Barnes PRT4 | O | O | O | O | O | O | O | O |
| MARSS | 1 | X | O | O | O | O | O | O |
| MCR | O | O | O | O | O | O | O | O |

O Instrument operated successfully
X Instrument did not operate
1 MARSS switched off 1105
2 2D cloud probe switched off during the flight
3 2D cloud probe was very noisy

Table 1: Summary of instruments for each flight

3.. Flight A074 GULFEX 1 23rd March 1991

This was the first GULFEX flight and, primarily, was undertaken as an instrument test. The operating area was to the south east of Bahrain as far east as Ras Al Khaimah and then south west over Saudi Arabia. Subsequent to the flight, the Nephanalysis carried out by S Div showed that the aircraft may have been flying in a very old plume. During the flight the boundary layer was extremely hazy but it was difficult to make out any significant smoke plume. Vertical saw tooth patterns were carried out for the majority of the flight with the aircraft going from 50ft to just above the convective boundary layer where the visibility improved considerably.

The synoptic situation showed an, active, developing low pressure system moving into the Gulf with a light south westerly ahead of the cold front.

Table 2 summarises the runs and profiles made in A074 and table 3 shows the MCR configuration used for each part of the flight. (N.B. the number in brackets after any times refers to a DRS event mark and the cabin column refers to whether the aircraft was pressurised or not during the run or profile. P = pressurised, U = unpressurised and B implies both states occurred during the run.)

| RUN NO | START (GMT) | END (GMT) | HEIGHT (ft) | HEADING (deg) | CABIN | COMMENTS |
|---|---|---|---|---|---|---|
| | 101310 | | | | | Take off Bahrain |
| P1 | 102508(2) | 105317(9) | 50-20,000ft | 100 | P | Initial profile (over 7/8 Ci very hazy |
| R1.1 | 111310(15) | 112132(17) | 50-8,000ft | 100 | B | Start of saw tooth p over sea - ascending |
| R1.2 | 112202(18) | 113216(21) | 8,000-50ft | 100 | U | Saw tooth descending |
| R1.3 | 113216(21) | 115743(29) | 50-20,000ft | 100 | B | Saw tooth ascending |
| R2.1 | 121724(35) | 122331(37) | 50-8,000ft | 250 | B | New saw tooth profile sea - ascending |
| R2.2 | 122715(39) | 123237(41) | 8,000-3,000ft | 250 | U | descending |
| R2.3 | 123237(41) | 123810(43) | 3,000-8,000ft | 250 | U | ascending |
| R2.4 | 123905(44) | 124812(45) | 8,000-50ft | 250 | U | descending |
| R2.5 | 124812(45) | 125702(49) | 50-8,000ft | 230 | U | ascending, 7/8 Ci hazy |
| R2.6 | 125702(49) | 130550(53) | 8,000-50ft | 260 | U | descending |
| R2.7 | 130550(53) | 131447(54) | 50-8,000ft | 260 | U | ascending |
| R2.8 | 131447(54) | 132052(57) | 8,000-2,000ft | 250-200 | U | descending, ending land (desert) |
| R3.1 | 132127(58) | 132709(60) | 2,000-8,000ft | 190 | U | New saw tooth profile desert - ascending |
| R3.2 | 132748(61) | 133350(62) | 8,000-2,000ft | 185 | U | descending |
| R4.1 | 133434(63) | 134025(65) | 2,000-8,000ft | 220 | U | New saw tooth profile desert - ascending |
| R4.2 | 134046(66) | 134701(68) | 8,000-2,000ft | 220 | U | descending |
| R4.3 | 134713(70) | 135323(73) | 2,000-8,000ft | 210 | U | ascending |
| P2 | 135812(74) | 140844(77) | 8,000-18,000ft | 040 | P | Profile ascent, 7/8 Ci v hazy |
| P3 | 140844(77) | 142949(87) | 18,000-50ft | 040-350 | B | Profile descent over sea |
| P4 | 142949(87) | 144514(91) | 50-16,000ft | 350-325 | B | Profile ascent over the s |
| | | 150435 | | | | Land Bahrain |

Table 2: Summary of profiles and runs for flight A074

| RUN NO. | MCR CONFIGURATION |
|---|---|
| P1 | CBB, HBB 104531, CBB 105115 (LW CAL) |
| R1.1 | Nad |
| R1.2 | Nad, HBB 112459, Off 112500, Nad 112811 |
| R1.3 | HBB 113806, Zen 1150 (SW CAL), Zen 1153 (LW CAL) |
| R2.1 | Zen |
| R2.2 | HBB, Zen 123047 |
| R2.3 | Zen |
| R2.4 | Nad |
| R2.5 | Nad |
| R2.6 | CBB |
| R2.7 | Nad |
| R2.8 | Nad |
| R3.1 | Nad |
| R3.2 | CBB |
| R4.1 | CBB |
| R4.2 | HBB, Zen 134046 |
| R4.3 | Zen, CBB 134810, HBB 135137 |
| P2 | Nad, CBB 140411, HBB 140744 |
| P3 | HBB, Zen 141218, Nad 142542 |
| P4 | Nad, HBB 144227 |

Nad - Nadir
Zen - Zenith
CBB - Cold Black Body
HBB - Hot Black Body
LW CAL - Long Wave Calibration
SW Cal - Short Wave Calibration

Table 3: Summary of MCR configurations for flight A074

## 4. Flight A075 GULFEX 2 24th March 1991

This was the first GULFEX flight to be flown through a visibly thick smoke plume. A large proportion of the flight was carried out in the northern Gulf close to Kuwait (i.e. in the near field of the sources) where the surface wind was a light north westerly. However the higher you went the more the wind went round to a south westerly. The smoke was very thick and appeared to be coming mainly from a source south of Kuwait City. All the smoke was present below 14,000ft and at times there was some cumulus and altocumulus mixed in with it.

The synoptic situation showed a deep low pressure system over Jordan, slowly moving east. The associated cold front had cleared through Kuwait and Bahrain overnight and had now become slow moving over the southern Gulf. Cloud from the front remained over the central Gulf.

Tables 4, 5, 6 and 7 summarize the runs and profiles, CCN counter operations, MCR configurations and bottle samples respectively for this flight.

| RUN NO | START (GMT) | END (GMT) | HEIGHT (ft) | HEADING (deg) | CABIN | COMMENTS |
|---|---|---|---|---|---|---|
| | 064040 | | | | | Take off Bahrain |
| P1 | 064814(1) | 071411(5) | 50ft-FL200 | 320-250 | P | Initial profile ascending out of plume |
| R1.1 | 073706(8) | 074209(10) | FL200 | 250 | P | Box pattern above plume |
| R1.2 | 074330(11) | 074846(15) | FL200 | 160 | P | Box pattern |
| R1.3 | 075241(16) | 075642(17) | FL200 | 070 | P | Box pattern |
| R1.4 | 075750(18) | 080124(19) | FL200 | 335 | P | Box pattern |
| R1.5 | 080401(20) | 082156(22) | FL200 | 225 | P | Over plume, some Cu associated with it |
| R1.6 | 082523(23) | 083330(24) | FL160 | 045-155 | | Over plume |
| P2 | 083823(27) | 085732(30) | FL160-50ft | 155-335 | | Profile descending out of plume |
| R2.1 | 085910(31) | 091100(32) | 1000ft | 340 | B | Run across plume under ScAc layer |
| R3.1 | 091458(33) | 092312(35) | 2000ft | 140 | U | Run across plume |
| R3.2 | 092627(36) | 093232(37) | FL050 | 320 | U | Run across plume |
| R3.3 | 094151(38) | 094420(40) | FL140 | 150 | P | Run across plume |
| R3.4 | 094851(41) | 095336(42) | FL100 | 310 | P | Run across plume |
| R3.5 | 095953(44) | 100759(4) | FL100 | 230 | P | Run across plume |
| R4.1 | 105027(5) | 110122(7) | FL100 | 080-040 | P | Run through plume, mixed cloud and smoke |
| R4.2 | 110408(9) | 111634(10) | FL120 | 215-200 | P | Run through plume |
| P3 | 112651(12) | 114918(16) | FL200-250ft | 220-080 | P | Profile through plume |
| P4.1 | 115205(18) | 115910 | 1000ft-FL080 | 140 | B | Start of sawtooth profiles - ascending |
| P4.2 | 115910 | 120739(21) | FL080-50ft | 140 | B | Descending |
| P4.3 | 120739(21) | 121541(2) | 50ft-FL080 | 140 | P | Ascending, clear above hazy below |
| P4.4 | 121541(2) | 122444(6) | FL080-50ft | 150 | P | Descending |
| P4.5 | 122444(6) | 123346(7) | 50ft-FL080 | 150 | P | Ascending |
| P4.6 | 123346(7) | 124235(9) | FL080-50ft | 150 | P | Descending |
| P4.7 | 124235(9) | 125106(10) | 50ft-FL080 | 150 | P | Ascending |
| | | 130305 | | | | Land Bahrain |

Table 4: Summary of profiles and runs for flight A075

| ALLEVIATOR START | ALLEVIATOR END | HEIGHT | COMMENTS |
|---|---|---|---|
| 0645?? | 064640 | 1,000ft | transit |
| 0657?? | 065957 | FL160 | P1 |
| 0713?? | 0714?? | FL200 | P1 |
| 072400 | 072709 | FL200 | Transit |
| 074311 | 074519 | FL200 | R1.2 |
| 075442 | 075656 | FL200 | R1.3 |
| 081455 | 081655 | FL200 | R1.5 |
| 082633 | 083026 | FL160 | Calibrate, R1.6 |
| 084606 | 084818 | FL100-FL060 | Calibrate, P2 |
| 085728 | 085932 | 50 FT | P2 |
| 0922 | | | Cabin air possibly saturated |
| 0942?? | 094410 | FL140 | R3.3 |
| 0959?? | 100147 | FL100 | Possibly saturated, R3.5 |
| 102238 | 102515 | FL200 | Transit |
| 103301 | 103540 | FL200 | Transit |
| 105027 | 105233 | FL100 | Saturated, R4.1 |
| 105847 | 110048 | FL100 | Saturated, R4.1 |
| 110840 | 111042 | FL120 | Saturated, R4.2 |
| 114006 | 114220 | FL100-FL080 | Calibrate, saturated, P3 |
| 124938 | 125204 | FL070-FL080 | P4.7 |

Table 5: Summary of CCN counter operations for flight A075

| RUN NO. | MCR CONFIGURATION |
|---|---|
| P1 | Nad, HBB 065425 (LW CAL), Nad 070606, CBB 071216 (LW CAL) |
| R1.1 | Zen (SW CAL) |
| R1.2 | Zen |
| R1.3 | Zen |
| R1.4 | Zen |
| R1.5 | Zen |
| R1.6 | Zen, CBB 083823 (LW CAL) |
| P2 | CBB |
| R2.1 | CBB |
| R3.1 | CBB, Zen 092035 |
| R3.2 | Zen |
| R3.3 | Zen |
| R3.4 | HBB |
| R3.5 | Zen |
| R4.1 | HBB, Zen 105106 |
| R4.2 | Zen |
| P3 | Zen (SW CAL) |
| P4.1 | HBB, Nad 115421 |
| P4.2 | Nad |
| P4.3 | Nad |
| P4.4 | Nad |
| P4.5 | Nad |
| P4.6 | HBB |
| P4.7 | HBB |

Nad - Nadir
Zen - Zenith
CBB - Cold Black Body
HBB - Hot Black Body
LW CAL - Long Wave Calibration
SW Cal - Short Wave Calibration

**Table 6: Summary of MCR configurations for flight A075**

| BOTTLE NO. | PURGE START | FILL START | FILL END | HEIGHT | COMMENTS |
|---|---|---|---|---|---|
| R17 | 105000 | 105400 | 105700 | FL100 | Run 4.1 |
| R31 | 110000 | 110538 | 110800 | FL120 | Run 4.2 |

**Table 7: Summary of bottle samples for flight A075**

## 5. Flight A076 GULFEX 3 25th March 1991

On the climb out of Bahrain the aircraft pressurization failed and for the rest of the flight the aircraft was forced to remain below 8,000ft. This caused problems with the DRS overheating and failing especially near the beginning of the flight. A thick smoke plume was once again encountered in the northern part of the Gulf and some cloud was mixed in with it. The majority of the flight was spent in this area i.e. in the near field of the plume. At the end of the flight a transit to Riyadh was made to pick up some spare parts for the acu. The nephanalysis indicates that this transit was close to or in the plume from the fires.

The synoptic situation showed a very slack pressure area over the northern Gulf and a slow moving, complex frontal system over the southern Gulf.

Tables 8, 9, 10 and 11 summarize the runs and profiles, CCN counter operations, MCR configurations and bottle samples respectively for this flight.

| RUN NO | START (GMT) | END (GMT) | HEIGHT (ft) | HEADING (deg) | CABIN | COMMENTS |
|---|---|---|---|---|---|---|
| | 064230 | | | | | Take off Bahrain |
| R1.1 | 082934(1) | 084224(2) | FL080 | 150 | B | Run through plume |
| P1 | 084300(3) | 085838(7) | FL080-50ft | 225-45 | B | Profile through plume descending, very dark at times |
| P2 | 090154(10) | 091527(20) | 100ft-FL080 | 325 | B | Profile through plume ascending |
| R2 | 095741(21) | 101144(22) | FL060 | 150 | B | Run through plume |
| R3 | 101708(24) | 103122(25) | FL060 | 280 | B | Run through plume |
| R4 | 103314(27) | 105045(30) | FL060 | 075 | B | Run through plume, high SO2 values |
| R5 | 110308(34) | 112007(37) | FL080 | 140-205 | B | Run through plume |
| | | 123612 | | | | Land Riyadh ACU U/S |

Table 8: Summary of profiles and runs for flight A076.

| ALLEVIATOR START | ALLEVIATOR END | HEIGHT | COMMENTS |
|---|---|---|---|
| 0649?? | 0652?? | FL080-FL100 | Transit |
| 0823 | | FL080 | Cabin air |
| 0830 | | | Cabin air |
| 0840 | | | Saturated, cabin air |
| 0848 | | | Cabin air |
| 0855 | | | Cabin air |
| 0904 | | | Cabin air |
| 1104 | | | Cabin air |
| 1112 | | | Cabin air |
| 112924 | 113104 | FL080 | Transit |
| 114117 | 114425 | FL080 | Transit |
| 115312 | 1155?? | FL080 | Transit |
| 120431 | 120635 | FL080 | Transit |

Table 9: Summary of CCN counter operations for flight A076

| RUN NO. | MCR CONFIGURATION |
|---|---|
| R1.1 | CBB, Zen |
| P1 | Zen, HBB 0849, Nad 085647 |
| P2 | Zen. |
| R2 | Nad |
| R3 | Zen |
| R4 | HBB, Nad 103433, CBB 104635 |
| R5 | CBB |

Nad - Nadir
Zen - Zenith
CBB - Cold Black Body
HBB - Hot Black Body
LW CAL - Long Wave Calibration
SW Cal - Short Wave Calibration

Table 10: Summary of MCR configurations for flight A076

| BOTTLE NO. | PURGE START | FILL START | FILL END | HEIGHT | COMMENTS |
|---|---|---|---|---|---|
| R34 | 073300 | 073500 | 073800 | FL080 | No run Number |
| R03 | 075000 | 080200 | 080600 | FL080 | - |
| R36 | 100100 | 102400 | 102600 | FL060 | - |
| R19 | 102900 | 104000 | 104200 | FL060 | SOx 500 increasing, 03 50 |
| R06 | 110640 | 111545 | 111838 | FL080 | SOx 30, 03 62 |
| R16 | 120339 | 120848 | 120913 | FL080 | SO2 20, 03 16, NOx 0, Transit to Riyadh |

Table 11: Summary of bottle samples for flight A076

## 6. Flight A077 GULFEX 4 26th March 1991

For the first time during the detachment the surface winds were blowing down the Gulf and a visible plume could be seen from Kuwait to Bahrain over the sea. A long downwind run underneath the centre of the plume was carried out early in the flight. Unfortunately thunderstorms, associated with a 500mb trough and medium level instability, developed from midday onwards and these were too severe to fly through so flying through the plume was restricted to the northern part of the Gulf where the cloud cleared. Here the plume was very thick and dark and at times the visibility was nil. The saw tooth profiles at the end of the sortie along the Saudi Arabian coast from Kuwait showed that the main plume quite quickly moved offshore away from Kuwait but a thinner plume at a much lower altitude moving into Saudi Arabia was encountered as Bahrain was approached. During this flight measurements of the near and intermediate field were made.

The synoptic situation showed an upper trough to the west of the Gulf and thunderstorms were breaking out ahead of this.

Tables 12, 13, 14 and 15 summarize the MCR configurations, runs and profiles, CCN counter operations, and bottle samples respectively for this flight.

| RUN NO. | MCR CONFIGURATION |
|---|---|
| R1.1 | Zen (SW CAL) |
| R1.2 | Zen |
| P1 | Zen, HBB 080254 (LW CAL), CBB (LW CAL) |
| P2 | Nad |
| R2 | Nad, Zen 091044, HBB 092207 |
| P3 | HBB |
| R3.1 | Nad |
| R3.2 | Nad |
| R3.3 | Nad |
| P4 | HBB |
| R3.4 | Nad |
| P5 | CBB |
| R4.1 | Nad, Zen 122207 |
| R4.2 | HBB, Zen 123849 |
| R4.3 | Zen |
| R4.4 | Zen, HBB 132809 (LW CAL), Zen 133052 |
| R4.5 | Zen, Nad 134511 |
| R5.1 | Zen, HBB 140256, Nad 140354 |
| R5.2 | Nad, CBB 142407 |
| R5.3 | CBB, HBB 142833, Nad 143254 |

Nad - Nadir
Zen - Zenith
CBB - Cold Black Body
HBB - Hot Black Body
LW CAL - Long Wave Calibration
SW Cal - Short Wave Calibration

Table 12: Summary of MCR configurations for flight A077

| RUN NO | START (GMT) | END (GMT) | HEIGHT (ft) | HEADING (deg) | CABIN | COMMENTS |
|---|---|---|---|---|---|---|
| | 064255 | | | | | Take off Bahrain |
| R1.1 | 074702(22) | 075300(23) | FL200 | 150 | P | Flying into sun above plume |
| R1.2 | 075401(24) | 075958(25) | FL200 | 060 | P | Across sun above plume |
| P1 | 080234(26) | 082437(34) | FL200-1000ft | 005-255 | B | Descending profile outside of plume |
| P2 | 083453(38) | 083623(39) | 1000ft-50ft | 240 | U | Ascending profile under plume |
| R2 | 083745(40) | 092247 | 1000ft | 130 | U | Run under plume downwind |
| P3 | 092247(43) | 093620(46) | 1000ft-FL150 | 050 | B | Ascending profile through plume |
| R3.1 | 094359(47) | 100000(50) | 2000ft | 270-230 | U | Run across wind under plume |
| Run 3.2 | 100157(52) | 101700(53) | 4000ft | 005-035 | U | Run across wind through plume |
| R3.3 | 102534(55) | 104104(56) | FL060 | 230 | B | Run across plume |
| P4 | 104240(57) | 104906(58) | FL060-FL120 | 060 | B | Ascending profile to above plume |
| R3.4 | 105150(59) | 110555(63) | FL120 | 230 | P | Run across wind above plume |
| P5 | 115350(67) | 121618(70) | FL220-50ft | 240-025 | B | Descending profile through plume |
| R4.1 | 122014(72) | 123458(74) | FL040 | 215 | U | Run across wind under plume |
| R4.2 | 123759(75) | 125858(77) | FL070 | 025 | U | Run across wind through plume |
| R4.3 | 125440(78) | 130943(79) | FL055 | 210 | U | Run across wind through plume - enter base, out of top |
| R4.4 | 131206(80) | 133256(83) | FL085 | 025-210 | P | Run across wind through plume - enter top, out of base |
| R4.5 | 133524(84) | 134959(86) | FL120 | 210 | P | Run across wind above plume |
| R5.1 | 140140(88) | 141420(91) | FL120-50ft | 135-150 | P | Start of sawtooth profiles - descending |
| R5.2 | 141420(91) | 142442(93) | 50ft-FL120 | 150-140 | P | Ascending |
| R5.3 | 142442(93) | 143804(96) | FL120-50ft | 145 | P | Descending |
| | | 145545 | | | | Land Bahrain |

Table 13: Summary of profiles and runs for flight A077

| ALLEVIATOR START | ALLEVIATOR END | HEIGHT | COMMENTS |
|---|---|---|---|
| 0540?? | | Ground | Calibration, possibly saturated |
| 0645?? | 064721 | FL090-FL110 | Transit |
| 0657?? | 065910 | FL180-FL200 | Transit |
| 070848 | 071045 | FL200 | Transit |
| 071950 | 072150 | FL200 | Transit |
| 073054 | 0733?? | FL200 | Transit |
| 074250 | 074548 | FL200 | Transit |
| 0757?? | 075910 | FL200 | R1.2 |
| 080907 | 081115 | FL140 | P1 |
| 0823 | | | Saturated, cabin air |
| 0832 | | | Saturated, cabin air |
| 0844 | | | Saturated, cabin air |
| 0853 | | | Saturated, cabin air |
| 090730 | | | Saturated, cabin air |
| 0925 | | | Cabin air |
| 102543 | 102751 | FL060 | R3.3 |
| 104759 | - | | Cabin air |
| 105416 | 1058?? | FL120 | R3.4 |
| 120855 | 121032 | FL075-FL060 | saturated, P5 |
| 1229 | | | Saturated, cabin air |
| 1238 | | | Saturated, cabin air |
| 131559 | 131941 | FL085 | Saturated, R4.4 |
| 133041 | 133248 | FL085 | Saturated, R4.4 |
| 134100 | 134300 | FL120 | R4.5 |
| 140515 | 140732 | FL085 | Possibly saturated, R5.1 |
| 141750 | 142023 | FL050-FL075 | R5.2 |
| 143014 | 143222 | FL070-FL050 | R5.3 |

Table 14: Summary of CCN counter operations for flight A077

| BOTTLE NO. | PURGE START | FILL START | FILL END | HEIGHT | COMMENTS |
|---|---|---|---|---|---|
| R37 | 094436 | 094645 | 094706 | FL020 | Run 3.1, SO2 28, NOx 0, 03 70 |
| R29 | 100122 | 101124 | 101248 | FL040 | Run 3.2, SO2 28, NOx 0, 03 60 |
| R14 | 102113 | 103126 | 103311 | FL060 | Run 3.3, SO2 9, NOx 0, 03 (23) while filling |
| R23 | 090301 | 090418 | 090552 | FL010 | Under plume, SO2 40, NOx 0, 03 60 |
| G01 | 105304 | 105836 | 110127 | FL120 | SO2 -, NOx 0, 03 56 |
| R08 | 111222 | 111417 | 112104 | FL120 | 03 58, 12000ft climbing |
| H03 | 114205 | 115006 | 115300 | FL220 | 03 70 |
| H05 | 122005 | 122530 | 122649 | FL040 | Below plume |
| R04 | 123000 | 123400 | 123628 | FL040 | In plume |
| G02 | 123800 | 124100 | 124300 | FL070 | - |
| R02 | 125500 | 130300 | 130500 | FL055 | - |
| R18 | 130600 | 130700 | 130950 | FL050 | - |
| R30 | 131300 | 131530 | 131700 | FL085 | - |

Table 15: Summary of bottle samples for flight A077

## 7. Flight A078 GULFEX 5 28th March 1991

From altitude two distinct sources are visible; one to the south of Kuwait City and a much weaker one to the north of Kuwait City. The aim of this flight was to make measurements at several altitudes, in the near field, across the plume from the southern source in order to calculate its source strength. A very thick plume up to 16,000ft with multiple layers in the vertical was encountered. The main layer of the plume was capped by a thin layer of Ac. Significant downwind evolution of the plume was found in the sawtooth profiles back to Bahrain.

The synoptic situation showed a weak high pressure system building over saudi Arabia giving light north westerly winds over the surface of the Gulf. However, there was significant wind shear in the vertical.

Tables 16, 17, 18 and 19 summarize the runs and profiles, CCN counter operations, MCR configurations and bottle samples respectively for this flight.

| RUN NO | START (GMT) | END (GMT) | HEIGHT (ft) | HEADING (deg) | CABIN | COMMENTS |
|---|---|---|---|---|---|---|
| | 092215 | | | | | Take off Bahrain |
| R1.1 | 102617(8) | 103001(9) | FL240 | 215 | P | Survey run |
| R1.2 | 103220(10) | 103805(11) | FL240 | 030 | P | Survey run |
| P1 | 104025(13) | 111514(27) | FL240-50ft | 220-030 | P | Descending profile upwind of plume |
| R2 | 112943(30) | 113735(32) | FL160 | 120-110 | P | Run above plume |
| P2 | 113735(32) | 115405(33) | FL160-100ft | 105-115 | B | Descending profile through plume |
| R3.1 | 120704(36) | 122730(37) | 4700ft | 215 | U | Run across wind through plume |
| R3.2 | 123124(38) | 125103(39) | FL065 | 025 | U | Run across wind through plume |
| R3.3 | 125226(40) | 130934(41) | FL080 | 215-210 | U | Run across wind through plume |
| R3.4 | 131554(43) | 132726(45) | FL145 | 030 | P | Run across wind through plume |
| R3.5 | 133057(46) | 134734(47) | FL145 | 220 | P | Run across wind through plume |
| P3 | 135125(49) | 140705(50) | FL145-50ft | 030 | B | Descending profile through plume |
| R3.6 | 141001(53) | 142710(58) | 2000-5000ft | 210 | U | Run through plume |
| R3.7 | 142814(59) | 143802(60) | FL050 | 030 | U | Run across wind through plume |
| R4.1 | 144118(61) | 145722(66) | 1000ft-FL170 | 145 | B | Start of sawtooth profile ascending |
| R4.2 | 145722(66) | 151417(67) | FL170-1000ft | 150 | B | Descending |
| R4.3 | 151500(68) | 153046(69) | 1000ft-FL170 | 150 | B | Ascending |
| | | 155000 | | | | Land Bahrain |

Table 16: Summary of profiles and runs for flight A078

| ALLEVIATOR START | ALLEVIATOR END | HEIGHT | COMMENTS |
|---|---|---|---|
| 0533 | | Ground | Calibrate |
| 0930?? | 093144 | FL090-1000 FT | Transit |
| 094438 | 094652 | FL200-FL210 | Transit |
| 095655 | 095933 | FL240 | Transit |
| 100820 | 101155 | FL240 | Transit |
| 1024?? | 102629 | FL240 | Transit |
| 103959 | 104208 | FL240-FL220 | P1 |
| 1052?? | 105538 | FL150-FL100 | P1 |
| 111112 | 111327 | 2000-700 FT | Possibly saturated, P1 |
| 113248 | 113431 | FL160 | R2 |
| 132430 | 132630 | FL150 | Saturated, R3.4 |
| 133603 | 133840 | FL150 | Calibrate, saturated, R3.5 |
| 145357 | 145555 | FL140-FL160 | R4.1 |
| 152728 | 152940 | FL160-FL170 | R4.3 |

Table 17: Summary of CCN counter operations for flight A078

| RUN NO. | MCR CONFIGURATION |
|---|---|
| R1.1 | Nad |
| R1.2 | Nad |
| P1 | HBB (LW CAL), CBB 105028 (LW CAL), HBB 111417 |
| R2 | CBB, Nad 113013 |
| P2 | Nad |
| R3.1 | Zen |
| R3.2 | Zen |
| R3.3 | Zen |
| R3.4 | HBB, Nad 132024 |
| R3.5 | Nad |
| P3 | HBB |
| R3.6 | Zen |
| R3.7 | Zen |
| R4.1 | HBB, Zen 144218 |
| R4.2 | Zen |
| R4.3 | Zen |

Nad - Nadir
Zen - Zenith
CBB - Cold Black Body
HBB - Hot Black Body
LW CAL - Long Wave Calibration
SW Cal - Short Wave Calibration

Table 18: Summary of MCR configurations for flight A078

| BOTTLE NO. | PURGE START | FILL START | FILL END | HEIGHT | COMMENTS |
|---|---|---|---|---|---|
| R42 | 133040 | 133400 | 133800 | FL145 | In 'lofted' plume |

Table 19: Summary of bottle samples for flight A078

## 8. Flight A079 GULFEX 6 29th March 1991

The main aim of this flight was to study the plume in its far field (1,000Km or more). An old plume (more than 3 days old) was found over central and southern Saudi Arabia. It was suprisingly high (15,000ft) and very thin but still visible. Several runs through and across it were made. It was found to be well mixed i.e the plume had top hat characteristics, and was covering a very large area.

The synoptic situation showed a low pressure area over southern Saudi Arabia and the winds at upper levels from the west.

Tables 20, 21, 22 and 23 summarize the MCR configurations, runs and profiles, CCN counter operations, and bottle samples respectively for this flight.

| RUN NO. | MCR CONFIGURATION |
|---|---|
| P1 | Nad, HBB 065004 |
| P2.1 | CBB (LW CAL) |
| P2.2 | CBB, HBB 074734 |
| P2.3 | HBB,Nad 081733 |
| R1.1 | Nad, Zen 082834 |
| R2.1 | Zen, Nad 083828 |
| R3.1 | Nad |
| R4.1 | HBB, CBB 085220 |
| R5.1 | HBB |
| P3 | Zen, CBB 101943, HBB 102836 |
| R6.1 | CBB, Zen 110035, Nad 110736 |
| R7.1 | Zen, Nad 113506 |
| P4 | Nad, Zen 120331 |
| R8.1 | Zen, Nad 121945 |
| R9.1 | Zen |
| R10.1 | Zen |
| R11.1 | Nad |
| R12.1 | Nad |
| R13.1 | Zen |
| P5.1 | Zen (SW CAL), HBB 135648 (LW CAL) |
| P5.2 | HBB (LW CAL) |
| P5.3 | CBB (LW CAL) |
| P5.4 | CBB, Nad 1420 |

Nad - Nadir
Zen - Zenith
CBB - Cold Black Body
HBB - Hot Black Body
LW CAL - Long Wave Calibration
SW Cal - Short Wave Calibration

Table 20: Summary of MCR configurations for flight A079

| RUN NO | START (GMT) | END (GMT) | HEIGHT (ft) | HEADING (deg) | CABIN | COMMENTS |
|---|---|---|---|---|---|---|
| | 063255 | | | | | Take off Bahrain |
| P1 | 064714(6) | 071450(14) | 50ft-FL200 | 335-320 | B | Profile through thin plume - ascending |
| P2.1 | 071739(15) | 074624(18) | FL200-50ft | 140-120 | B | Start of sawtooth profile - descending |
| P2.2 | 074624(18) | 080149(26) | 50ft-FL130 | 120-130 | B | Ascending |
| P2.3 | 080149(26) | 082019(30) | FL130-50ft | 130 | B | Descending |
| R1.1 | 082505(31) | 083000(33) | FL050 | 220-221 | U | Run across wind |
| R2.1 | 083300(34) | 084505(37) | FL080 | 040 | U | Run across wind |
| R3.1 | 084636(38) | 084854(39) | FL080 | 315 | P | Run across wind |
| R4.1 | 085052(41) | 085829(45) | FL080 | 135 | P | Run across wind |
| R5.1 | 090324(46) | 091825(51) | FL120 | 230 | P | Run across wind |
| P3 | 101749(65) | 103534(72) | FL150-1000ft | - | B | Descending profile - looking for plume |
| R6.1 | 105331(78) | 110811(86) | 150ft | 095-110 | U | Run looking for plume |
| R7.1 | 112929(89) | 114501(97) | 150ft-FL150 | 295-300 | B | Run looking for plume |
| P4 | 115435(99) | 120553(105) | FL170-120 | 135 | P | Descending profile through plume |
| R8.1 | 121148(106) | 122051(108) | FL145 | 215 | P | Run through plume |
| R9.1 | 122134(109) | 123315(110) | FL145 | 150 | P | Run through plume |
| R10.1 | 123428(111) | 125519(112) | FL145 | 265 | P | Run through plume |
| R11.1 | 125645(113) | 131611(114) | FL145 | 145 | P | Run through plume |
| R12.1 | 131729(115) | 133504(116) | FL145 | 265 | P | Run through plume, FSSP and PCASP anti-correlated |
| R13.1 | 133613(117) | 135201(118) | FL145 | 150 | P | Run through plume |
| P5.1 | 135540 | 140258(126) | FL170-FL100 | 360 | P | Start of sawtooth profile - descending |
| P5.2 | 140326(127) | 141009(128) | FL100-FL170 | 360 | P | Ascending |
| P5.3 | 141027(129) | 141741(131) | FL170-FL100 | 360 | P | Descending |
| P5.4 | 141757(132) | 142528(133) | FL100-FL170 | 360 | P | Ascending |
| P5.5 | 142546(134) | 143251(135) | FL160-FL100 | 005 | P | Descending |
| P5.6 | 143308(136) | 144025(137) | FL100-FL170 | 360 | P | Ascending |
| P5.7 | 144046(138) | 144753(139) | FL170-FL100 | 360 | P | Descending |
| P5.8 | 144809(140) | 145532(141) | Fl100-FL170 | 360 | P | Ascending |
| P5.9 | 145555(142) | 150308(143) | Fl170-FL100 | 005 | P | Descending |
| P5.10 | 150325(144) | 151045(145) | FL100-FL170 | 005-340 | P | Ascending |
| P5.11 | 151103(146) | (147) | FL160-FL100 | 340 | P | Descending |
| P5.12 | 151838(148) | (149) | FL100-FL170 | 340 | P | Ascending |
| P5.13 | 152626(150) | 154121(151) | FL170-FL100 | 340-355 | B | Descending |
| | | 155155 | | | | Land Bahrain |

Table 21: Summary of profiles and runs for flight A079

| ALLEVIATOR START | ALLEVIATOR END | HEIGHT | COMMENTS |
|---|---|---|---|
| 0533 | | Ground | Calibration |
| 070002 | 0701?? | FL110 | P1 |
| 071305 | 071529 | FL197-FL200 | P1 |
| 085412 | 085615 | FL080 | Possibly saturated, R4.1 |
| 090459 | 090659 | FL120 | R5.1 |
| 091528 | 091733 | FL120 | R5.1 |
| 09357? | 09387? | FL230 | Transit |
| 094821 | 095056 | FL230 | Transit |
| 100250 | 100455 | FL170 | Transit |
| 101611 | 101800 | FL150 | P3 |
| 104500 | 104700 | FL128-FL140 | Transit |
| 105907 | 110150 | FL150 | R6.1 |
| 111233 | 111426 | FL150 | Transit |
| 112650 | 112844 | FL150 | Transit |
| 113724 | 113924 | FL150 | Possibly saturated, R7.1 |
| 114826 | 115035 | FL150 | Possibly saturated, transit |
| 115920 | 110122 | FL135-FL150 | Possibly saturated, P4 |
| 121038 | 121239 | FL145 | R8.1 |
| 121930 | 122130 | FL145 | R8.1 |
| 123036 | 123309 | FL145 | Possibly saturated, R9.1 |
| 124315 | 124521 | FL145 | Possibly saturated, R10.1 |
| 125502 | 125708 | FL145 | Possibly saturated, R10.1 |
| 130725 | 130925 | FL145 | Calibration, R11.1 |
| 131814 | 132024 | FL145 | Calibration, R12.1 |
| 133054 | 133300 | FL145 | R12.1 |
| 134233 | 134527 | FL145 | R13.1 |
| 135753 | 135949 | FL150-FL130 | Possibly saturated, P5.1 |
| 141535 | 141718 | FL120-FL105 | Possibly saturated, P5.4 |
| 142608 | 142700 | FL170-FL160 | Possibly saturated, P5.5 |
| 143607 | 143723 | FL127-FL140 | Possibly saturated, P5.6 |
| 145007 | 145126 | FL120-FL140 | Possibly saturated, P5.8 |
| 150324 | 150423 | FL100-FL110 | Possibly saturated, P5.10 |
| 151533 | 151642 | FL125-FL120 | Possibly saturated, P5.11 |
| 152409 | 152628 | FL155-FL170 | P5.13 |

Table 22: Summary of CCN counter operations for flight A079

| BOTTLE NO. | PURGE START | FILL START | FILL END | HEIGHT | COMMENTS |
|---|---|---|---|---|---|
| H06 | 081900 | 082700 | 082900 | FL050 | - |
| H12 | 083200 | 083800 | 084000 | FL080 | - |
| R21 | 084900 | 084700 | 085500 | FL080 | In puff of smoke!, SO2 20, NOx 5, 03 60 |
| SO2 | 090724 | 091200 | 091800 | FL120 | Run 5.1 SO2 —, NOx B/G, 03 60 |
| R20 | 113000 | 113500 | 113700 | FL150 | - |
| SO3 | 114300 | 121100 | 121950 | FL145 | In plume |
| R40 | 122100 | 122440 | 122700 | FL145 | - |
| R27 | 130500 | 130937 | 131232 | Fl145 | - |
| R11 | 140720 | 141707 | 141935 | FL125-FL100 | Sawtooth through plume. 141500 two pumps |
| R24 | 142700 | 142802 | 142911 | | In FSSP layer; 4 fills |
| | | 143951 | 144042 | | |
| | | 145345 | 145840 | | |
| | | 145909 | 145848 | | |

Table 23: Summary of bottle samples for flight A079

## 9. Flight A080 GULFEX 7 30th March

Once again the plume was being advected straight down the Gulf and this flight was undertaken to investigate its near field and intermediate field. Shallow saw tooth profiles were carried out through the initial plume rise from Kuwait and across wind runs were done at several heights in the near field and intermediate field. The plume was very thick and had a complex structure due to vertical wind shear. The flight pattern was restricted by the limitations of Iranian airspace.

The synoptic situation showed a weak upper trough moving into the Gulf quite rapidly which was producing a lot of high cloud and the surface winds were from a north westerly direction.

Tables 24, 25, 26 and 27 summarize the CCN counter operations, runs and profiles, MCR configurations and bottle samples respectively for this flight.

| ALLEVIATOR START | ALLEVIATOR END | HEIGHT | COMMENTS |
|---|---|---|---|
| 051900 | 053000 | Ground | Calibration with film |
| 064506 | 064717 | FL120-FL130 | Transit |
| 065630 | 065852 | FL185-FL195 | Transit |
| 070757 | 070957 | FL170 | Transit |
| 071911 | 072111 | FL170 | Transit |
| 073050 | 073323 | FL170 | Transit |
| 075309 | 075508 | FL100-FL080 | P1 |
| 080348 | 080549 | FL030-FL020 | P1 |
| 083622 | 083728 | FL075 | R1.6 |
| 084250 | 084402 | FL145-FL155 | Possibly saturated, R1.6 |
| 112827 | 113029 | FL140-FL150 | P3 |
| 114008 | 114245 | FL150 | Transit |
| 120214 | 120430 | FL180 | Transit |
| 121337 | 121519 | FL180 | Transit |
| 122220 | 122411 | FL080 | Completely saturated, R4.1 |
| 144650 | 144838 | FL070-FL050 | Saturated, R6.2 |
| 150136 | 150328 | FL080-FL095 | Saturated, R6.3 |
| 151206 | 151400 | FL080-FL065 | Saturated, R6.4 |
| 152230 | 152430 | 400 - 2000 FT | Saturated, R6.5 |
| 153302 | 153459 | FL110-FL130 | R6.5 |

Table 24: Summary of CCN counter operations for flight A080

| RUN NO | START (GMT) | END (GMT) | HEIGHT (ft) | HEADING (deg) | CABIN | COMMENTS |
|---|---|---|---|---|---|---|
| | 063225 | | | | | Take off Bahrain |
| P1 | 0764412(10) | 080706(19) | FL170-1000ft | 215-025 | P | Descending profile outside plume |
| R1.1 | 082025(21) | 082227(25) | FL100-FL080 | 120 | P | Starting sawtooth profiles through plume rise - descending |
| R1.2 | 082227(25) | 082450(26) | FL080-FL100 | 120 | P | Ascending, 7/8 Cs and 3/8 Cu |
| R1.3 | 082450(26) | 082756(27) | FL100-FL070 | 100 | P | Descending |
| R1.4 | 082756(27) | 083013(28) | FL070-FL090 | 100 | P | Ascending |
| R1.5 | 083013(28) | 083413(29) | FL090-FL055 | 100 | P | Descending |
| R1.6 | 083413(29) | 084441(30) | FL055-FL160 | 100 | P | Ascending |
| R1.7 | 094441(30) | 085500 | FL160-FL060 | 100 | P | Descending |
| P2 | 085717(33) | 090322(34) | FL060-50ft | 275 | B | Descending profile through plume |
| R2.1 | 091834(46) | 094352(49) | 1000ft | 195 | U | Run downwind through plume |
| R3.1 | 094730(54) | 095311(55) | 250ft | 115 | U | MARSS runs |
| R3.2 | 095629(57) | 100520(60) | 250ft | 280-315 | U | MARSS runs |
| R2.2 | 101300(64) | 103118(66) | FL090-FL085 | 005 | U | Run across wind through plume |
| R2.3 | 103335(67) | 105101(71) | FL087 | 210-200 | U | Run across wind through plume,7/8 Cs |
| R2.4 | 105418(73) | 111046(75) | FL060 | 005 | U | Run across wind through plume |
| P3 | 111524(78) | 112928(79) | 500ft-FL150 | 285-200 | B | Ascending profile through plume |
| R4.1 | 122224(86) | 123704(87) | FL080 | 095-110 | P | Run close to top of plume |
| R4.2 | 123905(88) | 124959(91) | FL065 | 100-130 | U | Run close to top of plume |
| R5.1 | 125036(92) | 125318(93) | FL065 | 025-350 | U | Run across wind through plume |
| R5.2 | 125448(94) | 130910(96) | FL065 | 220 | U | Run across wind through plume |
| P4 | 131439(98) | 132934(102) | 500ft-FL080 | 030 | U | Ascending profile through plume |
| R5.3 | 133500(104) | 135134(105) | 4800ft | 210-200 | U | Run across wind through plume |
| R5.4 | 135355(106) | 141318(113) | 2000ft | 015-025 | U | Run close to base of plume |
| R5.5 | 141658(117) | 143235(118) | FL070 | 200-215 | P | Run across wind through plume, 7/8 CsAc |
| R6.1 | 143340(121) | 144008(126) | FL070-FL130 | 105 | P | Starting sawtooth profile - ascending |
| R6.2 | 144008(126) | 145323(129) | Fl130-500ft | 105 | P | Descending |
| R6.3 | 145323(129) | 150700(132) | 500ft-FL130 | 105 | P | Ascending |
| R6.4 | 150700(132) | 152229(135) | FL130-500ft | 105-260 | P | Descending |
| R6.5 | 152229(135) | 153511(136) | 500ft-FL130 | 260 | P | Ascending |
| R6.6 | 15351(136) | 154628(137) | FL130-4000ft | 260 | | Descending |
| | | 155504 | | | | Land Bahrain |

Table 25: Summary of profiles and runs for flight A080

| RUN NO. | MCR CONFIGURATION |
|---|---|
| P1 | CBB, Zen 074843, Nad 074912 |
| R1.1 | CBB, Nad 082111 |
| R1.2 | Nad |
| R1.3 | Nad |
| R1.4 | Nad |
| R1.5 | Nad |
| R1.6 | Nad |
| P2 | HBB |
| R2.1 | Nad, Zen 094039, Nad 094151 |
| R3.1 | Nad |
| R3.2 | Nad |
| R2.2 | HBB, Nad 101359 |
| R2.3 | Nad |
| R2.4 | CBB, HBB 110619 (LW CAL) |
| P3 | CBB |
| R4.1 | CBB |
| R4.2 | CBB, Zen 124749 |
| R4.3 | HBB |
| R5.2 | HBB, CBB 125613 |
| P4 | HBB |
| R5.3 | Nad |
| R5.4 | HBB, occasionally to Zen |
| R5.5 | CBB |
| R6.1 | CBB, HBB 143436 (LW CAL) |
| R6.2 | HBB, Nad 145352 |
| R6.2 | Nad |

Nad - Nadir
Zen - Zenith
CBB - Cold Black Body
HBB - Hot Black Body
LW CAL - Long Wave Calibration
SW Cal - Short Wave Calibration

Table 26: Summary of MCR configurations for flight A080

| BOTTLE NO. | PURGE START | FILL START | FILL END | HEIGHT | COMMENTS |
|---|---|---|---|---|---|
| R22 | 102158 | 102253 | 102545 | FL850 | Run 2.2, in plume; point B |
| R07 | 103756 | 104512 | 101720 | FL085 | Run 2.3, SO2 50, NOx 2, 03 66 Higher 03 on one side of plume |
| R26 | 125756 | 123127 | 123239 | FL080 | Run 4.1 |
| S01 | 124344 | 125106 | 125500 | FL065 | Run 5.1, Point C, SO2 230, NOx 6, 03 62, Into Tehran airspace. (point C?) |
| R10 | 133900 | 143445 | 134647 | FL048 | Tenuous plume, SO2 100, NOx 5, 03 70 |
| R05 | 145140 | 145346 | 145450 | FL005-FL010 | Profile up |
| R09 | 152140 | 152244 | 152351 | FL005-FL015 | SO2 10, NOx 5, 03 60 |

Table 27: Summary of bottle samples for flight A080

## 10. Flight A081 GULFEX 8 31st March 1991

The final GULFEX flight was carried out to investigate the plume originating from the sources to the north of Kuwait City and to find how it merged with the southern plume. The surface wind was blowing almost straight down the Saudi Arabian coast from Kuwait and the northern plume could easily be distinguished from the southern plume close to Kuwait. Several transects through this plume were carried out and it was found to be much weaker than the southern plume. The initial rise of the plume took it to 14,000ft. A zig zag track was then flown down the gulf to see how the two plumes merged. Away from the sources the plume was observed to be no higher than 10,000ft.

The synoptic situation showed high pressure to the west of the Gulf and the north westerly flow ahead of it was quite deep.

Tables 28, 29, 30 and 31 summarize the runs and profiles, CCN counter operations, MCR configurations and bottle samples respectively for this flight.

| RUN NO | START (GMT) | END (GMT) | HEIGHT (ft) | HEADING (deg) | CABIN | COMMENTS |
|---|---|---|---|---|---|---|
| | 063335 | | | | | Take off Bahrain |
| P1 | 075250(15) | 081921(18) | FL200-500ft | 190-015 | | Profile upwind of northern plume - descending |
| P2 | 083613(21) | 084904(22) | FL140-1000ft | 130 | B | Ascending profile through plume |
| R1.1 | 090158(24) | 091901(25) | FL085 | 225 | U | Run across northern plume |
| R1.2 | 092100(27) | 093631(32) | FL095 | 040-025 | P | Run across northern plume |
| R1.3 | 094018(34) | 100028(38) | FL085 | 220-315 | B | Run across northern plume |
| R2.1 | 100212(40) | 100719(42) | FL085-FL095 | 105 | B | Run below plume |
| R2.2 | 100719(42) | 102600(43) | FL095 | 180 | P | Start zig zag through plume, high PCASP values |
| R2.3 | 102717(44) | 104414(49) | FL095 | 065 | P | Run through plumes (northern and southern) |
| R2.4 | 104537(50) | 110133(53) | FL095 | 205 | P | Run through plumes, Ac above |
| R2.5 | 110246(54) | 111359(55) | FL095 | 070 | P | Run through plumes |
| R2.6 | 111541(56) | 113001(58) | Fl095 | 205 | P | Run through plumes |
| R2.7 | 113121(59) | 114427(60) | FL095 | 070 | P | Run through plumes |
| R2.8 | 114557(61) | 120101(66) | FL095 | 220 | P | Run through plumes |
| | | 121535 | | | | Land Bahrain |

Table 28: Summary of profiles and runs for flight A081

| ALLEVIATOR START | ALLEVIATOR END | HEIGHT | COMMENTS |
|---|---|---|---|
| 0410 | | Ground | Calibration |
| 064121 | 064315 | FL090-FL105 | Transit |
| 065208 | 065410 | FL180-FL190 | Transit |
| 070300 | 070500 | FL200 | Calibrate, transit |
| 072043 | 072247 | FL200 | Transit |
| 073242 | 073428 | FL200 | Transit |
| 074305 | 074513 | FL200 | Transit |
| 080720 | 080900 | FL080-FL065 | P1 |
| 081745 | 081938 | FL015-500 FT | P1 |
| 092350 | 092518 | FL095 | Saturated, R1.2 |
| 100608 | 100819 | FL095 | Possibly saturated, R2.1 |
| 102100 | 102319 | FL095 | Completely saturated, R2.2 |
| 103758 | 103958 | FL095 | Saturated, R2.3 |
| 104958 | 105210 | FL095 | Saturated, R2.4 |
| 112729 | 112929 | FL095 | Saturated, R2.6 |
| 113848 | 114048 | FL095 | Saturated, R2.7 |
| 115050 | 115238 | FL095 | Saturated, R2.8 |
| 120022 | 120240 | FL095 | R2.8 |

**Table 29: Summary of CCN counter operations for flight A081**

| RUN NO. | MCR CONFIGURATION |
|---|---|
| P1 | CBB |
| P2 | HBB |
| R1.1 | Nad |
| R1.2 | Nad, Zen 092738 |
| R1.3 | CBB, Nad, Zen 095112 |
| R2.1 | HBB, Zen 100322 |
| R2.2 | Zen |
| R2.3 | Zen, Nad 103055 |
| R2.4 | Nad |
| R2.5 | Nad |
| R2.6 | Nad, Zen 112144 |
| R2.7 | Nad |
| R2.8 | Zen, HBB 115413 (LW CAL), CBB |

Nad - Nadir
Zen - Zenith
CBB - Cold Black Body
HBB - Hot Black Body
LW CAL - Long Wave Calibration
SW Cal - Short Wave Calibration

**Table 30: Summary of MCR configurations for flight A081**

| BOTTLE NO. | PURGE START | FILL START | FILL END | HEIGHT | COMMENTS |
|---|---|---|---|---|---|
| R01 | 090856 | 090956 | 091120 | FL085 | - |
| R12 | 092300 | 092614 | 092755 | FL095 | - |
| R28 | 094316 | 094500 | 094650 | FL085 | - |
| R25 | 095430 | 095530 | 095723 | FL084 | - |
| H04 | 102147 | 102200 | 102340 | FL095 | - |
| R15 | 115400 | 111054 | 111310 | FL095 | SO2 40, NOx 5, 03 70 |

**Table 31: Summary of bottle samples for flight A081**

**11. Bottle samples - flight cross reference table.**

| BOTTLE NUMBER | FLIGHT NUMBER |
|---|---|
| G01 | A077 |
| G02 | A077 |
| H03 | A077 |
| H04 | A081 |
| H05 | A077 |
| H06 | A079 |
| H12 | A079 |
| R01 | A081 |
| R02 | A077 |
| R03 | A076 |
| R04 | A077 |
| R05 | A080 |
| R06 | A076 |
| R07 | A080 |
| R08 | A077 |
| R09 | A080 |
| R10 | A080 |
| R11 | A079 |
| R12 | A081 |
| R14 | A077 |
| R15 | A081 |
| R16 | A076 |
| R17 | A075 |
| R18 | A077 |
| R19 | A076 |
| R20 | A079 |
| R21 | A079 |
| R22 | A080 |
| R23 | A077 |
| R24 | A079 |
| R25 | A081 |
| R26 | A080 |
| R27 | A079 |
| R28 | A081 |
| R29 | A077 |
| R30 | A077 |
| R31 | A075 |
| R34 | A076 |
| R36 | A076 |
| R37 | A077 |
| R40 | A079 |
| R42 | A078 |
| S01 | A080 |
| S02 | A079 |
| S03 | A079 |

Table 32: Summary of bottle samples for each flight.

12. Summary of filters exposed on each flight.

## SUMMARY OF FILTERS USED DURING GULFEX

Note - all volumes are as indicated by meter and require a pressure correction.

| FILTER NO | FLIGHT | HEIGHT FT | TIMES GMT | VOLUME M3 | PUMP RAM | LDG | DI /I | TAU | Babs 10-4 m-1 | Bscat | Wo | Dist from source (km) | ANALYSIS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

### OPTICAL FILTERS

| FILTER NO | FLIGHT | HEIGHT FT | TIMES GMT | VOLUME M3 | PUMP RAM | LDG | DI /I | TAU | Babs 10-4 m-1 | Bscat | Wo | Dist from source (km) | ANALYSIS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Opex 6 | 74 | 1500-8000 | 130456-132600 | 1.016 | P | L | .21 | 0.022 | 0.2 | 0.8 | 0.8 | 700 | - |
| Opex 7 | | Blank | | | | | | | | | | - | |
| Opex 8 | 75 | 2000 | 091400-092200 | 0.392 | P | L | .21 | 0.022 | 0.5 | 1.4 | 0.74 | 60 | - |
| Opex 9 | 75 | 10,000 | 100050-100750 | 0.489 | P | H | .73 | 0.088 | 1.6 | - | - | 60 | WSL |
| Opex10 | 75 | 10,000 | 105130-110130 | 0.709 | P | H | .83 | 0.118 | 1.5 | - | - | 30 | RAE(SEM) |
| Opex11 | 76 | 6000 | 100635-104230 | 1.082 | P | H | .96 | 0.173 | 0.8 | 3.2 | 0.73 | 60 | WSL |
| Opex12 | 77 | 4000 | 100312-101737 | 0.683 | P | L | .55 | 0.051 | 0.7 | 1.3 | 0.65 | 300 | - |
| Opex15 | 77 | 7000 | 123840-125142 | 1.313 | P | H | .81 | 0.111 | 0.8 | 3.9 | 0.83 | 100 | HARWELL |
| Opex13 | 78 | 5100 | 142200-143915 | (1.080) | R | L | .53 | 0.049 | 0.4 | 2.5 | (0.86) | 120 | - |
| Opex16 | 78 | 6500 | 123310-124519 | 0.567 | P | H | .84 | 0.123 | 2.0 | 3.2 | 0.6 | 120 | HARWELL |
| Opex14 | 79 | 8000 | 083335-085833 | (1.871) | R | L | .08 | 0.018 | 0.9 | 0.7 | (0.44) | 500 | - |
| Opex17 | 79 | 12000-17000 | 113637-121550 | 3.092 | P | L | .12 | 0.019 | 0.06 | - | - | 600 | - |
| Opex18 | 79 | 14500 | 123129-131335 | 0.635 | R | L | .03 | 0.016 | 0.04 | - | - | 700 | - |
| Opex19 | 79 | 14500 | 123129-131335 | 3.307 | P | L | .06 | 0.017 | 0.05 | - | - | 700 | RAE(SEM) |
| Opex20 | 80 | 9500-11000 | 143640-153300 | 3.705 | P | H | .81 | 0.111 | 0.3 | - | - | 250 | WSL |
| Opex21 | 80 | 6500 | 124355-130500 | 1.047 | P | H | .93 | 0.157 | 1.4 | 6.5 | 0.82 | 100 | HARSS+RAE(C) |
| Opex22 | 81 | 9500 | 103645-111740 | (2.618) | R | L | - | 0.018 | 0.05 | - | - | 210 | - |
| Opex23 | 81 | 8500-9500 | 0902441-093750 | 2.248 | P | H | .72 | 0.086 | 0.3 | 0.94 | 0.76 | 100 | HARWELL |

### SO2 FILTERS - NPTECH

| FILTER NO | FLIGHT | HEIGHT FT | TIMES GMT | VOLUME M3 | PUMP | SO4-- ugm-3 | Cl- ugm-3 | | Dist from source (km) | ANALYSIS |
|---|---|---|---|---|---|---|---|---|---|---|
| SO2-1 | 75 | 2000 | 091400-092200 | 0.392 | P | 6.9 | | | 100 | NPTECH |
| SO2-2 | 75 | 10,000 | 100050-100750 | 0.489 | P | 60 | | | 50 | NPTECH |
| SO2-3 | 75 | 10,000 | 105130-110130 | 0.709 | P | 94 | | | 60 | NPTECH |
| SO2-4 | 76 | 6000 | 100635-104230 | 1.082 | P | 123 | 9.6 | | 70 | NPTECH |
| WHAT-5 | 77 | 4000 | 100312-101737 | 0.683 | P | 11 | | | 320 | NPTECH |
| SO2-7 | 77 | 7000 | 123840-125142 | 1.313 | P | 33 | | | 100 | NPTECH |
| SO2-9 | 78 | 6500 | 123310-124519 | 0.567 | P | 108 | | | 120 | NPTECH |
| SO2-10 | 79 | 12000-17000 | 113637-121550 | 3.092 | P | 1.0 | | | 650 | NPTECH |
| SO2-11 | 79 | 14500 | 123129-131335 | 3.307 | P | 0.7 | | | 700 | NPTECH |
| SO2-12 | 80 | 9500-11000 | 143640-153300 | 3.705 | P | 15.0 | | | 350 | NPTECH |
| SO2-13 | 80 | 6500 | 124355-130500 | 1.047 | P | 115 | | | 200 | NPTECH |
| SO2-14 | 80 | 9000 | 101353-110756 | 2.852 | P | 72 | 12.6 | | 150 | NPTECH |
| SO2-15 | 80 | 4750 | 133455-135155 | 0.850 | P | 45 | | | 200 | NPTECH |
| SO2-16 | 81 | 8500 | 095627-102105 | 1.499 | P | 28 | | | 70 | NPTECH |
| SO2-17 | 81 | 9500 | 103645-111740 | 2.618 | P | 33 | | | 250 | NPTECH |
| BLANK | 81 | | | | | | | 1.02,1.07 ug | | |

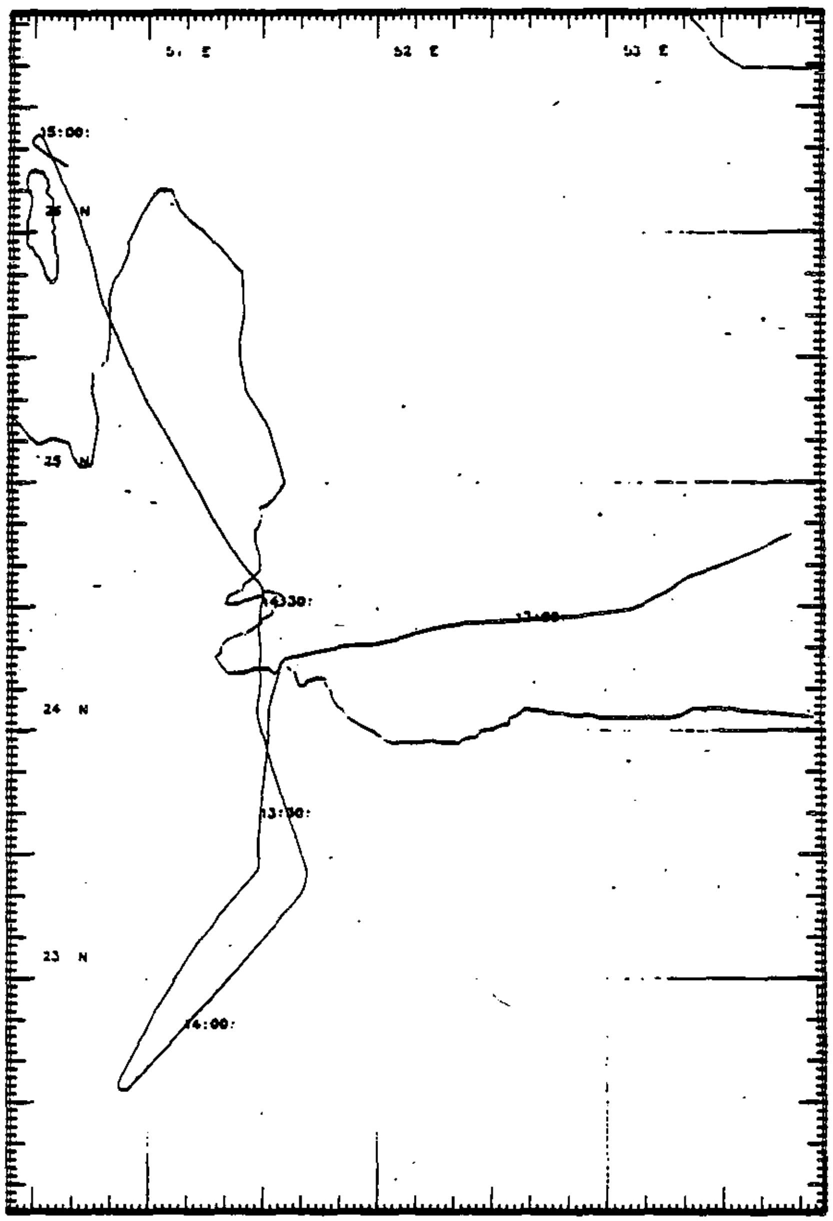
| REF | FLT | HT (ft) | Times (GMT) | Vol (m3) | | MASS (g) before | MASS (g) after | LOADING (ug) ( +- 20) | DENSITY (ugm-3) | PCASP (ugm-3) all/plume | Distance (KM) | COMMENTS analysis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Opex NW2 | 74 | 1500-8000 | 130456-132600 | (1.02) | R | 0.01558 | 1560 | 20 | (20.0) | | 500 | - |
| Opex NW3 | 75 | 2000 | 091400-092200 | (0.39) | R | 0.01538 | 1534 | * | * | * | 100 | - |
| Opex NW4 | 76 | 6000 | 100635-1042330 | (1.882) | R | 0.01571 | 1574 | 25 | (15.0) | | 50 | WSL |
| Opex NW5 | 81 | 9500 | 103645-111740 | 2.618 | P | 0.01558 | 1558 | * | * | * | 160 | - |
| Opex NW7 | 75 | 10,000 | 100050-100750 | (0.49) | R | 0.01553 | 1547 | * | * | * | 50 | - |
| Opex NW8 | 75 | 12,000 | 111105-111635 | 0.436 | P | 0.01587 | 1587 | * | * | * | 50 | - |
| Opex NW10 | 80 | 9000 | 101353-110756 | 2.852 | P | 0.01563 | 15741 | 110 | 39.0 | 73/120 | 100 | HARWELL |
| Opex NW11 | 80 | 4750 | 133445-135155 | 0.850 | P | 0.01576 | 1581 | 50 | 59.0 | 29/50 | 180 | WSL |
| Opex NW12 | 80 | 6500 | 124355-130500 | (1.05) | R | 0.015245 | 15280 | 35 | (33.0) | 95/95 | 180 | RAE(SEM) |
| Opex NW15 | 81 | 8500 | 095627-102105 | 1.499 | P | 0.01547 | 15539 | 70 | 47.0 | 37/75 | 50 | RAE(C) |
| Blanks- NW6 | | | | | | 0.01565 | 15648 | 2 | | | | |
| NW9 | | | | | | 0.01593 | 15912 | -18 | Repeatable to better than 20 ug. | | | |
| Opex MW1 | 77 | 7000 | 123840-125142 | 0.071 | R | 0.09312 | 9265 | -47(+9) | * | | 100 | WSL |
| | | 5500 | 125810-131020 | 0 | | | | | | | | |
| Opex MW2 | 79 | 10000-17000 | 135043-151830 | 6.472 | P | 0.09307 | 9289 | -18(+38) | 6.0 | | 700 | HARWELL |
| Blanks - MW3 | | | | | | 0.09335 | 9263 | -72 | | | | - |
| MW4 | | | | | | 0.09208 | 9162 | -46 | MEAN = -56 | | | - |
| MW7 | | | | | | 0.09332 | 9282 | -50 | | | | - |

QUARTZ - DESERT RESEARCH INSTITUTE

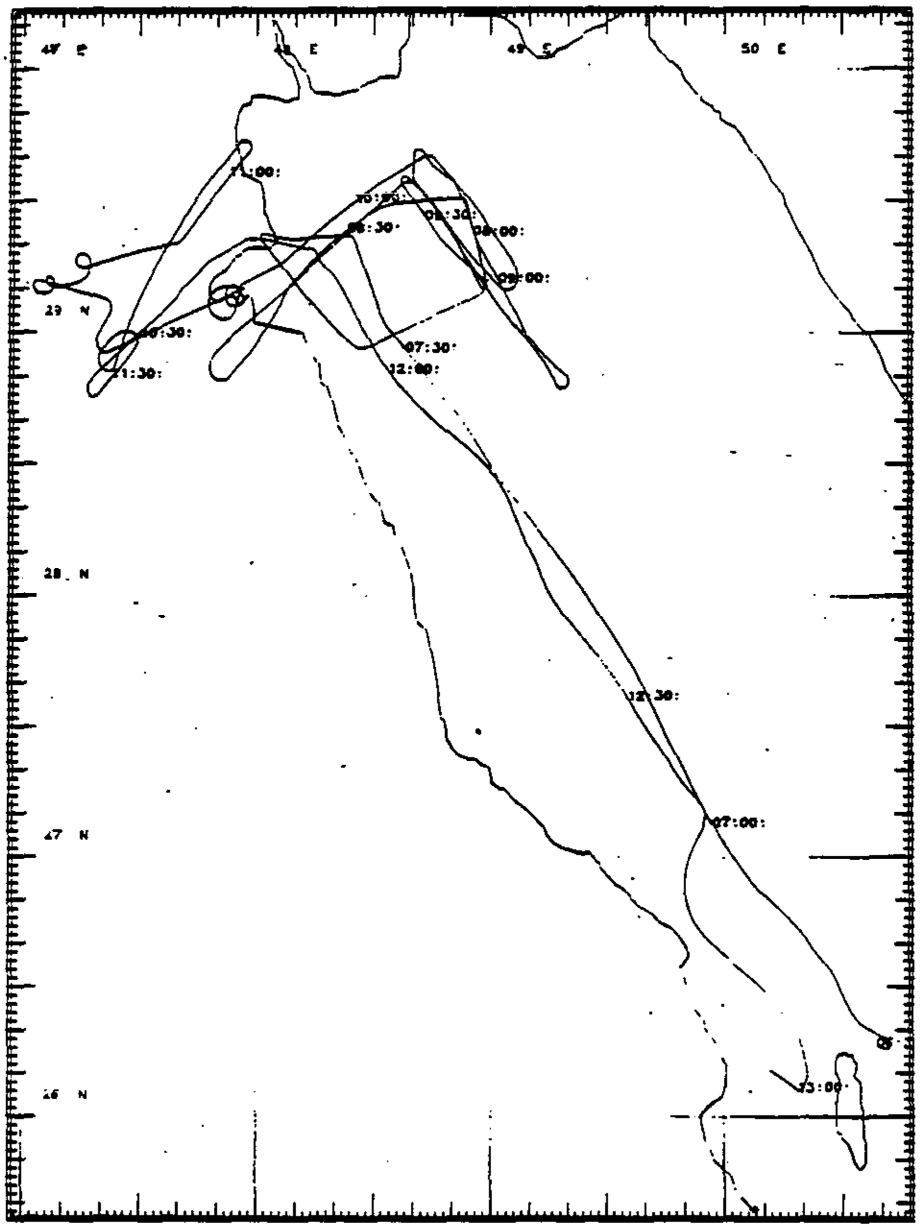
| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Quartz 1 | 78 | 6500 | 123310-124519 | (0.567) | R | L | 120 | DRI |
| Quartz 2 | 78 | 5100 | 142200-143915 | 1.080 | P | M | 120 | DRI |
| Quartz 3 | 78 | | 1453- | ** BLANK / CONTROL ** | | | | |
| Quartz 4 | 79 | 8000 | 083335-085833 | 1.871 | P | M | 500 | DRI |
| Quartz 5 | 79 | 12000-17000 | 113637-121550 | (3.092) | R | L | 600 | DRI |
| Quartz 6 | 80 | 9000 | 101353-110756 | (2.852) | R | H | 120 | DRI |
| Quartz 7 | 80 | 4750 | 133455-135155 | (0.850) | R | L | 220 | DRI |
| Quartz 8 | 81 | 8500 | 095627-102105 | (1.5) | R | L | 100 | DRI |
| Quartz 9 | 81 | 8500-9500 | 090241-093750 | (2.25) | R | L | 120 | DRI |

13. **Flight track plots.**

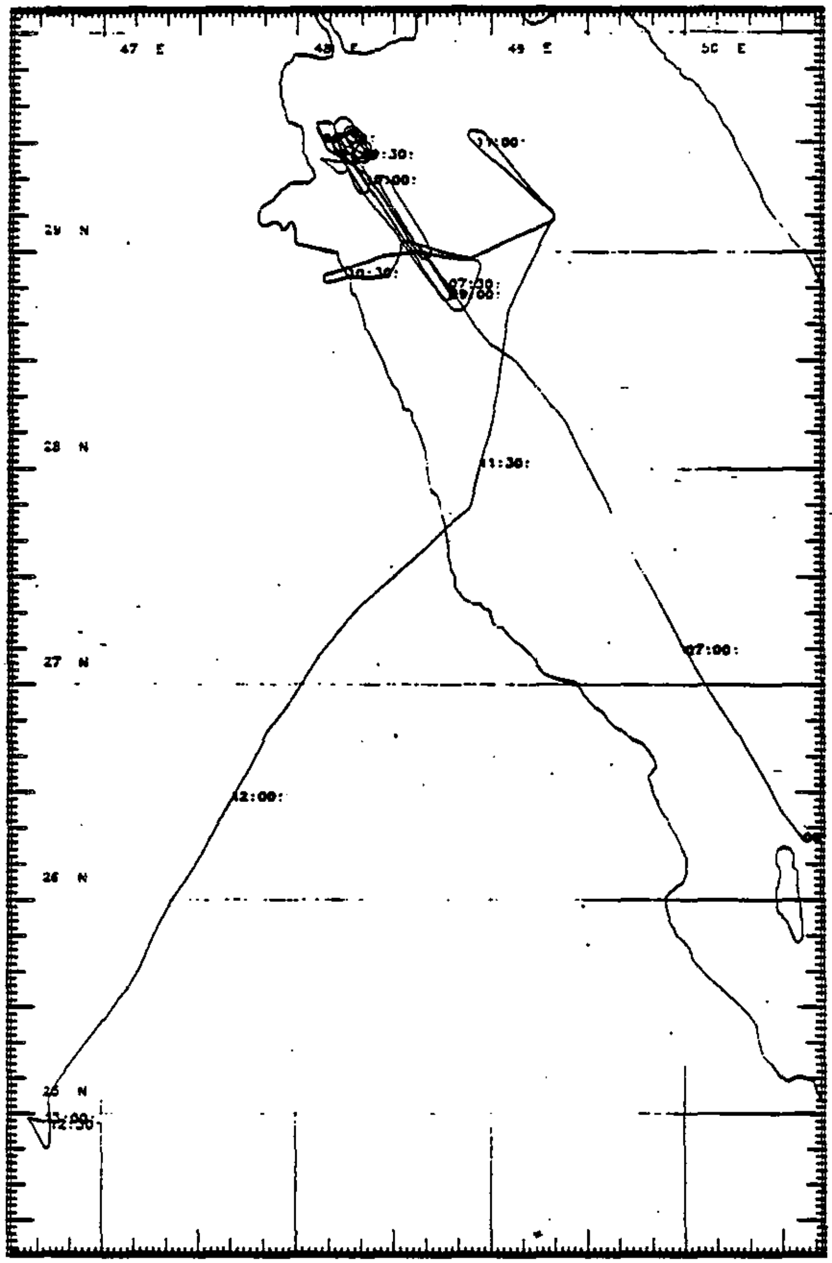
A074 23 March 1991



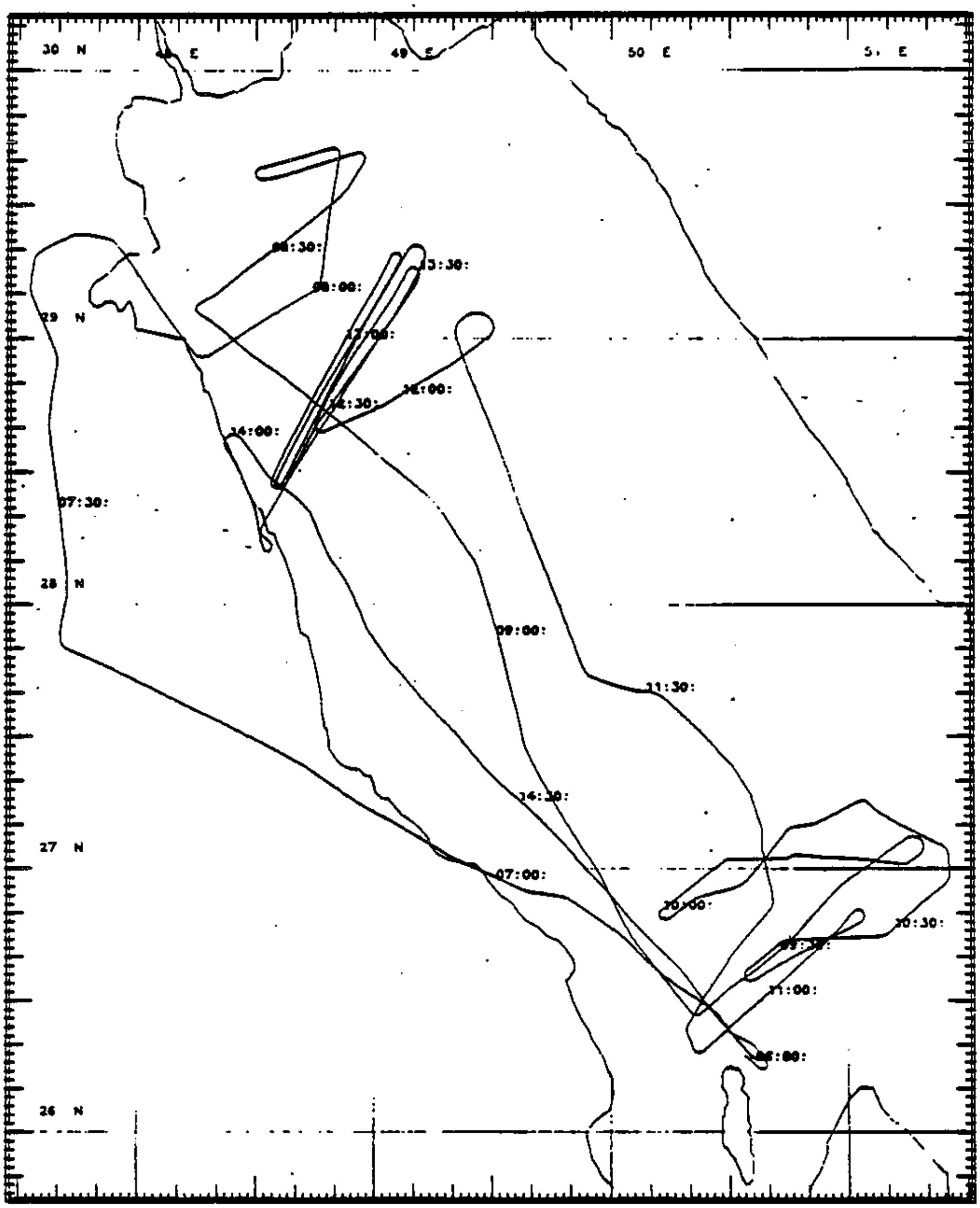
A075 24 March 1991



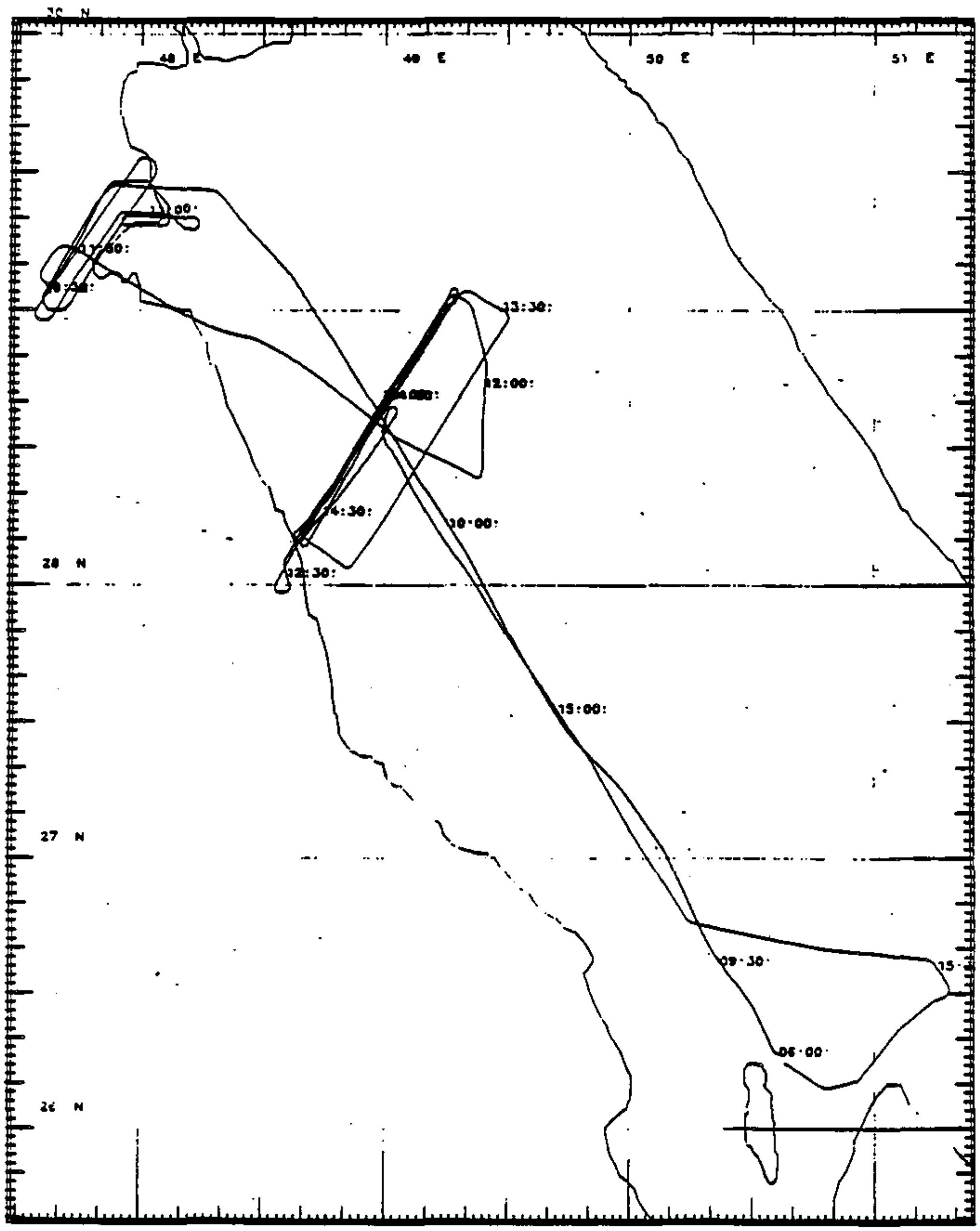
A076 25 March 1991



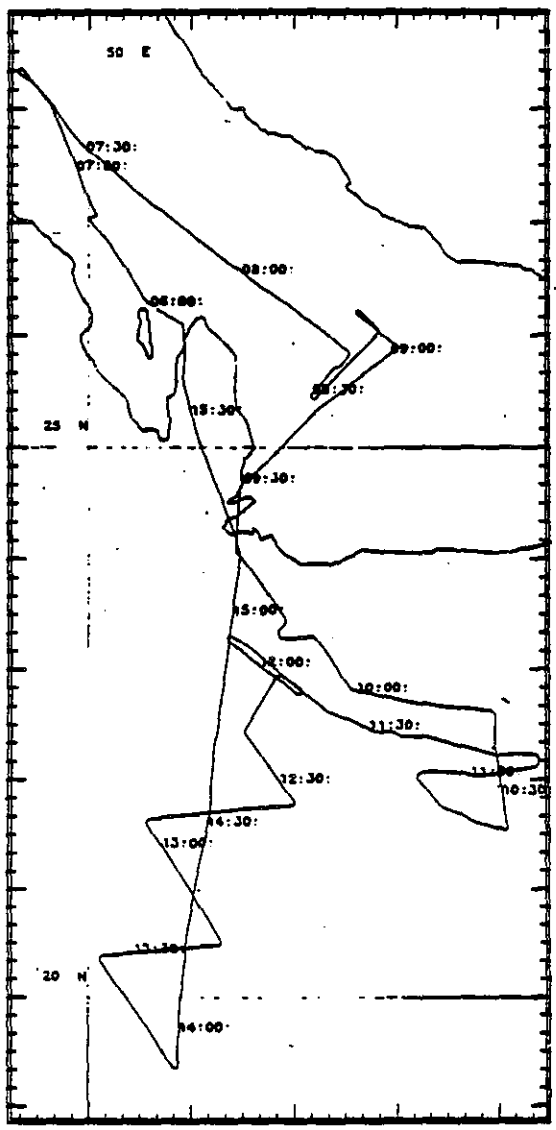
A077 26 March 1991



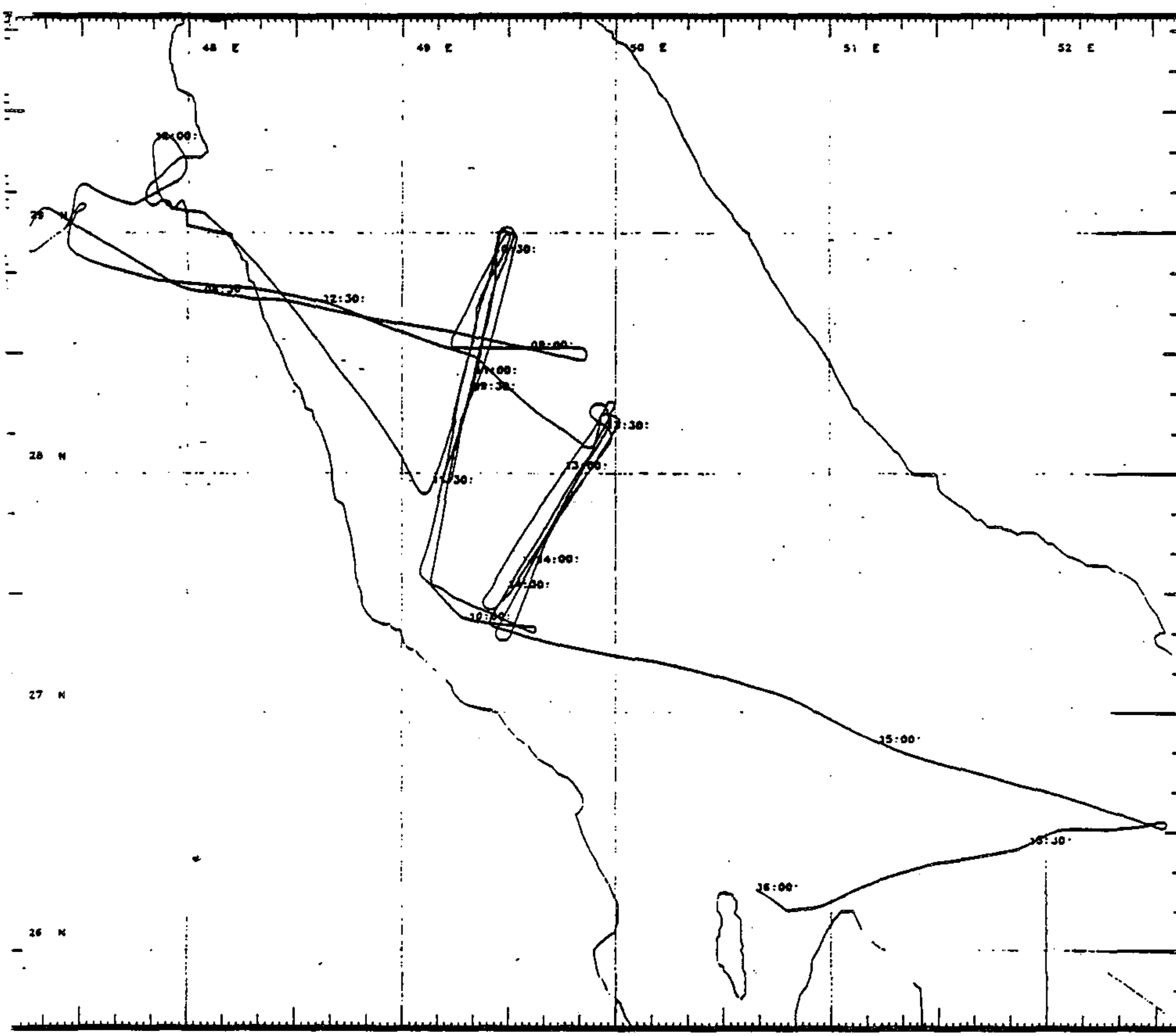
A078 28 March 1991



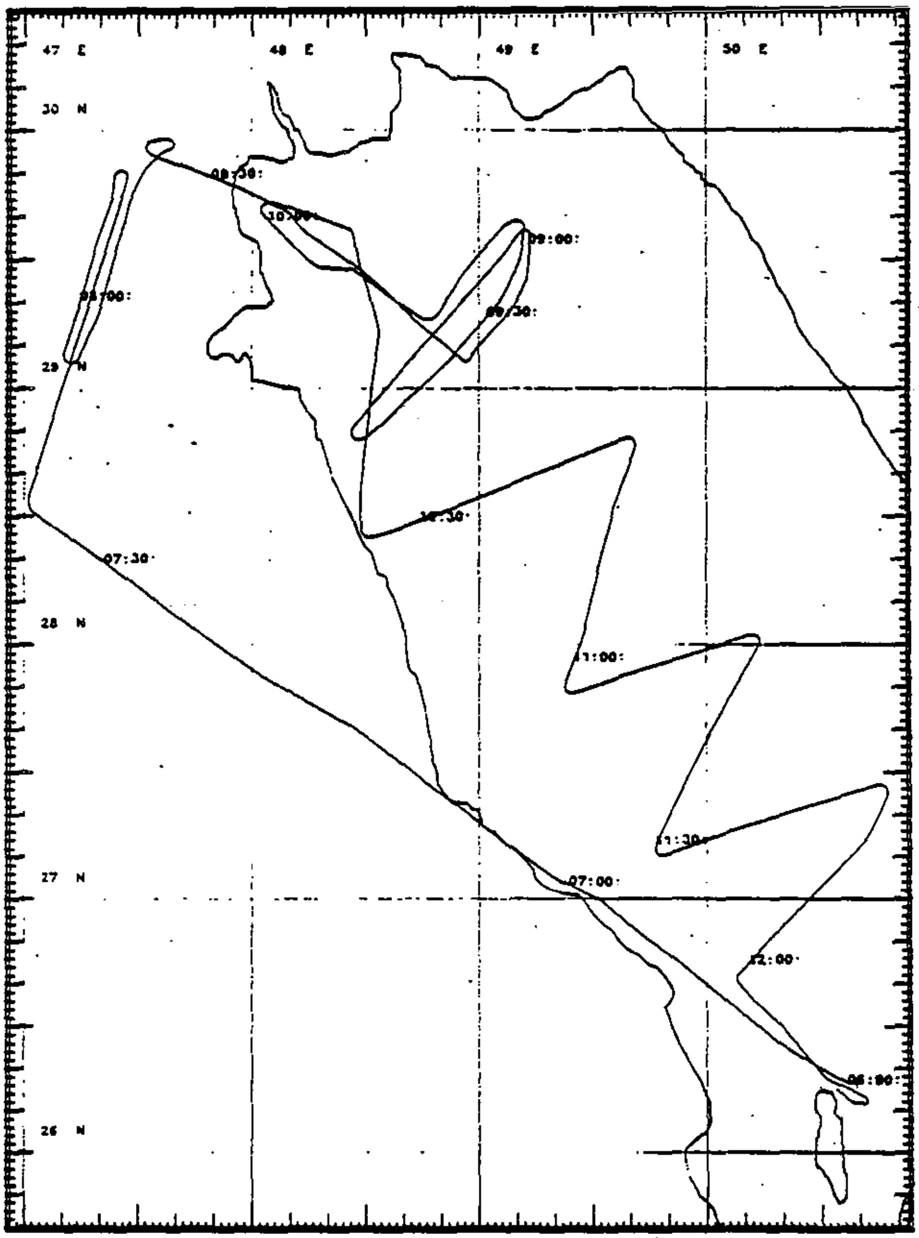
A079 29 March 1991



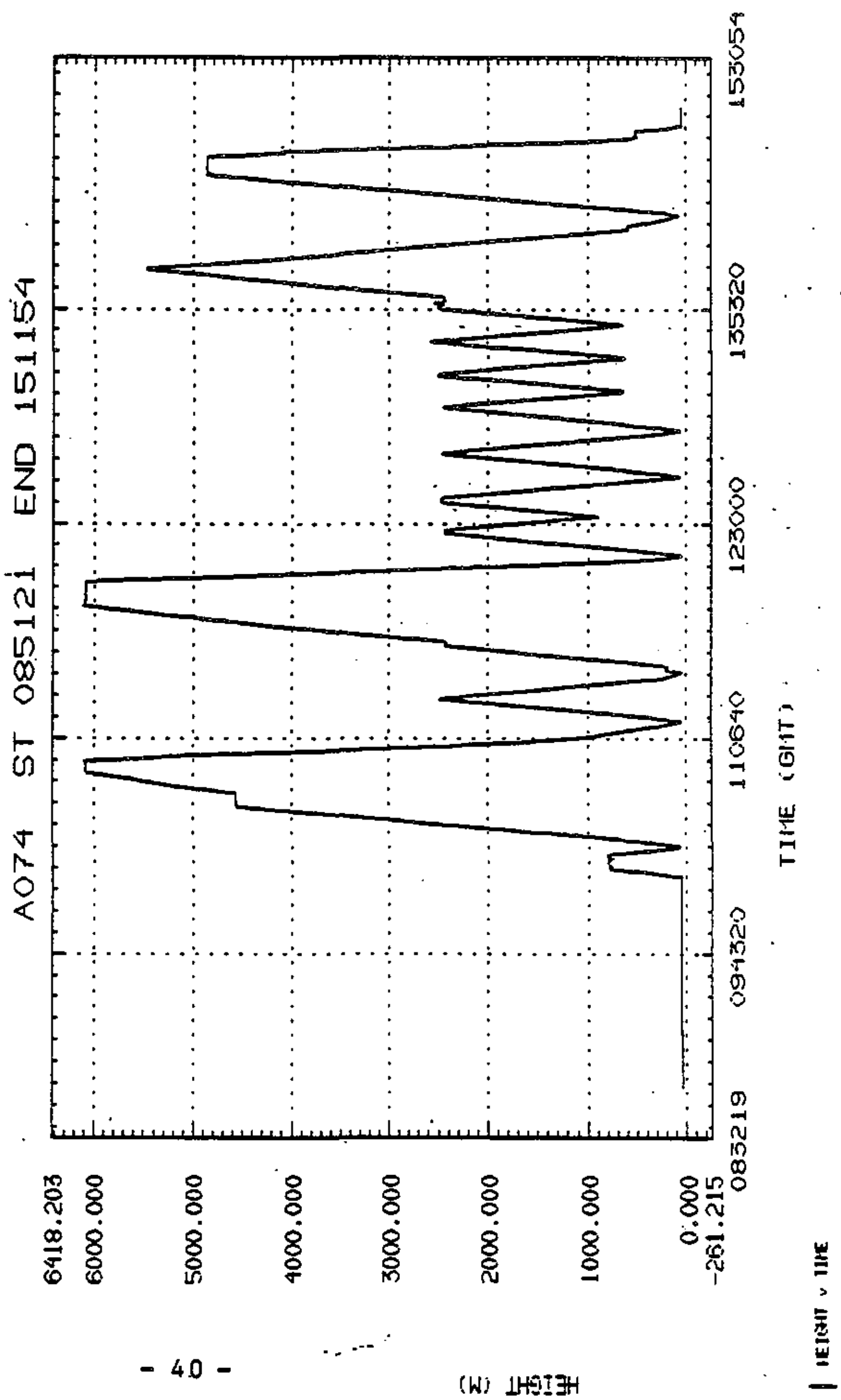
A080 30 March 1991



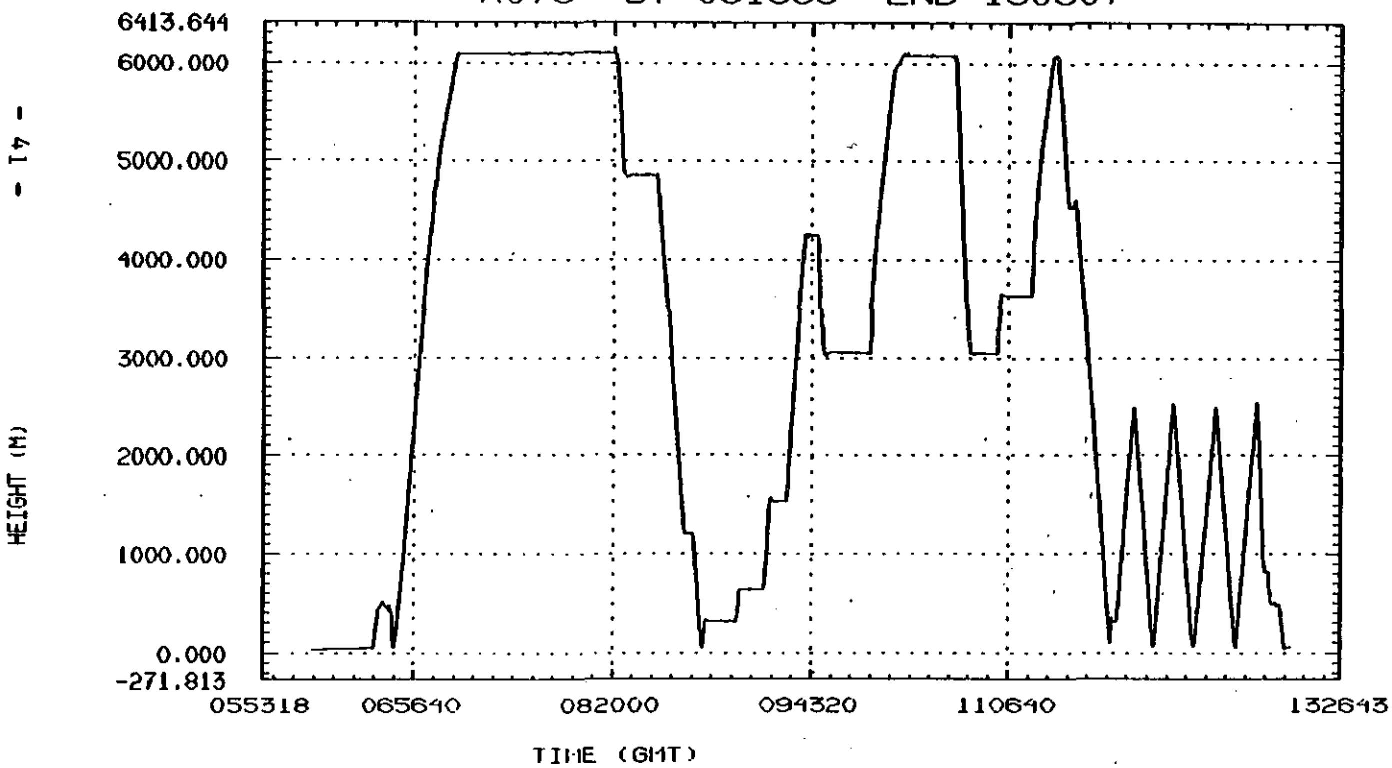
A081 31 March 1991



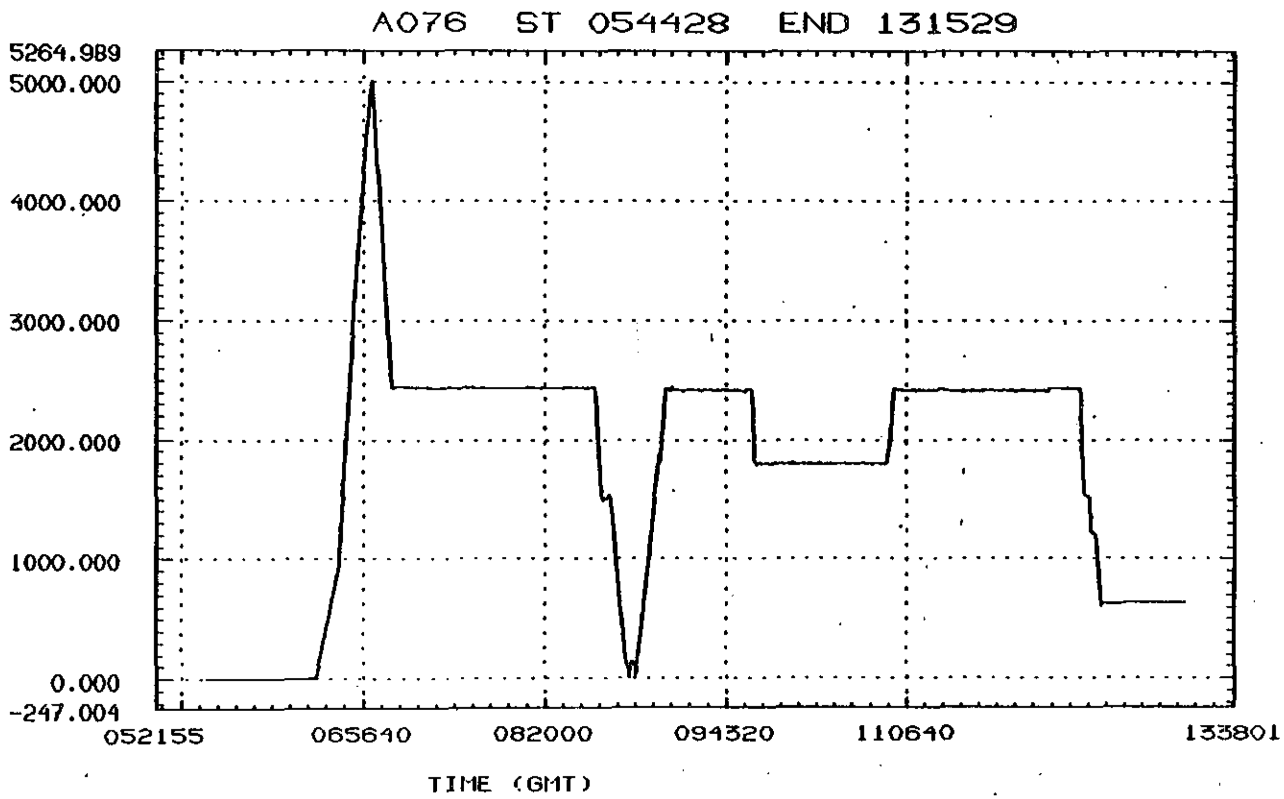
**14. Height time series for each flight.**



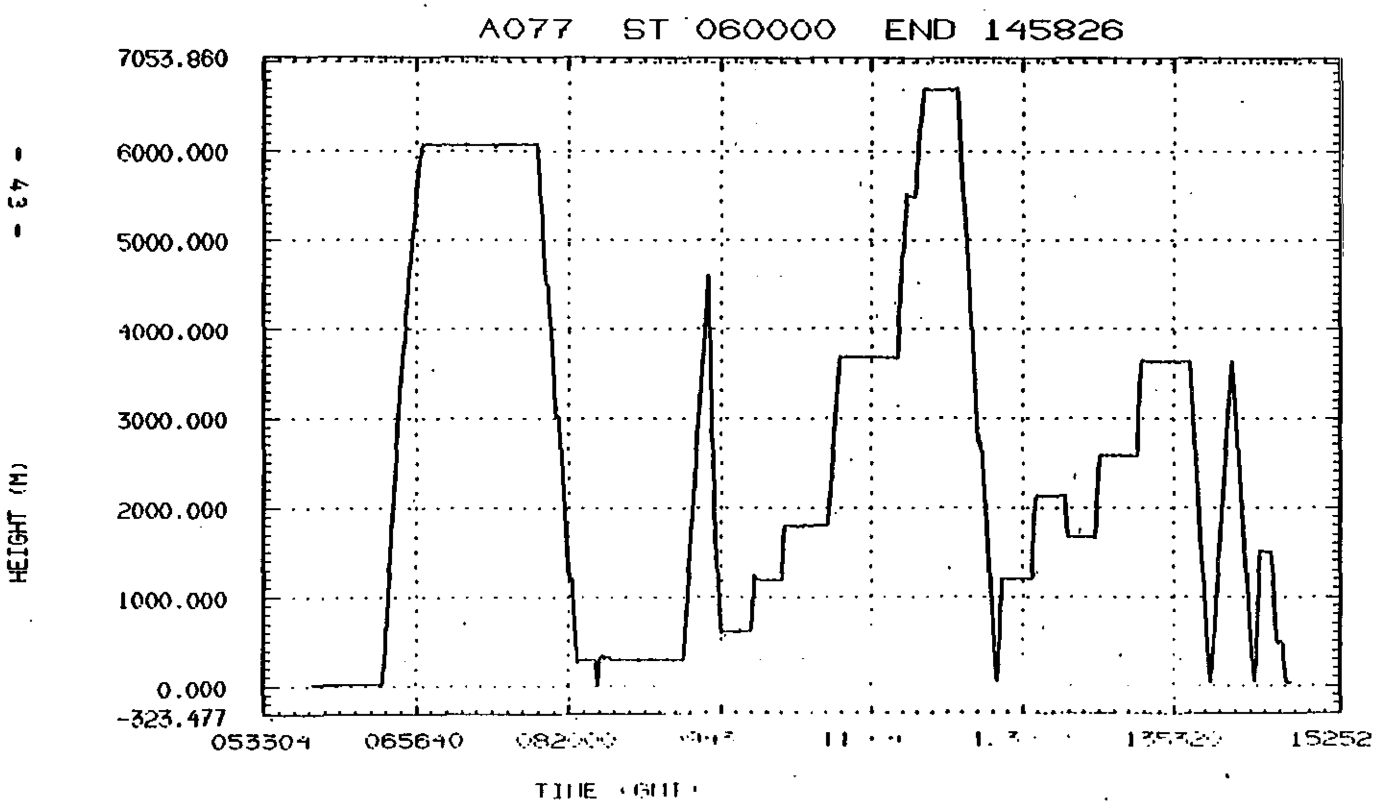
A075 ST 061355 END 130607



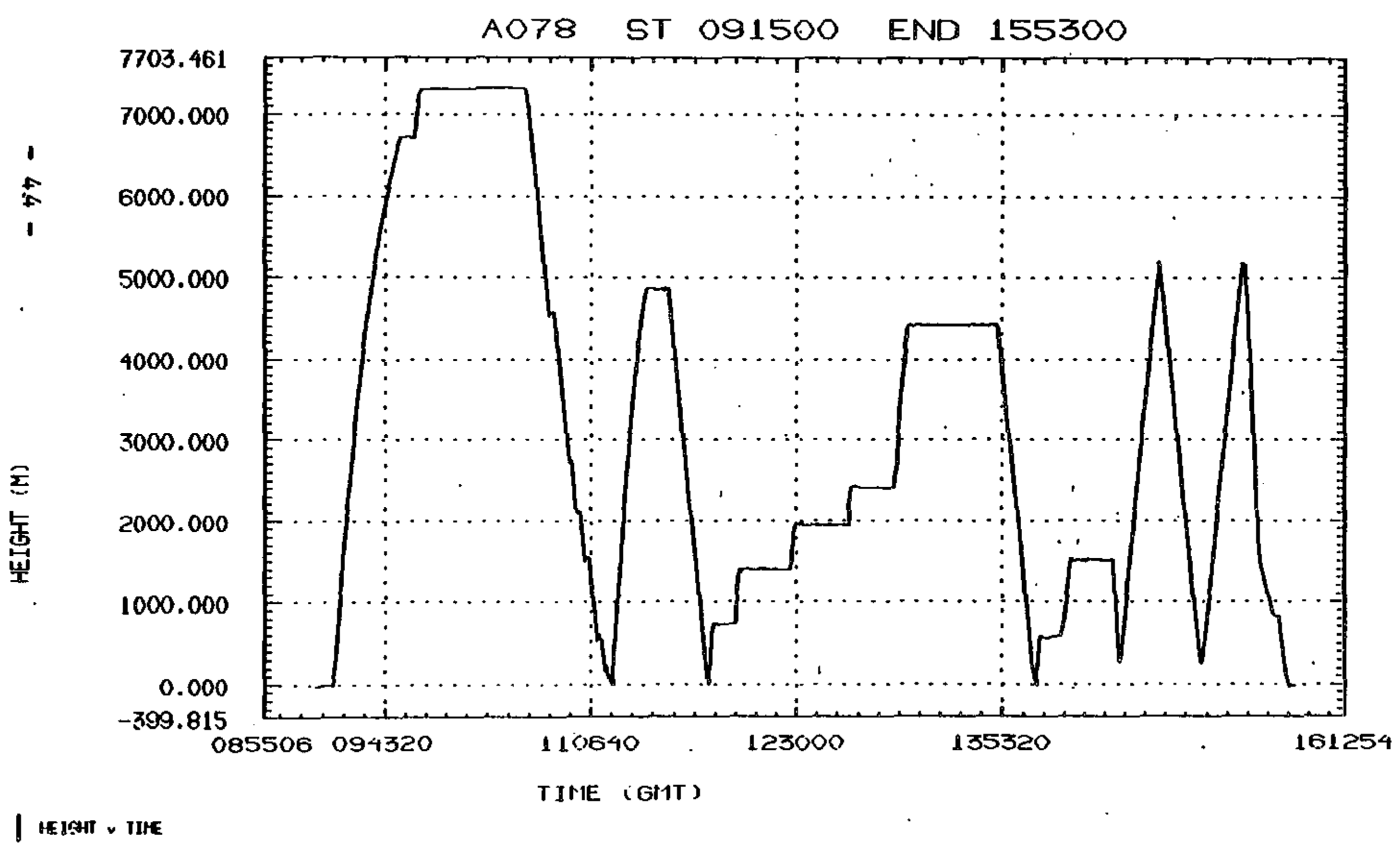

HEIGHT v TIME



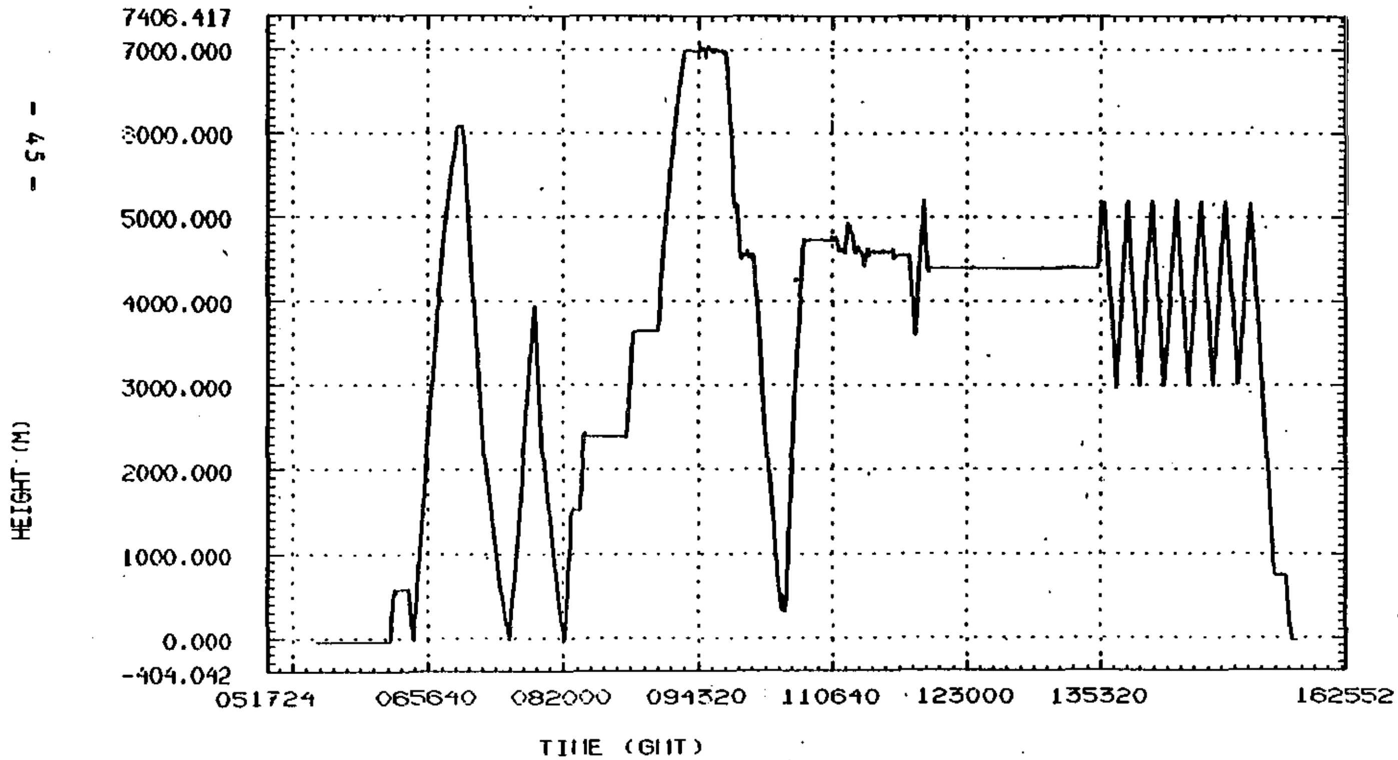

HEIGHT v TIME



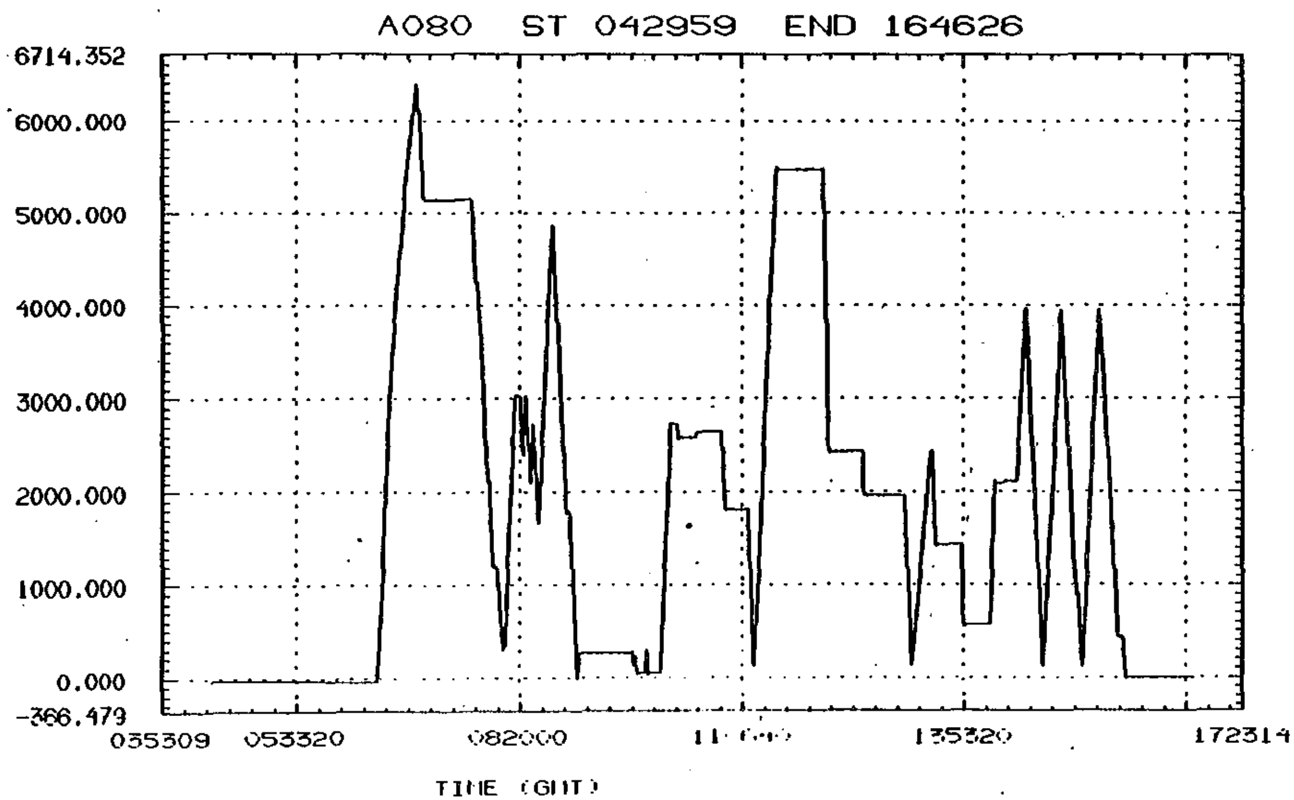

HEIGHT v TIME


A078 ST 091500 END 155300
7703.461
7000.000
6000.000
5000.000
4000.000
3000.000
2000.000
1000.000
0.000
-399.815
HEIGHT (M)
085506 094320 110640 123000 135320 161254
TIME (GMT)
HEIGHT v TIME

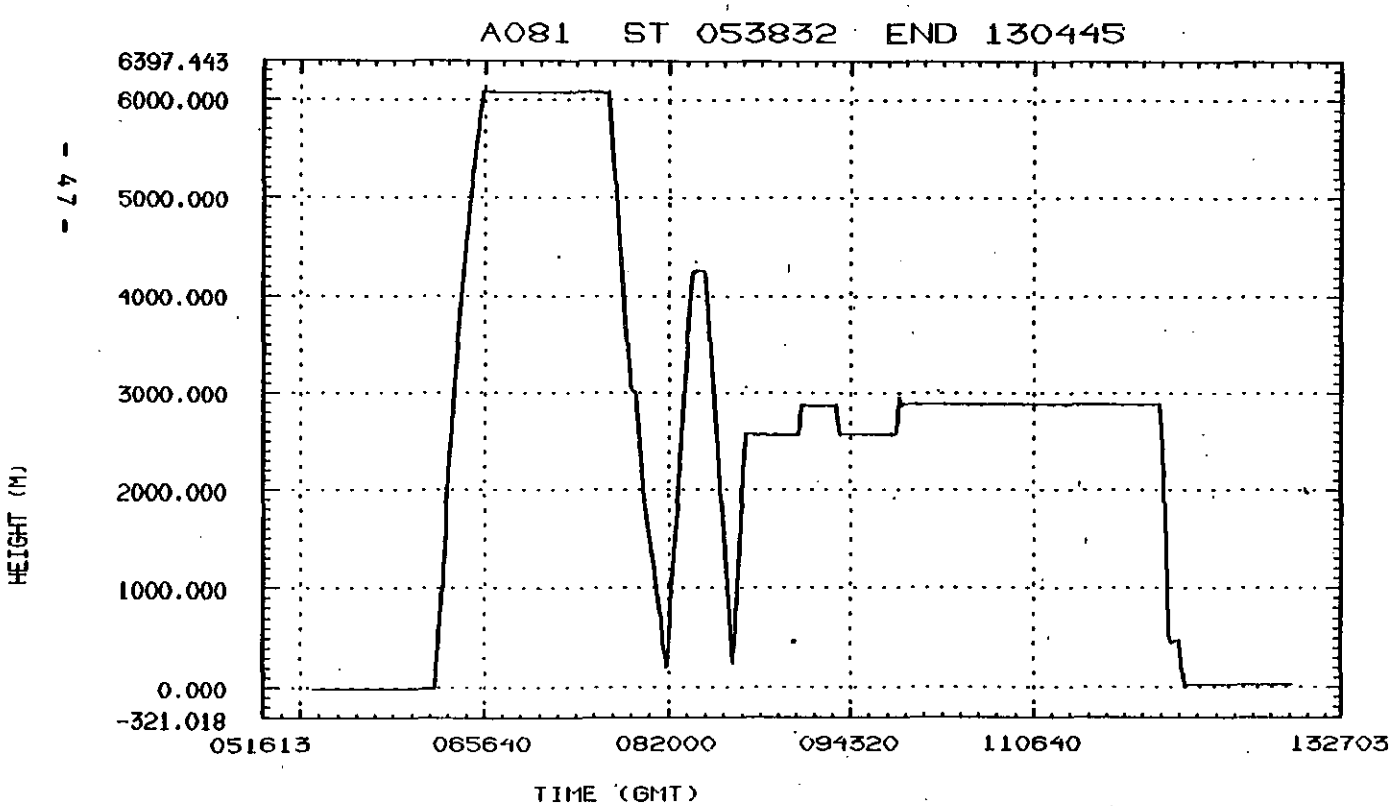
A079 ST 054748 END 155530




HEIGHT v TIME



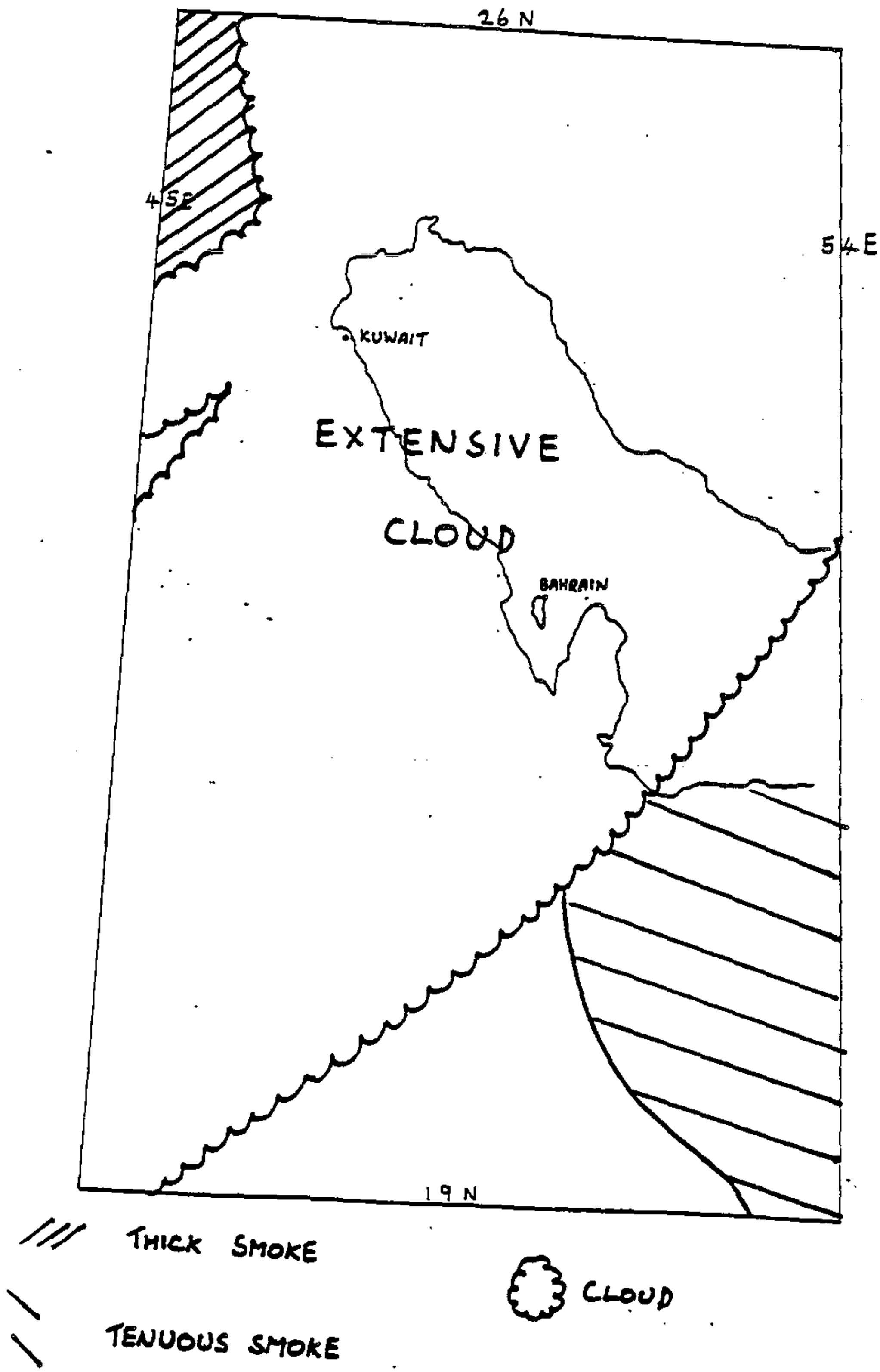

HEIGHT v TIME



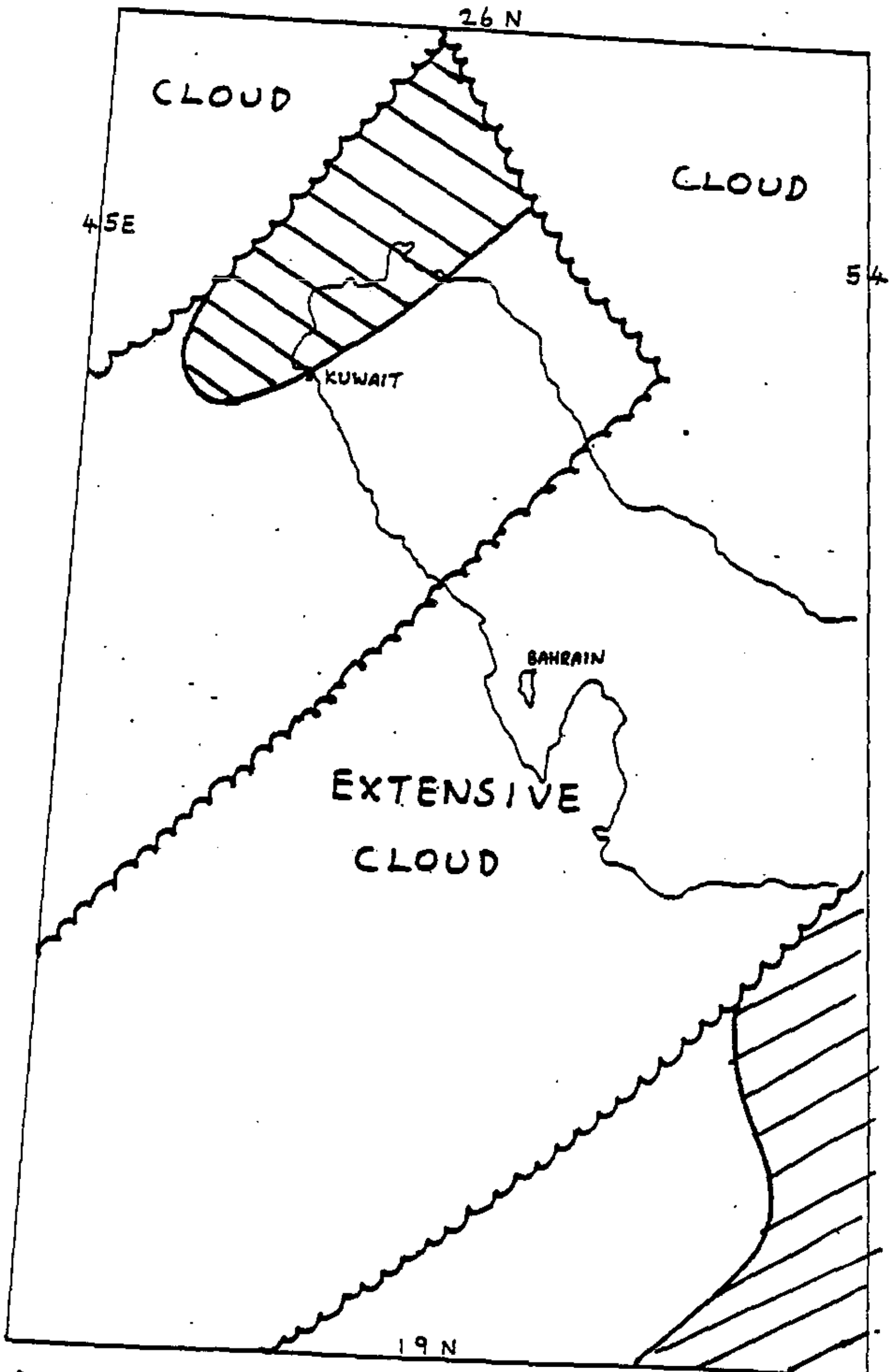

HEIGHT v TIME

15. **S Div Nephanalysis for each flight.**

13:00z 23 March 1991 A074



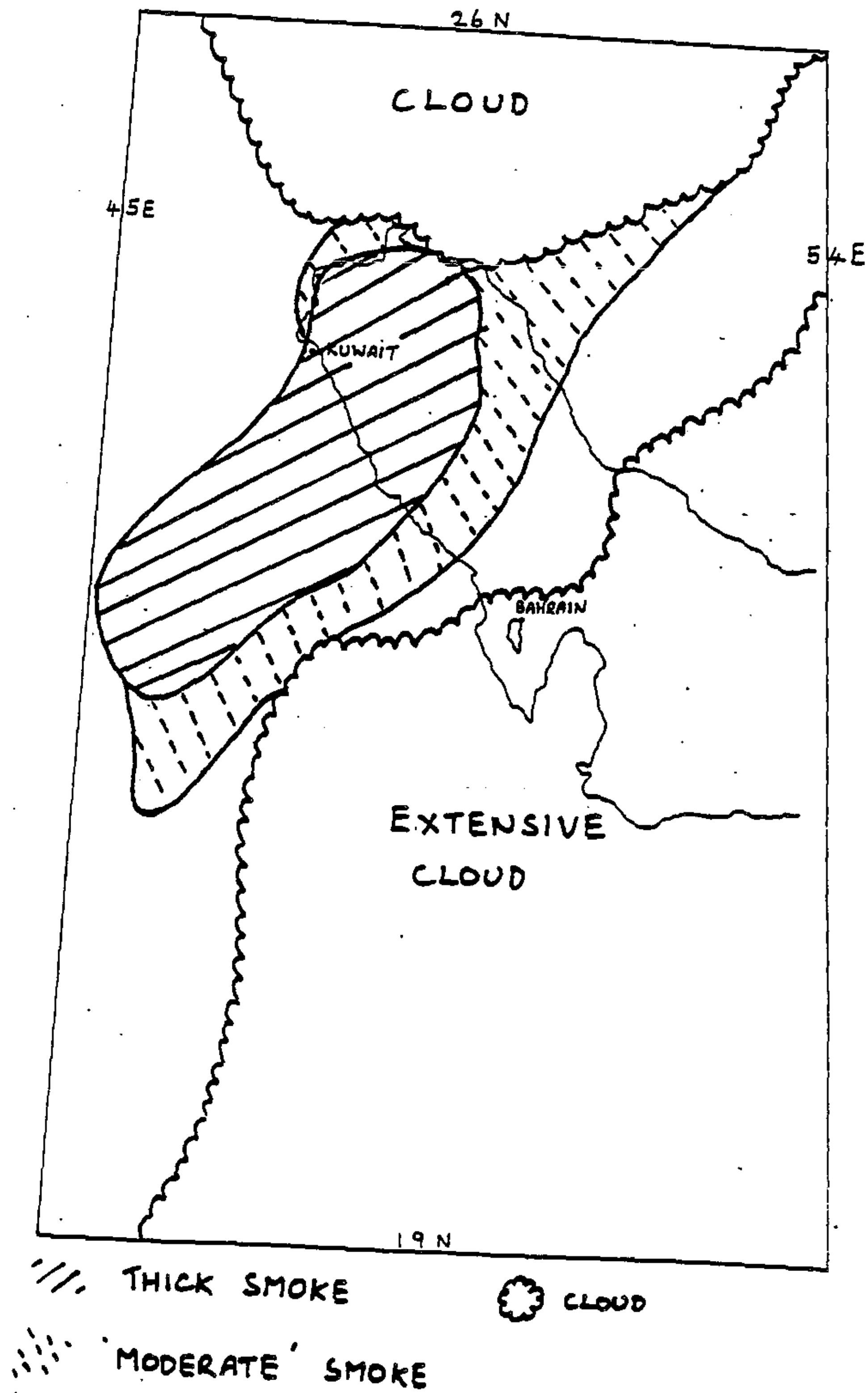
14:00z 24 March 1991 A075



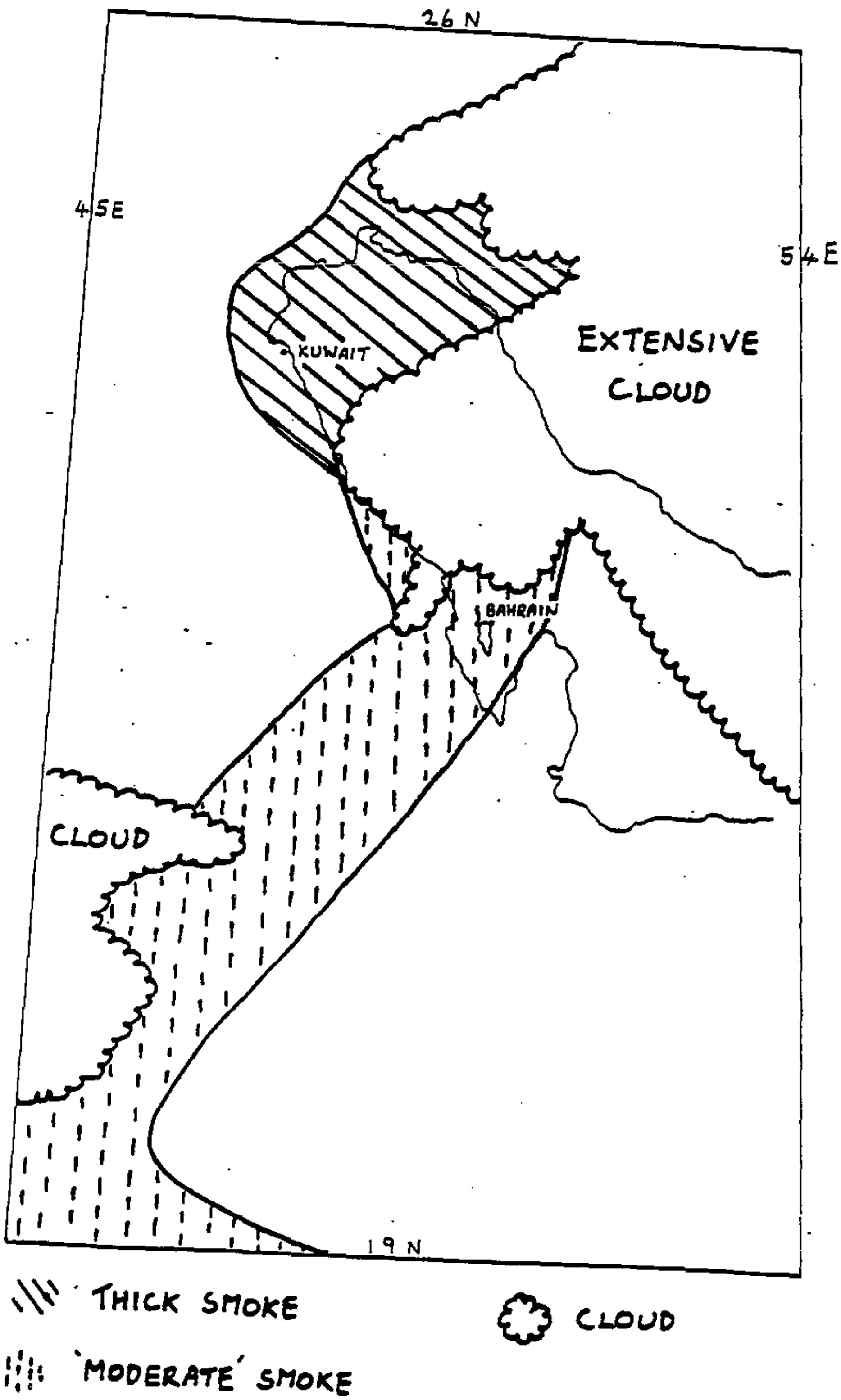

MIXED SMOKE AND CONVECTIVE CLOUD

TENUOUS SMOKE    CLOUD

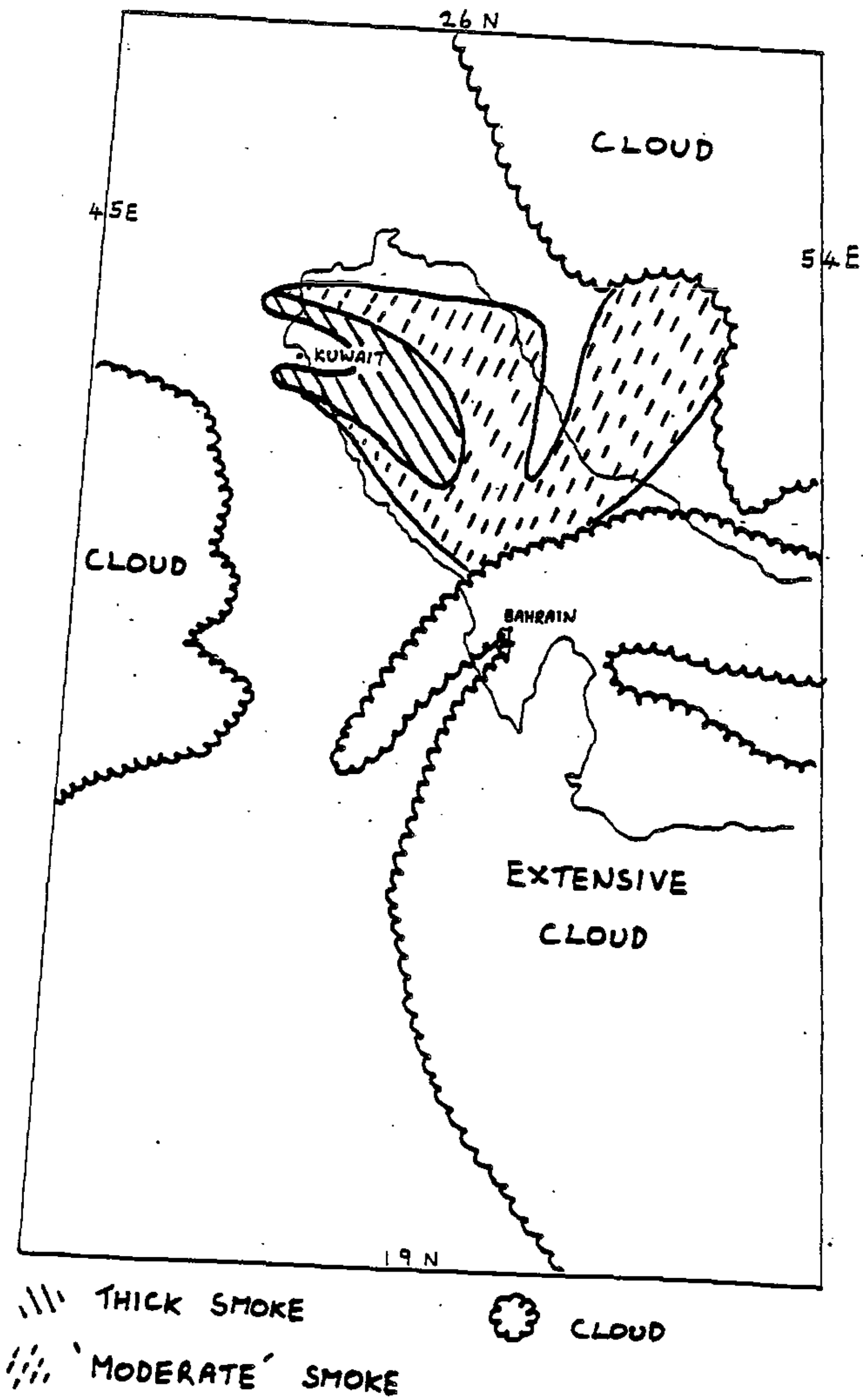
13:00z 25 March 1991 A076



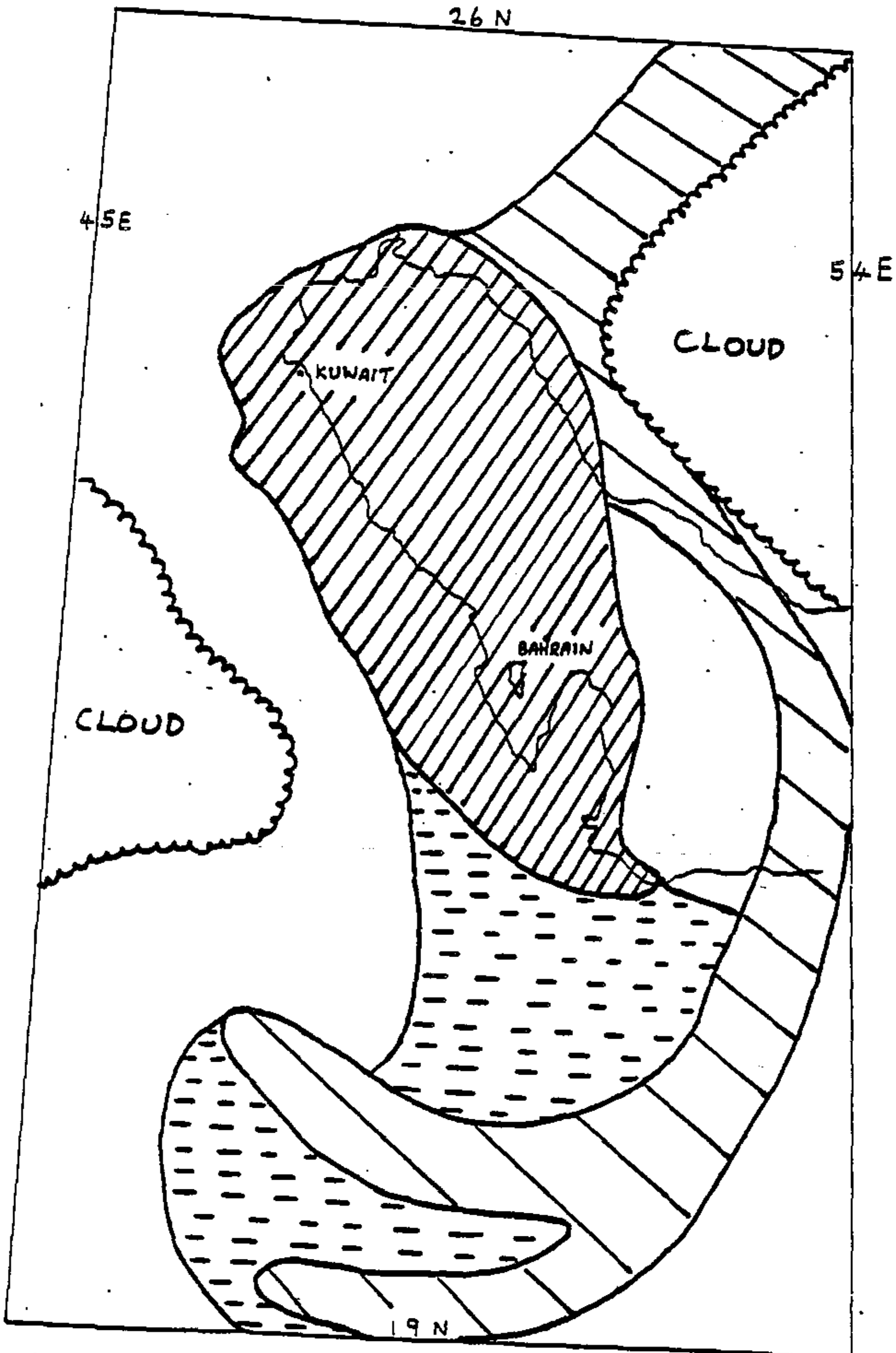
13:00z 26 March 1991 A077



11:00z 28 March 1991 A078



13:00z 29 March 1991 A079



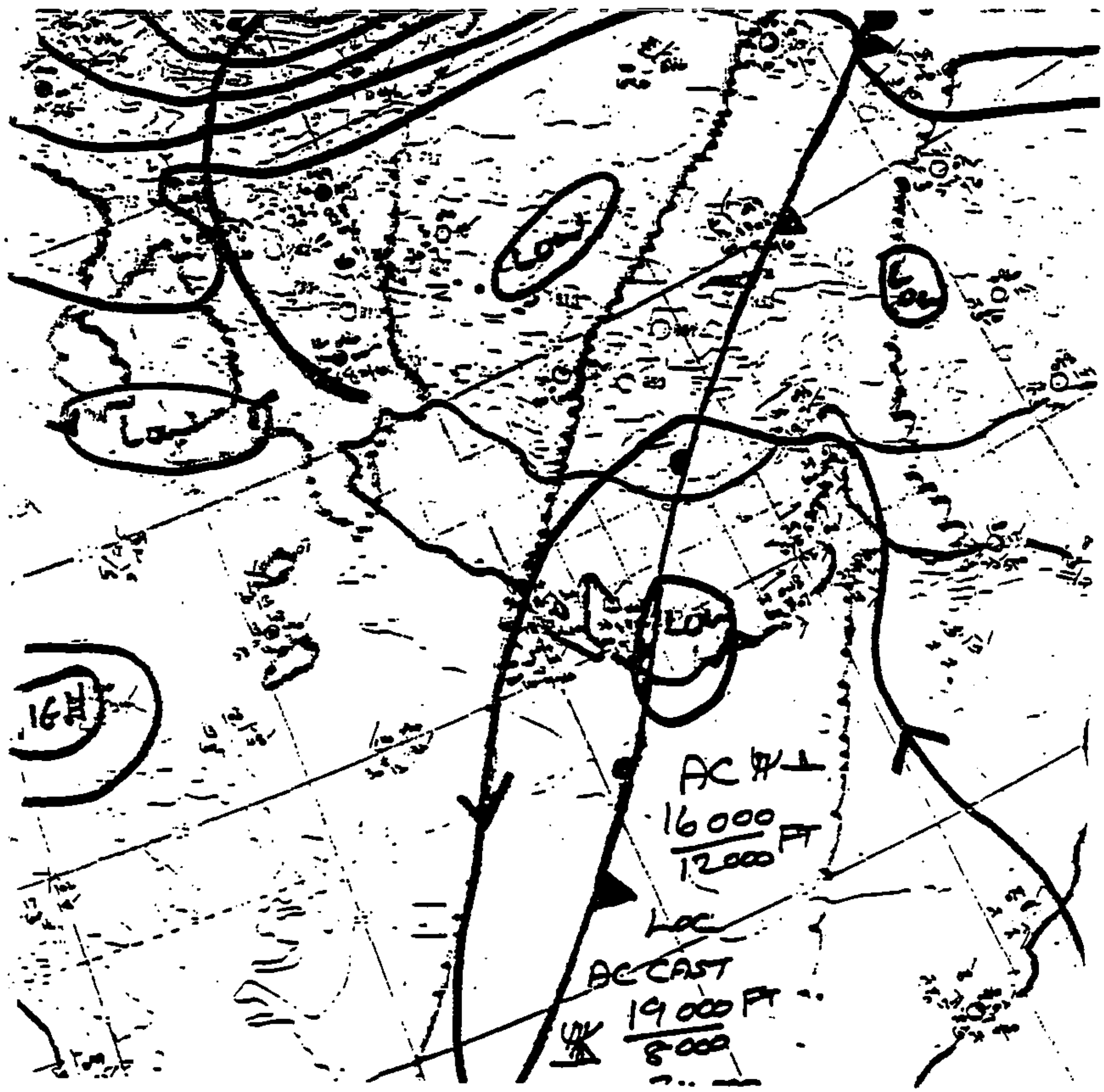

/// THICK SMOKE    CLOUD

\\ 'MODERATE' SMOKE    -·-·- TENUOUS SMOKE

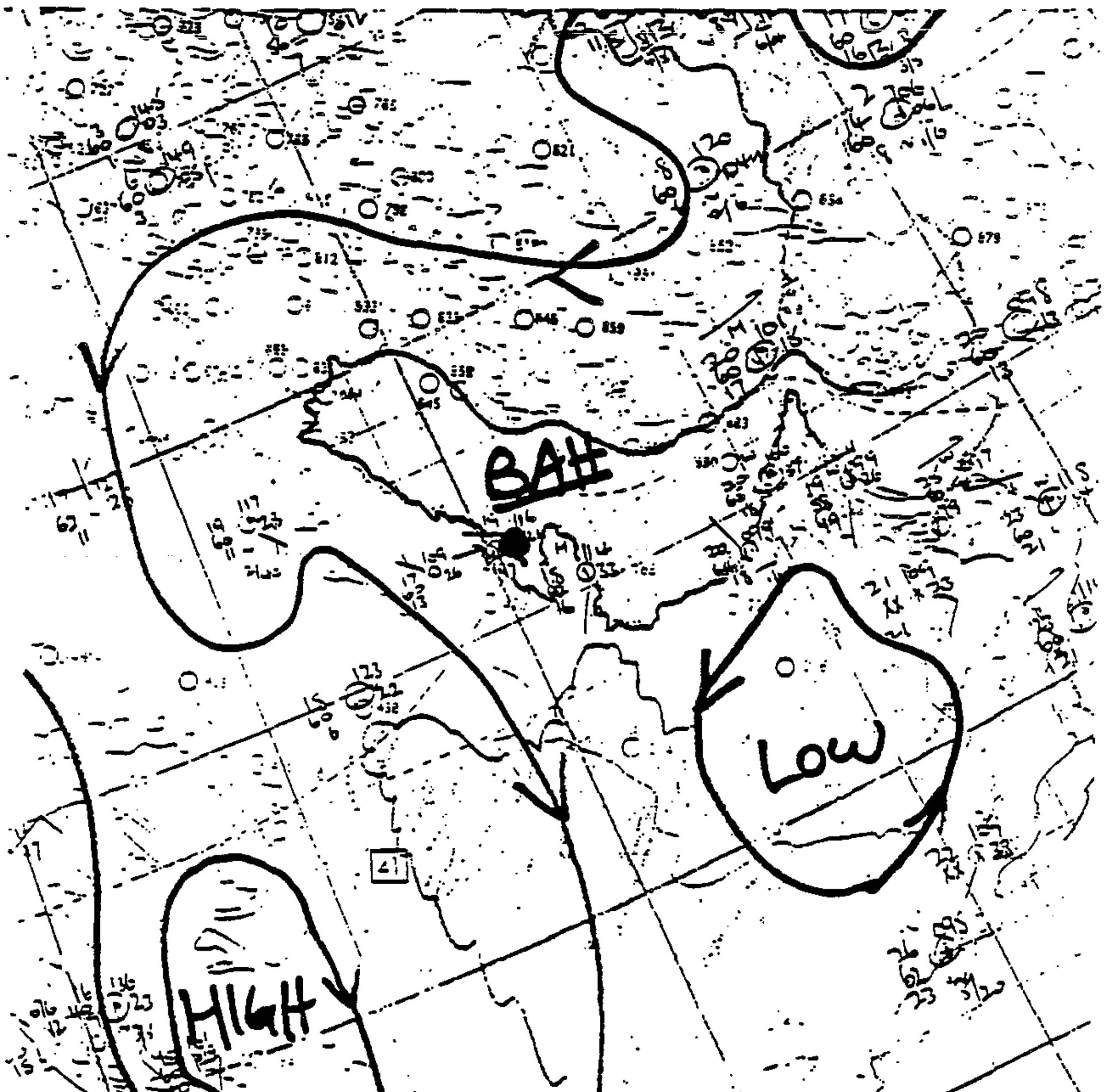
16. Synoptic charts for each flight.

0001 z 24 MARCH 1991 A074

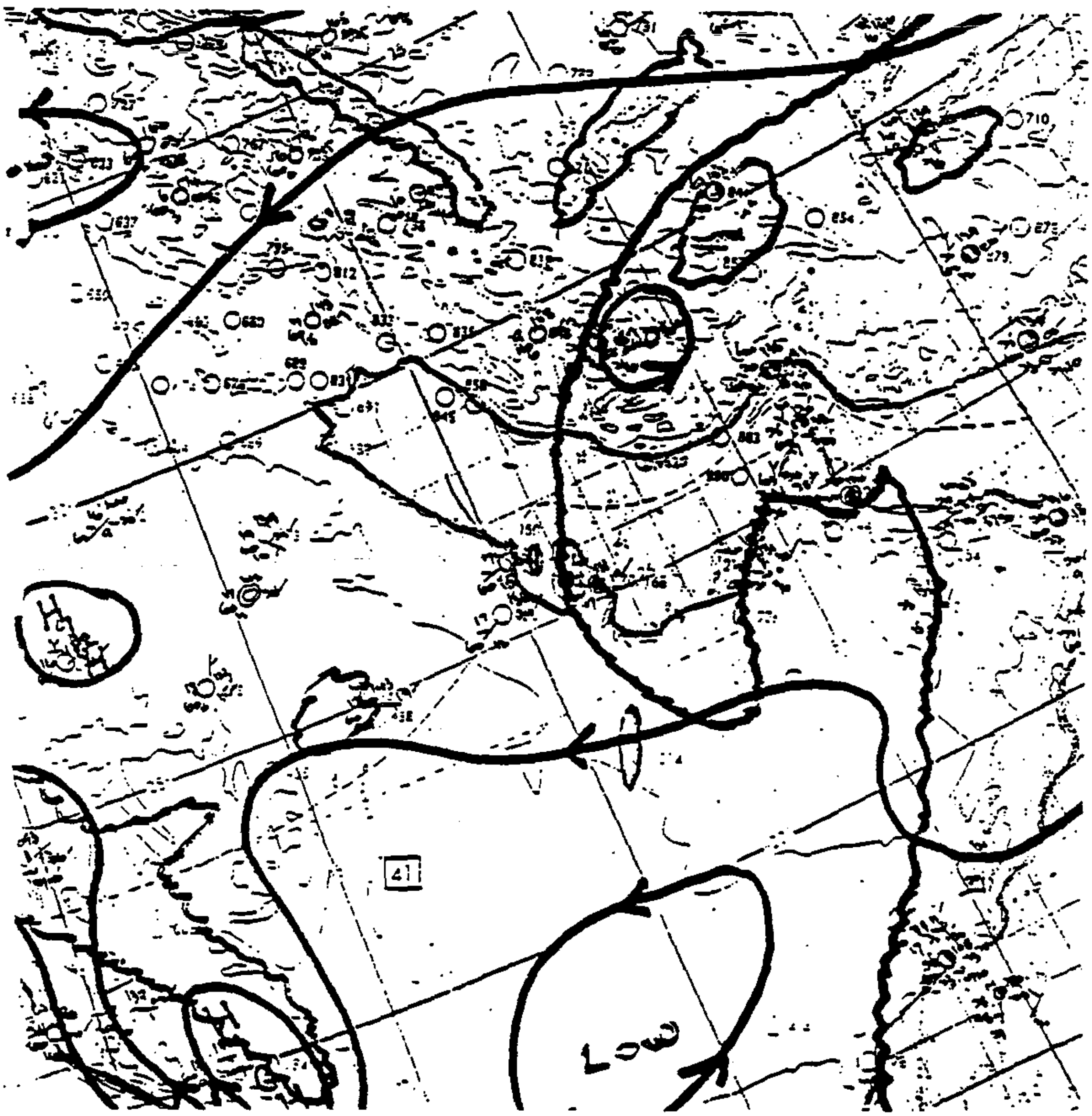
0001z 25 MARCH 1991 A075



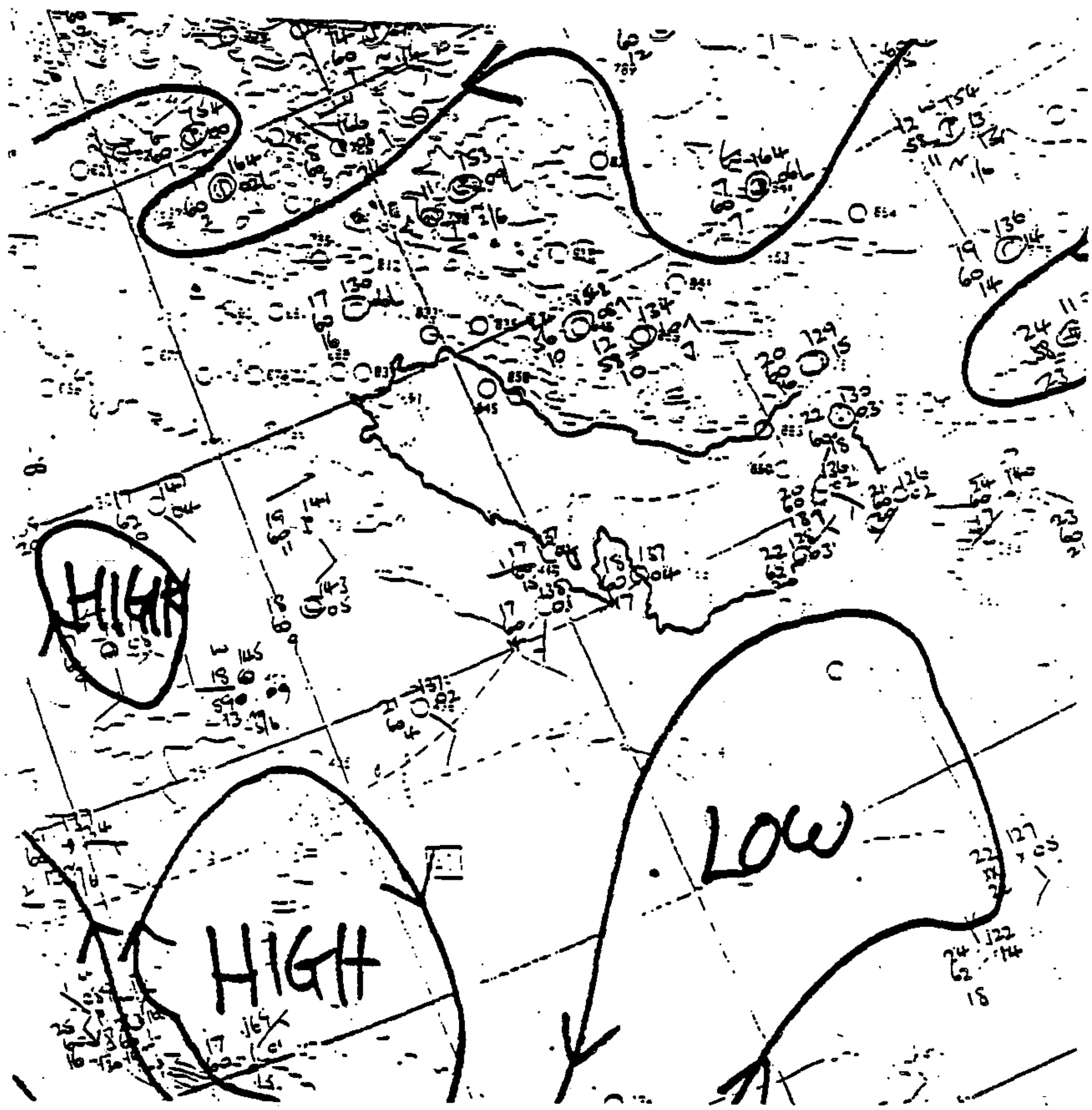
0001Z 28 MARCH 1991 A072



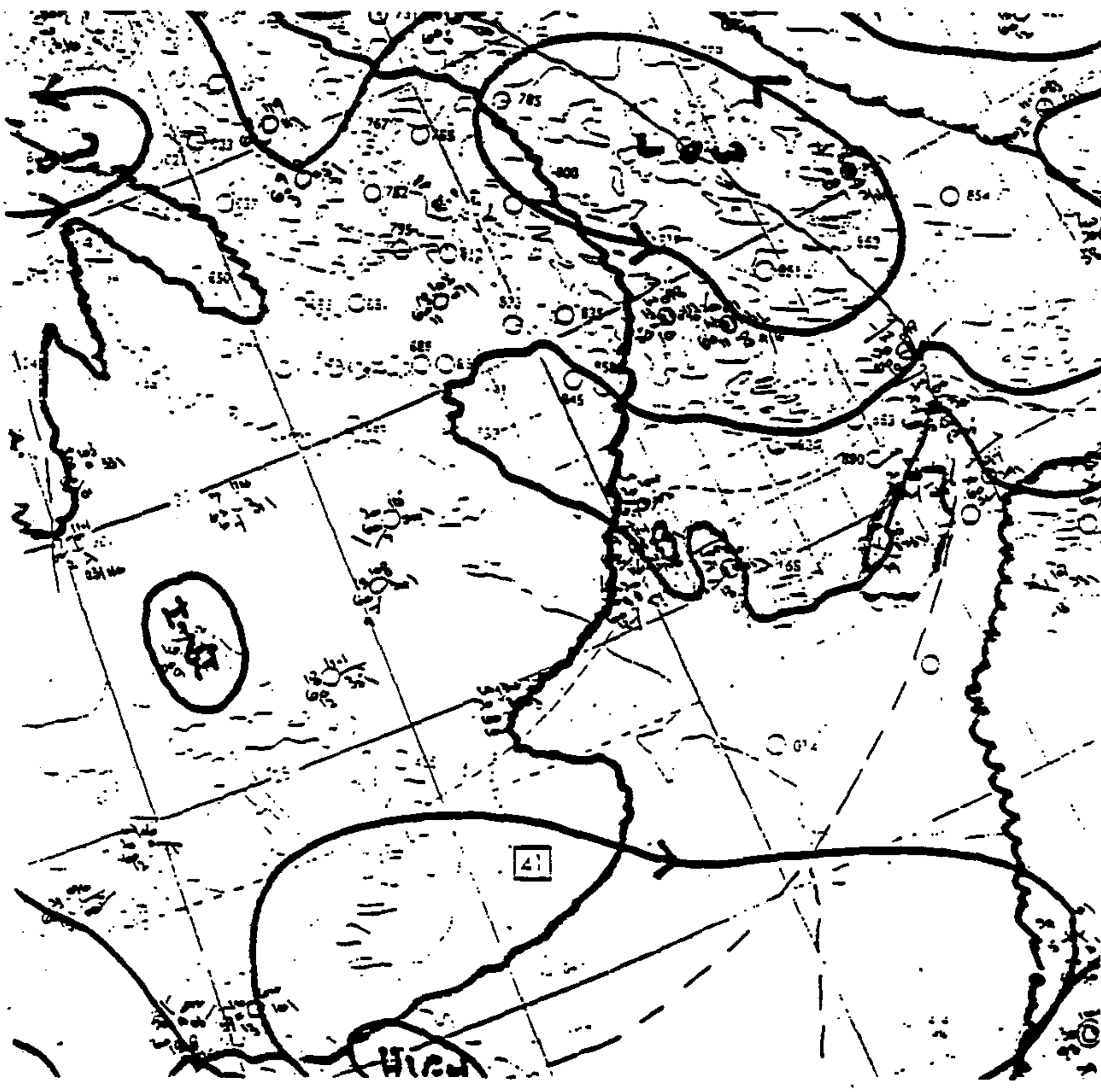
00012 29 MARCH 1991 A074



0001z 30 MARCH 1991 AOEC



0001 z 31 MARCH 1991 A081



17. **Summary of videos recorded for each flight.**

Tables 33 to 53 summarize what is seen on the video tapes from each of the flights. To view one of these tapes contact the aircraft manager on ext 5400.

| TAPE COUNTER | TIME GMT | CAMERA | COMMENTS |
|---|---|---|---|
| 0000 | 103040 | FFC | |
| 2115 | 111300 | FFC | A/C at low point over sea |
| 2811 | 113200 | FFC | A/C at low point over sea |
| 2839 | 113248 | | Left turn, almost into sun |
| 3161 | 114231 | | Right turn |
| 3459 | 1152 | | Coastline? |
| 3674 | 115911 | | Left turn into sun |
| 4198 | 121730 | | A/C low point over sea. Occasional ships |
| | 124700 | | ? Visible to right |
| 4999 | 124812 | | Low pass over sandbar - A/C low point |
| 5421 | 130548 | | A/C low point over sea - into sun glint |
| 5671 | 131635 | | End |

**Table 33: Summary of tape 105 for flight A074**

| TAPE COUNTER | TIME GMT | CAMERA | COMMENTS |
|---|---|---|---|
| 0000 | 131720 | FFC | Turning left. Coastline |
| 1601 | 134711 | | Low point |
| 1879 | 135343 | | Left turn |
| 3038 | 142517 | | Coastline A/C low |
| 3193 | 143002 | | A/C low point. Islands |
| 3270 | 143230 | | Coastline |
| 4166 | 150242 | | Runway lights |
| 4221 | 150440 | | Touchdown |
| 4343 | 150903 | | End |

**Table 34: Summary of tape 106 for flight A074**

| TAPE COUNTER | TIME GMT | CAMERA | COMMENTS |
|---|---|---|---|
| 0000 | | DFC | No clock set |
| 0981 | 063944 | | T/O |
| 1384 | 064806 | | A/C reflection - low point |
| 1561 | 065200 | FFC | |
| 1922 | 070036 | | Into Sc. |
| 2166 | 070645 | | Clear Sc. |
| 3200 | 073611 | | Sharp left |
| 3271 | 073825 | DFC | Sea, broken small Cu. |
| 3390 | 074210 | | Right turn. Small Cu surface not clear, Smoke |
| 3501 | 074506 | | Fires visible More 074630 |
| 3673 | 075132 | | Right turn |
| 3718 | 075303 | FFC | Plume ahead/below |
| 3826 | 075644 | | Left turn |
| 3960 | 080127 | | Left turn. Flying above Cu tops. Minor turns |
| 4487 | 082037 | | Right turn |
| 4772 | 083139 | DFC | |
| 4814 | 083314 | | Left turn. Smoke below |
| 4851 | 083434 | | Sea surface? |
| 4876 | 083545 | FFC | |
| 4958 | 083900 | DFC | Sea surface, descending. Oil slick |
| 5114 | 084522 | FFC | Hazy, no horizon |
| | 085030 ish | | Left turn |
| 5304 | 085318 | DFC 2 sec | Waves |
| | 0856 | | Descending |
| 5406 | 085734 | | A/C low point |
| | 0908 | | Heading into plume |
| | 0911 | | Slow climbing left turn |
| 5873 | 091751 | | End. No clear horizon - smoky |

Table 35: Summary of tape 107 for flight A075

| TAPE COUNTER | TIME GMT | CAMERA | COMMENTS |
|---|---|---|---|
| 005 | 091839 | FFC | Hazy |
| 0093 | 091956 | DFC | A/c shadow on sea and sun glint |
| 0303 | 092314 | | Right turn. Prob 180deg |
| 0603 | 092821 | FFC | Just above cloud tops |
| 0767 | 093118 | | Enter smoke/cloud |
| | 0933 ish | | Right turn |
| 1030 | 093625 | | Horizon |
| 1400 | 094411 | | Left turn to gloom below white cloud above dark line ahead |
| 1737 | 095151 | | Approaching cloud sheet |
| 1811 | 095337 | | Left turn |
| 2070 | 1000 | | Very hazy. Near plume top |
| 2243 | 100428 | DFC 25secs | Cloud/smoke. Descending |
| 2422 | 100916 | | Slow right turn. Smoke/cloud, clear above. Into sun |
| 2634 | 101510 | | Climbing 360deg. Into sun again |
| 2803 | 102000 | | Another 360deg |
| 3248 | 103257 | | Turn right |
| 3323 | 103519 | | Then left |
| 3489 | 104040 | | Left again. Lots of Cu. |
| 3621 | 104500 | | Another left |
| | 104845 | | Into cloud/plume |
| 3785 | 105030 | | Boom just visible. |
| 4026 | 105852 | DFC | Smoke/cloud |
| 4092 | 110115 | FFC | Thick haze |
| | 1110 | | Much of last 20m - dense smoke or white cloud |
| | 1115 | | Suggestion of horizon |
| 4516 | 111649 | | Climbing into clear |
| 4626 | 112102 | | Right turn |
| 4725 | 112454 | DFC | Smoke/cloud still turning |
| 4737 | 112521 | FFC | |
| 4902 | 113150 | | Right turn in 180deg then descending |
| 5078 | 113858 | | Into plume. Dense smoke and white cloud |
| 5327 | 114920 | | Level off-below plume base? then down again |
| 5742 | 120710 | DFC 12secs | Descent to waves low point 120746 |
| 5779 | 120849 | | End |

Table 36: Summary of tape 108 for flight A075

| TAPE COUNTER | TIME GMT | CAMERA | COMMENTS |
|---|---|---|---|
| | 120944 | FFC | Hazy |
| 0188 | 121231 | DFC | Over sea. White spot on right - Fire/Flare Smoke/plume visible on FFC to right of boom at 1212 - Probable spot visible on DFC at 121320. |
| 0276 | 121407 | FFC | |
| 0881 | 122446 | | A/c low point. Climb into haze then smoke |
| 1664 | 124124 | | Descend back to smoke base to low point at - climb back to plume. Thick smoke and haze to end. |
| 2326 | 125800 | | End |

Table 37: Summary of tape 109 for flight A075

| TAPE COUNTER | TIME GMT | CAMERA | COMMENTS |
|---|---|---|---|
| 0000 | | | |
| 0124 | 062700 | DFC | |
| 0273 | 062919 | FFC | Unstable picture |
| | 04035 | | Airbus |
| 1005 | 064229 | | Take off |
| 1365 | 065000 | | Hazy horizon |
| 1803 | 070000 | | Nice blue sky above haze |
| 1852 | 070112 | | Clock zeroed. Clear horizon |
| 1878 | | DFC | Waves. Clock setting |
| 1940 | 070900 | FFC | Clock restart. Hazy horizon |
| 2139 | 071400 | | Cu and smoke ahead |
| 2440 | 072200 | | First smoke wisps |
| 2510 | 072353 | | Cu base just below |
| 2689 | 072857 | DFC 6sec | Uniform grey. A/c below Cu base |
| 3065 | 074000 | | Smoke slowly getting denser |
| 3127 | 074152 | | Right turn. A/c below Cu base |
| 3235 | 074515 | | Right turn. |
| 3341 | 074836 | | Left turn. A/c below Cu base |
| 3476 | 075300 | | Left turn. |
| 3593 | 075654 | | Left turn. Some turns earlier - too hazy to time |
| 3774 | 080300 | | Descending? Denser smoke. Turn follows - no horizon. 0808 - Cu above. |
| 3950 | 080908 | | Left Turn. 0816 - uniform grey - turn? |
| 4190 | 081744 | | Left turn. |
| 4254 | 082004 | DFC 6sec | Streaky smoke |
| 4263 | 082024 | | Left turn. Still below Cu base |
| 4372 | 082427 | | Right turn. |
| 4426 | 082630 | | Left turn. Faint horizon |
| 4468 | 082805 | DFC 23sec | Sea surface. Right turn |
| 4648 | 083500 | | Denser, then clearing |
| 4973 | 084751 | | Dense at 0845, horizon 0847. Left turn. |
| 5047 | 085050 | | Exit bottom of plume |
| 5174 | 085602 | DFC | Sea |
| 5237 | 085839 | | A/c low point. Shadow 1/3 Ac on screen |
| 5274 | 090011 | FFC | In right turn |
| 5378 | 090934 | | Climb to plume base. Into plume 0910. |
| 5663 | 091657 | | Plume base right turn |
| 5710 | 091859 | | End |

Table 38: Summary of tape 110 for flight A076

| TAPE COUNTER | TIME GMT | CAMERA | COMMENTS |
|---|---|---|---|
| 0004 | 0922590 | FFC | Grey |
| 0006 | 092257 | DFC 14secs | Smoke. Turn about 0925 Right at 0926 |
| 0463 | 093015 | | Turn right Coastline |
| 0560 | 093115 | | Right turn |
| 0757 | 093529 | DFC 50secs | Coastline/sunglint/smoke/turning right |
| 0921 | 093838 | | Right |
| 1191 | 094405 | DFC 3secs | Smoke |
| 1573 | 095228 | | Right turn |
| | 095403 | DFC 3secs | Smoke. Turning right? |
| 1680 | 095500 | | Nose down. Left turn, coastline A/c below plume base |
| 2284 | 101000 | | Grey - occasional Cu bases |
| 2296 | 101022 | DFC 8secs | Smoke |
| | 101330 ish | | Turn (no horizon) |
| 2591 | 101824 | DFC 6secs | Sea - turning? |
| | 102120 | To:- FFC very bad | |
| 2769 | 102331 | DFC 8sec | Grey. FFC featureless and unstable picture |
| | 102700 | FFC | A/c in Rt turn. |
| 2980 | 102946 | DFC 32secs | Smoke. FFC picture clear. V. Hazy |
| 3037 | 103130 | | Right turn. Just below Cu bases |
| 3196 | 103621 | DFC 6secs | Grey |
| 3250 | 103801 | DFC 4secs | Grey |
| 3482 | 104525 | DFC | Sea, smoke wisps |
| 3648 | 105057 | | Right turn |
| | 1055 | | More wisps |
| 3854 | 105800 | FFC | Sea had faded on DFC. FFC grey |
| 4183 | 110934 | DFC 4secs | Grey. Blue appearing above |
| 4489 | 112048 | DFC | Sea surface - hazy. Smoke 1122 to |
| | 112944 | | Coastline? |
| 4774 | 113142 | FFC | Horizon visible |
| 4788 | 113216 | | Right turn above haze |
| 5166 | 114732 | DFC | Desert |
| 5357 | 115526 | FFC | Hazy |
| 5741 | 121200 | | End |

Table 39: Summary of tape 111 for flight A076

| TAPE COUNTER | TIME GMT | CAMERA | COMMENTS |
|---|---|---|---|
| 0000 | 121300 | FFC | Hazy |
| 0066 | 121354 | DFC | Desert |
| 0147 | 121511 | FFC | Hazy |
| 0681 | 122410 | DFC | Desert. Wadis. Descending |
| 0912 | 122830 | FFC | Hazy ground detail |
| | 123100 | | Township. Turn right for Riyadh |
| | 1235 | | Runway in sight |
| 1612 | 124317 | | End. |

Table 40: Summary of tape 112 for flight A076

| TAPE COUNTER | TIME GMT | CAMERA | COMMENTS |
|---|---|---|---|
| 0000 | 062722 | | Start |
| 0655 | 063758 | | Take off Bahrain |
| 2252 | 071325 | DFC | |
| 2657 | 072429 | to FFC | Plume ahead |
| 2983 | 073357 | DFC | Over fires and smoke |
| 3348 | 074518 | | Over coast |
| | | | Over plume |
| 3810 | 080033 | FFC | |
| 3934 | 080453 | DFC | Oil slicks |
| 3980 | 080630 ish | | Ships and wakes |
| | | | oil slicks |
| 4212 | 081456 | FFC | Plume ahead |
| 4295 | 081758 | DFC | |
| 4592 | 082910 | FFC | |
| 4690 | 083200 | DFC | |
| | 083623 | | Shadow or reflection |
| 5065 | 084802 | FFC | Below plume |
| 5072 | 084818 | DFC | |
| 5161 | 085156 | FFC | Small plume off rig |
| 5176 | 085233 | DFC | |
| 5321 | 085838 | FFC | Plume above |
| 5486 | 090543 | DFC | |
| 5534 | 090748 | FFC | Various ships and oil installations |
| 5793 | 091910 | | |

Table 41: Summary of tape 113 for flight A077

| TAPE COUNTER | TIME GMT | CAMERA | COMMENTS |
|---|---|---|---|
| 0000 | 092010 | FFC | Start recording |
| 0122 | 092159 | DFC | |
| 0132 | 092207 | FFC | |
| | 0931 | FFC | Into base plume/cloud |
| 2269 | 100632 | DFC 12secs | Sea |
| 2908 | 102430 | DFC 8secs | |
| 3041 | 102828 | FFC | Rain |
| 3010 | 102919 | DFC 7secs | |
| 3638 | 104734 | DFC | Cumulus below |
| 3654 | 104809 | FFC | |
| 3858 | 105506 | DFC | |
| | 110030 | | |
| 4193 | 110657 | FFC | Above plume/cumulus |
| 4318 | 111129 | DFC 9secs | Cloud tops |
| 4354 | 111249 | DFC | |
| 4361 | 111303 | FFC | |
| | 1118 | FFC | Thro' Cu/CB tops |
| 5568 | 120140 | DFC 46secs | |
| 5736 | 120856 | FFC | Into top of plume |
| 5780 | 121054 | FFC | Out of plume |
| 5887 | 121542 | DFC | Sea |
| 5978 | 121945 | FFC | Plume above |
| 6043 | 122240 | FFC | End tape |

Table 42: Summary of tape 114 for flight A077

| TAPE COUNTER | TIME GMT | CAMERA | COMMENTS |
|---|---|---|---|
| 0005 | 122338 | FFC | In plume - picture breakup. Dense plume |
| 0746 | 123550 | | Right turn |
| 0949 | 123945 | DFC 20secs | Smoke tops |
| 1291 | 124646 | DFC 26secs | Grey, then out of plume base |
| 1997 | 130305 | DFC 8sec | Grey |
| 2200 | 130814 | DFC 13sec | Plume tops |
| 2283 | 131026 | | Left turn at plume top |
| 2300 | 131052 | DFC | Little detail |
| 2321 | 131125 | FFC | Still turning. Above plume |
| 2436 | 131433 | | Into plume, along top |
| 2510 | 131635 | DFC 13sec | Close to tops |
| 2842 | 132600 | | Plume base |
| 2892 | 132731 | | Right turn below plume base, into plume |
| 3043 | 133200 | | Tops. Then above plume |
| 3611 | 135000 | | Left turn, then right, thro' sun |
| 3878 | 135906 | | Right turn, above plume |
| | 140300 | | Left ... slightly |
| 4026 | 140415 | DFC 6sec | Little detail |
| 4082 | 140616 | | Right turn into plume - quickly below plume |
| 4277 | 141322 | | A/c low point. Climb thro' thin plume - thinning fast |
| 4573 | 142430 | | Plume thicker, Cu Sc |
| 4701 | 142924 | DFC | peninsula, sea and smoke |
| 4764 | 143152 | FFC | Thickening plume - dusk. Descending |
| 4914 | 143750 | | Low point behind a tanker |
| 5284 | 145304 | | Right turn after flying thro' plume/cloud |
| 5329 | 145500 | | Line-up |
| 5412 | 145830 | | End |

Table 43: Summary of tape 118 for flight A077

| TAPE COUNTER | TIME GMT | CAMERA | COMMENTS |
|---|---|---|---|
| 0000 | | DFC | Concrete |
| 0657 | 092140 | | Rolling concrete |
| 0683 | 092219 | | Lift off |
| 0813 | 092434 | FFC | |
| 3027 | 101852 | DFC 25sec | Land |
| 3109 | 102122 | DFC 1min | Oil slick |
| 3168 | 102314 | DFC 1.25min | Oil slick |
| 3226 | 102503 | DFC | Land and oil. Town at 3268 |
| 3548 | | | Kuwait City. Coastline 3594 |
| 3632 | | | Oil slick edge |
| 3760 | | | Harbour |
| 3832 | 104500 | | 4003 - Fire |
| 4134 | | | Cultivation, town, coastline 4260 |
| 4323 | | | Coastline, land A/C low turn |
| 4435 | | | Coastline, sea |
| 4504 | | | A/c shadow |
| 4566 | 111145 | FFC | |
| 4667 | | | Smoke |
| 4758 | 111917 | DFC 3sec | |
| 4768 | 111938 | DFC | Oil slicks |
| 4808 | | | Coastline, land |
| 5058 | 1131 | | Fires |
| 5125 | | | Refinery - coastline, sea |
| 5262 | 113943 | | Smoke |
| 5283 | 114036 | FFC | Smoke/cloud tops |
| 5347 | | | Enter plume |
| 5434 | 114700 | | Increasing gloom, boom fades at 114715 |
| 5449 | 114738 | DFC 10sec | Grey |
| 5476 | 114838 | DFC 10sec | Smoke still very thick |
| 5488 | 114921 | DFC 6sec | Clearance visible |
| 5535 | 115124 | DFC 20sec | Fire |
| 5562 | | | A/c below plume/low |
| 5764 | 120130 | DFC 6sec | |
| 5859 | | | Turn to dense bit, reenter plume |
| 6050 | | | Climbing into plume |
| 6066 | 121506 | | End |

Table 44: Summary of tape 121 for flight A078

| TAPE COUNTER | TIME GMT | CAMERA | COMMENTS |
|---|---|---|---|
| 0000 | 121611 | FFC | No boom visible |
| 0029 | 121640 | DFC 10sec | Grey |
| 0061 | 1217 | | Boom silhouette. Boom clearly vis. (nice out-of-the-clag sequence) |
| 0400 | | | Still heavy smoke |
| 0505 | 122418 | DFC 10sec | Smoke |
| 0624 | 122624 | DFC | Oil slicks |
| 0638 | | | Coastline, land |
| 0684 | | | Army convoy |
| 0688 | 122742 | FFC | Heading back into smoke |
| 1349 | | | Thick, but boom still visible |
| 1806 | | | Plume edge, bank towards sunglint |
| 1950 | | | Back to plume |
| 2409 | 130641 | DFC 5sec | |
| 2524 | | | Climbing turn into sun, out of plume |
| 2671 | 131358 | DFC 15sec | Smoke tops |
| 2836 | 131844 | DFC 20sec | Smoke tops |
| 2946 | | | Down into plume - along plume top |
| 3103 | 132647 | DFC 10sec | Grey |
| 3737 | | | Turn thro' sun |
| 3999 | 135628 | DFC 10sec | Tops |
| 4012 | | | Into plume |
| 4067 | | | Very thick |
| 4100 | 140008 | DFC 49sec | Some surface detail - below plume |
| 4218 | 140422 | DFC 24sec | Sea surface |
| 4293 | | | A/c low point |
| 4338 | 140845 | DFC 4sec | Turn into sun, sunglint |
| 4452 | 141307 | DFC 7sec | |
| 4553 | | | Bright line between sea/plume |
| 4643 | | | Climb to plume |
| 4728 | | | Plume top |
| 4797 | 142626 | DFC 5sec | |
| 5062 | | | Plume bottom |
| 5222 | | | Reenter plume |
| 5440 | | | Plume top |
| 5503 | 145535 | DFC 5sec | |
| 5651 | | | Into plume |
| 5745 | | | Boom just visible |
| 5835 | | | Boom barely visible |
| 5894 | | | Boom not visible, sunset |
| 5932 | 151435 | | End |

Table 45: Summary of tape 119 for flight A078

| TAPE COUNTER | TIME GMT | CAMERA | COMMENTS |
|---|---|---|---|
| 0000 | 062332 | FFC | taxi |
| 0557 | 063220 | | Rolling |
| 1300 | | | Low level - waves! |
| 1495 | 065100 | | Into plume |
| 1890 | 070014 | | Plume top |
| 1947 | 070142 | DFC 5secs | |
| 2454 | 071500 | | Left turn. |
| 2504-2554 | | | Spectacular lens flare |
| 2819 | 072517 | | Into plume |
| 2909 | 072753 | DFC 5secs | |
| 3064 | 073237 | DFC 20secs | Sea surface |
| 3107 | 073355 | | Leave plume |
| 3305 | 074007 | DFC 23secs | Sea surface |
| 3404 | 074317 | DFC | Sea surface - a/c shadow - sunglint |
| 3499 | 074623 | | Shadow more than fills screen - low point |
| 3575 | 074854 | FFC | |
| 3819 | 075706 | | Plume top |
| 4004 | 080336 | | Into plume |
| 4219 | 081117 | | Bottom |
| 4462 | 082019 | | Low point |
| 4472 | 082040 | | Right turn |
| 4516 | 082224 | | Plume base |
| 4545 | 082327 | DFC 17sec | Island visible on FFC - Right turn. Plume not clear |
| 4724 | 083023 | | Left turn |
| 4865 | | | Island |
| 5018 | | | Plume visible again |
| 5068 | 084410 | | Into plume top |
| 5092 | 084508 | | Left turn |
| 5184 | 084858 | | Left turn |
| 5304 | 0854 | | Into plume. |
| 5410 | 0854 | | Right turn. |
| 5822 | 091634 | | End. |

Table 46: Summary of tape 117 for flight A079

| TAPE COUNTER | TIME GMT | CAMERA | COMMENTS |
|---|---|---|---|
| 0005 | 091728 | FFC | |
| 0300 | | | Plume 'horizon' visible |
| 0797 | 093040 | | Left turn |
| 1177 | 093810 | | Left turn. Surface visible, blue sky - no smoke?? |
| 1580 | 094654 | | Right turn |
| 1644 | 094824 | | Left turn |
| 1804 | 095210 | | Right turn |
| 2081 | 0959 | | Left |
| 2415 | | | Clouds getting nearer |
| 2711 | 1016 | | A type 2 Cu to the left. A/c turns right |
| 3195 | 103033 | Dunes and rocks | |
| 3348 | | | A/c shadow |
| 3372 | | | Oxbow shapes |
| 3400 | | | A/c shadow. Beautiful curves |
| 3629 | 104444 | FFC | |
| 3688 | 104642 | | Right turn |
| 3774 | | | Descending |
| 3843 | 1052 | | Right turn |
| 4000-4072 | | | A/c drives round Cu |
| 4296 | 110815 | | Left turn |
| 4737 | 1125 | | Plume ahead? Right turn, then left |
| 4931 | 113248 | | End |

Table 47: Summary of tape 120 for flight A079

| TAPE COUNTER | TIME GMT | CAMERA | COMMENTS |
|---|---|---|---|
| 0000 | 1215 | DFC | Desert - relatively featureless after 120/3195 |
| 0548 | | | Herringbone pattern |
| 0686 | 122644 | FFC | |
| 0842 | 122939 | DFC 6sec | |
| 1025 | 123315 | | Right turn into sun |
| 1158 | 123558 | DFC | Dunes |
| 1450 | 124214 | FFC | Into sun |
| 2006 | 125520 | | Turn left |
| 2124 | 125820 | DFC 25secs | Dunes |
| 2650 | 131239 | DFC | Dunes |
| 2773 | 131610 | | Right turn |
| 3000 | | | Still dunes |
| 3213 | 132933 | FFC | Into sun |
| 3239 | 133020 | DFC 13secs | Ridges |
| 3388 | 133506 | | Left turn |
| 3772 | 134753 | DFC | Ridges/dunes |
| 3949 | 1354 | | Left turn |
| 3979 | 135503 | FFC | |
| 4652 | 142004 | DFC | Dunes |
| 4707 | 142210 | FFC | |
| 4900 | | | Smoke visible |
| 5130 | 143911 | DFC 13sec | Dunes |
| 5284 | 144537 | | Sunset |
| 5473 | 145339 | DFC 1min | Dunes |
| 5816 | 150840 | | Last of the light - quite pretty |
| 6030 | 151830 | | End |

Table 48: Summary of tape 124 for flight A079

| TAPE COUNTER | TIME GMT | CAMERA | COMMENTS |
|---|---|---|---|
| 0000 | 062626 | FFC | take off |
| 0414 | | | Rolling |
| 0590 | | | Smoke? |
| 2431 | 071714 | | Right turn |
| 2476 | 071825 | DFC 11secs | (Land) Smoke on FFC to right |
| | 0-724 | | Distant smoke |
| 2933 | 073132 | DFC | Well used desert track |
| 3011 | 073355 | | Right turn |
| 3021 | 073413 | FFC 9secs | Smoke plumes bottom right |
| | 073430 | DFC | Fires visible - Desert oil spill? |
| 3066 | 073535 | | Right turn, then left |
| 3163 | 073834 | FFC | Line of small Cu |
| 3293 | 074240 | DFC | Desert and tracks, smoke at left side |
| 3431 | 074706 | | Left turn. Odd formation 3480 074845 |
| 3559 | 075118 | FFC | Smoke at altitude above A/c |
| 3691 | 075546 | | Right turn below Cu into hazy smoke. |
| 3756 | 075758 | DFC | Desert and cloud shadows, A/c descending |
| 3826 | 080025 | | Left turn - A/c shadow - multi tracked desert |
| 3930 | 080403 | FFC | Fires ahead/right |
| 4009 | 080650 | DFC | A/c shadow |
| 4012 | 0807 | | Turn right - |
| 4027 | 080731 | FFC | towards fires |
| | 080825 | | Turn left - fires to left. Surface oil spill. Climbing |
| | 081308 | | Gentle right |
| 4296 | 081713 | | Right turn just over Cu tops - smoke ahead |
| 4430 | 082213 | DFC 20sec | |
| | 0824 | | Nose down towards plume |
| 4608 | 0829 | | Just over plume |
| | 083030 | | Entered outer edges |
| 4711 | 0833 | | In thick bit |
| | 0835 | | Plume gloom |
| 4796 | 083620 | | Thickest - boom still visible (just) |
| | 0838 | | Plume gloom |
| 4887 | 0840 | | Exiting |
| 5012 | 0845 | | Clear but thick bit ahead. Enter at 084620 ish |
| | 0849 | | Thickening plume gloom |
| 5183 | 0852 | | Exit below plume |
| 5252 | 085454 | | Left turn |
| | 0858 | | Below plume, fire to left. Thick bit ahead |
| 5432 | 090229 | | Enter thick bit. Structure visible - prob near top |
| 5517 | 090610 | | Right turn. Still near top. Plume gloom by 0909. Between layers 0913-14 |
| 5750 | 091625 | | Right turn back to PG. Layered 0923 |
| 5919 | 092400 | | End |

Table 49: Summary of tape 115 for flight A080

| TAPE COUNTER | TIME GMT | CAMERA | COMMENTS |
|---|---|---|---|
| 0007 | 092456 | FFC | Plume Gloom - close to top (0927) |
| 0842 | 093230 | | Left turn |
| 0624 | 0935 | | Layered |
| 0732 | 093700 | | |
| 0750 | 093720 | DFC | |
| 1003 | 094234 | | |
| | 094450 | | Turns, a touch of coastline |
| 1138 | 094521 | | Oil spills by 0926. |
| 1273 | 094813 | FFC | Overcast |
| 1348 | 094951 | DFC | Shadow/reflection |
| 1512 | 095329 | | Climbing/turn. Good shadow 095415 to turn |
| 1564 | 095440 | | and descend again |
| | 1000 | | Good reflection, shadow wing, oil 1003 |
| 2005 | 100519 | | Right turn and climb |
| 2045 | 100620 | FFC | |
| 2313 | 101320 | | Into plume |
| 2508 | 101836 | | Into plume |
| | | | Plume gloom by 1022. 1032.5 thick bit and camera flare |
| 3178 | 103816 | DFC 9secs | Grey |
| 3400 | 104520 | | Ac As becoming visible. Odd patch upper right 104940 |
| 3575 | 105102 | | Right turn. Into plume 1053.5 |
| | 1058 | | Plume Gloom - upper cloud still just visible, then goes. Dense 1102 |
| 3932 | 110312 | DFC 4secs | White |
| 4084 | 110832 | DFC 6secs | Light grey |
| 4184 | 111050 | | Right turn |
| 4220 | 111327 | Video off until | NOT ON TAPE LOG |
| 4220 | 122441 | | 71 minutes and its still Plume Gloom |
| 4455 | 123326 | | Upper cloud visible , close to top of plume |
| | 124011 | | Small Right turns |
| | 1243 | | Upper cloud |
| | 1250 ish | | Left turn |
| 4963 | 125315 | | Left turn, still close to top of plume |
| 5375 | 131022 | | Cloud and sunglint. Left turn |
| 5554 | 131806 | | End |

Table 50: Summary of tape 116 for flight A080

| TAPE COUNTER | TIME GMT | CAMERA | COMMENTS |
|---|---|---|---|
| 0003 | 131849 | FFC | Gloomy |
| | | | Clear of smoke |
| 0616 | 132844 | | Left turn and back in again |
| 0769 | 133130 | | Right turns |
| 1683 | 135030 | | Coastline |
| 1734 | 135142 | | Left turn Descend, sandband 1352.5 |
| | 140000 | | A/c low - some smoke |
| 2271 | 140503 | DFC 10sec | No detail |
| 2571 | 141314 | | Left turns into plume gloom |
| 3227 | 143237 | | Left turn over coastline |
| 3409 | 143820 | | White gloom for a change. Above cloud by 1440. Cumulus |
| 3884 | 145414 | DFC 6sec | Sea surface. Night approacheth |
| 4189 | 150500 | | Night |
| 4277 | 150811 | | End |

**Table 51: Summary of tape 122 for flight A080**

| TAPE COUNTER | TIME GMT | CAMERA | COMMENTS |
|---|---|---|---|
| 0001 | 062421 | FFC | T/O |
| | 063200 | | Rolling |
| 0868 | 063900 | | Smoke |
| 1494 | 065200 | | Gradually clearing. Coastline just appearing |
| | 0659 ish | | Over coast |
| | 0705 | | Getting thicker again |
| 2519 | 071732 | DFC 14secs | Sand and tracks |
| 2719 | 072309 | DFC | Sand and tracks |
| 2874 | 072740 | | Crossroads |
| 3099 | 073430 | | Right turn |
| 3107 | 44 | FFC | Desert haze |
| 3249 | 073907 | DFC | Much desert many tracks |
| 3468 | 074611 | FFC | Smoke to right |
| 3617 | 0751505 | | Left turn. Hazy horizon |
| 3973 | 080320 | | Descending then turn left |
| 4002 | 080422 | | Fires ahead. Still turning |
| 4215 | 081200 | | Smoke ahead/right A/c descending |
| | 32 to 38 | | Patterns (odd) A/c shadow at 081844 |
| 4434 | 082004 | | 5 parallel "tracks" |
| | 14 | | More |
| 4491 | 082214 | | Fire at right A/c turns and climbs |
| 4594 | 082609 | FFC | Fires ahead. Approaching plume from upwind |
| 4815 | 083446 | | Staying above plume until |
| 4908 | 083830 | | Enter plume. Hazy |
| 5113 | 084648 | DFC | Sea, descending. Not very-low point 084910 |
| 5195 | 085011 | FFC | Hazy horizon. Climbing back to smoke |
| 5438 | 090027 | | Left turn |
| 5559 | 090540 | DFC | Sea, some smoke |
| 5632 | 090851 | FFC | Hazy |
| 5848 | 091824 | | Thicker bit |
| 5884 | 092000 | | End |

Table 52: Summary of tape XXX for flight A081

| TAPE COUNTER | TIME GMT | CAMERA | COMMENTS |
|---|---|---|---|
| 0000 | 092033 | FFC | Very hazy |
| 0946 | 093634 | | Left turn. Thickish band at A/c level - last 5 mins |
| 1346 | 094446 | | Getting thicker. Right turn |
| 1424 | 094630 | | Level out - near plume base |
| 1651 | 095134 | DFC | sunglint |
| 1866 | 095640 | FFC | Greyish |
| 2018 | 100024 | | Right turn. Straighten between layers cloud/smoke |
| 2252 | 100627 | | Right turn |
| | 102125 | | Denser bit |
| 3526 | 104415 | | Right turn into camera flare |
| 4031 | 110134 | | Left turn. Unmitigated grey |
| 4370 | 111356 | | Right turn |
| 4786 | 112956 | | Left turn. |
| | 1145 | | Turning, No horizon - all grey |
| 5535 | 120104 | | Left turn. Sea surface - brighter |
| | 1207 | | Descending |
| 5755 | 121042 | | Right turn |
| | 1212 | | BRN approach and landing |
| 5924 | 121815 | | End |

**Table 53: Summary of tape XXX for flight A081**

## 18. Other Information Available

Standard plots have been produced for each flight and these are stored at MRF. For each run and profile the following parameters have been plotted:

(a) temperature,

(b) dew point,

(c) TWC dew point,

(d) total water,

(e) northward wind component,

(f) eastward wind component,

(g) uncorrected vertical velocity,

(h) corrected liquid water content,

(i) total scattering coefficient,

(j) ozone,

(k) pressure height,

(l) upper vis clear,

(m) upper vis red,

(n) lower vis clear,

(o) lower vis red,

(p) $SO_2$,

(q) NO,

(r) $NO_x$,

(s) FSSP concentration and

(t) PCASP concentration.

Also for each profile a tephigram and hodograph has been plotted. To view and get more information on these contact Doug Johnson Ext 5734.

METEOROLOGICAL OFFICE

# Meteorological Research Flight

Y46 Building

Dr Peter Hill
NOAA
Office of the Chief Scientist
Arabian Gulf Program Office
Herbert C Hoover Bldg, Room 1617M
14th & Constitution N.W.
Washington, D.C. 20230
U S A

Our Reference M/MRF/9/5/16

Date 10 October 1991

Dear Dr Hill,

Thank you for your fax of 8 October 91.

I enclose two reports:

✓(a) Our preliminary report of June 91 (which you already have a fax of)
(b) Our paper submitted to Nature.

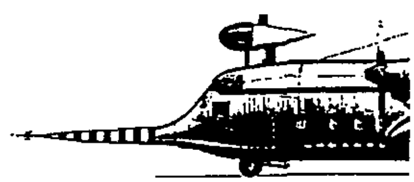
They are essentially the same, although our estimates of emissions have been updated slightly in (b), which is also slightly shorter because of the page limitations in Nature.

I hope these are useful; I look forward to receiving a copy of the completed folder.

Yours sincerely,

Geoff Jenkins

Dr G J Jenkins
Head, Meteorological Research Flight





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Meteorological Office
Meteorological Research Flight

# Observations in March 1991 of the oil smoke plume from Kuwait by the UK Meteorological Office C-130 aircraft

## Preliminary Report

June 1991

Meteorological Office
Meteorological Research Flight
RAE FARNBOROUGH
GU14 6TD

## Introduction

About 600 naturally pressurised oil wells were set alight in Kuwait in late February 1991, injecting massive quantities of smoke, sulphur dioxide ($SO_2$) , unburnt hydrocarbons and nitrogen oxides ($NO_x$=NO+$NO_2$) into the atmosphere; estimates for the burning rate vary from 2 to 6 Mbarrels per day ($MBd^{-1}$). The main source areas, as indicated by ground surveys and infrared satellite images, are shown in figure 1. Assessments of the impact of the pollution from Kuwait have been made (those from the UK Meteorological Office and from the Hamburg group were reported in Nature, 30 May 1991) but there are large uncertainties due to the lack of information on the magnitude and the characteristics of the emissions and the resulting plume.

In order to investigate the nature of the plume, the chemical and particulate composition of the smoke, and its effect on visible and thermal radiation, the C-130 aircraft of the Meteorological Office Research Flight (MRF) was based in Bahrain during late March 1991 and from there made a total of 57h of observations in eight flights into and around the plume. This is a preliminary report of the the first airborne measurements of the plume both close to source (up to 200km) and in the far field (1000km from source).

## Meteorology and plume behaviour

Based on a mixture of visual, photographic and in situ measurements over the period of the investigation, the typical appearance of the plume can be summarised as follows. Smoke from individual oil wells combined and continued to rise so that the plume top reached about 5000m; shallow convective clouds were observed to form on the windward edge of the plume on many occasions. On the majority of days there was a marked directional wind shear in the vertical leading to differential advection of the plume with, for example, the lower part of the plume being transported southeastwards down the Gulf, with the upper part heading across the Gulf towards Iran.

There has been speculation that, as a result of radiative self heating aerosol may be carried upwards (often referred to as self-lofting) into the stratosphere, where its long lifetime would allow transport over considerable distances. Visual observations showed the plume top to be relatively well defined on most occasions, although sometimes with an uneven structure on the upper surface. On one or two occasions only a detached smoke layer was seen a few tens of metres above the main top. Over the eight days of measurements, the maximum height at which substantial aerosol enhancement was seen was 5km; at a distance of 120km from source. Therefore, based on these observations over a limited period we deduce that significant amounts of aerosol were not being lofted into the stratosphere, in agreement with recent assessments.

## Near field measurements of particulates and chemistry

On 28 March 1991 a flight was undertaken to investigate the smoke plume in the near field of the source region in order to quantify the magnitude and character of the emissions from the southern oil well fires. Multiple vertical profiles and cross wind horizontal runs through the plume were executed approximately 120km downwind of the source (defined for the purposes of this report as 29°N, 48°E.) as shown in figure 1.

A laser scattering probe was used to measure smoke particle concentrations and deduce the mass of smoke particles per unit volume (smoke density). Continuous measurements of $SO_2$, $NO_x$ and ozone ($O_3$) were made from the C-130 and in addition, samples of polluted air were pumped into stainless steel flasks, which have subsequently been analysed for $C_2$-$C_8$ hydrocarbons.

Figure 2 shows data from a descending profile carried out alongwind through the centre of the plume. A significant vertical wind shear was present and the plume as indicated by the particulate and gaseous pollutants had a complex vertical structure, on this occasion made up of two main layers; an upper one with a top at 4,600m and base 3,600m and a much deeper and denser lower layer with a top at 3,200m and base 1,000m. The lower layer was capped by thin altocumulus cloud. Figure 2 a-d show the smoke density, the liquid water content and the wind speed and direction respectively. Figure 3 a-c show the $SO_2$, $O_3$ and $NO_x$ mixing ratios and the sum of the $O_3$ and the $NO_x$ mixing ratios. From the close correspondence between the sum of $NO_x$ and $O_3$ within the plume, and the $O_3$ profile obtained earlier in the flight outside the plume (figure 3d), it can be seen that $NO_x + O_3$ is better conserved than either $NO_x$ or $O_3$ separately.

Seven horizontal, cross wind runs through the plume were carried out at heights between 1,420m, and 4,420m. Each run was over the same ground position as shown in figure 1. Figures 4 a-d show measurements from the run at 2,440m (near the centre of the lower plume) of smoke density, total scattering coefficient as measured by the integrating nephelometer, $SO_2$, $NO_x$, and $O_3$ and the sum of $NO_x$ and $O_3$. A clearly defined plume 50km wide is seen. The highest concentrations found during this horizontal run were $500\mu gm^{-3}$ of smoke, 400ppbv of $SO_2$ and 40ppbv of $NO_x$. In both the vertical profiles and horizontal runs all the plume indicators ($SO_2$,

$NO_x$, particulates, scattering coefficient) were highly correlated; this behaviour was consistently exhibited over several days of measurements close to the source, with the correlation coefficient between $SO_2$ and smoke density, for example, typically greater than 90%. (For comparison, maximum hourly concentrations in Central London are typically 300 ppbv for $SO_2$ and $NO_x$, and $100\mu gm^{-3}$ of black smoke. UK maximum ozone concentrations usually reach 150 ppb at some period in summertime.)

In the lower layer as seen in the profile and horizontal runs, $NO_x$ and $O_3$ mixing ratios are negatively correlated while their sum shows little horizontal variation (figure 4d). The negative correlation between $O_3$ and $NO_x$ is indicative of the reaction between $O_3$ and NO. This lack of horizontal variation indicates that there has been no detectable loss of $O_3$ either by reactions with smoke particles or in the conversion of $SO_2$ to sulphate. In the upper layer shown in figure 3c (also evident from higher level horizontal runs) it is clear that the negative correlation between $NO_x$ and $O_3$ no longer exists, indicating that some degree of photochemical oxidant production has already been initiated by the ambient solar radiation.

Results of the hydrocarbon analysis of three flasks (out of a total of 44) filled in different parts of the plume are summarised in table 1. The maximum mixing ratios of benzene and toluene determined from the samples are lower than the corresponding mixing ratios in a sample of air taken beside a busy road in Bracknell, U.K. However, n-hexane mixing ratios in the flasks filled in the plume were substantially greater than in the Bracknell sample.

The flask which showed the highest mixing ratios of hydrocarbons of any of the flasks analysed (sample A) was filled at an altitude of 2600m as the C-130 penetrated the densest part of a

Table 1:

| Species | Sample A 30 March 91 Mixing Ratio (ppbv) | Sample A ethane Ratio | Sample B 30 March 91 Mixing Ratio (ppbv) | Sample B ethane Ratio | Sample C 29 March 91 Mixing Ratio (ppbv) | Sample C ethane Ratio |
|---|---|---|---|---|---|---|
| ethane | 25.111 | 1.000 | 5.440 | 1.000 | 1.330 | 1.000 |
| ethene | 13.030 | 0.519 | 1.851 | 0.340 | 0.034 | 0.026 |
| propane | 19.952 | 0.794 | 2.345 | 0.431 | 0.453 | 0.340 |
| propene | 1.637 | 0.065 | 0.220 | 0.040 | 0.026 | 0.020 |
| benzene | 1.057 | 0.042 | 0.215 | 0.040 | 0.044 | 0.033 |
| toluene | 1.309 | 0.052 | 0.203 | 0.037 | 0.025 | 0.019 |
| n-hexane | 5.052 | 0.201 | 0.409 | 0.075 | 0.013 | 0.010 |
| NMHC(T) | 339.6 | 13.53 | 45.92 | 8.44 | 6.266 | 4.71 |

smoke plume on the 30 March 1991, 120km from the source. A second flask filled on the same day (sample B) at an altitude of 1500m near the bottom of the plume was more typical of several of the polluted flask samples. Since hydrocarbons with very different life times, such as ethane and ethene, are found in similar proportions in both sample A and B it is likely that the lower mixing ratios in sample B are due to a dilution through turbulent mixing rather than chemical loss.

**Far field measurements of particulates and chemistry**

For several days at the end of March a low pressure system was present in the upper air to the north west of Kuwait. On 29 March 1991 satellite images showed smoke over the central deserts of Saudi Arabia some distance from Kuwait oriented roughly southwest-northeast and being advected to the northeast. The C-130 was deployed to make measurements in this area of smoke; its flight track is shown in figure 1. The $O_3$ mixing ratios and particle concentrations observed in a horizontal run through the area of smoke are shown in figure 5 a and b; smoke particle concentrations are enhanced by several hundred particles per $cm^3$ and $O_3$ mixing ratios are enhanced by 40-60ppbv over the already high values in adjacent clear air.

It is likely that the enhanced ozone in this more distant plume is formed from ozone precursors released from the oil fires. In contrast to the hydrocarbon samples collected near the fires, the contents of a flask (sample C, table 1) filled in the smoke shows a different distribution of hydrocarbons. This sample still has relatively high mixing ratios of many of the longer lived hydrocarbons, such as ethane and propane, while the mixing ratios of the short lived hydrocarbons such as ethene and propene are substantially reduced. The mixing ratio of ethane in this sample compared with that in sample B, 120km from source, indicates that the plume dispersion has not been very efficient. The very low mixing ratios of the shorter lived species suggest that significant degradation through OH attack has taken place consistent with the enhanced ozone within the plume. Although the $NO_x$ mixing ratios in the plume were below the limit of detection (5ppbv), the potential for further ozone production cannot be ruled out because mixing ratios of only several pptv are required to generate ozone. However the absence of many of the more reactive and therefore short lived hydrocarbons from the plume at this time means that any further ozone production will proceed at a much slower rate.

The observations of this mature area of smoke on 29 March suggests an interpretation of some of the clear air observations in the near field. During many of the vertical profiles made near the source region but out of the visible plume, ozone mixing ratios much greater than the normal free tropospheric background (30-40 ppbv) were encountered (e.g. figure 3d), associated with somewhat increased particle density. It is likely that the enhanced ozone mixing ratios observed in the clear air are due to precursor emissions several days earlier which have remained near, or returned to, the source area.

## Morphology of smoke particles

Ambient air was passed through Nuclepore polycarbonate filters with a 0.4$\mu$m pore size projected about 0.4m from the aircraft skin on an extendable boom. Some of these filter samples were studied with a scanning electron microscope to determine the smoke particle morphology. Figure 6a shows a typical smoke particle from a filter exposed 180km from the source, on 30 March 1991. The smoke particles are composed of spherules having a mass mode diameter of approximately 0.1$\mu$m which form chains of hundreds in number and several microns in length. These chains are common features of oil smoke.

Particles on filters exposed over 1000km from Kuwait (figure 6b) have a different appearance to those from the near field; although the spherule size is similar in both cases the spherules in the far field are more likely to be closely packed into near-spherical clusters. This behaviour has been noted in laboratory experiments, in air aged at high humidity.

## Estimates of the magnitude of emissions from the fires

Although it was not the original intention of the measurements to estimate the emissions from the fires, the series of multiple horizontal runs and vertical profiles through the plume carried out on two of the days allow such an estimate to be attempted. The magnitude of sulphur emissions was estimated by determining the flux of sulphur in the plume, calculated from the product of the sulphur concentration across a vertical.crosswind plane through the plume and the wind component perpendicular to this plane. $SO_2$ measurements were used, together with the winds measured by the aircraft.

For 28 March 1991, when the aircraft measurements captured essentially the entirety of the plume about 120km from the southern oilfields, we estimate the source strength of these fields to be 6 Mt $yr^{-1}$ of sulphur. As the oil has a known sulphur mass fraction an estimate of sulphur emissions will allow the total emissions from the oil well fires to be deduced. Assuming a value of 3.3% for the southern oilfields, this corresponds to an oil burning rate of 182 Mt $yr^{-1}$. We assume, based on previous estimates, that the southern oilfields account for 85% of the total burning rate; this implies a total rate of 214 Mt $yr^{-1}$ or 4.1 $MBd^{-1}$. A flux calculation on 30 March 1991 gives a similar burning rate. Because of the motion of the plume, and time taken to make the multiple passes through it (typically 3 hours), the plume sampling will not be instantaneous; it is considered subjectively that this and the complex structure of the plume will lead to errors in estimating the source strength of ± 40%. Thus the range of uncertainty for the burning rate is 2.5-5.7 $MBd^{-1}$. A far larger number of passes through the plume, or the use of a lidar system able to make a two dimensional scan of the plume cross section, would be needed in order to narrow the uncertainties in this estimate.

Using the relationships between concentrations of various pollutants measured by the C-130, we can directly estimate the source strength of other constituents; these are shown in table 2. Carbon gas (ie the sum of $CO + CO_2 + CH_4 + NMHC$) is the residual when calculated emissions of S, $NO_x$, and particulate carbon are subtracted from the total. Also shown in the table are estimates of emissions from three recently published assessments.

Table 2:

| Component | This Study Mt $yr^{-1}$ | Browning et al.[4] Mt $yr^{-1}$ | Small[3] Mt $yr^{-1}$ | Bakan et al.[5] Mt $yr^{-1}$ |
|---|---|---|---|---|
| Total Burn Rate | 214 | 80 | 63 | 161 |
| Carbon Gas | 203 | 60 | 63 | - |
| Fine Particulate Carbon | 4.6† | 5 | 5.8 | 16.1 |
| Sulphur | 6.1* | 2 | - | - |
| Nitrogen Oxides | 0.24† | 0.5 | - | - |

† Assuming the same emission factors for the southern and northern fires.
* Assuming a 1.5% sulphur content for the northern fields which contribute 15% overall to the emissions.

### Effect of the smoke on radiation

The effect of the smoke plume on radiation is illustrated in figure 7, showing measurements taken during a horizontal run on 31 March 1991 through the centre of the plume at 2900m about 65km from source. The plume, with a top at 3600m and a base at 1700m, was being blown down the Gulf by winds at all levels from the northwest. The plume was well defined by the smoke density, and the aircraft flew just beyond the densest region before turning. The total shortwave (0.3-3$\mu$m) downwelling flux was reduced from its clear sky value of 800 $Wm^{-2}$ outside the plume to essentially zero in the centre, and associated changes were seen in the infrared and microwave regions.

Figure 7c shows the downward hemispheric infrared (4–50$\mu$m) fluxes measured by a pyrgeometer to be increased by 45 W $m^{-2}$ in the centre of the plume compared with that in clear air due to the increased emission from the smoke particles. At infrared wavelengths scattering due to the individual spherules will be negligible although the carbon chains may still scatter a significant amount of radiation.

Also plotted in figure 7c is the vertical downward radiance at 11.1$\mu$m measured by a multi-channel, narrow field of view (1.5°) radiometer mounted on the aircraft. The radiance in this atmospheric window channel was closely correlated with the variation in broadband infrared flux, with an increase in radiance of 20 mW $m^{-2}$ $ster^{-1}$ $(cm^{-1})^{-1}$ in the plume, except for the peak at 45 km along the run which is thought to be due to a small cloud at the top of the plume, also seen in the microwave measurements (figure 7d).

Figure 7d shows the effect the plume had on downward radiances (or brightness temperatures) at 89 and 157GHz measured by a microwave radiometer. Atmospheric emission at these frequencies is principally controlled by water vapour absorption and liquid water. The increase in brightness temperature in the plume at 157 GHz (22K) is three times the increase at 89 GHz (8K) but both are well correlated with the infrared radiance. The close correlation between the infrared fluxes and microwave radiances was seen on several occasions when there was no trace of liquid water in the plume.

## Discussion

The observation that significant amounts of smoke were not present above 5km bears out previous predictions by the UK Meteorological Office and others. Our best estimate of oil burning rate is greater than those previously assumed, but the greater $CO_2$ emissions that this implies would still have a negligible effect on global climate through the greenhouse effect. Our best estimate of particulate emissions is similar to that assumed in the Meteorological Office study; the greater burning rate which we deduce is offset by a lower smoke emission factor. The sulphur emissions calculated from airborne measurements are considerably higher than those taken in the Meteorological Office assessment and, although we would expect the acidity of rainfall episodes to be no higher than previously predicted, these episodes would extend further downwind across Southern Asia. As predicted, increased photochemical oxidant concentrations were observed both close to the source and further afield. The emissions of nitrogen oxides are smaller than those assumed in the Meteorological Office study; for this reason and because they are rapidly removed, they are unlikely to influence the global $NO_x$ background and therefore will have little impact on global tropospheric ozone. Our measurements thus support the conclusions of several recent assessments that, whilst effects on a global scale, including those on the Asian summer monsoon, are likely to be insignificant, they may be significant on a regional scale.


### Acknowledgements

We would like to acknowledge a great number of people without whose assistance these measurements would not have been possible, in particular the Royal Air Force MRF C-130 aircrew and RAF Muharraq for aircraft facilities. The co-operation of Sheik Essa bin Abdulla Alkhalifa and the State of Bahrain Ministry of Development and Industry, and that of the many Gulf states who speedily granted permission for the aircraft to operate with maximum flexibility in the area, was essential to the success of the study.


### Figures

1. The location of aircraft tracks for the near and far field flights.
2. A vertical cross section of the plume made in a descending profile on 28 March 1991, 120km from the source, (a) smoke density, (b) liquid water content, (c) wind direction , (d) wind speed. The large apparent smoke density values at 3km are due to the liquid water cloud.
3. As figure 2, for (a) $SO_2$, (b) $O_3$, (c) $NO_x$, $O_3$+$NO_x$ (thick line). (d) $O_3$ outside the plume,

upwind of the source.

4. A horizontal cross section through the plume at 2,440m on 28 March 1991 of (a) smoke density, (b) total scattering coefficient, (c) $SO_2$, (d) $O_3$ (solid line), $NO_x$ (dashed line) and $O_3$+$NO_x$ (dotted line).

5. Horizontal run through the area of smoke (about 1000km from Kuwait) on 29 March 1991 showing (a) $O_3$ (b) smoke concentrations at an altitude of 4400m.

6. Scanning electron micrographs of smoke particles collected on filters exposed in the plume on (a) 30 March 1991, 180km from the source and (b) 29 March 1991, about 1000km from the source.

7. An illustration of the effect of the smoke on downwelling radiation during a crosswind run through the centre of the plume. *a* smoke density, *b* shortwave flux, *c* infrared flux and 11 $\mu$m radiance (in units of mW $m^{-2}$ $ster^{-1}$ $(cm^{-1})^{-1}$) and *d* the microwave brightness temperatures at 89 and 157 GHz.

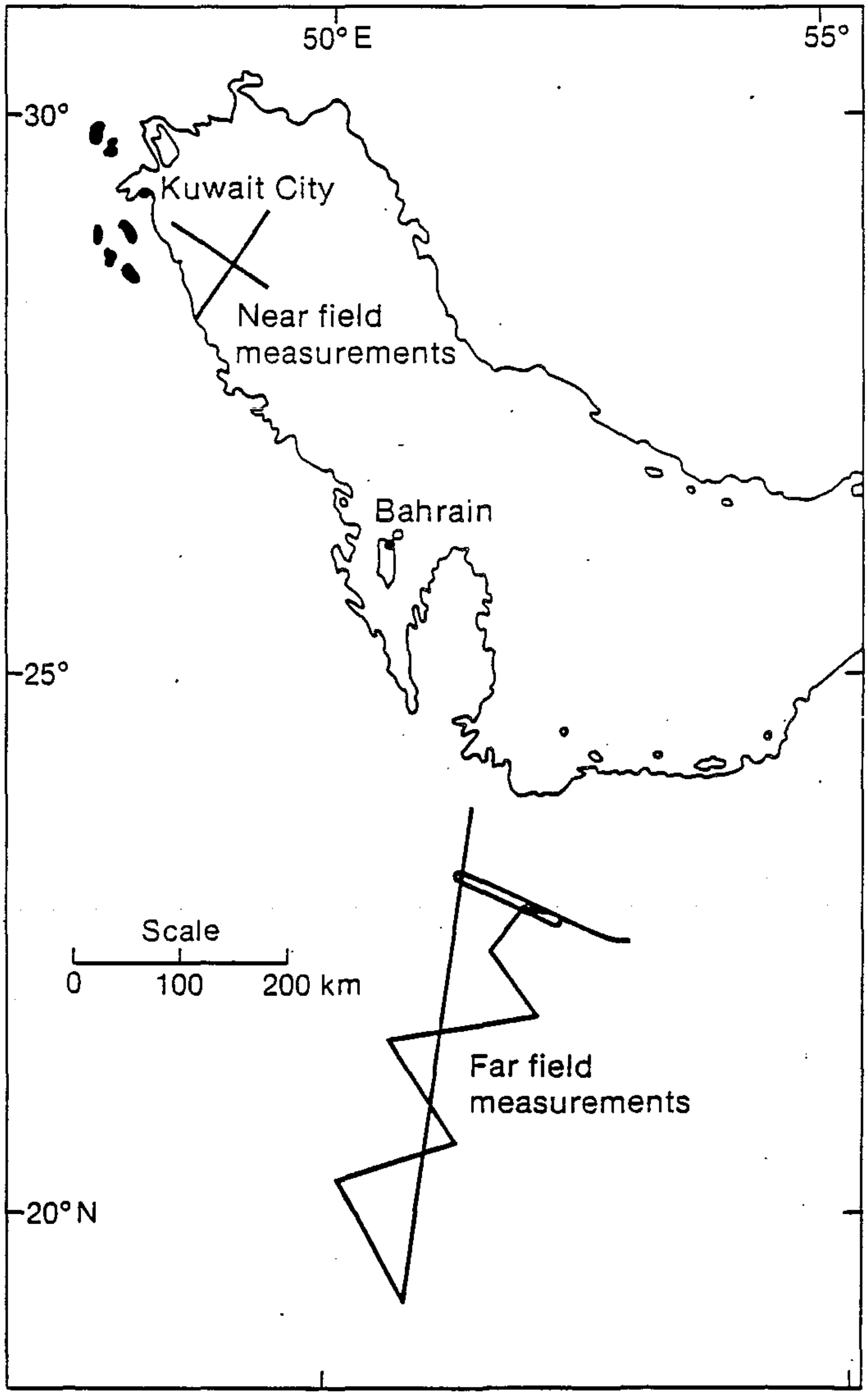

50° E
55°
30°
Kuwait City
Near field
measurements
Bahrain
25°
Scale
0
100
200 km
Far field
measurements
20° N

Figure 1.

Figure 2.

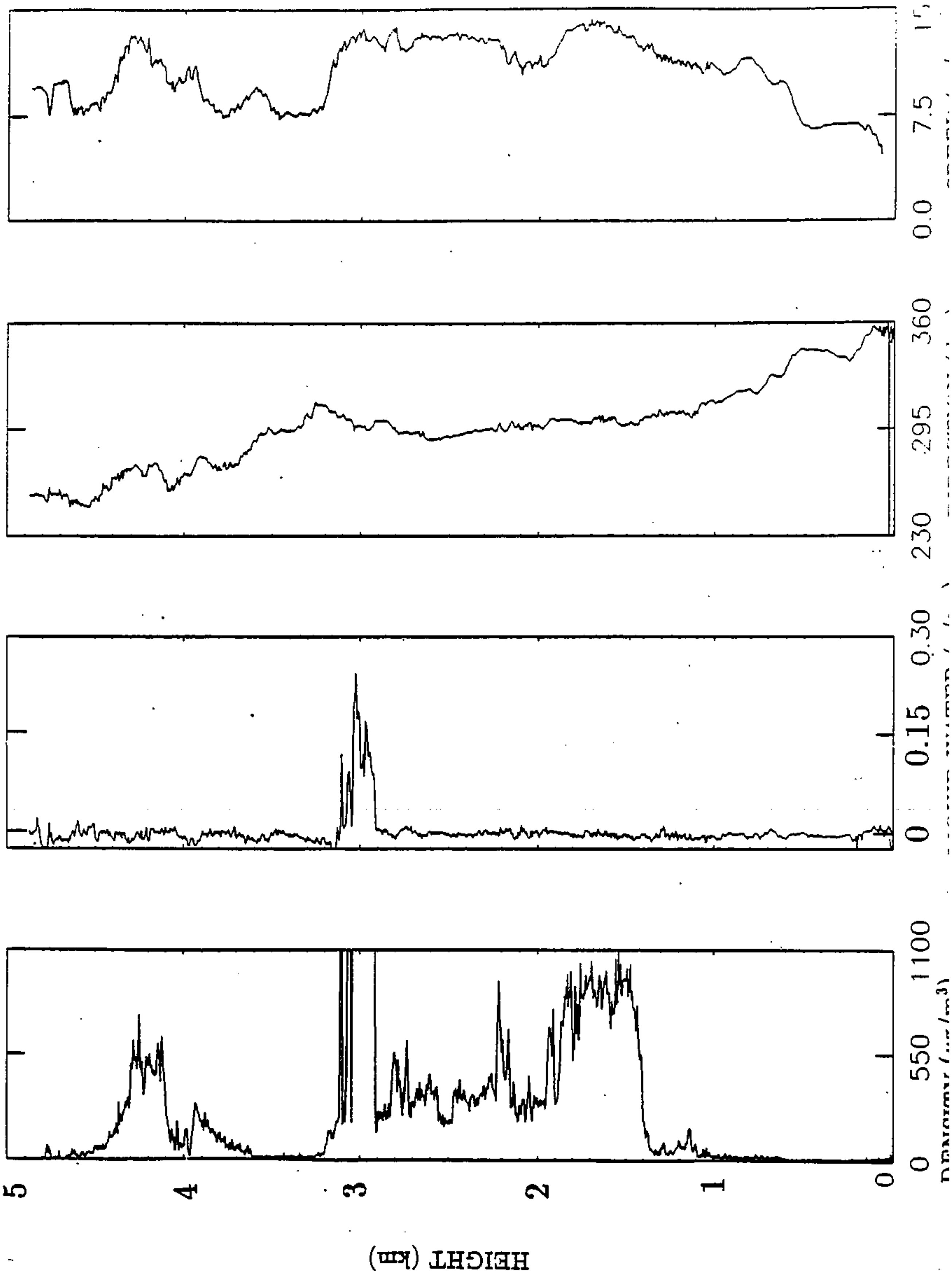
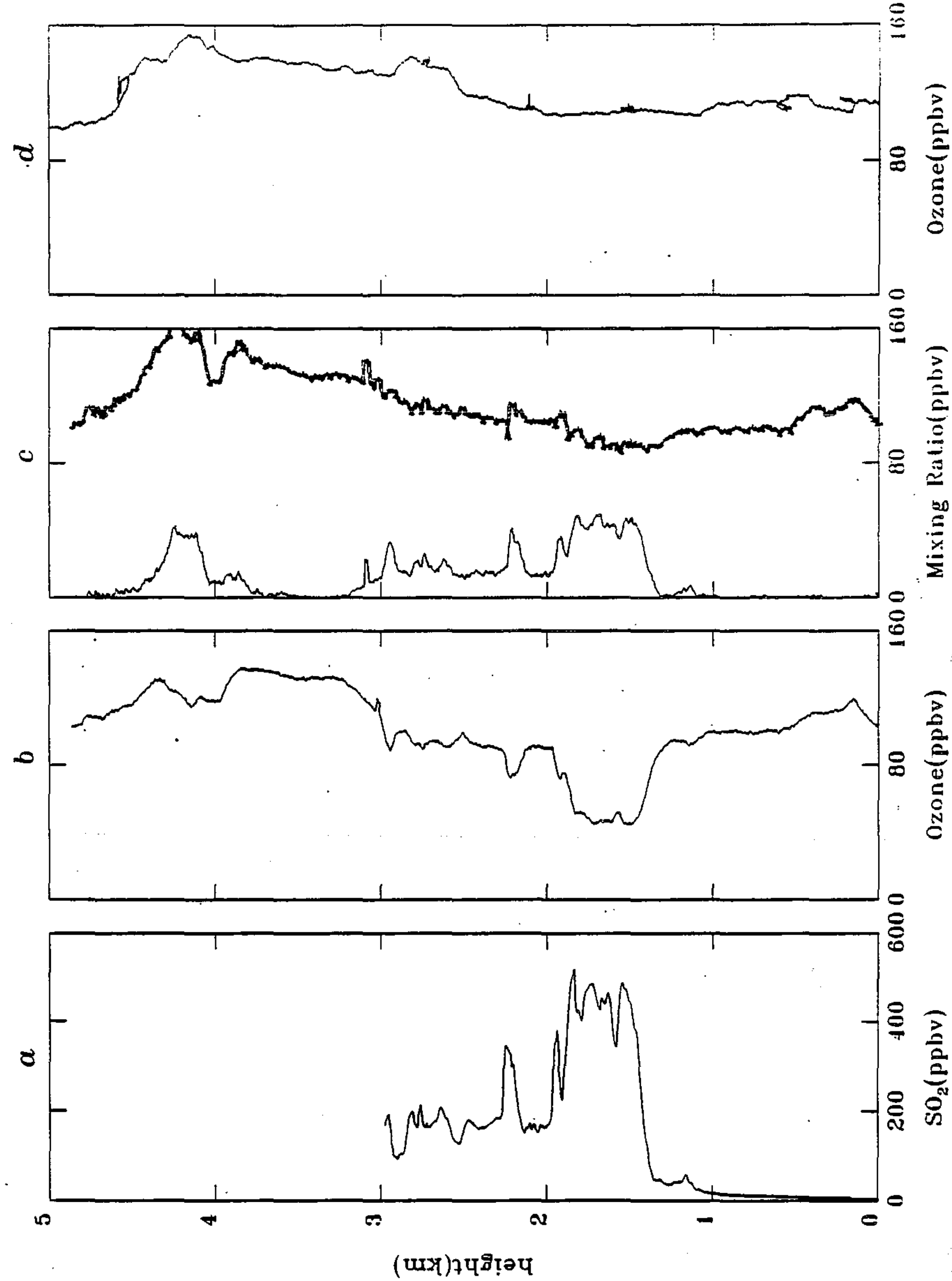
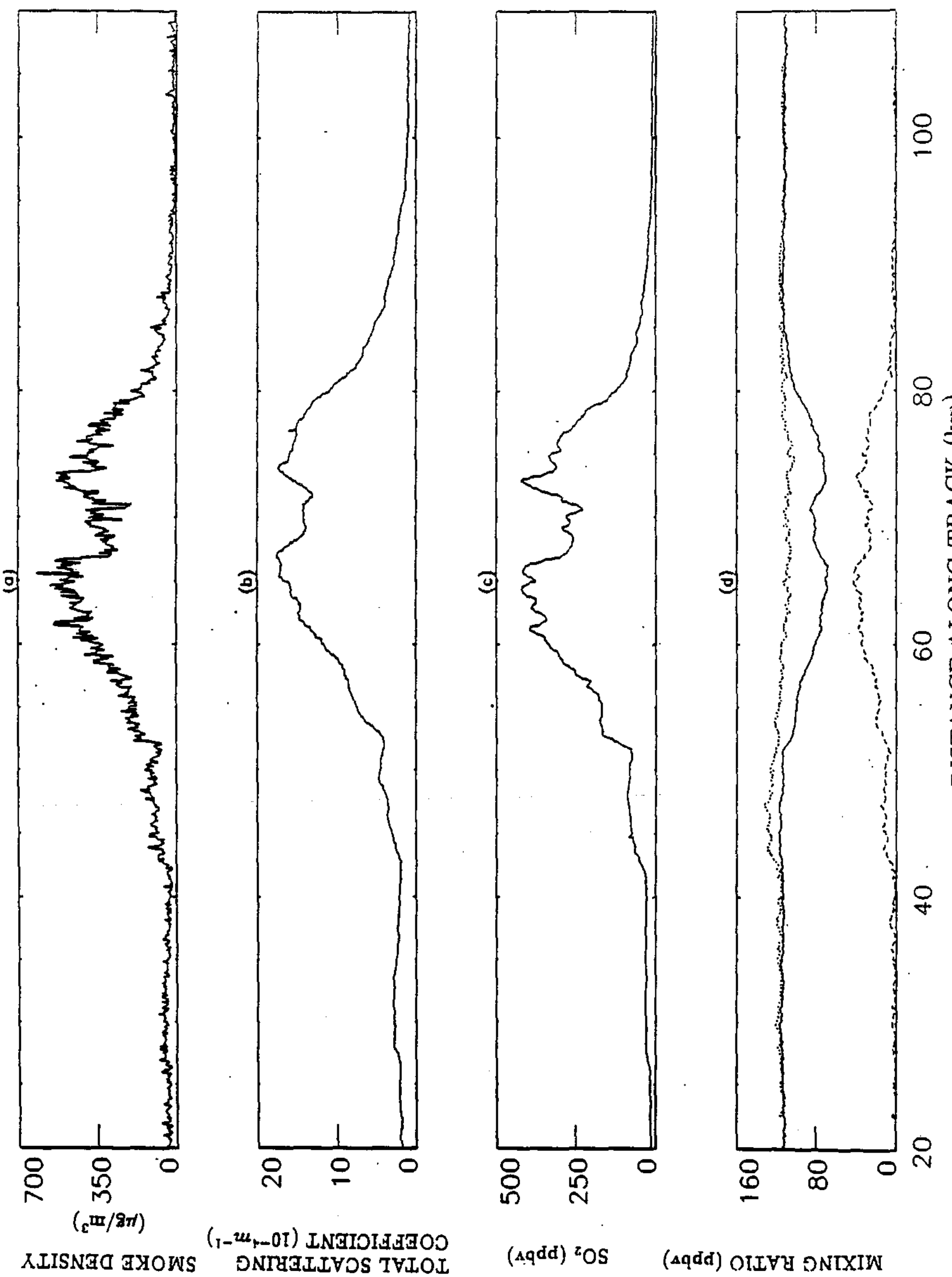


Figure 3.



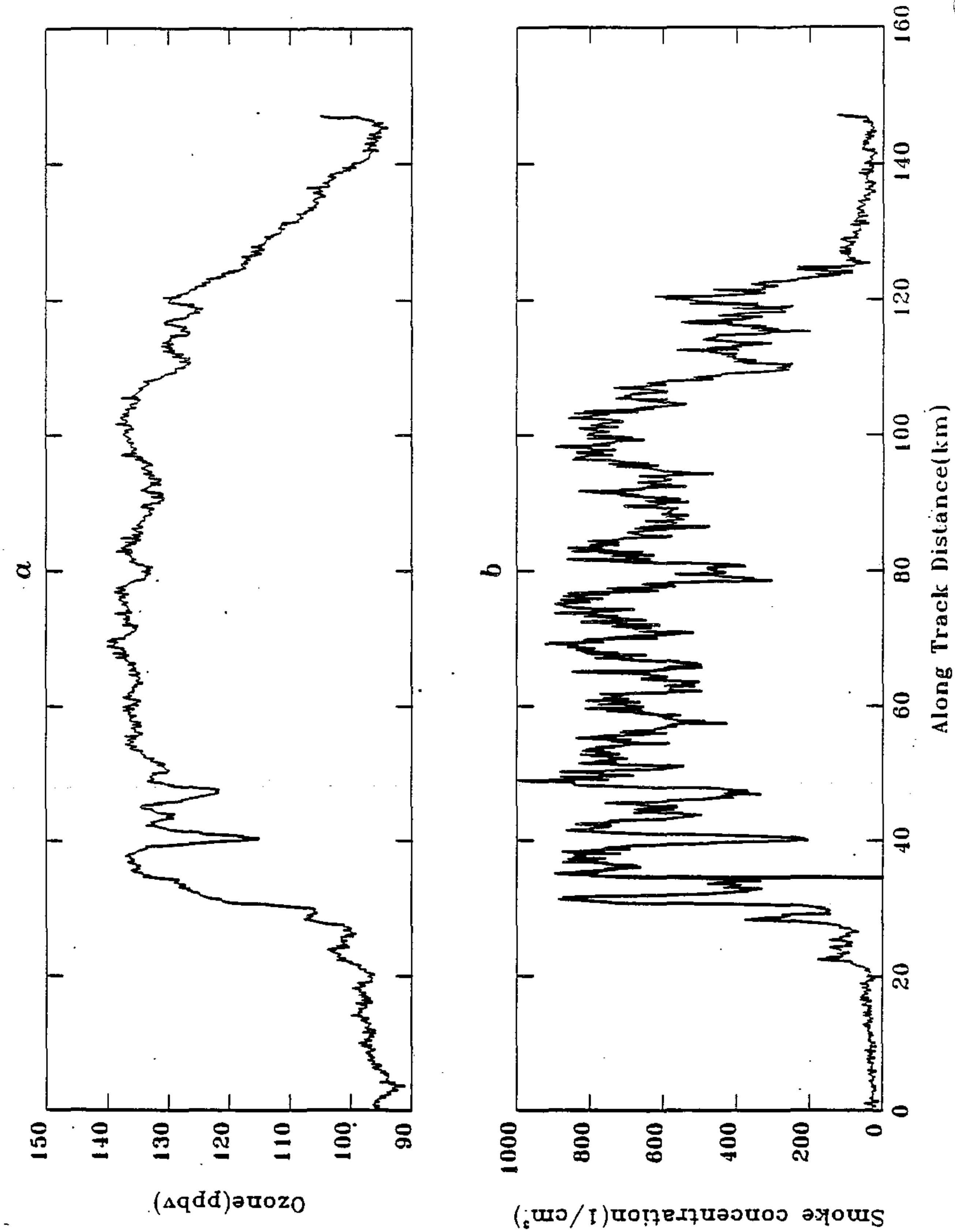
a
b
c
d
$SO_2$(ppbv)
Ozone(ppbv)
Mixing Ratio(ppbv)
Ozone(ppbv)
height(km)

Figure 4.



(a)
(b)
(c)
(d)
SMOKE DENSITY (μg/m³)
TOTAL SCATTERING COEFFICIENT (10⁻⁴m⁻¹)
SO₂ (ppbv)
MIXING RATIO (ppbv)
DISTANCE ALONG TRACK (km)
700
350
0
20
10
0
500
250
0
160
80
0
20
40
60
80
100

Figure 5.



a
b
Ozone(ppbv)
150
140
130
120
110
100
90
Smoke concentration(1/cm$^3$)
1000
800
600
400
200
0
Along Track Distance(km)
0
20
40
60
80
100
120
140
160

(a)

(b)

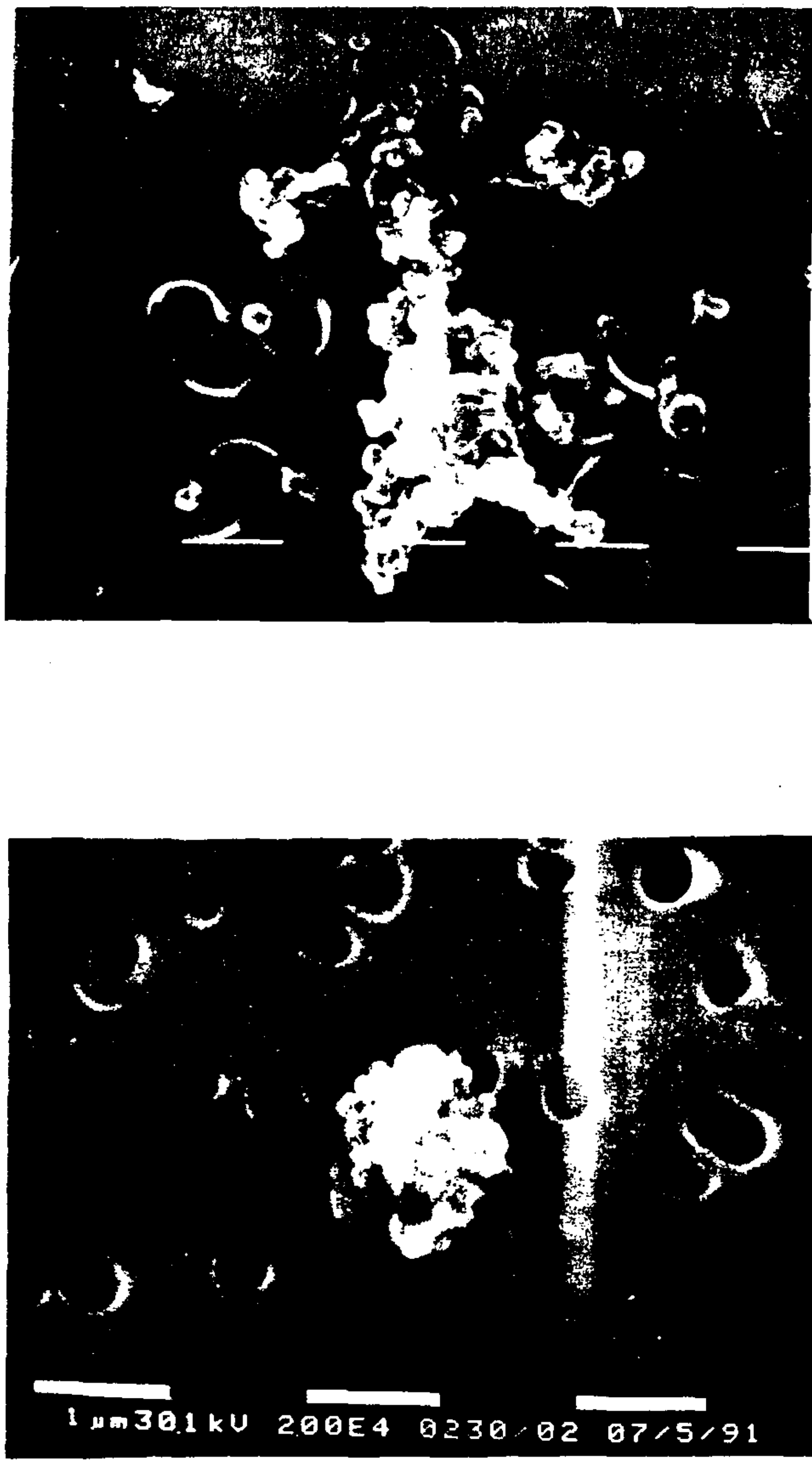



Figure 6.

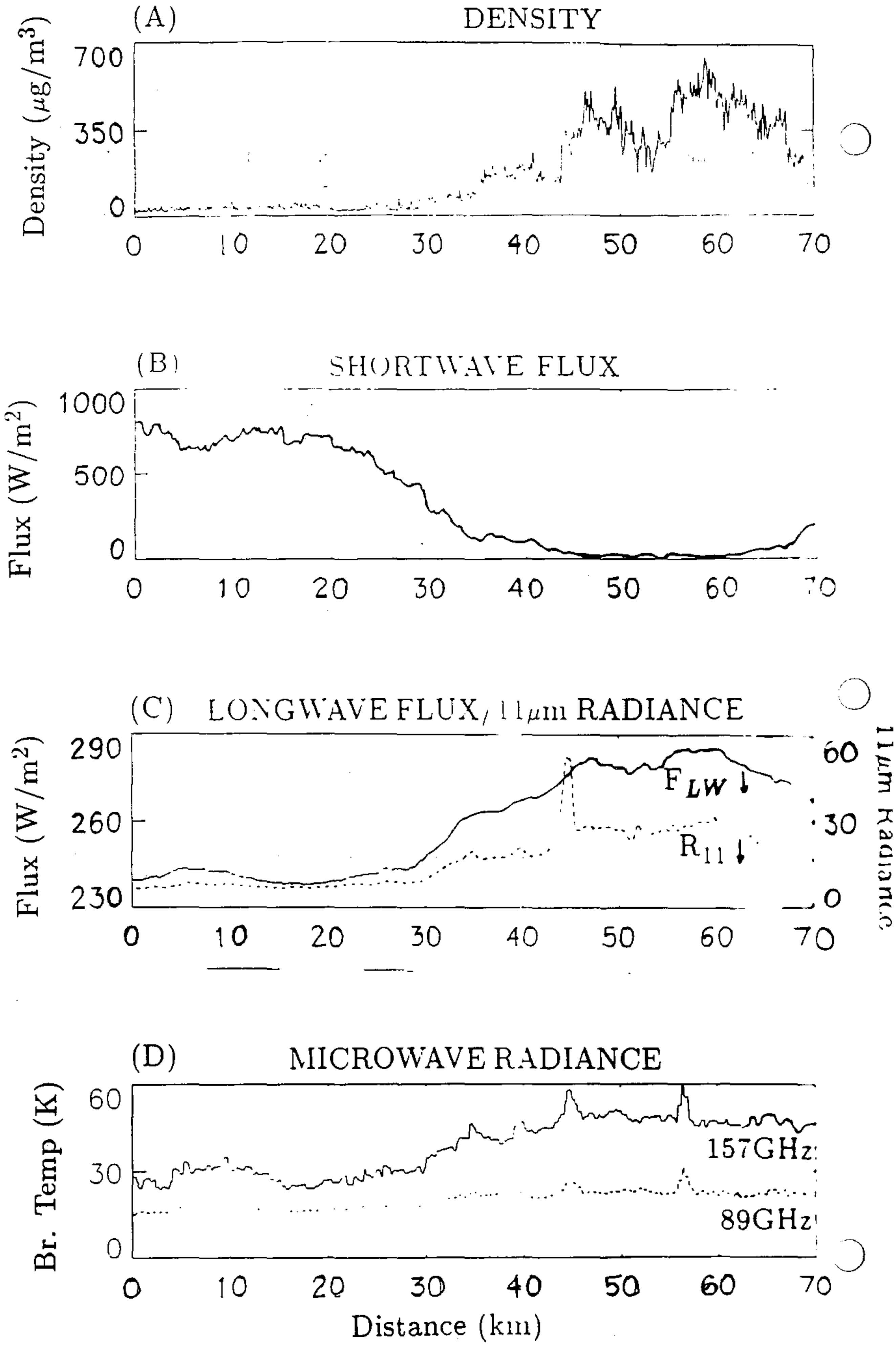

(A) DENSITY
Density (μg/m³)
700
350
0
0 10 20 30 40 50 60 70
(B) SHORTWAVE FLUX
Flux (W/m²)
1000
500
0
0 10 20 30 40 50 60 70
(C) LONGWAVE FLUX/ 11μm RADIANCE
Flux (W/m²)
290
260
230
F LW ↓
R 11 ↓
60
30
0
11μm Radiance
0 10 20 30 40 50 60 70
(D) MICROWAVE RADIANCE
Br. Temp (K)
60
30
0
157GHz
89GHz
0 10 20 30 40 50 60 70
Distance (km)

Figure 7

METEOROLOGICAL OFFICE
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14th & Constitution N.W.
Washington, D.C. 20230
U S A

Our Reference M/MRF/9/5/16

Date 10 October 1991

Dear Dr Hill,

Thank you for your fax of 8 October 91.

I enclose two reports:

(a) Our preliminary report of June 91 (which you already have a fax of)
(b) Our paper submitted to Nature.

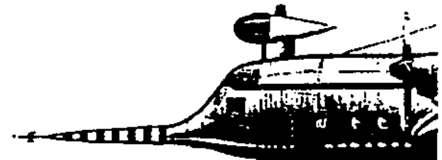
They are essentially the same, although our estimates of emissions have been updated slightly in (b), which is also slightly shorter because of the page limitations in Nature.

I hope these are useful; I look forward to receiving a copy of the completed folder.

Yours sincerely,

Geoff Jenkins

Dr G J Jenkins
Head, Meteorological Research Flight



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# Airborne observations of the physical and chemical characteristics of the Kuwait oil smoke plume

by

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**Abstract**

Airborne measurements in the densest part of the smoke plume at about 120km from the burning wells in Kuwait in late March 1991 showed typical particulate mass densities of 500-1000$\mu gm^{-3}$, mixing ratios of 500-1000ppbv of sulphur dioxide and 30-60ppbv of nitrogen oxides. 1000km from Kuwait, ozone was enhanced by about 50ppbv within the area of smoke. The oil burn rate was estimated from sulphur fluxes to be 3.9±1.6 Mbarrels $d^{-1}$. Significant amounts of smoke were observed only below 5000m and the measured attenuation of solar radiation by the smoke was similar to those assumed in recent assessments.

## Introduction

About 600 naturally pressurised oil wells were set alight in Kuwait in late February 1991, injecting massive quantities of smoke, sulphur dioxide ($SO_2$), unburnt hydrocarbons and nitrogen oxides ($NO_x$=NO+$NO_2$) into the atmosphere. Assessments [1,2,3] of the impact of these pollutants are subject to large uncertainties in the magnitude and the characteristics of the emissions and the resulting plume.

To investigate the chemical and particulate composition of the smoke, and its effect on visible and thermal radiation, the C-130 aircraft of the Meteorological Office Research Flight made 57h of observations in eight flights into and around the plume in March 1991. This paper reports the first airborne measurements of the plume both close to source (up to 200km) and in the far field (1000km from source).

## Meteorology and plume behaviour

Typically the smoke from individual oil well fires combined and rose so that the plume top reached about 4,500m with, on many occasions, shallow convective clouds forming on the windward edge of the plume. There was a marked vertical wind shear leading to differential advection of the plume, e.g. the lower part of the plume being transported southeastwards down the Gulf, with the upper part moving over Iran.

There has been speculation that, due to radiative self heating, aerosol may be lofted [1] into the stratosphere, where its long lifetime would allow transport over considerable distances. Visual observations showed the plume top to be well defined with a maximum height of 5000m. On one or two occasions a detached smoke layer was seen a few tens of metres above the main top. These observations in springtime show that the smoke was confined to the lower half of the troposphere and significant amounts were not being lofted into the stratosphere, in agreement with recent assessments [2,3].

## Near field measurements of particulates and chemistry

Vertical profiles and cross wind horizontal runs through the plume were executed on 28 March 1991, 120km downwind of the source (defined as 29°N, 48°E) south of Kuwait City. This distance was chosen as it was close enough to the source areas that the totality of the emissions could be measured while not so close that the inhomogeneity of the individual sources rendered the measurements unrepresentative.

A Passive Cavity Aerosol Spectrometer Probe (PCASP) was used to measure smoke particle concentrations and deduce the mass of smoke particles per unit volume (smoke density). Continuous measurements were made of $SO_2$, $NO_x$ and ozone ($O_3$) with accuracies[5] of ± 5%, ± 10% and ± 5% respectively. Stainless steel flasks were pressurised with ambient air and subsequently analysed for $C_2$-$C_8$ hydrocarbons.

Figure 1 shows pollutant concentrations, together with the sum of $O_3$ and $NO_x$ mixing ratios, from a descending profile carried out alongwind through the centre of the plume. Also shown is an $O_3$ profile obtained earlier outside the plume. The plume had a complex vertical structure, made up of two main layers; an upper one with a top at 4,600m and base 3,600m and a deeper, denser lower layer with a top at 3,200m and base 1,000m. The lower layer was capped by thin (200m) altocumulus with droplets of high concentration (270 $cm^{-3}$) and small effective radius (2.5$\mu$m). The upper layer was advected eastwards while the lower layer was advected southeastwards down the Gulf, trapped by a weak temperature inversion at the top of the liquid water cloud.

Seven horizontal, cross wind runs over the same ground position were carried out at 1,420m, 1,520m (twice),1980m, 2,440m and 4,420m (twice). Figures 2 a-d show measurements from a run through a 50km wide plume (near the centre of the lower layer at 2,440m) of pollutants, total scattering coefficient and $NO_x$+$O_3$. In both the vertical profiles and horizontal runs all the plume indicators ($SO_2$, $NO_x$, particulates, scattering coefficient) were highly correlated; this correlation was observed over several days of measurements close to the source.

In the lower layer $NO_x$ and $O_3$ mixing ratios were negatively correlated, indicative of the gas phase titration of $O_3$ by NO, while their sum showed little horizontal variation (figure 2d) indicating little loss of $O_3$ either by reactions with smoke particles or in the oxidation of $SO_2$ to sulphate. In the upper layer the observed correlation between $NO_x$ and $O_3$ was zero or positive, indicating that photochemical oxidant production had already been initiated.

Analyses of hydrocarbon samples taken in different parts of the plume are summarised in table 1. The flask which showed the highest mixing ratios of hydrocarbons (sample A) was filled at an altitude of 2600m in the densest part of a smoke plume on 30 March 1991, 120km from source. The aggregate of the carbon contained in all of the non-methane hydrocarbons (NMHC) which can be identified, implies the presence of at least 340 ppbv of carbon as unburnt hydrocarbons.

Assuming unidentified species having a flame ionization response are hydrocarbons implies a carbon content of over 460ppbv. A second flask filled on the same day (sample B) at an altitude of 1500m near the bottom of the plume was a more typical sample; when compared with a UK urban air sample the maximum mixing ratios of benzene and toluene in the plume sample were lower but that of n-hexane was substantially greater.

Two supersaturation cloud condensation nuclei (CCN) spectra taken on 28 March 1991, one just below the top of the upper smoke layer at 4,500m and the other in clear air at 5,200m, indicate the plume contains an order of magnitude more CCN for a given supersaturation. For example at 0.6% supersaturation CCN concentration increased from $140cm^{-3}$ to $2000cm^{-3}$. In the thicker parts of the plume, CCN were so numerous ($>4000cm^{-3}$) that the counter became overloaded.

**Far field measurements**

On 29 March 1991 satellite images showed smoke over central Saudi Arabia some distance from Kuwait oriented southwest-northeast and being advected to the northeast. The $O_3$ mixing ratios and particle concentrations observed in a horizontal run through this area of smoke are shown in figure 3 a and b.

In this more distant plume, it is likely that the ozone, enhanced by 40-60ppbv over the already high values in the adjacent clear air, is formed from ozone precursors ($NO_x$ and NMHC) released from the oil fires. In contrast to the hydrocarbon samples collected near the fires, sample C (table 1), taken in this distant plume, has a different distribution of hydrocarbons. It still has relatively high mixing ratios of the longer lived hydrocarbons, such as ethane and propane. but short lived hydrocarbons such as ethene and propene are substantially reduced. The low mixing ratios of shorter lived species suggest that significant OH degradation has occurred consistent with the enhanced ozone. Although the $NO_x$ mixing ratios in the plume were below the limit of detection (5ppbv), the potential for further ozone production remains because mixing ratios of only several pptv are required to generate ozone [6]. However the absence of many of the more reactive and therefore short lived hydrocarbons means that further ozone production will proceed at a slower rate.

The observations of this mature area of smoke suggests an interpretation of some of the clear air observations in the near field. During many of the vertical profiles made near the source region but outside the visible plume, ozone mixing ratios much greater than the normal free tropospheric background (30-40 ppbv) were encountered (e.g. figure 1d), associated with somewhat increased particle density. The enhanced ozone mixing ratios observed in the clear air were probably formed from $NO_x$ and NMHC in smoke emitted several days earlier which remained near, or returned to, the source area.

## Morphology of smoke particles

During flights in the smoke plume ambient air was drawn through polycarbonate filters which were subsequently studied with a scanning electron microscope (SEM). Figure 4a shows a typical smoke particle from a filter exposed 180km from the source, on 30 March 1991. The smoke particles are composed of spherules of diameter approximately 0.1$\mu$m which form chains of hundreds in number and several microns in length, as observed in other studies [1,7].

Particles on filters exposed over 1000km from Kuwait (figure 4b) have a different appearance to those from the near field; although the spherule size is similar in both cases, the spherules in the far field are more likely to be closely packed into near-spherical clusters. Similar behaviour has been noted [8] in laboratory experiments, in air aged at high humidity.

The PCASP determines the number and size distribution of particles by passing them through a laser beam and measuring the scattered light intensity, using a relationship between intensity and size derived using latex spheres of known radius. The smoke density is calculated by integrating the size distribution assuming (a) 100% collection efficiency, (b) the non-spherical particles in the plume scatter the same amount of light as spheres of the same mass (we conclude from previous laboratory[7] and theoretical[9] work that, for the shape of the particle encountered, this assumption is reasonable) and (c) the density of the smoke particles is $1 gcm^{-3}$, in line with Sokolik[10]. Support for this approach comes from the mass loading of the filter samples, which suggest that the absolute determination of smoke density from the PCASP is not grossly in error, and the linear relationship between $SO_2$ concentrations and smoke density (see below) which confirms the instrumental response to smoke density is linear. Nevertheless, the uncertainties in these assumptions lead us to believe that the absolute values of smoke density could be up to 2-3 times higher than those shown. The relative variations in the plots are still valid.

**Emission estimates**

The magnitude of sulphur emissions was estimated from the flux of sulphur through a crosswind plane determined from the product of sulphur concentration and the wind component perpendicular to the plane. $SO_2$ measurements from the horizontal runs and vertical profiles through the plume were used, together with the winds measured by the aircraft. Above 3000m where the $SO_2$ monitor will not operate, PCASP measurements were used to derive proxy $SO_2$ values through the linear relationship evident in figures 1 and 2.

On 28 March 1991, when virtually all of the plume about 120km from the southern oilfields was sampled, the estimated sulphur emissions were 5.7Mt $yr^{-1}$. Assuming a value of 3.3% for the sulphur content of the southern oilfields [11], this source strength corresponds to an oil burning rate of 172.1Mt $yr^{-1}$. We assume, based on previous estimates [12,13] that the southern oilfields account for 85% of the total burning rate; implying a total rate of 202.5Mt $yr^{-1}$ or 3.9MB$d^{-1}$. An estimate for 30 March 1991 gives a similar burning rate. A subjective estimate of the error in this source strength is ±40% based on the temporal evolution and spatial variability over the 3h measurement period.

Using the relationships between concentrations of $SO_2$, $NO_x$ and particulates, we estimate the source strength of $NO_x$ and particulates from the sulphur source strength (table 2). Carbon as gas (ie the mass of carbon contained in CO, $CO_2$, $CH_4$ and NMHC) is estimated from the residual mass after the mass emissions of sulphur, nitrogen and particulate carbon are subtracted from the total mass emitted and an allowance is made for the hydrogen content.

**Effect of the smoke on radiation.**

Figure 5 shows the effect of the smoke on the radiation during a horizontal run on 31 March 1991 through the centre of the plume 700m below its top about 65km from source. The total shortwave (0.3–3$\mu$m) downwelling flux was reduced from its clear sky value of 800 W $m^{-2}$ outside the plume to zero in the centre, and corresponding changes were seen in the infrared and microwave regions.

The single scattering albedo, $\omega_0$, of the smoke was estimated in two independent ways. Firstly, hemispheric reflectances of the plume top were measured, using upward and downward looking pyranometers, to be between 5–8% over a range of solar zenith angles (25°–48°). The Ginzburg and Sokolik [14] method shows that these reflectances correspond to a value of $\omega_0$ in the range 0.5 to 0.55, but with an uncertainty of $\pm$0.1 due to assumptions made about the scattering properties of oil smoke. Secondly, volume absorption coefficients were measured from filters exposed in the plume using the integrating sandwich technique [15] and these, when combined with the nephelometer scattering coefficients give values for $\omega_0$ in the range 0.55–0.70($\pm$0.1). Thus the likely range of $\omega_0$ is 0.50–0.65 which is higher than previously published values for oil smoke[4,7,10] but lower than that of 0.8–1.0 measured in non-carbonaceous aerosols [14].

The broadband optical depth of the smoke was estimated from the change in downwelling shortwave flux as the aircraft ascended or descended through the plume. Figure 6 shows the derived optical depth as a function of smoke column density for three profiles through the plume top. Solar heating rates in the plume were calculated from shortwave flux divergences in a profile at local noon on 30 March 1991, 140 km from the source. The heating rate was typically of the order 50 K $d^{-1}$ throughout the depth (2300m) of the smoke. It was nearly constant in the plume because the smoke density increased from the top to the base. At a distance of 250km from the source the smoke density was a factor of four lower and the heating rates were 20 K $d^{-1}$. This compares with typical clear sky values of 1 K $d^{-1}$.

Figure 5c shows the downward hemispheric infrared (4–50$\mu$m) fluxes to be greater in the centre of the plume relative to clear air by 45 W $m^{-2}$ and the vertical downward radiance at 11.1$\mu$m to be increased by 20 mW $m^{-2}$ $ster^{-1}$ $(cm^{-1})^{-1}$. These were measured by a pyrgeometer[16] and a narrow field of view (1.5°) radiometer[17] respectively. The peak in radiance at 45 km along the run is probably due to cloud above and is also seen in the microwave measurements (figure 5d). The broadband infrared optical depth for a vertical path through the smoke was calculated in a similar manner to the visible optical depth. It was estimated to be 0.34 ± 0.05 for the profile on 30 March 1991. The 11.1$\mu$m radiometer was not operated in this profile but the maximum vertical optical depth calculated from the horizontal run in figure 5c was 0.30 ± 0.02 which was 75% of the corresponding broadband optical depth. Infrared cooling rates in the plume were calculated from the flux divergences to be 2.1 K $d^{-1}$ which is 1.0 K $d^{-1}$ greater than that in adjacent clear air. Assuming smoke densities based on the PCASP measurements, the visible extinction coefficient was deduced from the optical depth to be 7–13$m^2g^{-1}$ which is in broad agreement with other measurements of oil smoke[7,18] The 11.1$\mu$m infrared absorption coefficient was deduced to be 0.7–1.3$m^2g^{-1}$ in agreement with laboratory measurements[19].

Figure 5d shows the effect the plume had on downward radiances (or brightness temperatures) at 89 and 157GHz measured by a microwave radiometer. Atmospheric emission at these frequencies is principally controlled by water vapour and liquid water. The increase in brightness temperature in the plume at 157 GHz (22K) is three times the increase at 89 GHz (8K) but both are well correlated with the infrared radiance. This correlation was seen on several occasions when there was no trace of liquid water in the plume. The microwave radiance increase is surprisingly high and cannot be explained by variation in water vapour within the plume nor by the observed levels of $SO_2$. Bruce et al [20] present measurements of the absorption coefficient of diesel soot at 94GHz which are over an order of magnitude too small to account for our results.

## Discussion

Our best estimate of oil burning rate is greater than those previously assumed [1,2,3]. However the greater $CO_2$ emissions that this implies represents only 3% of total annual fossil fuel emissions and would still have a negligible effect on global climate through the greenhouse effect. The sulphur emissions calculated are considerably higher than those taken by Browning et al.[2], and although we would expect the acidity of rainfall episodes to be no higher than previously predicted because this is limited by droplet saturation, these episodes will extend further downwind across Southern Asia. As predicted[2], increased photochemical oxidant concentrations were observed both close to the source and further afield. However the emissions of $NO_x$ are smaller than those previously assumed[2]; for this reason and because they are rapidly removed, they are unlikely to influence the global $NO_x$ background or global tropospheric ozone.

The estimated smoke emission rate, even with our large uncertainties, is similar to the range used in previous assessments[1,2,3]. Furthermore, the product of our derived visible extinction coefficient and smoke emission rate (the factor which determines the radiative impact of the plume for a given meteorological situation) is independent of the uncertainties in our estimate of smoke density and is similar to that inferred from Browning et al[2]. Previous assessments[2,3] assume that the smoke did not scatter radiation; the scattering which we observed would be insufficient to significantly alter their conclusions. The observed infrared effects, though previously ignored, will only very slightly ameliorate the predicted daytime surface cooling. Our measurements thus confirm the assumptions used in recent assessments[1,2,3] and the observations that significant amounts of smoke were not present above 5000m bears out their predictions. This study provides strong support for their conclusions that, whilst there may be significant effects on a regional scale, those on a global scale, including the Asian summer monsoon, are likely to be insignificant.

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**Figures**

1. A vertical cross section of the plume made in a descending profile on 28 March 1991, 120km from the source, (a)smoke density($\mu g/m^3$), (b) $SO_2$(ppbv), (c) $O_3$ (solid line) and $NO_x$ (dotted line), (d) $O_3$ outside the plume (solid line) and $O_3+NO_x$ in the plume. (dotted line).

2. A horizontal cross section through the plume at 2,440m on 28 March 1991 of (a) smoke density, (b) total scattering coefficient at 0.48$\mu$m as measured by an integrating nephelometer, (c) $SO_2$, (d) $O_3$ (solid line), $NO_x$ (dashed line) and $O_3+NO_x$ (dotted line).

3. Horizontal run at an altitude of 4400m through the area of smoke (about 1000km from Kuwait) on 29 March 1991 showing (a) $O_3$ (b) smoke concentrations.

4. Scanning electron micrographs of smoke particles collected on filters exposed in the plume on (a) 30 March 1991, 180km from the source and (b) 29 March 1991, about 1000km from the source. The filters were mounted on an extendable boom 0.4m from the aircraft skin

and the air drawn over the filters isokinetically[15]. The dark holes in the photograph are the pores in the filter.

5. An illustration of the effect of the smoke on downwelling radiation during a crosswind run through the centre of the plume. (a) smoke density, (b) shortwave flux, (c) infrared flux, $F_{LW}$, and 11 $\mu$m, $R_{11}$, radiance (in units of mW $m^{-2}$ $ster^{-1}$ $(cm^{-1})^{-1}$) and (d) the zenith microwave brightness temperatures at 89 and 157 GHz.

6. Broad-band shortwave optical depths of the plume from three different ascending or descending profiles flown through the plume as a function of the total column density of smoke in the path. The profile on 29 March 1991 was further away from the source and lower smoke densities were encountered.

## Tables

Table 1. Hydrocarbon analyses of 1.6 litre stainless steel flasks, by Gas Chromatography-Flame Ionisation Detection. Sample A: most polluted sample 120km from source, Sample B: typical polluted sample at a similar distance, Sample C: typical far field sample (1000km from source).

Table 2. Estimates of oil well source strengths derived from observations and for comparison those assumed by recent assessments[1,2,3]. The mass of hydrogen contained in $H_2S$ and hydrocarbons in the fuel has been taken into account when determining the different components of the emissions.

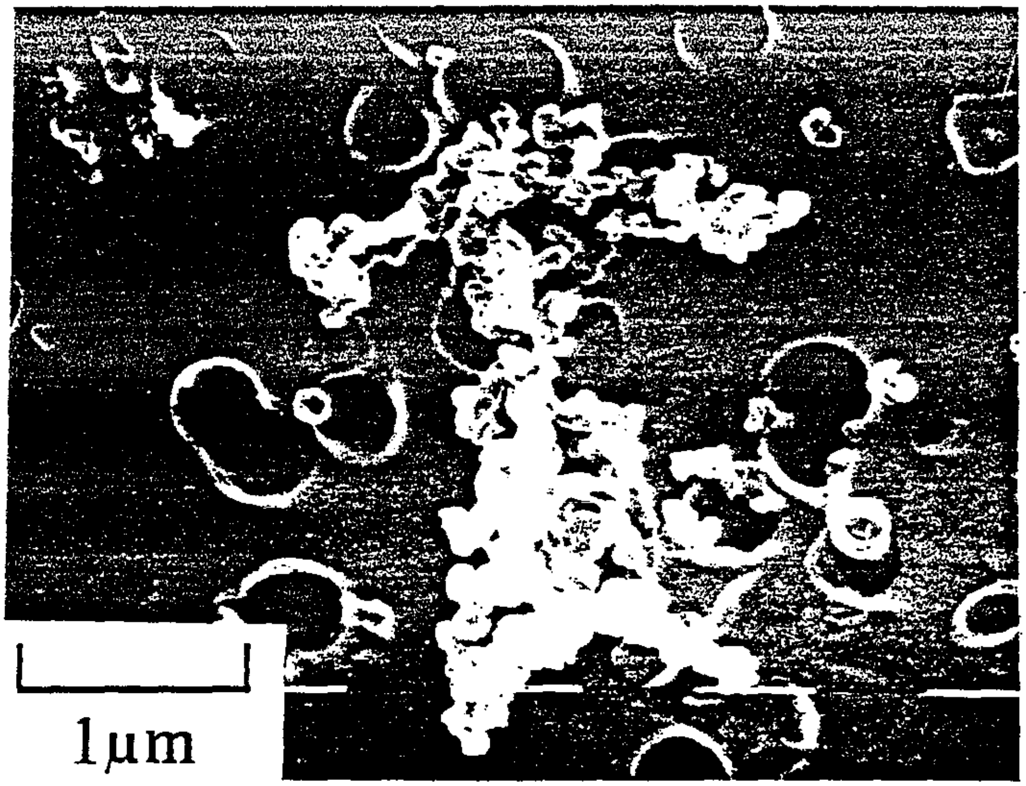
Table 1:

| Species | Sample A 30 March 91 Mixing Ratio (ppbv) | Sample A ethane Ratio | Sample B 30 March 91 Mixing Ratio (ppbv) | Sample B ethane Ratio | Sample C 29 March 91 Mixing Ratio (ppbv) | Sample C ethane Ratio |
|---|---|---|---|---|---|---|
| ethane | 25.111 | 1.000 | 5.440 | 1.000 | 1.330 | 1.000 |
| ethene | 13.030 | 0.519 | 1.851 | 0.340 | 0.034 | 0.026 |
| propane | 19.952 | 0.794 | 2.345 | 0.431 | 0.453 | 0.340 |
| propene | 1.637 | 0.065 | 0.220 | 0.040 | 0.026 | 0.020 |
| benzene | 1.057 | 0.042 | 0.215 | 0.040 | 0.044 | 0.033 |
| toluene | 1.309 | 0.052 | 0.203 | 0.037 | 0.025 | 0.019 |
| n-hexane | 5.052 | 0.201 | 0.409 | 0.075 | 0.013 | 0.010 |
| NMHC | 339.6 | 13.53 | 45.92 | 8.44 | 6.266 | 4.71 |

Table 2:

| Component | This Study Mt $yr^{-1}$ | Browning et al.[2] Mt $yr^{-1}$ | Small[1] Mt $yr^{-1}$ | Bakan et al.[3] Mt $yr^{-1}$ |
|---|---|---|---|---|
| Total Burn Rate | 202.5 | 80 | 63 | 161 |
| Carbon as gas | 161.2§ | 60 | 63 | - |
| Fine Particulate Carbon | 6.4†‡ | 5 | 5.8 | 16.1 |
| Sulphur | 6.1* | 2 | - | - |
| Nitrogen in Oxides | 0.42† | 0.5 | - | - |

**† Assuming the same emission factors for the southern and northern fires.**
*** Assuming a 1.5% sulphur content for the northern fields which contribute 15% overall to the emissions.**
**§ Deposits from large partially burned oil droplets near the well heads may reduce this total.**
**‡ This quantity could be up to 2–3 times higher with a commensurate reduction in carbon as gas.**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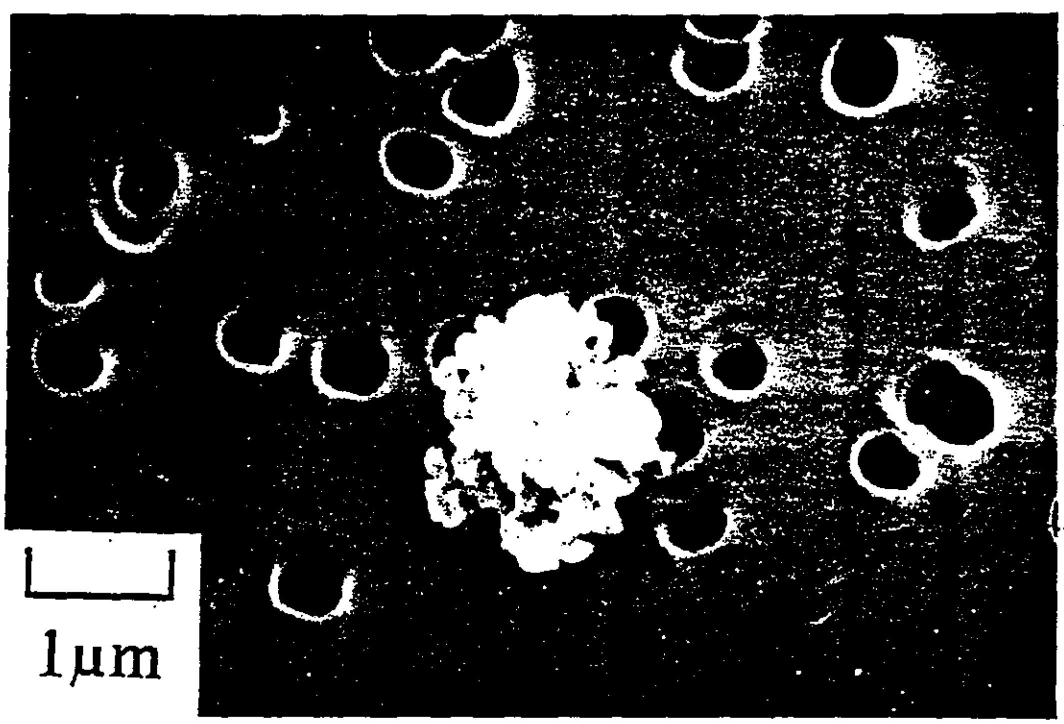
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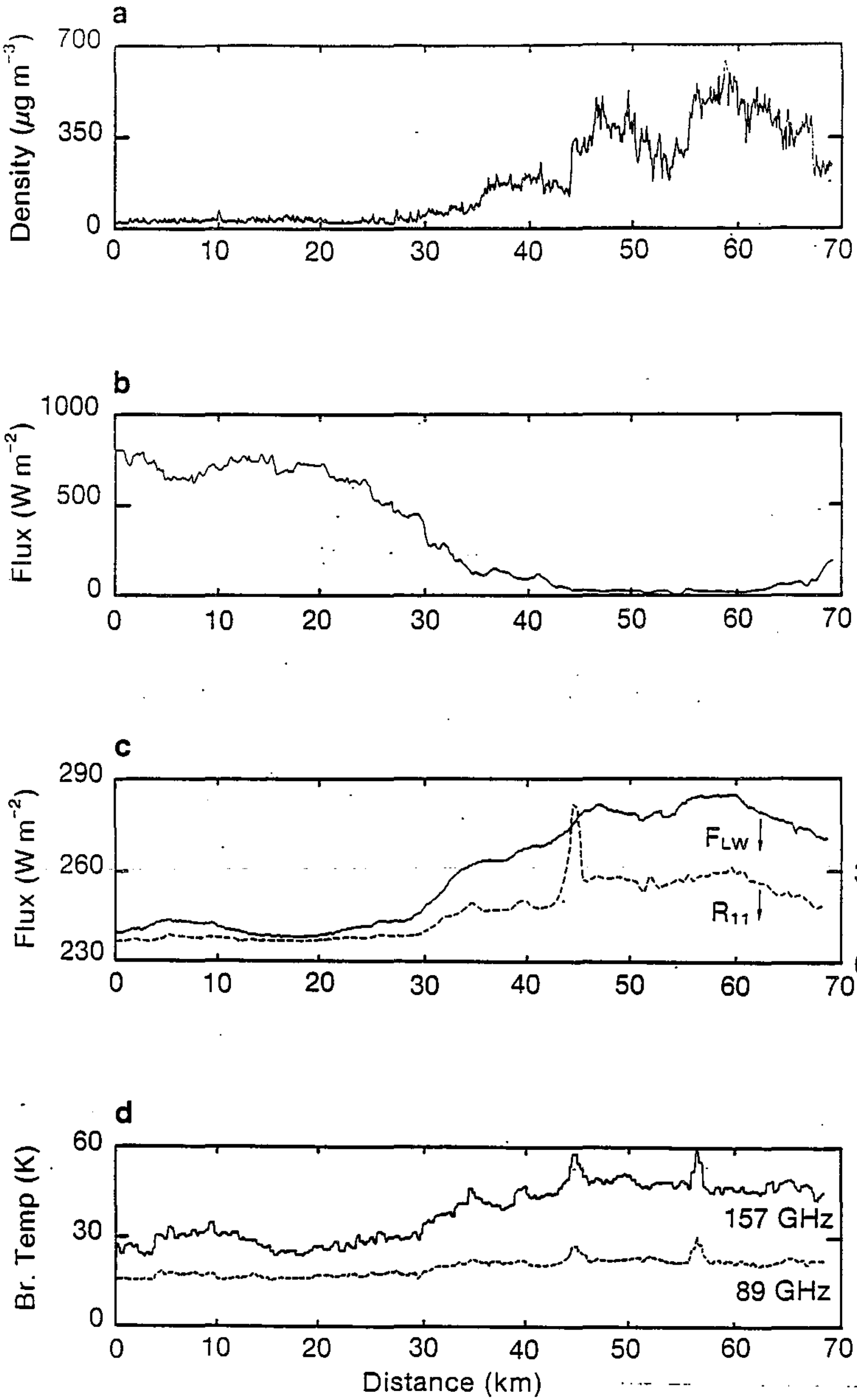
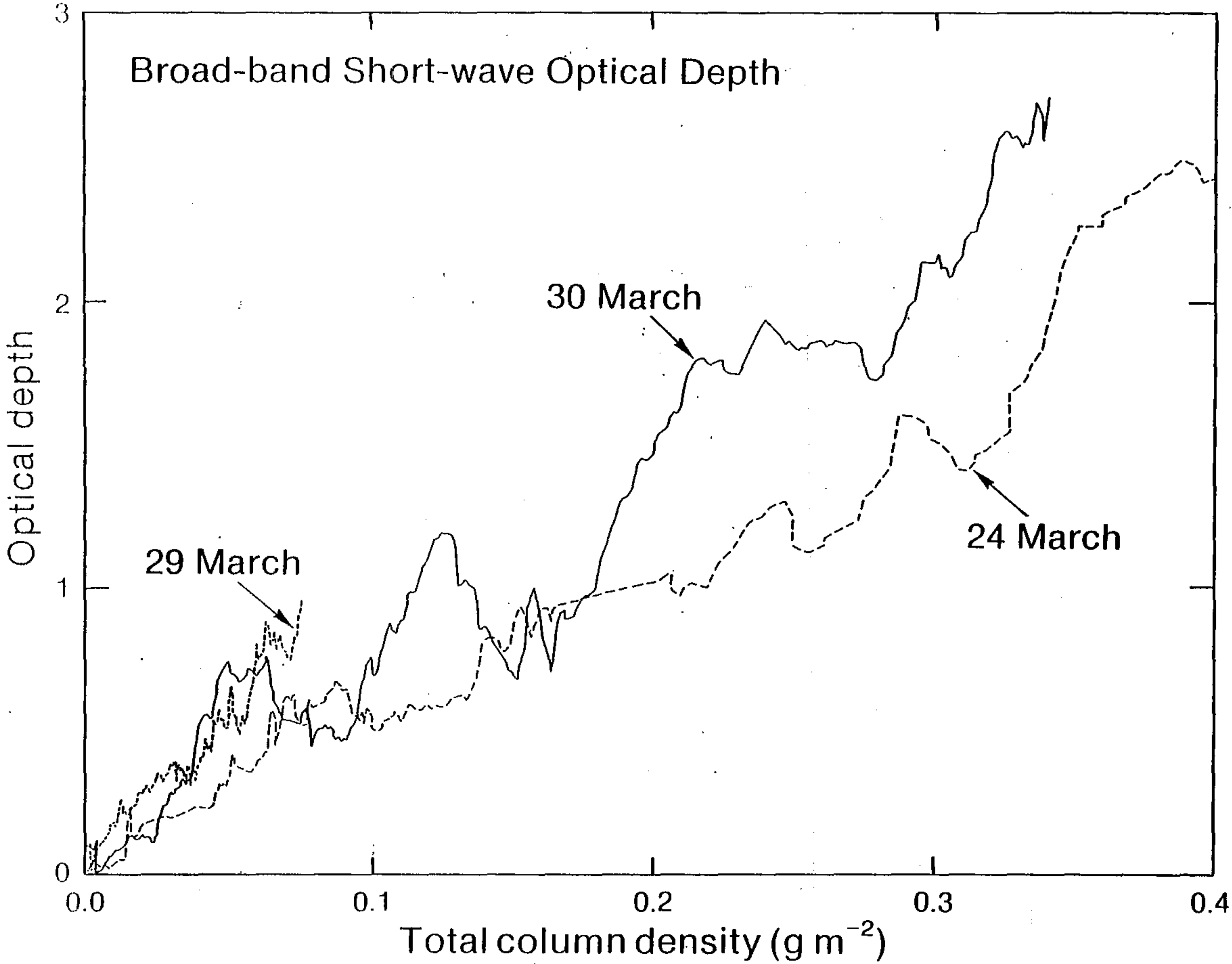
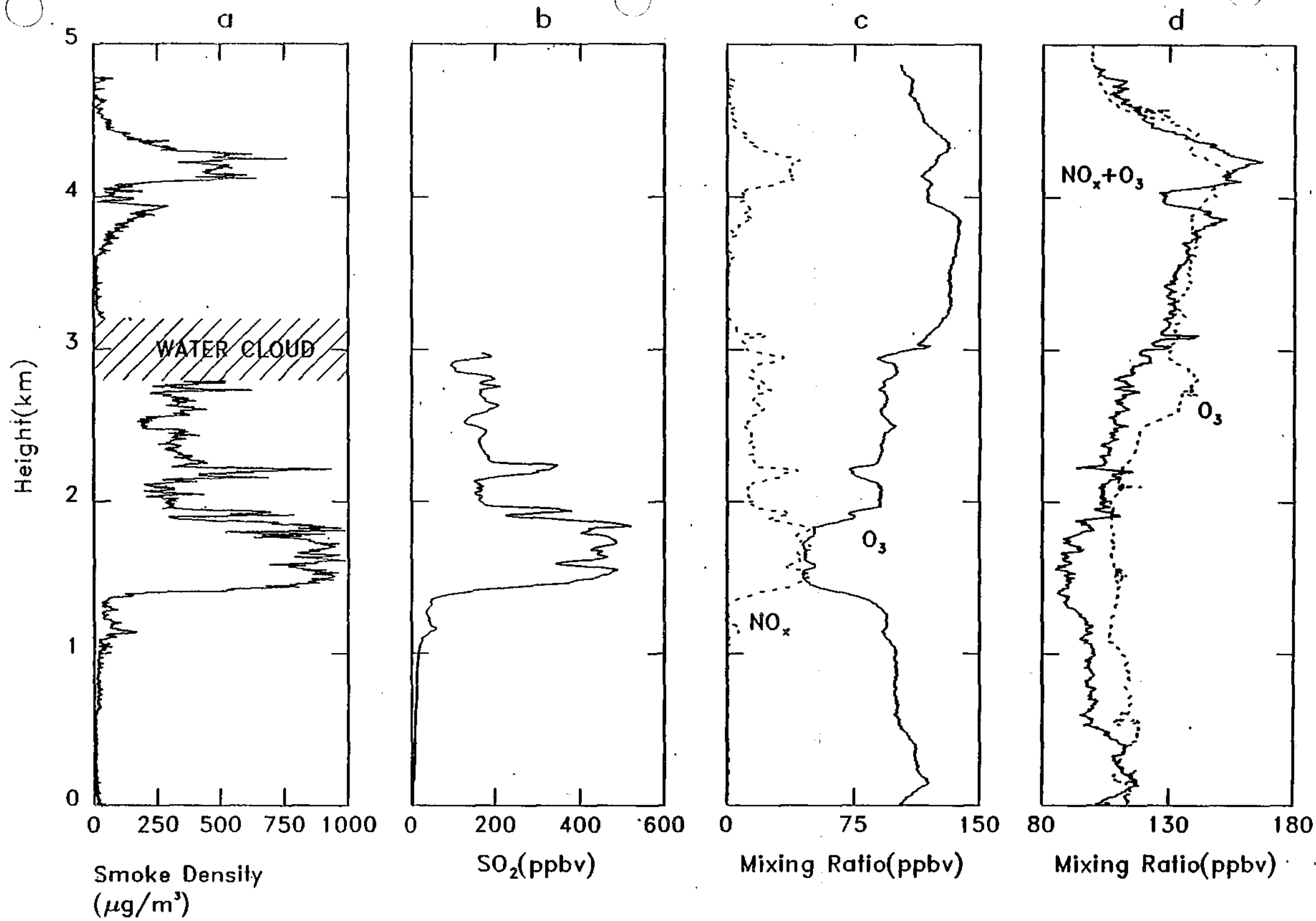


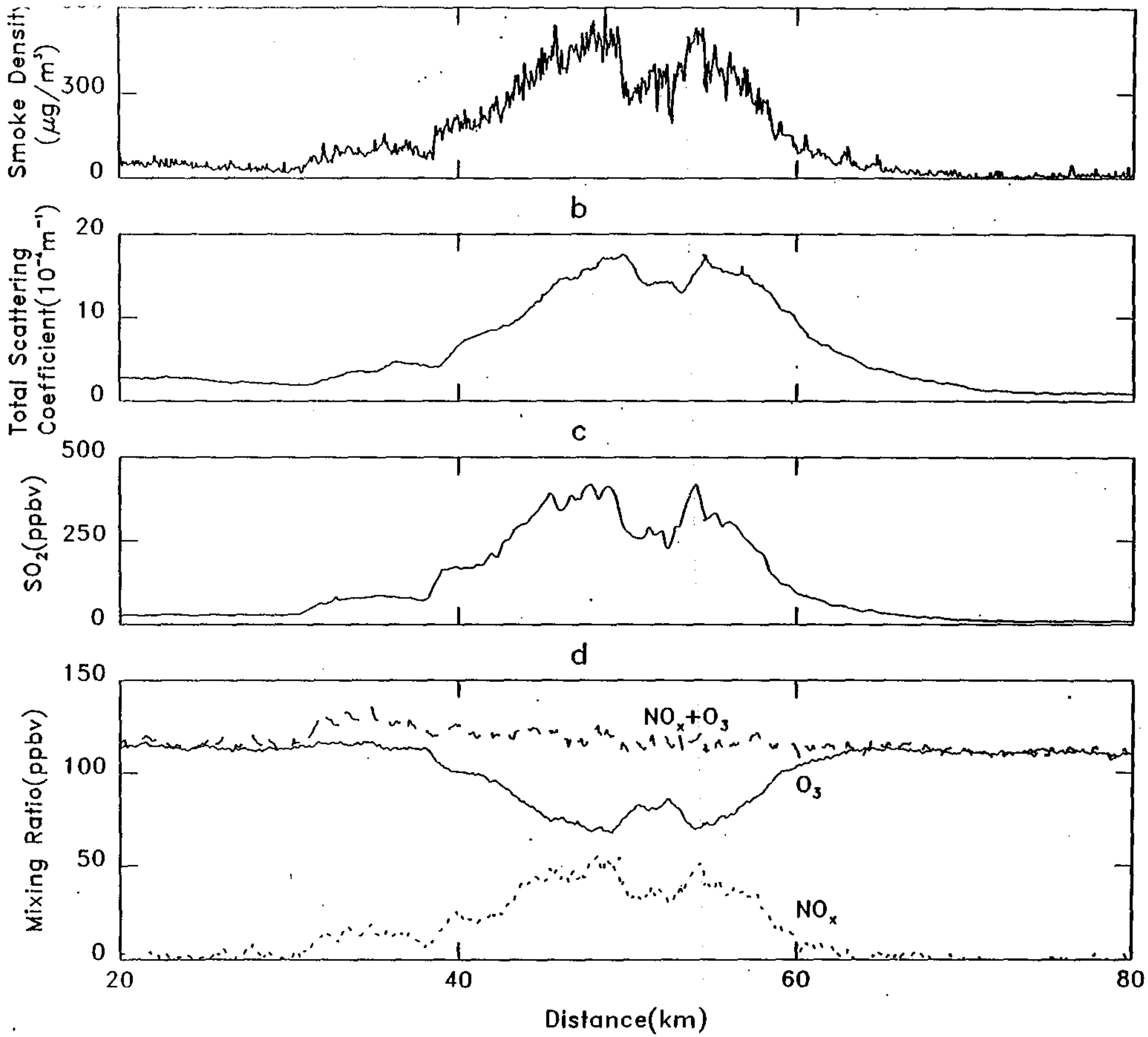
a
Density (μg m⁻³)
700
350
0
b
Flux (W m⁻²)
1000
500
0
c
Flux (W m⁻²)
290
260
230
11 μm Radiance
60
30
0
F_LW
R_11
d
Br. Temp (K)
60
30
0
157 GHz
89 GHz
0 10 20 30 40 50 60 70
Distance (km)

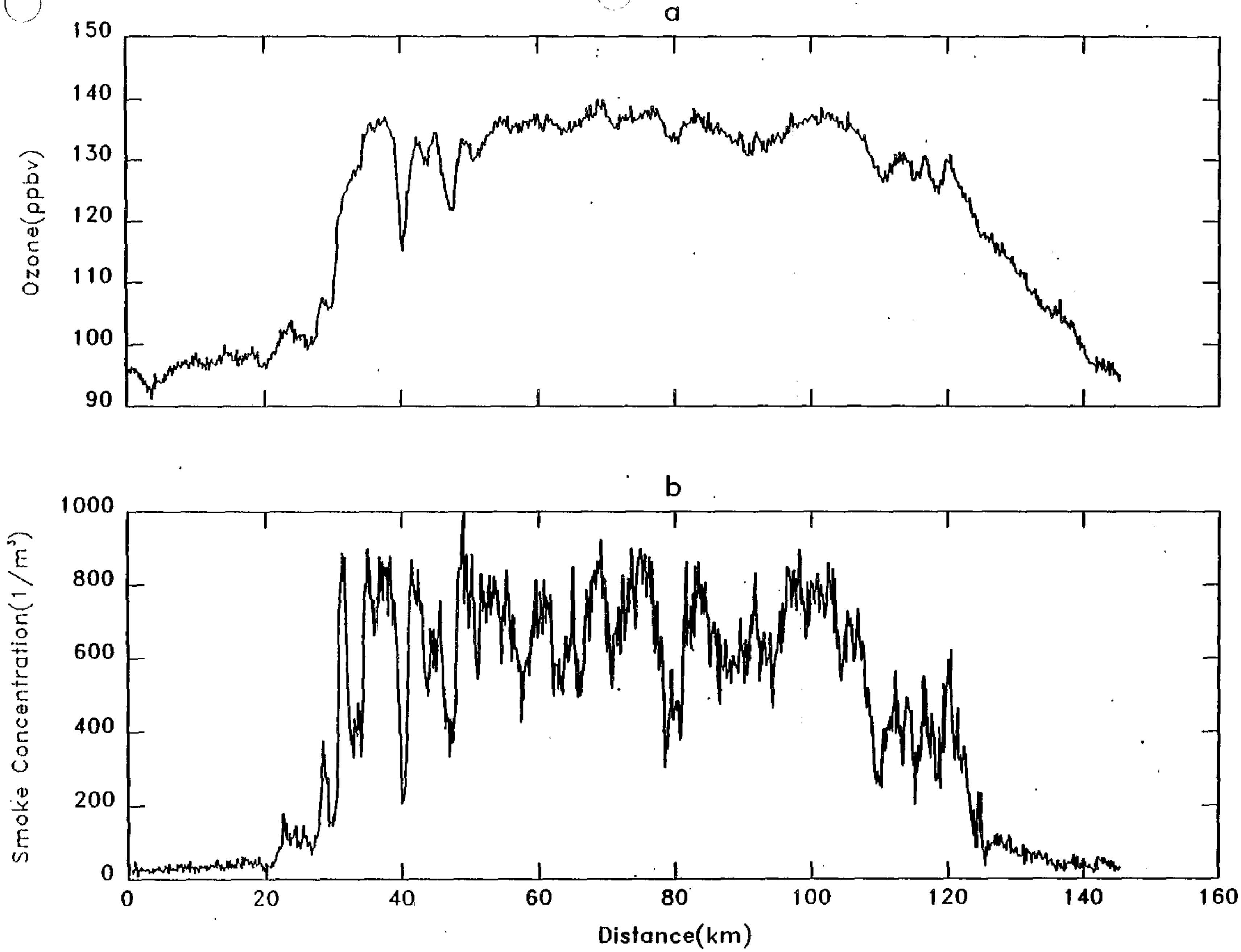


Broad-band Short-wave Optical Depth
30 March
29 March
24 March
Optical depth
Total column density (g m$^{-2}$)
0
1
2
3
0.0
0.1
0.2
0.3
0.4



a
b
c
d
Height(km)
WATER CLOUD
Smoke Density
($\mu$g/m$^3$)
$SO_2$(ppbv)
$NO_x$
$O_3$
Mixing Ratio(ppbv)
$NO_x+O_3$
$O_3$
Mixing Ratio(ppbv)


Smoke Density (μg/m³)
0
300
b
Total Scattering Coefficient(10⁻⁴m⁻¹)
0
10
20
c
SO₂(ppbv)
0
250
500
d
Mixing Ratio(ppbv)
0
50
100
150
NOₓ+O₃
O₃
NOₓ
20
40
60
80
Distance(km)


a
b
Ozone(ppbv)
Smoke Concentration(1/m³)
Distance(km)
150
140
130
120
110
100
90
1000
800
600
400
200
0
20
40
60
80
100
120
140
160

Aircraft Research Instrumentation
Electra N308D
Kuwait Oil Fire Project
May 6, 1991

File NCAR

RAF-Supplied Instrumentation:

I. Airborne Data System
  A. Acquisition: ADS
  B. Display: New Sparc-based System

II. Aircraft Position, Velocity and Attitude
  A. Honeywell Inertial Navigation System
  B. Litton INS, LTN-51
  C. Loran C, Advanced Navigation Inc., ANI-7000
  D. GPS

III. Static Pressures

IV. Dynamic Pressures

V. Temperatures

VI. Dew Point and Humidity

VII. Flow Angle Sensors, Radome
  A. Attack - Rosemount Model 1221F1VL Differential Pressure Transducer (ADIFR)
  B. Sideslip - Rosemount Model 1221F1VL Differential Pressure Transducer (BDIFR)

VIII. Cloud/Aerosol Physics
  A. Particle Measuring Systems Model PCASP - Window Mount
  Aerosol Size Distribution, 0.12 to 3.12 µm

  B. Particle Measuring Systems Model FSSP-300 - Window Mount
  Aerosol Size Distribution, 0.30 to 20.0 µm

  C. Particle Measuring Systems Model FSSP-100 - Right Pylon
  Droplet Size Distribution, 2 to 47 µm

  D. Particle Measuring Systems Model 260X - Left Pylon
  Droplet Size Distribution, 40 to 600 µm

  E. Particle Measuring Systems Model KLWC-1 - Left Pylon
  Liquid Water Content 0 - 3 g $m^{-3}$

  F. Counter Flow Virtual Impactor (CVI) - Top Front Right Mounting Plate. Droplet Composition (XCVF1, XCVF2, XCVTT, XCVST, XCVFH)

G. TSI Model 3760 CN Counter - Forward Cabin Mount plumbed with CVI - (XCNTS,XPCN,XFCN,FCBADS,TCBADS)

IX. Radiation Fluxes

A. Visible Radiation - RAF Modified Eppley Model PSP Pyranometers - 2 units: Upward looking (SWT), Downward looking (SWB)

B. Infrared Radiation - RAF Modified Eppley Model PIR Pyrageometers - 2 units: Upward looking (IRT), Downward looking (IRB)

C. Ultraviolet Radiation - RAF Modified Eppley Model TUV Pyranometers - 2 units: Upward looking (UVT), Downward looking (UVB)

D. Remote Surface Temperature - Barnes PRT-5, 2 units, Upward looking (RSTT), Downward looking (RSTB)

X. Geometric Altitude

XI. Air Chemistry

A. NCAR Modified TECO Model 49 Ozone Analyzer - (TEO3,TET,TEP)

B. U. of Maryland Modified TECO Model 48 Carbon Monoxide Analyzer - (CMODE, XCO)

C. NCAR modified TECO Model 42 Nitrogen Oxides Analyzer - (XNO,XNOX,XSTAT,XO2F,XNOF)

D. TECO Model 43A Sulfur Dioxide Analyzer - (XSO2)

E. NCAR Fast Ozone (NO) - (O3FS,O3FF,O3FT,O3FP,O3FN)

F. RAF Chemical Ozone (dye) - (O3CS,O3CP,O3CT,O3CF)

G. Continuous Peroxides - (PERSA,PERSB,PERFA,PERFB,PERST)

H. Speciated Peroxides - (PEROF)

I. Formaldehyde (XFORS,XFORF)

XII. NAILS (Back-scatter mode only)

XIII. Photography

Forward, Left, and Down-looking Video

<u>User-Supplied Instrumentation</u>

I. SRI Nd:YAG Lidar (1 µm)

II. U. of Hawaii Aerosol Ensemble (Tony Clarke)

A. TSI Model 3760 CN Counter - Forward Cabin Mount plumbed into separate inlet - (CNTS2)

B. Aethelometer - Aerosol Elemental Carbon - Forward Cabin Closet - (XTH01, XTH02)

III. Drexel University (Alan Bandy)

Gas Chromatograph with flame photometric detection - Measurements of $H_2S$, $SO_2$, OCS, and $CS_2$ - (XDET,XDET5,XDETT,XDT10)

IV. NOAA/ERL/CIRES (Barry Bodhaine, Russ Schnell)

Aerosol Nephelometer - Aerosol Scattering Coefficient - (X449, X536, X690, XNPBG, XNPMF, XNPT, XNPP)

Aethelometer - Aerosol Elemental Carbon (XATH1,XATH2,XATH3,XFILF)

V. Desert Research Institute (Jim Hudson)

CCN Counter (XCNEX, XCNCF)

VI. NIST (George Mulholland)

Transmission Cell Reciprocal Nephelometer (TCRN) - Aerosol optical scattering, extinction and absorption at 0.5 µm - (XRAT, XPMTB, XI0)

VII. NCAR/SSSF

L2D2 Drop Sondes

VIII. University of North Dakota

SF-6 Analyzer (XSF6)

| | | |
|---|---|---|
| lat0, lon0 | = | Latitude, Longitude of starting point |
| lat1, lon1 | = | Latitude, Longitude of ending point |
| Palt | = | Altitude in meters |
| Hdg | = | Aircraft heading |
| Dist | = | Distance of mid-point of flight leg from Kuwait |
| Width | = | Length of flight leg |
| Temp | = | Temperature |
| TDP | = | Dew Point temperature |
| WS,WD | = | Wind velocity and direction |
| WI | = | Not presently used |
| TEO3C | = | Maximum Ozone concentration during pass |
| SO2 | = | Maxmum $SO_2$ concentration during pass |
| CN | = | Maximum counts measured by fine CN counter during pass (not a concentration) |
| CNC.3 | = | maximum concentration of particles > 0.3 μm diameter |

Flt 1 May 19, 1991

Flight Leg Statistics

| Start | Stop | lat0<br>Temp | lon0<br>TDP | lat1<br>WS | lon1<br>WD | <br>WI | Palt(m)<br>TEO3C | Hdg<br>SO2 | Dist<br>CN | Width<br>CNC.3 |
|---|---|---|---|---|---|---|---|---|---|---|
| 063500 | 070900 | 27.690 | 49.606 | 29.160 | 48.013 | | 5490.4 | 312.3 | 4.2 | 122.8 |
| | | -5.6 | -27.8 | 32.7 | 286.1 | 0.0 | 66.3 | 9.2 | 1. | 1.45 |
| 071830 | 072200 | 29.529 | 47.988 | 29.325 | 48.214 | | 3676.7 | 143.7 | 15.1 | 17.2 |
| | | 5.9 | -26.5 | 22.8 | 289.6 | 0.0 | 83.8 | 7.2 | 0. | 0.00 |
| 073100 | 075050 | 29.097 | 48.400 | 27.929 | 49.500 | | 3991.3 | 140.1 | 114.5 | 90.5 |
| | | 6.5 | -14.3 | 27.5 | 280.0 | 0.0 | 85.1 | 7.5 | 0. | 0.00 |
| 075730 | 080810 | 28.066 | 49.900 | 27.699 | 49.318 | | 2471.7 | 240.9 | 114.3 | 40.0 |
| | | 15.7 | -18.6 | 19.6 | 288.3 | 0.0 | 97.9 | 39.3 | 0. | 0.00 |
| 081200 | 082200 | 27.709 | 49.423 | 27.323 | 48.906 | | 2773.4 | 237.0 | 115.9 | 37.3 |
| | | 14.5 | -13.6 | 22.4 | 280.9 | 0.0 | 89.5 | 6.3 | 0. | 0.00 |
| 082500 | 083000 | 27.330 | 48.983 | 27.161 | 48.722 | | 2778.1 | 241.2 | 119.1 | 18.1 |
| | | 14.3 | -13.9 | 21.0 | 289.3 | 0.0 | 77.1 | 6.4 | 0. | 0.00 |
| 083110 | 085020 | 27.116 | 48.745 | 27.708 | 50.173 | | 2765.7 | 52.3 | 154.6 | 91.3 |
| | | 14.3 | -19.3 | 25.2 | 293.7 | 0.0 | 104.6 | 97.6 | 1. | 0.00 |
| 085110 | 091510 | 27.740 | 50.186 | 27.219 | 48.775 | | 2329.2 | 253.2 | 117.5 | 89.1 |
| | | 15.4 | -11.8 | 22.7 | 295.9 | 0.0 | 101.2 | 76.2 | 0. | 0.00 |
| 091700 | 093700 | 27.261 | 48.766 | 27.909 | 50.080 | | 1976.9 | 52.2 | 144.3 | 86.0 |
| | | 20.6 | -15.5 | 23.5 | 292.0 | 0.0 | 101.6 | 127.2 | 0. | 0.00 |
| 093800 | 095800 | 27.944 | 50.077 | 27.359 | 48.978 | | 1515.1 | 245.5 | 116.4 | 72.9 |
| | | 19.7 | -4.5 | 24.6 | 306.2 | 0.0 | 93.6 | 110.1 | 0. | 0.00 |
| 105100 | 105340 | 25.365 | 49.346 | 25.258 | 49.500 | | 1950.4 | 127.6 | 234.1 | 10.9 |
| | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 105700 | 110220 | 25.208 | 49.650 | 25.303 | 49.333 | | 2278.4 | 284.8 | 228.0 | 19.7 |
| | | 21.6 | -1.9 | 11.8 | 242.9 | 0.0 | 49.2 | 7.7 | 3. | 0.93 |
| 110400 | 111750 | 25.266 | 49.330 | 25.788 | 50.164 | | 2340.2 | 38.4 | 227.5 | 57.4 |
| | | 19.3 | -1.7 | 15.6 | 269.1 | 0.0 | 51.1 | 8.8 | 8. | 0.00 |
| 111900 | 112310 | 25.855 | 50.197 | 26.117 | 50.176 | | 2735.0 | 339.5 | 213.3 | 14.2 |
| | | 17.5 | -1.8 | 25.4 | 262.3 | 0.0 | 38.5 | 6.3 | 3. | 0.00 |
| 112800 | 113240 | 26.231 | 50.444 | 26.252 | 50.736 | | 1117.4 | 72.4 | 230.4 | 17.6 |
| | | 25.6 | -9.4 | 23.1 | 320.6 | 0.0 | 85.4 | 38.5 | 14. | 0.60 |

Flt 3 May 21,1991

Flight Leg Statistics

| Start | Stop | lat0 | lon0 | lat1 | lon1 | | Palt(m) | Hdg | Dist | Width |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Temp | TDP | WS | WD | WI | TEO3C | SO2 | CN | CNC.3 |
| 085200 | 085630 | 27.639 | 49.070 | 27.484 | 48.810 | | 3640.6 | 242.1 | 105.5 | 17.7 |
| | | 7.3 | -6.8 | 17.2 | 286.9 | 0.0 | 46.1 | 25.9 | 1400. | 7.42 |
| 094000 | 095600 | 27.493 | 48.837 | 28.111 | 49.890 | | 2735.7 | 54.5 | 129.2 | 71.2 |
| | | 13.9 | -4.3 | 14.1 | 276.1 | 0.0 | 63.4 | 35.1 | 13200. | 26.53 |
| 095850 | 101800 | 28.157 | 49.960 | 27.532 | 48.907 | | 2429.4 | 240.8 | 106.1 | 71.4 |
| | | 17.8 | -3.0 | 15.2 | 283.8 | 0.0 | 1709.3 | 143.5 | 16400. | 28.20 |
| 102050 | 103700 | 27.513 | 48.862 | 28.096 | 49.899 | | 2130.2 | 52.4 | 130.0 | 69.5 |
| | | 19.8 | -3.5 | 15.2 | 274.3 | 0.0 | 65.2 | 60.7 | 14000. | 12.69 |
| 104000 | 105840 | 28.113 | 49.975 | 27.541 | 48.930 | | 1824.6 | 236.2 | 106.4 | 69.7 |
| | | 23.9 | -2.2 | 15.6 | 281.2 | 0.0 | 74.0 | 77.9 | 14700. | 23.61 |
| 110300 | 111830 | 27.558 | 48.974 | 28.110 | 49.900 | | 902.1 | 55.1 | 129.7 | 62.8 |
| | | 27.8 | -1.6 | 10.8 | 357.9 | 0.0 | 63.3 | 70.9 | 20000. | 31.29 |
| 114300 | 121400 | 27.425 | 50.242 | 26.153 | 52.251 | | 1805.1 | 118.9 | 305.3 | 138.6 |
| | | 23.4 | -3.1 | 18.9 | 306.3 | 0.0 | 66.2 | 60.8 | 9700. | 19.73 |
| 123400 | 124710 | 25.799 | 52.961 | 25.024 | 52.469 | | 3033.6 | 216.6 | 353.4 | 51.4 |
| | | 14.6 | -8.6 | 17.3 | 312.9 | 0.0 | 1852.5 | 36.5 | 4800. | 21.50 |
| 125400 | 130800 | 25.200 | 52.626 | 25.985 | 53.115 | | 2595.8 | 22.3 | 354.5 | 51.5 |
| | | 18.9 | -10.0 | 17.5 | 296.7 | 0.0 | 58.6 | 45.3 | 4900. | 20.15 |
| 131300 | 132630 | 25.806 | 52.995 | 25.053 | 52.541 | | 2120.4 | 213.0 | 355.7 | 49.2 |
| | | 21.6 | -1.1 | 18.6 | 307.0 | 0.0 | 65.3 | 70.8 | 8100. | 19.56 |
| 132900 | 134740 | 25.107 | 52.557 | 26.009 | 53.171 | | 908.4 | 22.7 | 356.8 | 61.0 |
| | | 30.9 | -1.9 | 16.3 | 327.7 | 0.0 | 58.8 | 43.1 | 6100. | 20.19 |

Flt 6 May 26, 1991

Flight Leg Statistics

| Start | Stop | lat0 | lon0 | lat1 | lon1 | | Palt(m) | Hdg | Dist | Width |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Temp | TDP | WS | WD | WI | TEO3C | SO2 | CN CNC.3 | |
| 082420 | 083040 | 28.109 | 49.395 | 28.350 | 49.837 | | 4842.5 | 30.8 | 120.9 | 29.4 |
| | | -1.1 | -20.0 | 73.1 | 298.9 | 0.0 | 87.7 | 53.7 | 12900.549.86 | |
| 083200 | 085200 | 28.364 | 49.808 | 27.386 | 48.779 | | 4317.2 | 255.3 | 109.3 | 80.8 |
| | | 1.8 | -8.2 | 73.9 | 324.7 | 0.0 | 83.1 | 7.8 | 6200.489.87 | |
| 085320 | 091150 | 27.430 | 48.766 | 28.250 | 49.962 | | 4253.7 | 30.8 | 129.9 | 83.8 |
| | | 3.6 | -15.9 | 73.4 | 299.7 | 0.0 | 89.7 | 49.2 | 19800.357.88 | |
| 091500 | 093830 | 28.247 | 49.828 | 27.484 | 48.415 | | 3290.5 | 255.1 | 96.5 | 94.0 |
| | | 8.7 | -3.5 | 50.2 | 316.9 | 0.0 | 76.8 | 128.7 | 46500.429.09 | |
| 094010 | 100200 | 27.526 | 48.417 | 28.332 | 49.849 | | 3037.8 | 30.8 | 121.9 | 95.9 |
| | | 10.5 | -2.5 | 67.4 | 304.0 | 0.0 | 73.2 | 98.1 | 44800.568.92 | |
| 100300 | 102700 | 28.361 | 49.838 | 27.440 | 48.480 | | 2732.1 | 255.2 | 99.9 | 95.1 |
| | | 12.4 | -3.0 | 65.6 | 333.3 | 0.0 | 72.0 | 69.9 | 31800.576.45 | |
| 103020 | 105330 | 27.405 | 48.457 | 28.343 | 49.835 | | 2738.3 | 30.8 | 120.9 | 96.4 |
| | | 13.3 | -2.5 | 54.8 | 307.1 | 0.0 | 69.8 | 64.0 | 48400.582.04 | |
| 105620 | 110600 | 28.361 | 49.888 | 27.997 | 49.341 | | 2749.5 | 255.6 | 104.7 | 38.0 |
| | | 13.3 | -3.7 | 53.4 | 320.3 | 0.0 | 71.4 | 41.8 | 25900.578.87 | |
| 112730 | 114000 | 26.752 | 50.376 | 26.175 | 49.764 | | 2742.0 | 210.8 | 196.3 | 48.1 |
| | | 14.1 | -3.3 | 64.0 | 124.0 | 0.0 | 79.0 | 118.[illegible] | 20100.573.85 | |
| 114130 | 120020 | 26.201 | 49.727 | 27.029 | 50.717 | | 2590.7 | 31.2 | 202.1 | 74.1 |
| | | 14.1 | -4.0 | 62.1 | 323.9 | 0.0 | 81.0 | 92.3 | 112500.600.06 | |
| 120140 | 121530 | 27.036 | 50.685 | 26.267 | 50.143 | | 3039.6 | 210.9 | 205.6 | 52.6 |
| | | 12.1 | -0.8 | 33.5 | 108.1 | 0.0 | 72.6 | 52.0 | 14200.625.87 | |
| 121700 | 122750 | 26.233 | 50.052 | 26.249 | 49.337 | | 3036.0 | 300.6 | 179.9 | 42.9 |
| | | 12.1 | -2.4 | 56.9 | 358.5 | 0.0 | 50.2 | 6.6 | 2300.515.35 | |
| 122900 | 123400 | 26.289 | 49.349 | 26.244 | 49.758 | | 3938.9 | 75.6 | 193.0 | 24.7 |
| | | 5.6 | -10.1 | 67.9 | 247.0 | 0.0 | 69.5 | 7.3 | 2000.598.41 | |
| 123600 | 125500 | 26.333 | 49.874 | 26.910 | 50.581 | | 3646.2 | 211.1 | 199.5 | 52.5 |
| | | 8.8 | -13.5 | 75.6 | 46.5 | 0.0 | 81.7 | 7.0 | 2600.557.58 | |
| 125400 | 130540 | 26.970 | 50.622 | 26.253 | 50.150 | | 3641.3 | 210.9 | 206.5 | 47.9 |
| | | 8.8 | -10.7 | 9.2 | 19.0 | 0.0 | 76.5 | 22.9 | 7400.528.56 | |
| 130700 | 131830 | 26.226 | 50.070 | 26.208 | 49.282 | | 3039.9 | 255.5 | 180.5 | 47.3 |
| | | 12.1 | -2.5 | 63.0 | 197.3 | 0.0 | 64.8 | 6.5 | 3200.514.45 | |
| 132000 | 133700 | 26.248 | 49.301 | 26.227 | 50.670 | | 2741.9 | 76.2 | 228.5 | 82.2 |
| | | 14.8 | -1.8 | 46.8 | 321.9 | 0.0 | 69.4 | 27.4 | 7400.520.99 | |
| 134000 | 135540 | 26.252 | 50.009 | 25.220 | 51.074 | | 2733.6 | 166.5 | 306.5 | 69.5 |
| | | 15.8 | -0.2 | 55.1 | 308.8 | 0.0 | 75.7 | 63.0 | 12200.572.23 | |
| 140000 | 140400 | 25.396 | 51.618 | 25.621 | 51.696 | | 2736.8 | 31.5 | 296.5 | 13.1 |
| | | 15.6 | 0.2 | 65.7 | 85.7 | 0.0 | 3981.4 | 91.9 | 14200.551.95 | |
| 141300 | 142030 | 26.109 | 51.730 | 26.314 | 51.327 | | 2738.0 | 301.4 | 254.9 | 26.6 |
| | | 15.2 | -1.1 | 22.5 | 305.9 | 0.0 | 1721.6 | 46.5 | 15300.568.68 | |

Flt 7 May 27,1991

Flight Leg Statistics

| Start | Stop | lat0 | lon0 | lat1 | lon1 | | Palt(m) | Hdg | Dist | Width |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Temp | TDP | WS | WD | WI | TEO3C | SO2 | CN | CNC.3 |
| 094850 | 095020 | 27.997 | 49.790 | 27.927 | 49.896 | | 5460.5 | 112.1 | 134.3 | 7.4 |
| | | -5.9 | -13.0 | 61.6 | 358.9 | 0.0 | 26.0 | 8.3 | 15700. | 432.54 |
| 095230 | 095530 | 27.865 | 49.977 | 27.898 | 49.822 | | 5461.1 | 306.5 | 131.3 | 9.5 |
| | | -6.1 | -13.3 | 57.4 | 352.8 | 0.0 | 28.4 | 8.3 | 17800. | 460.56 |
| 102130 | 104140 | 27.974 | 49.791 | 28.088 | 48.650 | | 5462.9 | 103.4 | 72.7 | 68.7 |
| | | -5.6 | -13.6 | 66.8 | 243.6 | 0.0 | 27.9 | 8.3 | 52000. | 30.95 |
| 104300 | 105520 | 28.074 | 48.778 | 28.120 | 49.997 | | 5448.4 | 104.5 | 134.7 | 73.2 |
| | | -5.6 | -13.1 | 77.7 | 215.8 | 0.0 | 23.3 | 8.4 | 104300. | 366.31 |
| 105820 | 112000 | 28.107 | 49.949 | 28.125 | 48.484 | | 4867.8 | 282.2 | 65.8 | 87.9 |
| | | -1.6 | -9.0 | 56.1 | 327.9 | 0.0 | 39.6 | 24.3 | 33000. | 128.68 |
| 112300 | 114000 | 20.110 | 40.465 | 20.126 | 50.004 | | 4266.6 | 96.2 | 134.9 | 92.4 |
| | | 3.0 | -4.1 | 64.4 | 213.6 | 0.0 | 38.2 | 21.9 | 38400. | 84.68 |
| 114120 | 120300 | 28.190 | 50.015 | 28.251 | 48.593 | | 3679.2 | 282.5 | 63.5 | 85.4 |
| | | 5.6 | -1.5 | 50.1 | 320.4 | 0.0 | 38.7 | 29.3 | 49700. | 55.40 |
| 120540 | 122130 | 28.239 | 48.546 | 28.232 | 49.835 | | 2735.5 | 105.0 | 123.4 | 77.4 |
| | | 13.5 | -2.4 | 54.1 | 213.3 | 0.0 | 39.2 | 20.6 | 42400. | 74.67 |
| 122400 | 124500 | 28.213 | 49.927 | 28.232 | 48.613 | | 1809.6 | 282.8 | 65.1 | 78.9 |
| | | 21.9 | 0.5 | 52.5 | 348.8 | 0.0 | 35.0 | 16.6 | 49100. | 49.80 |
| 124740 | 130540 | 28.223 | 48.566 | 28.209 | 49.826 | | 913.5 | 95.7 | 123.4 | 75.6 |
| | | 28.7 | -0.9 | 46.9 | 199.4 | 0.0 | 28.7 | 7.7 | 51300. | 21.25 |
| 130840 | 131220 | 28.295 | 49.735 | 28.496 | 49.708 | | 615.4 | 326.3 | 110.8 | 10.7 |
| | | 31.4 | -1.7 | 44.2 | 250.7 | 0.0 | 26.6 | 4.5 | 42600. | 79.96 |
| 131330 | 132030 | 28.510 | 49.651 | 28.184 | 49.395 | | 921.4 | 336.7 | 101.5 | 23.1 |
| | | 29.9 | 0.9 | 55.3 | 30.6 | 0.0 | 26.6 | 5.4 | 6300. | 42.74 |
| 132300 | 132920 | 28.163 | 49.425 | 28.489 | 49.654 | | 1799.4 | 13.5 | 108.0 | 22.0 |
| | | 21.2 | -1.2 | 50.1 | 300.9 | 0.0 | 29.4 | 14.4 | 42300. | 61.31 |
| 133330 | 133910 | 28.481 | 49.653 | 28.183 | 49.429 | | 2727.4 | 238.6 | 103.2 | 20.7 |
| | | 13.5 | -1.7 | 57.0 | 311.6 | 0.0 | 38.1 | 36.3 | 58600. | 123.66 |
| 134200 | 134850 | 28.104 | 49.433 | 28.514 | 49.666 | | 3643.6 | 12.2 | 108.2 | 25.7 |
| | | 6.5 | -2.6 | 55.7 | 292.5 | 0.0 | 35.6 | 47.0 | 64200. | 147.38 |
| 135340 | 140100 | 28.549 | 49.704 | 28.115 | 49.415 | | 4857.6 | 193.5 | 104.5 | 28.8 |
| | | -2.2 | -7.9 | 74.0 | 112.9 | 0.0 | 32.8 | 11.5 | 103800. | 173.86 |
| 140200 | 140700 | 28.056 | 49.456 | 27.933 | 49.919 | | 4859.3 | 102.9 | 135.3 | 28.5 |
| | | -2.3 | -7.6 | 52.7 | 351.2 | 0.0 | 30.8 | 13.7 | 23100. | 189.57 |
| 141300 | 142200 | 27.681 | 50.041 | 27.072 | 50.298 | | 2734.8 | 147.3 | 180.8 | 36.0 |
| | | 14.4 | -0.7 | 61.7 | 30.2 | 0.0 | 400.3 | 16.7 | 27400. | 127.40 |

Flt 8 May 28,1991

Flight Leg Statistics

| Start | Stop | lat0 | lon0 | lat1 | lon1 | | Palt(m) | Hdg | Dist | Width |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Temp | TDP | WS | WD | WI | TEO3C | SO2 | CN | CNC.3 |
| 072200 | 074300 | 26.651 | 51.430 | 26.127 | 53.093 | | 4564.6 | 107.7 | 349.5 | 103.7 |
| | | 2.2 | -8.6 | 24.1 | 308.5 | 0.0 | 1877.1 | 7.4 | 1500. | 96.30 |
| 074400 | 075920 | 26.072 | 53.148 | 25.087 | 52.543 | | 4560.3 | 213.1 | 354.6 | 64.6 |
| | | 2.9 | -10.5 | 27.6 | 319.0 | 0.0 | 33.2 | 7.4 | 13700. | 63.63 |
| 080500 | 081300 | 25.236 | 52.627 | 25.694 | 53.009 | | 4560.4 | 33.3 | 357.4 | 33.8 |
| | | 2.4 | -9.4 | 18.8 | 312.7 | 0.0 | 33.0 | 7.4 | 4300. | 42.54 |
| 081500 | 082130 | 25.792 | 52.964 | 25.957 | 52.554 | | 4556.6 | 297.1 | 326.5 | 26.1 |
| | | 2.4 | -9.8 | 20.9 | 310.6 | 0.0 | 34.8 | 7.4 | 2900. | 45.08 |
| 082900 | 084300 | 26.132 | 52.132 | 26.432 | 51.376 | | 1813.7 | 294.8 | 253.4 | 48.1 |
| | | 22.5 | -10.3 | 20.5 | 299.2 | 0.0 | 67.4 | 14.4 | 14300. | 74.69 |
| 084400 | 091800 | 26.434 | 51.317 | 26.250 | 49.292 | | 1813.3 | 274.0 | 178.6 | 121.9 |
| | | 21.4 | -2.4 | 22.8 | 295.1 | 0.0 | 74.8 | 21.7 | 37800. | 81.03 |
| 092320 | 095020 | 26.326 | 49.094 | 27.128 | 50.695 | | 1132.1 | 58.8 | 198.0 | 105.2 |
| | | 23.4 | -12.1 | 16.1 | 327.2 | 0.0 | 67.9 | 21.5 | 33900. | 114.91 |
| 095200 | 101820 | 27.154 | 50.657 | 26.536 | 49.108 | | 1811.1 | 251.4 | 159.7 | 98.7 |
| | | 21.8 | -9.0 | 19.5 | 298.8 | 0.0 | 71.8 | 15.0 | 27700. | 117.23 |
| 102000 | 104210 | 26.485 | 49.136 | 27.098 | 50.680 | | 2132.6 | 58.5 | 199.2 | 98.2 |
| | | 19.9 | -12.9 | 21.0 | 306.5 | 0.0 | 75.6 | 16.6 | 90000. | 154.51 |
| 104400 | 110200 | 27.114 | 50.643 | 26.690 | 49.569 | | 3255.7 | 249.2 | 166.3 | 68.3 |
| | | 11.5 | 0.0 | 27.4 | 282.0 | 0.0 | 63.0 | 17.7 | 21700. | 138.14 |
| 110400 | 111730 | 26.672 | 49.655 | 27.116 | 50.681 | | 3346.4 | 57.3 | 197.7 | 66.0 |
| | | 10.6 | -7.4 | 23.8 | 307.7 | 0.0 | 54.0 | 6.3 | 11000. | 136.46 |
| 112100 | 115400 | 27.112 | 50.565 | 26.231 | 48.484 | | 3961.6 | 250.1 | 164.2 | 133.5 |
| | | 6.3 | -7.7 | 26.0 | 302.0 | 0.0 | 34.5 | 6.9 | 1800. | 141.62 |
| 122200 | 123700 | 26.396 | 49.232 | 26.234 | 50.343 | | 1841.1 | 95.0 | 214.8 | 67.2 |
| | | 22.6 | 0.7 | 16.2 | 318.4 | 0.0 | 62.8 | 5.2 | 3900. | 156.96 |

Flt 9 May 29,1991

Flight Leg Statistics

| Start | Stop | lat0 | lon0 | lat1 | lon1 | | Palt(m) | Hdg | Dist | Width |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Temp | TDP | WS | WD | WI | TEO3C | SO2 | CN | CNC.3 |
| 080000 | 082300 | 26.852 | 50.242 | 27.993 | 49.399 | | 4252.1 | 323.7 | 107.5 | 78.8 |
| | | 5.3 | -23.4 | 22.4 | 282.9 | 0.0 | 36.2 | 4.2 | 25000. | 15.81 |
| 083200 | 083900 | 27.927 | 49.489 | 28.228 | 49.827 | | 3679.4 | 33.3 | 123.0 | 25.8 |
| | | 9.7 | -13.4 | 18.0 | 288.5 | 0.0 | 29.7 | 4.2 | 72400. | 15.51 |
| 084100 | 085910 | 28.233 | 49.872 | 27.680 | 48.789 | | 3650.9 | 243.8 | 95.6 | 71.4 |
| | | 9.1 | -16.6 | 19.2 | 279.6 | 0.0 | 29.5 | 4.2 | 84600. | 20.96 |
| 090500 | 092400 | 27.672 | 48.811 | 28.223 | 49.830 | | 474.2 | 53.8 | 123.3 | 67.7 |
| | | 24.3 | 1.5 | 18.2 | 340.9 | 0.0 | 44.6 | 14.9 | 76500. | 44.92 |
| 093100 | 095100 | 28.228 | 49.922 | 27.677 | 48.766 | | 2122.4 | 246.6 | 95.0 | 75.3 |
| | | 18.7 | -3.2 | 23.8 | 296.4 | 0.0 | 61.5 | 53.2 | 53600. | 82.42 |
| 095600 | 100800 | 27.648 | 48.727 | 28.036 | 49.363 | | 465.3 | 45.3 | 104.5 | 43.3 |
| | | 24.4 | 0.7 | 16.1 | 345.0 | 0.0 | 53.1 | 24.5 | 39800. | 32.37 |
| 100900 | 101700 | 28.074 | 49.366 | 28.385 | 49.070 | | 459.3 | 336.6 | 79.3 | 24.1 |
| | | 25.2 | 0.0 | 15.0 | 6.2 | 0.0 | 38.8 | 5.0 | 9000. | 13.06 |
| 101800 | 102430 | 28.419 | 49.103 | 28.584 | 49.473 | | 470.0 | 53.8 | 96.0 | 23.8 |
| | | 25.2 | 0.0 | 15.2 | 341.9 | 0.0 | 36.5 | 4.1 | 16800. | 9.28 |
| 102700 | 104300 | 28.599 | 49.517 | 28.301 | 48.531 | | 472.1 | 255.1 | 59.2 | 61.2 |
| | | 28.5 | -2.2 | 16.9 | 335.8 | 0.0 | 41.3 | 20.1 | 44300. | 27.02 |
| 104630 | 110110 | 28.268 | 48.535 | 28.592 | 49.482 | | 1051.8 | 59.7 | 96.4 | 59.4 |
| | | 25.2 | -11.0 | 18.1 | 325.4 | 0.0 | 58.2 | 48.1 | 67200. | 70.65 |
| 110500 | 112440 | 28.588 | 49.500 | 28.198 | 48.310 | | 2121.9 | 249.4 | 58.0 | 74.4 |
| | | 18.5 | -2.8 | 20.5 | 297.1 | 0.0 | 56.8 | 50.2 | 74200. | 85.57 |
| 112730 | 114300 | 28.183 | 48.296 | 28.599 | 49.481 | | 2586.1 | 63.6 | 96.2 | 74.4 |
| | | 15.2 | -2.4 | 22.3 | 295.6 | 0.0 | 1194.6 | 28.1 | 48500. | 58.26 |
| 114600 | 120540 | 28.615 | 49.557 | 28.223 | 48.369 | | 3040.6 | 253.7 | 58.1 | 74.2 |
| | | 12.3 | -3.0 | 22.1 | 284.3 | 0.0 | 29.3 | 4.1 | 20000. | 37.29 |
| 120840 | 122310 | 28.227 | 48.332 | 28.606 | 49.525 | | 3651.4 | 65.3 | 98.6 | 74.3 |
| | | 8.4 | -11.5 | 21.6 | 288.9 | 0.0 | 30.5 | 4.9 | 7500. | 45.81 |
| 122500 | 125420 | 28.640 | 49.495 | 28.195 | 48.244 | | 1052.6 | 255.2 | 56.9 | 78.7 |
| | | 25.6 | -3.5 | 30.8 | 334.4 | 0.0 | 54.4 | 49.0 | 68200. | 48.56 |
| 125700 | 131200 | 28.168 | 48.200 | 28.426 | 49.080 | | 512.6 | 68.0 | 78.6 | 54.5 |
| | | 28.0 | -4.7 | 17.5 | 344.0 | 0.0 | 44.6 | 24.3 | 38700. | 37.42 |
| 131800 | 132800 | 28.148 | 49.318 | 27.806 | 49.844 | | 511.9 | 85.3 | 135.1 | 36.4 |
| | | 27.8 | -9.6 | 22.9 | 341.3 | 0.0 | 43.1 | 4.1 | 15300. | 6.67 |
| 133420 | 135200 | 27.728 | 50.283 | 26.555 | 50.673 | | 1477.7 | 158.1 | 216.3 | 67.2 |
| | | 26.5 | -0.4 | 20.7 | 321.0 | 0.0 | 55.3 | 23.4 | 25400. | 35.42 |

Flt 10 May 30,1991
Flight Leg Statistics

| Start | Stop | lat0 / Temp | lon0 / TDP | lat1 / WS | lon1 / WD | WI | Palt(m) / TEO3C | Hdg / SO2 | Dist / CN | Width / CNC.3 |
|---|---|---|---|---|---|---|---|---|---|---|
| 045500 | 050400 | 26.895 | 50.203 | 27.318 | 49.890 | | 3035.8 | 322.0 | 153.5 | 29.3 |
| | | 13.6 | -7.0 | 21.3 | 285.5 | 0.0 | 45.3 | 6.4 | 2900. | 43.64 |
| 050900 | 054800 | 27.540 | 49.723 | 29.250 | 47.943 | | 3827.6 | 310.4 | 2.3 | 139.3 |
| | | 5.2 | -11.3 | 21.4 | 266.6 | 0.0 | 80.9 | 7.1 | 3800. | 60.29 |
| 060600 | 061400 | 28.644 | 48.012 | 28.799 | 48.518 | | 1091.0 | 63.7 | 39.6 | 31.5 |
| | | 24.5 | -6.4 | 17.8 | 344.4 | 0.0 | 68.6 | 747.5 | 119700. | 248.33 |
| 061700 | 062700 | 28.805 | 48.580 | 28.608 | 47.933 | | 1381.2 | 259.0 | 32.7 | 40.2 |
| | | 23.3 | -3.1 | 16.7 | 331.0 | 0.0 | 68.3 | 508.2 | 117100. | 264.10 |
| 062940 | 064230 | 28.581 | 47.899 | 28.893 | 48.755 | | 1681.0 | 62.8 | 49.9 | 53.9 |
| | | 20.2 | -8.1 | 15.1 | 317.8 | 0.0 | 70.9 | 237.0 | 117400. | 235.54 |
| 064520 | 065900 | 28.904 | 48.808 | 28.619 | 47.932 | | 727.9 | 294.7 | 32.2 | 54.7 |
| | | 27.6 | -3.2 | 20.8 | 350.9 | 0.0 | 75.9 | 312.9 | 116500. | 158.17 |
| 070200 | 071400 | 28.619 | 47.966 | 28.868 | 48.693 | | 548.0 | 62.2 | 47.0 | 45.5 |
| | | 28.0 | 2.2 | 10.2 | 344.9 | 0.0 | 67.7 | 180.3 | 110100. | 114.36 |
| 071900 | 072150 | 28.865 | 48.755 | 28.823 | 48.580 | | 1966.4 | 259.8 | 42.0 | 10.7 |
| | | 20.0 | -11.4 | 14.2 | 303.4 | 0.0 | 78.3 | 5.5 | 2000. | 29.67 |
| 074400 | 075100 | 28.396 | 48.159 | 28.089 | 48.538 | | 2535.3 | 136.3 | 69.1 | 27.9 |
| | | 16.2 | -5.6 | 15.4 | 302.4 | 0.0 | 77.0 | 137.3 | 57700. | 90.18 |
| 075730 | 080800 | 28.111 | 48.837 | 27.779 | 48.207 | | 1987.4 | 242.3 | 78.2 | 41.7 |
| | | 18.7 | -7.2 | 17.1 | 344.6 | 0.0 | 82.5 | 319.7 | 92800. | 147.45 |
| 081100 | 082540 | 27.749 | 48.149 | 28.264 | 49.064 | | 2273.1 | 51.7 | 82.8 | 61.3 |
| | | 17.5 | -3.9 | 16.6 | 303.1 | 0.0 | 81.8 | 134.5 | 54000. | 92.19 |
| 082900 | 084800 | 28.304 | 49.108 | 27.702 | 47.987 | | 1093.0 | 247.5 | 81.1 | 74.4 |
| | | 25.9 | -2.9 | 14.5 | 337.9 | 0.0 | 70.6 | 150.9 | 71300. | 92.51 |
| 085100 | 091400 | 27.661 | 47.924 | 28.319 | 49.308 | | 1381.9 | 59.2 | 93.2 | 90.0 |
| | | 23.4 | -8.9 | 15.8 | 332.6 | 0.0 | 72.9 | 180.2 | 80900. | 111.40 |
| 092300 | 093600 | 28.217 | 49.123 | 27.853 | 48.311 | | 3792.0 | 244.3 | 75.7 | 52.4 |
| | | 7.8 | -21.0 | 17.1 | 269.5 | 0.0 | 71.1 | 7.0 | 2300. | 91.03 |
| 093900 | 100440 | 27.687 | 48.380 | 27.383 | 50.302 | | 4096.9 | 69.7 | 170.7 | 116.5 |
| | | 6.4 | -24.4 | 24.7 | 299.9 | 0.0 | 65.3 | 7.3 | 2300. | 50.23 |
| 100900 | 104530 | 27.286 | 50.183 | 27.276 | 50.269 | | 2280.8 | 79.8 | 172.5 | 5.2 |
| | | 21.7 | -4.1 | 16.6 | 289.3 | 0.0 | 86.4 | 89.1 | 26100. | 82.33 |
| 105240 | 105900 | 26.824 | 50.468 | 26.418 | 50.600 | | 806.2 | 162.7 | 218.2 | 23.2 |
| | | 28.1 | -5.9 | 16.1 | 348.7 | 0.0 | 57.5 | 4.8 | 2400. | 52.60 |

Flt 11 May 31,1991

Flight Leg Statistics

| Start | Stop | lat0 | lon0 | lat1 | lon1 | | Palt(m) | Hdg | Dist | Width |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Temp | TDP | WS | WD | WI | TEO3C | SO2 | CN | CNC.3 |
| 045900 | 051400 | 0.000 | 0.000 | 0.000 | 0.000 | | 3641.7 | 339.7 | 3370.7 | 0.0 |
| | | 8.6 | -8.5 | 130.1 | 339.8 | 0.0 | 60.6 | 6.9 | 1700. | 46.65 |
| 051700 | 054330 | 0.000 | 0.000 | 0.000 | 0.000 | | 3796.9 | 349.6 | 3370.7 | 0.0 |
| | | 7.6 | -14.7 | 131.4 | 349.8 | 0.0 | 62.6 | 7.1 | 2600. | 96.36 |
| 054500 | 055600 | 0.000 | 0.000 | 0.000 | 0.000 | | 3802.5 | 345.4 | 3370.7 | 0.0 |
| | | 7.5 | -17.9 | 132.6 | 345.6 | 0.0 | 56.5 | 7.1 | 34100. | 45.64 |
| 055800 | 060900 | 0.000 | 0.000 | 0.000 | 0.000 | | 3799.2 | 344.7 | 3370.7 | 0.0 |
| | | 7.6 | -14.5 | 128.9 | 344.9 | 0.0 | 62.3 | 7.1 | 17900. | 57.60 |
| 062800 | 063500 | 27.556 | 48.634 | 27.113 | 48.546 | | 2585.3 | 205.1 | 118.0 | 24.3 |
| | | 17.5 | -3.0 | 13.3 | 268.5 | 0.0 | 63.1 | 7.5 | 8800. | 66.33 |
| 063600 | 064400 | 27.084 | 48.502 | 27.264 | 47.999 | | 2588.3 | 290.5 | 104.8 | 31.6 |
| | | 16.2 | -4.6 | 12.6 | 262.8 | 0.0 | 70.1 | 75.7 | 40800. | 73.69 |
| 064530 | 065800 | 27.227 | 47.970 | 26.772 | 48.796 | | 2589.7 | 137.0 | 140.4 | 55.2 |
| | | 18.2 | -2.6 | 15.4 | 286.9 | 0.0 | 72.1 | 68.8 | 21400. | 83.51 |
| 065940 | 070950 | 26.785 | 48.858 | 27.172 | 48.338 | | 2582.5 | 299.0 | 111.9 | 37.4 |
| | | 17.2 | -3.8 | 15.1 | 267.4 | 0.0 | 72.0 | 53.9 | 34600. | 71.62 |
| 071100 | 072300 | 27.135 | 48.282 | 26.437 | 47.873 | | 2583.0 | 211.2 | 150.1 | 44.8 |
| | | 18.2 | -3.7 | 13.9 | 277.5 | 0.0 | 75.1 | 129.6 | 31900. | 85.07 |
| 072400 | 073540 | 26.408 | 47.909 | 27.009 | 48.384 | | 2273.5 | 33.7 | 121.6 | 42.6 |
| | | 20.6 | -3.1 | 13.6 | 317.6 | 0.0 | 80.2 | 131.2 | 21000. | 99.45 |
| 073730 | 074900 | 26.963 | 48.440 | 26.301 | 48.038 | | 2279.6 | 212.5 | 157.5 | 43.0 |
| | | 19.9 | -2.9 | 10.1 | 276.6 | 0.0 | 77.2 | 79.7 | 16900. | 87.87 |
| 075030 | 080720 | 26.277 | 48.091 | 27.272 | 48.602 | | 2617.8 | 17.5 | 110.9 | 61.3 |
| | | 17.5 | -3.5 | 17.4 | 294.3 | 0.0 | 82.3 | 106.0 | 25500. | 85.56 |
| 080830 | 082000 | 27.285 | 48.560 | 26.624 | 48.161 | | 2883.3 | 213.2 | 140.1 | 42.7 |
| | | 15.7 | -4.0 | 13.2 | 294.9 | 0.0 | 75.1 | 70.8 | 23400. | 70.22 |
| 082200 | 083420 | 26.573 | 48.208 | 27.316 | 48.632 | | 3202.8 | 22.9 | 109.3 | 47.1 |
| | | 12.5 | -5.3 | 14.8 | 298.7 | 0.0 | 76.1 | 50.6 | 16400. | 86.74 |
| 083600 | 085630 | 27.341 | 48.594 | 25.979 | 48.205 | | 3495.4 | 202.4 | 175.8 | 77.1 |
| | | 11.3 | -9.4 | 17.5 | 296.1 | 0.0 | 65.6 | 36.6 | 14100. | 91.40 |
| 085800 | 092200 | 25.963 | 48.273 | 27.287 | 48.858 | | 1669.5 | 33.8 | 116.2 | 78.8 |
| | | 22.8 | -4.0 | 12.7 | 18.7 | 0.0 | 62.3 | 9.7 | 5400. | 73.75 |

NCAR National Center for Atmospheric Research
P.O. Box 3000, Boulder, CO 80307-3000

NEWS RELEASE

1991-10 For release: June 24, 1991, P.M.

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Manager, NCAR Media Relations
(303) 497-8607

*NCAR Scientists Release Preliminary Results from Kuwait Oil Fires Study*

BOULDER, CO—Two research aircraft, one from the National Center for Atmospheric Research (NCAR) and one from the University of Washington, as well as a team of scientists from NCAR and other institutions have just returned from a month-long study of smoke plumes blackening the skies over the burning Kuwaiti oil fields. Lawrence Radke, co–project leader from NCAR, along with Peter Hobbs of the University of Washington, said the scientists studied the smoke because of effects on clouds, preciptation processes, radiation, and atmospheric chemistry and because this unprecedented air pollution event, by its very magnitude, can provide insights into controversies over atmospheric responses which could be caused by more subtle pollution sources.

The potential for environmental havoc, regional weather modification (especially in reference to the Indian monsoon and precipitation processes), and poisonous clouds and rains have all received considerable attention. The purpose of this on-site project was to provide the quantitative detail to either support or refute these speculations. Some preliminary results are now becoming available.

For example, according to Radke, for catastrophic environmental effects to occur, the smoke had to fulfill several conditions: it had to be very black, not absorb water, and loft itself into the stratosphere. The smoke turned out to be only half as black as predicted, with individual wells producing smokes ranging from white to black.

-more-

Also the smoke proved to be hydroscopic, rather than hydrophobic, as predicted. Thus the smoke will interact with clouds and precipitation and thereby be comparatively quickly removed from the atmosphere.

Self-lofting held up no better than the first two conditions. Although the smoke became more buoyant in the midday heat, rising higher into the atmosphere, these very dynamics diluted the plumes and ultimately halted the self-lofting. The highest altitude at which the smoke was observed was 18,000 feet (5,500 meters) after two days in the air. No further significant rise was expected because of the then diluted nature of the smoke cloud. If the particles had reached the stratosphere, where they could remain for months, they could have damaged the environment much more than they would in the troposphere, where they are removed within days.

Another important concern was the effect of smoke on regional precipitation. Theoretically, injecting cloud-active aerosols into clouds would decrease rainfall by spreading the cloud moisture among a larger number of cloud condensation nuclei, thus producing a greater number of droplets too small to fall out as rain. In reality, the aerosols vary greatly in size, so the larger smoke particles may facilitate precipitation formation. Another hypothesis suggests that the injection of black carbon particles into white clouds would increase rainfall by causing the clouds to absorb (rather than reflect) a significant amount of solar radiation. The warmer clouds would rise to higher, cooler altitudes, where condensation and rainfall would be enhanced. In addition, this change in cloud reflectivity, if large-scale, could ultimately affect the earth's radiation balance by increasing surface temperature. Because there were few clouds in the Kuwaiti sky during May (the team encountered only one region of altocumulus, and the data from this encounter are awaiting analysis), these questions have not yet been answered.

The scientists also searched for the poisonous hydrogen sulfide gas and the main acid rain constituent, sulfur dioxide. Evidently, because the hydrogen sulfide was burned quickly by the fires and readily oxidized to sulfur dioxide, it was not a threat. As for acid rain, the fires produced approximately 65 pounds (30 kilograms) of sulfur dioxide per second, an amount equivalent to 6–12 power plants or one recently erupted volcano. "Although a big source," says

-more-

Radke, "its effects would be local and moderate," somewhat increasing acid rain downwind of the plume.

But, he adds, "We're certainly going to have some regional weather modification near the fires." For example, the Kuwaiti ground is gradually getting blacker from incompletely burned oil and carbon falling out of the atmosphere. This will change the local reflectivity, since the desert is originally rather bright but oil on the surface will cause it to be less so.

Radke describes the smoke and the difficulty of comprehending the plume's scale: "When we flew over it in the plane, the black plume stretched from horizon to horizon, covering thousands of square miles. Inside of the plume at 3,000 feet (about 900 meters) altitude and 20 miles (about 30 kilometers) downwind of the fire, all sunlight was gone; it was completely dark in the airplane. But when we looked at satellite pictures, we saw that the plume is very small globally."

In Kuwait, the research team found some surprises: models of the smoke plume dynamics were inaccurate, the importance of the effects of blowing sand on the plume hadn't been accounted for, and the plumes were affected by unexpected wave activity created by complicated small-scale airflow patterns.

Using multiple-wavelength lidars aboard NCAR's Electra to measure molecular and particle scattering, observers could detect both the sensitivity and distribution of smoke within the plumes. They obtained strong circumstantial evidence that the particles grew in size more rapidly than expected as the plume dispersed and aged.

To get an overview of the gas phase species emitted from the fires, chemists on the project measured emission fluxes and their photochemical reactivity. According to NCAR chemist Gregory Kok, they found the photochemical reactivity (measured in terms of excess ozone) was 20 to 30 parts per billion (ppb), compared to over 100 ppb in Los Angeles on a sunny day.

Says Radke, "These fires provide an exaggerated example of air pollution. There's never been this much oil burned in such a primitive fashion over such a long period."

-End-

Writer: Anatta, NCAR Media Relations

**Measurements of Formaldehyde and Hydroperoxides in the Kuwait Oil Fire Plume**

1. 1991 Fall Meeting

G L Kok, W T Luke, and R D Schillawski (Research Aviation Facility, National Center for Atmospheric Research*, Post Office Box 3000, Boulder, CO 80307-3000; 303-497-1070)

As part of the airborne measurements in the Kuwait oil fire smoke plumes, analysis for formaldehyde (HCHO) and hydroperoxides ($H_2O_2$ and ROOH) were conducted. The HCHO measurements were made using a continuous wet chemical technique based on the Hantzsch reaction. The continuous dual-enzyme technique was used to determine $H_2O_2$ and a lower limit on the organic hydroperoxides. HCHO concentrations were typically 5-10 ppbv at 80 nm downwind. At the head of the plume from the southern field, the HCHO concentration was in excess of 50 ppbv. On some flights, a close correlation between $SO_2$ and HCHO was observed. No significant changes in the concentrations of hydroperoxides were observed. Increases of $H_2O_2$ from 1-2 ppbv were observed within the plume.

*The National Center for Atmospheric Research is sponsored by the National Science Foundation

**Some Dynamical Influences on the Smoke Plumes from the Oil Fires of Kuwait** **1. 1991 Fall Meeting**

W A Cooper, L F Radke, and D H Lenschow (Research Aviation Facility, National Center for Atmospheric Research*, Post Office Box 3000, Boulder, CO 80307-3000; 303-497-1038; OMNET: NCAR.RAF) (sponsor: P V Hobbs)

When the smoke plumes from the oil fires of Kuwait moved along the coast of Saudi Arabia, complicated interactions occurred involving the redistribution of absorbed energy by the smoke, land-sea-breeze circulations, and the regional mesoscale airflow. An instrumented research aircraft was used to observe the air motions and radiation fields within and near the smoke plumes during May and June 1991.

During these flights, a common observation was strong horizontal convergence of the wind field into the plume, even at low levels where a cooler outflow might have been expected. Absorption of solar energy at the top of the smoke layer, and shielding of lower layers, led to differential heating and hence to local circulation patterns. However, the strong static stability of the atmosphere limited the effects of the changes in buoyancy, and hence limited the degree to which the smoke rose in the atmosphere in response to solar heating.

In addition, the large (100 km) widths of the smoke plumes permitted unusually good characterization of the turbulent wind fluctuations responsible for spreading of the smoke. Examples of measured variance spectra and deduced characteristic time scales for the turbulent air motions will be presented. These are used to relate the observed plume dimensions to predictions of simple models of turbulent diffusion.

*The National Center for Atmospheric Research is sponsored by the National Science Foundation

**Ozone and Sulfur Dioxide Measurements in the Kuwait Oil Fire Plume**

1. 1991 Fall Meeting

R D Schillawski, G L Kok, and W T Luke (Research Aviation Facility, National Center for Atmospheric Research*, Post Office Box 3000, Boulder, CO 80307-3000; 303-497-1042)

In-plume and background measurements of ozone ($O_3$) and sulfur dioxide ($SO_2$) were made during May and early June of 1991 from the NCAR Electra. Three different techniques were used for $O_3$ measurements, ultraviolet absorption, nitric oxide chemiluminescence, and Rhodamine 6G dye chemiluminescence. $SO_2$ levels were made using the pulsed florescence technique. This presentation will compare the performance of the $O_3$ instruments, show the results of the $O_3$ and $SO_2$ measurements, and discuss these results as compared with those of other species, or made by other investigators.

*The National Center for Atmospheric Research is sponsored by the National Science Foundation

**Reactive Trace Gas Measurements and Photochemistry in the Kuwait Oil Fire Smoke Plume**

1. 1991 Fall Meeting

W T Luke, G L Kok, and R D Schillawski (Research Aviation Facility, National Center for Atmospheric Research*, Post Office Box 3000, Boulder, CO 80307-3000; 303-497-1018)

A variety of reactive trace gases ($O_3$, CO, NO, NOy, $SO_2$) were measured from the NCAR Electra both inside and outside the Kuwait oil fire smoke plume in May and June, 1991. At a range of 80 km from the fires, NOy concentrations varied from less than 0.5 ppbv outside the plume to almost 70 ppbv at an altitude of 1100 m; nitric oxide (NO) typically comprised only 5-10% of total NOy inside the plume. Sulfur dioxide levels reached a maximum of over 700 ppbv, while CO peaked at over 500 ppbv at the same location. Close to the fires, high NOx and low UV levels allowed a significant fraction of the ambient ozone to be titrated. At a distance of 160 km downwind, however, net photochemical ozone production was observed, and averaged less than 2 ppbv per hour throughout the plume. The trace gas data will be discussed in terms of regional photochemistry and emission budgets, and will be used to infer combustion characteristics at the blazing well heads.

* The National Center for Atmospheric Research is sponsored by the National Science Foundation

**A Review of the United States Interagency Airborne Study of the Smokes From the 1991 Kuwait Oil Fires**

1. Ocean Sciences Meeting

L F Radke (Research Aviation Facility, National Center for Atmospheric Research*, Post Office Box 3000, Boulder, CO 80307-3000; 303-497-1032)

P V Hobbs (Atmospheric Sciences Department, AK-40, University of Washington, Seattle, WA 98195; 206-543-6027; OMNET: P.HOBBS)

As the Iraqi army fled Kuwait in March 1991, they damaged or destroyed 749 oil wells, most of which were ignited. The resulting fires produced an extraordinary large plume of black smoke that had both local and regional effects on the Gulf States and the potential for global effects.

As part of the interagency United States effort (coordinated by the National Science Foundation) to assess the impacts of the fires on the atmosphere, the University of Washington (UW) and the National Center for Atmospheric Research (NCAR) mounted an airborne study of the smoke from the Kuwait fires utilizing the UW Convair and the NCAR Electra research aircraft.

During the period 16 May through 12 June 1991, some 200 research flying hours were flown to study the smoke form the Kuwait oil fires. The primary goals of the studies were to determine the chemical and physical nature and the radiative properties of the smoke, the fluxes of various materials in the smoke, and the potential effects of the smoke on weather, climate and air quality.

The key result of our preliminary analysis is that predictions of very large scale, even global scale climate modification are not supported. These predictions had been predicated on an optically very dark smoke being solar self-lofted to the tropopause where cloud and precipitation scavenging would be minimized by both elevation and expected particle hydrophobicity. This would lead to a long atmospheric residence time for the smoke particles. To the contrary, we found the smokes to be substantially "whiter" than expected (single scattering albedo at visible wavelengths ~0.6). While solar heating of the smokes introduced interesting dynamics in the plume, self-lofting was found to have limited effectiveness (the smoke plume top was never observed above 6 km after travel times of up to two days). Finally because of water soluble salts in the fuel and oxidation of $SO_2$ to sulfate, the smoke particles were hygroscopic rather than hydrophobic and thus have a rather limited tropospheric residence time.

*The National Center for Atmopsheric Reserach is sponsored by the Natinoal Science Foundation

## Solar Heating of the Kuwaiti Oil Fire Plume and Induced Self-Lofting and Dynamics

1. 1991 Fall Meeting

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The optically black smoke plume from the hundreds of burning oil wells in Kuwait was initially forecast to have a potentially significant regional and global climatic effect by virtue of the smoke's expected optical properties and long atmospheric residence times. An important factor in long residence times is the mechanism of solar self-lofting, where much of the smoke would rise high in the troposphere and perhaps into the lower stratosphere and thus largely escape cloud and precipitation scavenging. The role of solar self-lofting of the soot particles, whereby optically black particles absorb solar radiation, heat the surrounding air and through increased buoyancy rise to high altitudes was strongly supported by recent large-scale test fires of aviation fuel (JP-4) which produces a dense, dark, smoke (visible wavelength single scattering albedo of ~0.3). Airborne observations showed that the JP-4 smoke plume rose through a strong planetary boundary layer capping inversion in a few hours. However, both direct sampling and visual observations together with multi-wavelength lidar observations (0.5, 1, and 10 $\mu$m) from the NCAR Electra, showed that while the Kuwaiti plume was significantly modified by solar heating, self-lofting was comparatively ineffective in transporting the soot particles to higher altitudes. The maximum altitude where particle concentrations appeared above the normal background levels never exceeded about 6 km. However, self-lofting in the form of small convective elements within the larger plume were frequently observed by lidar.

The reasons for this limited role for self-lofting is evidently due to a combination of a much "whiter" than expected smoke plume (single scattering albedo ~0.6), a comparatively stable atmosphere and rather rapid dilution of the smokes. This latter effect was caused by both strong winds and solar induced plume dynamics. Plume dynamical effects were observed on a variety of scales including strong low level convergence along the length of the smoke plume.

*The National Center for Atmospheric Research is sponsored by the National Science Foundation

FLT 1491 (SOUTH FIELD SOURCE STUDY)
EMISSION FACTORS (in g C/kg)
University of Washington

Fuel Carbon Fraction (Cf) = 0.85

| Sample Time | Particle* | Soot | TOC(a)** | CO | CO2 | CH4 | TOC(v) | SO2* | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 0536 | 12.1 | 3.3 | 4.4 | 5.2 | 827.8 | 1.2 | 8.1 | 33.8 | 6.5 K ft CS sample*** |
| 0549 | 15.0 | 3.5 | 5.7 | 6.0 | 818.4 | 1.8 | 14.5 | 31.8 | 5.5 K ft CS sample |
| 0604 | 20.5 | 4.3 | 8.1 | 7.2 | 809.5 | 2.1 | 18.8 | 36.8 | 4.5 K ft CS sample |
| 0616 | 25.2 | 5.7 | 9.7 | 7.9 | 791.5 | 3.4 | 31.7 | 35.3 | 3.5 K ft CS sample |
| 0629 | 29.2 | 5.6 | 11.8 | 7.7 | 791.2 | 3.1 | 30.6 | 29.7 | 2.5 K ft CS sample |
| 0717 | 42.2 | 9.5 | 16.3 | 5.5 | 816.0 | 0.7 | 1.9 | 69.0 | Minagish pool fire sample |
| 0757 | 51.5 | 16.5 | 17.5 | 9.5 | 802.0 | 1.8 | 2.8 | 31.7 | Magwa pool fire sample |
| CS Average: | 20.4 | 4.5 | 7.9 | 6.8 | 807.7 | 2.3 | 20.8 | 33.5 | |
| CS Std Dev: | 7.0 | 1.1 | 3.0 | 1.2 | 16.2 | 0.9 | 10.2 | 2.8 | |

* Particle and SO2 emission factors in g/kg

** TOC(a) = Total organic carbon in aerosol
Estimated as (Particle mass conc. - Soot conc.)/2

*** CS = Cross section of Magwa/Burgan aggregate plume

FLT 1491 (SOUTH FIELD SOURCE STUDY)
CARBON BUDGET DATA
University of Washington

RESULTS FOR MINAGISH AND MAGWA POOL FIRE SAMPLES

All concentrations in ug C/m3
Values in parentheses are percent of total carbon

| Sample Time | Soot | TOC(a)* | CO-C | CO2-C | CH4-C | TOC(v) | Total C |
|---|---|---|---|---|---|---|---|
| 0717 | 181.4 | 311.3 | 105.5 | 15535.7 | 12.9 | 37.0 | 16183.8 |
| (Minagish) | (1.1) | (1.9) | (0.7) | (96.0) | (0.1) | (0.2) | |
| 0757 | 165.4 | 175.3 | 94.8 | 8035.7 | 17.7 | 28.0 | 8516.9 |
| (Magwa) | (1.9) | (2.1) | (1.1) | (94.4) | (0.2) | (0.3) | |

* TOC(a) = Total organic carbon in aerosol

FLT 1491 (SOUTH FIELD SOURCE STUDY)
CARBON BUDGET DATA
University of Washington

RESULTS FOR MAGWA/BURGAN AGGREGATE PLUME CROSS SECTION STUDY

All concentrations in ug C/m3
Values in parentheses are percent of total carbon

| Sample Time | Soot | TOC(a)* | CO-C | CO2-C | CH4-C | TOC(v) | Total C |
|---|---|---|---|---|---|---|---|
| 0536 | 63.6 | 85.2 | 101.3 | 16071.4 | 23.0 | 158.0 | 16502.5 |
| | (0.4) | (0.5) | (0.6) | (97.4) | (0.1) | (1.0) | |
| 0549 | 80.3 | 131.4 | 137.1 | 18750.0 | 41.8 | 333.0 | 19473.6 |
| | (0.4) | (0.7) | (0.7) | (96.3) | (0.2) | (1.7) | |
| 0604 | 94.3 | 176.4 | 157.0 | 17678.6 | 46.6 | 411.0 | 18563.8 |
| | (0.5) | (1.0) | (0.8) | (95.2) | (0.3) | (2.2) | |
| 0616 | 358.2 | 612.9 | 498.8 | 49821.4 | 213.2 | 1996.0 | 53500.5 |
| | (0.7) | (1.1) | (0.9) | (93.1) | (0.4) | (3.7) | |
| 0629 | 309.1 | 645.0 | 424.3 | 43392.9 | 171.4 | 1677.0 | 46619.6 |
| | (0.7) | (1.4) | (0.9) | (93.1) | (0.4) | (3.6) | |
| Avg % of Total C: | 0.5 | 0.9 | 0.8 | 95.0 | 0.3 | 2.4 | |
| Std Dev: | 0.2 | 0.4 | 0.1 | 1.9 | 0.1 | 1.2 | |

* TOC(a) = Total organic carbon in aerosol

FLT 1488 (NORTH FIELD SOURCE STUDY)
EMISSION FACTORS (in g C/kg)
University of Washington

Fuel Carbon Fraction (Cf) = 0.85

| Sample Time | Particle* | Soot | TOC(a)** | CO | CO2 | CH4 | TOC(v) | SO2* | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 0413 | 33.3 | 8.5 | 12.4 | 4.9 | 820.5 | 0.6 | 3.1 | 31.2 | Black plume sample |
| 0445 | 25.8 | 0.9 | 12.4 | 3.2 | 830.4 | 0.3 | 2.7 | 24.1 | White plume sample |
| 0524 | 15.2 | 3.1 | 6.1 | 18.5 | 786.6 | 4.7 | 31.0 | 18.9 | 3 K ft CS sample*** |
| 0620 | 20.1 | 2.8 | 8.7 | 4.8 | 824.2 | 0.9 | 8.7 | 17.2 | 2 K ft CS sample |
| CS Average: | 17.7 | 2.9 | 7.4 | 11.6 | 805.4 | 2.8 | 19.8 | 18.0 | |
| CS Std Dev: | 3.5 | 0.2 | 1.8 | 9.7 | 26.6 | 2.7 | 15.8 | 1.2 | |

* Particle and SO2 emission factors in g/kg

** TOC(a) = Total organic carbon in aerosol
Estimated as (Particle mass conc. - Soot conc.)/2

*** CS = Cross section of North field plume

FLT 1488 (NORTH FIELD SOURCE STUDY)
CARBON BUDGET DATA
University of Washington

RESULTS FOR BLACK AND WHITE INDIVIDUAL PLUME SAMPLES

All concentrations in ug C/m3
Values in parentheses are percent of total carbon

| Sample Time | Soot | TOC(a)* | CO-C | CO2-C | CH4-C | TOC(v) | Total C |
|---|---|---|---|---|---|---|---|
| 0413 | 172.1 | 250.4 | 99.6 | 16607.1 | 11.3 | 63.0 | 17203.6 |
| (Black plume) | (1.0) | (1.5) | (0.6) | (96.5) | (0.1) | (0.4) | |
| 0445 | 39.8 | 537.6 | 137.1 | 35892.9 | 14.5 | 118.0 | 36739.9 |
| (White plume) | (0.1) | (1.5) | (0.4) | (97.7) | (0.04) | (0.3) | |

* TOC(a) = Total organic carbon in aerosol

FLT 1488 (NORTH FIELD SOURCE STUDY)
CARBON BUDGET DATA
University of Washington

RESULTS FOR NORTH FIELD PLUME CROSS SECTION STUDY

All concentrations in ug C/m3
Values in parentheses are percent of total carbon

| Sample Time | Soot | TOC(a)* | CO-C | CO2-C | CH4-C | TOC(v) | Total C |
|---|---|---|---|---|---|---|---|
| 0524 | 16.8<br>(0.4) | 33.1<br>(0.7) | 100.7<br>(2.2) | 4285.7<br>(92.5) | 25.7<br>(0.6) | 169.0<br>(3.6) | 4631.0 |
| 0620 | 19.9<br>(0.3) | 62.0<br>(1.0) | 34.3<br>(0.6) | 5892.9<br>(97.0) | 6.4<br>(0.1) | 62.0<br>(1.0) | 6077.5 |
| Avg % of Total C: | 0.4 | 0.9 | 1.4 | 94.8 | 0.4 | 2.3 | |
| Std Dev: | 0.1 | 0.2 | 1.1 | 3.2 | 0.4 | 1.8 | |

* TOC(a) = Total organic carbon in aerosol

KUWAIT · SUMMER 1991 University of Washington CANNISTER SAMPLES (PARTIAL RESULTS)

| Sample No. | Can S/N | Date | Time | Altitude ft. | Comments | H2 ppbv | CO ppbv | CO ppbv | CH4 ppbv | CO2 ppmv | TO-12 g/m-3 | N2O ppbv |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flight 1477 | | | | | | | | | | | | |
| 1 | RF7 | 16-May-91 | 724 | 16,500 | Clear (background sample | 533 | 79 | 92 | 1749 | 367 | 334.0 | 342.7 |
| | | | | | | 526 | 79 | | | | | 343.1 |
| 2 | RF5 | 16-May-91 | 823 | 10,500 | Haze, top of smoke layer over Kuwait | 541 | 132 | | | | 881.5 | |
| | | | | | | 563 | 133 | 149 | 1762 | 428 | | |
| Flight 1480 | | | | | | | | | | | | |
| 3 | RP5 | 22-May-91 | 1032 | 5,000 | Haze, smoke over Kuwait | 572 | 260 | 284 | 1841 | 387 | 650.1 | 342.2 |
| | | | | | | 535 | 263 | | | | | |
| | | | | | | 564 | 261 | | | | | |
| | | | | | | 587 | 264 | | | | | |
| 4 | RF6 | 22-May-91 | 1053 | 4,700 | Haze, smoke over Arabian gulf. | 527 | 137 | 154 | 1797 | 368 | 106.3 | 343.3 |
| | | | | | | 536 | 137 | | | | | |
| 5 | RF13 | 22-May-91 | 1124 | 4,000 | Clear, background sample | | | 123 | 1792 | 362 | 77.6 | 343.6 |
| Flight 1481 | | | | | | | | | | | | |
| 6 | RF14 | 27-May-91 | 703 | 8,000 | Haze; plune sample at 80C0 ft. | | | 152 | 1782 | 381 | 259.7 | 340.6 |

| Sample No. | Can S/N | Date | Time | Altitude ft. | Comments | H2 ppbv | CO ppbv | CO ppbv | CH4 ppbv | CO2 ppmv | TO-12 ug/m-3 | N2O ppbv |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Flight 1481 (continued)** | | | | | | | | | | | | |
| 8 | RF16 | 27-May-91 | 814 | 4,000 | Haze, plume sample | | | 240 | 1824 | 378 | 283.4 | 342.4 |
| 9 | RF1 | 27-May-91 | 914 | 2,500 | Haze, smoke from Kuwait oil fires | 716 | 206 | 231 | 1806 | 375 | 308.9 | 340.7* |
| | | | | | | 548 | 208 | | | | | 343.0 |
| | | | | | | 512 | 208 | | | | | |
| | | | | | | 515 | 208 | | | | | |
| 10 | RF2 | 27-May-91 | 1118 | 11,500 | Haze, smoke sample; sample in plume ESE of Bahrain | 575 | 106 | 119 | 1758 | 366 | 53.3 | 341.6 |
| | | | | | | 542 | 106 | | | | | 342.9 |
| | | | | | | 530 | 106 | | | | | |
| | | | | | | 530 | 106 | | | | | |
| **Flight 1482** | | | | | | | | | | | | |
| 11 | RF3 | 28-May-91 | 1130 | 12,000 | Clear; ambient sample above plume. | 555 | 79 | 84 | 1757 | 362 | 76.3 | 342.6 |
| | | | | | | 535 | 79 | | | | | |
| | | | | | | 526 | 79 | | | | | |
| | | | | | | 530 | 80 | | | | | |
| 12 | RF4 | 28-May-91 | 1206 | 10,100 | Haze smoke sample. | 534 | 151 | 163 | 1778 | 373 | 104.2 | 341.4 |
| | | | | | | 542 | 151 | | | | | |
| | | | | | | 524 | 152 | | | | | |
| | | | | | | 532 | 151 | | | | | |
| | | | | | | 520 | 152 | | | | | |
| | | | | | | 516 | 152 | | | | | |
| 13 | RF81 | 28-May-91 | 1248 | 8,100 | Haze, smoke sample; measurements at time of sample: CO 0.1 ppm, CO2 392 ppm | 546 | 133 | 148 | 1777 | 369 | 83.4 | 343.6 |
| | | | | | | 528 | 133 | | | | | |
| 14 | RF82 | 28-May-91 | 1329 | 6,100 | Haze, smoke sample; | 511 | 280 | 310 | 1807 | 384 | 231.6 | 334.4 |
| | | | | | | 521 | 281 | | | | | |
| | | | | | | 554 | 284 | | | | | |
| | | | | | | 555 | 285 | | | | | |

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| Sample No. | Can S/N | Date | Time | Altitude ft. | Comments | H2 ppbv | CO ppbv | CO ppbv | CH4 ppbv | CO2 ppmv | TO-12 ug/m-3 | N2O ppbv |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flight 1482 (continued) | | | | | | | | | | | | |
| 15 | RF83 | 28-May-91 | 1401 | 4,100 | Haze, smoke sample; | 524<br>517 | 190<br>190 | 213 | 1816 | 372 | 255.6 | 342.1 |
| Flight 1484 | | | | | | | | | | | | |
| 16 | RF84 | 31-May-91 | 828 | | Haze, smoke sample; | 524<br>517 | 350<br>352 | 381<br>374 | 1809<br>1810 | 394<br>394 | 238.4 | 343.0 |
| 17 | RF33 | 31-May-91 | 843 | | Haze, smoke sample (same plume as for can RF 84) | | | 396 | 1815 | 399 | 245.6 | 346.0<br>345.3 |
| 18 | RF34 | 31-May-91 | 920 | | Haze, smoke sample, | | | 151 | 1791 | 365 | 62.0 | 341.5<br>341.1 |
| 19 | RF35 | 31-May-91 | 932 | | Haze, smoke sample (same plume as for can RF 34) | | | 144 | 1793 | 364 | 53.6 | 342.0<br>342.0 |
| 20 | RF36 | 31-May-91 | 1006 | | Haze, smoke sample (white plume); | | | 210 | 1789 | 368 | 134.9 | 342.6 |
| 21 | RF41 | 31-May-91 | 1038 | 3,500 | Haze, plume sample | 531<br>552 | 292<br>294 | 313 | 1848 | 384 | 538.0 | 341.4 |

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| Sample No. | Can S/N | Date | Time | Altitude ft. | Comments | H2 ppbv | CO ppbv | CO ppbv | CH4 ppbv | CO2 ppmv | TO-12 ug/m-3 | N2O ppbv |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flight 1484 (continued) | | | | | | | | | | | | |
| 22 | RF42 | 31-May-91 | 1053 | 3,500 | Haze, main plume sample. | 558 | 313 | 334 | 1848 | 381 | 565.1 | |
| | | | | | | 557 | 315 | | | | | |
| 23 | RF43 | 31-May-91 | 1111 | 5,000 | Haze, plume sample 20 mi. | 540 | 446 | 470 | 1817 | 402 | 475.4 | 343.4 |
| | | | | | from fire at 5000 ft. | 559 | 446 | | | | | |
| Flight 1485 | | | | | | | | | | | | |
| 24 | RF44 | 02-Jun-91 | 716 | 8,000 | Haze, plume sample at | 531 | 121 | | | | | 344.0 |
| | | | | | 8000 ft. | 526 | 121 | 140 | 1780 | 379 | 206.5 | |
| 25 | RF45 | 02-Jun-91 | 809 | 5,600 | Haze, plume sample at | 564 | 301 | 332 | 1802 | 405 | 298.7 | 344.9 |
| | | | | | 5600 ft. | 548 | 303 | | | | | 342.8* |
| Flight 1486 | | | | | | | | | | | | |
| 25 | RF46 | 03-Jun-91 | 842 | 3,000 | Haze, plume sample at | 525 | 278 | 296 | 1811 | 378 | 275.9 | 343.6 |
| | | | | | 3000 ft. | 528 | 280 | | | | | |
| 27 | RF47 | 03-Jun-91 | 923 | 3,500 | Haze, plume sample at | 524 | 428 | | | | 462.1 | 344.2 |
| | | | | | 3500 ft. | 536 | 432 | 448 | 1829 | 398 | | |
| 28 | RF48 | 03-Jun-91 | 939 | 3,500 | Haze, plume sample | 517 | 283 | 297 | 1828 | 380 | 365 6 | 344.2 |
| | | | | | | 523 | 284 | | | | | |
| | | | | | | | | | | | | 340 9* |
| | | | | | | | | | | | | 339.8 |

* calibrated just before run

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| Sample No. | Can S/N | Date | Time | Altitude ft. | Comments | H2 ppbv | CO ppbv | CO ppbv | CH4 ppbv | CO2 ppmv | FO-12 ug/m-3 | N2O ppbv |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flight 1486 (continued) | | | | | | | | | | | | |
| 29 | RF89 | 03-Jun-91 | 959 | 3,500 | Haze, plume sample | 543 | 270 | 288 | 1818 | 378 | 265.7 | 342.8 |
| | | | | | | 542 | 271 | | | | | 342.4 |
| 30 | RF90 | 03-Jun-91 | 1021 | 3,500 | Haze, plume sample | 541 | 303 | 314 | 1823 | 379 | 353.8 | 342.2* |
| | | | | | | 536 | 305 | | | | | |
| 31 | RF91 | 03-Jun-91 | 1040 | 3,500 | Haze, plume sample | 536 | 187 | 202 | 1784 | 369 | 177.4 | 342.5* |
| | | | | | | 547 | 188 | | | | | |
| | | | | | | 527 | 185 | | | | | |
| | | | | | | 520 | 186 | | | | | |
| 32 | RF92 | 03-Jun-91 | 1101 | 3,500 | Haze, plume sample | 534 | 224 | 246 | 1802 | 377 | 249.5 | 341.3 |
| | | | | | | 528 | 225 | | | | | |
| 33 | RF9 | 03-Jun-91 | 1119 | 3,500 | Haze, plume sample | 516 | 197 | 218 | 1794 | 369 | 189.8 | 340.2 |
| | | | | | | 526 | 198 | | | | | |
| 34 | RF10 | 03-Jun-91 | 1145 | 3,500 | Haze, plume sample | 533 | 176 | 194 | 1787 | 366 | 191.3 | 340.6 |
| | | | | | | 530 | 177 | | | | | 342.3 |
| 35 | RF11 | 03-Jun-91 | 1205 | 3,500 | Haze, plume sample | 578 | 190 | 209 | 1805 | 370 | 260.4 | 343.3 |
| | | | | | | 574 | 190 | | | | | |
| 36 | RF12 | 03-Jun-91 | 1312 | | Clear, background sample | 528 | 71 | 83 | 1757 | 353 | [illegible] | 342.9 |
| | | | | | | 520 | 72 | | | | | |

* calibrated just before run

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| Sample No. | Can S/N | Date | Time | Altitude ft. | Comments | H2 ppbv | CO ppbv | CO ppbv | CH4 ppbv | CO2 ppmv | TO-12 ug/m-3 | N2O ppbv |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flight 1487 | | | | | | | | | | | | |
| 37 | RF69 | 05-Jun-91 | 801 | 2,500 | Haze, plume sample at 2500 ft. | | | 277 | 1813 | 405 | 315.4 | 335.5 |
| 38 | RF70 | 05-Jun-91 | 818 | 2,700 | Haze, plume sample at 2700 ft. | | | 158 | 1793 | 366 | 111.2 | 340.5 |
| 39 | RF71 | 05-Jun-91 | 830 | 2,700 | Haze, plume sample at 2700 ft. | | | 149 | 1803 | 363 | 122.2 | 340.6<br>346.4 |
| Flight 1488 | | | | | | | | | | | | |
| 40 | RF72 | 08-Jun-91 | 413 | | Haze, black plume sample | | | 280 | 1780 | 390 | 107.9 | 341.1<br>344.6 |
| 41 | RF49 | 08-Jun-91 | 424 | | Haze, black plume sample | | | 255 | 1781 | 388 | 140.2 | |
| 42 | RF50 | 08-Jun-91 | 445 | | Haze, white plume sample | | | 350 | 1786 | 423 | 162.7 | 341.2<br>343.9 |
| 43 | RF51 | 08-Jun-91 | 457 | | Haze, white plume sample | | | 565 | 1791 | 416 | 244.3 | |

| Sample No. | Can S/N | Date | Time | Altitude ft. | Comments | H2 ppbv | CO ppbv | CO ppbv | CH4 ppbv | CO2 ppmv | TO-12 ug/m-3 | N2O ppbv |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Flight 1488 (continued)** | | | | | | | | | | | | |
| 44 | RF52 | 08-Jun-91 | 524 | 3,000 | Haze, plume sample 20 mi. downwind at 3000 ft. | | | 282 | 1807 | 388 | 213.9 | 344.9* 347.5 |
| 45 | RF93 | 08-Jun-91 | 553 | 2,500 | Haze, plume sample; | 1037<br>610<br>549<br>554 | 193<br>195<br>195<br>195 | 217 | 1793 | 384 | 158.4 | 341.7 |
| 46 | RF94 | 08-Jun-91 | 620 | 2,000 | Haze, plume sample; | 1017<br>640<br>562<br>556 | 141<br>141<br>141<br>141 | 158 | 1771 | 368 | 106.9 | 341.2 |
| 47 | RF95 | 08-Jun-91 | 637 | 2,000 | Haze, plume sample; | 856<br>556<br>528 | 139<br>139<br>139 | 157 | 1775 | 368 | 78.7 | 342.0 |
| 48 | RF96 | 08-Jun-91 | 717 | | Clear, background sample below smoke; | 875<br>805<br>806 | 80<br>81<br>80 | 94 | 1759 | 361 | 45.4 | 338.6 |
| 49 | RF29 | 08-Jun-91 | 736 | | Clear, background sample East of smoke; | 771<br>572<br>551 | 84<br>84<br>84 | 98<br>55 | 1755<br>1757 | 359<br>358 | 37.7 | 340.9 |
| **Flight 1489** | | | | | | | | | | | | |
| 50 | RF30 | 09-Jun-91 | 635 | 1,000 | Haze, black plume sample | | | 115 | 1778 | 371 | 34.9 | 342.5* |
| 51 | RF31 | 09-Jun-91 | 645 | 1,000 | Haze, black plume sample | 537<br>528<br>524 | 116<br>117<br>[illegible] | 130 | 1776 | [illegible] | [illegible] | 340.8* |

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| Sample No. | Can S/N | Date | Time | Altitude ft | Comments | H2 ppbv | CC ppbv | CO ppbv | CH4 ppbv | CO2 ppmv | 70-12 ug/m-3 | N20 ppbv |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flight 1489 (continued) | | | | | | | | | | | | |
| 52 | RF32 | 09-Jun-91 | 710 | 1,000 | Haze, black plume sample | | | 198 | 1784 | 376 | 151.4 | 341.6 |
| | | | | | | | | 195 | 1786 | 376 | | |
| 53 | RF21 | 09-Jun-91 | 725 | 1,000 | Haze, white plume sample | 546 | 207 | 208 | 1789 | 396 | 406.2 | |
| | | | | | | 548 | 208 | | | | | |
| 54 | RF22 | 09-Jun-91 | 747 | 1,000 | Haze, large black plume | 568 | 363 | 380 | 1790 | 376 | 637.2 | 338.5 |
| | | | | | | 555 | 366 | | | | | 338.4 |
| 55 | RF23 | 09-Jun-91 | 759 | 5,000 | Haze, main plume sample at 5000 ft. | 575 | 440 | 461 | 1784 | 404 | 347.4 | 342.4 |
| | | | | | | 558 | 443 | | | | | 341.9 |
| 56 | RF24 | 09-Jun-91 | 816 | 5,000 | Haze, main plume sample | 546 | 184 | 197 | 1786 | 373 | 116.0 | 343.0 |
| | | | | | | 532 | 186 | | | | | |
| | | | | | | 535 | 186 | | | | | |
| Flight 1490 | | | | | | | | | | | | |
| 57 | RF77 | 11-Jun-91 | 927 | 4,500 | Haze, plume sample | | | 118 | 1778 | 362 | 50.7 | 340.8 |
| 58 | RF53 | 11-Jun-91 | 540 | | Background, west of plume. | | | 105 | 1769 | 360 | 72.[illegible] | 340.0 |
| 59 | RF54 | 11-Jun-91 | 601 | 4,000 | Plume sample | | | 252 | 1787 | 379 | 166.0 | 342.8 |

KUWAIT - SUMMER 1991 University of Washington

| Sample No. | Can S/N | Date | Time | Altitude ft. | Comments | H2 ppbv | CO ppbv | CO ppbv | CH4 ppbv | CO2 ppmv | TO-12 ug/m-3 | N2O ppbv |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flight 1450 (continued) | | | | | | | | | | | | |
| 60 | RF55 | 11-Jun-91 | 621 | 4,500 | Plume sample | | | 288 | 1781 | 380 | 160.6 | 343.9 |
| 61 | RF56 | 11-Jun-91 | 640 | 4,500 | Plume sample | | | 377 | 1822 | 392 | 355.7 | 339.4 |
| | | | | | | | | | | | | 342.1 |
| 62 | RF65 | 11-Jun-91 | 704 | 4,500 | Plume sample; | 545 | 221 | 238 | 1787 | 375 | 181.7 | 341.0 |
| | | | | | | 567 | 222 | | | | | |
| 63 | RF66 | 11-Jun-91 | 729 | 4,500 | Plume sample; | 537 | 163 | 182 | 1785 | 370 | 131.5 | 342.9 |
| | | | | | | 539 | 163 | 177 | 1785 | 370 | | |
| 64 | RF67 | 11-Jun-91 | 806 | 4,500 | Plume sample; | 820 | 175 | 192 | 1860 | 374 | 318.4 | 344.2 |
| | | | | | | 819 | 176 | | | | | |
| 65 | RF68 | 11-Jun-91 | 840 | 4,500 | Plume sample; | 583 | 117 | 132 | 1783 | 364 | 48.8 | 341.9 |
| | | | | | | 583 | 112 | 123 | 1775 | 363 | | |
| Flight 1491 | | | | | | | | | | | | |
| 69 | RF78 | 12-Jun-91 | 536 | 6,500 | Haze, plume sample at 6500 ft. | | | 287 | 1798 | 388 | 220.7 | 342.3 |
| 70 | RF7[illegible] | 12-Jun-91 | 549 | 5,500 | Haze, plume sample at 5500 ft. | | | 354 | 1833 | 395 | 396.2 | 342.2 |

| Sample No. | Can S/N | Date | Time | Altitude ft. | Comments | $H_2$ ppbv | CO ppbv | CO ppbv | $CH_4$ ppbv | $CO_2$ ppmv | TO-12 ug/m-3 | $N_2O$ ppbv |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Flight 1491 (continued)** | | | | | | | | | | | | |
| 71 | RF80 | 12-Jun-91 | 604 | 4,500 | Haze, plume sample at 4500 ft. | | | 391 | 1842 | 39[illegible] | 474.0 | *343.8 |
| 72 | RF97 | 12-Jun-91 | 616 | 3,500 | Haze, plume sample at 3500 ft. | 614 (3)<br>628 (3) | 969<br>973 | 1029 | 2153 | 465 | 2058.8 | 358.4 |
| 73 | RF98 | 12-Jun-91 | 629 | 2,500 | Haze, plume sample at 2500 ft. | 596 (3)<br>614 (3) | 845<br>848 | 890 | 2075 | 450 | 1739.6 | 342.7<br>343.9 |
| 74 | RF99 | 12-Jun-91 | 642 | 1,500 | Haze below plume sample at 1500 ft. | 500<br>515 | 98<br>98 | 113 | 1780 | 359 | 62.7 | 340.9 |
| 75 | RF100 | 12-Jun-91 | 717 | 900 | Haze, pool fire plume sample; | 532<br>517<br>757<br>614 | 271<br>272<br>270<br>269 | 296<br>293 | 1781<br>1777 | 367<br>386 | 99.9 | |
| 76 | RF85 | 12-Jun-91 | 757 | 900 | Haze, Magwa plume sample | 862<br>613 | 247<br>249 | 275 | 1788 | 372 | 90.7 | |

* calibrated just before run

# SUMMARY OF "GRAB BAG" CHEMICAL SAMPLES OBTAINED BY UNIVERSITY OF WASHINGTON IN THE KUWAIT OIL FIRE STUDY (16 MAY – 12 JUNE 1991)

| Date, 1991 | UW Flight # | Samples Collected†* | Time of Sample (UTC) | Notes |
|---|---|---|---|---|
| May 16 | 1477 | 37 | 0704 | Background above smoke |
| | | C | 0724 | Background above smoke |
| | | H,37,G,47,C | 0823 | Smoke from South Fires at 10,500 ft |
| | | H,37,G,47 | 0846 | Smoke at 9,000 ft |
| | | 37,G | 0859 | Smoke at 9,000 ft |
| | | 37,G,47 | 0924 | Mid-plume at 8,000 ft |
| | | 37,47 | 0938 | Smoke at 7,000 ft |
| | | 37,47,H,G | 1020 | Power failure, short sample |
| May 18 | 1478 | 37 | 0621 | Background above smoke |
| | | 37 | 0643 | Background above smoke |
| | | 37,H,G | 0732 | Background below smoke |
| | | 37,H,G | 0757 | Thickest smoke from South Fires, 4,000 ft |
| | | 37,H,G | 0806 | Thickest smoke from South Fires, 4,000 ft |

* C = Rasmussen "cans" – for gaseous organics, THC, CO, $CO_2$, $N_2O$, $CH_4$, and Freons
Q = Quartz filters for organic aerosols
37 = 37 mm Teflon filters for soot, mass, elemental analysis, inorganic ions
47 = 47 mm Teflon filters for inorganic ions
H = Impregnated filters for $H_2S$
G = Electron microscope grids for morphological and elemental analysis of individual particles
N = Nucleopore filters for SEM analysis

† In addition to the "grab" samples listed here continuous measurements of NO, $NO_2$, $SO_2$, CO, $CO_2$, $O_3$ were made aboard the aircraft.

| Date, 1991 | UW Flight # | Samples Collected† * | Time of Sample (UTC) | Notes |
|---|---|---|---|---|
| May 22 | 1480 | G | 0719 | Old smoke near Qatar |
| | | 37,G | 1019 | Point A, 3,500 ft, between Kuwait and Bahrain |
| | | 37,G,C | 1032 | Point B smoke, 5,000 ft, between Kuwait and Bahrain |
| | | 37,G,C | 1053 | Point C smoke, 4,700 ft, between Kuwait and Bahrain |
| | | 37,C | 1124 | Background, 4,000 ft |
| May 27 | 1481 | 37,G,C | 0703 | Point C, 8,000 ft, (No "D") |
| | | 37,C | 0738 | Point E, 4,000 ft, cross section ~30 miles south of Al Burgan |

(Cont.)

* C = Rasmussen "cans" – for gaseous organics, THC, CO, $CO_2$, $N_2O$, $CH_4$, and Freons
Q = Quartz filters for organic aerosols
37 = 37 mm Teflon filters for soot, mass, elemental analysis, inorganic ions
47 = 47 mm Teflon filters for inorganic ions
H = Impregnated filters for $H_2S$
G = Electron microscope grids for morphological and elemental analysis of individual particles
N = Nucleopore filters for SEM analysis

† In addition to the "grab" samples listed here continuous measurements of NO, $NO_2$, $SO_2$, CO, $CO_2$, $O_3$ were made aboard the aircraft.

| Date, 1991 | UW Flight # | Samples Collected† * | Time of Sample (UTC) | Notes |
|---|---|---|---|---|
| May 27 | 1481 | 37,H | 0755 | Point F, 4,000 ft, cross section ~30 miles south of Al Burgan |
| | | C,Q,H,G | 0814 | Point G, 4,200 ft, cross section ~30 miles south of Al Burgan |
| | | 37,C | 0914 | Point H, 2,500 ft, cross section ~30 miles south of Al Burgan |
| | | 37,G | 0934 | Point D, 4,000 ft, on return from Kuwait to Manama |
| | | 37,H | 1011 | Point C, 8,900 ft, on return from Kuwait to Manama |
| | | 37,G | 1031 | Point B, 12,000 ft, on return from Kuwait to Manama |
| | | 37,G | 1045 | Point A, 12,000 ft, on return from Kuwait to Manama |
| | | 37,C | 1118 | Point X, Background?, 11,500 feet, south of Bahrain (Plume accord to PVH) |

* C = Rasmussen "cans" – for gaseous organics, THC, CO, $CO_2$, $N_2O$, $CH_4$, and Freons
Q = Quartz filters for organic aerosols
37 = 37 mm Teflon filters for soot, mass, elemental analysis, inorganic ions
47 = 47 mm Teflon filters for inorganic ions
H = Impregnated filters for $H_2S$
G = Electron microscope grids for morphological and elemental analysis of individual particles
N = Nucleopore filters for SEM analysis

† In addition to the "grab" samples listed here continuous measurements of NO, $NO_2$, $SO_2$, CO, $CO_2$, $O_3$ were made aboard the aircraft.

| Date, 1991 | UW Flight # | Samples Collected† * | Time of Sample (UTC) | Notes |
|---|---|---|---|---|
| May 28 | 1482 | 37,C | 1130 | Background, above smoke |
| | | 37,C | 1206 | Smoke, 10,100 ft, cross section near Selig |
| | | 37,C | 1248 | Smoke, 8,100 ft, cross section near Selig |
| | | 37,C | 1329 | Smoke, 6,100 ft, cross section near Selig |
| | | 37,C | 1401 | Smoke, 4,100 ft, cross section near Selig |
| | | 37 | 1452 | Background below smoke |
| May 29 | 1483 | | | (Wing-tip inter-comparison with NCAR Electra at 085201 UTC on Convair Systron) |
| | | 37,G | 0941 | Background below smoke |
| | | 37,G | 1028 | Mid-plume, 7,000 ft |

* C = Rasmussen "cans" – for gaseous organics, THC, CO, $CO_2$, $N_2O$, $CH_4$, and Freons
Q = Quartz filters for organic aerosols
37 = 37 mm Teflon filters for soot, mass, elemental analysis, inorganic ions
47 = 47 mm Teflon filters for inorganic ions
H = Impregnated filters for $H_2S$
G = Electron microscope grids for morphological and elemental analysis of individual particles
N = Nucleopore filters for SEM analysis

† In addition to the "grab" samples listed here continuous measurements of NO, $NO_2$, $SO_2$, CO, $CO_2$, $O_3$ were made aboard the aircraft.

| Date, 1991 | UW Flight # | Samples Collected† * | Time of Sample (UTC) | Notes |
|---|---|---|---|---|
| May 31 | 1484 | 37,C,G | 0828 | Point C (black, or dark gray plume(s)), Al Burgan Area |
| | | Q,C,H,G | 0843 | Point C', 2nd sample of above |
| | | 37,C | 0920 | Point D, (Isolated black plume), Al Burgan Area |
| | | Q,C | 0932 | Point D (2nd sample of same isolated black plume) |
| | | 37,C,G | 1006 | Point E (White plume), Al Burgan Area |
| | | 37,C,G | 1038 | Point F, 3,500 ft (Composite Burgan plume) |
| | | Q,G,H,C | 1051 | Point F, 2nd sample (Composite Burgan plume) |
| | | 37,C | 1111 | Point G, 5,000 ft, (Composite Burgan plume) |
| | | 37,G | 1125 | Smoke, 5,000 ft |

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Q = Quartz filters for organic aerosols
37 = 37 mm Teflon filters for soot, mass, elemental analysis, inorganic ions
47 = 47 mm Teflon filters for inorganic ions
H = Impregnated filters for $H_2S$
G = Electron microscope grids for morphological and elemental analysis of individual particles
N = Nucleopore filters for SEM analysis

† In addition to the "grab" samples listed here continuous measurements of NO, $NO_2$, $SO_2$, CO, $CO_2$, $O_3$ were made aboard the aircraft.

| Date, 1991 | UW Flight # | Samples Collected† * | Time of Sample (UTC) | Notes |
|---|---|---|---|---|
| June 2 | 1485 | 37 | 0655 | 8,000 ft, Composite Plume South of Al Burgan |
| | | Q,C | 0716 | 8,000 ft, 2nd sample of above, Composite Plume South of Al Burgan |
| | | 37 | 0746 | 5,600 ft, Composite Plume South of Al Burgan |
| | | Q,C | 0809 | 5,600 ft, 2nd sample of above, Composite Plume South of Al Burgan |
| June 3 | 1486 | Q,C | 0842 | Smoke, center of plume, 3,000 ft |
| | | 37,C,G | 0923 | Lagranian drift measurements in composite plume. Point A, 3,500 ft |
| | | 37,C | 0939 | Lagranian drift measurements in composite plume. Point B, 3,500 ft |

(Cont.)

* C = Rasmussen "cans" – for gaseous organics, THC, CO, $CO_2$, $N_2O$, $CH_4$, and Freons
Q = Quartz filters for organic aerosols
37 = 37 mm Teflon filters for soot, mass, elemental analysis, inorganic ions
47 = 47 mm Teflon filters for inorganic ions
H = Impregnated filters for $H_2S$
G = Electron microscope grids for morphological and elemental analysis of individual particles
N = Nucleopore filters for SEM analysis

† In addition to the "grab" samples listed here continuous measurements of NO, $NO_2$, $SO_2$, CO, $CO_2$, $O_3$ were made aboard the aircraft.

| Date, 1991 | UW Flight # | Samples Collected† * | Time of Sample (UTC) | Notes |
|---|---|---|---|---|
| June 3 | 1486 | 37,C,G | 0959 | Lagranian drift measurements in composite plume. Point C, 3,500 ft |
| | | 37,C | 1021 | Lagranian drift measurements in composite plume. Point D, 3,500 ft |
| | | 37,C,G | 1040 | Lagranian drift measurements in composite plume. Point E, 3,500 ft |
| | | 37 | 1101 | Lagranian drift measurements in composite plume. Point F, 3,500 ft |
| | | 37,C,G | 1119 | Lagranian drift measurements in composite plume. Point G, 3,500 ft |
| | | 37,C | 1146 | Point H, 3,500 ft (100 miles from A), Lagranian measurements in composite plume. |
| | | Q,C,G | 1205 | Point I, Ht?, Lagranian measurements in composite plume. |

(Cont.)

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Q = Quartz filters for organic aerosols
37 = 37 mm Teflon filters for soot, mass, elemental analysis, inorganic ions
47 = 47 mm Teflon filters for inorganic ions
H = Impregnated filters for $H_2S$
G = Electron microscope grids for morphological and elemental analysis of individual particles
N = Nucleopore filters for SEM analysis

† In addition to the "grab" samples listed here continuous measurements of NO, $NO_2$, $SO_2$, CO, $CO_2$, $O_3$ were made aboard the aircraft.

| Date, 1991 | UW Flight # | Samples Collected† * | Time of Sample (UTC) | Notes |
|---|---|---|---|---|
| June 3 | 1486 | 37,G | 1234 | Point J, 2,700 ft (near base), Lagranian measurements in composite plume. |
| | | 37,G | 1251 | Point K, 3,500 ft, Lagranian measurements in composite plume. |
| | | 37,C | 1312 | Background |
| June 5 | 1487 | 37,C,G | 0801 | Smoke from composite North Plume (exploration measurements) 2,500 ft |
| | | 37,C,G | 0818 | Smoke from composite North Plume (1st proper sample at mid-point) 2,700 ft |
| | | Q,G,C,H | 0830 | Smoke from composite North Plume (2nd sample, mid-point) 2,700 ft |
| | | | | Flight cut short due to generator failure |

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Q = Quartz filters for organic aerosols
37 = 37 mm Teflon filters for soot, mass, elemental analysis, inorganic ions
47 = 47 mm Teflon filters for inorganic ions
H = Impregnated filters for $H_2S$
G = Electron microscope grids for morphological and elemental analysis of individual particles
N = Nucleopore filters for SEM analysis

† In addition to the "grab" samples listed here continuous measurements of NO, $NO_2$, $SO_2$, CO, $CO_2$, $O_3$ were made aboard the aircraft.

| Date, 1991 | UW Flight # | Samples Collected† * | Time of Sample (UTC) | Notes |
|---|---|---|---|---|
| June 8 | 1488 | 37,C,G | 0413 | Subiriyah (North Field), A-1, Isolated black plume |
| | | Q,C,H | 0424 | Subiriyah (North Field), A-2, Same plume |
| | | 37,C,G | 0445 | Subiriyah (North Field), B-1, White plume (black behind) |
| | | Q,C,G,H | 0457 | Subiriyah (North Field), B-2, same plume |
| | | 37,C | 0524 | Smoke from composite North Plume, Point C, 3,000 ft (top of plume), cross section 20 miles from upwind edge of fires |
| | | 37,C,G | 0541 | Smoke from composite North Plume, Point D, 2,200 ft (middle plume), cross section 20 miles from upwind edge of fires |

(Cont.)

* C = Rasmussen "cans" – for gaseous organics, THC, CO, $CO_2$, $N_2O$, $CH_4$, and Freons
Q = Quartz filters for organic aerosols
37 = 37 mm Teflon filters for soot, mass, elemental analysis, inorganic ions
47 = 47 mm Teflon filters for inorganic ions
H = Impregnated filters for $H_2S$
G = Electron microscope grids for morphological and elemental analysis of individual particles
N = Nucleopore filters for SEM analysis

† In addition to the "grab" samples listed here continuous measurements of NO, $NO_2$, $SO_2$, CO, $CO_2$, $O_3$ were made aboard the aircraft.

| Date, 1991 | UW Flight # | Samples Collected† * | Time of Sample (UTC) | Notes |
|---|---|---|---|---|
| June 8 | 1488 | Q,C,H,G | 0553 | Smoke from composite North Plume, D-2, 2nd sample, cross section 20 miles from upwind edge of fires |
| | | 37,C | 0620 | Smoke from composite North Plume, E-1 (lower plume), cross section 20 miles from upwind edge of fires |
| | | Q,C,H,G | 0637 | Smoke from composite North Plume, E-2, 2nd sample, cross section 20 miles from upwind edge of fires |
| | | 37,C | 0717 | Background below sample |
| | | 37,C | 0736 | Background east of smoke |
| June 9 | 1489 | 37,C,G | 0635 | A, individual, black plume, (Minagish) |
| | | Q,C,H,N | 0645 | A-2, same plume |
| | | 37,C,G,N | 0710 | B, white plume (Minagish?) |

(Cont.)

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37 = 37 mm Teflon filters for soot, mass, elemental analysis, inorganic ions
47 = 47 mm Teflon filters for inorganic ions
H = Impregnated filters for $H_2S$
G = Electron microscope grids for morphological and elemental analysis of individual particles
N = Nucleopore filters for SEM analysis

† In addition to the "grab" samples listed here continuous measurements of NO, $NO_2$, $SO_2$, CO, $CO_2$, $O_3$ were made aboard the aircraft.

| Date, 1991 | UW Flight # | Samples Collected† * | Time of Sample (UTC) | Notes |
|---|---|---|---|---|
| June 9 | 1489 | Q,C,G,N,H | 0723 | B-2, same plume |
| | | 37,C,G | 0747 | C, large black plume (Umm Gadair) |
| | | 37,C | 0759 | Composite plume from North Field(?), 5,000 ft, Enroute from Kuwait to Bahrain |
| | | Q,C | 0816 | Composite plume from North Field(?), Enroute from Kuwait to Bahrain |
| | | 37,G | 0842 | Composite plume from North Field(?), 3,500 ft, Enroute from Kuwait to Bahrain |
| June 11 | 1490 | 37,C,H | 0540 | Background, West of plume, 4,500 ft |
| | | 37,C,G,H | 0601 | Point B |
| | | 37,C,G,H | 0621 | Point 1, (~25 n. miles from South fields), 4,500 ft |
| | | Q,C,G,H | 0640 | Point 2, 4,500 ft. Lagrangian drift measurements in composite plume |

(Cont.)

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Q = Quartz filters for organic aerosols
37 = 37 mm Teflon filters for soot, mass, elemental analysis, inorganic ions
47 = 47 mm Teflon filters for inorganic ions
H = Impregnated filters for $H_2S$
G = Electron microscope grids for morphological and elemental analysis of individual particles
N = Nucleopore filters for SEM analysis

† In addition to the "grab" samples listed here continuous measurements of NO, $NO_2$, $SO_2$, CO, $CO_2$, $O_3$ were made aboard the aircraft.

| Date, 1991 | UW Flight # | Samples Collected† * | Time of Sample (UTC) | Notes |
|---|---|---|---|---|
| June 11 | 1490 | 37,C | 0704 | Point 3, 4,500 ft. Lagrangian drift measurements in composite plume |
| | | Q,C,G | 0729 | Point 4, 4,500 ft. Lagrangian drift measurements in composite plume |
| | | 37 | 0751 | Point 5, 4,500 ft. Lagrangian drift measurements in composite plume |
| | | Q,C,G | 0806 | Point 6, 4,500 ft. Lagrangian drift measurements in composite plume |
| | | 37 | 0826 | Point 7, 4,500 ft. Lagrangian drift measurements in composite plume |
| | | Q,C,G | 0840 | Point 8, 4,500 ft. Lagrangian drift measurements in composite plume |
| | | 37 | 0903 | Point 9, 4,500 ft. Lagrangian drift measurements in composite plume |
| | | Q,C,G | 0927 | Point 10, 4,500 ft. Lagrangian drift measurements in composite plume (~126 miles from Bahrain) |

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Q = Quartz filters for organic aerosols
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47 = 47 mm Teflon filters for inorganic ions
H = Impregnated filters for $H_2S$
G = Electron microscope grids for morphological and elemental analysis of individual particles
N = Nucleopore filters for SEM analysis

† In addition to the "grab" samples listed here continuous measurements of NO, $NO_2$, $SO_2$, CO, $CO_2$, $O_3$ were made aboard the aircraft.

| Date, 1991 | UW Flight # | Samples Collected† * | Time of Sample (UTC) | Notes |
|---|---|---|---|---|
| June 12 | 1491 | 37,C,G,H | 0536 | Top of plume, 6,500 ft. Cross section of south plume |
| | | 37,C,G,H | 0549 | 5,500 ft. Cross section of south plume |
| | | 37,C,G,H | 0604 | 4,500 ft. Cross section of south plume |
| | | 37,C,G,H | 0616 | 3,500 ft. Cross section of south plume |
| | | 37,C | 0629 | 2,500 ft. Cross section of south plume |
| | | 37,C | 0642 | Below smoke, 1,500 ft. Cross section of south plume |
| | | 37,G,H | 0707 | Individual pool fire plume (Minagish) |
| | | Q,C,G,H | 0717 | Same plume, 2nd sample |
| | | 37,G,H | 0747 | Individual pool fire (Al Magwa) |
| | | Q,C,G,H | 0757 | Same plume, 2nd sample |

(Cont.)

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Q = Quartz filters for organic aerosols
37 = 37 mm Teflon filters for soot, mass, elemental analysis, inorganic ions
47 = 47 mm Teflon filters for inorganic ions
H = Impregnated filters for $H_2S$
G = Electron microscope grids for morphological and elemental analysis of individual particles
N = Nucleopore filters for SEM analysis

† In addition to the "grab" samples listed here continuous measurements of NO, $NO_2$, $SO_2$, CO, $CO_2$, $O_3$ were made aboard the aircraft.

| Date, 1991 | UW Flight # | Samples Collected† * | Time of Sample (UTC) | Notes |
|---|---|---|---|---|
| June 12 | 1491 | G,H | 0823 | Old smoke, 10,000 ft |
| | | 37,G | 0828 | Old smoke, 10,000 ft |

Analyses completed as of July 30, 1991

C – $N_2O$, CO, $CO_2$, THC, $CH_4$, Freons, HC speciation approximately 30% complete

37's – mass, soot approximately 20% complete

N – to be analyzed this week

H,Q – sent to Saltzman and Kalman for analyses

47,G – to be analyzed this fall at University of Washington

37's – elemental and ionic composition to be analyzed this fall at FSU and University of Washington

* C = Rasmussen "cans" – for gaseous organics, THC, CO, $CO_2$, $N_2O$, $CH_4$, and Freons
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† In addition to the "grab" samples listed here continuous measurements of NO, $NO_2$, $SO_2$, CO, $CO_2$, $O_3$ were made aboard the aircraft.

University of Washington

Kuwait Filter Data (odd #'s w/3.0 μm cyclone, even #'s w/o)

37 mm Teflon - Mass Concentration, Optical Absorption

| Filter No. | Flight, Date 1991 | Bag Fill Time | I/Io | Black Carbon (μg / m³) | Mass Conc. (μg / m³) | Comments |
|---|---|---|---|---|---|---|
| 1 | 1477 | 0704 | 0.998 | 0.2 | 26 | Bkgd |
| 2 | 5/16 | 0704 | 0.992 | 0.7 | 58 | Bkgd |
| 3 | | 0823 | 0.883 | 17.9 | 143 | |
| 4 | | 0823 | 0.871 | 17.4 | 235 | |
| 5 | | 0846 | 0.965 | 4.0 | 88 | |
| 6 | | 0846 | 0.971 | 3.3 | 48 | |
| 7 | | 0859 | 0.944 | 4.8 | 56 | |
| 8 | | 0859 | 0.950 | 4.0 | 84 | |
| 9 | | 0924 | 0.732 | 31.1 | 235 | |
| 10 | | 0924 | 0.723 | 30.9 | 995 | |
| 11 | | 0938 | 0.831 | 20.2 | 149 | |
| 12 | | 0938 | 0.839 | 17.9 | 139 | |
| 13 | | 1020 | 0.741 | 76.7 | 656 | |
| 14 | | 1020 | 0.723 | 79.7 | 433 | |
| 17 | 1478 | 0621 | 0.989 | 1.0 | 36 | Bkgd |
| 18 | 5/18 | 0621 | 0.984 | 1.3 | 51 | Bkgd |
| 19 | | 0732 | 0.985 | 1.4 | 67 | Bkgd |
| 20 | | 0732 | 0.989 | 0.9 | 46 | Bkgd |
| 21 | | 0757 | 0.583 | 70.8 | 521 | |
| 22 | | 0757 | 0.511 | 76.6 | 491 | |
| 23 | | 0806 | 0.481 | 90.5 | 551 | |
| 24 | | 0806 | 0.493 | 79.7 | 580 | |
| 25 | | 0837 | 0.584 | 51.7 | 327 | |
| 26 | | 0837 | 0.583 | 45.6 | 525 | |
| 29 | 1480 | 1019 | 0.702 | 40.3 | 309 | |
| 30 | 5/22 | 1019 | 0.619 | 48.9 | 805 | |
| 31 | | 1032 | 0.581 | 63.4 | 448 | |
| 32 | | 1032 | 0.510 | 63.0 | 890 | |
| 33 | | 1053 | 0.815 | 20.9 | 142 | |
| 34 | | 1053 | 0.805 | 19.6 | 360 | |
| 35 | | 1124 | 0.973 | 3.6 | 50 | |
| 36 | | 1124 | 0.945 | 6.5 | 94 | |

| Filter No. | Flight, Date 1991 | Bag Fill Time | I/Io | Black Carbon (μg / m³) | Mass Conc. (μg / m³) | Comments |
|---|---|---|---|---|---|---|
| 41 | 1481 | 0703 | 0.745 | 27.8 | 155 | |
| 42 | 5/27 | 0703 | 0.762 | 24.3 | 167 | |
| 43 | | 0738 | 0.593 | 49.6 | 272 | |
| 44 | | 0738 | 0.553 | 52.1 | 365 | |
| 45 | | 0755 | 0.710 | 30.8 | 175 | |
| 46 | | 0755 | 0.711 | 27.5 | 260 | |
| 47 | | 0914 | 0.663 | 32.4 | 226 | |
| 48 | | 0914 | 0.660 | 32.9 | 260 | |
| 49 | | 0943 | 0.644 | 36.1 | 204 | |
| 50 | | 0943 | 0.667 | 37.3 | 135 | |
| 51 | | 1011 | 0.718 | 24.9 | 93 | |
| 52 | | 1011 | 0.741 | 21.3 | 150 | |
| 53 | | 1031 | 0.890 | 9.3 | 38 | |
| 54 | | 1031 | 0.872 | 11.6 | 42 | |
| 55 | | 1045 | * | * | 157 | |
| 56 | | 1045 | 0.755 | 24.6 | 61 | |
| 57 | | 1118 | 0.843 | 10.6 | 97 | |
| 58 | 1482 | 1118 | 0.843 | 11.3 | 143 | |
| 59 | 5/28 | 1130 | 0.990 | 0.7 | 10 | Bkgd |
| 60 | | 1130 | 0.988 | 0.8 | 33 | Bkgd |
| 61 | | 1206 | 0.780 | 20.6 | 276 | |
| 62 | | 1206 | 0.786 | 21.4 | 188 | |
| 63 | | 1248 | 0.807 | 17.6 | 169 | |
| 64 | | 1248 | 0.841 | 15.6 | 109 | |
| 65 | | 1329 | 0.494 | 60.5 | 410 | |
| 66 | | 1329 | 0.576 | 52.0 | 391 | |
| 67 | | 1401 | 0.707 | 27.6 | 198 | |
| 68 | | 1401 | 0.695 | 31.7 | 117 | |
| 69 | | 1452 | 0.847 | 14.4 | ** | |
| 70 | | 1452 | 0.863 | 13.6 | 205 | |
| 73 | 1483 | 0941 | 0.993 | 0.4 | 12 | Bkgd |
| 74 | 5/29 | 0941 | 0.990 | 0.6 | 22 | Bkgd |
| 75 | | 1028 | 0.770 | 19.5 | 111 | |
| 76 | | 1028 | 0.766 | 18.8 | 121 | |
| 79 | 1484 | 0828 | 0.511 | 60.3 | 872 | |
| 80 | 5/31 | 0828 | 0.496 | 64.3 | 936 | |
| 81 | | 0920 | 0.843 | 15.0 | 90 | |
| 82 | | 0920 | 0.856 | 14.3 | 145 | |

| Filter No. | Flight, Date 1991 | Bag Fill Time | I/Io | Black Carbon ($\mu g / m^3$) | Mass Conc. ($\mu g / m^3$) | Comments |
|---|---|---|---|---|---|---|
| 83 | | 1006 | 0.780 | 21.3 | 190 | |
| 84 | | 1006 | 0.795 | 20.2 | 120 | |
| 85 | | 1038 | 0.495 | 61.0 | 505 | |
| 86 | | 1038 | 0.479 | 66.3 | 448 | |
| 87 | | 1111 | 0.249 | 109.6 | 708 | |
| 88 | | 1111 | 0.300 | 101.2 | 841 | |
| 89 | | 1125 | 0.908 | 7.1 | 144 | |
| 90 | | 1125 | 0.915 | 7.2 | 70 | |
| 93 | 1485 | 0655 | 0.901 | 8.8 | 55 | |
| 94 | 6/02 | 0655 | 0.909 | 8.7 | 88 | |
| 95 | | 0746 | 0.828 | 16.6 | 113 | |
| 96 | | 0746 | 0.863 | 13.1 | 139 | |
| 99 | 1486 | 0923 | 0.324 | 110.6 | 732 | |
| 100 | 6/03 | 0923 | 0.363 | 92.5 | 719 | |
| 101 | | 0939 | 0.516 | 60.0 | 363 | |
| 102 | | 0939 | 0.589 | 45.1 | 314 | |
| 103 | | 0959 | 0.532 | 44.7 | 303 | |
| 104 | | 0959 | 0.517 | 48.0 | 344 | |
| 105 | | 1021 | 0.443 | 57.2 | 335 | |
| 106 | | 1021 | 0.468 | 56.1 | 385 | |
| 107 | | 1040 | 0.673 | 31.8 | 212 | |
| 108 | | 1040 | 0.681 | 31.9 | 163 | |
| 109 | | 1101 | 0.623 | 32.1 | 233 | |
| 110 | | 1101 | 0.625 | 36.2 | 282 | |
| 111 | | 1119 | 0.602 | 33.3 | 225 | |
| 112 | | 1119 | 0.643 | 29.6 | 236 | |
| 113 | | 1146 | 0.632 | 26.5 | 234 | |
| 114 | | 1146 | 0.703 | 21.7 | 150 | |
| 115 | | 1234 | 0.838 | 11.9 | 107 | |
| 116 | | 1234 | 0.842 | 12.4 | 130 | |
| 117 | | 1251 | 0.725 | 23.1 | 102 | |
| 118 | | 1251 | 0.760 | 21.6 | 202 | |
| 119 | | 1312 | 0.959 | 2.9 | 12 | Bkgd |
| 120 | | 1312 | 0.963 | 2.7 | 14 | Bkgd |
| 123 | 1487 | 0801 | 0.796 | 18.4 | 100 | |
| 124 | 6/05 | 0801 | 0.825 | 14.8 | 129 | |
| 125 | | 0818 | 0.800 | 17.9 | 66 | |
| 126 | | 0818 | 0.792 | 20.0 | 156 | |

| Filter No. | Flight, Date 1991 | Bag Fill Time | I/Io | Black Carbon ($\mu g / m^3$) | Mass Conc. ($\mu g / m^3$) | Comments |
|---|---|---|---|---|---|---|
| 129 | 1488 | 0413 | 0.127 | 156.7 | 606 | Black Plume |
| 130 | 6/08 | 0413 | 0.102 | 190.4 | 760 | Black Plume |
| 131 | | 0445 | 0.649 | 42.3 | 1105 | White Plume |
| 132 | | 0445 | 0.679 | 40.2 | 1145 | White Plume |
| 133 | | 0524 | 0.837 | 15.8 | 68 | |
| 134 | | 0524 | 0.801 | 20.7 | 118 | |
| 135 | | 0541 | 0.451 | 73.4 | 459 | |
| 136 | | 0541 | 0.517 | 66.2 | 446 | |
| 137 | | 0620 | 0.762 | 23.3 | 194 | |
| 138 | | 0620 | 0.810 | 19.4 | 114 | |
| 139 | | 0717 | 0.987 | 1.2 | 9 | Bkgd |
| 140 | | 0717 | 0.983 | 1.7 | 10 | Bkgd |
| 141 | | 0736 | 0.992 | 0.5 | 12 | Bkgd |
| 142 | | 0736 | 0.989 | 0.8 | 18 | Bkgd |
| 145 | 1489 | 0635 | 0.871 | 12.6 | 84 | Black Plume |
| 146 | 6/09 | 0635 | 0.891 | 11.3 | 41 | Black Plume |
| 147 | | 0710 | 0.873 | 11.4 | 203 | White Plume |
| 148 | | 0710 | 0.931 | 6.7 | 168 | White Plume |
| 149 | | 0747 | 0.638 | 35.4 | 186 | Black Plume |
| 150 | | 0747 | 0.661 | 34.5 | 199 | Black Plume |
| 151 | | 0759 | 0.344 | 98.4 | 617 | |
| 152 | | 0759 | 0.330 | 104.7 | 615 | |
| 153 | | 0842 | 0.494 | 49.0 | 254 | |
| 154 | | 0842 | 0.485 | 53.0 | 264 | |
| 157 | 1490 | 0540 | 0.970 | 2.0 | 28 | Bkgd |
| 158 | 6/11 | 0540 | 0.985 | 1.0 | 31 | Bkgd |
| 159 | | 0601 | 0.513 | 60.9 | 410 | |
| 160 | | 0601 | 0.582 | 53.5 | 405 | |
| 161 | | 0621 | 0.579 | 45.2 | 313 | |
| 162 | | 0621 | 0.673 | 35.0 | 257 | |
| 163 | | 0704 | 0.476 | 59.0 | 267 | |
| 164 | | 0704 | 0.485 | 61.7 | 166 | |
| 165 | | 0751 | 0.738 | 23.7 | 120 | |
| 166 | | 0751 | 0.752 | 22.7 | 127 | |
| 167 | | 0826 | 0.775 | 19.5 | 120 | |
| 168 | | 0826 | 0.759 | 21.6 | 145 | |
| 169 | | 0903 | 0.881 | 9.5 | 75 | |
| 170 | | 0903 | 0.882 | 10.2 | 143 | |

| Filter No. | Flight, Date 1991 | Bag Fill Time | I/Io | Black Carbon ($\mu g$ / $m^3$) | Mass Conc. ($\mu g$ / $m^3$) | Comments |
|---|---|---|---|---|---|---|
| 173 | 1491 | 0536 | 0.498 | 67.0 | 296 | |
| 174 | 6/12 | 0536 | 0.509 | 67.3 | 340 | |
| 175 | | 0549 | 0.403 | 79.6 | 442 | |
| 176 | | 0549 | 0.383 | 88.2 | 411 | |
| 177 | | 0604 | 0.362 | 98.0 | 511 | |
| 178 | | 0604 | 0.375 | 97.8 | 551 | |
| 179 | | 0616 | 0.032 | 361.6 | 1702 | |
| 180 | | 0616 | 0.037 | 362.0 | 1634 | |
| 181 | | 0629 | 0.091 | 291.9 | 1745 | |
| 182 | | 0629 | 0.073 | 333.5 | 1620 | |
| 183 | | 0642 | 0.925 | 5.0 | 76 | |
| 184 | | 0642 | 0.969 | 2.1 | 92 | |
| 185 | | 0707 | 0.228 | 188.6 | 819 | Pool Fire |
| 186 | | 0707 | 0.255 | 181.4 | 957 | Pool Fire |
| 187 | | 0747 | 0.203 | 171.0 | 613 | Pool Fire |
| 188 | | 0747 | 0.228 | 166.9 | 587 | Pool Fire |
| 189 | | 0828 | 0.863 | 9.9 | 55 | |
| 190 | | 0828 | 0.870 | 9.7 | 74 | |

Notes: Black carbon is inferred assuming a specific absorption of 10 $m^2/g$
I / Io is optical transmittance of the filtrate
* Ring torn, no optical measurement
** Hole in filter, no mass measurement

**Emissions Factors for Particles, Elemental Carbon and Trace Gases From the Kuwait Oil Fires**

1. 1991 Fall Meeting

K K Laursen, R J Ferek and P V Hobbs (Atmospheric Sciences Department, AK-40, University of Washington, Seattle, WA 98195; 206-543-6027; OMNET: P.HOBBS)

Emission factors (i.e. mass of a species emitted into the atmosphere per unit mass of fuel burned) have been determined for particles, soot, total organic carbon in particles and vapor, CO, $CO_2$, $CH_4$, $SO_2$ and $NO_x$ for the Kuwait oil fires. Particle emission factors are about 2%, which is only about one-third of the value used in previous "nuclear winter" calculations. This, in conjunction with the low soot emission factors for the Kuwait fires, substantially reduces the amount of cooling expected to occur at the earth's surface as a result of smoke from a nuclear war. Emission factors for several of the individual Kuwait oil fires are presented and differences between black and white plumes and the plumes from pool fires are discussed. Carbon budget data for the plumes are presented; the majority of the burned carbon is present as $CO_2$. Fluxes for several combustion products in the plume will be presented and compared with fluxes from other sources.

**Ozone Chemistry in the Plume From the Kuwait Oil Fires**

1. 1991 Fall Meeting

J A Herring and P V Hobbs (Atmospheric Sciences Department, AK 40, University of Washington, Seattle, WA 98195; 206-543-6027; OMNET: P.HOBBS)

Ozone depletion was observed in the core of the plume from the Kuwait oil fires. Most of this depletion occurred within 1 km of the fires and was due to the reaction of ozone with NO. At 40 km from the fires, ozone was found to be further depleted, probably due to reactions with alkenes. Heterogeneous processes, such as the reaction of ozone on soot particles, may have also contributed to the ozone depletion.

As expected, ozone was produced in diffuse regions of the plume where ultraviolet flux was higher than in the core. However, due to the relatively low concentrations of $NO_x$, ozone production was slow. Nevertheless, since ozone was produced in a much larger volume than it was depleted, the plume as a whole was a significant source of ozone on a regional scale. Up to a distance of about 400 km from the fires, we calculate that the plume contained about 0.2 million kilograms of ozone in excess of ambient values.

1. 1991 Fall Meeting

## Chain-Aggregate Aerosols in the Smoke From the Kuwait Oil Fires

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R E Weiss (Radiance Research, 12202 9th Ave NW, Seattle, WA 98177; 206-363-6610)
P V Hobbs (Atmospheric Sciences Department, AK-40, University of Washington, Seattle, WA 98195; 206-543-6027; OMNET: P.HOBBS)

Airborne in situ measurements have been obtained of the non-sphericity of the smoke particles from the Kuwait fires. An electro-optical scattering (EO) technique was used in which changes in light scattering are measured when smoke particles are subjected to a pulsed electric field (2 kV $cm^{-1}$). Non-spherical particles align with the field, thus increasing their scattering cross section relative to random orientations. With the field removed, the particles orient randomly; the time required for random orientation ($\tau$) is related to the chain length of the aggregates. Smoke samples were analyzed from continuous flow through an isokinetic port at 8 Hz and averaged over 4 seconds (~320 m of aircraft travel).

Measurements were taken in the plumes from individual oil fires, composite smoke from groups of burning oil wells, and in aged smoke. Chained aggregates of black carbon were the principal non-spherical component of the smoke and were responsible for about one-half of the short-wave optical depth. Smoke from individual wells varied considerably in appearance; some fires produced notably white smoke and others very black smoke. Smoke from burning pooled oil tended to appear black. EO measurements in the individual black plumes indicated that substantial soot aggregates formed within seconds of combustion and EO enhancement in scattering was typically 40 percent, with $\tau$ between 2 to 4 ms. Very little chain aggregate formation was detected in the white plumes. Typical EO enhancement in the white smoke was less than 5 percent, which is typical of biomass smoke or sea salt. Aged smoke exhibited significant but reduced EO enhancement compared with the black smoke, typically 20 to 30 percent. Most of the aggregate growth appears to have occurred very near the fires; rather small changes in EO properties were detected with time in the aged smoke.

**Fluxes and Compositions of Emissions From the Kuwait Oil Fires**

1. 1991 Fall Meeting

R J Ferek, P V Hobbs (Atmospheric Sciences Department, AK-40, University of Washington, Seattle, WA 98195; 206-543-6027; OMNET: P.HOBBS)
R E Weiss (Radiance Research, 12202 9th Ave NW, Seattle, WA 98195)

Gaseous and particulate emissions from the Kuwait oil fires were measured in fourteen research flights aboard the University of Washington's Convair research aircraft during the period 16 May through 12 June 1991. In this paper we discuss a number of surprising results on the chemistry of the smoke from the fires that limit the long-range consequences of the emissions, but which exacerbate their local and regional impact.

Flux calculations indicate that the combined oil and gas fire emissions were equivalent to the consumption of approximately 5 million barrels of oil per day. The combustion appeared to be relatively efficient, with about 96% of the fuel carbon burned emitted as $CO_2$. Particulate smoke emissions averaged only 2% of the fuel burned, of which only about 20% was soot. On average, about two-thirds of the mass of the smoke was accounted for by salt, sulfate and soot. The salt most likely originated from oil field brines, which were ejected from the wells along with the oil. The salt accounts for the fact that many of the plumes were white in appearance. Although sulfate may be emitted as a minor component of the brines it is also produced in the plume by rapid oxidation of $SO_2$ (~50% per hour during the first few hours after emission), probably through heterogeneous reactions on particles. Due to their high salt and sulfate content, a large fraction of the particles in the smoke were efficient CCN.

**An Overview of the United States Interagency Airborne Study of the Smoke From the 1991 Kuwait Oil Fires**

1. 1991 Fall Meeting

P V Hobbs (Atmospheric Sciences Department, AK-40, University of Washington, Seattle, WA 98195; 206-543-6027; OMNET: P.HOBBS)
L F Radke (Research Aviation Facility, National Center for Atmospheric Research, PO Box 3000, Boulder, CO 80307-3000; 303-497-1032)

As the Iraqi army fled Kuwait in March 1991 they damaged or destroyed 749 oil wells, 610 of which were ignited. The resulting fires produced an extraordinary large plume of black smoke that had significant local and regional effects on the Gulf States and the potential for global effects.

As part of the interagency United States effort (coordinated by the National Science Foundation) to assess the impacts of the fires on the atmosphere, the University of Washington (UW) and the National Center for Atmospheric Research (NCAR) mounted an airborne study of the smoke from the Kuwait fires utilizing the UW Convair and NCAR Electra research aircraft.

During the period 16 May through 12 June 1991, some 200 research flying hours were flown to study the smoke from the Kuwait oil fires. The primary goals of the studies were to determine the chemical and physical nature and the radiative properties of the smoke, the fluxes of various materials in the smoke, and the potential effects of the smoke on weather, climate and air quality.

A key result of this study is that the significant impacts of the smoke are most likely confined to the Gulf Region. Thus, during our five week study, the smoke was never observed above about 6 km; generally it spread out well below this height at one or more temperature inversions. Vertical transport mechanisms, such as self-lofting due to solar heating, were of limited effectiveness. Consequently, transport of the smoke to the stratosphere (which would have produced global transfer of the smoke) was negligible. Also, because the smoke particles contain a significant mass of water soluble compounds, they are efficient cloud condensation nuclei and should have short atmospheric lifetimes because of efficient cloud scavenging.

**Optical Extinction Properties of Smoke From the Kuwait Oil Fires**

1. 1991 Fall Meeting

R E Weiss (Radiance Research, 12202 9th Ave NW, Seattle, WA 98177; 206-363-6610)
P V Hobbs (Atmospheric Sciences Department, AK-40, University of Washington, Seattle, WA 98195; 206-543-6027; OMNET: P.HOBBS)

Airborne in situ measurements have been made of the optical coefficients for extinction and the single-scattering albedo for smoke from the Kuwait oil fires. The measurements were made using a single-pass, 6.4 m long, transmission photometer for extinction and a high sensitivity, chopper-stabilized nephelometer for scattering. The single-scattering albedo and absorption coefficients were determined from the ratio and difference between the extinction and scattering coefficients, respectively. Both instruments were matched for wavelength response at 538 nm and equivalent air exchange rate. Measurement response was approximately 1 sec. Additional measurements for specific extinction ($m^2$ $g^{-1}$) were determined by averaging the extinction coefficients over periods for which filter samples were taken (typically about 10 seconds).

Measurements include smoke from individual well and pool fires, the composite smoke from clusters of individual fires, and the aged smoke well downwind from Kuwait. The smoke from individual fires appeared as white, black and grayish plumes, or combinations where black and white smoke was being emitted from different regions of a fires. The single-scattering albedo varied from 0.95 for the white smoke to 0.36 for the black smoke from the well and pool fires. Less variability was detected in the composite smoke. The single-scattering albedo increased to about 0.5 in the near field composite smoke and was relatively invariable in the downwind aged smoke. Specific absorption in the aged smoke was typically about 2–3 $m^2$ $g^{-1}$, which suggests a mass fraction for black carbon of approximately 20 to 30 percent. For the regionally expansive smoke, approximately 40 to 50 percent of the optical depth was caused by absorption. Additional data regarding soot emission factors, based on the absorption data, will be presented.

**An Improved Filter-Pack Technique for Airborne Measurement of Low Concentrations of $SO_2$**

1. 1991 Fall Meeting

P V Hobbs, R J Ferek, D A Hegg and J A Herring (Atmospheric Sciences Department, AK-40, University of Washington, Seattle, WA 98195; 206-543-6027; OMNET: P.HOBBS)

Recent improvements to the carbonate-impregnated filter technique for measuring low-level $SO_2$ concentrations have resulted in dramatically improved performance. The improvements are: 1) a better cleaning procedure for the paper filter substrates resulting in approximately 60% reduction of their sulfate blank, 2) the use of an ion-exchange resin to remove the carbonate matrix from the sample extract resulting in a 100% increase in the signal-to-noise ratio, 3) the use of high-purity glycerol in the filter impregnate resulting in approximately 10% further reduction of blanks, and 4) improved chromatographic and standardization procedures for more accurate quantification of sample peaks. Combined, these improvements allow measurements to be made of $SO_2$ concentrations in marine background air with a $2\sigma$ uncertainty of $\pm$ 6 pptv and, based on this, a $3\sigma$ detection limit of 9 pptv for air volumes of 4 $m^3$ (which can be collected in 15 mins aboard our research aircraft). Measurements in polluted air show better than 95% collection efficiency, even at concentrations as high as 100 ppbv. Vertical profiles of $SO_2$ measured during three PSI research flights off the Washington Coast (one in clean marine air) showed concentrations ranging from 15–86 pptv in the mixed layer and from 40–93 pptv in the free troposphere.

Bahrain Debriefing of DOE Monitoring Team, August 20, 1991

Members of the DOE Team
(Contracted from Batelle Pacific Northwest Laboratories (PNL) and Brookhaven National Laboratory)

Scientific Team

| | |
|---|---|
| Peter Daum | Brookhaven |
| Ken Busness | Batelle |
| Stan Tomich | Batelle |
| Jake Hales | Batelle |

Flight Team
Bob Hannigan
Mike Warren
Karl Bergstrom

The original purpose of the monitoring flights funded by the US Department of Energy (DOE) was to sample the plume at distances from the mid to the far range. Initial plans to sample the plume over Saudi Arabia almost as far to the southeast as Oman were limited by airspace restrictions in the Empty Quarter. Several trips in the area indicated, however, that the plume over the Empty Quartar was so diffuse that it was difficult to locate and below the sensitivity of the instrument.

The flights were successful. The first flight was on July 31. A total of 13 flights was completed over 12 days. Two-thirds of the flights directly intersected the plume, the remainder conducted background measurements. The general area monitored was between latitude 22 and 28 degrees north and longitude 46 and 51 degrees east. The flights took gaseous and particulate samples and measured the plume's optical properties, dispersion and height. The DOE team was appreciative of the good support received from the Bahrain Environmental Protection Agency and Bahrain's Meteorological Service. The DOE aircraft team also received good support from MEPA and Aramco in Saudi Arabia.

General Plume Characteristics

The true character of the plume can only be addressed after the samples taken are analyzed in the laboratory, especially the data needed to understand the plume's dispersal in the vertical and horizontal, and to project human health effects. Once completed, the analysis will consolidate the data into a form that can be used in assessments.

1. The plume's optical density is particularly high close to the source, according to preliminary observations, with high densities sometimes occurring again as far as 200 kilometers downwind. Occasionally the plume retained integrity for great distances. The plume's optical density was greater than any cloud and ran the teams integrating nephelometer meter off the scale.

2. High optical density seems to be accompanied by self-lofting. This could easily be observed at various distances along the plume's length where the darker, more optically dense segments rose higher than the lighter parts of the plume. Since the carbon particles are good absorbers of solar radiation, the result is heating at the top of the plume and vertical movement of the plume's upper surface. At lower heights the plume is dark, cool and stable. Instruments measured increased turbulence within the plume with height. Where turbulence in the plume occured at 11,500 feet, for example, the top lofted to 15,000 feet.

3. The top of the plume ranged from 10,000 to 18,000 feet, indicating that the plume is confined to the lower troposphere. The lowest samples in the plume were usually taken at 2,000 to 3,000 feet. While occasionally the plume was sighted below this level, it was difficult to make accurate judgements about its lower boundaries. Typically, however, below 2,000 feet the atmosphere was hazy. The haze could represent surface dust but in industrial areas in Saudi Arabia it may be from the industrial facilities.

4. Where dust was observed lifting from the surface it seemed to be incorporated into the plume, reaching the top of the plume through convection. Once the dust was incorporated into the plume, the plume's color changed. Captured particulate samples also changed color, shifting from gray to brown. Testing will identify the dust fraction. When the plume has a high dust content, it has a different signature on satellite imagery, giving the impression that a hole through the plume is providing a view of the desert floor. In fact it is not the desert floor but the top of the plume with a heavy dust load. DOE will try to correlate the

change in the plume's dust content with the signature on the satellite imagery. The dust content of the plume was probably less than that recorded by NCAR/UW; perhaps reflecting the lower seasonal winds speeds.

Plume Chemistry

1. One of the primary concerns addressed by the DOE flights involved the fate of sulfur dioxide as the plume aged. The usual sulfur dioxide transformation to sulfate is by oxidation, in which the sulfur dioxide oxidized by the OH radical to form sulfuric acid and then sulfate. A second possible path of conversion was hypothesized in which trace metals could catalyze oxidation but preliminary evidence indicates this did not occur. The primary effect of distance on sulfur dioxide concentration is dilution as the plume diffuses. Maximum concentrations near the source were a few tenths of ppm and at greater distances the concentrations reached 5 ppb.

2. The plume is unusual compared to urban plumes in Europe and the U.S. It is low in nitrogen oxides when compared to areas in which high temperature combustion is common. The nitrogen oxide concentrations are in the low parts per billion, nowhere near what would be produced by power plants or automobiles. This indicates low-temperature combustion. Since nitrogen oxide concentration levels are low, the NOX is not available to help catalyze reactions within the plume and consequently the plume retains its original properties longer. The materials are not being transformed rapidly but are just diluting.

3. There is no evidence of ozone generation in the plume so far. This is unlike the ozone bulge commonly observed in the U.S. in which ozone levels are low near the source and increase as hydrocarbons oxidize nitrogen oxide to nitrogen dioxide, which then stimulates the formation of ozone. NCAR did detect a dip in the ozone level near the fires, possibly because it may have approached the source more closely.

Analysis planned in U.S. laboratories

Pollutant concentrations vary as a function of plume height and distance from the source. Sampled plume constitute included O3, SO2, NO , CO, and CO2.

1. Canister samples for gaseous organic constitutents. This will indicate how gaseous hydrocarbons evolve with distance.

2. Composite three stage filter that sampled aerosols, nitric acid and sulfur dioxide. The aerosols analysis will include major inorganic species. The first stage of analysis will focus on major inorganic constituents and possibly trace metals.

3. Separate analysis will be done for organic aerosols with a focus on major organic species including PAH's.

4. Aerosols number concentration and size distribution were also measured. Sampling was performed in two ranges. One instrument measures sizes from 0.1 to 3 microns, another from 3 to 47 microns.

5. Cloud condensation nuclei counts (ccn). Early indications are that ccn counts are about 3000 ccn per cubic centimeter, similar to the NCAR measurements. The particles are hydrophilic and should be retained in the atmosphere no longer than two to three weeks. At first DOE analysts thought that the particles would be pure elemental carbon and hydrophobic but the particles may have absorbed enough sulfur dioxide on their surface to make them polar, thus making them attractive to water. Ozone may also oxidize the surface of the particles, making them hydrophilic. The net result is that the supersaturation level needed for cloud formation may be similar to that for typical ccn rather than the elevated levels anticipated when it was assumed the particles were hydrophobic. It is possible that when the plume reaches the Intertropical Convergence Zone strong convection will result in a high degree of saturation and most of the particles my form cloud droplets. However, because there are so many ccn, the number of water droplets in the clouds may be smaller than the aerosol number concentration. In other words, even though the ITCZ air may be humid, there man not be enough water vapor avbailable for all of the particles present to serve as ccn. The clouds may also have an enhanced albedo, something which could show up on satellite imagery.

General Discussion

1. Data availability and funding. The data will be available to anyone who wants it. Analysis will begin in September and

most should be complete in mid October and November. Some of the integrated samples may take longer. DOE will deposit its data with NCAR and also make its data available independently. Funding for analyzing the samples has not been arranged but the analysis will proceed anyway.

2. Many Gulf scientists flew on the DOE aircraft, including Bahrainians in the Civil Aviation Affairs and Meterological Service and Saudis from Aramco and MEPA. Aramco in Dhahran provided forecasts. A Saudi scientist has been invited by the DOE team to join them in the US and join in analyzing the data.

3. Locating the plume. Modelling efforts that forecast the location of the plume are not entirely successful. A slight shifting of local weak high and low pressure cells can alter the location of the plume greatly at distances of several hundred kilometers from the source. Weather satellites are the biggest help. Meteosat imagery arrives in Manama in the mid-morning and the DOE aircraft took off immediately after receiving the imagery. The preferred takeoff time was 6AM to take advantage of the relatively cooler, denser air but the delay to wait for the imagery paid off in efficiency in locating the plume.

4. Plume stratification. The DOE team speculated that the stratification in the plume could reflect different plume patterns. Some levels could contain relict smoke that represents old plume locations.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
ATMOSPHERIC RESEARCH AND EXPOSURE ASSESSMENT LABORATORY
RESEARCH TRIANGLE PARK
NORTH CAROLINA 27711

September 10, 1991

MEMORANDUM

SUBJECT: Overview of the EPA/NASA In Plume and Ground Level Measurements Made in Kuwait July 28 to August 8, 1991

FROM: Robert K. Stevens
Chief, Source Apportionment Research Branch (MD-47)

Joseph P. Pinto
Research Scientist

TO: Gary J. Foley
Director, Atmospheric Research and Exposure Assessment Laboratory (MD-75)

Below is a summary of the major findings and preliminary conclusions based on the chemical and physical analysis of size fractioned plume and ground level samples collected recently in Kuwait. Jack Durham of the Gulf Task Force office requested we prepare this summary today to send to Peter Hill of NOAA who is assisting John Robinson of NOAA, to prepare a summary of research results obtained by the Interagency groups participating in this project. Appendix A is an inventory of samples collected in this study. We have not completed all the analyses. Thus far we have mass, XRF elemental composition, particle morphological measurements by SEM/XRF procedures and ion chromatographic data for $SO_2$, $HNO_3$ collected with annular denuders. We are still waiting for analysis of canisters for VOC's, elemental and condensable carbon and PAH analysis of samples collected with PUF and Tenex traps. We are also waiting for the results of NASA measurements ($CO_2$, CO,$CH_4$ TMHC).

## Results

1. The White oil fire plumes are enriched in fine particle (<2.0 µm) of crystalline salts of chlorides of sodium and calcium. Most of these particles are actually less than 0.5 µm in aerodynamic diameter. These plumes also contain several hundred $\mu g/m^3$ sulfur dioxide ($SO_2$) and sulfate. These plumes contain very little black carbon which suggest that these fires are fueled primarily by natural gas. These fine crystalline chloride salts are hydrophillic and can act as cloud condensation nuclei (see attached SEM/EDX spectra of one of the typical submicron particles from the white plumes).

2. The black oil fire plumes from the burning oil wells are enriched in sub-micron-carbon chain agglomerates, calcium carbonates, silicates, sulfates and sulfur dioxide. There are large >20 µm particles of oil droplets in these plumes but they appear to deposit rapidly. This probably accounts for black oil that covers the surface within the fields.

3. The chemical properties of super plumes (a mixture of the white and black plume downwind) are as expected, is a mixture of primarily the fine particles from the black and white plume fires. Since there are more black plume fires than white plumes the composition of the super plume more closely resembles the composition of the black plumes. Thus the fine particles of the super plume are dominated by the carbon chain agglomerates.

4. The ground level composition of fine particle aerosols collected in Kuwait City is a mixture of the super plume species (e.g., carbon chain agglomerates, chlorides) and automotive emissions (e.g., greater than 1 $\mu g/m^3$ of Pb and Br) and sulfate which may be associated with the oil fires and or the sulfur emission from the two electric power generating stations. During periods of air stagnation visibility decreased markedly to less than 1 km with a corresponding increase in fine and coarse particle mass. The fine particle become extremely black due primarily to the carbon chain agglomerates we have associated with the oil fires.

5. Several in plume and ground level samples were collected using Texex and PUF traps to isolate condensable and semi-volatile organics. Preliminary gc/ms analysis of PUF extracts indicated presence of 2, 4, 5, and 6 ringed polynuclear aromatic hydrocarbons. Analyses are in progress to identify and determine the amount of PAH's present in the plume and ground level samples .

6. Analysis to determine the amount of condensable organic and elemental carbon present in the plume and ground level samples are in progress.

7. One indoor sample was collected during a relatively clear day in Kuwait. Some evidence of automotive fine particle emissions were present in these samples along with oil fire emission species. Sulfur dioxide indoors was comparable to outdoor levels.

These results should be considered preliminary at this time. The KEPD are continuing to collect ground level samples within Kuwait City with the equipment the US EPA left with the Kuwait scientists.

We are seeking resources to obtain neutron activation analysis of the fine particle samples to determine the presence of trace elements that were not detected by XRF methods (e.g. As, Se, Cd, lanthanides, Na, F).

cc: Peter Hill, NOAA (FAX 8-202-377-0714)
Dale Pahl (MD-56)
James Vickery (MD-75)
Jack Durham (8-260-0154)

## APPENDIX A

Inventory of Samples Collected by EPA
Between July 28 and August 8, 1991

| Pollutants | Sites* | Methods | Number of Samples |
|---|---|---|---|
| 1. $SO_2$, $HNO_3$, $HNO_2$ | G,W,A,I | Denuder IC Analysis | 22 |
| 2. PAH's/Semi-volatile organics | G,W,A,I | Quartz filters, Tenex/PUF traps GC/MS/FID | 9 |
| 3. Non-Methane Hydrocarbons, halocarbons | G,W,A | Canister Samples GC/MS/FID/ECD | 28 |
| 4. Trace elements in fine (<2.5 µm) and coarse (>2.5 µm) particles | G,A,W,I | Teflon Filters, XRF, INAA | 22 |
| 5. Aerosol Size Distribution | G,A,W | Nuclepore Filters SEM/EDX | 10 |
| 6. Elemental and Volatilizable carbon (Ce, Cv) | G,A,W | Quartz Filters Combustion/FID | 13 |

*Site description = G = Ground level
A = Airborne (Helicopter)
W = Near Burning Wells
I = Indoor

PAH = polynuclear aromatic hydrocarbons, XRF = x-ray fluorescence analysis, INAA = instrumental neutron activation analysis, SEM/EDX = scanning electron microscopy/energy dispersive x-ray analysis.

**Summary of Analysis of VAPS Samples Collected During Helicoper Flights Collecting Oil Fire and Super Plume Samples Over Kuwait**

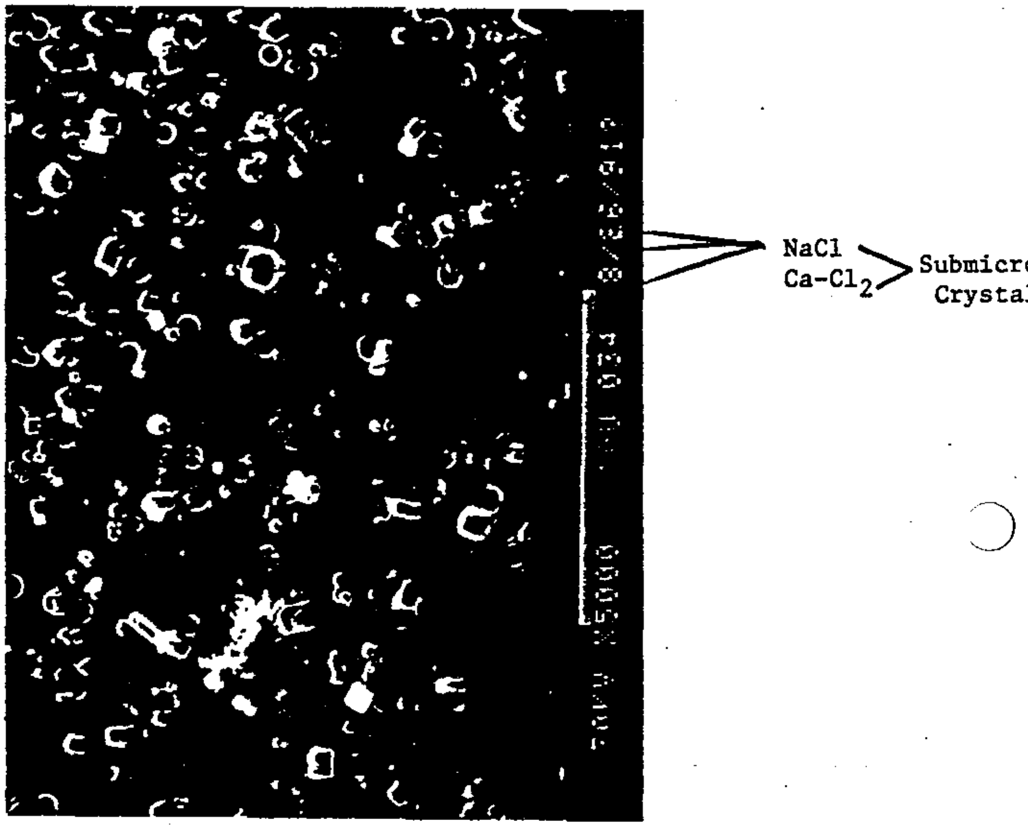
| Date[1] | µg/m³ | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fine Mass | $SO_2$ | $SO_4^=$ | S | Pb | Br | Ca | Al | Si | Cl | K | Cr | Ni | Zn | Fe | Sr | Sn |
| Black Plume 7/31 | 10,900 | 206 | 177 | 59 | - | - | 84 | - | 82 | 182 | 19 | 4.9 | - | - | 24 | - | - |
| Black Plume 8/02 | 755 | 133 | 9.3 | 3 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Black Plume 8/03 | 955 | 169 | 114 | 38 | - | - | 6 | - | - | 15 | - | - | - | - | - | - | 8 |
| Black Plume 8/05 | 493 | 12 | 25 | 8.4 | - | 0.6 | 34 | - | 48 | | 5.4 | - | | | 13 | | 4.5 |
| Super Plume 8/06 | 167 | 49 | 18 | 5.9 | | | 8.7 | | 7 | 10 | 1.6 | | | | 3.5 | | 0.2 |
| White Plume 8/07 | 4,356 | 319 | 630 | 210 | - | 21 | 415 | | | 3220 | 62 | | | | 5.4 | 18 | 8 |
| Super Plume 8/8 | 21.6 | 26 | 10 | 3.2 | | | 1.2 | | | 9 | 0.3 | | | | - | | - |

[1]Sampling times were between 0.5 to 30 minutes depending on the day the samples were collected. Typically less than 0.5 m³ of air was collected with the versatile air pollution sampler (VAPS) used by EPA to collect the $SO_2$ and aerosol samples.

Summary of Ground Level Air Quality Measurements
Made in Kuwait

| Date | $\mu G/m^3$ [4] | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fine Mass | $SO_2$ | $SO_4^=$ | S | Pb | Br | Ca | Al | Si | Cl | K | Cr | Ni | Fe | Zn | Sn | Sr |
| 7/28[1] | 62 | 11 | 6.9 | 2.3 | 0.12 | 0.04 | 4.34 | 1.74 | 5.12 | 0.14 | 0.70 | .01 | .01 | 1.67 | .02 | .04 | .02 |
| 8/03[1] | 26 | 5.4 | 4.0 | 1.3 | 0.17 | 0.05 | 1.27 | 0.72 | 2.01 | 0.10 | 0.28 | .003 | - | 0.69 | .01 | - | - |
| 8/07[1] | 100 | 11 | 5.8 | 1.95 | 1.80 | 0.60 | 3.34 | 0.8 | 3.6 | 3.7 | 0.7 | - | 0.2 | 1.3 | 0.18 | - | 0.01 |
| Indoor Sample[2] 7/31 | 7.4 | 7.6 | 1.8 | 0.6 | 0.05 | 0.02 | 1.06 | 0.3 | 1.0 | 0.5 | 0.2 | .002 | - | 0.4 | 0.02 | - | 0.01 |
| Near Plume[3] 8/6 | NA | 19 | 6 | 1.9 | - | 0.10 | 1.9 | - | 1.3 | 0.8 | 0.3 | - | - | 0.97 | 1.0 | - | - |

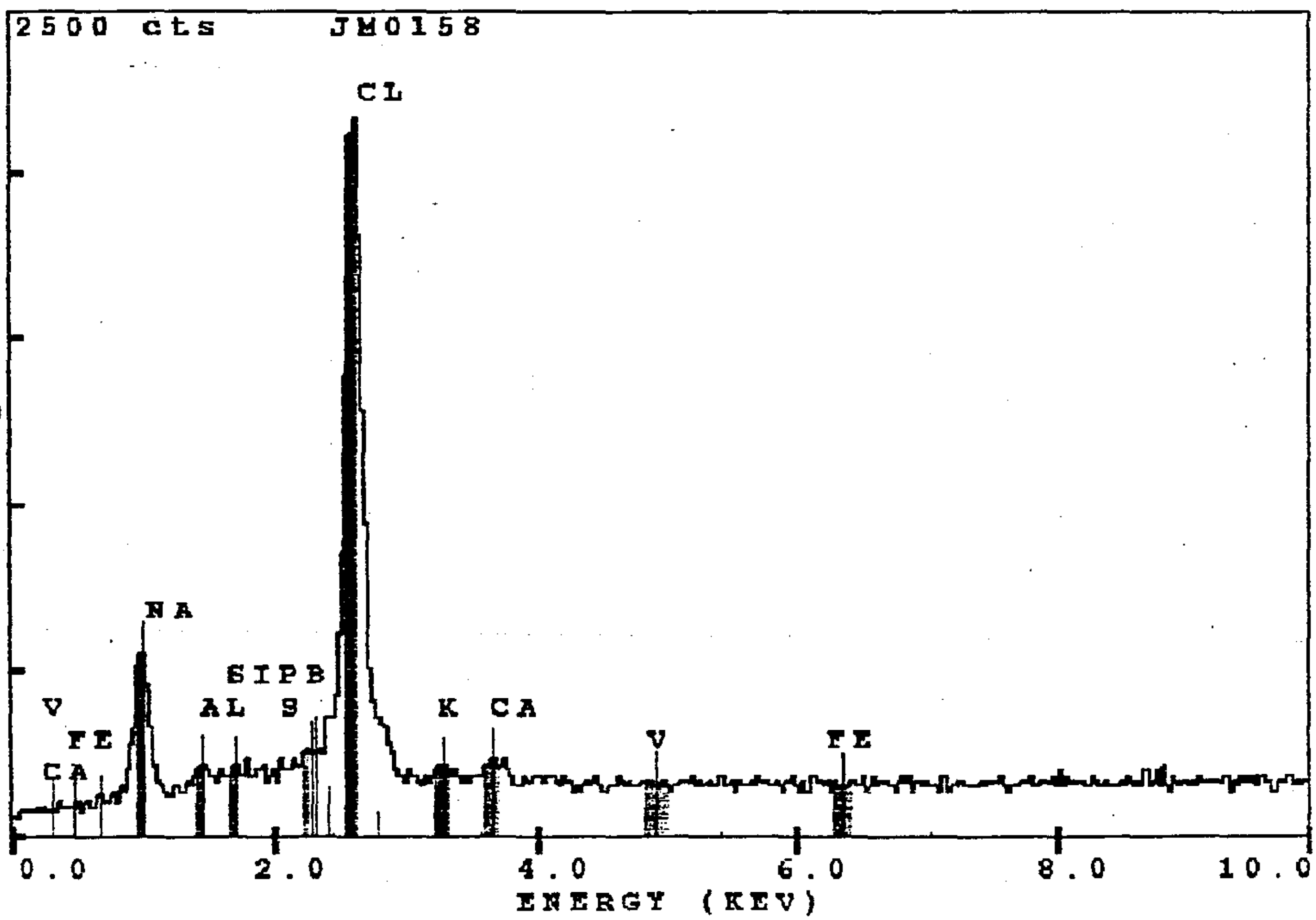
[1] = Date samples collected on roof of Kuwait Environmental Protection Div. (KEPD)
[2] = Date samples collected in family room of the Director of KEPD.
[3] = Date samples collected near burning white plume in Wafra oil fields.
[4] = $\mu g/m^3$ of selected species from samples collected with annular denuder systems.




WHITE PLUME

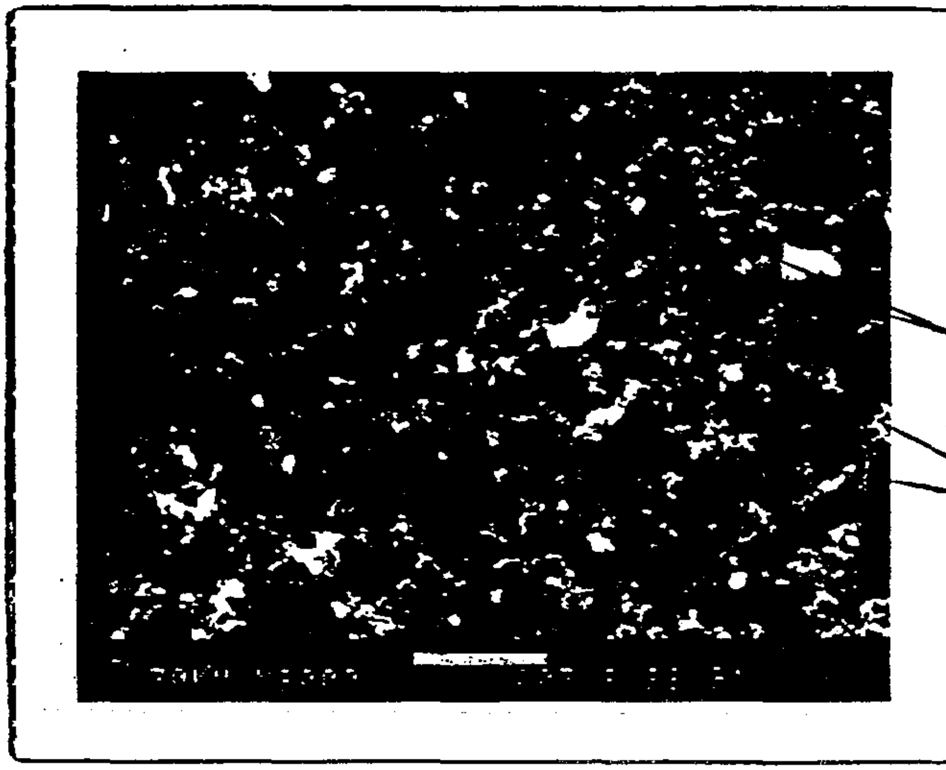
SEM PHOTOMICROGRAPH

KA B 07 NU ( Na Cl )




SEM SPECTRA OF SODIUM CHLORIDE

PARTICLE FROM WHITE PLUME




Super Plume Sample
Showing a mixture of
the chain agglomerates
and chloride particles

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
ATMOSPHERIC RESEARCH AND EXPOSURE ASSESSMENT LABORATORY
RESEARCH TRIANGLE PARK
NORTH CAROLINA 27711

September 10, 1991

MEMORANDUM

SUBJECT: Summary of Kuwait Oil Fire Monitoring Project

FROM: Robert K. Stevens RKS
Chief, Source Apportionment Research Branch (MD-47)

Joseph P. Pinto JP
Research Physicist (MD-84)

TO: Dr. Gary J. Foley
Director, Atmospheric Research and Exposure Assessment Laboratory (MD-75)

Below are three tables containing a summary of EPA's air quality measurements made at ground level sites in Kuwait (Table 1) and measurements made from a helicopter platform (Table 2) used to characterize Kuwait oil fire plumes. Table 3 contains a summary of canister sampling for volatile organic species (VOC's).

Since a major purpose of the helicopter sampling program was to characterize the chemistry of white and black plumes, separately, care was taken to choose plumes with minimum contamination by mixing from other plumes nearby. Individual plumes for sampling were chosen in the northwest corner of the northern oil fields. These plumes were judged to be least affected by mixing with others. In addition, we also obtained measurements in the "superplume", or the plume formed by mixing of all sources.

For the helicopter flights, samples were collected with a new type of dichotomous sampler. This device simultaneously collects inorganic gases [sulfur dioxide ($SO_2$) and nitric acid ($HNO_3$)] on denuders, and separates the fine (<2.5 µm) and coarse particles (>2.5 µm) and collects them on three separate filter media. One half of the fine particles are collected on a quartz filter and the other half on a Teflon filter. The coarse particles are collected on a Nuclepore filter. The mass and elemental composition of the particles collected on the coarse filters are determined by gravimetric and XRF methods respectively. Since 10% of the fine particles are also present on the coarse fraction, we are able to determine the particle size and morphological properties of the plume aerosols by SEM/EDX methods. The semivolatile organic species are collected on a Tenex trap located downstream of the quartz filter. The $SO_2$ and $HNO_3$ are measured by IC analysis of the extract of a denuder that precedes the Teflon filter. The mass and elemental composition of the fine particles are determined by gravimetric and XRF methods.

Ground level samples were collected: (1) from the roof of the air monitoring laboratory of the Kuwait Environmental Protection Department (KEPD); (2) at the residence of the director, Dr. Mahmood Y. Abdulraheem; (3) the perimeter of the Burgan oil fields; and (4) within 25 meters of the fire generating the white plume in the Al-Wafra oil field.

The ground level sampling focused on collecting duplicate fine particle samples, on a Teflon filter to measure mass and elemental composition and the second one a quartz filter followed by a PUF trap to collect the semi-volatiles. Annular denuders preceded the filter packs to collect $SO_2$ and $HNO_3$.

Volatile organic compounds were collected in Summa polished canisters during several helicopter flights and at several ground level loctions. Table 3 contains the dates and location of the canister sample collection. We will analyze some of the canister samples at EPA but most will be sent to Dr. Rei Rassmussen, Oregon Graduate Center since he provided the VOC sampling system for this project. We will need to find $12,000 to fund the analysis of these samples.

We have completed the XRF measurements of all the airborne and ground level samples collected in July and August. The XRF elemental composition data are attached. We need to send these samples to U of MD where we can have Dr. John Ondov determine the trace concentrations of V, Cr, lanthanides, As and Se by INAA. We estimate this can be completed in 4 weeks at a cost of $14,000.

We need to measure the aliphatic and PAH content in the plume and ground level samples to compare with data obtained by KEPD and other groups monitoring the Kuwait oil fire emissions. We estimate $15,000 will be required to obtain these measurements reliably. We left (on loan) about $10,000 in air quality sampling equipment with KEPD. They need some additional equipment to continue their air quality monitoring program in preparation for the fall WHO human PAH exposure study. I estimate the cost of this supplemental equipment and additional QA measurements to be $35,000. This includes upgrading their microblance, fine particle micro-environmental samplers equipped with PUF traps, pumps and flow measuring equipment and QA analysis of micro-environmental samples.

**Table 1**
<u>Ground Level Samples</u>

| Date | Location | Samples Collected | | | |
|---|---|---|---|---|---|
| | | Denuders $SO_2$, $HNO_3$ | Quartz/PUFs Ce,Cv,Organics Semi-Vol.Cond. | Teflon Mass, Elemental XRF,INAA | Nuclepore Mass, Elemental SEM/L |
| 7/28-7/29 | Roof of KEPD | X | X(1) (2) | X(3) | X |
| 7/31-8/01 | | X | X | X(4) | |
| 8/03-8/04 | | X | X | X | |
| 8/07-8/08 | | X | X | X | |
| 7/28-7/29 | Indoor | X | X | X | |
| 8/05 | Al-Wafra Field | X | X | X | |
| 8/07 | Al-Burgan Field | X | X | X | |

(1) Cv,Ce to be done
(2) gc/ms/FID, to be done
(3) INAA to be done
(4) pH of extract obtained

**Table 2**
**Helicopter Plume Samples**
**July 31 to August 8, 1991**
**All sampling was performed between 8-10 AM**

| Date | Location | Samples Collected | | | |
|---|---|---|---|---|---|
| | | Denuder | Fine Particles | | Coarse Particles |
| | | ($SO_2$, $HNO_3$) | Quartz-TENNEX (Organics eg PAH, Aliphatics[2] Cv,Ce | Teflon Mass, elemental composition (s,v,ni,Pb) INAA[3] | Nuclepore Mass, SEM/EDEX Morphological |
| 7/21/91 | North Fields Multiple Plumes | X | X | X | X |
| 8/02/91 | Al Burgan Black Plumes | X | X | X | X |
| 8/03/91 | North Field Black Plume Sampling | X | X | X | X |
| 8/05/91 | Near Field Super Plume | X | X | X | X |
| 8/06/91 | Al Burgan Super Plume | X | X | X | X |
| 8/07/91 | North Fields White Plume Sampling | X | X | X | X |
| 8/08/91 | Near Source Super Plume | X | | X | |

[1]Ce,Cv to be measured
[2]GC/MS/FID of the organics to be analyzed
[3]INAA to be measured

A total 22 separate airborne samples were collected on 7 helicopter flights. Additional samples could have been collected, however NASA measurements took priority over EPA monitoring requests.

Table 3
Canister Sampling

Helicopter

| Date | Type of | Canister Samples Number |
|---|---|---|
| 8-03-91 | North Field Black Plume | 9 |
| 8-04-91 | Near Field Super Plume | 2 |
| 8-05-91 | Near Field Super Plume | 8 |
| 8-07-91 | North Field Super Plume | 4 |

Ground Levels

| Date | Type of | Canister Samples Number |
|---|---|---|
| 8-03-91 | KEPD | 3 |
| 8-05-91 | Burgan Field Near oil lake | 1 |
| 8-05-91 | Al-Wafra Near Field | 1 |
| 8-07-91 | Al-Wafra White Plume Expt | 2 (duplicates) |

# Kuwait Oil Fires : Helicopter Operations

## History:

- March 1991 - United Nations Action Plan developed to coordinate the international response to the health and environmental concerns resulting from the oil fires in Kuwait.

- April 24 - United States Policy Coordinating committee on Oceans, International Environment, and Science (chaired by the Department of State) recommends the near-field sampling experiments suggested by NASA/EPA , utilizing the NASA helicopter borne sampling techniques, be implemented as part of the U.S. interagency response to the Kuwait oil fires as soon as possible.

- April 27-30, the Secretary-General of the World Meteorological Organization (WMO) convened a conference in Geneva to coordinate international responses to the atmospheric part of the UN Action Plan.

- May 17 - U.S. Policy Coordinating Committee agrees to fully support the UN response and to integrate U.S. efforts into the United Nations program (WMO/WHO).

# Kuwait Oil Fires : Helicopter Operations

## History:

- June 11 - Saudi Arabian Government ( MEPA) informs U.S. Embassy that a Saudi Civil Defense helicopter and crew will be committed to the NASA/EPA near-field sampling experiments.
- Saudi scientific participation in the project is to be coordinated through Dr. Al-Thuwainy, Director of MEPA in Riyadh.
- Project becomes joint U.S./Saudi effort.
- July 3 - Kuwaiti Government agrees to scientific participation in experiments and to grant overflight clearances and laboratory facilities at EPD in Kuwait City.
- Kuwaiti scientific participation by EPD and KISR anticipated.
- Project becomes joint U.S./Saudi Arabian/Kuwaiti effort.

# Kuwait Oil Fires : Helicopter Operations

## I. Purpose: Characterization of source emissions.

Identification and Quantification of combustion emissions at the source of burning Kuwaiti oil wells is necessary for assessing potential regional health issues, atmospheric and environmental impacts, and verification of combustion/dispersion model predictions.

## II. Approach: Coordination of selected helicopter and ground based measurements.

A helicopter based smoke plume sampling system has been developed and used by the NASA-Langley Research Center to study global biomass burning emissions from several global habitats. Research scientists from NASA and the U.S. EPA have collaborated to develop a basic smoke sampling package (instrumentation, measurement objectives, etc.) that combine ground and airborne helicopter measurements in the near-field to quantitatively characterize of many of the important oil fire emissions.

## III. Measurements:

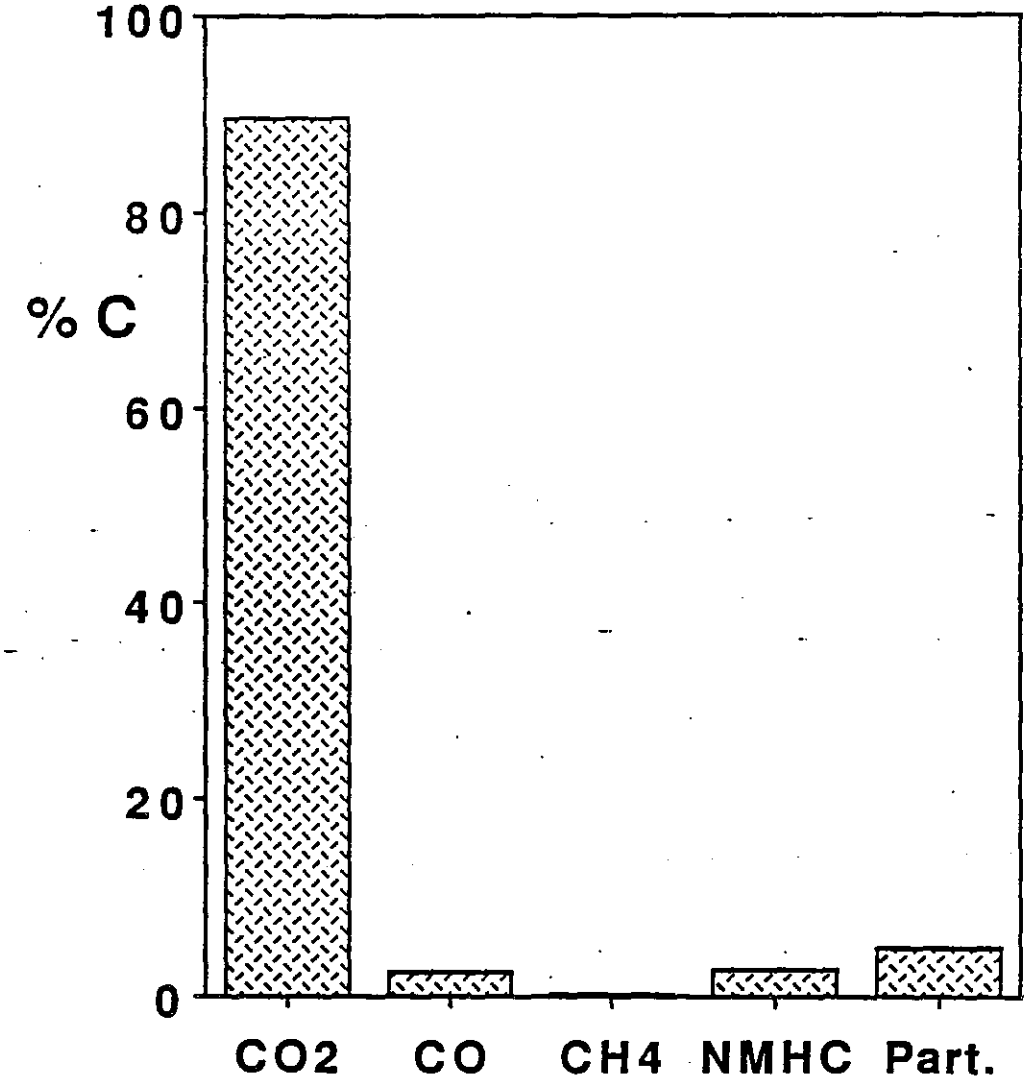
### A.) NASA/EPA :

- Carbon dioxide, carbon monoxide, methane
- Total hydrocarbons, light hydrocarbons
- Nitrous oxide
- Sulfur dioxide
- Polynuclear Aromatic Hydrocarbons
- Acid aerosols (sulfate, nitrate, etc.)
- Trace metals
- Elemental carbon / organic carbon
- Total aerosol burden
- Aerosol size distribution
- Particle morphology

Kuwait Oil Fires

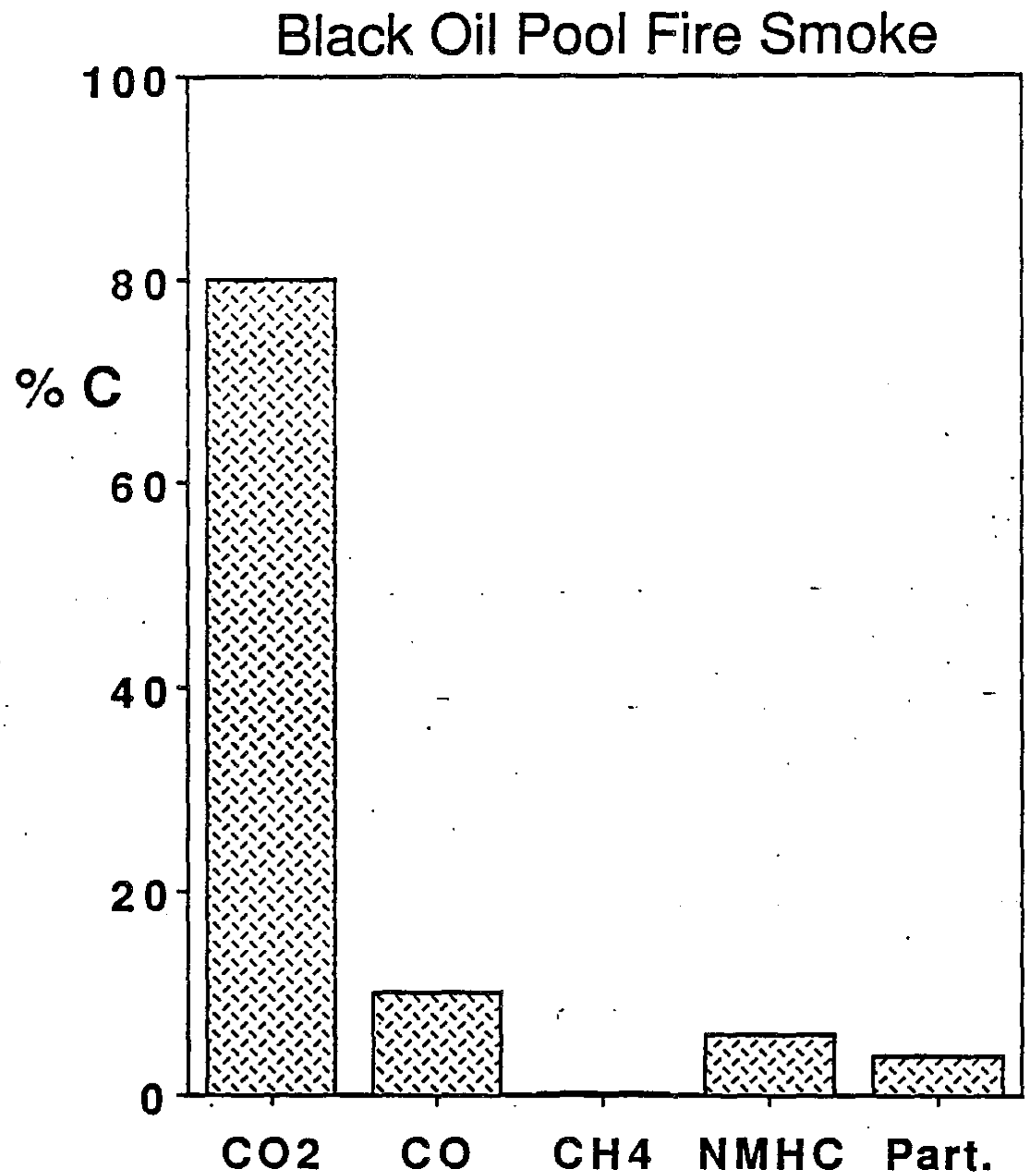
NASA Helicopter Measurements

Black Smoke Plumes



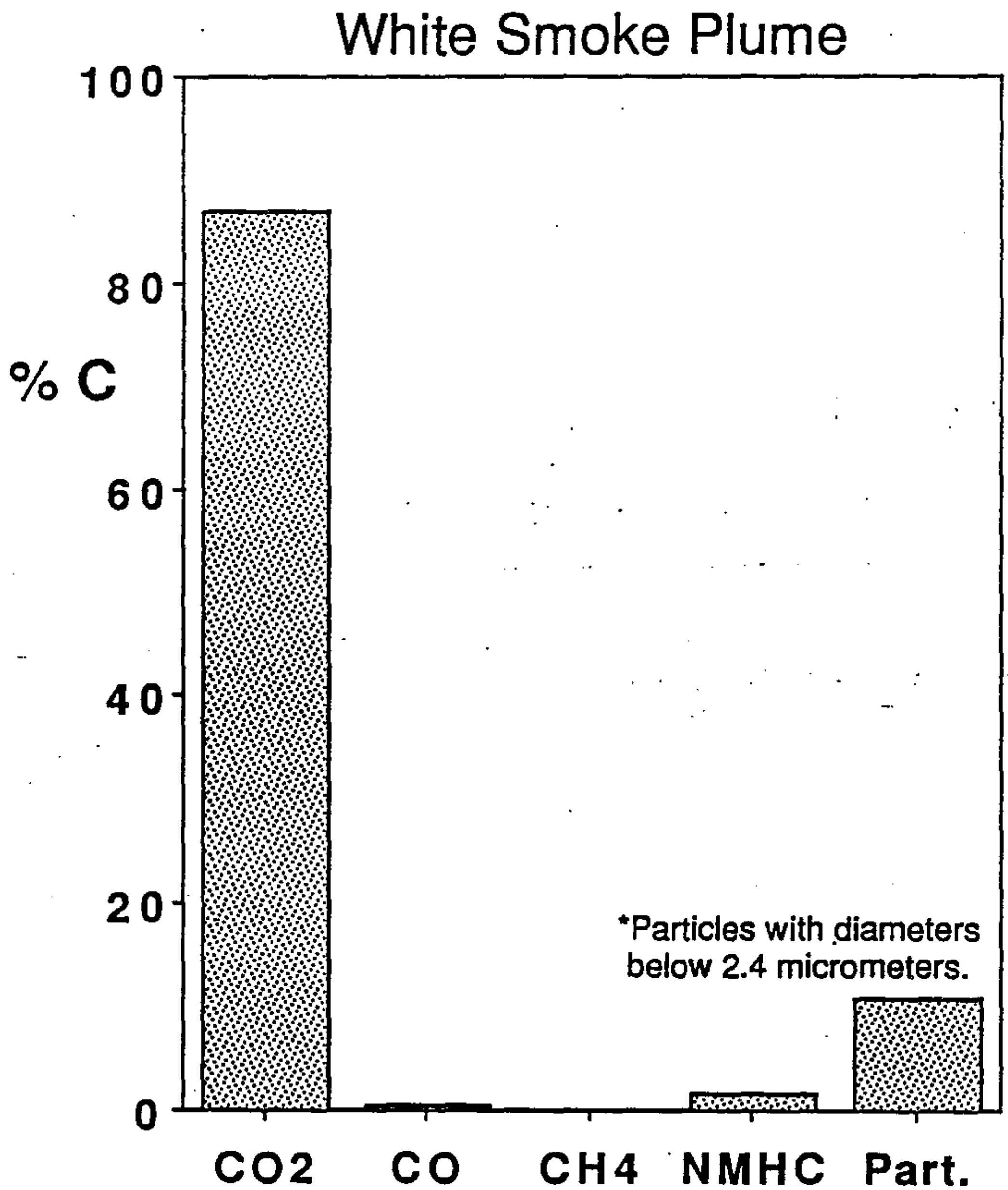

Carbon partitioning in black smoke.

# Kuwait Oil Fires
## NASA Helicopter Measurements



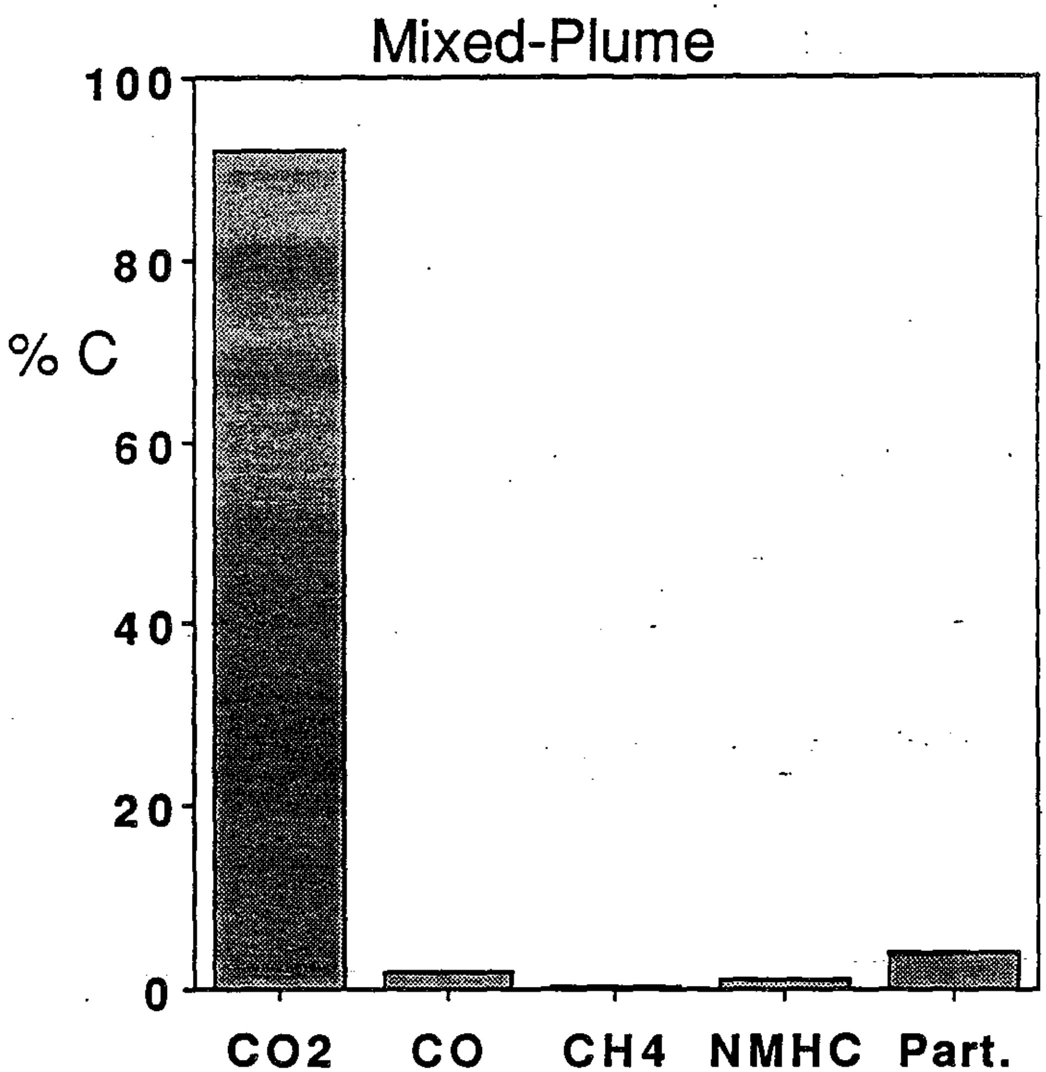

Carbon partitioning in black pool-fire smoke.

## Kuwait Oil Fires
## NASA Helicopter Measurements




Carbon partitioning in white smoke.

## Kuwait Oil Fires
NASA Helicopter Measurements

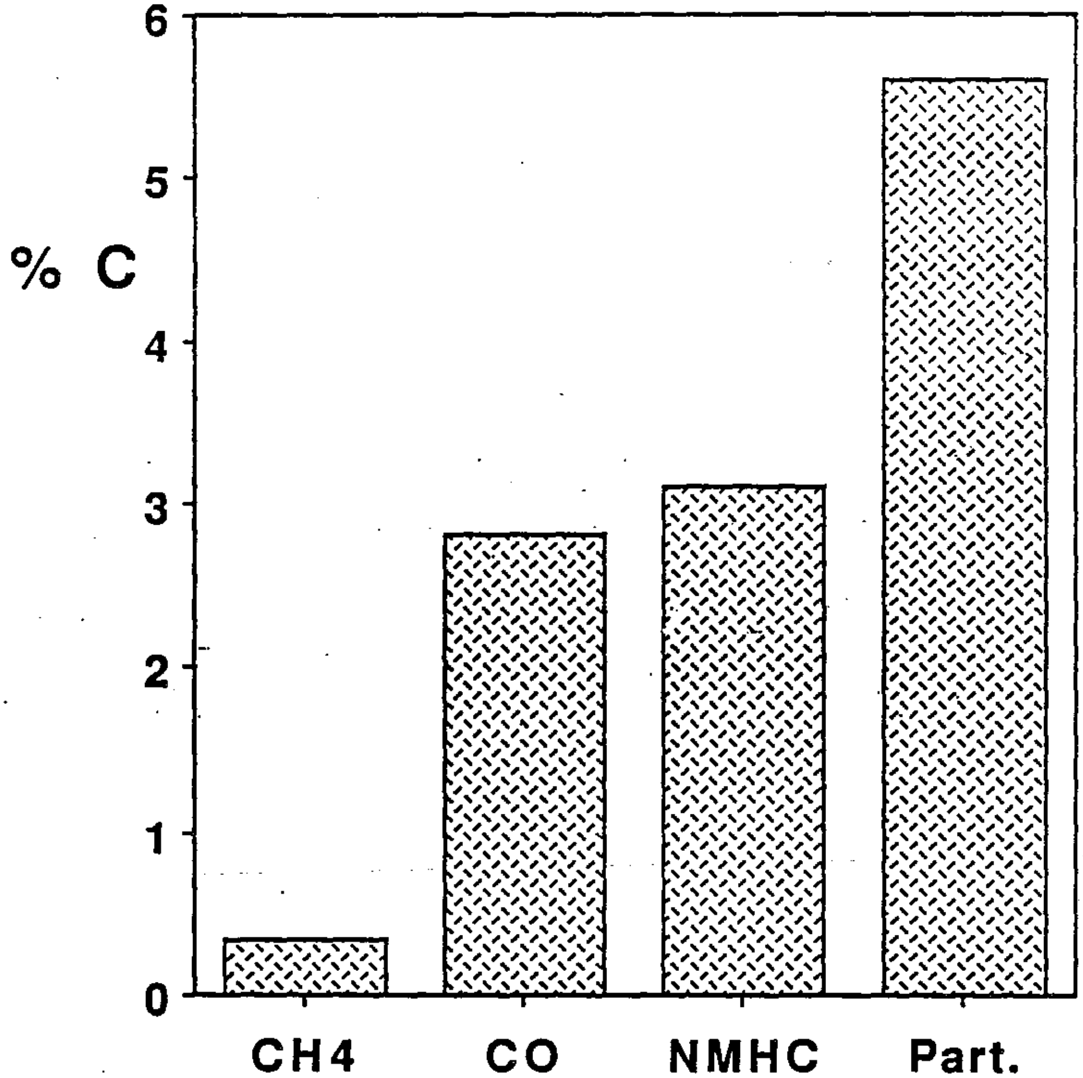



Carbon partitioning in mixed-plume smoke.

# Kuwait Oil Fires

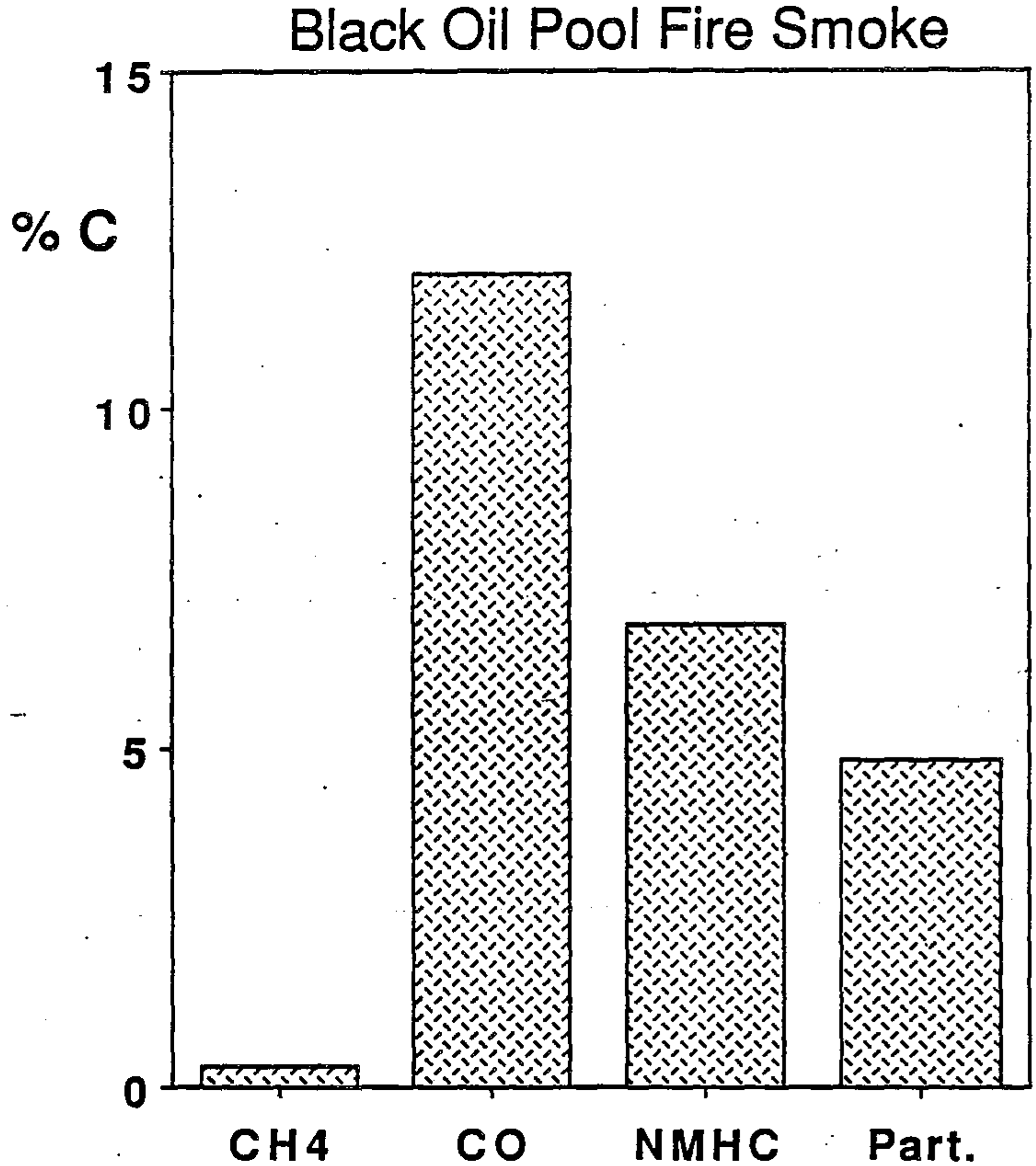
## NASA Helicopter Measurements

### Black Smoke Plumes



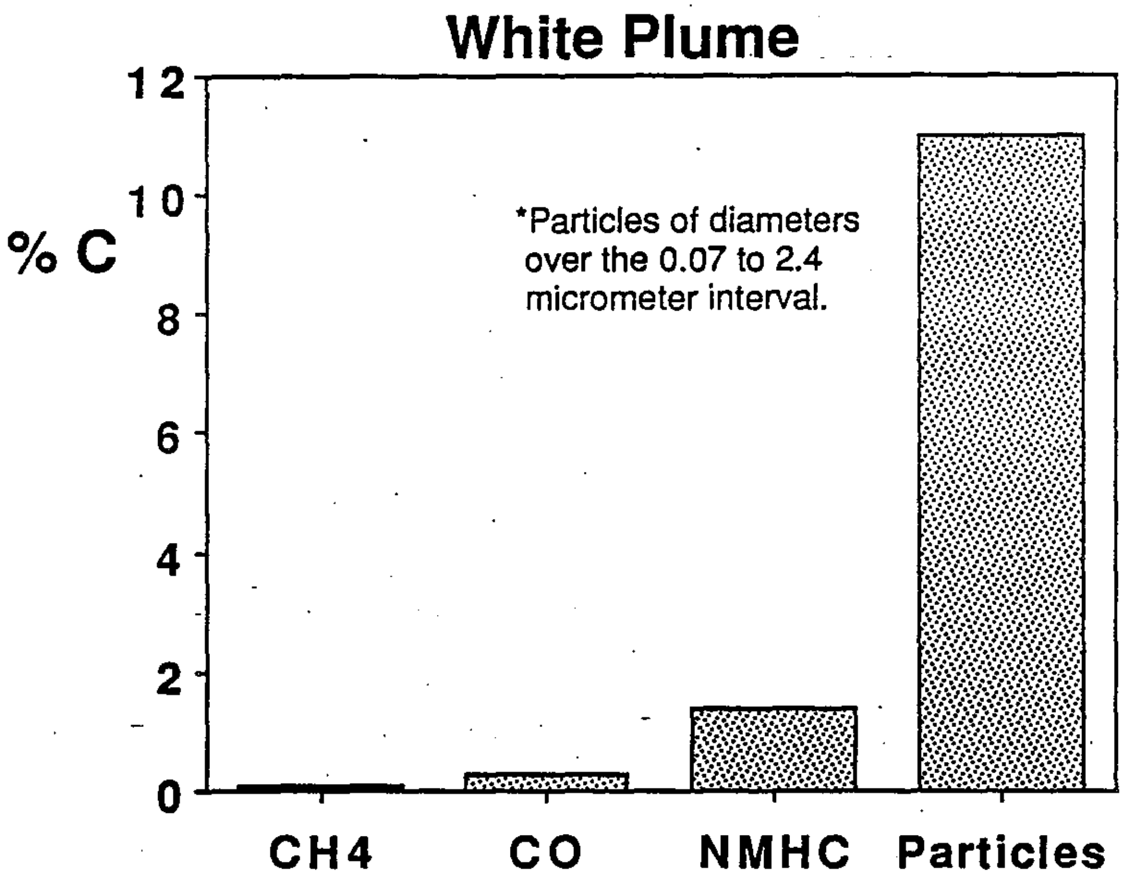

Percentage of carbon normalized to combustion produced carbon in carbon dioxide.

## Kuwait Oil Fires
### NASA Helicopter Measurements




Percentage of carbon normalized to combustion produced carbon in carbon dioxide.

# KUWAIT OIL FIRES
## NASA Helicopter Measurements

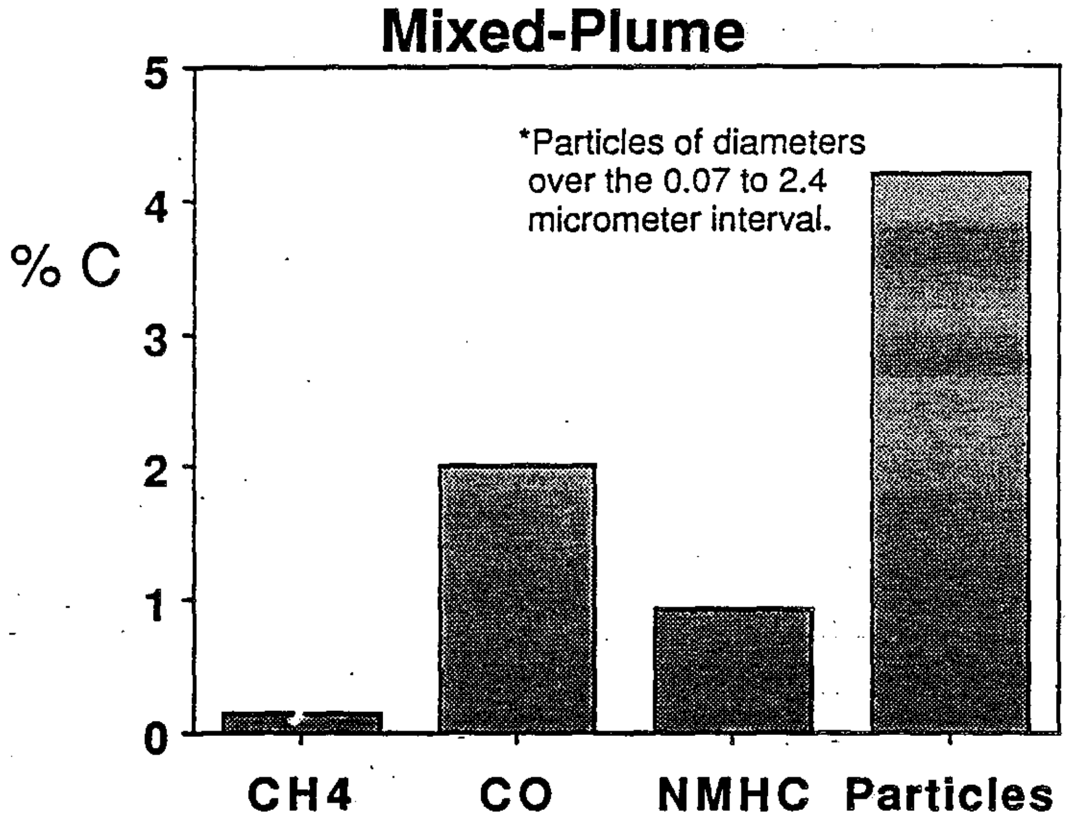



**Percentages of carbon normalized to combustion produced carbon in carbon dioxide (mass/mass).**

Measurements obtained in a large white verticle smoke plume in the northern oil fields of Kuwait on August 7, 1991.

Note the very high proportion of particulate carbon produced relative to carbon monoxide. Since particles of diameters greater than 2.4 micrometers have not been analyzed yet, this percentage would increase.

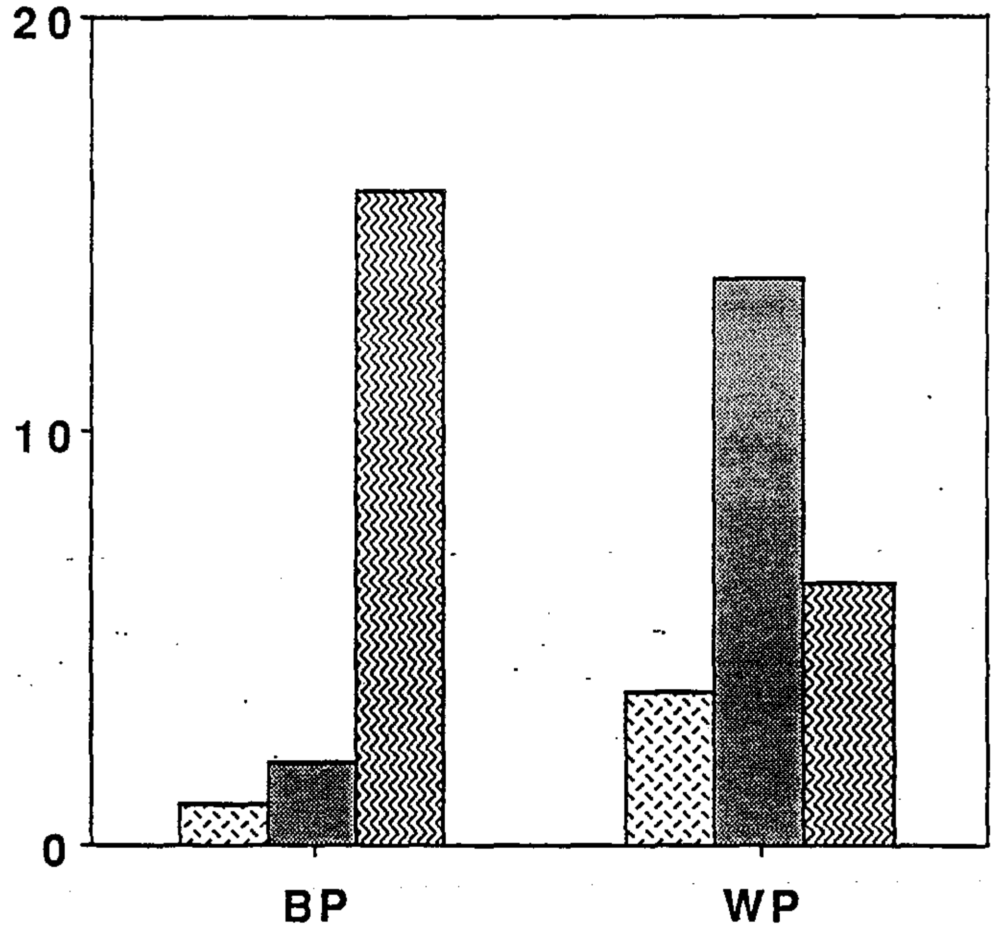
# Kuwait Oil Fires
# NASA Helicopter Measurements




**Percentages of carbon normalized to combustion produced carbon in carbon dioxide (mass/mass).**

Measurements obtained in the mixed-plume of the southern oil fields of Kuwait on August 6, 1991.

# Kuwait Oil Fires
## NASA Helicopter Measurements




Total particles(mg), Cl- (%T), SO4 (%T)

Wesley R. Cofer III, NASA-Langley Research Center, Atmospheric Sciences Division, (804) 864-5835

KUWAIT OIL FIRES - NASA/EPA Near-Field Helicopter Source Characterizations. Gas Concentrations.

Mission 1, July 31, 1991. Northern Oil Fields. Winds 300°, 10 Kts. Takeoff 7:10 AM.

| | | | | Concentrations in ppmv | | | | |
|---|---|---|---|---|---|---|---|---|
| Sample # | Type | Time | Altitude | $CO_2$ | CO | $CH_4$ | TNMHC | $N_2O$ |
| 1 | background | 7:25 LT | 1000 ft | 366 | 1.28 | 1.82 | 0.76 | 0.319 |
| 2 | " | 7:30 | 1000 ft | 368 | 0.21 | 1.79 | 0.61 | 0.318 |
| 3 | " | 7:34 | 200 ft | 365 | 0.24 | 1.79 | 0.85 | 0.319 |
| 4 | Bk oil pool-1 | 7:44 | 350 ft | 399 | 14.1 | 1.85 | 5.91 | 0.322 |
| 5 | " | 7:49 | 350 ft | 409 | 12.2 | 1.84 | 8.96 | 0.325 |
| 6 | " | 7:52 | 350 ft | 429 | 18.1 | 1.88 | 9.52 | 0.350 |
| 7 | " | 7:55 | 350 ft | 398 | 11.5 | 1.82 | 4.49 | 0.324 |
| 8 | " | 7:58 | 350 ft | 412 | 12.1 | 1.81 | 5.87 | 0.331 |
| 9 | " | 8:00 | 350 ft | 422 | 11.6 | 1.84 | 4.04 | 0.323 |
| 10 | Bk oil pool-2 | 8:03 | 300 ft | 419 | 10.3 | 1.83 | 4.48 | 0.323 |
| 11 | " | 9:37 | 300 ft | 399 | 9.4 | 1.83 | 3.94 | 0.319 |
| 12 | " | 9:27 | 300 ft | 422 | 6.7 | 1.85 | 3.54 | 0.320 |
| 13 | background | 8:10 | 800 ft | 405 | 5.80 | 1.81 | 0.89 | 0.320 |

Wesley R. Cofer III, NASA-Langley Research Center, Atmospheric Sciences Division, (804) 864-5835

KUWAIT OIL FIRES - NASA/EPA Near-Field Helicopter Source Characterizations. Gas Concentrations.

Mission 2, August 1, 1991. Northern Oil Fields. Winds 320°, 16 Kts. Takeoff 8:40 AM.

| | | | | ----------- Concentrations in ppmv ----------- | | | | |
|---|---|---|---|---|---|---|---|---|
| Sample # | Type | Time | Altitude | $CO_2$ | CO | $CH_4$ | TNMHC | $N_2O$ |
| 1 | Vert. Bk Pl-2. | 9:45 LT | 250 ft | 375 | 1.60 | 1.79 | 0.57 | 0.320 |
| 2 | " | 10:05 | 250 ft | 403 | 0.90 | 1.80 | 0.95 | 0.322 |
| 3 | " | 9:55 | 250 ft | 397 | 1.11 | 1.80 | 0.87 | 0.317 |
| 4 | | 10:03 | 250 ft | 424 | 1.20 | 1.81 | 1.21 | 0.323 |
| 5 | | 10:00 | 250 ft | 446 | 1.22 | 1.82 | 1.95 | 0.323 |
| 6 | | 9:51 | 250 ft | 391 | 0.83 | 1.80 | 1.42 | 0.322 |
| 7 | " | 9:47 | 250 ft | 427 | 3.11 | 1.81 | 1.48 | 0.321 |
| 8 | Vert. Bk Pl-1 | 9:34 | 300 ft | 397 | 1.85 | 1.84 | 2.12 | 0.322 |
| 9 | " | 9:37 | 300 ft | 410 | 2.82 | 1.88 | 2.55 | 0.321 |
| 10 | " | 9:27 | 300 ft | 395 | 3.35 | 1.87 | 2.93 | 0.319 |
| 11 | Bk oil pool-3. | 9:24 | 300 ft | 418 | 4.33 | 1.83 | 4.62 | 0.320 |
| 12 | background | 9:17 | 900 ft | 364 | 0.90 | 1.77 | 0.83 | 0.320 |
| 13 | " | 9:09 | 900 ft | 357 | 0.72 | 1.76 | 0.94 | 0.323 |
| 14 | " | 9:07 | 900 ft | 356 | 0.87 | 1.82 | 1.23 | 0.321 |
| 15 | " | 10:14 | 300 ft | 355 | 0.63 | 1.76 | 0.82 | 0.320 |
| 16 | " | 10:16 | 400 ft | 354 | 0.70 | 1.79 | 0.73 | 0.322 |

Wesley R. Cofer III, NASA-Langley Research Center, Atmospheric Sciences Division, (804) 864-5835

KUWAIT OIL FIRES - NASA/EPA Near-Field Helicopter Source Characterizations. Gas Concentrations.

Mission 3, August 2, 1991. Southern Oil Fields. Winds 300°, 12 Kts. Takeoff 10:50 AM.

| | | | | ---------- Concentrations in ppmv ---------- | | | | |
|---|---|---|---|---|---|---|---|---|
| Sample # | Type | Time | Altitude | $CO_2$ | CO | $CH_4$ | TNMHC | $N_2O$ |
| 1 | Bk-Oil-Pool-4. | 11:25 LT | 250 ft | 394 | 2.27 | 5.61 | 15.40 | 0.328 |
| 2 | " | 11:28 | 250 ft | 401 | 2.29 | 1.98 | 1.85 | 0.324 |
| 3 | " | 11:31 | 250 ft | 393 | 3.27 | 2.57 | 3.37 | 0.325 |
| 4 | | 11:35 | 250 ft | 390 | 2.16 | 1.80 | 1.78 | 0.318 |
| 5 | | 11:38 | 250 ft | 393 | 1.51 | 1.81 | 1.15 | 0.323 |
| 6 | background | 11:41 | 250 ft | 366 | 0.83 | 1.78 | 0.62 | 0.320 |
| 7 | " | 11:44 | 250 ft | 359 | 0.85 | 1.78 | 0.76 | 0.321 |

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KUWAIT OIL FIRES - NASA/EPA Near-Field Helicopter Source Characterizations. Gas Concentrations.

Mission 4, August 3, 1991. Northern Oil Fields. Winds 280°, 10 Kts. Takeoff 8:30 AM.

| | | | | Concentrations in ppmv | | | | |
|---|---|---|---|---|---|---|---|---|
| Sample # | Type | Time | Altitude | $CO_2$ | CO | $CH_4$ | TNMHC | $N_2O$ |
| 1 | background | 8:52 LT | 600 ft | 369 | 0.59 | 1.80 | 0.79 | 0.321 |
| 2 | " | 8:53 | 600 ft | 373 | 0.78 | 1.81 | 0.67 | 0.316 |
| 3 | oil lake,no fire | 9:17 | 100 ft | 412 | 4.44 | 1.81 | 1.69 | 0.321 |
| 4 | Vert. Bk Plume 3. | 9:25 | 200 ft | 441 | 0.90 | 1.81 | 2.30 | 0.324 |
| 5 | " | 9:29 | 200 ft | 450 | 1.33 | 1.82 | 2.62 | 0.321 |
| 6 | Bk-Oil-Pool-5. | 9:42 | 250 ft | 408 | 1.06 | 1.83 | 1.67 | 0.325 |
| 7 | " | 9:45 | 250 ft | 410 | 1.54 | 1.83 | 2.17 | 0.323 |
| 8 | " | 9:47 | 250 ft | 412 | 1.25 | 1.82 | 2.18 | 0.323 |
| 9 | Vert. Bk Plume 4. | 9:53 | 300 ft | 511 | 0.97 | 1.81 | 2.73 | 0.325 |
| 10 | | 9:55 | 300 ft | 546 | 1.14 | 1.82 | 2.44 | 0.321 |
| 11 | | 9:58 | 300 ft | 569 | 1.22 | 1.81 | 2.38 | 0.324 |
| 12 | background | 10:02 | 900 ft | 366 | 0.33 | 1.78 | 0.62 | 0.324 |
| 13 | " | 10:05 | 900 ft | 369 | 0.35 | 1.78 | 0.76 | 0.324 |

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KUWAIT OIL FIRES - NASA/EPA Near-Field Helicopter Source Characterizations. Gas Concentrations.

Mission 5, August 4, 1991. Northern Oil Fields. Winds 330°, 17 Kts. Takeoff 8:25 AM.

| | | | | Concentrations in ppmv | | | | |
|---|---|---|---|---|---|---|---|---|
| Sample # | Type | Time | Altitude | $CO_2$ | CO | $CH_4$ | TNMHC | $N_2O$ |
| 1 | background | 8:45 LT | 700 ft | 369 | 0.32 | 1.78 | 0.53 | 0.320 |
| 2 | " | 8:47 | 600 ft | 359 | 0.29 | 1.79 | 0.43 | 0.320 |
| 3 | oil pool no fire | 8:58 | 60 ft | 387 | 0.58 | 1.78 | 1.73 | 0.320 |
| 4 | " | 9:02 | 50 ft | 409 | 0.72 | 1.78 | 1.08 | 0.323 |
| 5 | Vert. Bk Plume 5. | 9:08 | 250 ft | 405 | 0.64 | 1.79 | 0.75 | 0.318 |
| 6 | " | 9:10 | 250 ft | 414 | 0.70 | 1.81 | 1.44 | 0.318 |
| 7 | " | 9:13 | 250 ft | 405 | 0.63 | 1.82 | 1.81 | 0.319 |
| 8 | " | 9:18 | 250 ft | 393 | 0.58 | 1.83 | 1.82 | 0.320 |
| 13 | Bk-Oil-Pool-6. | 9:38 | 300 ft | 397 | 0.66 | 1.81 | 2.20 | 0.325 |
| 14 | " | 9:40 | 300 ft | 424 | 0.89 | 1.82 | 2.62 | 0.323 |
| 15 | " | 9:43 | 300 ft | 395 | 0.82 | 1.80 | 1.87 | 0.319 |
| 16 | " | 9:45 | 300 ft | 409 | 0.85 | 1.81 | 1.51 | 0.321 |
| 17 | White Plume | 9:54 | 300 ft | 401 | 0.72 | 1.78 | 1.50 | 0.322 |
| 18 | background | 10:02 | 400 ft | 366 | 0.23 | 1.78 | 0.76 | 0.319 |
| 19 | " | 10:05 | 500 ft | 450 | 0.29 | 1.78 | 0.76 | 0.317 |

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KUWAIT OIL FIRES - NASA/EPA Near-Field Helicopter Source Characterizations. Gas Concentrations.

Mission 6, August 6, 1991. Southern Mixed Plume. Winds 330°, 5 Kts. Takeoff 8:02 AM.

| Sample # | Type | Time | Altitude | ---------- Concentrations in ppmv ---------- | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | $CO_2$ | CO | $CH_4$ | TNMHC | $N_2O$ |
| 1 | background | 8:08 LT | 300 ft | 373 | 0.32 | 1.77 | 0.63 | 0.323 |
| 2 | " | 8:10 | 300 ft | 369 | 0.44 | 1.78 | 0.34 | 0.319 |
| 3 | Mixed Plume | 8:13 | 800 ft | 402 | 0.50 | 1.83 | 0.81 | 0.319 |
| 4 | " | 8:16 | 700 ft | 400 | 0.66 | 1.85 | 0.87 | 0.319 |
| 5 | " | 8:17 | 600 ft | 397 | 0.70 | 1.85 | 0.87 | 0.318 |
| 6 | " | 8:20 | 600 ft | 393 | 0.56 | 1.80 | 0.74 | 0.321 |
| 7 | Mixed Plume | 8:26 | 1000 ft | 401 | 0.59 | 1.83 | 0.76 | 0.319 |
| 8 | " | 8:28 | 1000 ft | 402 | 0.47 | 1.82 | 0.83 | 0.321 |
| 9 | " | 8:30 | 1000 ft | 402 | 0.66 | 1.80 | 0.89 | 0.319 |
| 10 | " | 8:32 | 1000 ft | 399 | 0.96 | 1.86 | 1.02 | 0.321 |
| 11 | Mixed Plume | 8:45 | 1000 ft | 371 | 0.54 | 1.78 | 0.77 | 0.333 |
| 12 | " | 8:46 | 1000 ft | 400 | 1.41 | 1.83 | 0.88 | 0.324 |
| 13 | " | 8:48 | 1000 ft | 394 | 1.12 | 1.82 | 0.70 | 0.319 |
| 14 | " | 8:51 | 1000 ft | 396 | 1.01 | 1.80 | 0.61 | 0.324 |
| 15 | Mixed Plume | 9:04 | 1000 ft | 391 | 0.86 | 1.79 | 0.58 | 0.323 |
| 16 | " | 9:07 | 1000 ft | 389 | 0.88 | 1.80 | 0.57 | 0.321 |
| 17 | " | 9:09 | 1000 ft | 389 | 0.93 | 1.79 | 0.66 | 0.323 |
| 18 | " | 9:11 | 1000 ft | 388 | 1.02 | 1.80 | 0.59 | 0.319 |
| 19 | White Plume | 9:20 | 400 ft | 439 | 0.53 | 2.13 | 1.15 | 0.326 |
| 20 | background | 9:29 | 300 ft | 371 | 0.49 | 1.78 | 0.49 | 0.321 |

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KUWAIT OIL FIRES - NASA/EPA Near-Field Helicopter Source Characterizations. Gas Concentrations.

Mission 7, August 7, 1991. Northern Fields Whiteplume. Winds 320°, 9 Kts. Takeoff 8:00 AM.

| Sample # | Type | Time | Altitude | Concentrations in ppmv | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | $CO_2$ | CO | $CH_4$ | TNMHC | $N_2O$ |
| 1 | background | 8:30 LT | 800 ft | 363 | 0.22 | 1.75 | 0.45 | 0.318 |
| 2 | " | 8:31 | 800 ft | 362 | 0.17 | 1.75 | 0.33 | 0.323 |
| 3 | White Plume | 8:40 | 1000 ft | 396 | 0.34 | 1.79 | 0.89 | 0.318 |
| 4 | " | 8:42 | 1000 ft | 417 | 0.54 | 1.81 | 1.17 | 0.320 |
| 5 | " | 8:44 | 1000 ft | 442 | 0.56 | 1.82 | 1.26 | 0.318 |
| 6 | " | 8:46 | 1000 ft | 381 | 0.26 | 1.79 | 0.93 | 0.320 |
| 7 | White Plume | 8:53 | 1000 ft | 401 | 0.27 | 1.81 | 1.13 | 0.318 |
| 8 | " | 8:55 | 1000 ft | 377 | 0.25 | 1.78 | 0.95 | 0.318 |
| 9 | " | 8:57 | 1000 ft | 413 | 0.31 | 1.80 | 0.89 | 0.321 |
| 10 | " | 8:59 | 1000 ft | 397 | 0.26 | 1.79 | 0.92 | 0.321 |
| 11 | White Plume | 9:14 | 1000 ft | 417 | 0.42 | 1.81 | 0.91 | 0.324 |
| 12 | " | 9:21 | 1000 ft | 395 | 0.36 | 1.82 | 1.05 | 0.317 |
| 13 | " | 9:23 | 1000 ft | 524 | 0.58 | 1.88 | 1.69 | 0.321 |
| 14 | " | 9:25 | 1000 ft | 406 | 0.42 | 1.82 | 1.13 | 0.321 |
| 15 | background | 9:34 | 1000 ft | 369 | 0.20 | 1.78 | 0.62 | 0.319 |
| 16 | " | 9:43 | 1000 ft | 363 | 0.30 | 1.75 | 0.73 | 0.322 |

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KUWAIT OIL FIRES - NASA/EPA Near-Field Helicopter Source Characterizations. Particle Concentration.

Ion Chromatographic Analysis:

| Filter # | Bottle | Mission | Type | Tot wt | ---------- | ---------- | ug/$m^3$ | ---------- | ---------- | ---------- |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | $Cl^-$ | $NO_3^-$ | $SO_4$ | Na | $NH_4$ | K |
| 1 | 282 | 1 | O-P-F | 1.28 mg | 3 | 22 | 105 | 17 | 6 | 3 |
| 2 | 31 | 2 | BP | 2.44 | 90 | 70 | 400 | 75 | 32 | 10 |
| 3 | 25 | 2 | BP | (-) | 176 | 20 | 128 | 130 | 4 | - |
| 33 | 9 | 7 | WP | 5.7 | 885 | 6 | 90 | 265 | 5 | 3 |
| 34 | 8 | 7 | WP | 4.3 | 838 | 5 | 65 | 233 | 3 | 2 |
| 32 | 20 | 6 | SP | (-) | 25 | 4 | 30 | 11 | 2 | - |
| 19 | 30 | 6 | SP | 1.48 | 13 | 3 | 17 | 10 | 2 | - |
| 4 | 12 | 2 | BP | 3.88 | 54 | 3 | 117 | 61 | 7 | - |
| 5 | 29 | 2 | BP | 1.60 | 47 | - | 139 | 54 | 16 | - |
| 3 | 19 (2nd ext) | 2 | BP | (-) | 140 | 11 | 128 | 134 | 6 | - |
| 14 | 14 | 5 | WP | 2.5 | 738 | - | 105 | 393 | 17 | 32 |
| 6 | 33 | 2 | Bk | (-) | .8 | - | 2.2 | 1.9 | - | - |
| 7 | 254 | 2 | Bk | (-) | - | - | - | 2.6 | - | - |
| 15 | 27 | 4 | O-P-F | 0.9 | 1 | 7 | 140 | 28 | 19 | - |

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KUWAIT OIL FIRES - NASA/EPA Near-Field Helicopter Source Characterizations. Particle Concentration.

Ion Chromatographic Analysis:

| Filter # | Bottle | Mission | Type | Tot wt | $Cl^-$ | $NO_3^-$ | $SO_4$ | Na | $NH_4$ | K |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | ---------- ug/$m^3$ ---------- | | | | | |
| 12 | 133 | 6 | SP/Bkg | (-) | 2.1 | 2.0 | 9.4 | 5 | 2 | - |
| 10 | 7 | | BP | | 23 | | | 16 | 19 | 2 |
| 8 | 15 | 3 | O-P-F | | 23 | 3.0 | 88 | 49 | 13 | 1 |
| 16 | 36 | | | | | | 30.8 | | | |
| 9 | 11 | | | | | | 17.5 | | | |
| 13 | 24 | 6 | SP | (-) | 16 | 1.9 | 14 | 15 | 2 | - |
| 11 | 268 | | | | | | | 2 | 1 | - |
| 17 | 23 | | | | | | | 7 | 3 | - |

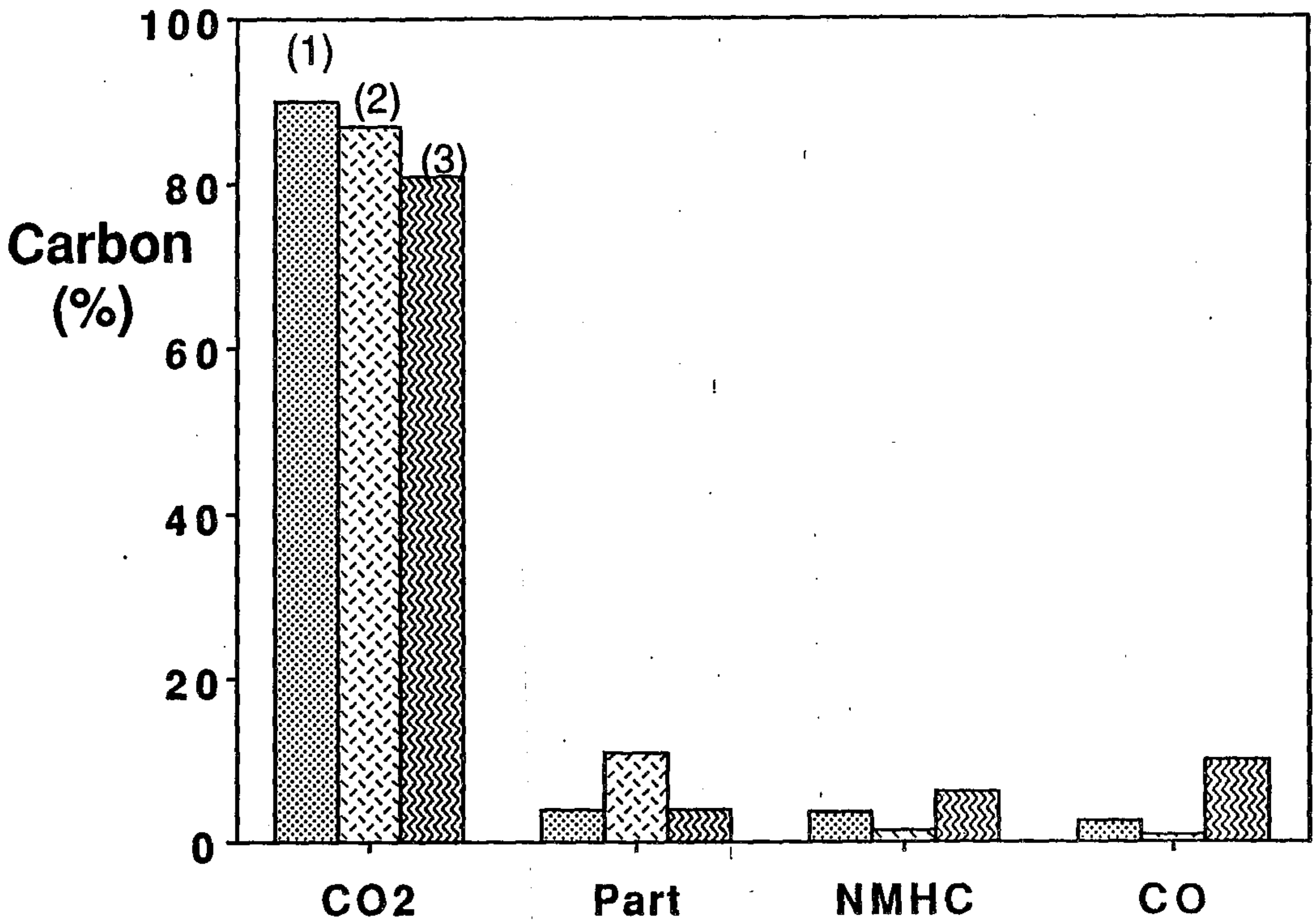


Figure 1. Carbon partitioning in (1) black plume, (2) white plume, and (3) oil pool fires. * Percentage of carbon in white plume reflects many non-carbon aerosol particles.

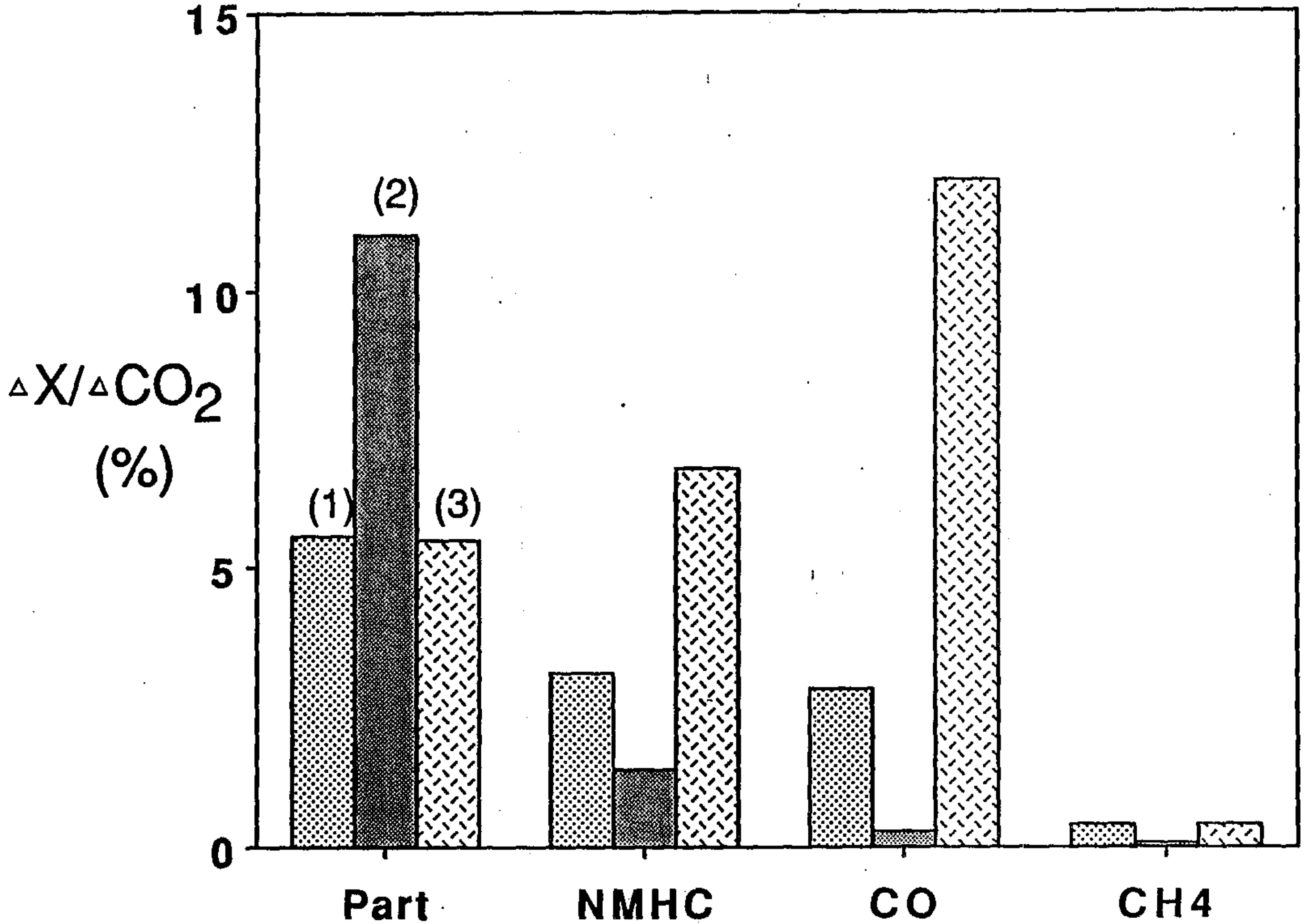


Figure 2. Normalized emission ratios for (1) black plumes, (2) white plumes, and (3) oil pool fires.

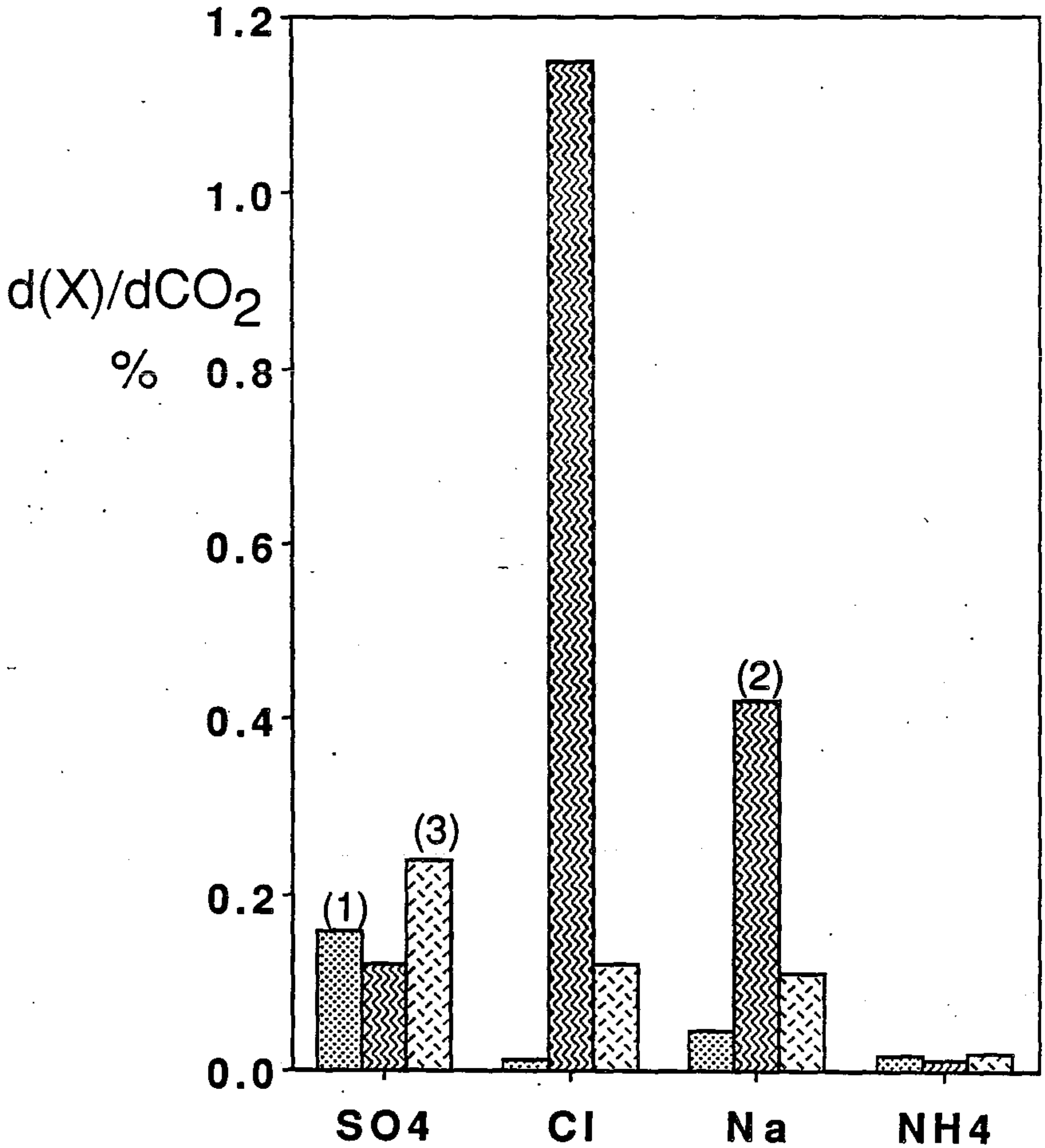


Figure 3. Emission ratios for water extracted aerosol ions. Key: (1) = oil pool fires, (2) = white smoke, (3) black plumes.

# NASA/EPA Helicopter Operations: Kuwaiti Oil Fires

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## Missions

Seven smoke sampling missions were conducted between July 31 and August 8, 1991, in the Sabriyah (northern oil field) and the Burgan oil field. A Royal Saudi Air Force UH1N (HUEY) helicopter and crew were used to acquire samples from selected oil fires representing different types of fires and smokes. The fires/smokes were generically categorized in this study as black smoke plumes, oil pool fire plumes, white smoke plumes, and mixed plumes (superplumes). A more complete description follows.

Black Smoke Plumes (BP) - Plumes resulting from essentially individual well fires with little pooling at their base and a sufficiently large amount of elemental carbon emissions to produce a visibly dark black smoke color.

Oil Pool Fires (O-P-F) - Fires that were substantially large ponds of burning oil typically surrounding one or more actively burning well heads. These fires usually produced dark black colored smoke emissions.

White Plumes (WP) - a significant number (est. about 10-15%) of the oil fires produced white smoke plumes. These white plumes were sometimes isolated, but many times they existed directly beside black smoke producing fires. Their coloration indicated a much different chemical composition.

Mixed or Superplume - the large plume resulting from the mixture of many individual smoke plumes from an oil field.

Smoke analyses focused on the above generic categories of fires/smokes and used gaseous measurements of carbon dioxide ($CO_2$), carbon monoxide (CO), methane ($CH_4$), nonmethane hydrocarbons (NMHC), nitrous oxide ($N_2O$), sulfur dioxide ($SO_2$), as well as carbon and sulfur aerosols. Aerosol measurements have been used to highlight particulate smoke characteristics for each category. Other analyses (e.g., % soot carbon generated, polynuclear aromatic hydrocarbons) are being conducted and results will be offered as soon as possible.

Figures

The partitioning of carbon compounds in the Kuwaiti smoke plumes are shown in figure 1. Total particle mass attributed to carbon appears in figure 1. Total carbon mass fractions shown in figure 1. are probably reasonable for all plumes studied but the white plumes, which contained large amounts of inorganic salts, and will be discussed later. As expected, most carbon emitted from the oil fire combustion can be accounted for as $CO_2$.

The same results, normalized to $CO_2$ ($\Delta X/\Delta CO_2$, where $\Delta X$ = compound of interest less its background concentration and $\Delta CO_2$ its plume concentration less background) are shown in figure 2. Normalization with $CO_2$ not only provides the percentages of non-$CO_2$ carbon compounds produced by the combustion, but also normalizes differences between individual samplings (sampling varability due to different times, locations in the plume, etc.). In figure 2, the relationship in concentrations of particles (Part), hydrocarbons (NMHC), carbon monoxide (CO), and methane ($CH_4$) emissions among the generic categories (BP, O-P-F, etc.) are more clearly seen.

Figure 3 shows emission ratios for the water extracted inorganic ions sulfate ($SO_4^{=}$), chloride ($Cl^-$), sodium ($Na^+$), and ammonium ($NH_4^+$) from smoke samples collected on filters over oil pool fires, white smoke plumes, and from black smoke plumes. It is readily apparent that chloride and sodium concentrations in the white plumes are substantially higher than in the oil pool fire and black plume smokes. Elevated levels of calcium and carbonates were also determined. Total sulfur concentrations (gaseous $SO_2$ + sulfate in the aerosol) for the smoke plumes averaged about 0.5%, which is lower than would be anticipated from the estimates of sulfur content in the Kuwaiti crude.

Figure 4 summarizes emission ratios determined for the mixed plume (superplume). Note the low concentrations for NMHC, CO, and $CH_4$. Particle (aerosol) concentrations, however, can be seen to be relatively high.

Results (Synopsis)

The precentage of carbon released as $CO_2$ is seen (figure 1) to be lowest in the oil pool fires. These fires also produce the highest levels of CO, NMHC, and $CH_4$ (see figure 2). They are thus the "dirtiest" and most polluting fires. Efficient combustion of hydrocarbon fuels produces mostly $CO_2$ and $H_2O$ as products. Production of particles and other gases represent incomplete combustion, and are produced at the expense of $CO_2$ and $H_2O$.

The very low levels of CO measured in the white plumes, particularly in light of the very high levels of aerosol particles measured, is notable. This result, however, may be explained by an examination of figure 3.

The exceptionally high emission ratios determined for sodium and chloride (figure 3) indicate overwhelmingly large amounts of inorganic salts for an oil combustion plume. This coupled with the distinctly white color of the plumes suggest that a large amount of liquid water may be associated with the white plume fires. Plume appearance coupled our with data would suggest that a steam/brine mixture may be emitted along with the combustion emissions. If so, this could account for the large amounts of aerosols that coexist with relatively low levels of combustion products (CO, NMHC, etc.) in the white smoke plumes.

## Conclusions

While the Kuwaiti oil fire smoke plumes manifest pronounced impacts on solar radiation in the Gulf region (sky color, ground temperatures, visibility, etc.), concentrations of indicators of combustion generated pollution suggest that the overall impact of the smoke from these fires may be less than anticipated. Sulfur emissions (both particulate and gaseous) appear to be an example of pollutants that are in lower than predicted concentrations. Carbon monoxide generated by the Kuwaiti fires (except for the oil pool fires) is another example of a pollutant at lower than expected smoke plume concentrations.

## Recommendation

Emphasis should be placed on determining the composition of the smoke aerosol. Since much of the smoke aerosol is in a respirable size, chemical compounds adsorbed or coated on particle surfaces could pose health hazards if such particles were trapped in/on the lungs.

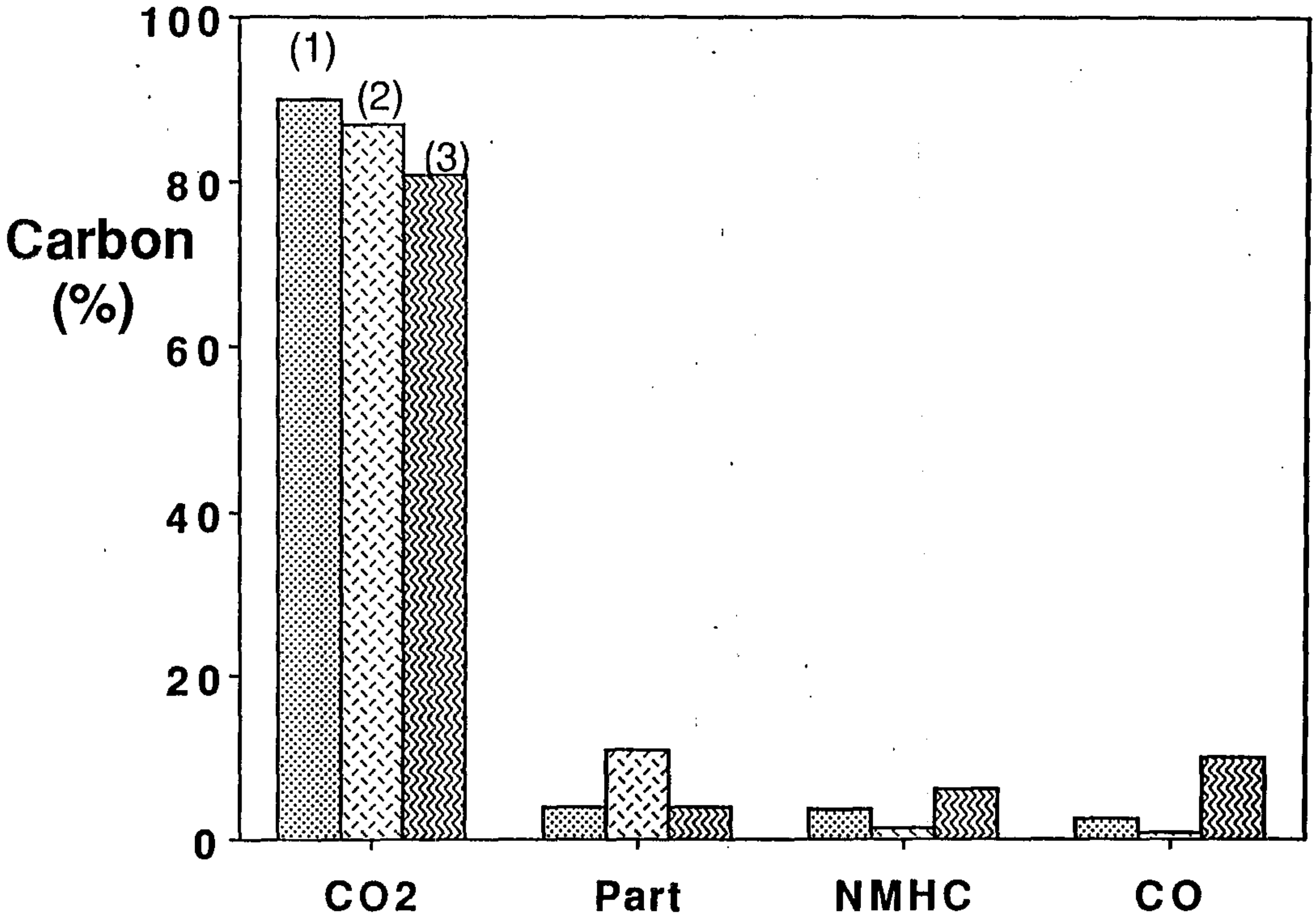


Figure 1. Carbon partitioning in (1) black plume, (2) white plume, and (3) oil pool fires. * Percentage of carbon in white plume reflects many non-carbon aerosol particles.

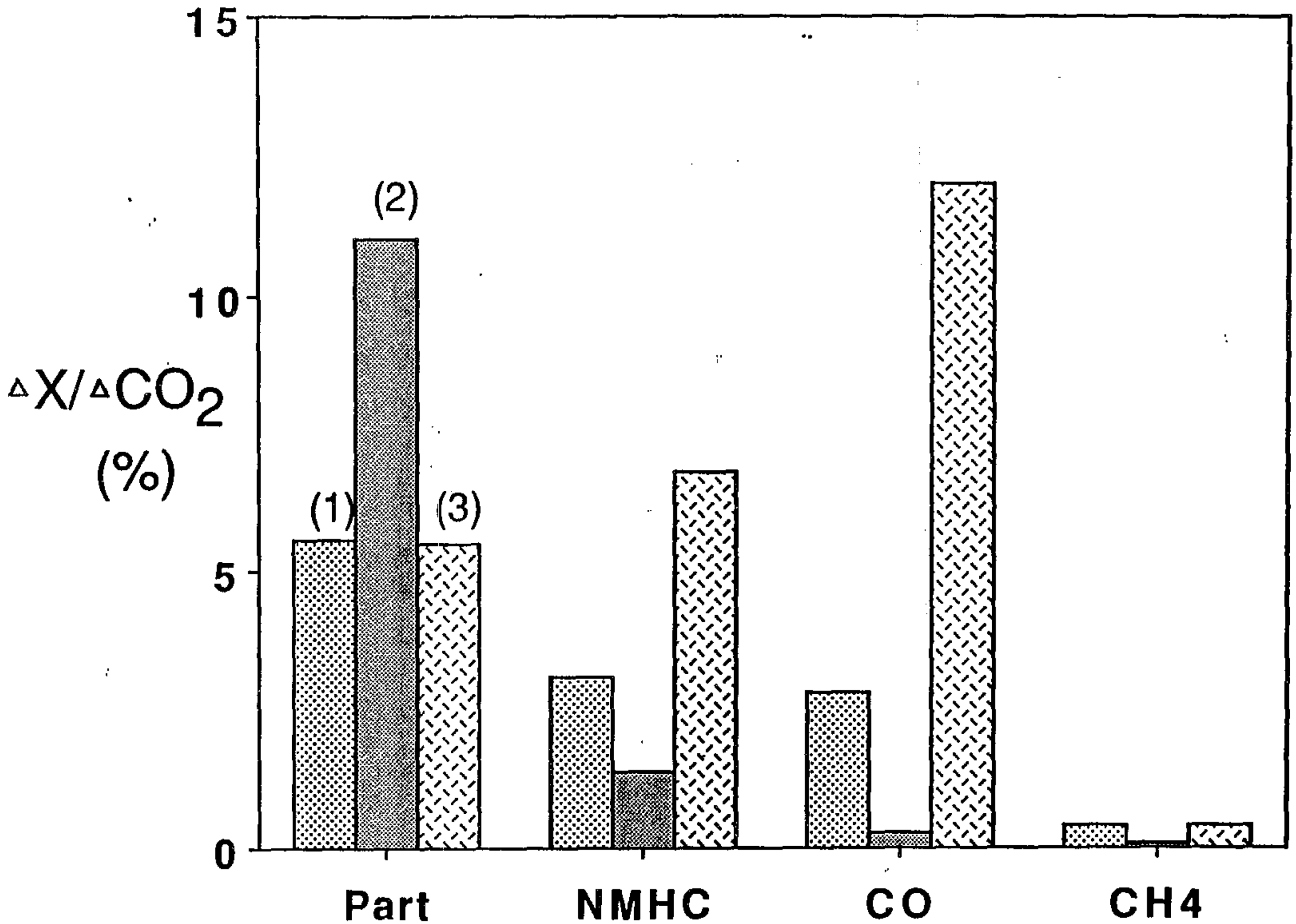


Figure 2. Normalized emission ratios for (1) black plumes, (2) white plumes, and (3) oil pool fires.

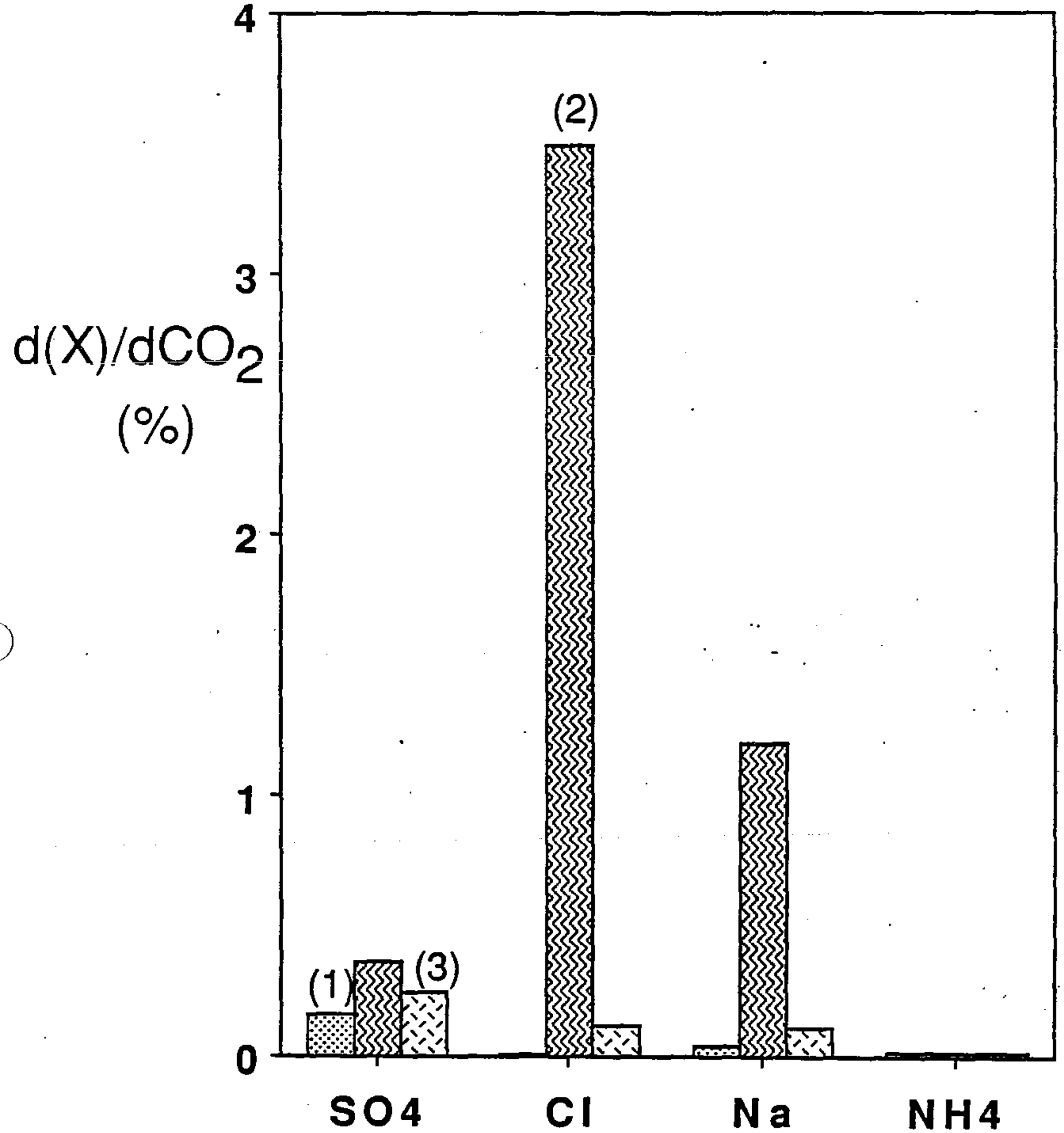


Figure 3. Emission ratios for water extracted aerosol ions. Key: (1) = oil pool fires, (2) = white smoke, (3) black plumes.

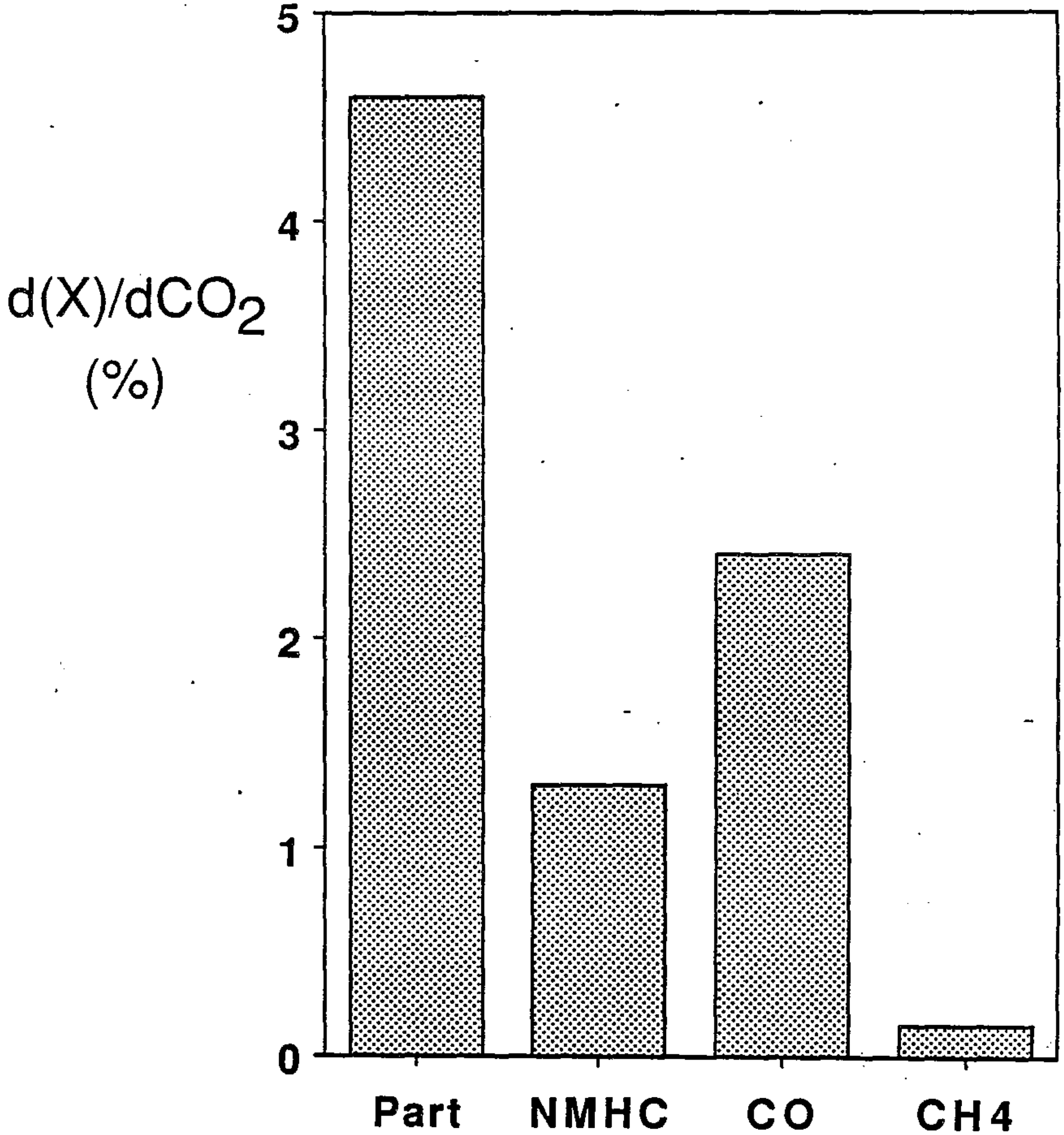


Figure 4. Normalized emission ratios for mixed plume (superplume).

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Paris, 27 May 1991

# FINAL REPORT

# MEASUREMENT CAMPAIGN OF THE REGIONAL MOBILE LABORATORY FOR MEASUREMENT OF AIR QUALITY IN KUWAIT

## 27 MARCH TO 4 APRIL 1991

PHILIPPE LAMELOISE
Director of AIRPARIF

GERARD THIBAUT
Engineer
Laboratoire Central de la Préfecture de Police

Comments on health consequencies
Doctors R. MASSE et J. LAFUMA
Atomic Energy Commissariat
Members of French Superior Hygien Council

Laboratory of Hygien of Paris City
Analyses (LHVP)
A. PERSON

Analyses of French Institut of Petroleum
(I F P)
M. PASQUEREAU

# RESULTS OF ATMOSPHERIC POLLUTION

# IN KUWAIT

## --- GLOSSARY ---

| | | |
|---|---|---|
| UNITS | : | - pollutants in $\mu g/m3$ of air at 20° C and normal atmospheric pressure<br>- weather conditions wind speed |
| N | : | site number on map |
| MOY | : | average over the period of measurement |
| MAX | : | maximum over 5 minutes for SO2, 03, CO, NO and NO2<br>maximum over 1 hour for BS |
| $SO_2$ | : | sulfur dioxide |
| CO | : | carbon monoxide |
| $0_3$ | : | ozone |
| NO | : | nitric oxide |
| $NO_2$ | : | nitrogen dioxide |
| BS | : | measurement of particles suspended in the air by the black smoke method in $\mu g/m3$ |
| HC | : | sample of gaseous hydrocarbons on activated charcoal support, analyzed in the laboratory by CPG + SM (length : one campaign) |
| VOC | : | volatile organic compounds |
| PAH | : | sample of polycyclic aromatic hydrocarbons filter + tenax and measurement in the laboratory by HPLC |
| PPA60: | | sample of particles on cellulose nitrate filter and PAH analyses |
| LHVP | : | Laboratory of Hygien of Paris City |
| IFP | : | French Institut of Petroleum |

# ATMOSPHERIC POLLUTION IN KUWAIT

## PART ONE

### I - INTRODUCTION :

In cooperation with the French and Kuwaiti environment and health ministries, a study of atmospheric pollution was undertaken from 26 march to 6 april 1991.

#### I-1 - Goals of the study

1°) Aid the Kuwaiti authorities of the ministry of public health which supervises the EPC in reactivations the air quality monitoring network in Kuwait City. This network, composed of three fixed stations set up in Kuwait City (see map 1) had been suspended during the Iraqui occupation and had not been able to be reactivated due to a lack of necessary equipment and electrical power.

2°) Inform the authorities of the ministries of the environment and health of the two countries of the levels of atmospheric pollution related to the burning oil wells.

We have therefore worked during the entire campaign in collaboration with the specialists of the EPC in consideration their proposal for measuring sites. We must emphasize the logic and technical aid given at all times by the detachment of the "Daguet division" in Kuwait City.

#### I-2 - Means

In order to reach the goals mentioned above, the departments and organizations responsible for monitoring air quality in the Paris region (AIRPARIF), Central Laboratory of the Prefecture of Police (LCPP) and Laboratory of Hygien of Paris City (LHVP) transported on site their mobile laboratory supplied with a portable generator and specifically equiped to measure atmospheric pollution in urban settings, as well as a team of two engineers.

The vehicle was transported by the special Air Force Plane TRANSAL C 160.

This equipment is composed of :

- a UV absorption ozone ($O_3$) , with its sensitivity test,

- a UV fluorescent sulfur dioxide ($SO_2$) analyzer, with its internal reference by calibrated permeation tube,

- an infrared absorption carbon monoxide analyzer linked to an external reference,

- a chemiluminescent nitrogen oxide ($NO + NO_2$) analyzer linked to an external reference (gaz bottle with a known quantity of NO),

- a sequential particle sampler on cellulose acetate filter, porosity 0,8 micron, for subsequent analysis in the laboratory of the compositions of particles there sampled (PPA60) (lenght of sampling = 1 hour), measurement of metals (nickel and vanadium were made by LHVP and IFP on these samplings (annex VI),

- a sequential particle sampler OPALE 500 for subsequent determination of the black smokes index by reflectometry (measurment of weight index).

This equipment was completed by systems for air sampling on specific solid supports with a view to the determination of others polluants :

- a sample on "tenax cartridge" with a view to the determination of "polycyclic aromatic hydrocarbons" (PAH),

- analyses of PAH and metals will also be made on PPA60 samples an on deposits from the black smokes sample,

- samples on activated charcoal tubes with a view to the determination of volatile organic compounds (HC)

PAH and HC samples were analysed by the "Laboratoire d'Hygiène" of the City of Paris and the conclusions appear in annexe VI. The following hydrocarbons were measured by LHVP on the actif charcoal samplings. Heptane, Octane, Nonane, Decane, Undecane, Tridecane, Benzene, Toluene, Ethy-benzene, Méta + Para Xylène, Ortho Xylène, 1, 2, 4 Triméthyl Benzène. Measurements of PAH (particulates phases) have been made by LHVP and IFP on samplings of black smokes (sampling on cellulose nitrate paper) analysed by HPLC fluorescence detector. PAH measured : fluoranthène, Benzo (a) Antracène, Antracène, Benzo (c) Pyrène, Benzo (b) Fluoranthène, Benzo (k) FLuoranthène, Benzo (a) Pyrène, Dibenzo (a, k) anthracène, Benzo (ghi) Perylène, Indeno (1,2,3 ; c, d) Pyrène, Pyrène for the VOC and PAH the levels in Paris City are added for comparison annex 6.

- the black smoke indexes were measured by the "Laboratoire d'Hygiène" of Paris City,

- manual detection of some pollutants by specific detector tubes (Draeger tubes).

The laboratory van is further equipped with meteorological sensors which can ben mounted on a telescopic pole at a hight of 9 meters and which allows acquisitions of the parameters of temperature, wind speed and wind direction. For the campaigns after the 3th of April the wind direction results were cancelled, the sensor appeared out of order.

The various pollutant gaz analysers and meteorological sensors are connected to a computer system which integrates supplied analog signals and allows mathematical processing of the recorded instantaneous values.

The computer system was programmed in such a way as to acquire for all parameters :

--> average values over 5 or 15 minutes,

--> instantaneous maximum values read by the instrument during each 5 minutes period (average signal over 3 seconds),

From these parameters the hourly averages and the averages for the length of each study were deduced.

# PART 2

## II - GENERAL NATURE OF THE KUWAITI ENVIRONMENT :

### II-1 - Kuwait

Before the Iraqi occupation and the events which followed, Kuwait had a population of about 2 millions inhabitants in an area of 16 000 km2, principally concentrated int the capital "Kuwait City" and its suburbs.

The main resource of the country is the extraction of crude oil by about 900 wells distributed among various oil fields :

- Al Rawdatayn, in the north
- Al Ahmadi et Al Maqwa, in the southeast,
- Al Wafra, in the extreme south,
- Al Burghan, in the center,
- Al Mutriba, in the northwest

(see map)

Production was about 2 million barrels (1)/day before the Iraqi invasion.

**(1) reminder : 1 barrel = about 159 liters**

Following the invasion, about 550 of the 900 wells were destroyed and set in fire, about 150 in the northern oil fields and 350 in the southern fields (see photos). According to information obtained from the Kuwait authorities, consumption of burning wells is on the order of 6 millions barrels/day.

### II-2 - Air Pollution

These fires are at the origin of massive emissions of smokes which darken the sky to the point of creating a black "night" even in the middle of the day. The population is thus facing very spectacular and therefore badly accepted pollution. We have thus sought to quantifie this pollution in order to better inform the authorities and the public on the basis of objective scientific data.

# PART 3

## III - ORGANIZATION OF THE STUDY

### III-1 - Principle of organization of the measurement campaigns

Considering the practical problems encountered in the field, that is :

- permanent lack of electrical power necessitating the use of a portable generator limited by a range of about 18 hours,

- security of equipment and personnel during night time operations,

It was not possible to use the laboratory van over long periods without survey. Consequently, two types of measurement campaigns were initiated :

1°) Diurnal (daytime) campaigns, either in town or near the oil fields (in the "plumes" of the fires). These campaigns could only be carried out over a limited time which varied, according to the site, from 3 to 8 hours ;

2°) Nocturnal (nighttime) campaigns organized according to security conditions :

*a)* in closed and guarded Kuwaiti EPC buildings,, during the night of 27-28 mars 1991,

*b)* on the French military "parking lot" of the New English School (SURRA quarter in the southeast of Kuwait City) ; former school building occupied by detachment of the Daguet division. On this parking lot, the laboratory van and its portable generator were able to be permanent guarded by the french military from the detachment . On this site, campaigns were conducted every night from the evening of 28 march to the morning of 5 april with the exception of the night of 29-30 march.

### III-2 - Measuring stations chosen :

As a function of the problems of installation and security elabored above, 14 campaigns varying in length from 3 to 16 hours were conducted.

During these campaigns, 8 measuring sites were studied :

- **station 1** : EOC headquarters, western quarter of Kuwait City in the industrial zone, near the "fourth ring" (4th "ring road") ;

- **station 2** : New English School, "camp of the Daguet detachment", SURRA quarter, southeast of Kuwait City, near the "fifth ring" ;

- **station 3** : Mansouriya hospital, downtown Kuwait City, near the "second ring" ;

- **station 4** : oil fields, north of Al Rawdatayn, about 150 km north of Kuwait City, near the Iraqi border ;

- **station 5** : in the village of Al Ahmadi, about 30 km south of Kuwait City near the Al Burgaam, Al Ahmadi and Al Magwa oil fields ;

- **station 6** : in the Al Ahmadi hospital a few hundred meters south of the Al Ahmadi oil fields ;

- **station 7** : on the "seventh ring", at the "international Airport" interchange, about 2 - 3 km northeast of the Al Magwa oil fields ;

- **station 8** : on the "Al Maqwa Road", within the oil fields, crossing the Al Magwa fields (to the west) and the Al Ahmadi fields (to the east).

All of these measuring stations (with the exception of station 4, located outside the map), are listed on the maps. Stations 4 is shown on the overall map of Kuwait.

### III-3 - Classification of the Measuring Stations

In view of the definitions of the measuring sites described above, it clearly appears that, throughout the 10 full days of study, two classes of measuring stations could be defined.

* Class A : measuring stations for "background pollution located int the city or suburbs, near habitations but far from the direct impact of the plumes emitted by burning wells. These stations are characterised, presumably by levels which are lower but to which the kuwaiti population is directly exposed over long periods of time. These stations are therefore of interest to overall health, according to the same classification defined above stations 1, 2, 3, 5 and 6 will be considered class A (background pollution). Unusual meteorological conditions may, however, cause these sites to be exposed to a high level of pollution.

* Class B : measuring stations for "proximity pollution" located in the middle of the oil fields in the immediate vincinity of the plumes, in the desert far from any habitations. The levels measured at these stations, presumably the highest, represent the "maximum risk" but to which only a small sample of the population is exposed (for example the personnel of the oil companies working in the fields or participating in the fire fighting operations).

Stations numbered 4, 7 et 8, according to the above numeration, will be considered characteristic of class B (proximity pollution).

# PART FOUR

## IV - "BACKGROUND POLLUTION" IN KUWAIT : RESULTS

This section will show results obtained from the measuring stations for background pollution (Class A : defined above). The measuring results graphs of hourly evolution, maps and bar graphs of frequencies us concentrations are available in the six annexes found at the end of this report.

### IV-1 - Measuring station n° 1 (E.P.C.) : Campaign n° 1

The study was conducted from 27 march 1991 at 5:00 p.m. (local time (1)) to 28march 1991 at 9 : 15 a. m., that is over a period of 16 hours 15 minutes. Computer integration of the gas pollutant levels was carried out every quarter hour.

In the course of this study, an analyzer and transducer breakdown prevented obtaining of reliable results with regard to SO2 "black smoke" and meteorological parameters.

During this first campaign, we haven't made any sampling of PAH and VOC.

With regard to the pollutants measured, the atmospheric pollution seemed very low :

*carbon monoxide (CO)*

general average (over 16 h 15 mn) : 1587 $\mu$g/m-3 ; maximum over 15 mn : 4234 $\mu$g/m-3 *ozone (03)*

general average : 23 µg/m-3 ; maximum over 15 mn : 79 µg/m-3

*nitrogen oxide (NO)*

general average : 77 µg/m-3 ; maximum over 15 mn : 227 µg/m-3

*nitrogen dioxide (NO2)*

general average : 54 µg/m-3 ; maximum over 15 mn : 94 µg/m-3

All of the levels measured over 15 minutes are represented on the graphs marked 27/3/91 in the annex.

## IV-2 - Measuring station n° 2 : "New English School" (Daguet Detachment) : campaigns n° 2, 5, 7, 9, 10, 12 et 14

The measurements taken at this station are all nocturnal : 7 nights were thus studied (campaign 2, 5, 7, 9, 10, 12 and 14). These 7 campaigns, of a total duration of about 86 hours yielded the results summarised in the synthetic table of results in the annex 5 ; it gives the average concentrations observed over the duration of each campaign and the maximal concentrations of gas pollutants over 15 minutes for campaign n° 2 and over 5 minutes fo the other campaigns, and the maximal hourly levels of black smokes.

The graphs of pollutants and meteorological parameters, in annexes 1 and 2, which correspond to the English School measuring site, show the results obtained in the course of the 7 campaigns conducted at measuring station n°2 (New English School).

In general, relatively low concentrations of the pollutants 03, CO, NO and N02 were observed.

Rather low concentrations (30-100 m-3) of SO2 were measured in 6 out of 7 campaigns.

During the night of 3-4 April (campaign n° 12), an average concentration of SO2 of 472 µg/m3 was observed over a period of more than 12 hours, with a peak lasting 5 minutes of over 2900 µg/m3. This same night, an average concentration of black smokes of 231 µg/m3 was observed, with an hourly maximum of 792 µg/m3. This pollution peak appears at 1 h 40 with a strength of wind speed and a growth of the temperature (+ 4° C) for a short time (25 minutes). This seems to indicate that the plume from the south oil field was falling down to the ground for a few minutes.

(1) local time = French standard time + 2 hours
= French daylight saving time + 1 hour

Throughout this report the times given are in local time.

It must be underlined that this night was marked by rather high winds (3,4 m/s on average ; with peaks at 12.4 m/s over 5 minutes) from the south south east sector oriented at 194° on the average ; this blowing the plume from the Al Maqwa and Al Ahmadi oil fields, closest to Kuwait City, across the city. During the other campaigns, the winds observed were in the majority from the north and northwest sectors, thus coming from the Gulf (see corresponding graphs in annex 11) showing the meteorological particularities of the night of 2-4 April 1991 - campaign n° 12 English School.

For the hydrocarbons (VOC), it is the campaign number 9 which shows the highest levels for all these parameters in the english school (night from 1 to 2 April 1991).

These levels are lower than in Paris for the light hydrocarbons and almost two times for the heavy ones and the aromatics. Strong enought levels were also measured during the 31/3 to 1/4 but only for paraffinics.

With regards to PAH, exept during the night from 3 to 4 of April where the levels are hight, the highest levels were registred in English School during the night from 28 to 29 March 1991 (campaign n° 2) : Fluoranthene (24 ng/m3) Benzo (ghi) perylene, indeno pyrene.

These levels are similars or are lowers that the parisian ones.

The HPLC analyses made by IFP of the black smokes sampled from 1 to 2 o'clock. The 4th of April are the highest mesured by this laboratory on Kuwait results for all the PAH exept Benzo (a) pyrene. This is surprising because this sampling is not the worst for the black smokes results. At the contrary the VOC levels measured this night are relatively low (campaign n° 10). No measurement of metals was made in English School.

## IV-3 - Measuring Station n° 3 : Mansouriya downtown Kuwait City : campaign n° 3

The study at this sitting was conducted 29 March 1991 from 11:35 am to 5:05 pm, that is, for a period of 5 hours 30 minutes.

This study was conducted with the goal of aiding the E.P.C. in restarting the fixed measuring station for atmospheric pollution of the Kuwait City network, shut down for 7 months. The measurements taken served as a reference and thus helped to calibrate the analysers in this station.

The results obtained with regard to gas pollutants are summarized in the graphs of day 29/3 (annex).

The levels measured were low.

Note, however, the high levels of $O_3$ : 81 $\mu$g/m3 over 5 h 30 min ; with a maximum over 5 minutes of 100 $\mu$g/m3.

Levels of CO were extremely low, less 700 $\mu$g/m3 in peaks over 5 minutes.

The results from the mobile laboratory correlated well with those from the fixed station in Mansouriya.

Levels of black smokes were an average of 99 $\mu$g/m3 over 5 hours for a maximal hourly value of 144 $\mu$g/m3. Due to theses low levels we did'nt made any measurement of PAH.

The VOC levels are the lowest for all the campaigns. They are largely lower that the Paris levels.

The nickel and vanadium concentration are also very low.

The meteorological conditions were marked with low speed winds average less than 2m/s from the northern sector (from the Gulf) ; high temperatures reaching 30° C around 2:00 pm, related to strong sunlight, which explains the high ozone levels (weather conditions on graph for 29/3 in annexe II).

### IV-4 - Measuring station n° 5 - Al Ahmadi village : campaign n° 6

The study was conducted on 31/3/91 from 11:00 am to 5:05 pm, that is, for a period of 6 h 5 min.

In spite of the relative proximity of the burning wells (about 1.5-2 km), average levels, over 6 hours were low ; 23 μg/m3 for ozone and 330 μg/m3 for CO (graph in annex). High average levels (over 6 hours) of SO2 and black smokes were recorded : 252 μg/m3 of SO2 and 159 μg/m3 of black smokes. Very high maximum levels of these two pollutants were recorded : 687 μg/m3 of SO2 over 5 minutes, 745 μg/m3 of black smoke as an hourly maximum.

The VOC levels measured are the highest for the campaigns made outside the oil fields. They are double compared with the parisians levels for the paraffinics hydrocarbons and are equal to these levels for the aromatics. But a strong value of ortho xylene (35 μg/m3) is shown.

These results show the action of the burning fields on the village.

Two analyses of PAH were made, one by LHVP on the 11 to 13 o'clock sampling, when the van was under the plume, the other by IFP on the 14 to 15 sampling, when the pollution was coming back to the field because of in draft.

The first sampling shows levels double more then the second for all PAH exepted indeno pyrene. The only value for indeno pyrene (40 ng/m3) is largely highest than the Paris levels.

No measurement of metals was made on this sampling site.

From the meteorological standpoint, very low winds were observed (0,6 m/s on average).

The direction of these winds, in great majority form the south to southwest sector, that is, in the direction of the wells, showed the importance of the in-drafs toward the wells created by the fires. From this standpoint, during this campaign a black plume was noticed passing at a high altitude in a north to south direction as well as winds in the opposite direction, that is, south to north, at ground level (see graphs of weather conditions on 31/3/91).

### IV-5 - Measuring station n° 6 - Al Ahmadi Hospital : campaign n° 8

The hospital, located northwest of the village, is very close to the wells (about 500 m to the south).

Note the significance of this site from the health standpoint, considering the type of population exposed (the sick especially lung patients).

This campaign was conducted on 1/4/91 from 12:25 pm to 5:40 pm, that is, over a period of 5 h 15 minutes.

The levels measured were relatively low for 03 and NO2, and very low for CO and NO. Rather high levels of SO2 and black smoke were observed principally at the beginning of the campaign (until about 4:30 pm) (see graphs for 01/04 in annex).

This sampling site was rarely under the plume of the oil fields, so the VOC and PAH levels are low.

Three measurements of nickel and vanadium were made between 15 and 18 o'clock. The concentration in vanadium are about 70 ng/m3 and so, low. The nickel, levels are anormaly high for one of the sampling. Maybe a problem of metrology because the sampled quantities are small for the measured concentrations.

From the meteorological standpoint, high winds (2,4 m/s on average) from the south and southwest sectors, thus toward the wells, were observed principally at the end of the campaign (graph for 01/04/91 in annex II).

### IV-6 - Conclusions Concerning Measurements of Background Pollution

The study carried out at the background pollution sites most often showed low or extremely low levels of CO and NO.

Under unfavorable meteorological conditions, with the plume emanating from the wells touching the ground, very high levels of the pollutants SO2 and black smokes were observed. These conditions occurred rarely : only on the night of 3-4 April. The meteorological results permitted, to show the complexity of the movements of air masses ; it was thus shown that at ground level the in-draft created by the combustion at the wells could be considerable in the direction "town-wells". It is in all likelihood this phenomenon that is the main parameter explaining the low levels most often observed.

High levels of PAH and VOC appears during the night from 3 to 4 of April 1991 in English School. A peak only limited to paraffinics hydrocarbons is also shown during the 31/3 to 1/4 night in the same site.

The campaign in Ahmadi village, where the sampling site was under the south oil fields plumes shows also high levels for the paraffinics hydrocarbons.

# PART FIVE

## V - "PROXIMITY POLLUTION" IN KUWAIT : RESULTS

### V-1 - Principle of the Campaign

Considering the results of background pollution observed (see part IV), it seemed of major importance to look for measuring sites in close proximity to the burning wells, directly in the plume emitted by the fires.

The mobility of the equiment and electrical autonomy (tractor-drawn electrical generator) out allowed for 3 campaigns responding to this desire to look for the maximum risk to be carried out.

## V-2 - Measuring Station n° 4 - Al Rawdatayn northen oil fields (near the Iraqi border) : campaign n° 4

The laboratory van was set up in the middle of the northern oil fields some 200 meters from the nearest burning wells at a location where, quite obviousy, the impact of the surrounding plumes was maximal. The campaign was conducted on 30/3/91 from 2:05 pm to 5:15 pm, that is, over a period of 3 h 10 min.

Very low or practically nonexistent levels of CO, NO and NO2 were observed.

High levels were observed of ozone (about 100 µg/m3 on average over 3 hours), SO2 (270 µg/m3 on average) and black smoke (265 µg/m3 on average). Manual detection evaluated CO2 levels at 600 ppm.

The small length of this campaign didn't allowed measurement of VOC and metals. The HAP measured by IFP are low.

From the meteorological standpoint, extremely violent winds were measured (8.4 m/s on average) with gusts of up to over 15 m/s or nearly 55 km/h), a phenomenon which confirms the important role of in-drafts at ground level created by the fires) (see graphs for 30/3/91 in annexe I)..

## V-3 - Measuring Station n° 7 - "Seventh Ring" : campaign n° 11

On the "Seven Ring" highway about 30 km south of downtown Kuwait City, at the level of the International Airport Interchange, this measuring station is located halfway between the Al Maqwa fields (to the west) and the Al Ahmadi fields (to the east) and is subjected to maximal fallout from the various plumes.

This campaign was conducted on 3/4/91 from 10:15 am to 6:05 pm, that is, for a period of 7 h 50 min.

Very low or practically nonexistent levels of CO, NO and NO2 were observed.

High levels of ozone (86 µg/m3 on average) and very significant levels of SO2 (495 µg/m3 on average with a maximum of 1223 over 5 minutes) and black smoke (595 µg/m3 on average over 7 hours with an hourly maximum of 1365) were recorded (see graphs for 3/4/91 in annex I).

Manual detection estimated the level of CO2 at 500-600 ppm.

VOC measured during the 11th campaign shows globaly the highest levels measured. Theses levels are particularely high for heavy paraffinics hydrocarbons (10 times the Paris levels). They are low for the aromatics.

PAH analyses made by IFP on the 17 to 18 h sampling show very low levels this the level of black smokes is very high.

PAH analyses made by LHVP on the 10 to 12 h samplings shows high levels for fluoranthene (37 ng/m3) and indeno pyrene (17 ng/m3) but other PAH have low levels.

On this site a sampling of 7 hours using a cardridge (tenax and glass fiber filter) was made to measure PAH in both gaseous and particulate phase. Analyses of these sampling showed quiet no PAH in gaseous phase exepted fluoranthene (17 ng/m3). Levels detected as the particulate phase were low for all PAH.

Measurement of metals on 11 h to 12 h and 17 h to 18 h show 200 ng/m3 of vanadium.

From the meteorological standpoint, extremely high winds from the eastern sector (toward the Al Ahmadi fields) were recorded (11 m/s on average with peaks over 5 minutes of about 20 m/s or about 75 km/h) (see graphs for 3/4/91 on annexe II).

### V-4 - Measuring Station n° 8 - Al Maqwa southern oil fields : campaign n° 13

This site was chosen in the middle of the oil fields some 250 meters from the nearest well.

The campaign was conducted on 4/4/91 from 11:05 am to 5:00 pm, that is, over a period of about 6 hours.

Very low levels of CO and NO rather low levels of NO2 ; rather high levels of ozon (71 µg/m3 on average over 6 hours) and very high levels of SO2 (215 µg/m3 on average, with a maximum over 5 minutes of 1833 µg/m3) were recorded.

Exceptionally high levels of black smoke were noted (818 µg/m3 on average with an hourly maximum of 2030) (see graphs for 4/4/91 in annex I).

Levels for VOC measured during this campaign are low exepted for heavy paraffinic hydrocarbons (decane, undecane, tridecane).

PAH analyses on 11 to 14 h sampling which is the worst sampling for back smokes give the highest levels for fluroanthene (110 ng/m3), Benzo (c) Pyrène (26 ng/m3), Benzo (a) Pyrène (30 ng/m3), Benzo (ghi) Perylène (26 ng/m3), Indeno Pyrène (41 mg/m3)). These levels, in average, are double from the parisian ones.

The metals concentrations (nickel and vanadium) are low.

High winds in the direction of the wells were recorded (5.8 m/s on average).

### V-5 - Conclusion Concerning Measurements of Proximity Pollution

The measurements of proximity pollution allowed the following conclusions to be drawn :

- absence of CO and NO pollutants ;
- very low levels of NO2 ;
- rather high levels of ozone ;
- very high levels of SO2 and black smoke.

With regard to VOC relatively high levels of heavy paraffinics hydrocarbons were shown. Levels of light hydrocarbons and aromatics are low exepted orthoxylene. The light hydrocarbons seems to be destroyed by combustion. The only heavy product are staying in the air.

The contamination of particules by PAH seams to be relatively low. It is largely changing for the differents sites and for the differents PAH. The gaseous phase didn't contain theses pollutant exepted fluoranthene.

The borne concentration of metals is also low.

At the proximity sites studied, very high winds were always found, confirming the in-draft near the wells.

# PART SIX

## VI - ASSESSMENT AND CONCLUSIONS

In conclusion, the study conducted from 24 March to 5 April 1991 in Kuwait showed that the atmospheric pollution was most often low at ground level at sites where the population is exposed. High levels were recorded at the sites in the vicinity of the wells or whenever their emissions influenced distant sites, but only relative to the pollutants ozone (occasionally, but may be of advective origin), SO2 and black smoke.

However the meteorological conditions, often very unstable and favorable to dispersion, which prevailed during the ten days of campaigns, must be underlined.

A meteorological situation with stable air masses and low wind speeds placing Kuwait City down wind of an oil field would certainly lead to higher levels.

Among the most striking conclusions, the following should be underlined :

- the near absence of CO ;

- the very low levels of NO ;

- the high levels of ozone, which may be considered "normal" taking into account the latitude and amount of sunshine which is related, and the high atmospheric instability (advection ?) ;

- the very high levels of SO2 and black smokes, either near the wells or in town with unfavorable weather conditions, this phenomenon rarely appears during the campaign.

Exepted in the 3 to 4 April, night in Kuwait City and in the oil fields, the VOC and PAH levels are lower than in Paris.

The graphs in annex III summarise these conclusions. These bar graphs of frequency VS concentration, established on the overall 5 minutes data for NO, NO2, CO, 03, SO2 and hourly data for NO, NO2, CO, O3, SO2 and black smokes and for all of the measurement campaigns over 10 days, take into consideration the overall exposure of the mobile laboratory and thus the cumulative exposure of a person following the vehicle during the 10 days of measurement.

The meteorological conditions proved to be very complex and marked by significant in-drafts in the direction of the fires, a phenomenon rather favorable to the dispersion of atmospheric pollution at ground level.

The table in annex 5 gives a synoptic summary of all of the measurements taken and of the results obtained throughout the 14 campaigns.

Finally, in annex V, for purposes of comparison, can be found the standards of air quality defined this the EEC directives as well as the average annual levels of SO2, black smoke and NOx (NO + NO2) in Paris, as well as the overall results of the various measurement campaigns, and maps of the region.

Doctors MASSE and LAFUMA from French Atomic Energy Commissariat accepted to comment the possible health consequancies of these pollutions levels.

Here is their opinion :

Airborne toxicants in Kuwait atmosphere have been measured repetedly between Marc 27 and April 4. Results showed a complicated situation with multiple pollutants involved, among which SO2 and black smokes were the two major constituants. The greatest concern comes from long term exposure to their combined effects on human airways.

On the ground basis of experimental data and epidemiological data, obtained up to now in northern countries from Europe and America, it may be feared that peak values of both pollutants be associated with increased morbidity and mortality due to bronchopulmonary diseases ; however, wether these observations apply or not to hot and dry climatic conditions is not known, and it may well be that no effect be observed.

Moreover, most measures made in Kuwait City were very comparable to those observed in Western cities and did not reach limit values set by WHO Guidelines for chronic exposure ; unexpectedly vanadium levels, which have been considered as good indices of fuel burning, remained fortunately low, and therefore there is no adverse synergism to predict from potential cytotoxicity on lung macrophages.

Although the risk of specific diseases appears to remain relatively low, it is recommended to survey groups at risk, and notely children and asthmatic patients, owing to the expected long duration of the situation.

As regards other pollutants like ozone, NOx and CO, their levels in Kuwait atmosphere appaeared lower than those observed in western big cities. Their contribution appeared therefore very limited.

Some possible carcinogens, such as polycyclic aromatic hydrocarbons and nickel, were detected at low concentration in black smokes. This drew the attention to the risk of cancer induction. However the levels of these toxicants are also actually lower than those observed in many urban atmospheres. Finally, it turns out that the only constituant which needs further informations is carbon black itself, which makes up the greatest moiety of the airborne particulate material. It is a ill dafined compound, strongly adsorbing putative carcinogens, whose nature may differ in fonction of burning conditions. It is recommended that the material be collected locally and sent to French laboratories for biogical assays, including estimate of carcinogenic potency. Preliminary results could be obtained within a few months.

# KUWAIT STUDY

## 27 march to 4 april 1991

***ANNEXE I***

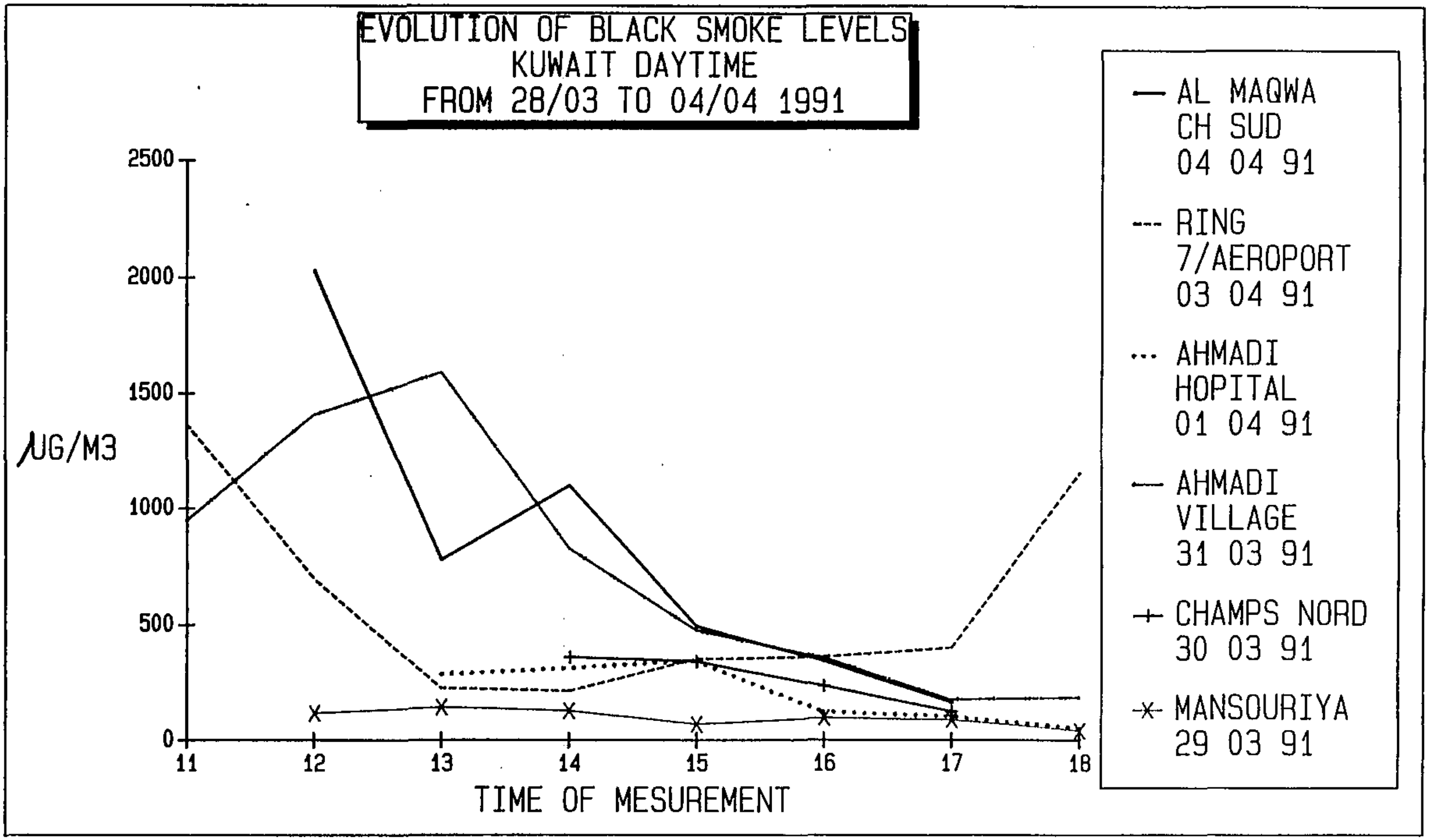
**Temporal evolution of measurements of atmospheric pollutants**

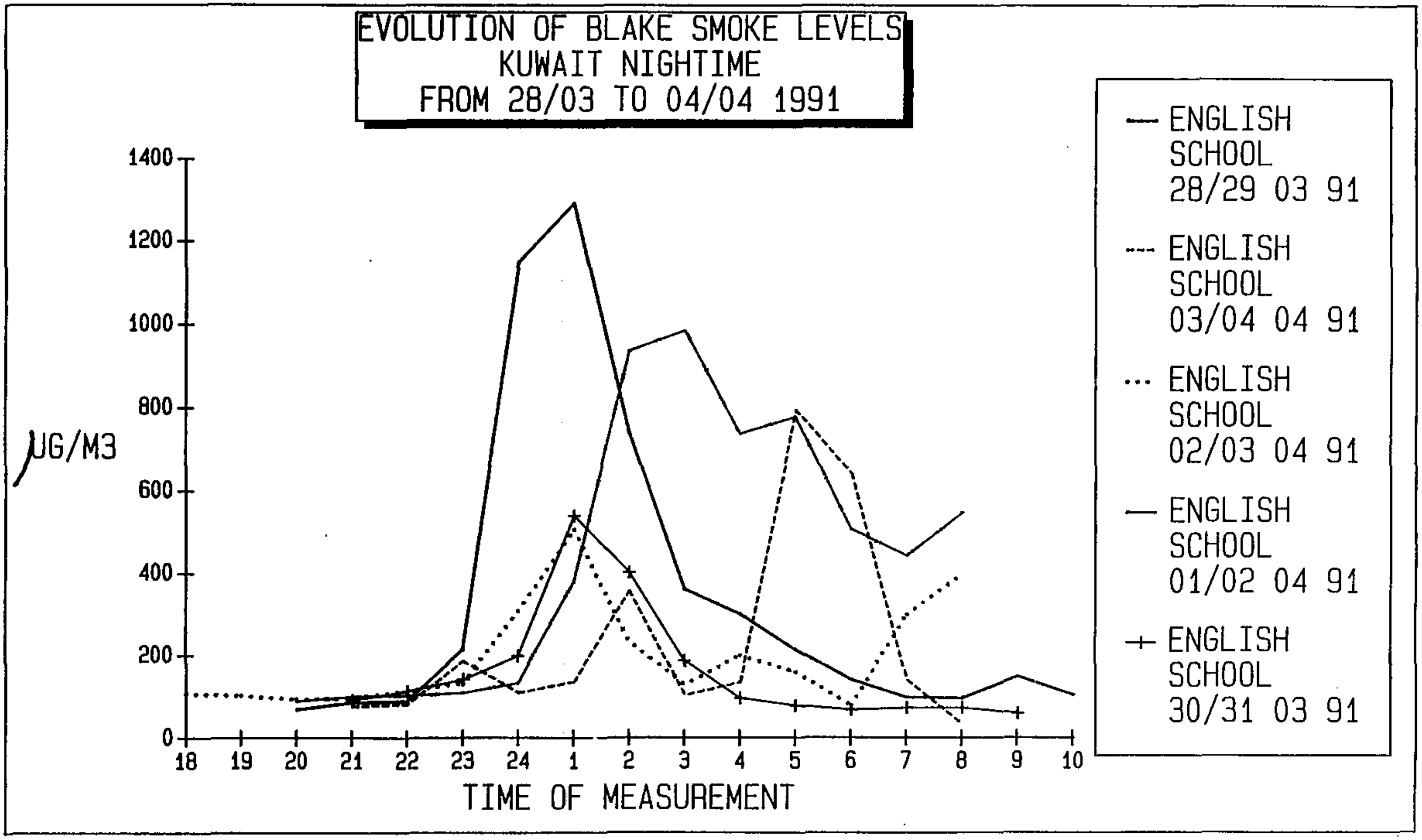
**$SO_2$, $O_3$, NO, $NO_2$**

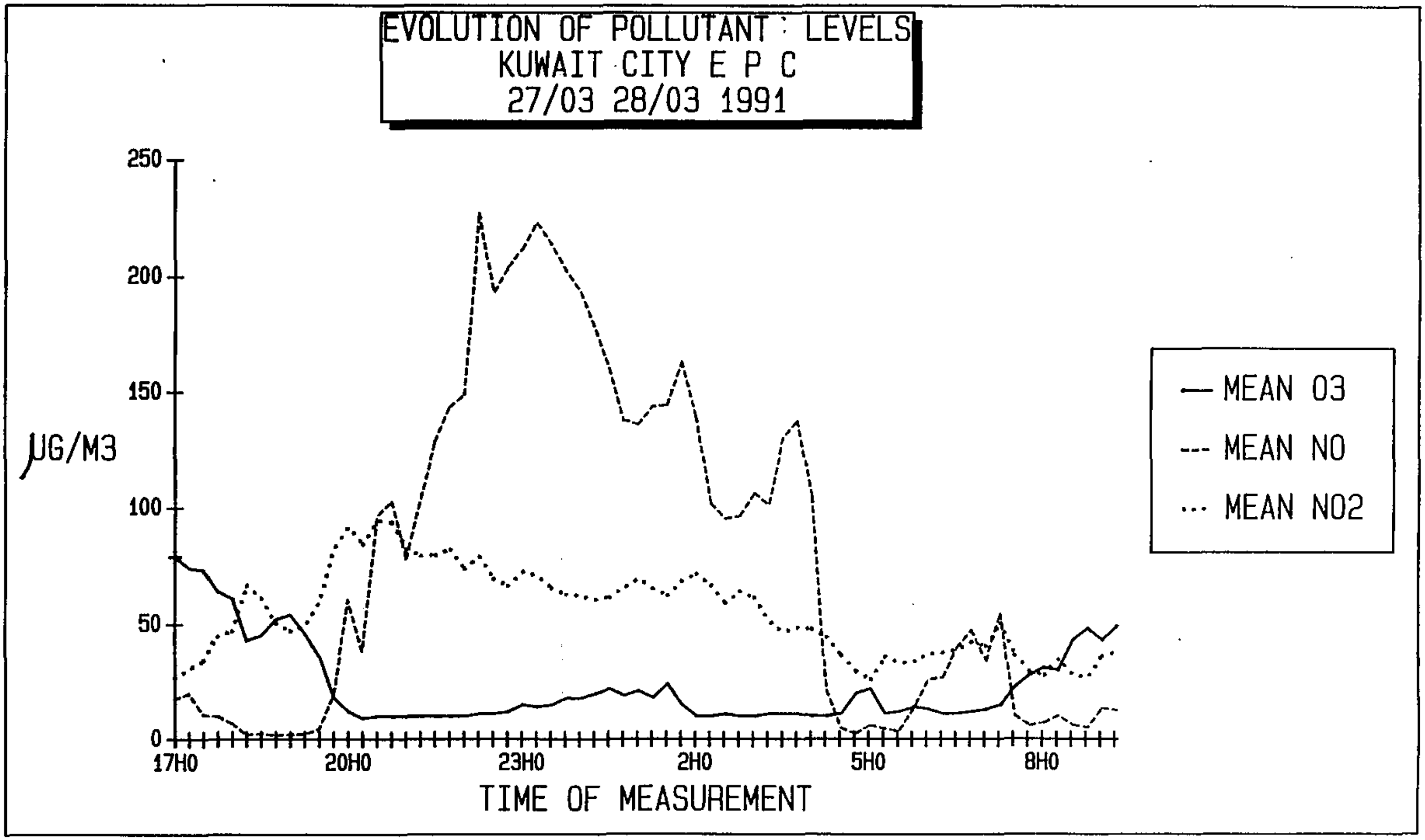
**Basic data integrated over 5 minutes**

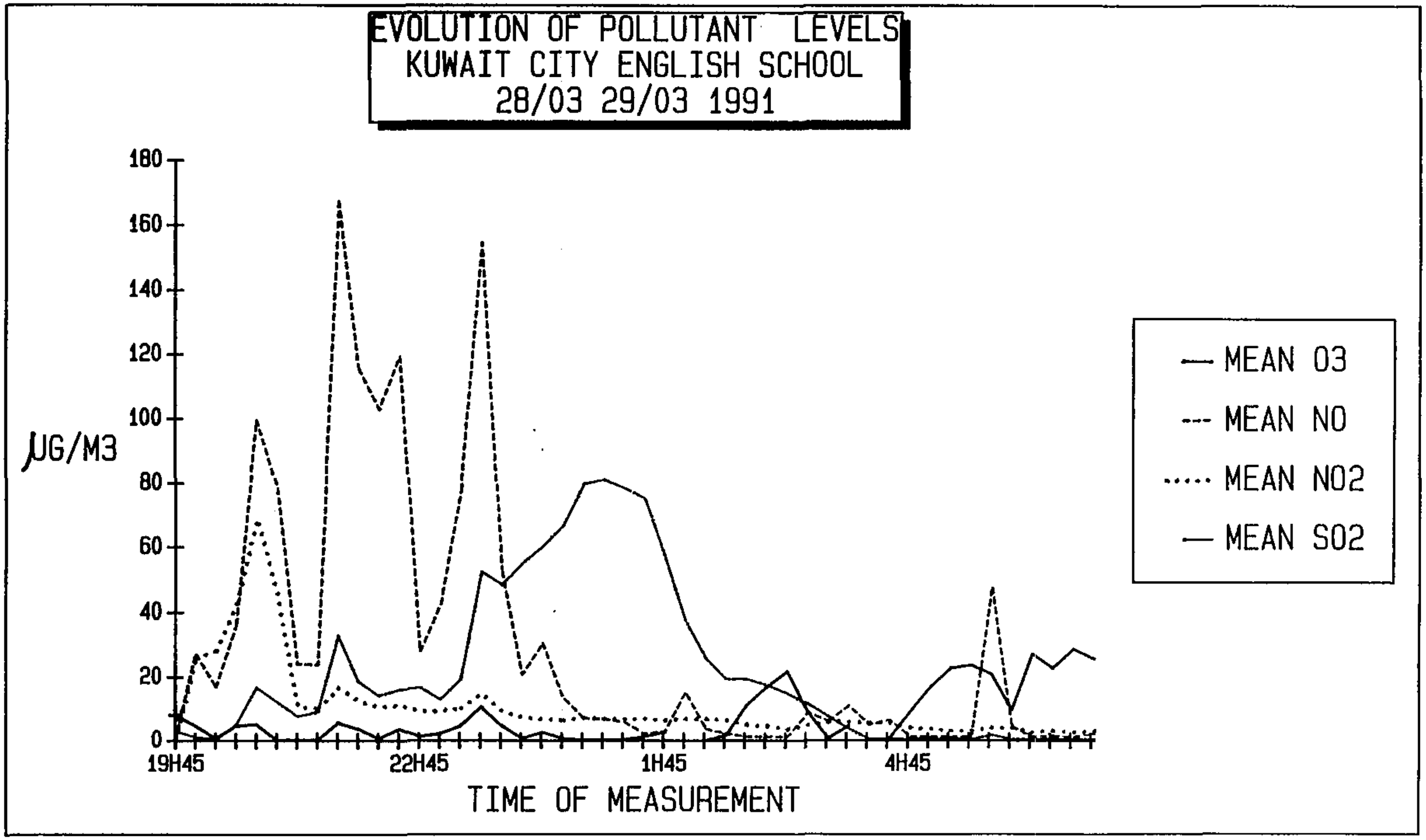
**BS "black smoke"**

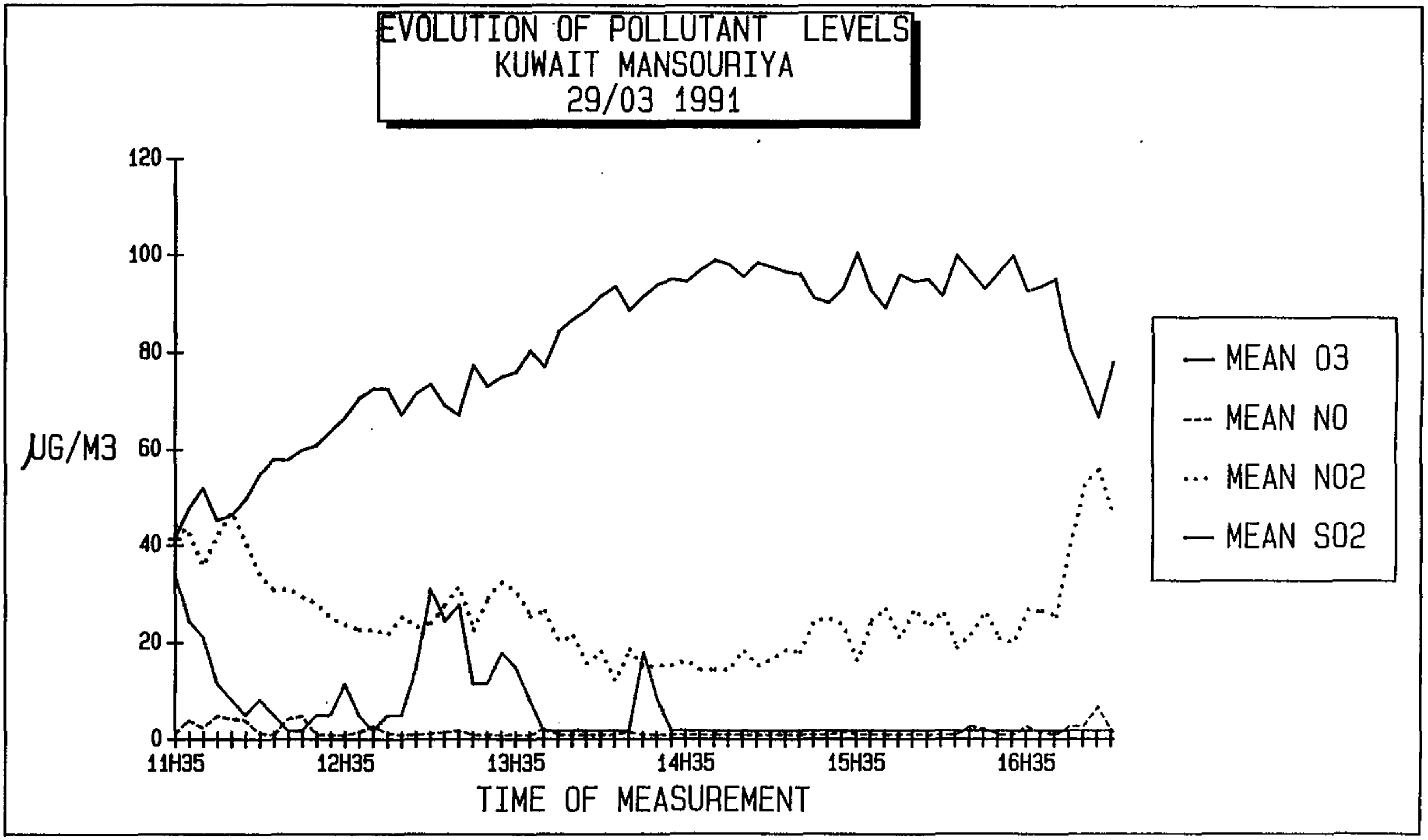
**Basic data integrated over 1 hour**

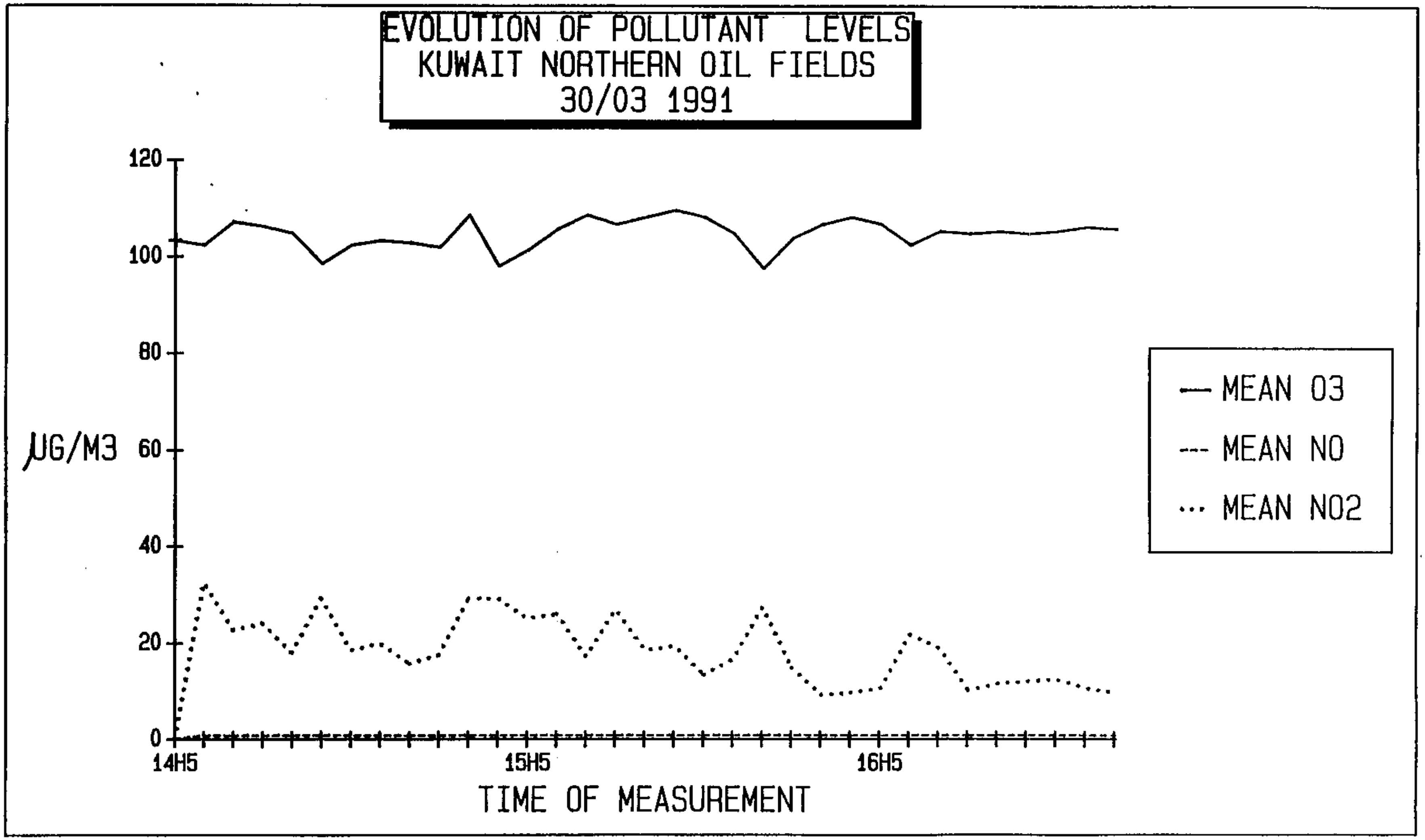

EVOLUTION OF BLACK SMOKE LEVELS
KUWAIT DAYTIME
FROM 28/03 TO 04/04 1991
µG/M3
2500
2000
1500
1000
500
0
11
12
13
14
15
16
17
18
TIME OF MESUREMENT
AL MAQWA CH SUD 04 04 91
RING 7/AEROPORT 03 04 91
AHMADI HOPITAL 01 04 91
AHMADI VILLAGE 31 03 91
CHAMPS NORD 30 03 91
MANSOURIYA 29 03 91


EVOLUTION OF BLAKE SMOKE LEVELS
KUWAIT NIGHTIME
FROM 28/03 TO 04/04 1991
UG/M3
1400
1200
1000
800
600
400
200
0
18 19 20 21 22 23 24 1 2 3 4 5 6 7 8 9 10
TIME OF MEASUREMENT
ENGLISH SCHOOL 28/29 03 91
ENGLISH SCHOOL 03/04 04 91
ENGLISH SCHOOL 02/03 04 91
ENGLISH SCHOOL 01/02 04 91
ENGLISH SCHOOL 30/31 03 91

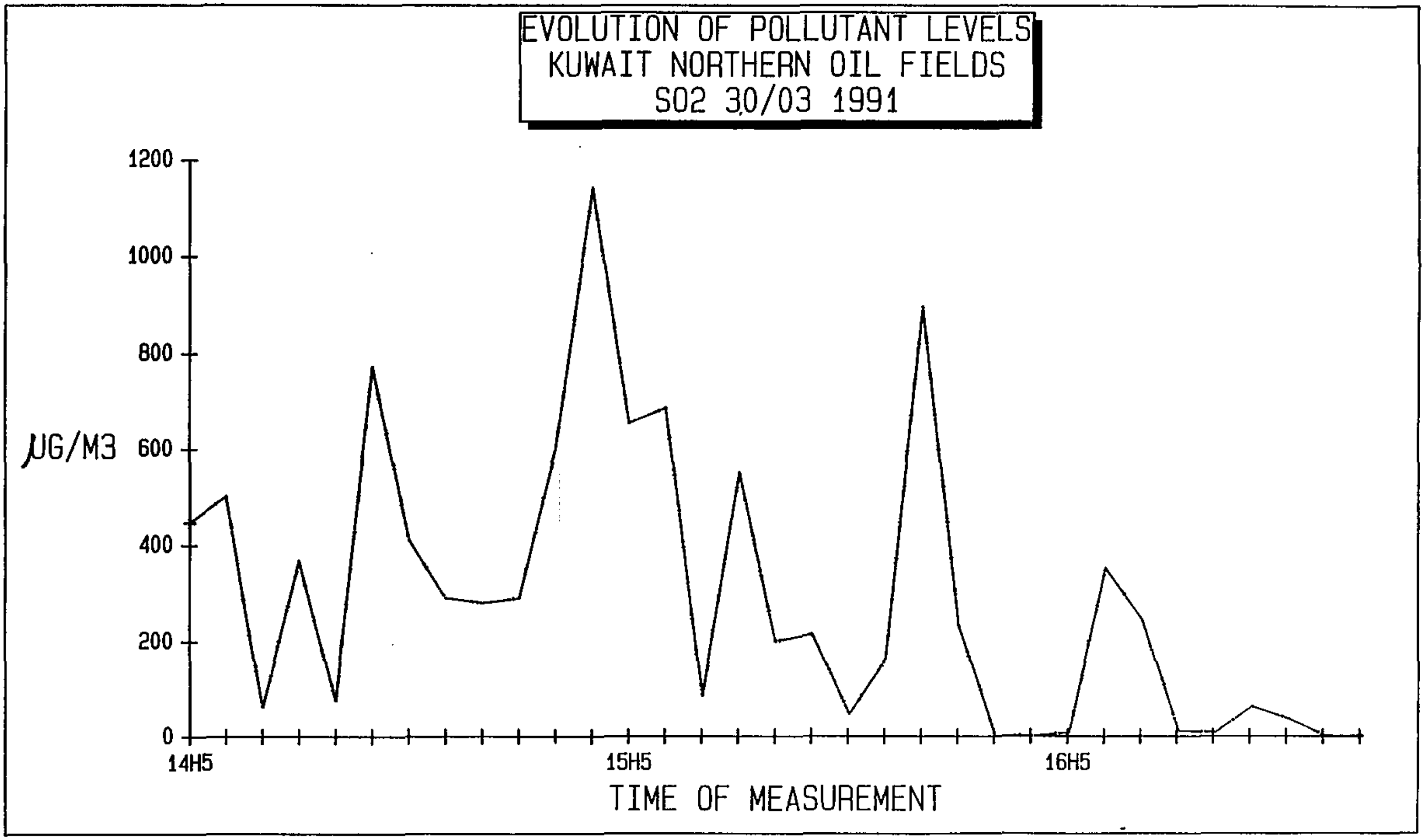

EVOLUTION OF POLLUTANT LEVELS
KUWAIT CITY E P C
27/03 28/03 1991
250
200
150
100
50
0
µG/M3
17H0
20H0
23H0
2H0
5H0
8H0
TIME OF MEASUREMENT
MEAN O3
MEAN NO
MEAN NO2


EVOLUTION OF POLLUTANT LEVELS
KUWAIT CITY ENGLISH SCHOOL
28/03 29/03 1991
µG/M3
180
160
140
120
100
80
60
40
20
0
19H45
22H45
1H45
4H45
TIME OF MEASUREMENT
MEAN O3
MEAN NO
MEAN NO2
MEAN SO2

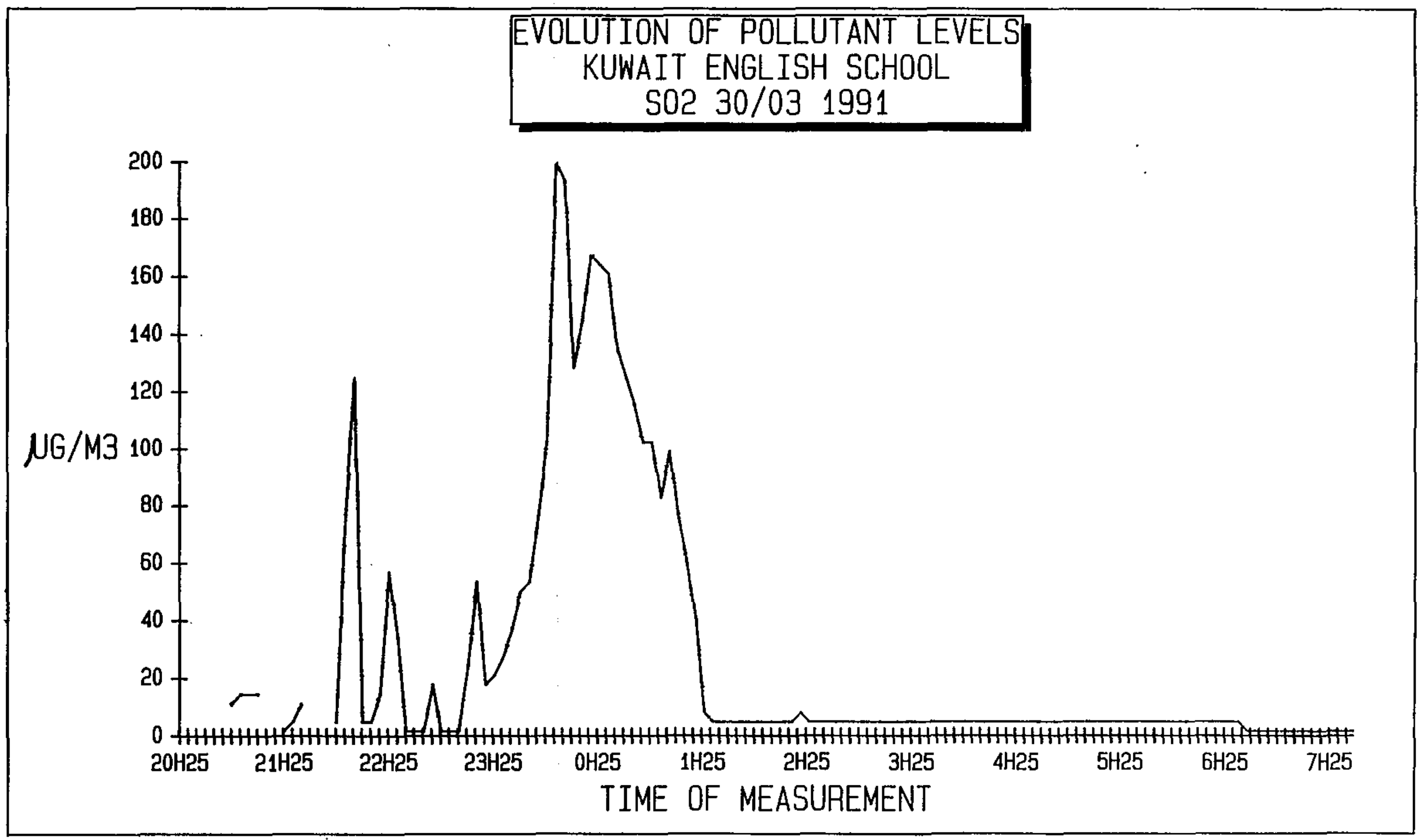

EVOLUTION OF POLLUTANT LEVELS
KUWAIT MANSOURIYA
29/03 1991
µG/M3
120
100
80
60
40
20
0
11H35
12H35
13H35
14H35
15H35
16H35
TIME OF MEASUREMENT
MEAN O3
MEAN NO
MEAN NO2
MEAN SO2



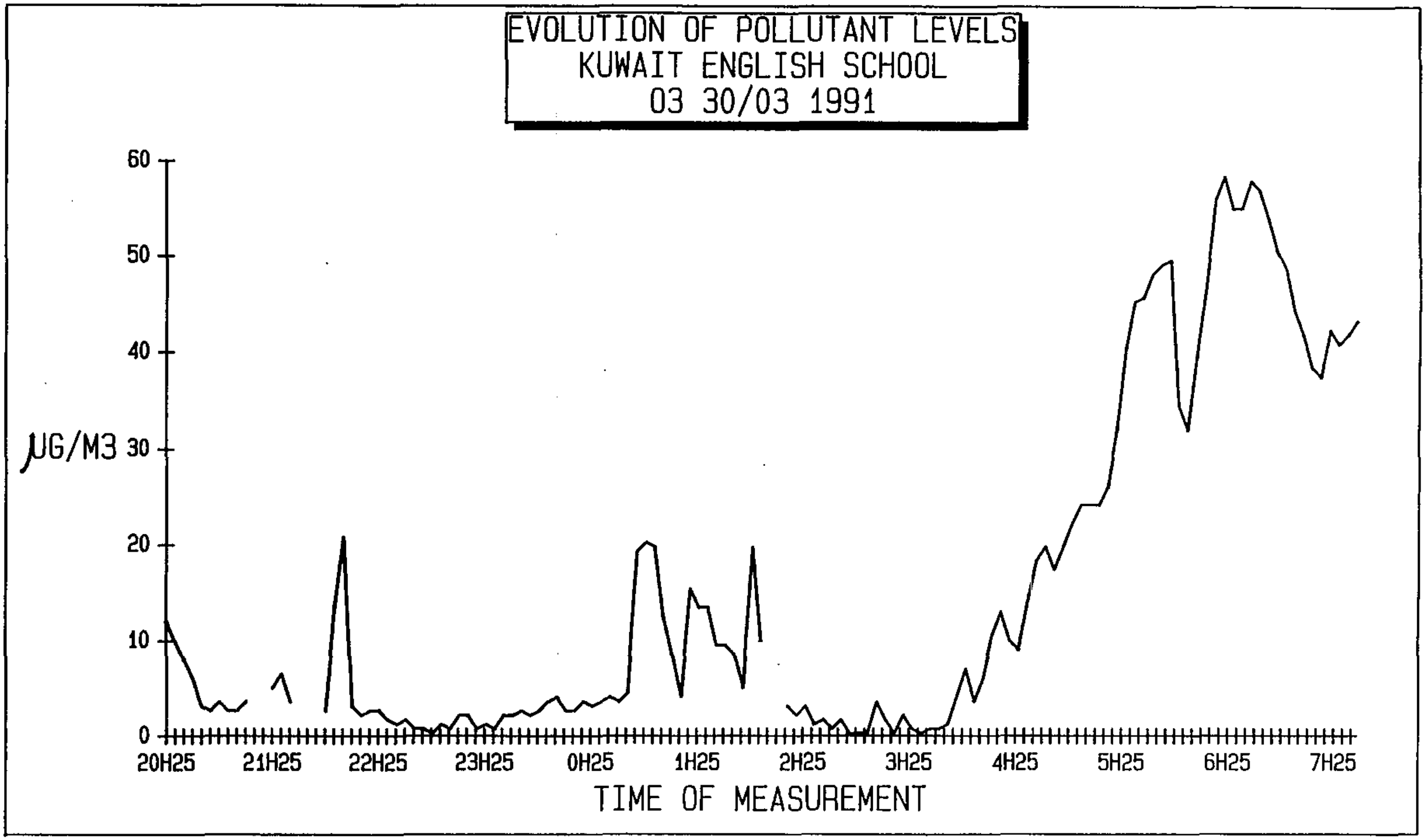
EVOLUTION OF POLLUTANT LEVELS
KUWAIT NORTHERN OIL FIELDS
30/03 1991
120
100
80
60
40
20
0
µG/M3
14H5
15H5
16H5
TIME OF MEASUREMENT
MEAN O3
MEAN NO
MEAN NO2

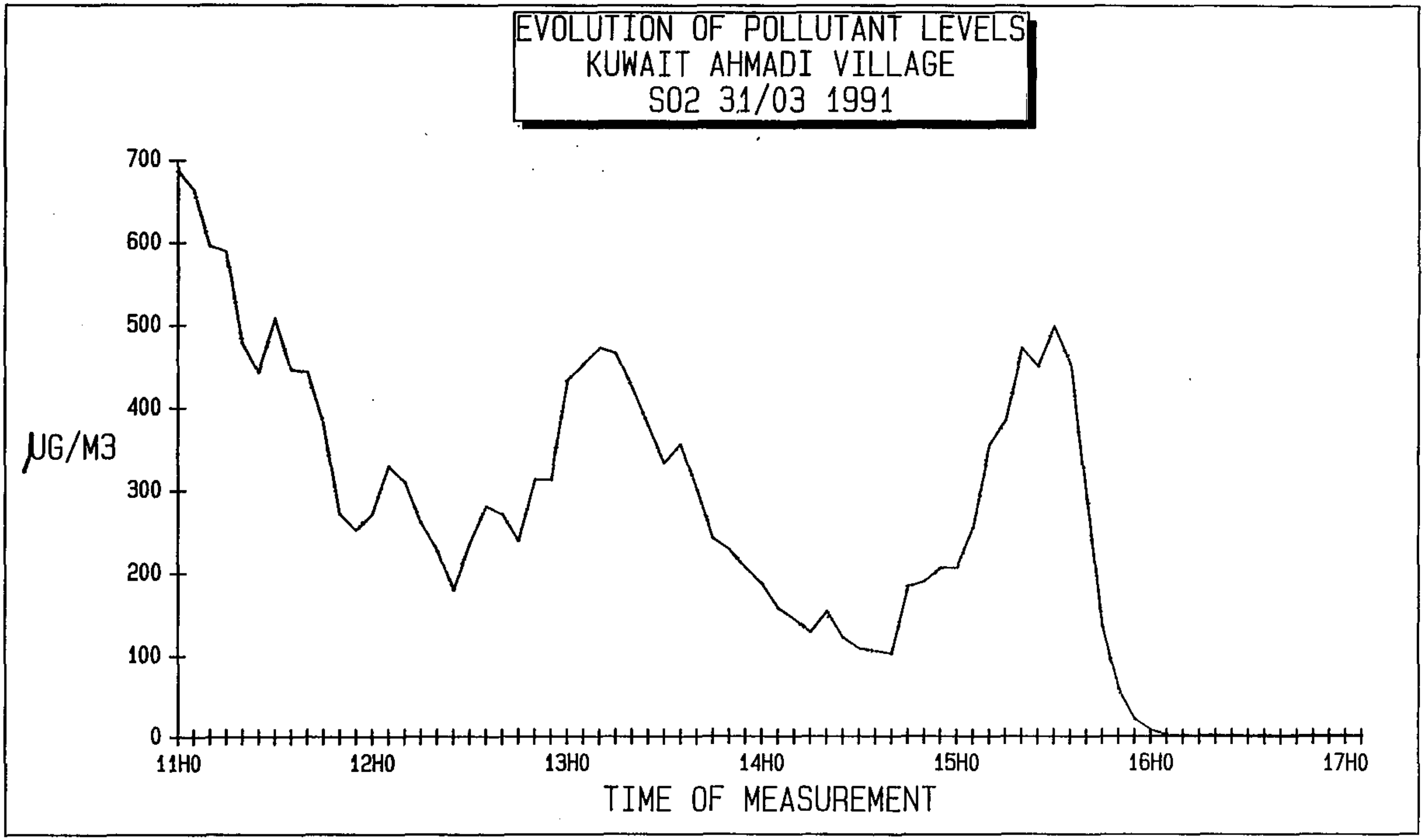


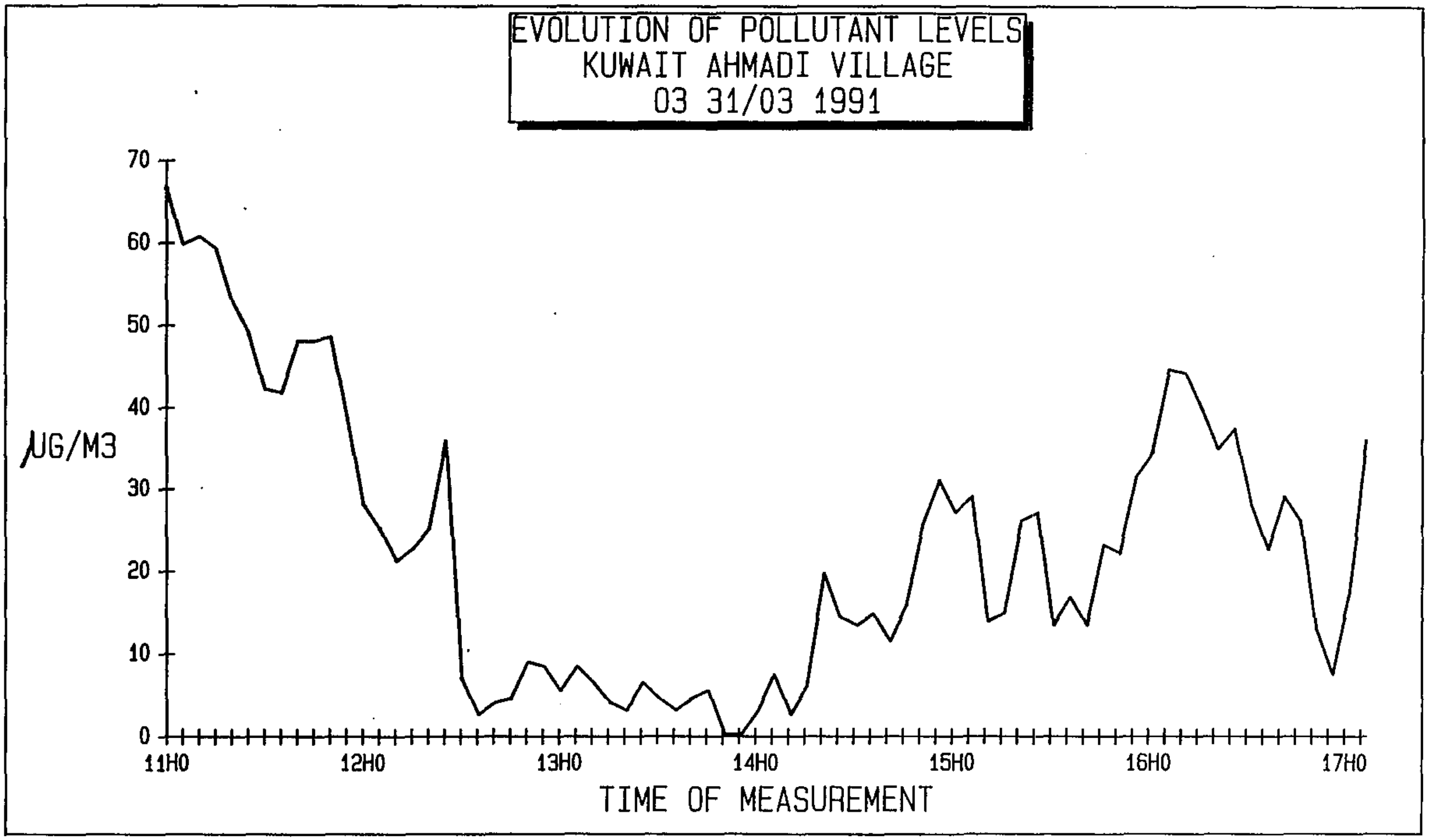
EVOLUTION OF POLLUTANT LEVELS
KUWAIT NORTHERN OIL FIELDS
SO2 30/03 1991
µG/M3
1200
1000
800
600
400
200
0
14H5
15H5
16H5
TIME OF MEASUREMENT



EVOLUTION OF POLLUTANT LEVELS
KUWAIT ENGLISH SCHOOL
SO2 30/03 1991
µG/M3
200
180
160
140
120
100
80
60
40
20
0
20H25
21H25
22H25
23H25
0H25
1H25
2H25
3H25
4H25
5H25
6H25
7H25
TIME OF MEASUREMENT


EVOLUTION OF POLLUTANT LEVELS
KUWAIT ENGLISH SCHOOL
03 30/03 1991
µG/M3
60
50
40
30
20
10
0
20H25
21H25
22H25
23H25
0H25
1H25
2H25
3H25
4H25
5H25
6H25
7H25
TIME OF MEASUREMENT


EVOLUTION OF POLLUTANT LEVELS
KUWAIT AHMADI VILLAGE
SO2 31/03 1991
µG/M3
700
600
500
400
300
200
100
0
11H0
12H0
13H0
14H0
15H0
16H0
17H0
TIME OF MEASUREMENT


EVOLUTION OF POLLUTANT LEVELS
KUWAIT AHMADI VILLAGE
03 31/03 1991
UG/M3
70
60
50
40
30
20
10
0
11H0
12H0
13H0
14H0
15H0
16H0
17H0
TIME OF MEASUREMENT

# KUWAIT STUDY

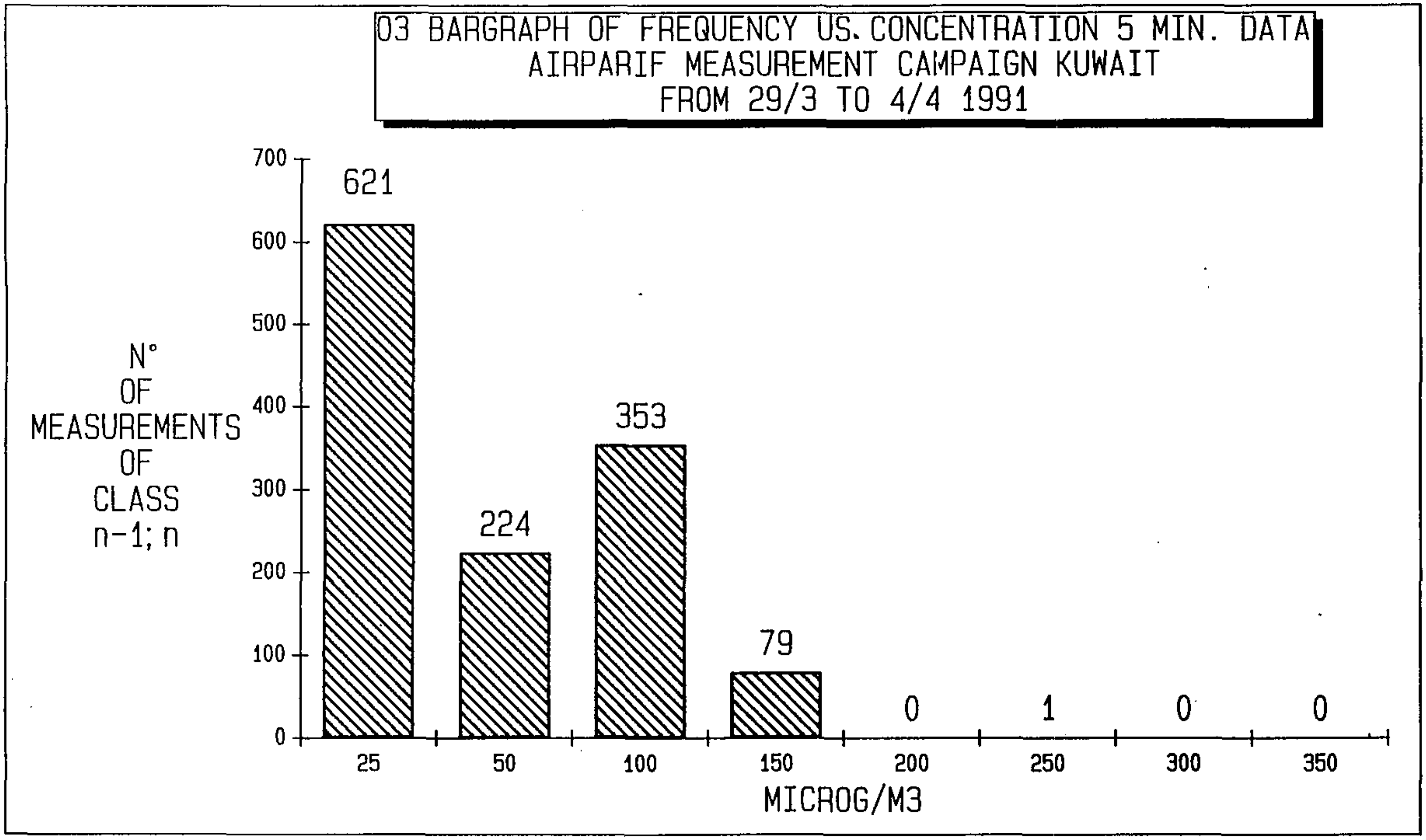
## 27 march to 4 april 1991

***ANNEXE III***

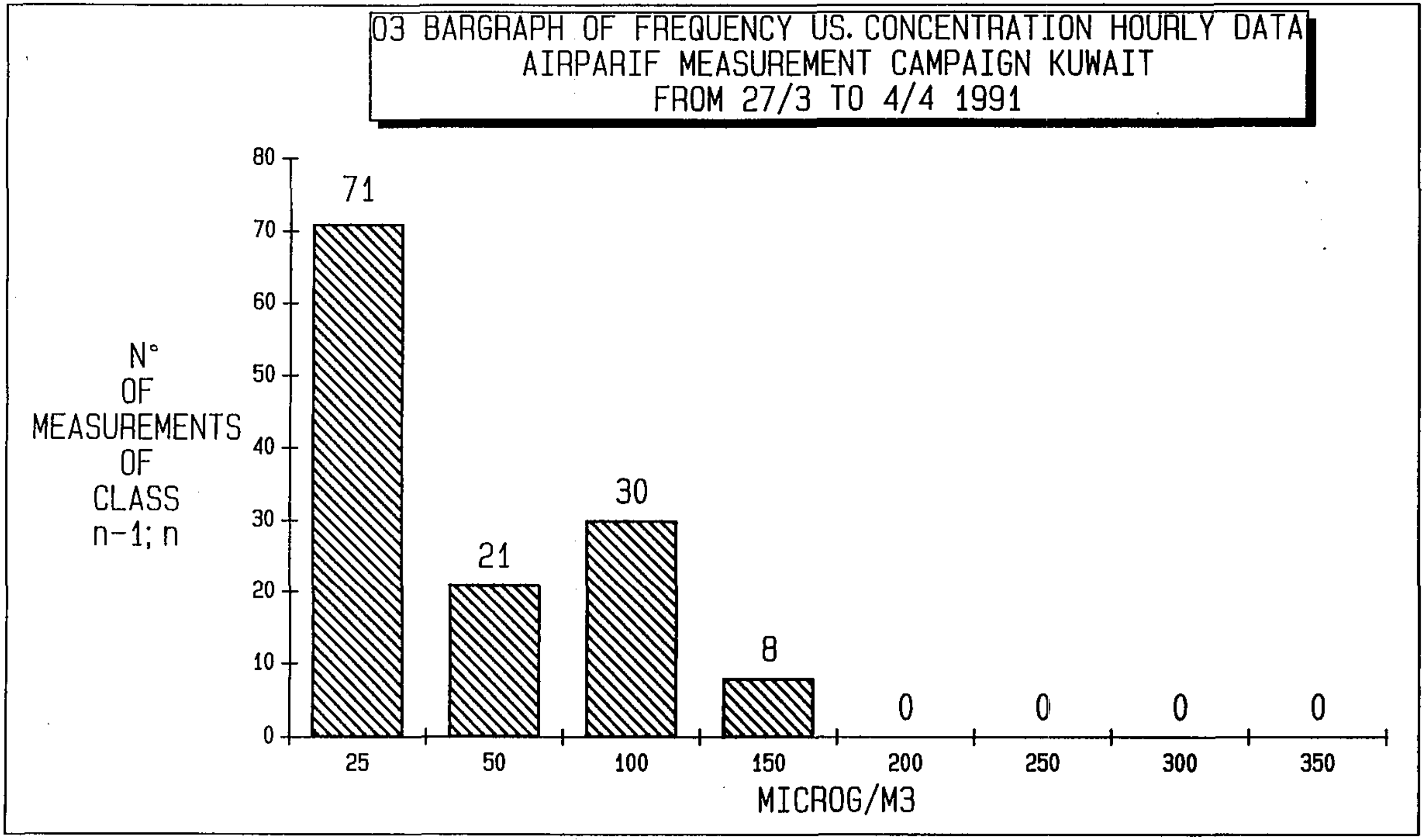
**Bar graphs of frequency VS concentration of the various pollutants**

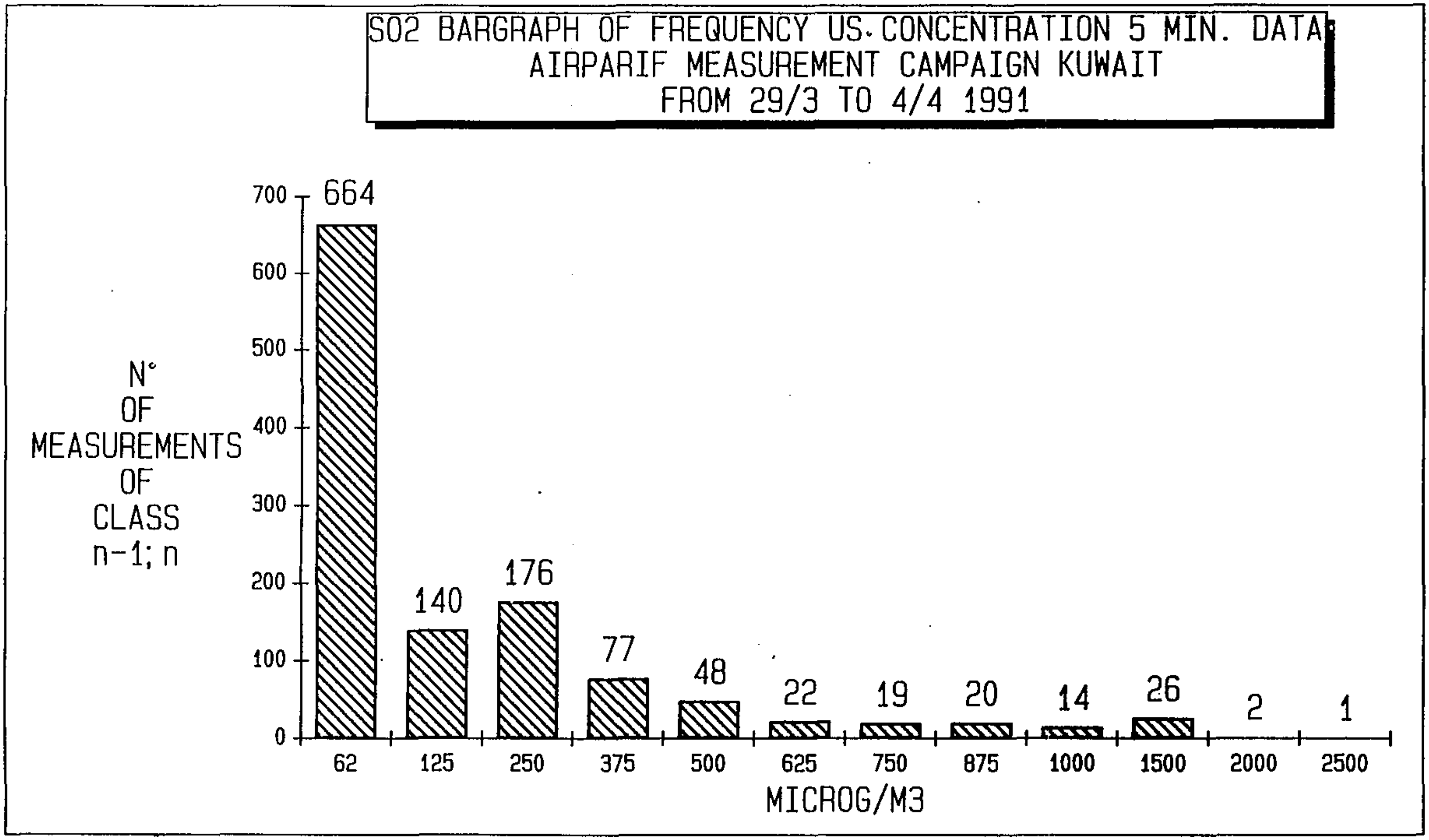
**established for the totality of the results of the various series of measurements**

**(5 minutes or 1 hour)**

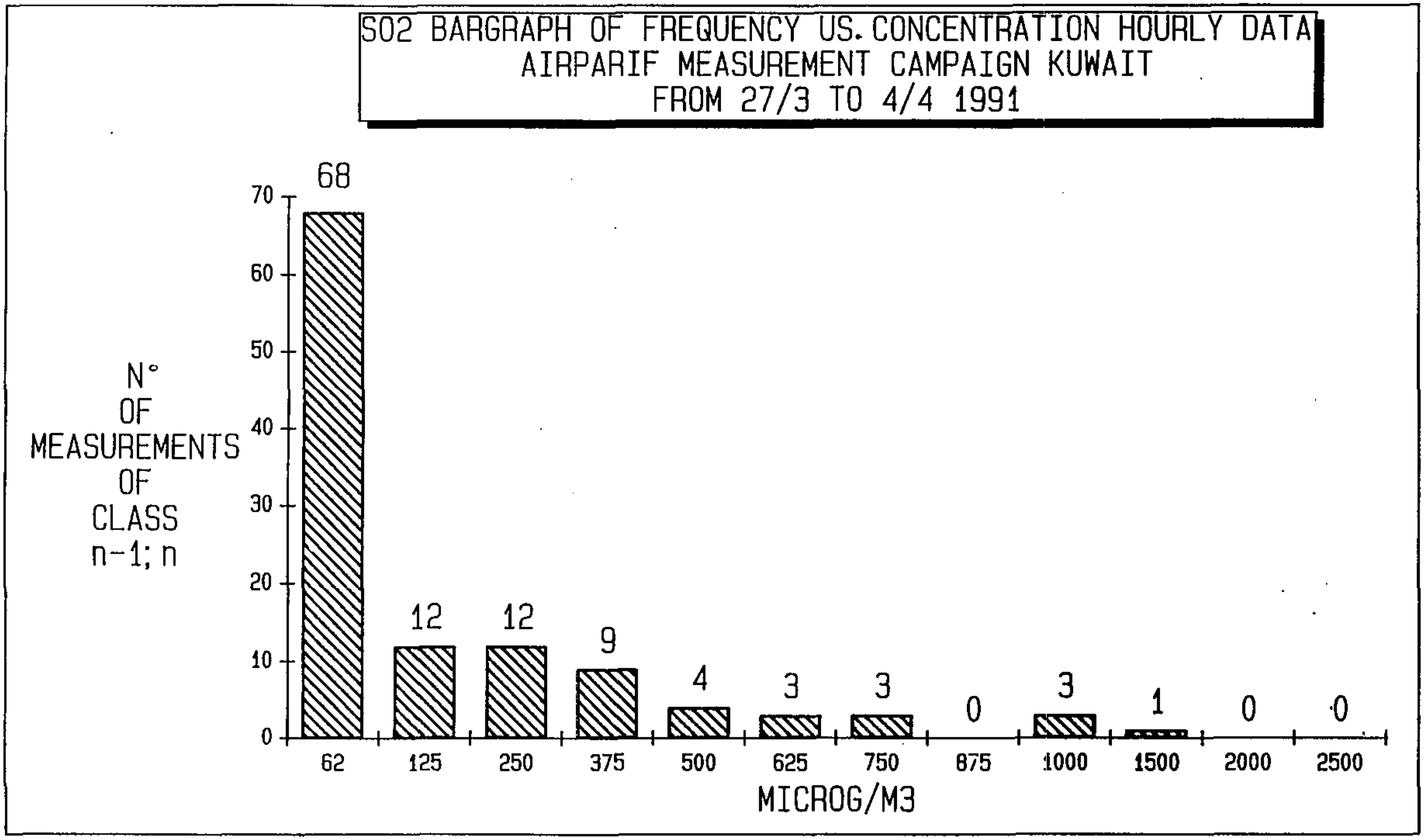


03 BARGRAPH OF FREQUENCY US. CONCENTRATION 5 MIN. DATA
AIRPARIF MEASUREMENT CAMPAIGN KUWAIT
FROM 29/3 TO 4/4 1991
N° OF MEASUREMENTS OF CLASS n-1; n
700
600
500
400
300
200
100
0
621
224
353
79
0
1
0
0
25
50
100
150
200
250
300
350
MICROG/M3

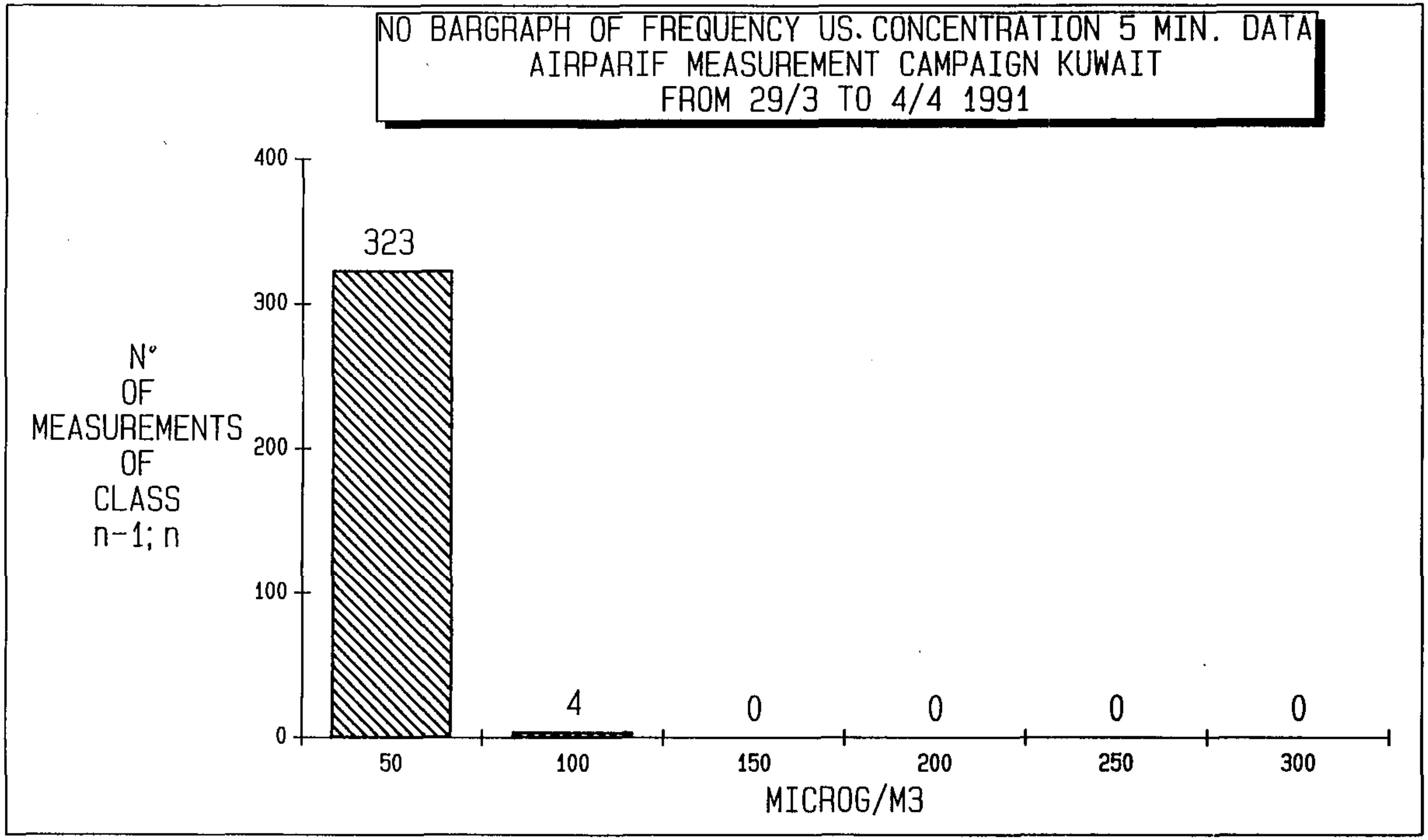

O3 BARGRAPH OF FREQUENCY US. CONCENTRATION HOURLY DATA
AIRPARIF MEASUREMENT CAMPAIGN KUWAIT
FROM 27/3 TO 4/4 1991
N°
OF
MEASUREMENTS
OF
CLASS
n-1; n
80
70
60
50
40
30
20
10
0
71
21
30
8
0
0
0
0
25
50
100
150
200
250
300
350
MICROG/M3

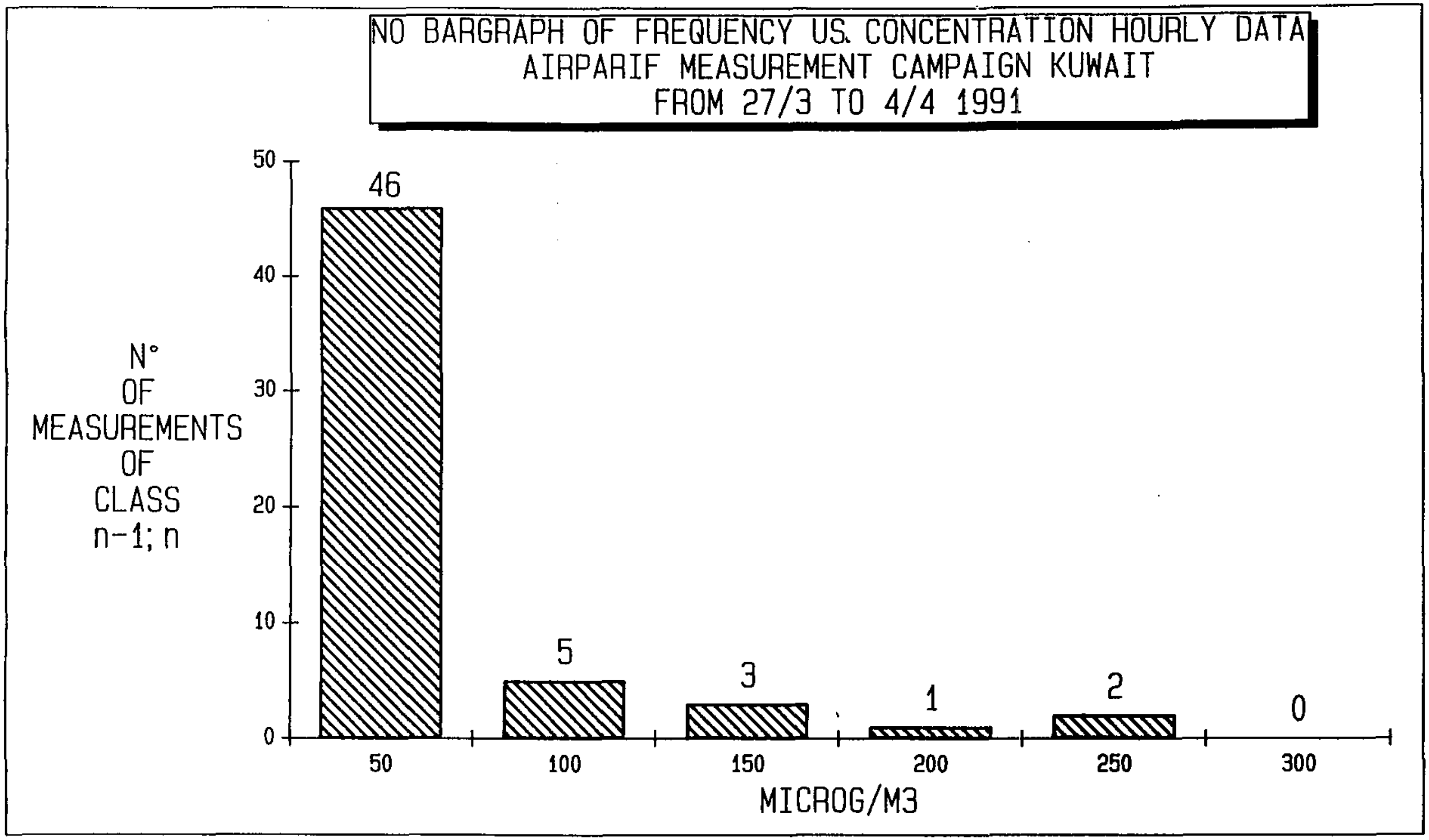


SO2 BARGRAPH OF FREQUENCY US. CONCENTRATION 5 MIN. DATA
AIRPARIF MEASUREMENT CAMPAIGN KUWAIT
FROM 29/3 TO 4/4 1991
N°
OF
MEASUREMENTS
OF
CLASS
n-1; n
700
600
500
400
300
200
100
0
664
140
176
77
48
22
19
20
14
26
2
1
62
125
250
375
500
625
750
875
1000
1500
2000
2500
MICROG/M3

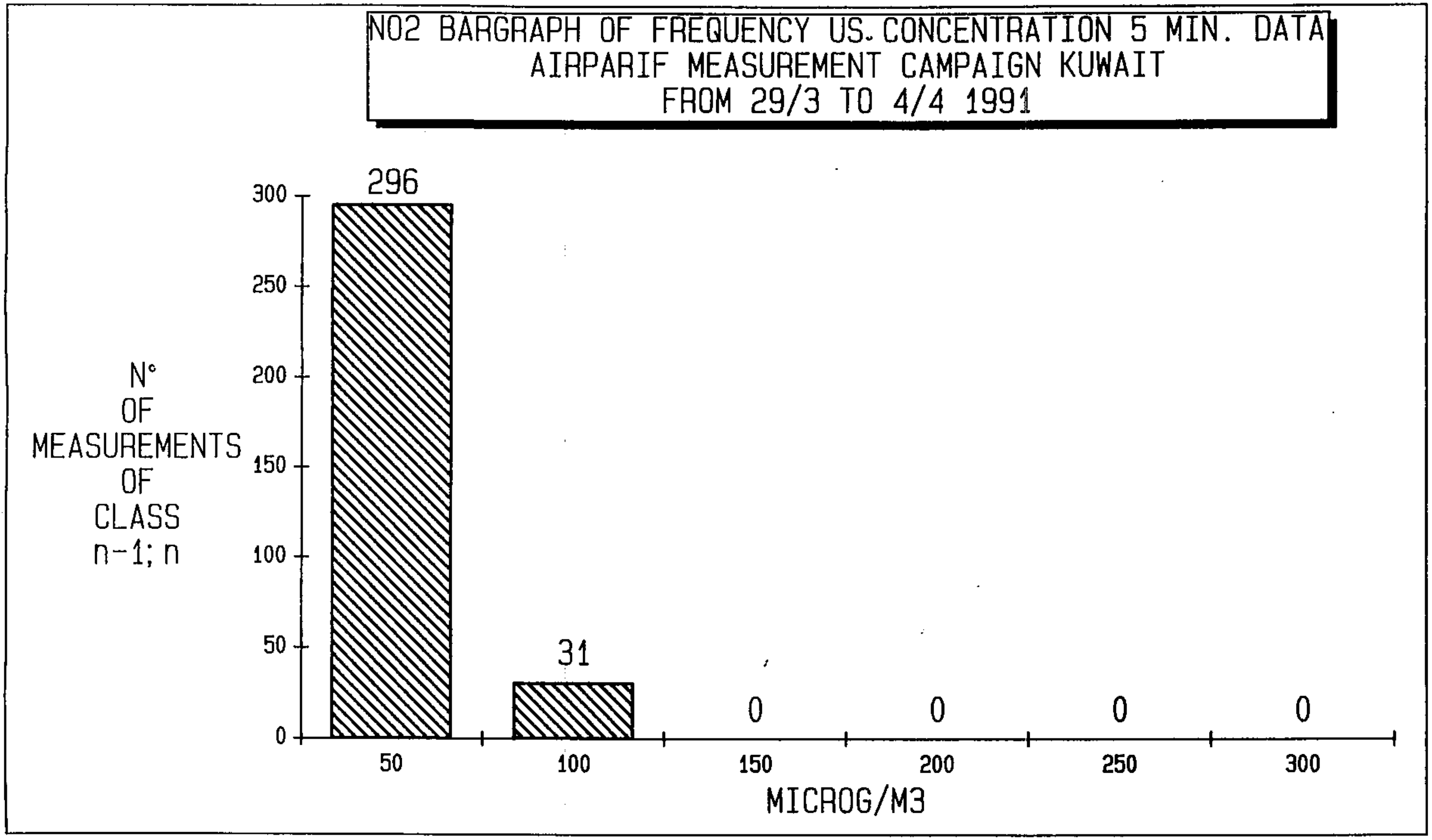


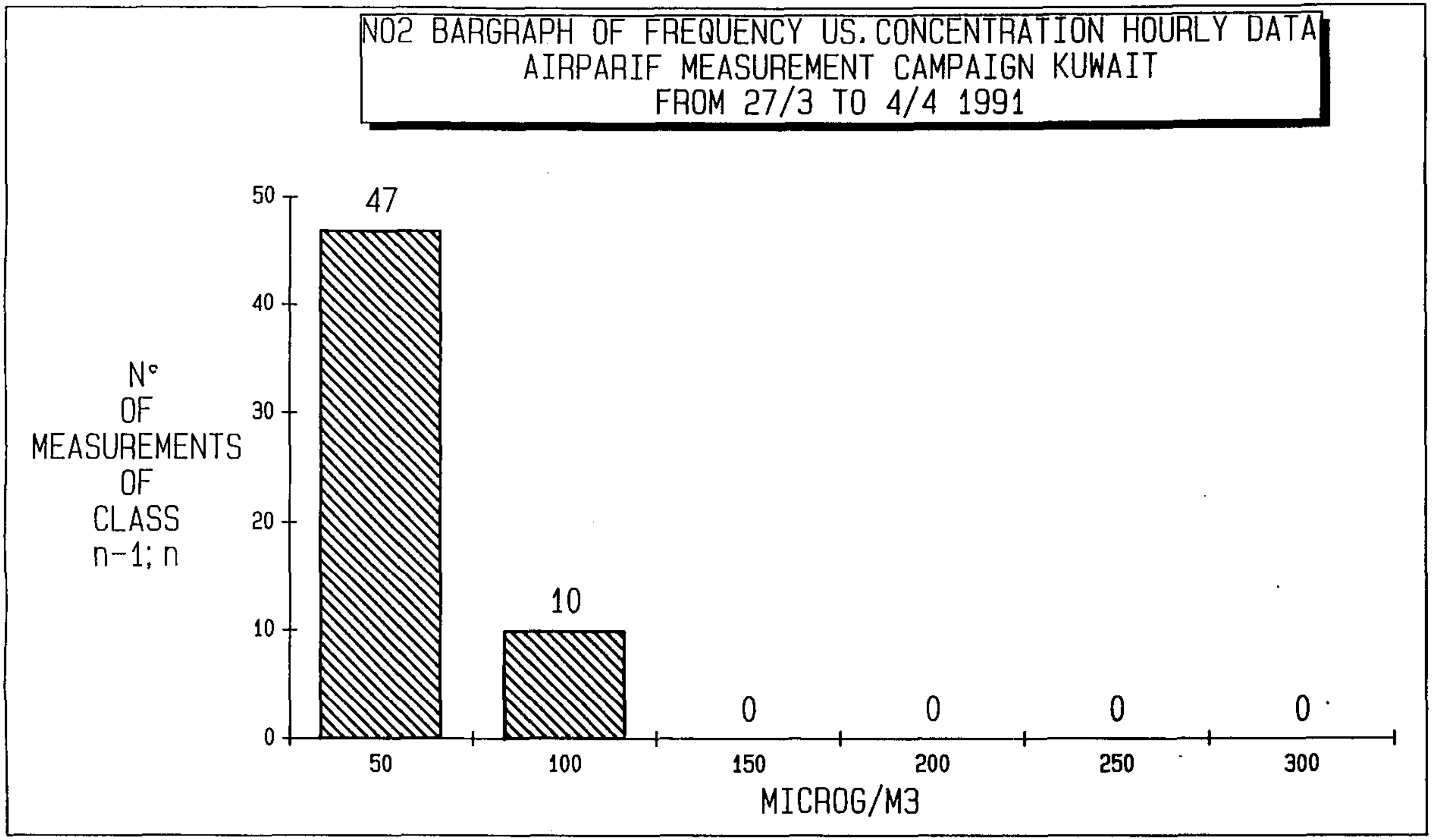
SO2 BARGRAPH OF FREQUENCY US. CONCENTRATION HOURLY DATA
AIRPARIF MEASUREMENT CAMPAIGN KUWAIT
FROM 27/3 TO 4/4 1991
N°
OF
MEASUREMENTS
OF
CLASS
n-1; n
0
10
20
30
40
50
60
70
68
12
12
9
4
3
3
0
3
1
0
0
62
125
250
375
500
625
750
875
1000
1500
2000
2500
MICROG/M3

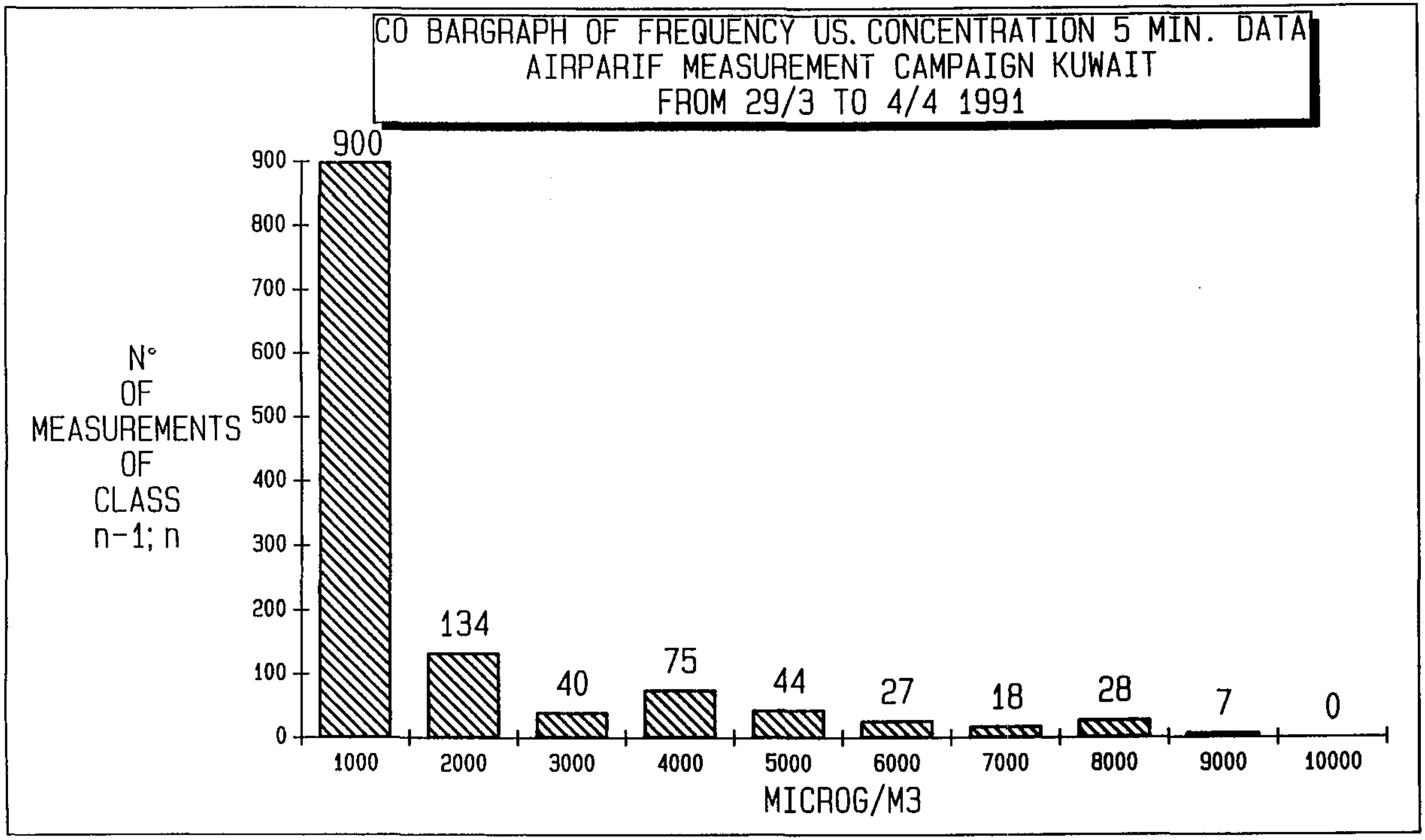

NO BARGRAPH OF FREQUENCY VS. CONCENTRATION 5 MIN. DATA
AIRPARIF MEASUREMENT CAMPAIGN KUWAIT
FROM 29/3 TO 4/4 1991
N°
OF
MEASUREMENTS
OF
CLASS
n-1; n
400
300
200
100
0
323
4
0
0
0
0
50
100
150
200
250
300
MICROG/M3

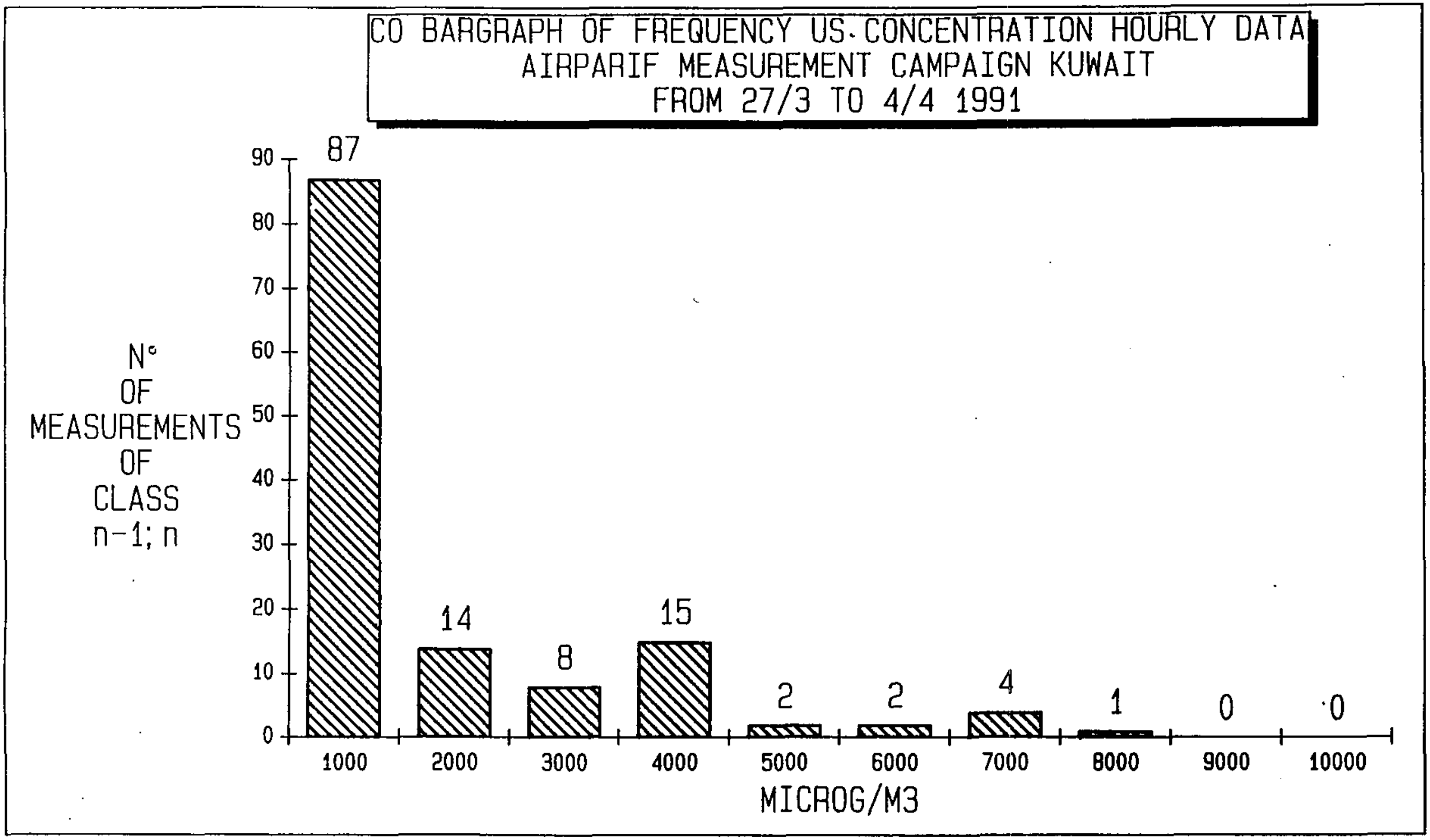


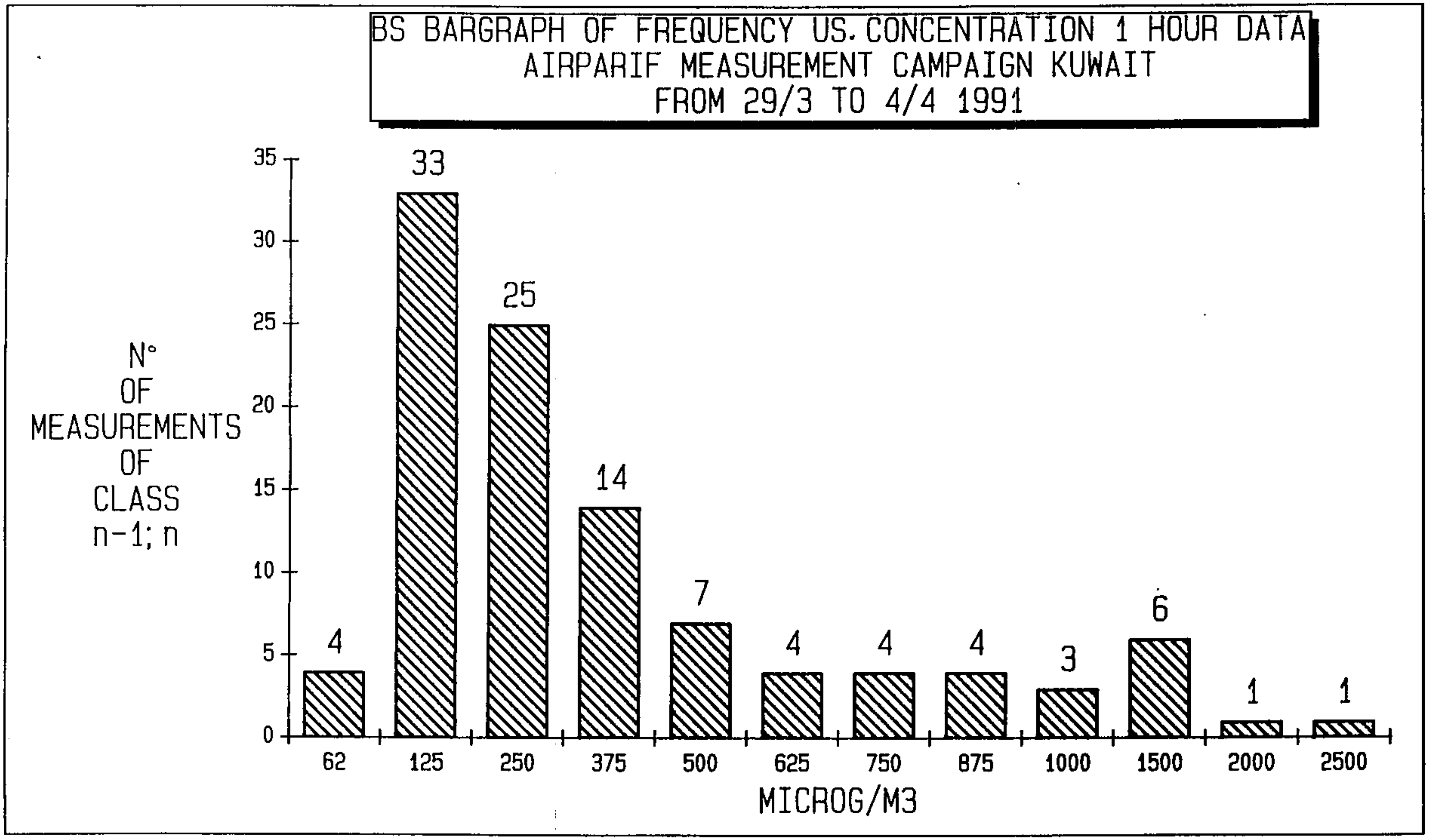
NO BARGRAPH OF FREQUENCY US. CONCENTRATION HOURLY DATA
AIRPARIF MEASUREMENT CAMPAIGN KUWAIT
FROM 27/3 TO 4/4 1991
N° OF MEASUREMENTS OF CLASS n-1; n
0
10
20
30
40
50
46
5
3
1
2
0
50
100
150
200
250
300
MICROG/M3


NO2 BARGRAPH OF FREQUENCY VS. CONCENTRATION 5 MIN. DATA
AIRPARIF MEASUREMENT CAMPAIGN KUWAIT
FROM 29/3 TO 4/4 1991
N° OF MEASUREMENTS OF CLASS n-1; n
300
250
200
150
100
50
0
296
31
0
0
0
0
50
100
150
200
250
300
MICROG/M3


NO2 BARGRAPH OF FREQUENCY US. CONCENTRATION HOURLY DATA
AIRPARIF MEASUREMENT CAMPAIGN KUWAIT
FROM 27/3 TO 4/4 1991
N°
OF
MEASUREMENTS
OF
CLASS
n-1; n
50
40
30
20
10
0
47
10
0
0
0
0
50
100
150
200
250
300
MICROG/M3


CO BARGRAPH OF FREQUENCY US. CONCENTRATION 5 MIN. DATA
AIRPARIF MEASUREMENT CAMPAIGN KUWAIT
FROM 29/3 TO 4/4 1991
N° OF MEASUREMENTS OF CLASS n-1; n
0
100
200
300
400
500
600
700
800
900
900
134
40
75
44
27
18
28
7
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
MICROG/M3


CO BARGRAPH OF FREQUENCY US. CONCENTRATION HOURLY DATA
AIRPARIF MEASUREMENT CAMPAIGN KUWAIT
FROM 27/3 TO 4/4 1991
N° OF MEASUREMENTS OF CLASS n-1; n
0
10
20
30
40
50
60
70
80
90
87
14
8
15
2
2
4
1
0
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
MICROG/M3


BS BARGRAPH OF FREQUENCY US. CONCENTRATION 1 HOUR DATA
AIRPARIF MEASUREMENT CAMPAIGN KUWAIT
FROM 29/3 TO 4/4 1991
N° OF MEASUREMENTS OF CLASS n-1; n
0
5
10
15
20
25
30
35
4
33
25
14
7
4
4
4
3
6
1
1
62
125
250
375
500
625
750
875
1000
1500
2000
2500
MICROG/M3

# KUWAIT STUDY

## 27 march to 4 april 1991

***ANNEXE IV***

**Results of measurements of "pollutants and meteorological parameters"**

**of the various measurement campaigns established hourly**

AIRPARIF : ATMOSPHERIC POLLUTION MEASUREMENT CAMPAIGN "KUWAIT"

KUWAIT CITY "ENVIRONNEMENT PROTECTION COUNCIL" 27 MARCH 1991 NIGHT

POLLUTION AND METEOROLOGICAL DATA; HOURLY MEANS

| DATE | TIME | O3 H ug/m3 | SO2 H ug/m3 | CO H ug/m3 | NO H ug/m3 | NO2 H ug/m3 | VV H m/s | DV H degré | T H oC |
|---|---|---|---|---|---|---|---|---|---|
| 27/03/91 | 18:00:00 | 68 | | 1014 | 12 | 39 | | | |
| 27/03/91 | 19:00:00 | 49 | | 836 | 2 | 56 | | | |
| 27/03/91 | 20:00:00 | 28 | | 765 | 22 | 71 | | | |
| 27/03/91 | 21:00:00 | 10 | | 1228 | 79 | 89 | | | |
| 27/03/91 | 22:00:00 | 10 | | 2153 | 131 | 78 | | | |
| 27/03/91 | 23:00:00 | 12 | | 3185 | 209 | 72 | | | |
| 28/03/91 | 00:00:00 | 16 | | 4181 | 208 | 65 | | | |
| 28/03/91 | 01:00:00 | 21 | | 3487 | 153 | 64 | | | |
| 28/03/91 | 02:00:00 | 17 | | 3096 | 148 | 67 | | | |
| 28/03/91 | 03:00:00 | 10 | | 1939 | 100 | 63 | | | |
| 28/03/91 | 04:00:00 | 11 | | 2082 | 118 | 48 | | | |
| 28/03/91 | 05:00:00 | 16 | | 552 | 9 | 34 | | | |
| 28/03/91 | 06:00:00 | 13 | | 196 | 12 | 35 | | | |
| 28/03/91 | 07:00:00 | 12 | | 498 | 37 | 40 | | | |
| 28/03/91 | 08:00:00 | 24 | | 302 | 19 | 36 | | | |
| 28/03/91 | 09:00:00 | 41 | | 338 | 9 | 31 | | | |
| 28/03/91 | 10:00:00 | 36 | | 847 | 45 | 46 | | | |
| | MEAN | 23 | | 1571 | 77 | 55 | | | |
| | MAXIMUM | 68 | | 4181 | 209 | 89 | | | |

AIRPARIF : ATMOSPHERIC POLLUTION MEASUREMENT CAMPAIGN "KUWAIT"

KUWAIT CITY ENGLISH SCHOOL 28 MARCH 1991 NIGHT

POLLUTION AND METEOROLOGICAL DATA; HOURLY MEANS

| DATE | TIME | O3 H ug/m3 | SO2 H ug/m3 | CO H ug/m3 | NO H ug/m3 | NO2 H ug/m3 | VV H m/s | DV H degré | T H oC |
|---|---|---|---|---|---|---|---|---|---|
| 28/03/91 | 21:00:00 | 3 | 8 | 2615 | 58 | 46 | 1 | 185 | 308 |
| 28/03/91 | 22:00:00 | 2 | 17 | 2366 | 82 | 12 | 1 | 216 | 404 |
| 28/03/91 | 23:00:00 | 2 | 15 | 3149 | 73 | 10 | 1 | 240 | 407 |
| 29/03/91 | 00:00:00 | 5 | 44 | 3327 | 76 | 10 | 1 | 242 | 404 |
| 29/03/91 | 01:00:00 | 1 | 72 | 1655 | 14 | 7 | 1 | 266 | 411 |
| 29/03/91 | 02:00:00 | 1 | 62 | 1050 | 6 | 7 | 2 | 270 | 426 |
| 29/03/91 | 03:00:00 | 7 | 20 | 694 | 2 | 6 | 1 | 243 | 421 |
| 29/03/91 | 04:00:00 | 9 | 9 | 729 | 7 | 5 | 1 | 172 | 402 |
| 29/03/91 | 05:00:00 | 7 | 0 | 872 | 3 | 5 | 1 | 175 | 391 |
| 29/03/91 | 06:00:00 | 19 | 1 | 907 | 14 | 3 | 1 | 173 | 403 |
| 29/03/91 | 07:00:00 | 26 | 0 | 890 | 1 | 3 | 1 | 169 | 407 |
| 29/03/91 | 08:00:00 | 7 | 22 | 1635 | 30 | 10 | 1 | 212 | 391 |
| | MEAN | 7 | 23 | 1657 | 31 | 10 | 1 | 214 | 398 |
| | MAXIMUM | 26 | 72 | 3327 | 82 | 46 | 2 | 270 | 426 |

AIRPARIF : ATMOSPHERIC POLLUTION MEASUREMENT CAMPAIGN "KUWAIT"

KUWAIT CITY "MANSOURIYA" 29 MARCH 1991 DAY

POLLUTION AND METEOROLOGICAL DATA; HOURLY MEANS

| DATE | TIME | O3 H ug/m3 | SO2 H ug/m3 | CO H ug/m3 | NO H ug/m3 | NO2 H ug/m3 | VV H m/s | DV H degré | T H oC |
|---|---|---|---|---|---|---|---|---|---|
| 29/03/91 | 13:00:00 | 65 | 6 | 142 | 2 | 26 | 2 | 184 | 25 |
| 29/03/91 | 14:00:00 | 77 | 13 | 237 | 1 | 26 | 2 | 203 | 28 |
| 29/03/91 | 15:00:00 | 95 | 4 | 120 | 1 | 15 | 2 | 178 | 29 |
| 29/03/91 | 16:00:00 | 94 | 2 | 36 | 1 | 22 | 2 | 205 | 29 |
| 29/03/91 | 17:00:00 | 90 | 2 | 77 | 2 | 30 | 2 | 205 | 28 |
| 29/03/91 | 18:00:00 | 86 | 14 | 279 | 3 | 42 | 2 | 289 | 28 |
| | MEAN | 85 | 7 | 149 | 2 | 27 | 2 | 211 | 28 |
| | MAXIMUM | 95 | 14 | 279 | 3 | 42 | 2 | 289 | 29 |

AIRPARIF : ATMOSPHERIC POLLUTION MEASUREMENT CAMPAIGN "KUWAIT"

KUWAIT NORTHERN OIL FIELDS 30 MARCH 1991 DAY

POLLUTION AND METEOROLOGICAL DATA; HOURLY MEANS

| DATE | TIME | O3 H ug/m3 | SO2 H ug/m3 | CO H ug/m3 | NO H ug/m3 | NO2 H ug/m3 | VV H m/s | DV H degré | T H oC |
|---|---|---|---|---|---|---|---|---|---|
| 30/03/91 | 15:00:00 | 103 | 437 | 24 | 1 | 21 | | | |
| 30/03/91 | 16:00:00 | 106 | 311 | 83 | 1 | 19 | | | |
| 30/03/91 | 17:00:00 | 105 | 81 | 210 | 1 | 13 | | | |
| | MEAN | 105 | 276 | 106 | 1 | 18 | | | |
| | MAXIMUM | 106 | 437 | 210 | 1 | 21 | | | |

AIRPARIF : ATMOSPHERIC POLLUTION MEASUREMENT CAMPAIGN "KUWAIT"

KUWAIT CITY ENGLISH SCHOOL 30 MARCH 1991 NIGHT

POLLUTION AND METEOROLOGICAL DATA; HOURLY MEANS

| DATE | TIME | O3 H ug/m3 | SO2 H ug/m3 | CO H ug/m3 | NO H ug/m3 | NO2 H ug/m3 | VV H m/s | DV H degré | T H oC |
|---|---|---|---|---|---|---|---|---|---|
| 30/03/91 | 22:00:00 | 11 | 18 | 1951 | | | 2 | 182 | 24 |
| 30/03/91 | 23:00:00 | 3 | 22 | 1441 | | | 0 | 259 | 23 |
| 31/03/91 | 00:00:00 | 2 | 55 | 2586 | | | 0 | 133 | 23 |
| 31/03/91 | 01:00:00 | 8 | 135 | 3766 | | | 0 | 139 | 22 |
| 31/03/91 | 02:00:00 | 11 | 27 | 4567 | | | 0 | 155 | 21 |
| 31/03/91 | 03:00:00 | 5 | 5 | 3072 | | | 0 | 157 | 21 |
| 31/03/91 | 04:00:00 | 2 | 5 | 1228 | | | 1 | 108 | 21 |
| 31/03/91 | 05:00:00 | 15 | 5 | 326 | | | 1 | 184 | 21 |
| 31/03/91 | 06:00:00 | 38 | 5 | 184 | | | 1 | 256 | 21 |
| 31/03/91 | 07:00:00 | 52 | 3 | 178 | | | 3 | 205 | 21 |
| | MEAN | 15 | 28 | 1930 | | | 1 | 178 | 22 |
| | MAXIMUM | 52 | 135 | 4567 | | | 3 | 259 | 24 |

AIRPARIF : ATMOSPHERIC POLLUTION MEASUREMENT CAMPAIGN "KUWAIT"

KUWAIT "AHMADI VILLAGE SOUTH" 31 MARCH 1991 DAY

POLLUTION AND METEOROLOGICAL DATA; HOURLY MEANS

| DATE | TIME | O3 H ug/m3 | SO2 H ug/m3 | CO H ug/m3 | NO H ug/m3 | NO2 H ug/m3 | VV H m/s | DV H degré | T H oC |
|---|---|---|---|---|---|---|---|---|---|
| 31/03/91 | 12:00:00 | 48 | 445 | 148 | | | 1 | 255 | 24 |
| 31/03/91 | 13:00:00 | 14 | 283 | 261 | | | 1 | 181 | 22 |
| 31/03/91 | 14:00:00 | 4 | 337 | 670 | | | 0 | 132 | 20 |
| 31/03/91 | 15:00:00 | 16 | 151 | 47 | | | 1 | 23 | 21 |
| 31/03/91 | 16:00:00 | 22 | 282 | 403 | | | 0 | 17 | 22 |
| 31/03/91 | 17:00:00 | 29 | 2 | 516 | | | 0 | 36 | 21 |
| | MEAN | 22 | 250 | 341 | | | 1 | 107 | 22 |
| | MAXIMUM | 48 | 445 | 670 | | | 1 | 255 | 24 |

AIRPARIF : ATMOSPHERIC POLLUTION MEASUREMENT CAMPAIGN "KUWAIT"

KUWAIT CITY ENGLISH SCHOOL 31 MARCH 1991 NIGHT

POLLUTION AND METEOROLOGICAL DATA; HOURLY MEANS

| DATE | TIME | O3 H ug/m3 | SO2 H ug/m3 | CO H ug/m3 | NO H ug/m3 | NO2 H ug/m3 | VV H m/s | DV H degré | T H oC |
|---|---|---|---|---|---|---|---|---|---|
| 31/03/91 | 23:00:00 | 2 | 7 | 925 | | | 0 | 330 | 22 |
| 01/04/91 | 00:00:00 | 4 | 19 | 1207 | | | 0 | 92 | 23 |
| 01/04/91 | 01:00:00 | 7 | 40 | 3140 | | | 0 | 235 | 22 |
| 01/04/91 | 02:00:00 | 16 | 349 | 3457 | | | 0 | 324 | 22 |
| 01/04/91 | 03:00:00 | 17 | 256 | 671 | | | 0 | 341 | 23 |
| 01/04/91 | 04:00:00 | 9 | 74 | 807 | | | 0 | 322 | 21 |
| 01/04/91 | 05:00:00 | 15 | 45 | 353 | | | 0 | 65 | 21 |
| 01/04/91 | 06:00:00 | 36 | 8 | 249 | | | 1 | 43 | 22 |
| 01/04/91 | 07:00:00 | 34 | 24 | 244 | | | 2 | 211 | 22 |
| 01/04/91 | 08:00:00 | 26 | 61 | 397 | | | 2 | 319 | 22 |
| | MEAN | 17 | 88 | 1145 | | | 1 | 228 | 22 |
| | MAXIMUM | 36 | 349 | 3457 | | | 2 | 341 | 23 |

AIRPARIF : ATMOSPHERIC POLLUTION MEASUREMENT CAMPAIGN "KUWAIT"

KUWAIT "AHMADI HOSPITAL" 01 APRIL 1991 DAY

POLLUTION AND METEOROLOGICAL DATA; HOURLY MEANS

| DATE | TIME | O3 H ug/m3 | SO2 H ug/m3 | CO H ug/m3 | NO H ug/m3 | NO2 H ug/m3 | VV H m/s | DV H degré | T H oC |
|---|---|---|---|---|---|---|---|---|---|
| 01/04/91 | 14:00:00 | 25 | 91 | 332 | 7 | 39 | 29 | 103 | 676 |
| 01/04/91 | 15:00:00 | 43 | 124 | 439 | 0 | 27 | 48 | 139 | 783 |
| 01/04/91 | 16:00:00 | 53 | 9 | 581 | 1 | 29 | 60 | 16 | 1151 |
| 01/04/91 | 17:00:00 | 55 | 2 | 522 | 0 | 30 | 60 | 5 | 1044 |
| 01/04/91 | 18:00:00 | 35 | 2 | 552 | 0 | 45 | 39 | 7 | |
| | MEAN | 42 | 46 | 485 | 2 | 34 | 47 | 54 | 914 |
| | MAXIMUM | 55 | 124 | 581 | 7 | 45 | 60 | 139 | 1151 |

AIRPARIF : ATMOSPHERIC POLLUTION MEASUREMENT CAMPAIGN " KUWAIT "

KUWAIT CITY " ENGLISH SCHOOL " 01 APRIL 1991 NIGHT

POLLUTION AND METEOROLOGICAL DATA; HOURLY MEANS

| DATE | TIME | O3 H ug/m3 | SO2 h ug/m3 | CO h ug/m3 | NO h ug/m3 | NO2 h ug/m3 | VV H m/s | DV h degré | T h oC |
|---|---|---|---|---|---|---|---|---|---|
| 01/04/91 | 20:00:00 | 2 | 60 | 984 | | | 0 | 34 | 21 |
| 01/04/91 | 21:00:00 | 3 | 81 | 3351 | | | 0 | 36 | 21 |
| 01/04/91 | 22:00:00 | 3 | 58 | 3434 | | | 0 | 271 | 20 |
| 01/04/91 | 23:00:00 | 6 | 30 | 3422 | | | 0 | 325 | 20 |
| 02/04/91 | 00:00:00 | 6 | 24 | 3891 | | | 0 | 332 | 20 |
| 02/04/91 | 01:00:00 | 4 | 105 | 5450 | | | 0 | 339 | 20 |
| 02/04/91 | 02:00:00 | 5 | 217 | 6702 | | | 0 | 326 | 19 |
| 02/04/91 | 03:00:00 | 23 | 201 | 7253 | | | 0 | 7 | 18 |
| 02/04/91 | 04:00:00 | 4 | 119 | 6269 | | | 0 | 22 | 18 |
| 02/04/91 | 05:00:00 | 5 | 94 | 6215 | | | 0 | 32 | 18 |
| 02/04/91 | 06:00:00 | 1 | 43 | 6132 | | | 0 | 38 | 17 |
| 02/04/91 | 07:00:00 | 0 | 9 | 4163 | | | 0 | 207 | 18 |
| | MEAN | 5 | 87 | 4772 | | | 0 | 164 | 19 |
| | MAXIMUM | 23 | 217 | 7253 | | | 0 | 339 | 21 |

AIRPARIF : ATMOSPHERIC POLLUTION MEASUREMENT CAMPAIGN "KUWAIT"

KUWAIT CITY ENGLISH SCHOOL 2 APRIL 1991 NIGHT

POLLUTION AND METEOROLOGICAL DATA; HOURLY MEANS

| DATE | TIME | O3 H ug/m3 | SO2 H ug/m3 | CO H ug/m3 | NO H ug/m3 | NO2 H ug/m3 | VV H m/s | DV H degré | T H oC |
|---|---|---|---|---|---|---|---|---|---|
| 02/04/91 | 18:00:00 | 14 | 6 | 53 | | | 1 | 327 | 21 |
| 02/04/91 | 19:00:00 | 7 | 5 | 694 | | | 1 | 323 | 21 |
| 02/04/91 | 20:00:00 | 1 | 5 | 445 | | | 1 | 333 | 21 |
| 02/04/91 | 21:00:00 | 1 | 6 | 919 | | | 0 | 346 | 21 |
| 02/04/91 | 22:00:00 | 2 | 47 | 1827 | | | 0 | 96 | 21 |
| 02/04/91 | 23:00:00 | 3 | 61 | 3090 | | | 0 | 34 | 19 |
| 03/04/91 | 00:00:00 | 2 | 124 | 2959 | | | 0 | 42 | 20 |
| 03/04/91 | 01:00:00 | 1 | 43 | 1827 | | | 0 | 274 | 19 |
| 03/04/91 | 02:00:00 | 2 | 5 | 1245 | | | 0 | 336 | 18 |
| 03/04/91 | 03:00:00 | 2 | 5 | 362 | | | 0 | 342 | 19 |
| 03/04/91 | 04:00:00 | 5 | 5 | 415 | | | 0 | 183 | 18 |
| 03/04/91 | 05:00:00 | 17 | 5 | 243 | | | 1 | 22 | 18 |
| 03/04/91 | 06:00:00 | 3 | 10 | 302 | | | 1 | 23 | 19 |
| 03/04/91 | 07:00:00 | 4 | 223 | 1115 | | | 1 | 34 | 20 |
| 03/04/91 | 08:00:00 | 20 | 126 | 2294 | | | 2 | 130 | 20 |
| | MEAN | 6 | 45 | 1186 | | | 1 | 190 | 20 |
| | MAXIMUM | 20 | 223 | 3090 | | | 2 | 346 | 21 |

AIRPARIF : ATMOSPHERIC POLLUTION MEASUREMENT CAMPAIGN "KUWAIT"

KUWAIT "RING 7 TH /AEROPORT" 03 APRIL 1991 DAY

POLLUTION AND METEOROLOGICAL DATA; HOURLY MEANS

| DATE | TIME | O3 H ug/m3 | SO2 H ug/m3 | CO H ug/m3 | NO H ug/m3 | NO2 H ug/m3 | VV H m/s | DV H degré | T H oC |
|---|---|---|---|---|---|---|---|---|---|
| 03/04/91 | 11:00:00 | 33 | | 83 | 8 | 52 | 5 | 251 | 23 |
| 03/04/91 | 12:00:00 | 55 | 174 | 36 | 16 | 47 | 8 | 108 | 22 |
| 03/04/91 | 13:00:00 | 89 | 198 | 0 | 0 | 24 | 10 | 45 | 22 |
| 03/04/91 | 14:00:00 | 104 | 534 | 0 | 1 | 28 | 12 | 281 | 22 |
| 03/04/91 | 15:00:00 | 112 | 613 | 0 | 0 | 23 | 13 | 287 | 22 |
| 03/04/91 | 16:00:00 | 123 | 345 | 0 | 1 | 18 | 13 | 304 | 22 |
| 03/04/91 | 17:00:00 | 115 | 948 | 6 | 2 | 27 | 12 | 326 | 22 |
| 03/04/91 | 18:00:00 | 109 | 945 | 112 | 24 | 45 | 13 | 305 | 23 |
| | MEAN | 93 | 537 | 30 | 7 | 33 | 11 | 238 | 22 |
| | MAXIMUM | 123 | 948 | 112 | 24 | 52 | 13 | 326 | 23 |

AIRPARIF : ATMOSPHERIC POLLUTION MEASUREMENT CAMPAIGN "KUWAIT"

KUWAIT CITY ENGLISH SCHOOL 3 APRIL 1991 NIGHT

POLLUTION AND METEOROLOGICAL DATA; HOURLY MEANS

| DATE | TIME | O3 H ug/m3 | SO2 H ug/m3 | CO H ug/m3 | NO H ug/m3 | NO2 H ug/m3 | VV H m/s | DV H degré | T H oC |
|---|---|---|---|---|---|---|---|---|---|
| 03/04/91 | 21:00:00 | 54 | 244 | 36 | | | 4 | 49 | 21 |
| 03/04/91 | 22:00:00 | 54 | 453 | 36 | | | 4 | 179 | 21 |
| 03/04/91 | 23:00:00 | 61 | 895 | 36 | | | 4 | 255 | 23 |
| 04/04/91 | 00:00:00 | 59 | 638 | 36 | | | 4 | 301 | 24 |
| 04/04/91 | 01:00:00 | 66 | 412 | 273 | | | 4 | 322 | 24 |
| 04/04/91 | 02:00:00 | 49 | 649 | 427 | | | 4 | 128 | 25 |
| 04/04/91 | 03:00:00 | 50 | 5 | 599 | | | 4 | 175 | 24 |
| 04/04/91 | 04:00:00 | 41 | 304 | 474 | | | 2 | 181 | 24 |
| 04/04/91 | 05:00:00 | 35 | 1369 | 652 | | | 2 | 182 | 23 |
| 04/04/91 | 06:00:00 | 37 | 524 | 504 | | | 2 | 251 | 23 |
| 04/04/91 | 07:00:00 | 30 | 29 | 433 | | | 2 | 200 | 23 |
| 04/04/91 | 08:00:00 | 24 | 5 | 480 | | | 2 | 253 | 22 |
| | MEAN | 47 | 461 | 332 | | | 3 | 206 | 23 |
| | MAXIMUM | 66 | 1369 | 652 | | | 4 | 322 | 25 |

AIRPARIF : ATMOSPHERIC POLLUTION MEASUREMENT CAMPAIGN "KUWAIT"

KUWAIT "AL MAQWA ROAD SOUTHERN OIL FIELDS" 04 APRIL 1991 DAY

POLLUTION AND METEOROLOGICAL DATA; HOURLY MEANS

| DATE | TIME | O3 H ug/m3 | SO2 H ug/m3 | CO H ug/m3 | NO H ug/m3 | NO2 H ug/m3 | VV H m/s | DV H degré | T H oC |
|---|---|---|---|---|---|---|---|---|---|
| 04/04/91 | 12:00:00 | 68 | 0 | 95 | 0 | 25 | 9 | 182 | 21 |
| 04/04/91 | 13:00:00 | 64 | 73 | 18 | 0 | 27 | 7 | 239 | 21 |
| 04/04/91 | 14:00:00 | 61 | 737 | 0 | 1 | 35 | 4 | 133 | 25 |
| 04/04/91 | 15:00:00 | 86 | 286 | 0 | 8 | 19 | 6 | 207 | 32 |
| 04/04/91 | 16:00:00 | 72 | 185 | 0 | 0 | 25 | 5 | 239 | 32 |
| 04/04/91 | 17:00:00 | 73 | 12 | 9 | 9 | 18 | 4 | 289 | 31 |
| | MEAN | 71 | 216 | 20 | 3 | 25 | 6 | 215 | 27 |
| | MAXIMUM | 86 | 737 | 95 | 9 | 35 | 9 | 289 | 32 |

AIRPARIF : ATMOSPHERIC POLLUTION MEASUREMENT CAMPAIGN "KUWAIT"

KUWAIT CITY ENGLISH SCHOOL 4 APRIL 1991 NIGHT

POLLUTION AND METEOROLOGICAL DATA; HOURLY MEANS

| DATE | TIME | O3 H ug/m3 | SO2 H ug/m3 | CO H ug/m3 | NO H ug/m3 | NO2 H ug/m3 | VV H m/s | DV H degré | T H oC |
|---|---|---|---|---|---|---|---|---|---|
| 04/04/91 | 21:00:00 | 2 | 226 | 2360 | | | 0 | 128 | 23 |
| 04/04/91 | 22:00:00 | 4 | 223 | 5860 | | | 0 | 180 | 23 |
| 04/04/91 | 23:00:00 | 5 | 114 | 3048 | | | 1 | 155 | 23 |
| 05/04/91 | 00:00:00 | 41 | 13 | 635 | | | 2 | 178 | 24 |
| 05/04/91 | 01:00:00 | 49 | 5 | 409 | | | 3 | 204 | 24 |
| 05/04/91 | 02:00:00 | 63 | 5 | 202 | | | 3 | 106 | 23 |
| 05/04/91 | 03:00:00 | 57 | 6 | 237 | | | 2 | 200 | 23 |
| 05/04/91 | 04:00:00 | 62 | 5 | 219 | | | 1 | 128 | 22 |
| 05/04/91 | 05:00:00 | 63 | 5 | 267 | | | 2 | 152 | 21 |
| 05/04/91 | 06:00:00 | 70 | 5 | 166 | | | 3 | 181 | 22 |
| 05/04/91 | 07:00:00 | 70 | 5 | 202 | | | 3 | 196 | 22 |
| 05/04/91 | 08:00:00 | 68 | 5 | 374 | | | 4 | 131 | 22 |
| | MEAN | 46 | 51 | 1165 | | | 2 | 162 | 23 |
| | MAXIMUM | 70 | 226 | 5860 | | | 4 | 204 | 24 |

SUSPENDED PARTICULATES (BLACK SMOKE) MEASUREMENT IN KUWAIT FROM 28 03 TO 04 04 1991

AIRPARIF MEASUREMENT CAMPAIGN results in ug/M3

| lo CAM | CAM 2 | CAM 3 | CAM 4 | CAM 5 | CAM 6 | CAM 8 | CAM 9 | CAM 10 | CAM 11 | CAM 12 | CAM 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| .IEU | ENG SCHOOL | MANSOURIYA | FIELD NORD | ENG SCHOOL | AHMADI VIL | AHMADI HOSP | ENG SCHOOL | ENG SCHOOL | RING 7/AER | ENG SCHOOL | AL MAQWA |
| )ATE | 28/29 3 | 29 3 | 30 3 | 30/31 3 | 31 3 | 01 04 | 01/02 04 | 02/3 04 | 3 04 | 03/4 04 | 4 04 |
| IEURE | | | | | | | | | | | |
| 11 | | | | | 946 | | | | 1365 | | |
| 12 | | 119 | | | 1406 | | | | 697 | | 2030 |
| 13 | | 144 | | | 1591 | 288 | | | 224 | | 778 |
| 14 | | 129 | 360 | | 827 | 316 | | | 212 | | 1100 |
| 15 | | 70 | 340 | | 475 | 347 | | | 351 | | 494 |
| 16 | | 98 | 235 | | 356 | 125 | | | 361 | | 344 |
| 17 | | 89 | 124 | | 175 | 106 | | | 400 | | 165 |
| 18 | | 42 | | | 185 | 55 | | 109 | 1151 | | |
| 19 | | | | | | | | 104 | | | |
| 20 | 69 | | | | | | 89 | 95 | | | |
| 21 | 86 | | | 92 | | | 101 | 98 | | 75 | |
| 22 | 90 | | | 114 | | | 103 | 116 | | 81 | |
| 23 | 214 | | | 142 | | | 109 | 134 | | 185 | |
| 24 | 1147 | | | 199 | | | 133 | 310 | | 108 | |
| 1 | 1291 | | | 539 | | | 379 | 507 | | 135 | |
| 2 | 740 | | | 402 | | | 936 | 235 | | 356 | |
| 3 | 361 | | | 187 | | | 984 | 130 | | 102 | |
| 4 | 301 | | | 96 | | | 736 | 202 | | 135 | |
| 5 | 214 | | | 78 | | | 777 | 161 | | 792 | |
| 6 | 141 | | | 68 | | | 506 | 80 | | 638 | |
| 7 | 98 | | | 73 | | | 442 | 301 | | 139 | |
| 8 | 96 | | | 73 | | | 547 | 401 | | 32 | |
| 9 | 149 | | | 60 | | | | | | | |
| 10 | 104 | | | | | | | | | | |
| IOYENNE | 340 | 99 | 265 | 163 | 745 | 206 | 449 | 199 | 595 | 232 | 819 |
| IAXIMUM | 1291 | 144 | 360 | 539 | 1591 | 347 | 984 | 507 | 1365 | 792 | 2030 |

# KUWAIT STUDY

## 27 March to 4 April 1991

*ANNEX V*

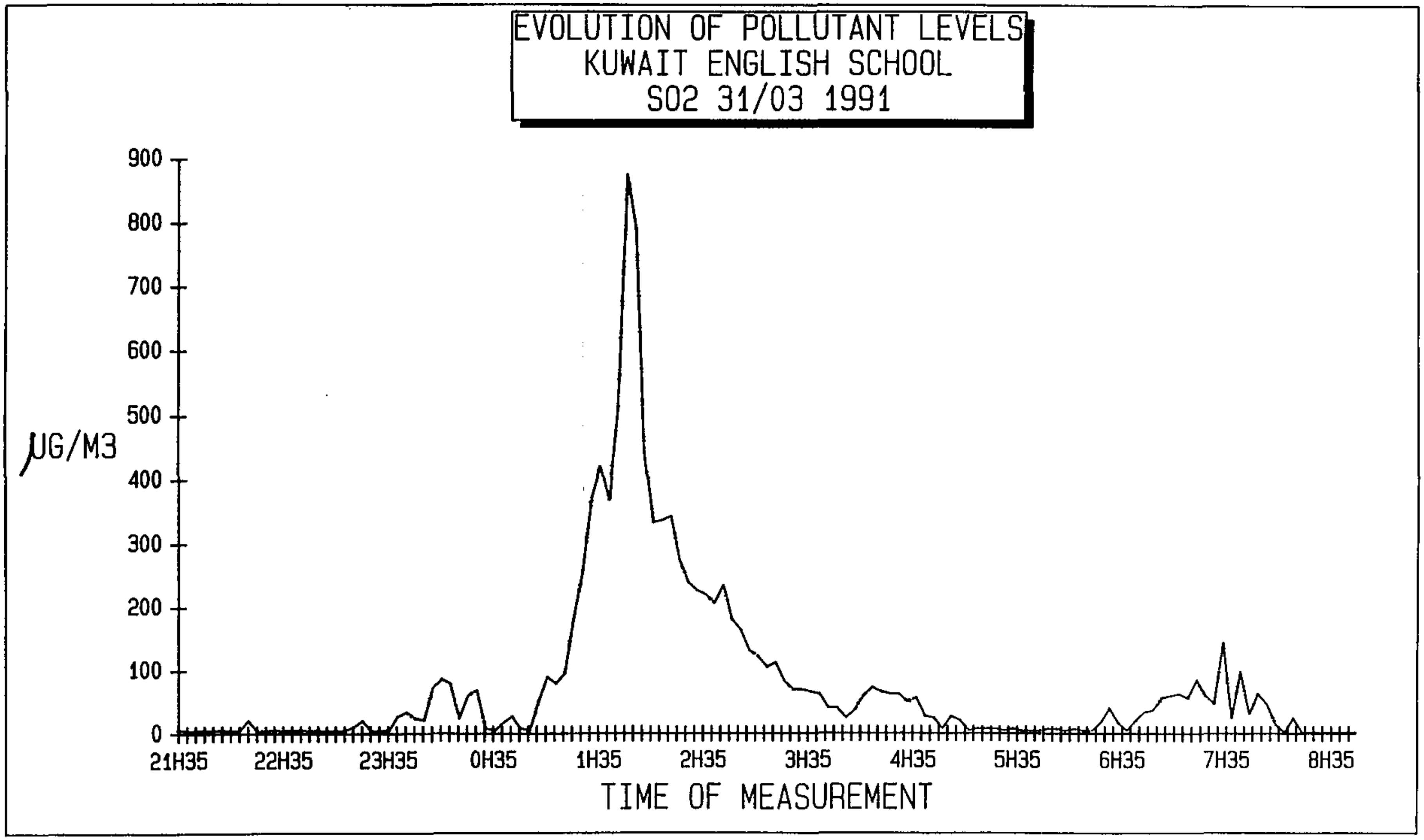
Overall Results

Maps of Kuwait

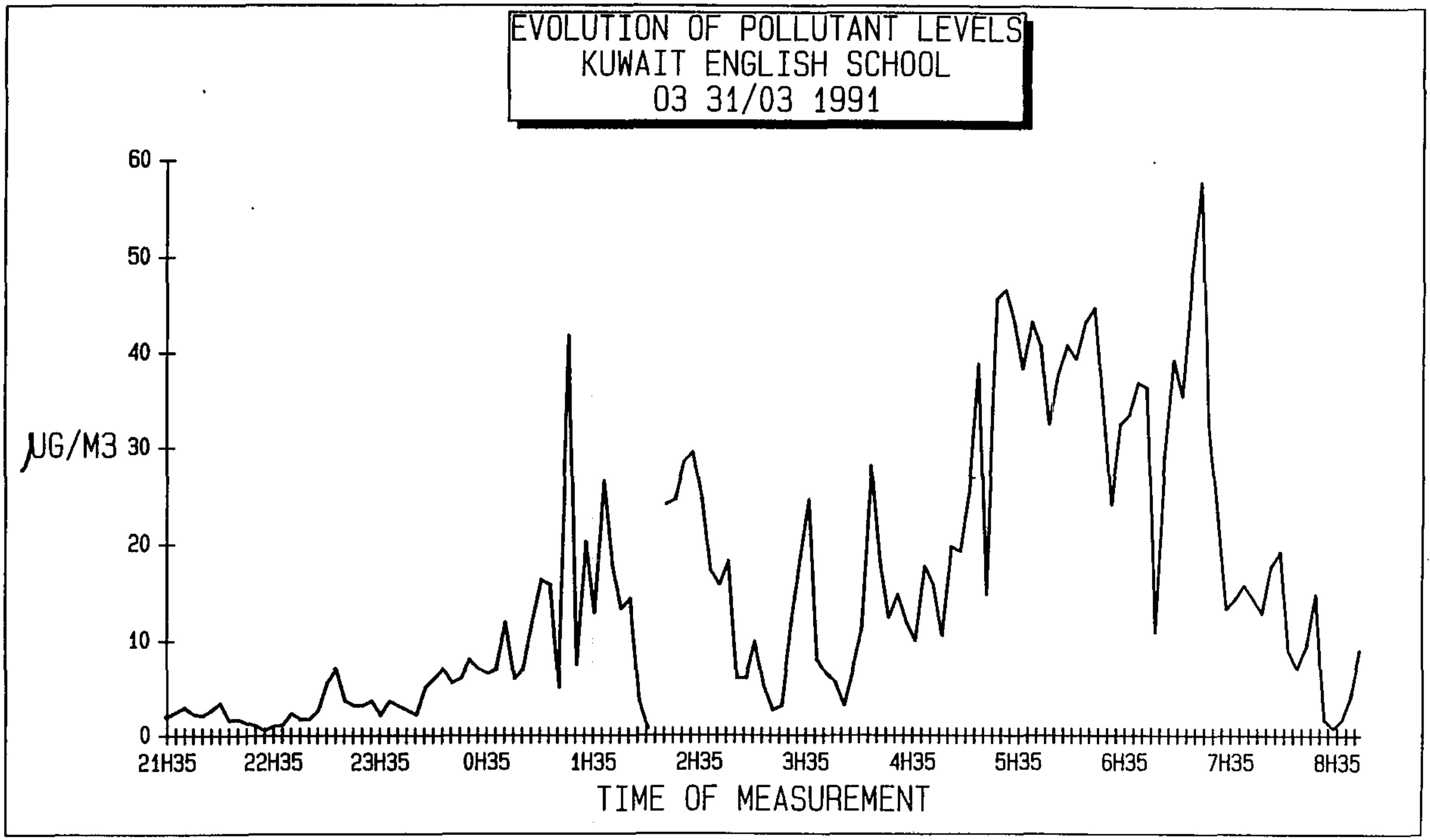
- EEC-WHO reference values

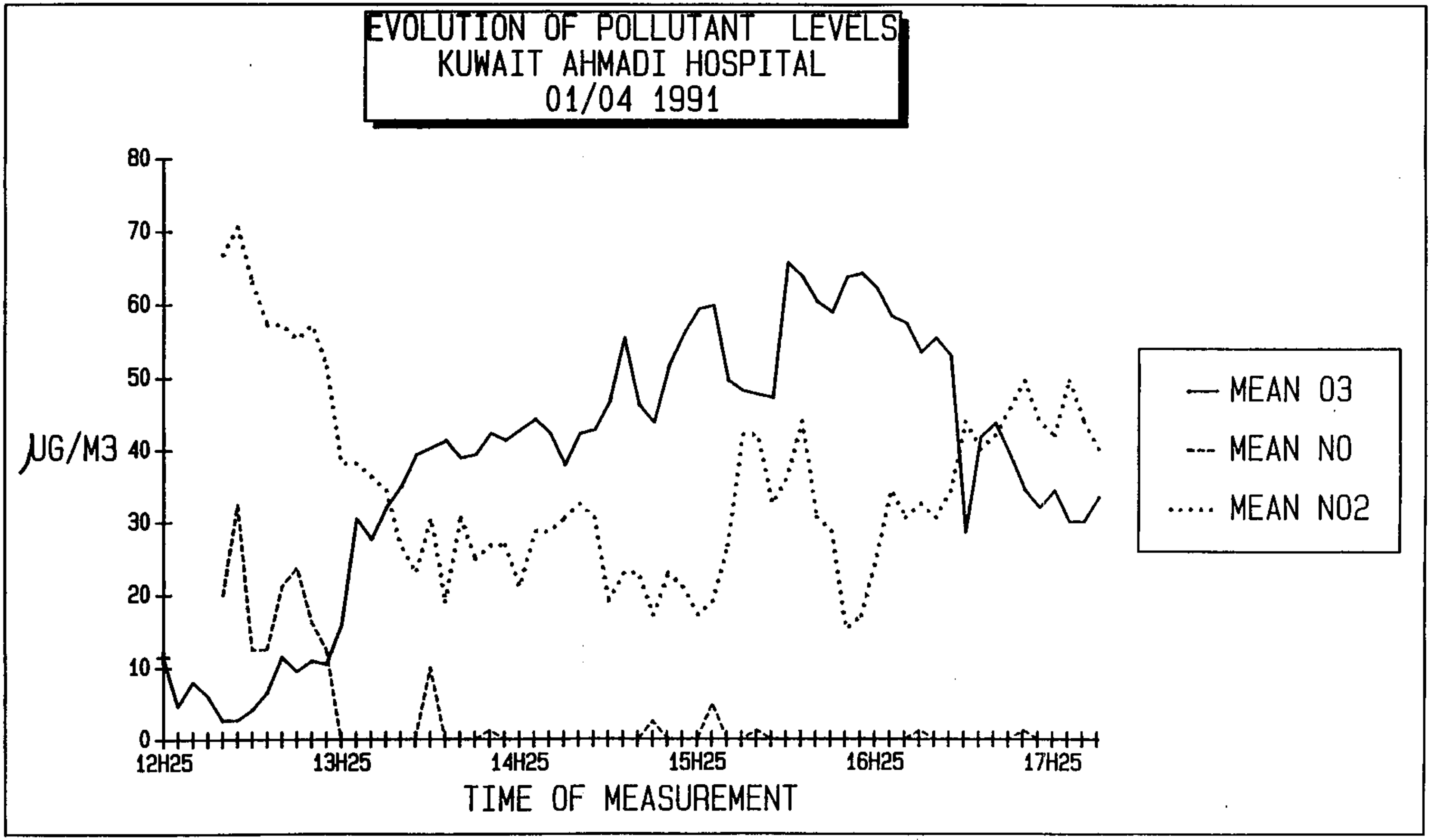
- addresses of local contacts

(WHO = World Health Organization)

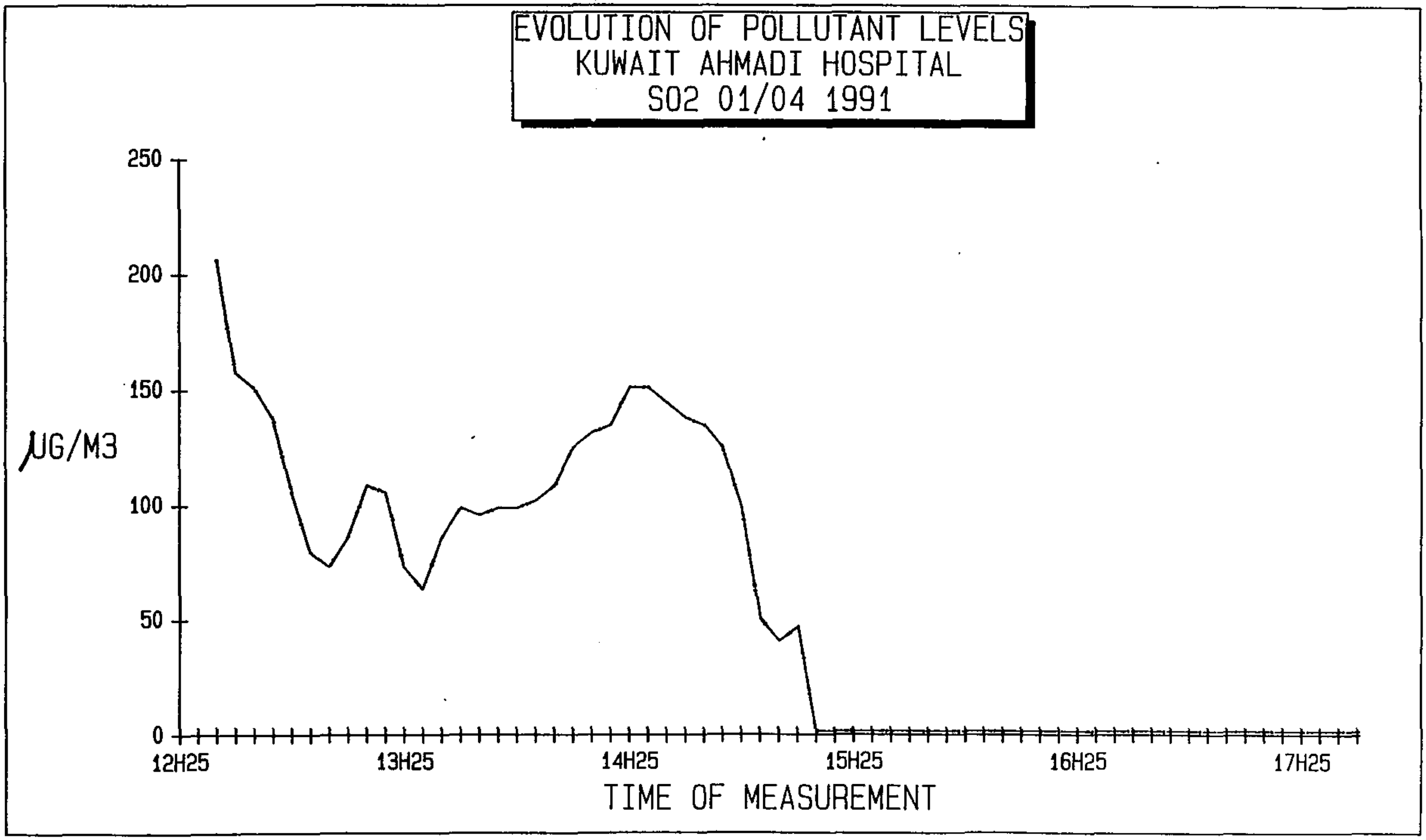


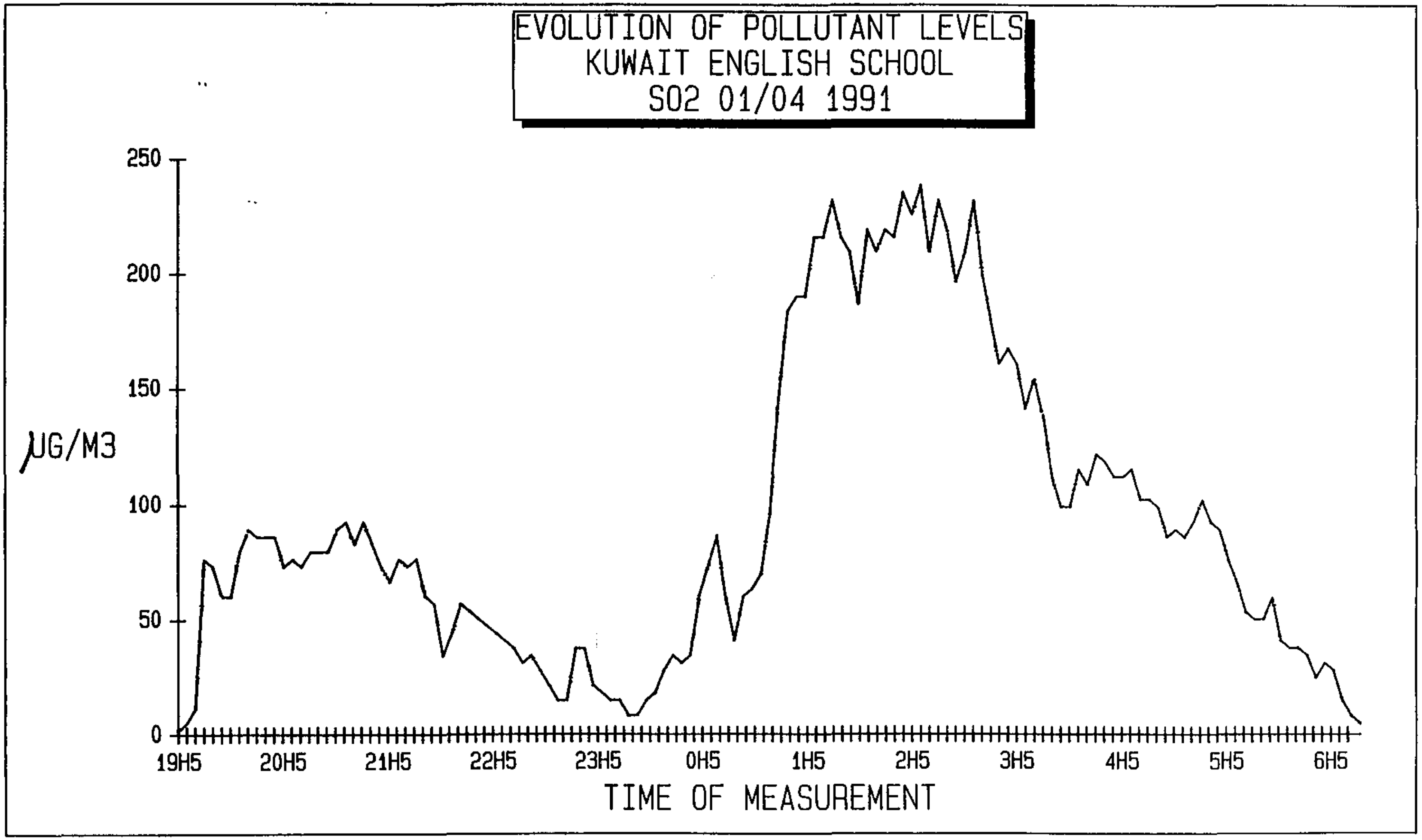
EVOLUTION OF POLLUTANT LEVELS
KUWAIT ENGLISH SCHOOL
SO2 31/03 1991
900
800
700
600
500
400
300
200
100
0
µG/M3
21H35
22H35
23H35
0H35
1H35
2H35
3H35
4H35
5H35
6H35
7H35
8H35
TIME OF MEASUREMENT

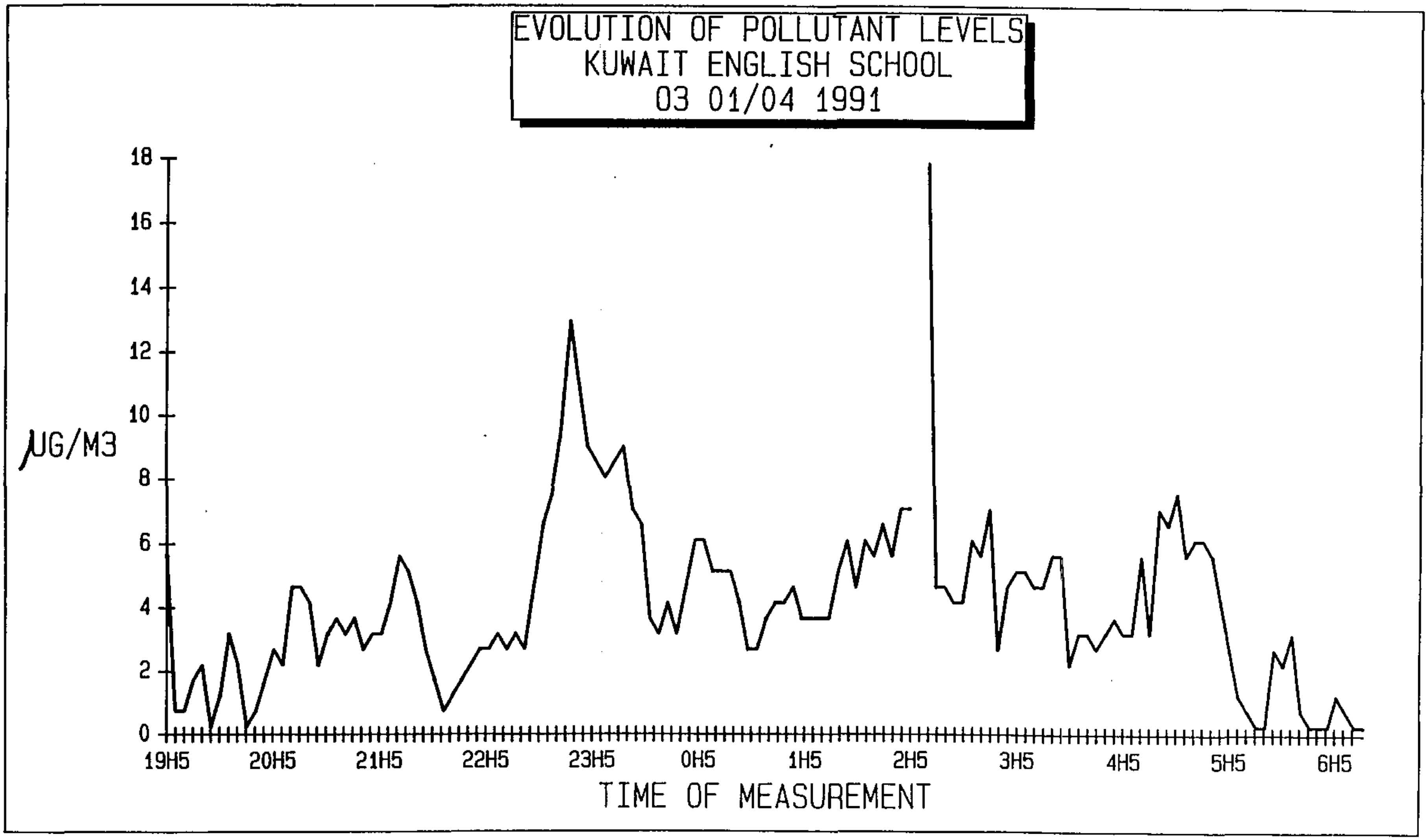

EVOLUTION OF POLLUTANT LEVELS
KUWAIT ENGLISH SCHOOL
03 31/03 1991
µG/M3
60
50
40
30
20
10
0
21H35
22H35
23H35
0H35
1H35
2H35
3H35
4H35
5H35
6H35
7H35
8H35
TIME OF MEASUREMENT



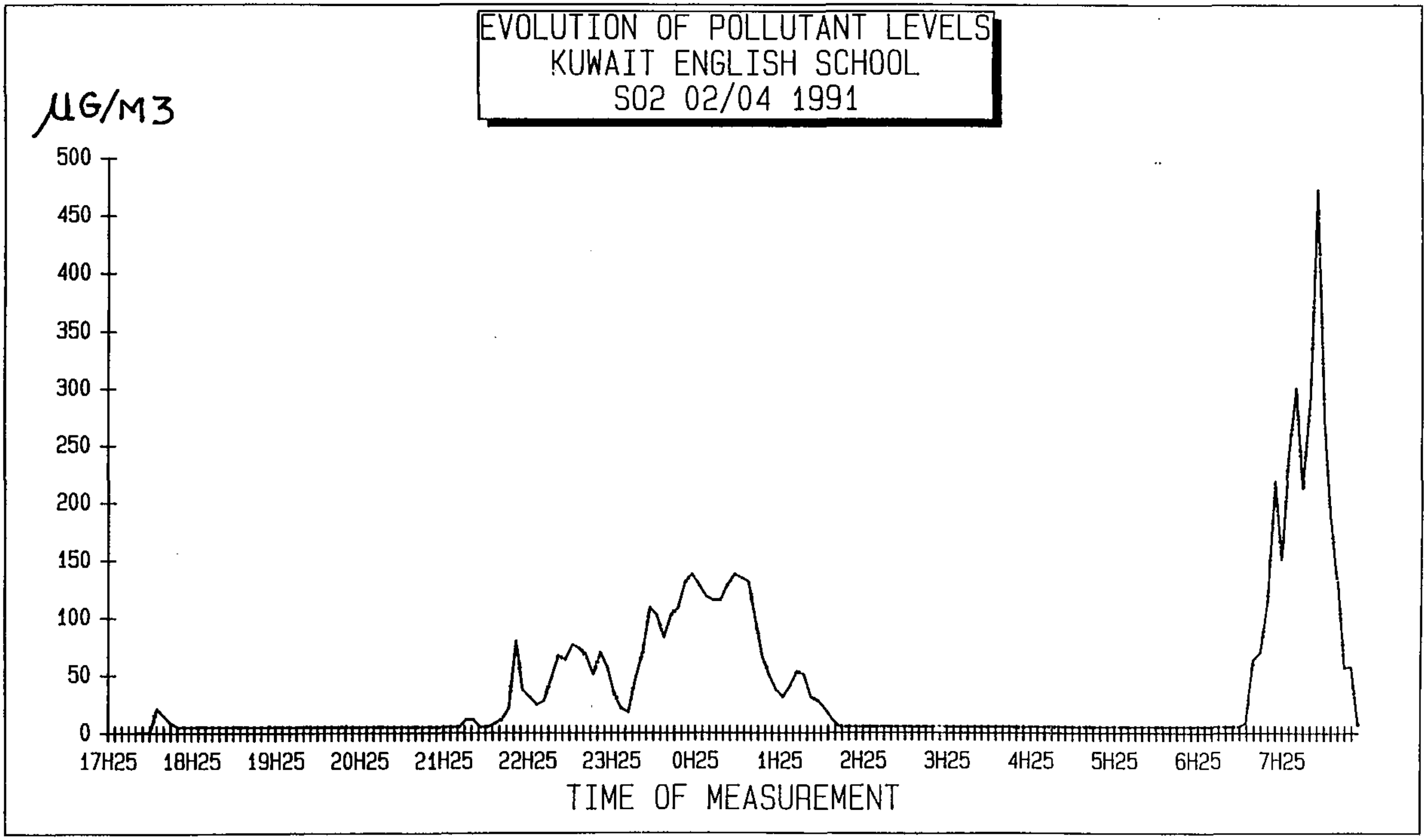
EVOLUTION OF POLLUTANT LEVELS
KUWAIT AHMADI HOSPITAL
01/04 1991
80
70
60
50
40
30
20
10
0
µG/M3
12H25
13H25
14H25
15H25
16H25
17H25
TIME OF MEASUREMENT
MEAN O3
MEAN NO
MEAN NO2

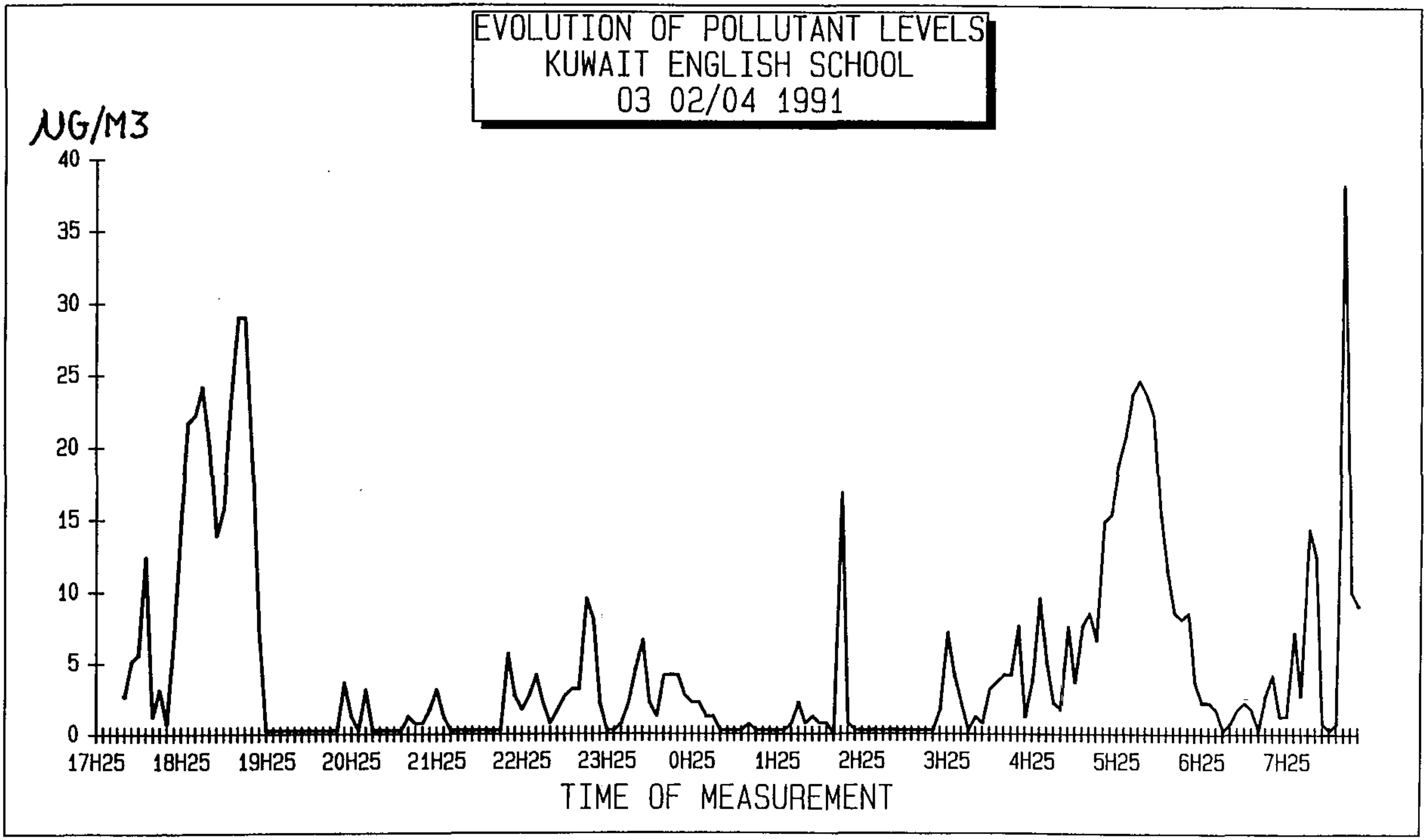

EVOLUTION OF POLLUTANT LEVELS
KUWAIT AHMADI HOSPITAL
SO2 01/04 1991
µG/M3
250
200
150
100
50
0
12H25
13H25
14H25
15H25
16H25
17H25
TIME OF MEASUREMENT

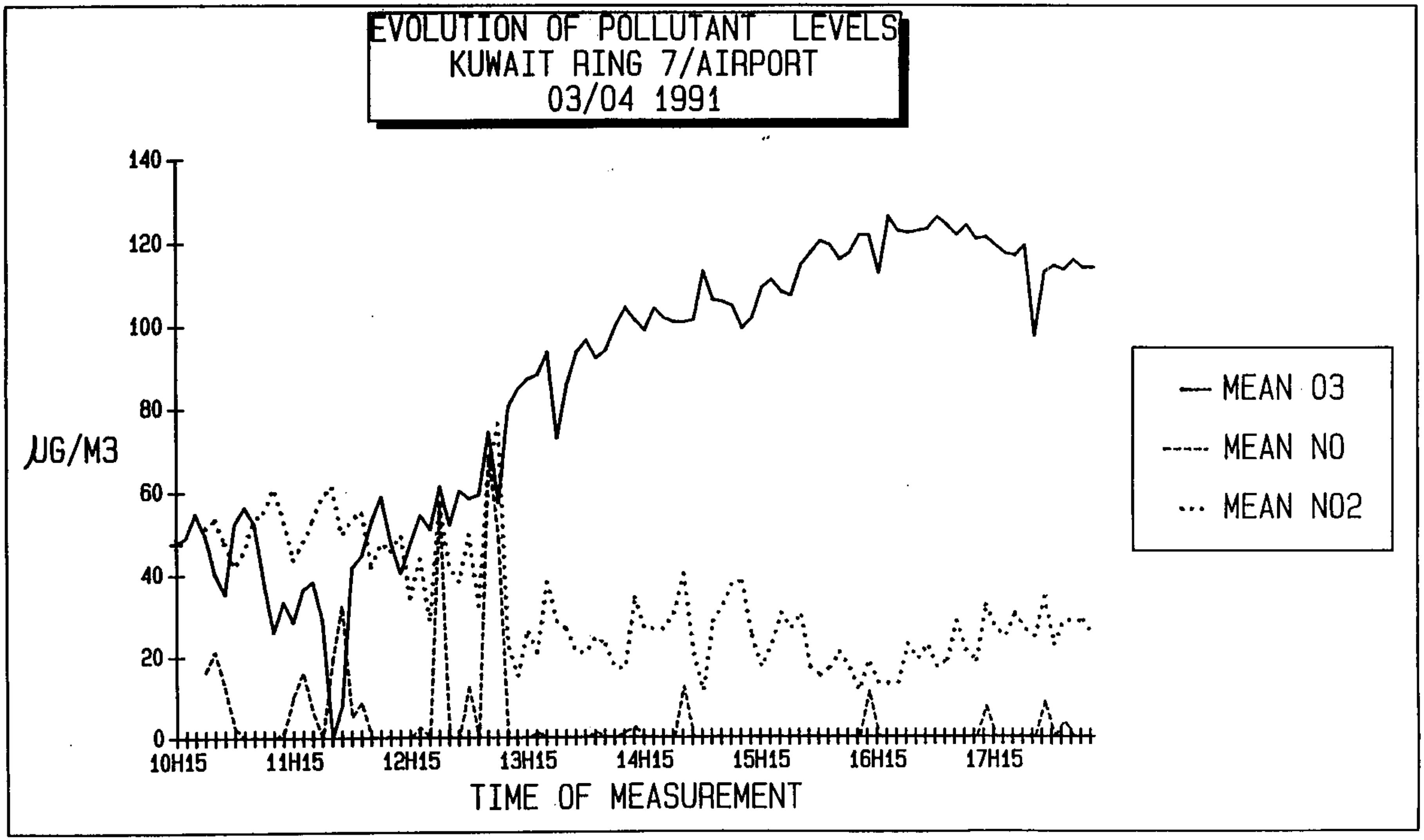

EVOLUTION OF POLLUTANT LEVELS
KUWAIT ENGLISH SCHOOL
SO2 01/04 1991
250
200
150
100
50
0
µG/M3
19H5
20H5
21H5
22H5
23H5
0H5
1H5
2H5
3H5
4H5
5H5
6H5
TIME OF MEASUREMENT



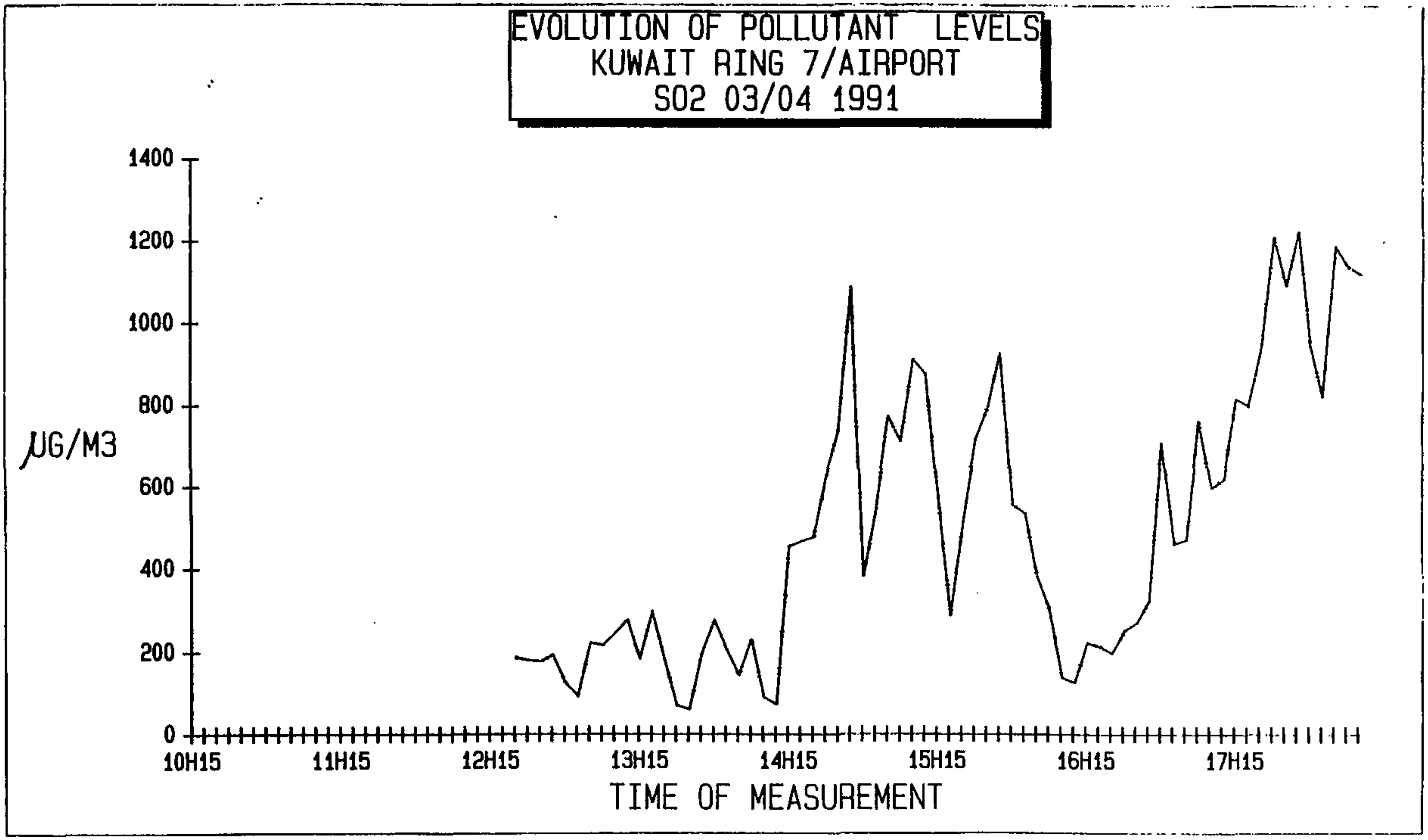
EVOLUTION OF POLLUTANT LEVELS
KUWAIT ENGLISH SCHOOL
03 01/04 1991
18
16
14
12
10
8
6
4
2
0
µG/M3
19H5
20H5
21H5
22H5
23H5
0H5
1H5
2H5
3H5
4H5
5H5
6H5
TIME OF MEASUREMENT


EVOLUTION OF POLLUTANT LEVELS
KUWAIT ENGLISH SCHOOL
SO2 02/04 1991
µG/M3
500
450
400
350
300
250
200
150
100
50
0
17H25
18H25
19H25
20H25
21H25
22H25
23H25
0H25
1H25
2H25
3H25
4H25
5H25
6H25
7H25
TIME OF MEASUREMENT

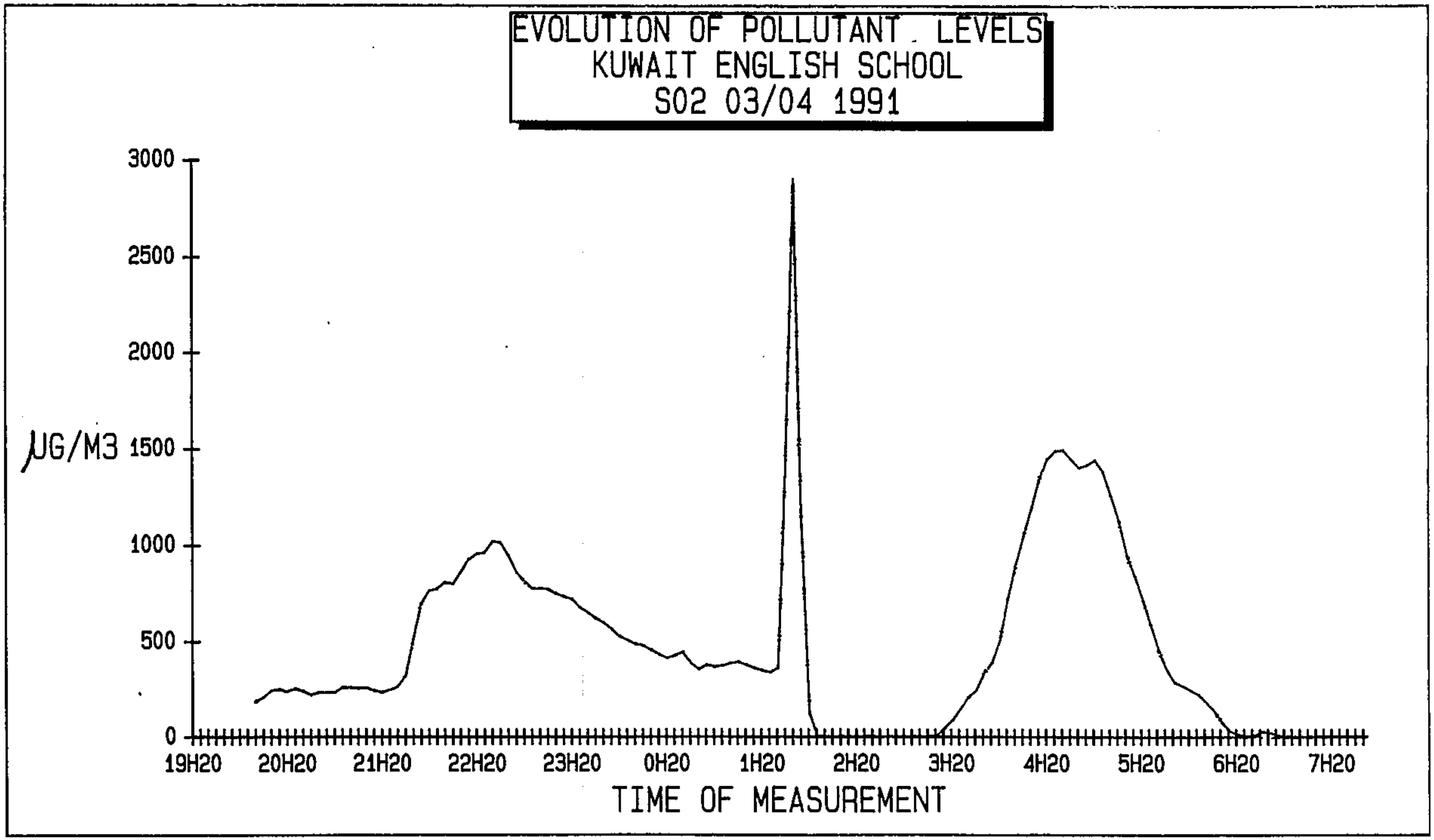

EVOLUTION OF POLLUTANT LEVELS
KUWAIT ENGLISH SCHOOL
03 02/04 1991
ΜG/M3
40
35
30
25
20
15
10
5
0
17H25
18H25
19H25
20H25
21H25
22H25
23H25
0H25
1H25
2H25
3H25
4H25
5H25
6H25
7H25
TIME OF MEASUREMENT



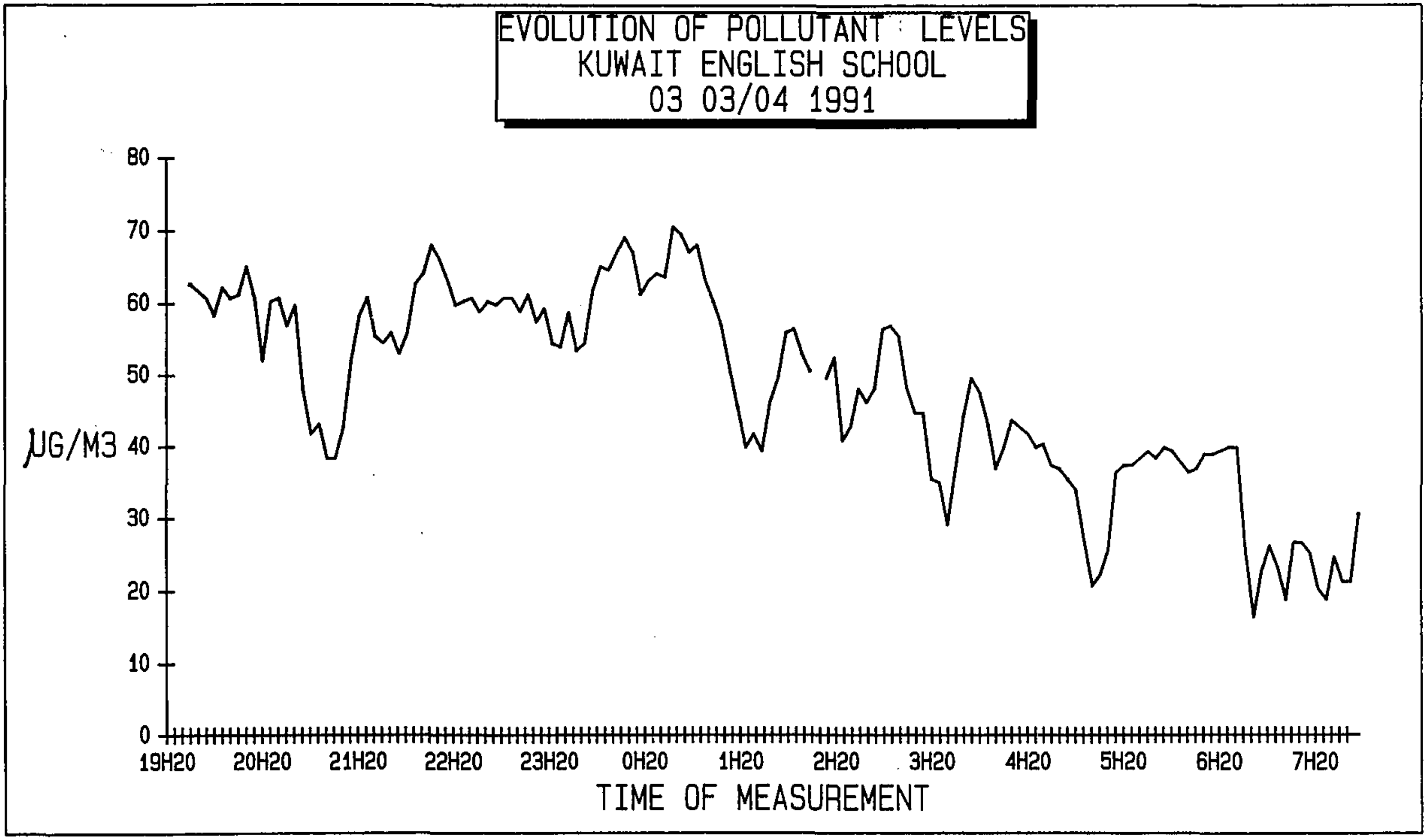
EVOLUTION OF POLLUTANT LEVELS
KUWAIT RING 7/AIRPORT
03/04 1991
140
120
100
80
60
40
20
0
µG/M3
10H15
11H15
12H15
13H15
14H15
15H15
16H15
17H15
TIME OF MEASUREMENT
MEAN O3
MEAN NO
MEAN NO2



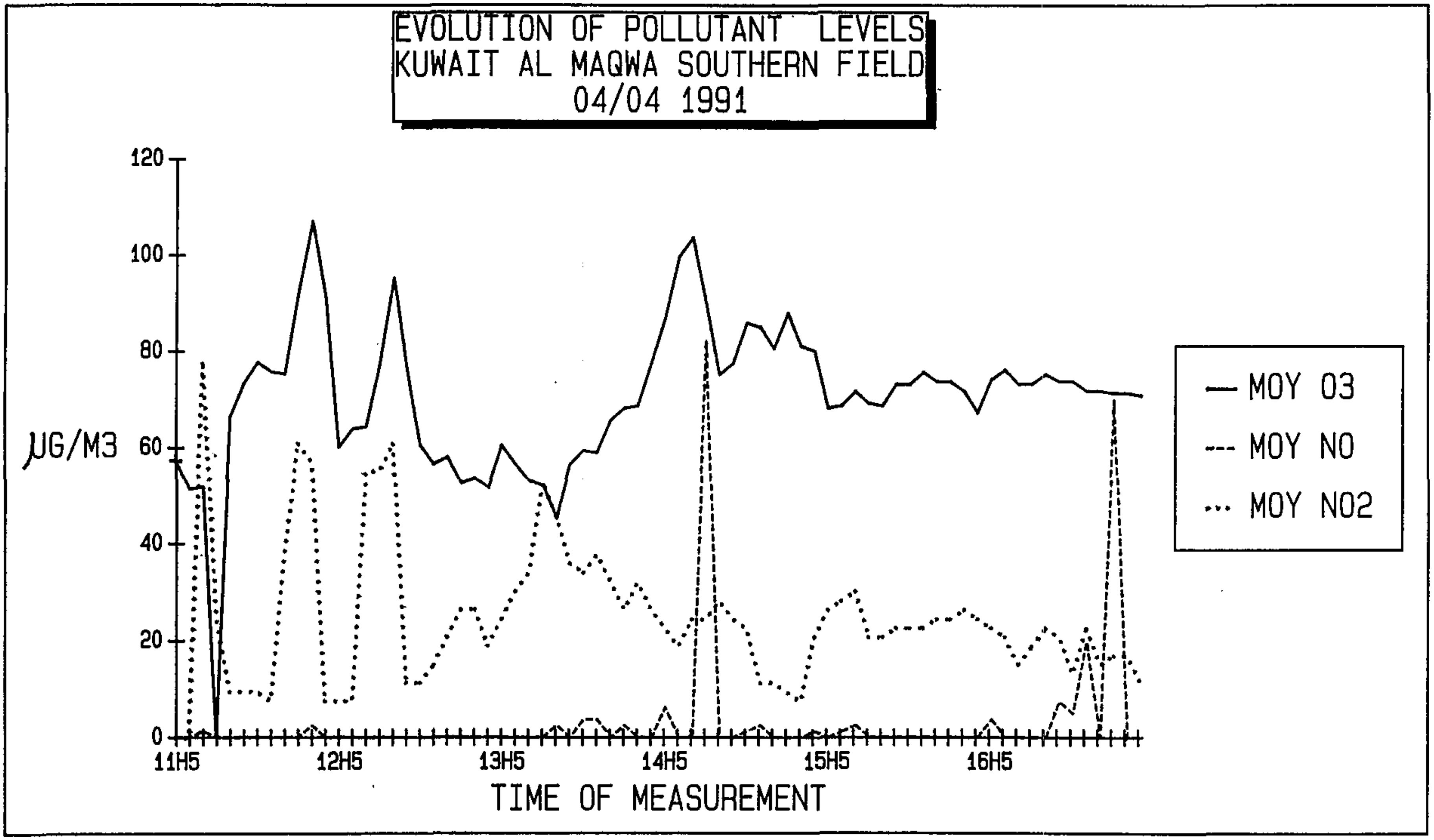
EVOLUTION OF POLLUTANT LEVELS
KUWAIT RING 7/AIRPORT
SO2 03/04 1991
1400
1200
1000
800
600
400
200
0
µG/M3
10H15
11H15
12H15
13H15
14H15
15H15
16H15
17H15
TIME OF MEASUREMENT



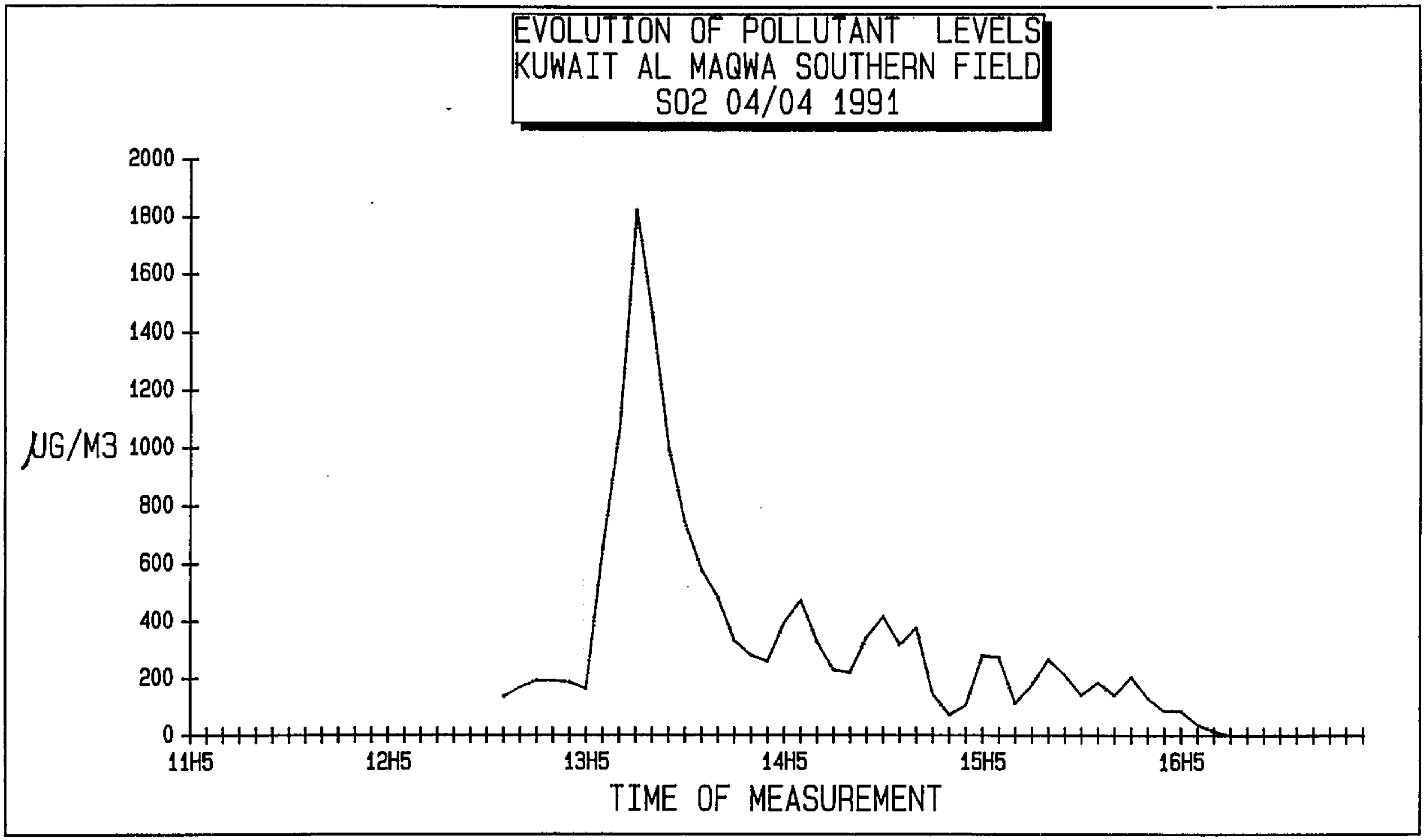
EVOLUTION OF POLLUTANT LEVELS
KUWAIT ENGLISH SCHOOL
SO2 03/04 1991
3000
2500
2000
µG/M3
1500
1000
500
0
19H20
20H20
21H20
22H20
23H20
0H20
1H20
2H20
3H20
4H20
5H20
6H20
7H20
TIME OF MEASUREMENT



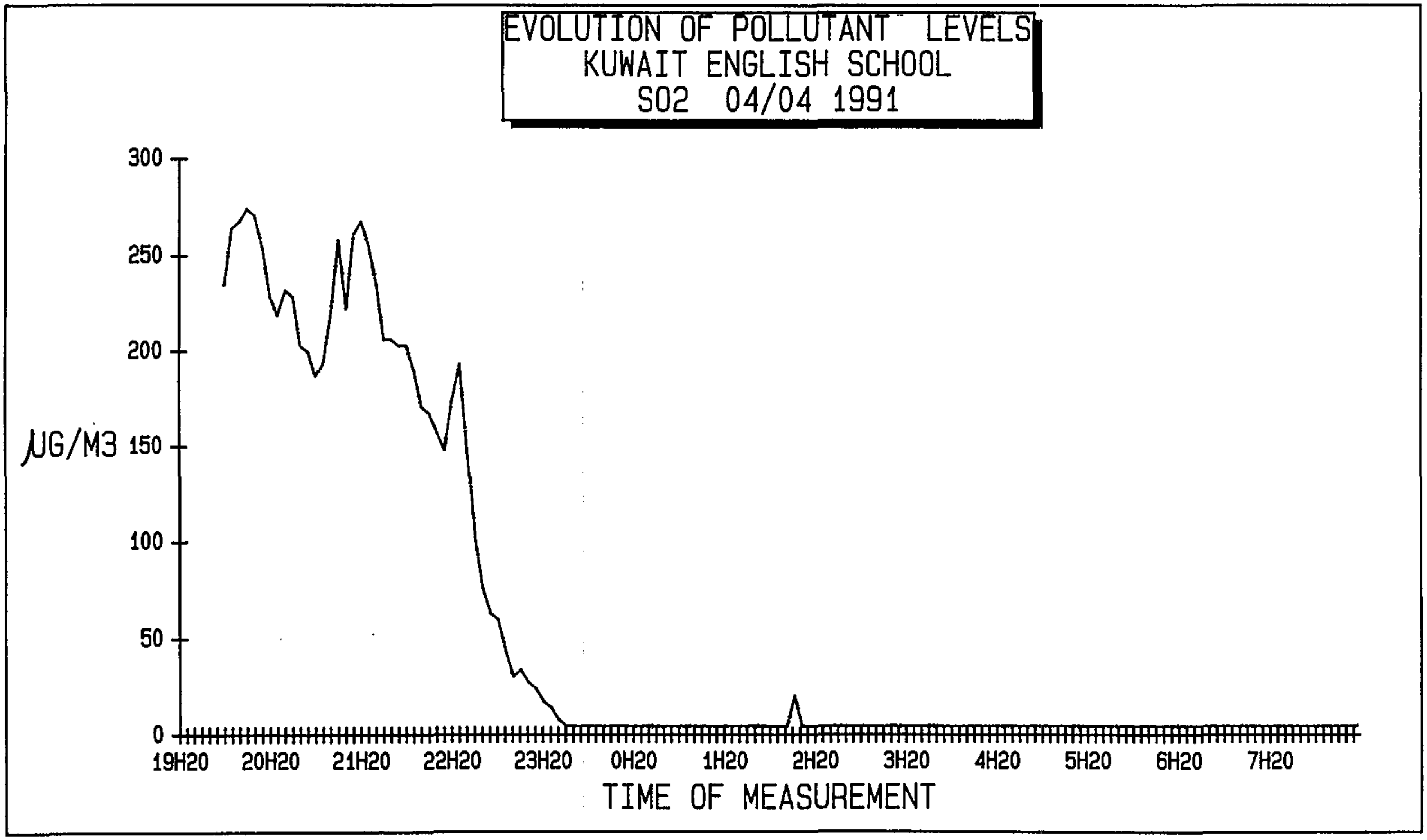
EVOLUTION OF POLLUTANT LEVELS
KUWAIT ENGLISH SCHOOL
03 03/04 1991
80
70
60
50
µG/M3 40
30
20
10
0
19H20
20H20
21H20
22H20
23H20
0H20
1H20
2H20
3H20
4H20
5H20
6H20
7H20
TIME OF MEASUREMENT



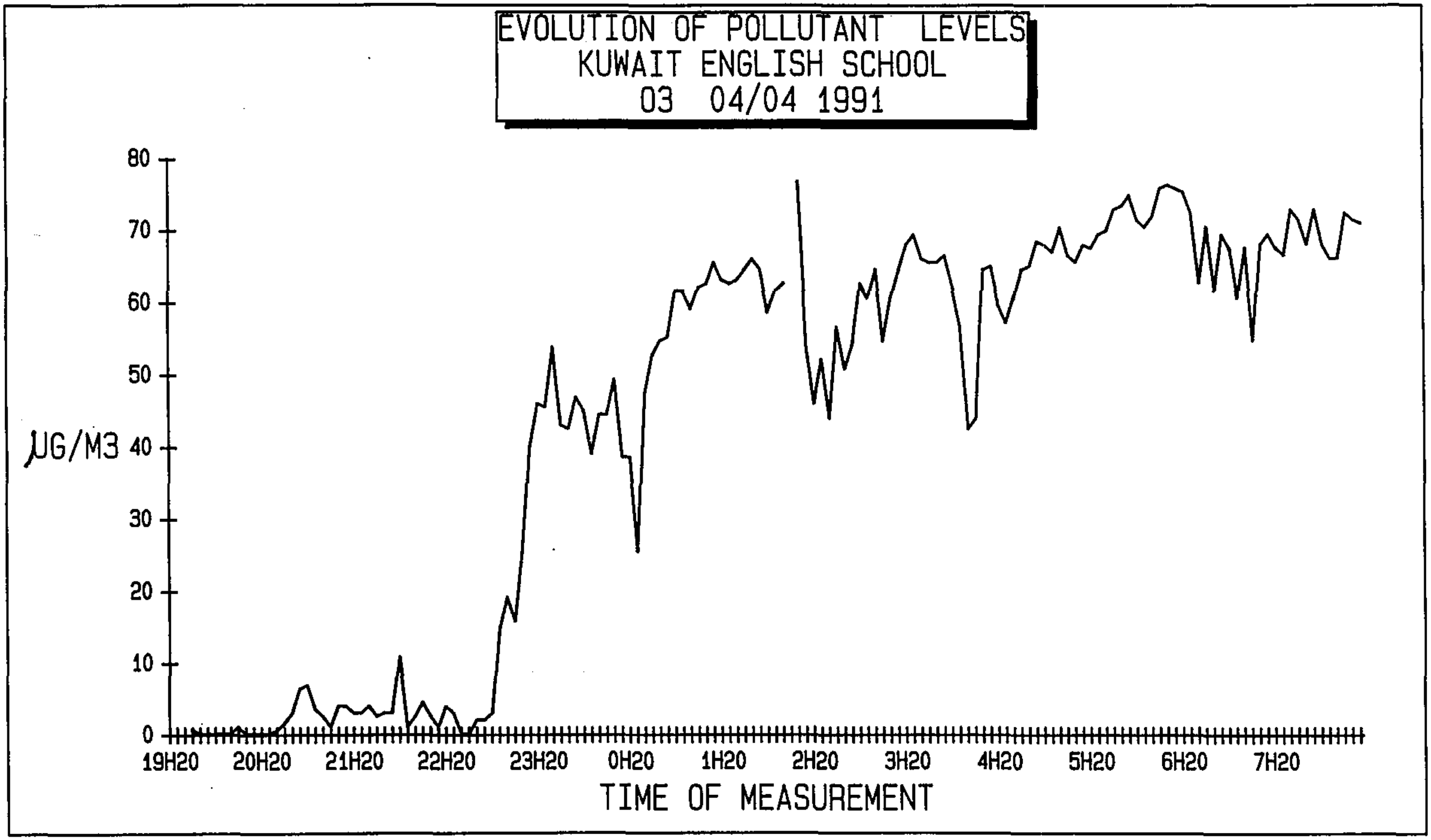
EVOLUTION OF POLLUTANT LEVELS
KUWAIT AL MAQWA SOUTHERN FIELD
04/04 1991
120
100
80
60
40
20
0
µG/M3
11H5
12H5
13H5
14H5
15H5
16H5
TIME OF MEASUREMENT
MOY O3
MOY NO
MOY NO2



EVOLUTION OF POLLUTANT LEVELS
KUWAIT AL MAQWA SOUTHERN FIELD
SO2 04/04 1991
µG/M3
2000
1800
1600
1400
1200
1000
800
600
400
200
0
11H5
12H5
13H5
14H5
15H5
16H5
TIME OF MEASUREMENT



EVOLUTION OF POLLUTANT LEVELS
KUWAIT ENGLISH SCHOOL
SO2 04/04 1991
µG/M3
300
250
200
150
100
50
0
19H20
20H20
21H20
22H20
23H20
0H20
1H20
2H20
3H20
4H20
5H20
6H20
7H20
TIME OF MEASUREMENT



EVOLUTION OF POLLUTANT LEVELS
KUWAIT ENGLISH SCHOOL
03 04/04 1991
µG/M3
80
70
60
50
40
30
20
10
0
19H20
20H20
21H20
22H20
23H20
0H20
1H20
2H20
3H20
4H20
5H20
6H20
7H20
TIME OF MEASUREMENT

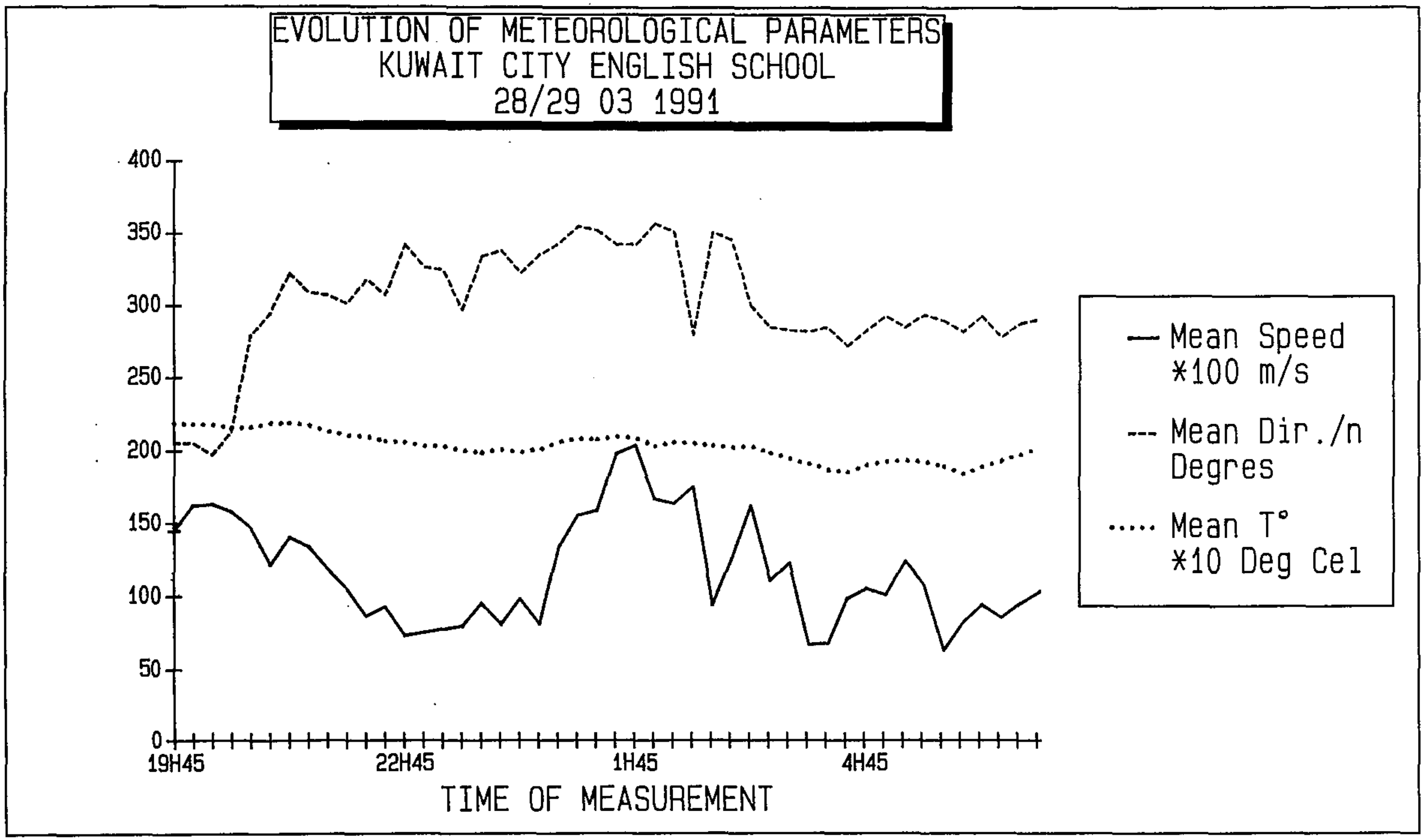
# KUWAIT STUDY

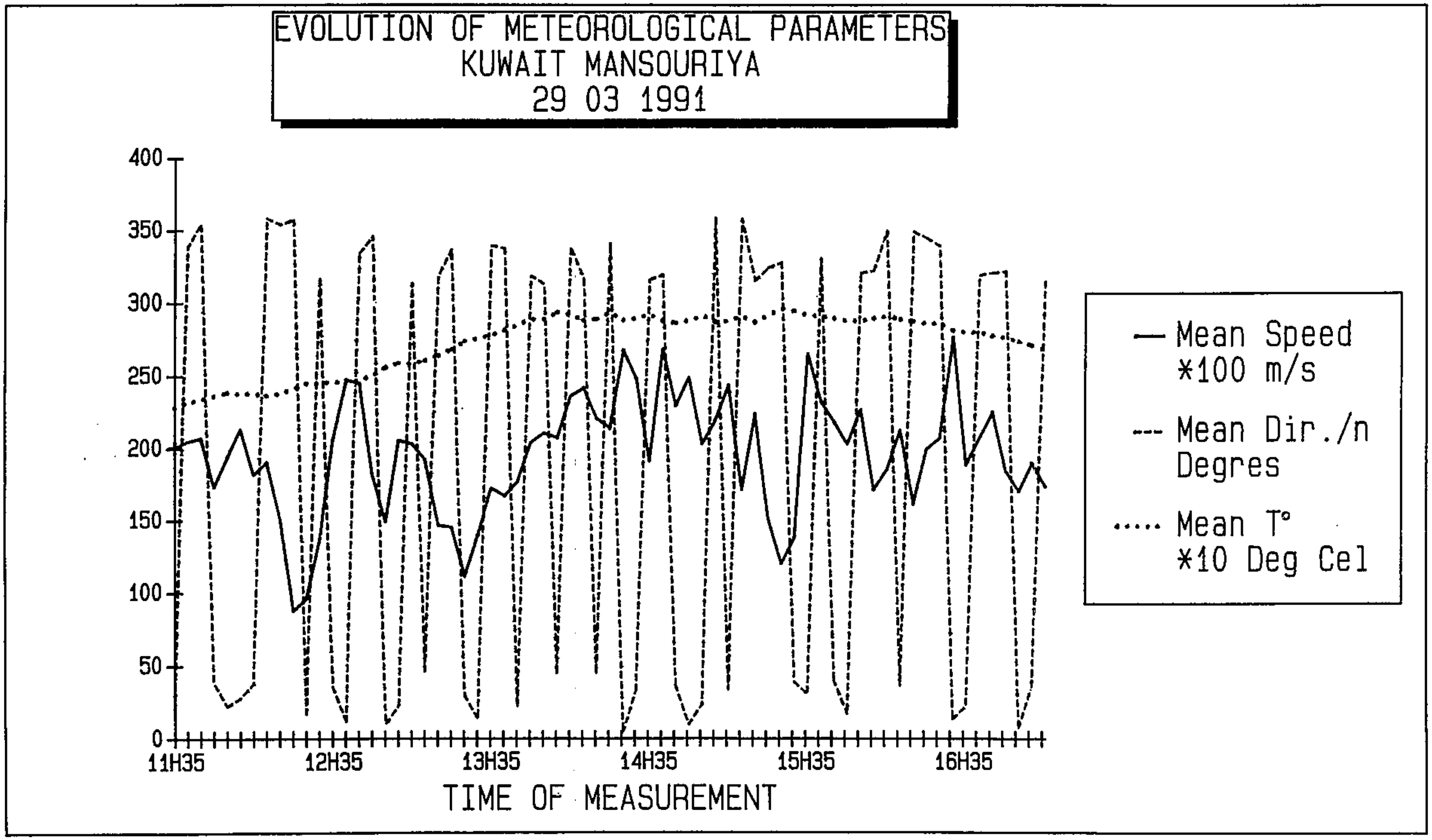
## 27 march to 4 april 1991

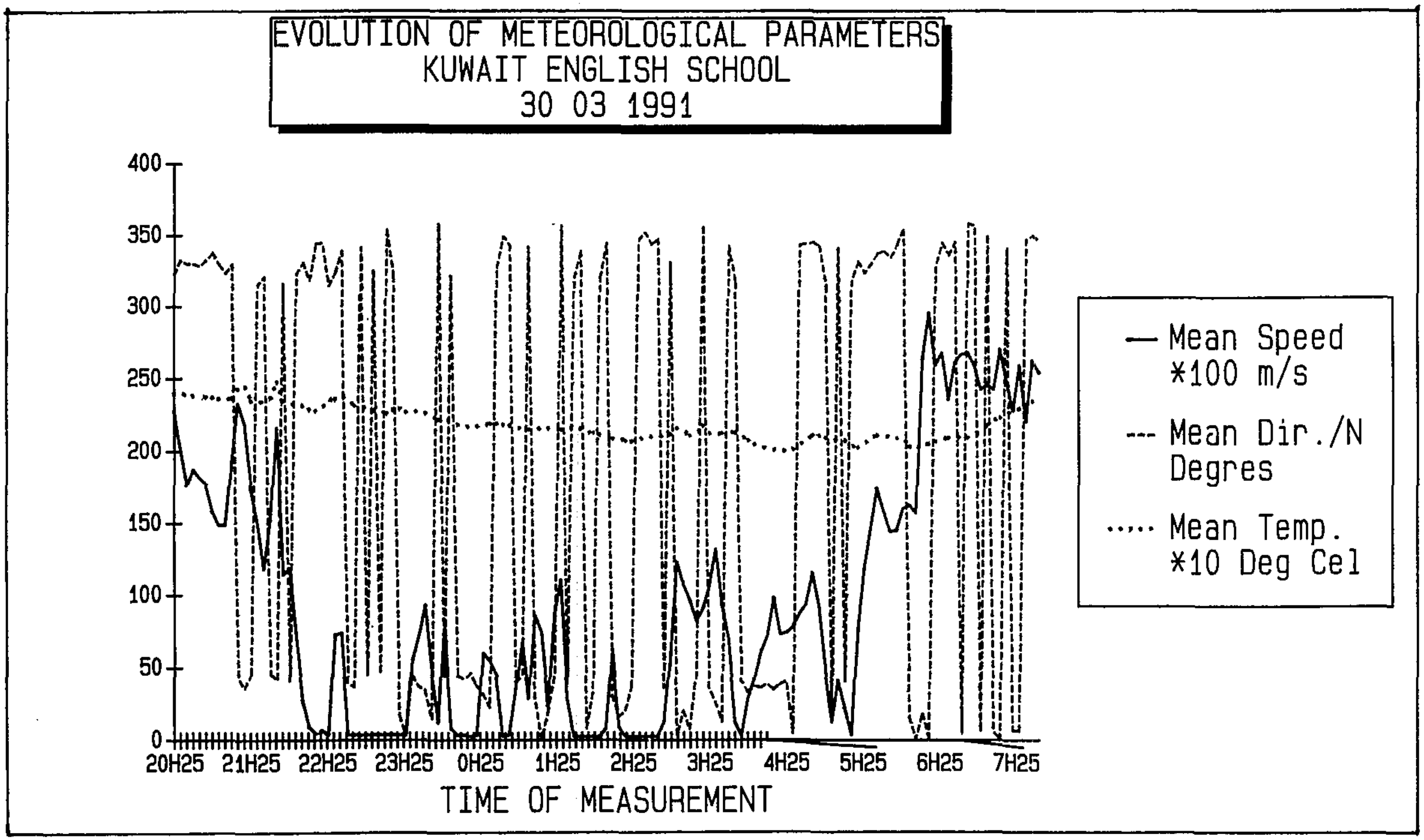
***ANNEXE II***

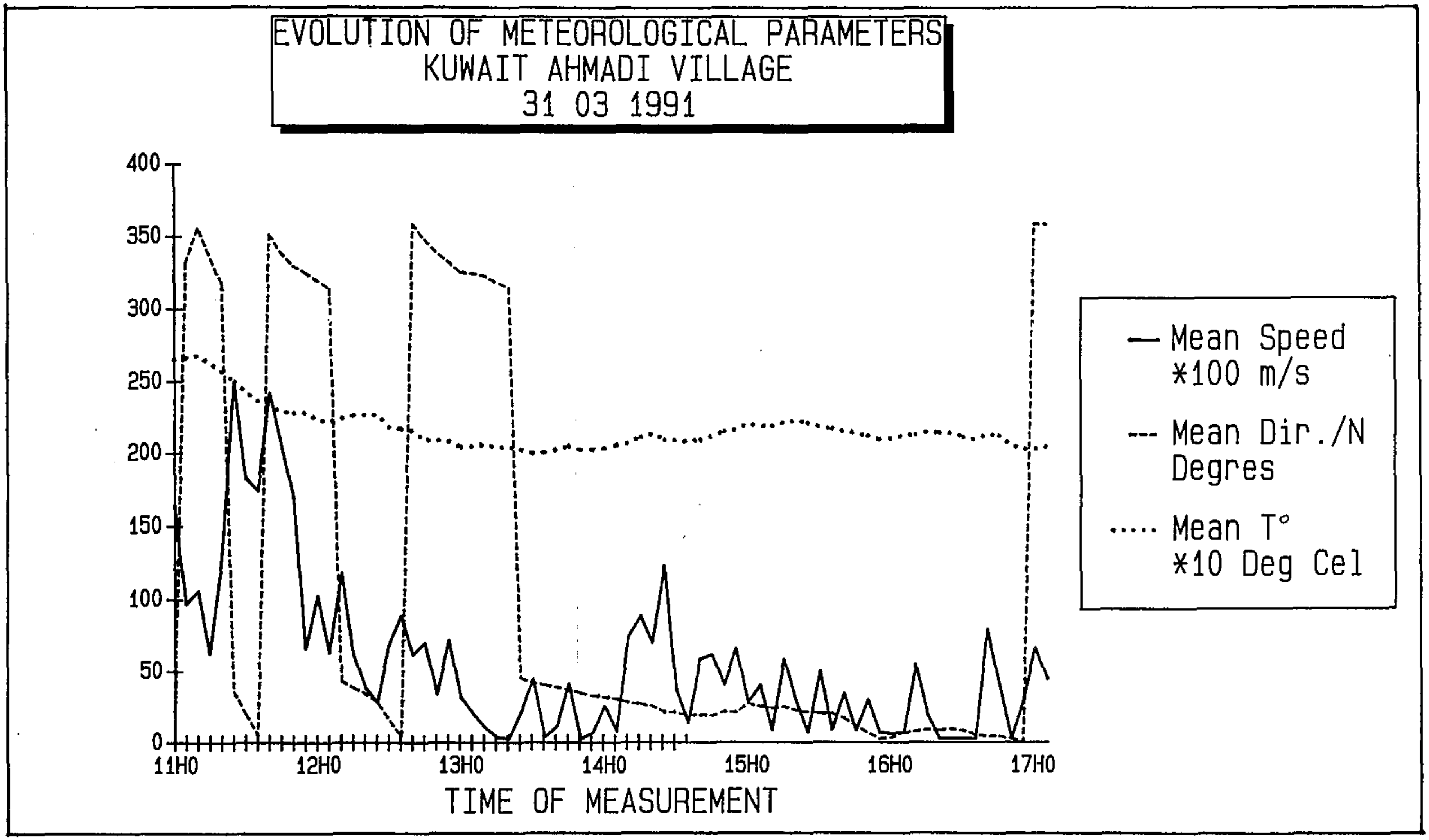
**Temporal evolution of measurements of meteorological parameters**

**Basic data integrated over 5 minutes**

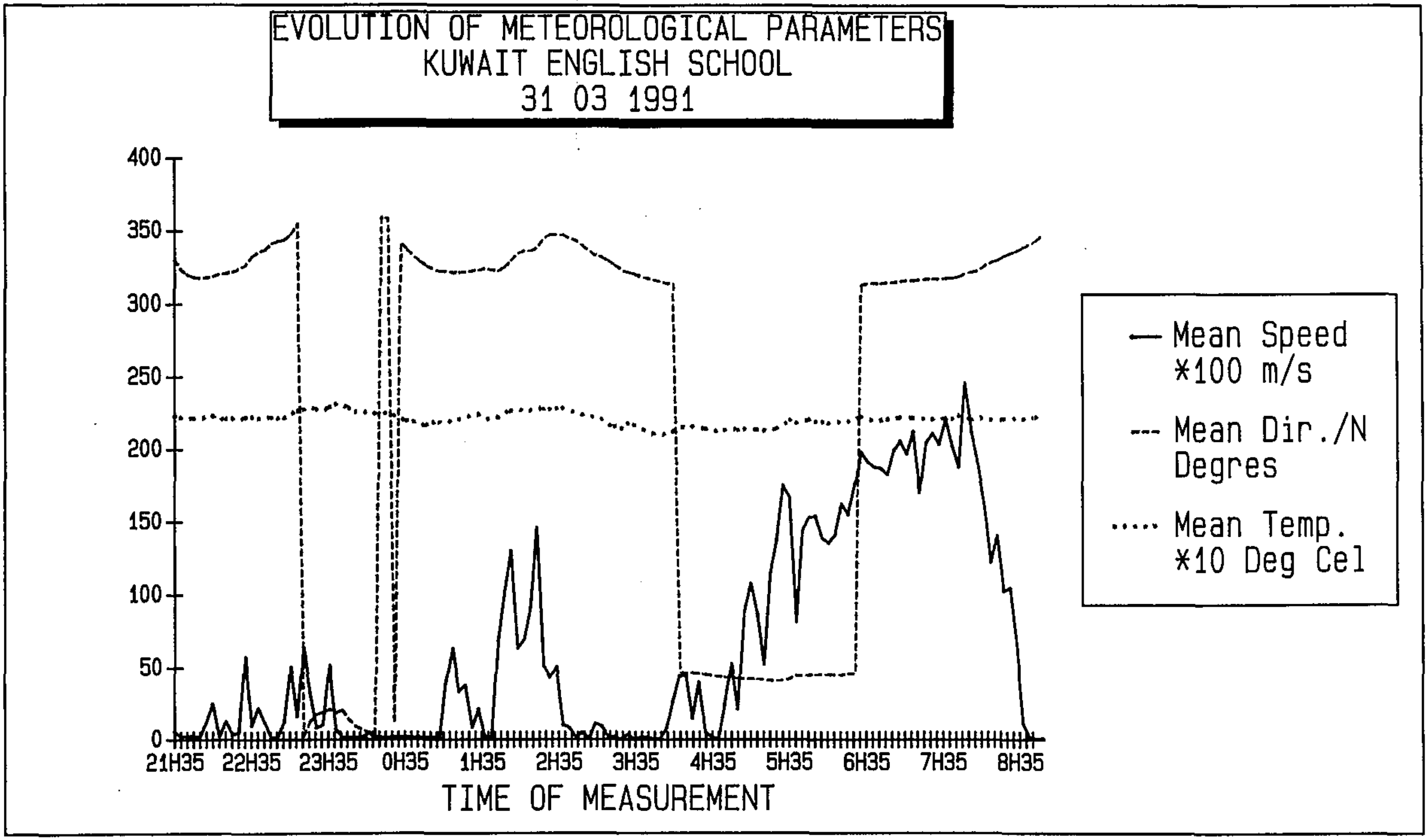

EVOLUTION OF METEOROLOGICAL PARAMETERS
KUWAIT CITY ENGLISH SCHOOL
28/29 03 1991
400
350
300
250
200
150
100
50
0
19H45
22H45
1H45
4H45
TIME OF MEASUREMENT
Mean Speed *100 m/s
Mean Dir./n Degres
Mean T° *10 Deg Cel


EVOLUTION OF METEOROLOGICAL PARAMETERS
KUWAIT MANSOURIYA
29 03 1991
400
350
300
250
200
150
100
50
0
11H35
12H35
13H35
14H35
15H35
16H35
TIME OF MEASUREMENT
Mean Speed *100 m/s
Mean Dir./n Degres
Mean T° *10 Deg Cel

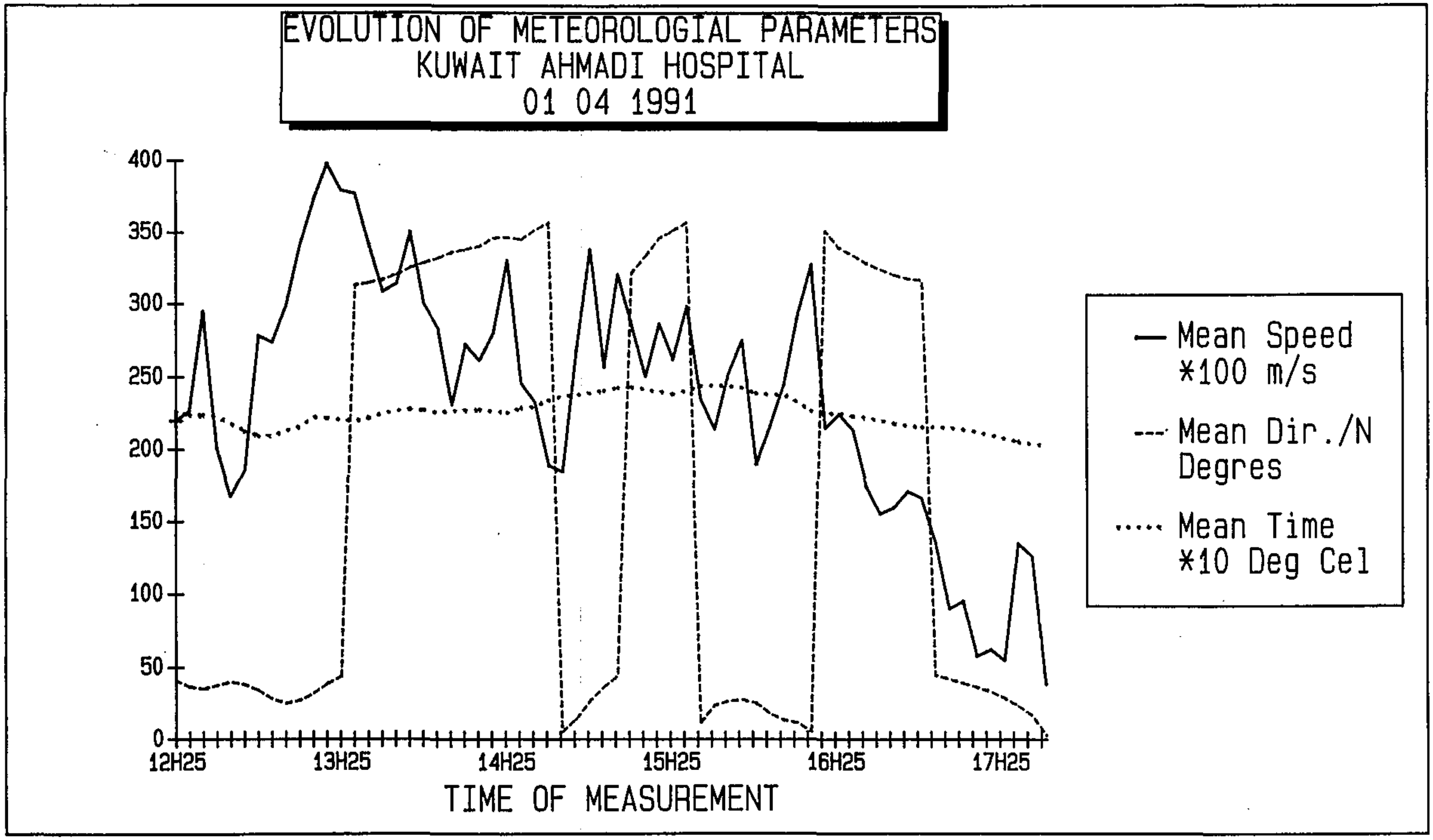

EVOLUTION OF METEOROLOGICAL PARAMETERS
KUWAIT ENGLISH SCHOOL
30 03 1991
400
350
300
250
200
150
100
50
0
20H25
21H25
22H25
23H25
0H25
1H25
2H25
3H25
4H25
5H25
6H25
7H25
TIME OF MEASUREMENT
Mean Speed *100 m/s
Mean Dir./N Degres
Mean Temp. *10 Deg Cel



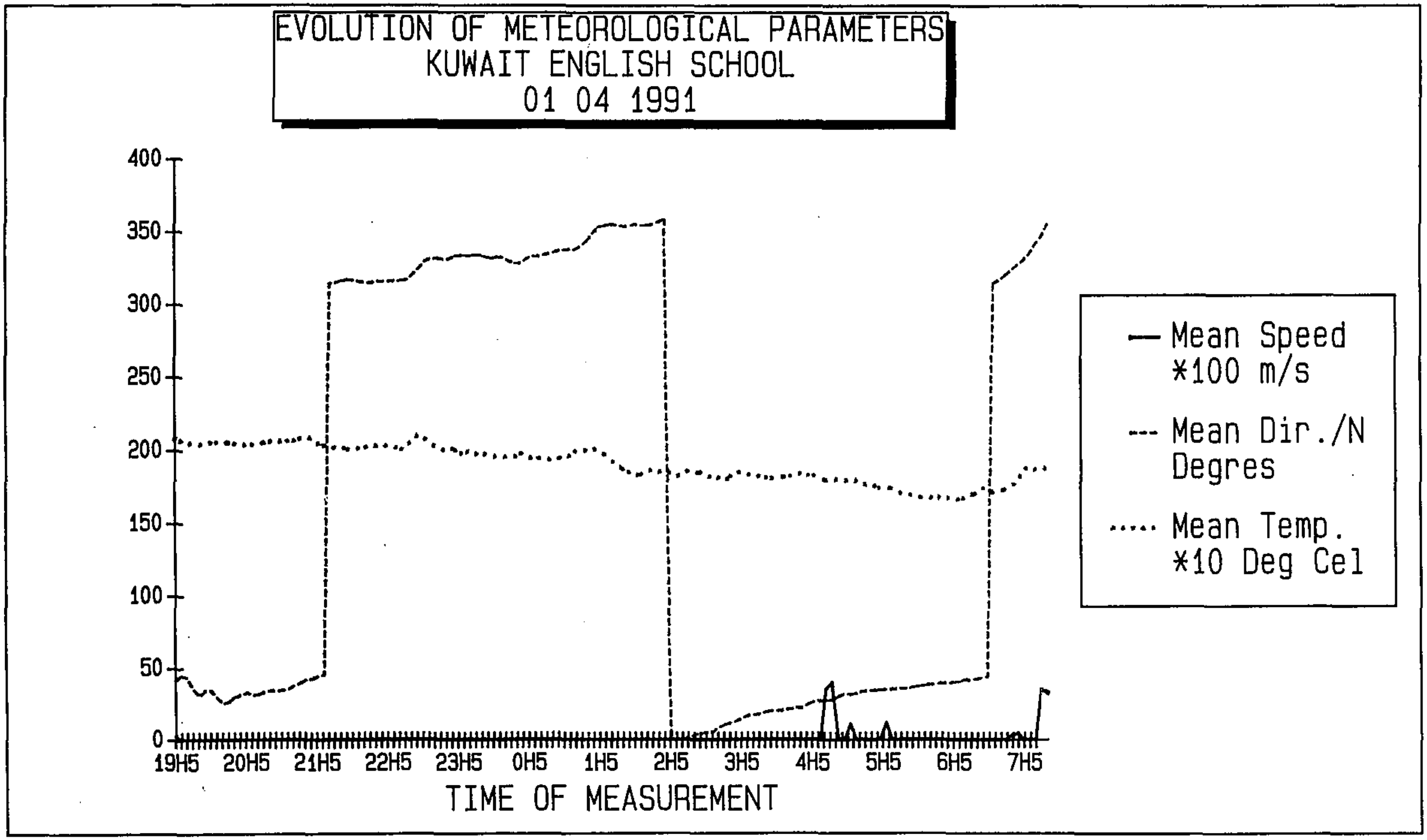
EVOLUTION OF METEOROLOGICAL PARAMETERS
KUWAIT AHMADI VILLAGE
31 03 1991
400
350
300
250
200
150
100
50
0
11H0
12H0
13H0
14H0
15H0
16H0
17H0
TIME OF MEASUREMENT
Mean Speed *100 m/s
Mean Dir./N Degres
Mean T° *10 Deg Cel



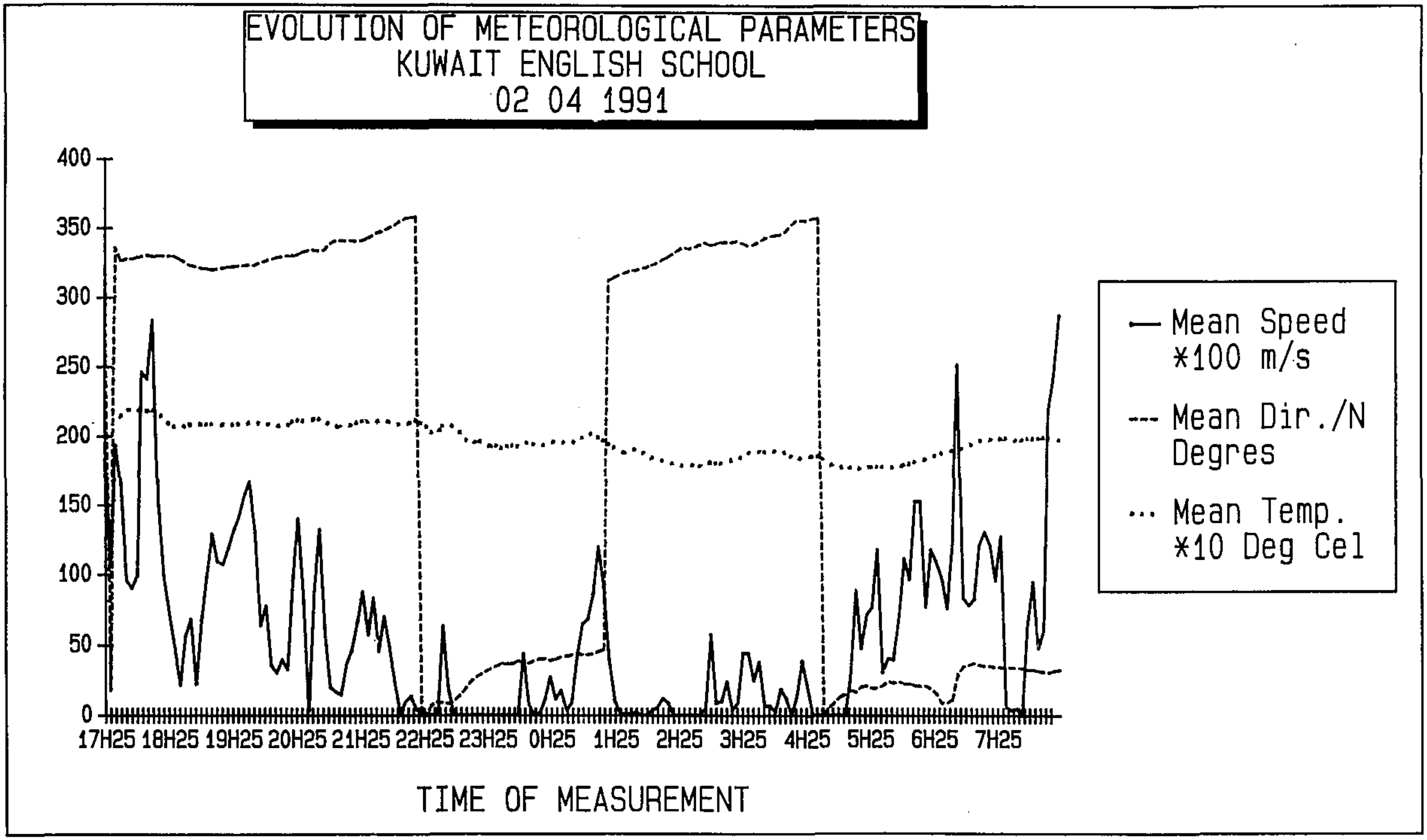
EVOLUTION OF METEOROLOGICAL PARAMETERS
KUWAIT ENGLISH SCHOOL
31 03 1991
400
350
300
250
200
150
100
50
0
21H35
22H35
23H35
0H35
1H35
2H35
3H35
4H35
5H35
6H35
7H35
8H35
TIME OF MEASUREMENT
Mean Speed *100 m/s
Mean Dir./N Degres
Mean Temp. *10 Deg Cel



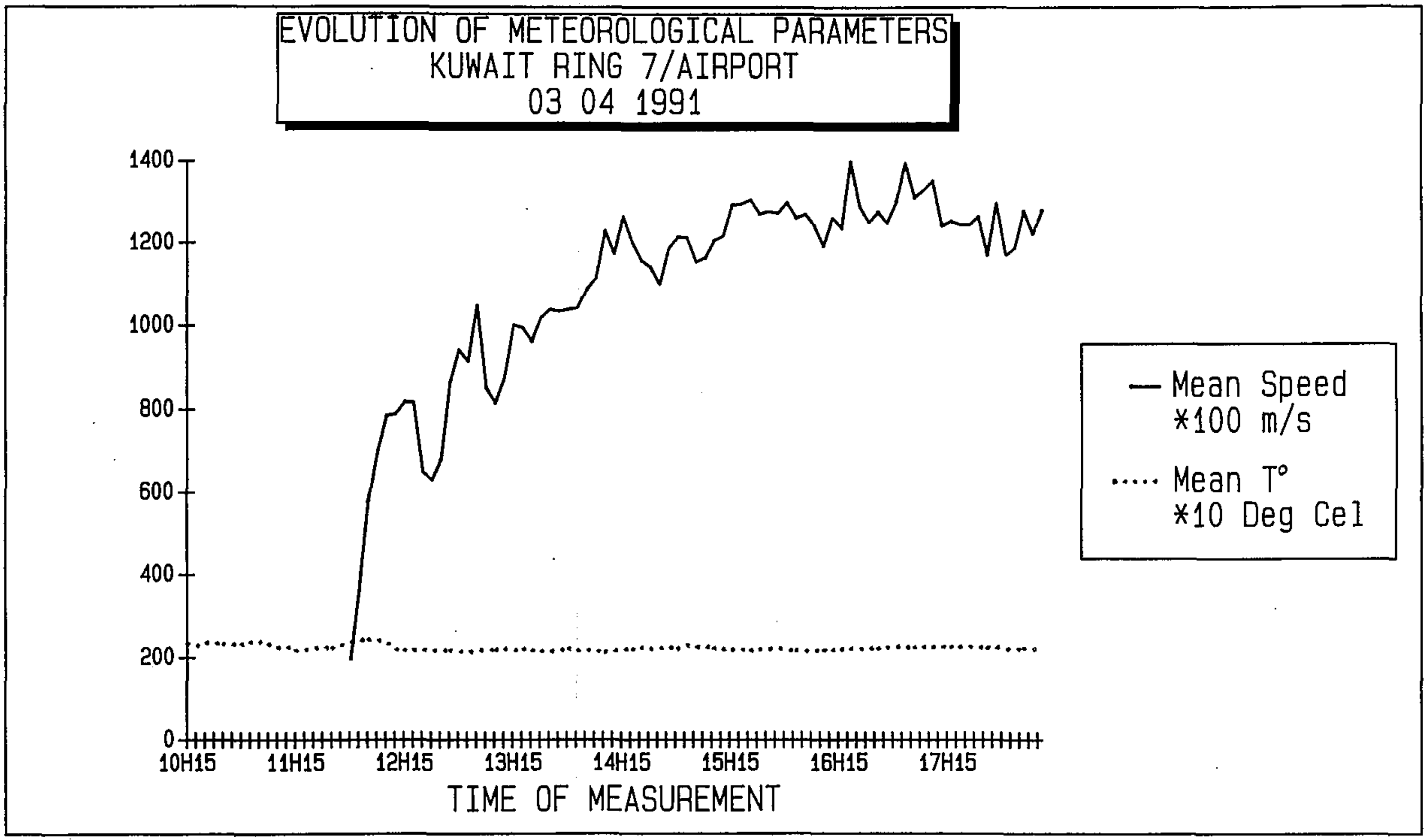
EVOLUTION OF METEOROLOGIAL PARAMETERS
KUWAIT AHMADI HOSPITAL
01 04 1991
400
350
300
250
200
150
100
50
0
12H25
13H25
14H25
15H25
16H25
17H25
TIME OF MEASUREMENT
Mean Speed *100 m/s
Mean Dir./N Degres
Mean Time *10 Deg Cel

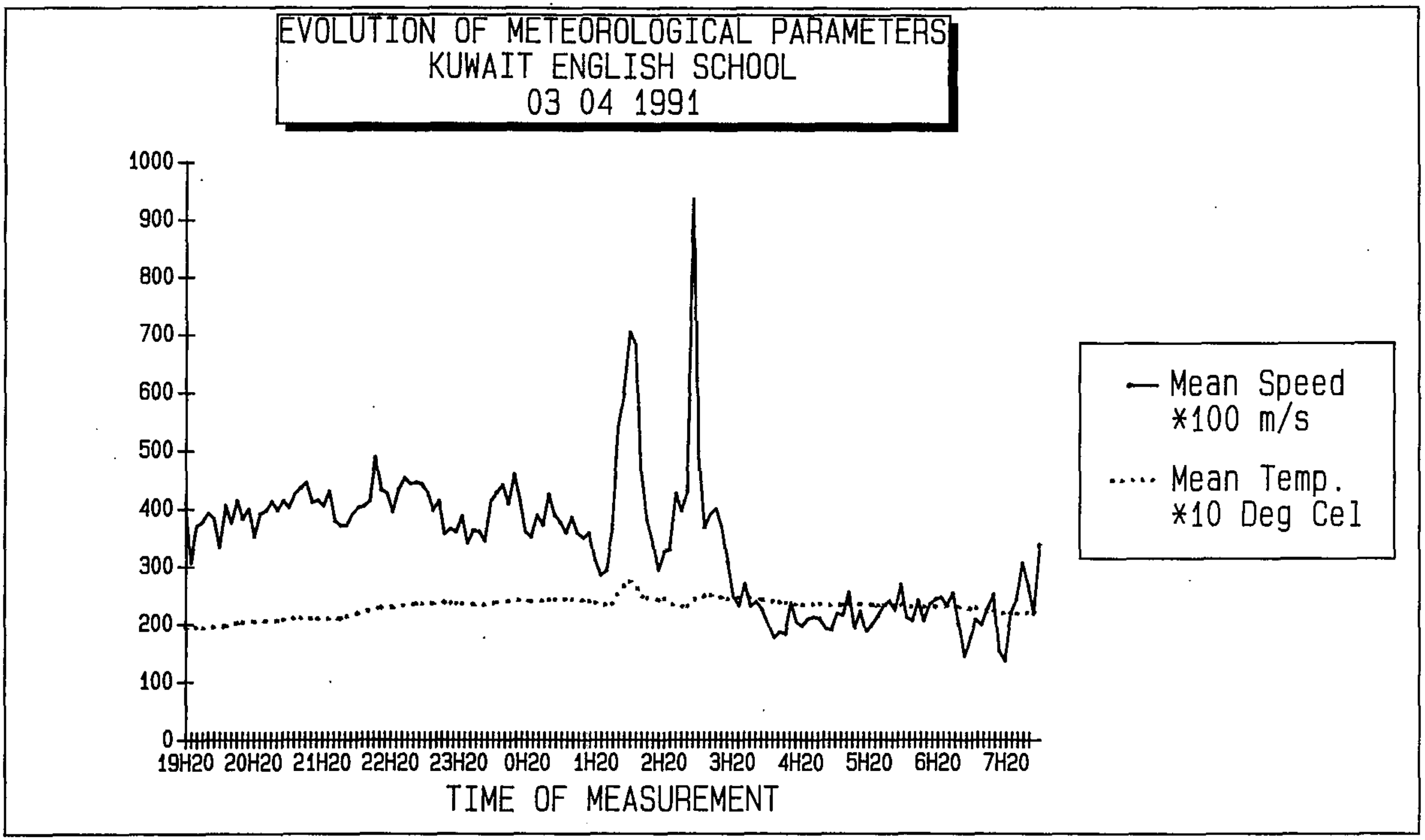


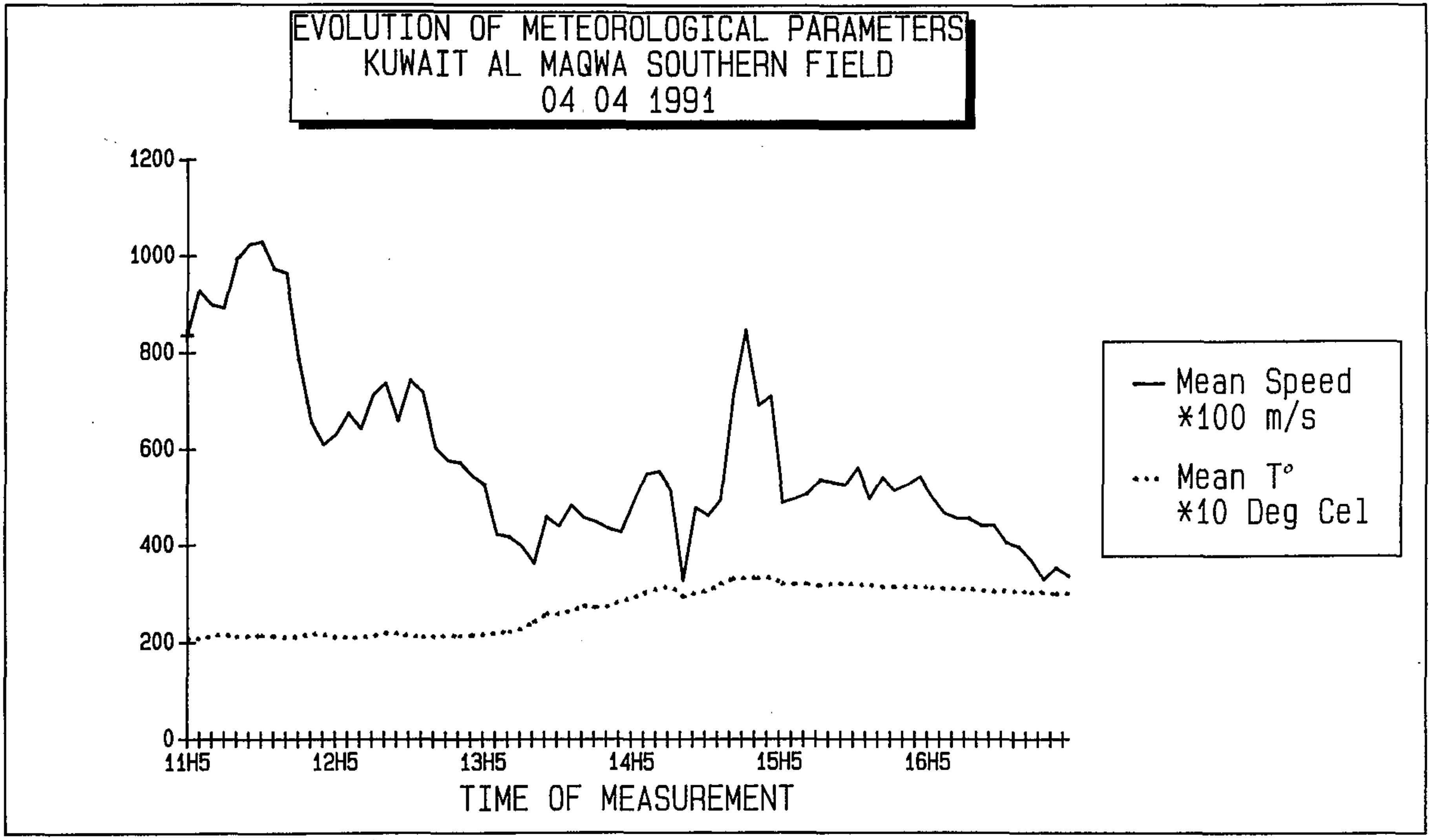
EVOLUTION OF METEOROLOGICAL PARAMETERS
KUWAIT ENGLISH SCHOOL
01 04 1991
400
350
300
250
200
150
100
50
0
19H5
20H5
21H5
22H5
23H5
0H5
1H5
2H5
3H5
4H5
5H5
6H5
7H5
TIME OF MEASUREMENT
Mean Speed *100 m/s
Mean Dir./N Degres
Mean Temp. *10 Deg Cel



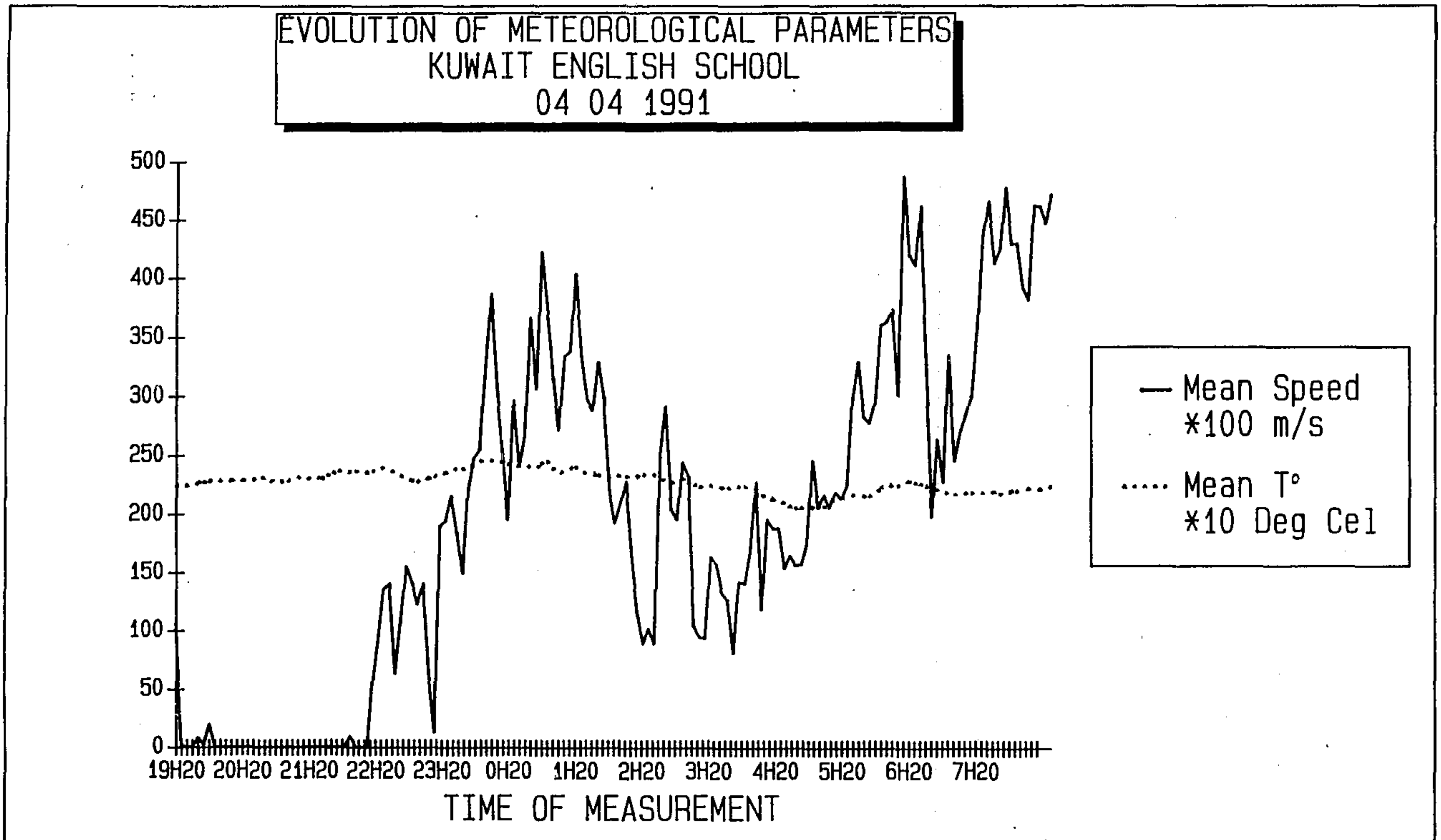
EVOLUTION OF METEOROLOGICAL PARAMETERS
KUWAIT ENGLISH SCHOOL
02 04 1991
400
350
300
250
200
150
100
50
0
17H25 18H25 19H25 20H25 21H25 22H25 23H25 0H25 1H25 2H25 3H25 4H25 5H25 6H25 7H25
TIME OF MEASUREMENT
Mean Speed *100 m/s
Mean Dir./N Degres
Mean Temp. *10 Deg Cel


EVOLUTION OF METEOROLOGICAL PARAMETERS
KUWAIT RING 7/AIRPORT
03 04 1991
1400
1200
1000
800
600
400
200
0
10H15
11H15
12H15
13H15
14H15
15H15
16H15
17H15
TIME OF MEASUREMENT
Mean Speed
*100 m/s
Mean T°
*10 Deg Cel


EVOLUTION OF METEOROLOGICAL PARAMETERS
KUWAIT ENGLISH SCHOOL
03 04 1991
1000
900
800
700
600
500
400
300
200
100
0
19H20 20H20 21H20 22H20 23H20 0H20 1H20 2H20 3H20 4H20 5H20 6H20 7H20
TIME OF MEASUREMENT
Mean Speed *100 m/s
Mean Temp. *10 Deg Cel



EVOLUTION OF METEOROLOGICAL PARAMETERS
KUWAIT AL MAQWA SOUTHERN FIELD
04 04 1991
1200
1000
800
600
400
200
0
11H5
12H5
13H5
14H5
15H5
16H5
TIME OF MEASUREMENT
Mean Speed
*100 m/s
Mean T°
*10 Deg Cel


EVOLUTION OF METEOROLOGICAL PARAMETERS
KUWAIT ENGLISH SCHOOL
04 04 1991
500
450
400
350
300
250
200
150
100
50
0
19H20 20H20 21H20 22H20 23H20 0H20 1H20 2H20 3H20 4H20 5H20 6H20 7H20
TIME OF MEASUREMENT
Mean Speed *100 m/s
Mean T° *10 Deg Cel

# *RESULTS OF THE MEASUREMENTS OF A*

| N of Campaign and map indicator() | PLACE | STARTING TIME AND DATE | ENDING TIME AND DATE | LENGHT | AVERAGE O3 | AVERAGE SO2 | AVERAGE CO | AVERAGE NO | AVERAGE NO2 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | KOWEIT CITY EPC (1/4Hourly) | 27/3/91 17HOO | 28/3/91 9H156 | 16H15 | 23 | X | 1587 | 77 | 54 |
| (2) 2 | KOWEIT CITY English school (1/4hourly) | 28/3/91 19H45 | 29/3/91 7HOO | 11H15 | 7 | 22 | 1635 | 30 | 10 |
| (3) 3 | KOWEIT CITY Mansouriya (5 Minutes) | 29/3/91 11H35 | 30/3/91 17H05 | 5H30 | 81 | 6 | 126 | 1 | 25 |
| (4) 4 | KOWEIT northern oil field | 30/3/91 14H05 | 30/3/91 17H15 | 3H10 | 96 | 269 | 127 | 1 | 16 |
| (2) 5 | KOWEIT CITY English School | 30/3/91 20H25 | 31/3/91 7H35 | 11H10 | 16 | 27 | 1758 | X | X |
| (5) 6 | KOWEIT SUD Ahmadi Village | 31/3/91 11H00 | 31/3/91 17H05 | 6H05 | 23 | 252 | 330 | X | X |
| (2) 7 | KOWEIT CITY English School | 31/3/91 21H35 | 1/4/91 8H45 | 11H10 | 15 | 79 | 1125 | X | X |
| (6) 8 | KOWEIT SUD Ahmadi Hospital | 1/4/91 12H25 | 1/4/91 17H40 | 5H15 | 38 | 56 | 500 | 3 | 35 |
| (2) 9 | KOWEIT CITY English School | 1/4/91 19H05 | 2/4/91 7H15 | 12H10 | 4 | 92 | 4813 | X | X |
| (2) 10 | KOWEIT CITY English School | 2/4/91 17H25 | 3/4/91 8H15 | 14H50 | 4 | 30 | 1299 | X | X |
| (7) 11 | KOWEIT south Ring 7 Aeroport | 3/4/91 10H15 | 3/4/91 18H05 | 7H50 | 86 | 495 | 16 | 4 | 33 |
| (2) 12 | KOWEIT CITY English School | 3/4/91 19H20 | 4/4/91 7H40 | 12H20 | 49 | 472 | 318 | X | X |
| (8) 13 | KOWEIT AL MAQWA southern oil field | 4/4/91 11H05 | 4/4/91 17H00 | 5H55 | 71 | 215 | 20 | 3 | 25 |
| (2) 14 | KOWEIT CITY English School | 4/4/91 19H20 | 5/4/91 8H15 | 12H55 | 44 | 55 | 1163 | X | X |
| MEAN OF ALL CAMPAIGNS | | | | | 40 | 159 | 1058 | 17 | 28 |
| MAXIMUM ON ALL CAMPAIGNS | | | | | 96 | 495 | 4813 | 77 | 54 |

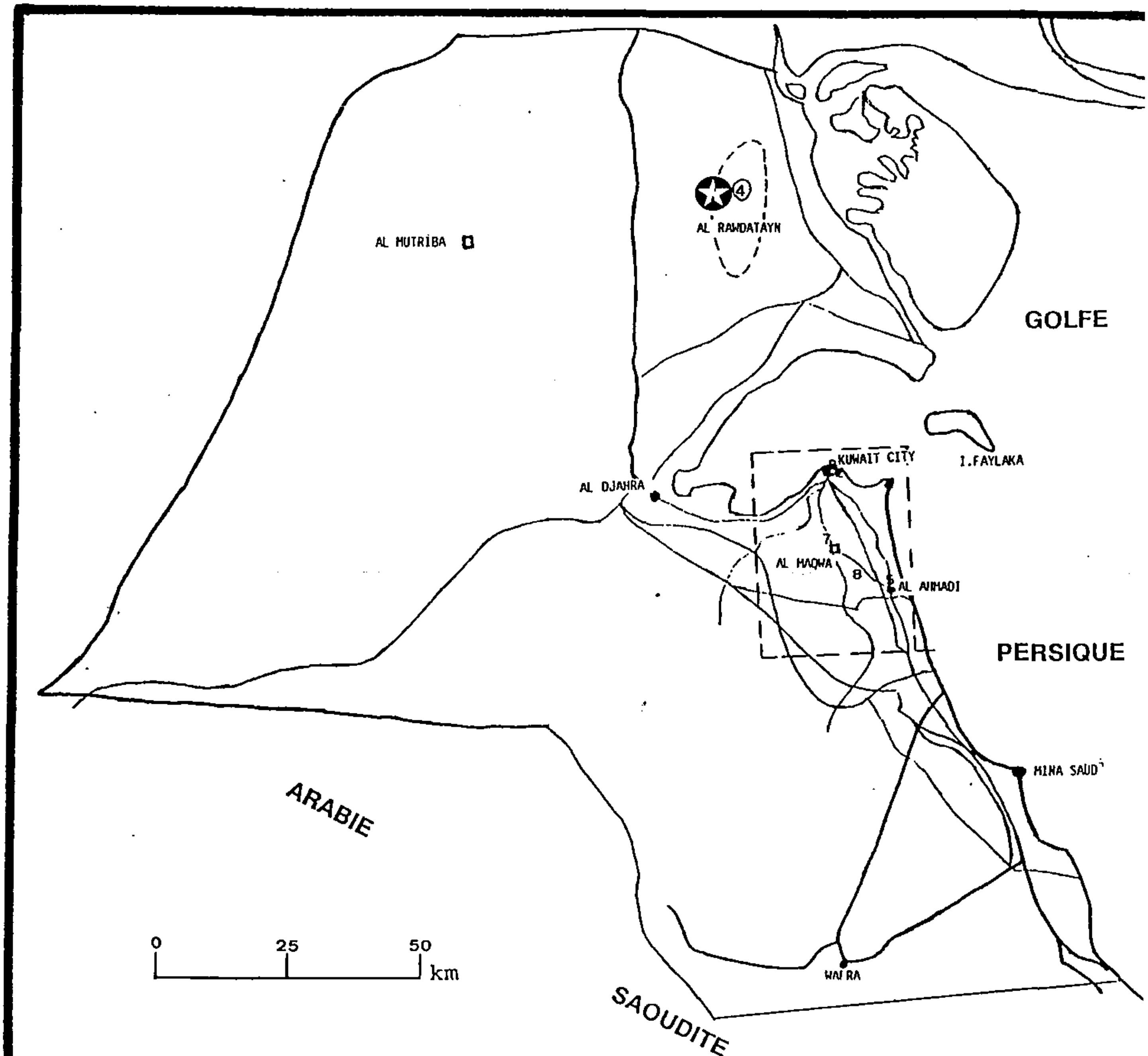
Results : Pollutants in microgrammes per cubic

| AVERAGE BS | MAXIMUM 5 Minutes O3 | MAXIMUM 5 Minutes SO2 | MAXIMUM 5 Minutes CO | MAXIMUM 5 Minutes NO | MAXIMUM 5 Minutes NO2 | MAXIMUM 1 Hour FN | AVERAGE WIND SPEED | OBSERVATIONS |
|---|---|---|---|---|---|---|---|---|
| X | 79 | X | 4234 | 227 | 94 | X | X | Day without pollution, no BS, no HC |
| 340 | 28 | 80 | 5027 | 167 | 69 | 1291 | 1,2 | BS no HC |
| 99 | 100 | 34 | 676 | 6 | 55 | 144 | 2 | Day without pollution HC and FN + PPA 60 |
| 265 | 110 | 1141 | 463 | 1 | 32 | 360 | 8,4 | in burning northern oil field. high win.ds. BS.VOC no weather data .Droeger CO2= 600 PPM OUher =0 |
| 163 | 58 | 199 | 7152 | X | X | 539 | 1 | HC and BS |
| 745 | 66 | 687 | 1885 | X | X | 1591 | 0,56 | underwind of southern field in the morning. noNO NO2 BS and HC.Droeger CO2=760 PPM other 0 |
| X | 58 | 199 | 7081 | X | X | X | 0,6 | HC, BS H.S |
| 206 | 66 | 206 | 1388 | 33 | 71 | 347 | 2,4 | No direct influence, except at the begining. well at 500m.BS,HC,PPA60 |
| 449 | 18 | 239 | 8576 | X | X | 984 | 0,1 | BS,HC |
| 198 | 29 | 138 | 7651 | X | X | 507 | 0,6 | morning cloud at altitude BS,HC |
| 595 | 126 | 1223 | 320 | 69 | 76 | 1365 | 11 | in the plume, but very hihg winds. BS,HC,HAP;PPA60 |
| 231 | 74 | 2911 | 747 | X | X | 792 | 3,4 | black cloud on ground. BS,HC |
| 818 | 107 | 1833 | 534 | 83 | 78 | 2030 | 5,8 | in the heart of the southern oil field, in the plume. BS,HC,PPA60 |
| X | 77 | 274 | 8576 | X | X | X | 2 | no BS HC |
| | | | | | | | | |
| 373 | 71 | 705 | 3879 | 84 | 68 | 904 | 3 | |
| 818 | 126 | 2911 | 8576 | 227 | 78 | 2030 | 11 | |

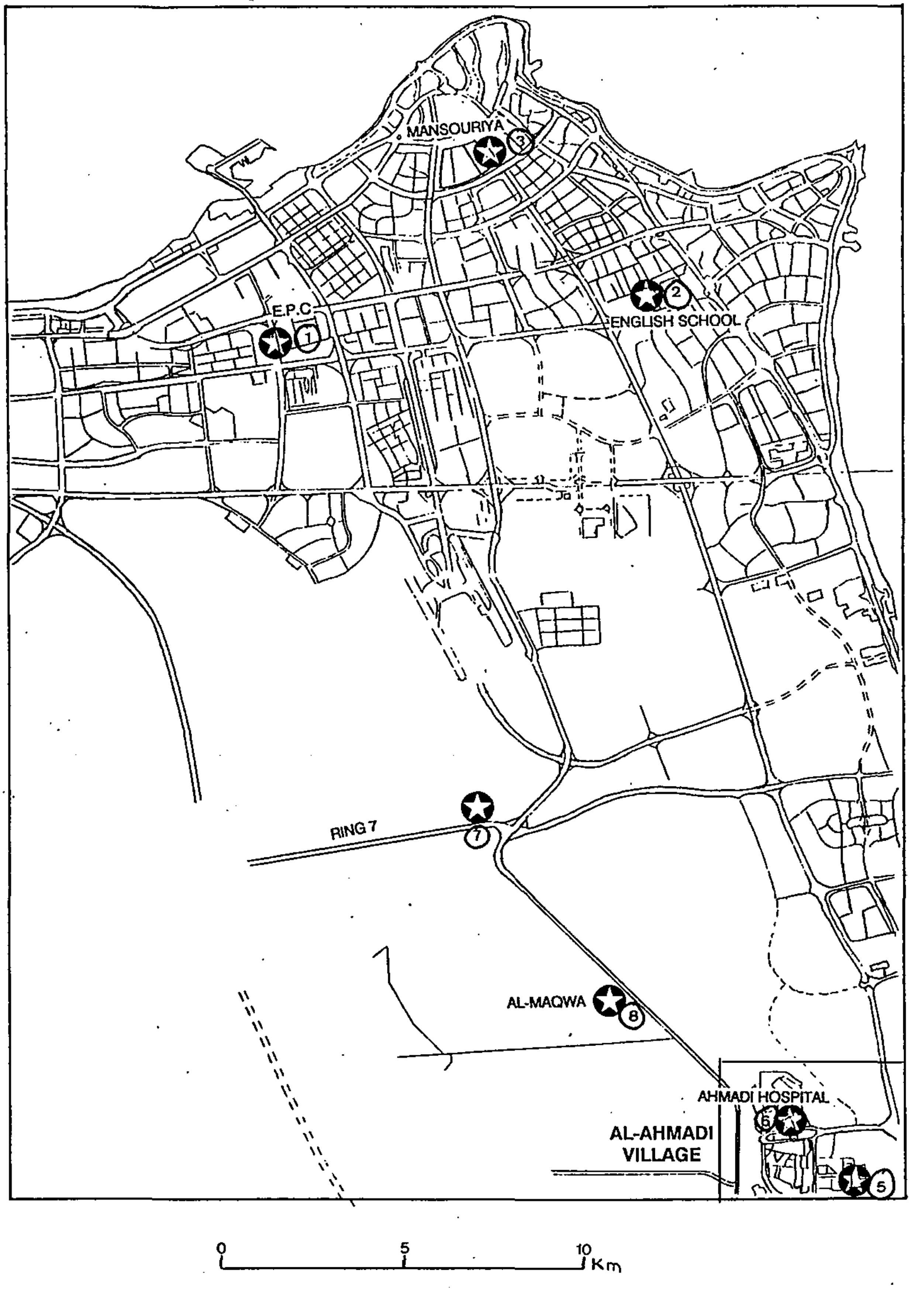
neter ; wind speed in meters per second

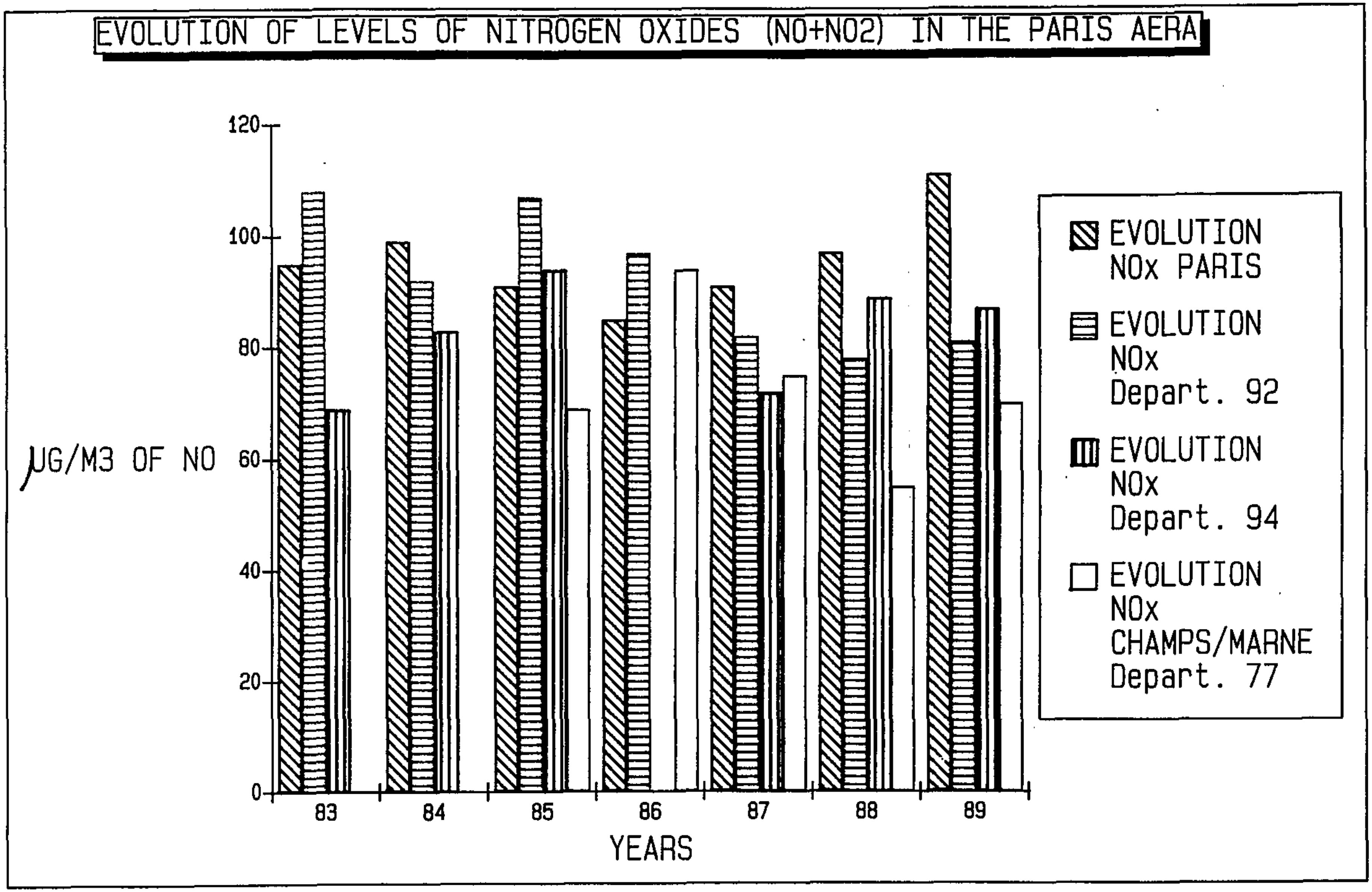
# *KUWAIT*

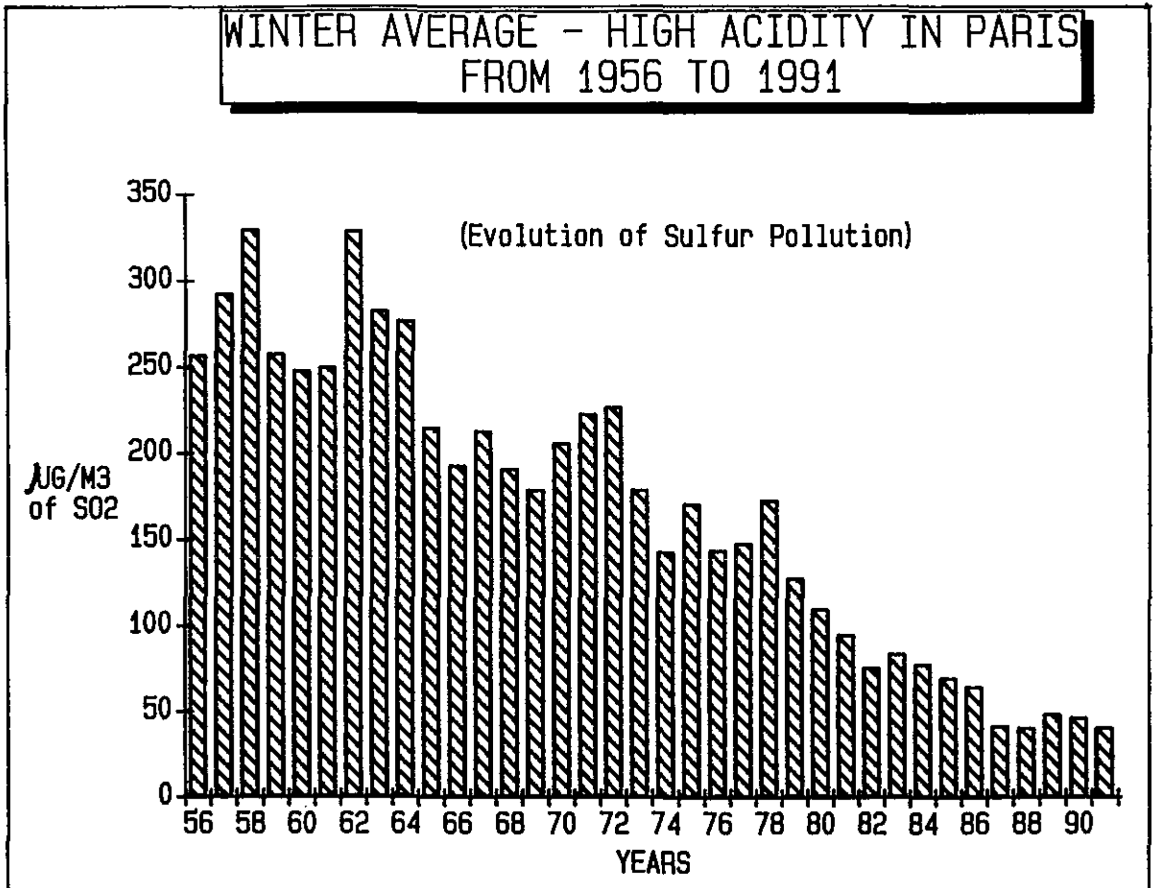
# *COUNTRY MAP*



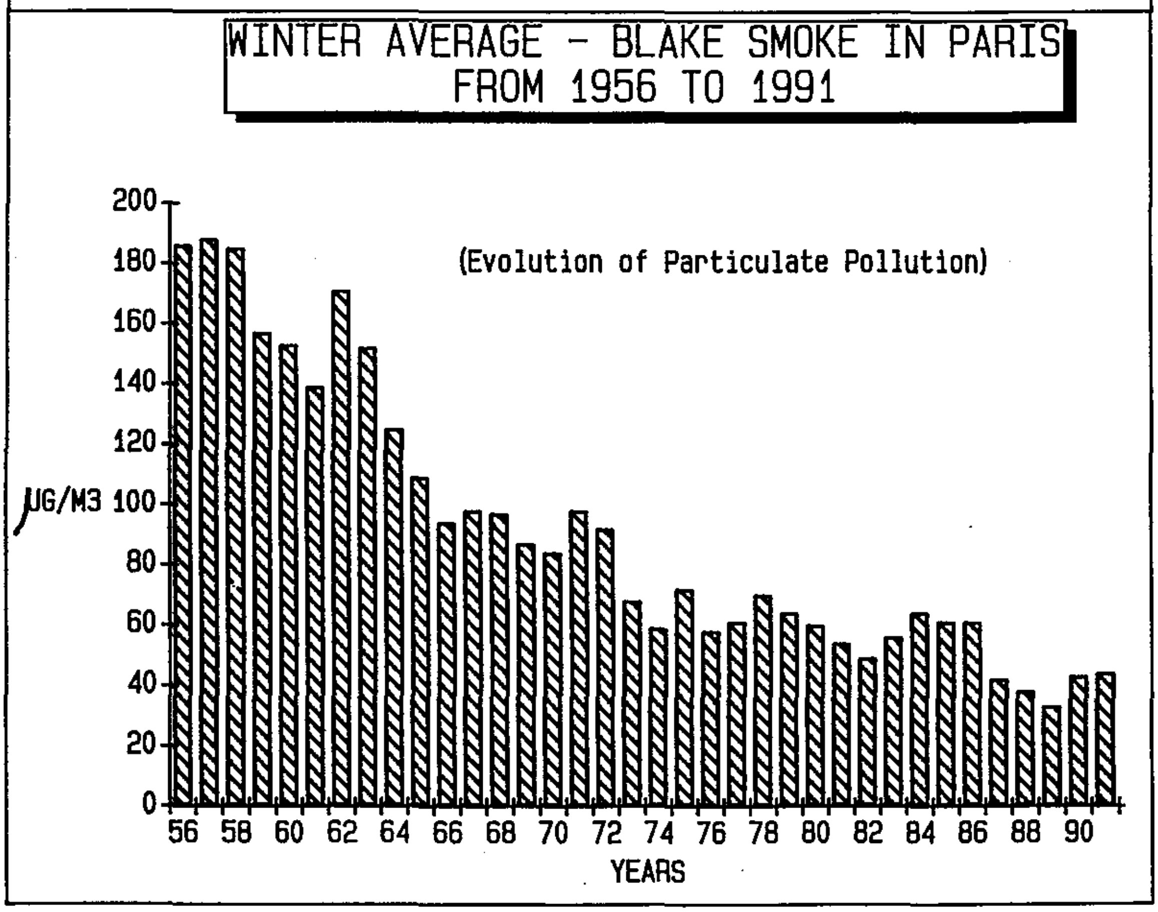
# KUWAIT CITY AND ENVIRONS
# DETAILED MAP




EVOLUTION OF LEVELS OF NITROGEN OXIDES (NO+NO2) IN THE PARIS AERA
µG/M3 OF NO
120
100
80
60
40
20
0
83
84
85
86
87
88
89
YEARS
EVOLUTION NOx PARIS
EVOLUTION NOx Depart. 92
EVOLUTION NOx Depart. 94
EVOLUTION NOx CHAMPS/MARNE Depart. 77



WINTER AVERAGE - HIGH ACIDITY IN PARIS
FROM 1956 TO 1991
(Evolution of Sulfur Pollution)
µG/M3
of SO2
350
300
250
200
150
100
50
0
56 58 60 62 64 66 68 70 72 74 76 78 80 82 84 86 88 90
YEARS

WINTER AVERAGE - BLAKE SMOKE IN PARIS
FROM 1956 TO 1991
(Evolution of Particulate Pollution)
µG/M3
200
180
160
140
120
100
80
60
40
20
0
56 58 60 62 64 66 68 70 72 74 76 78 80 82 84 86 88 90
YEARS

POLYCYCLIC AROMATIC HYDROCARBON (PAH) LEVELS OBSERVED IN CENTRAL PARIS ; SOURCE : " LABORATOIRE D'HYGIENE " OF CITY OF PARIS

Distribution of levels observed in Paris (LHVP site)
Winter period : from 11/02 to 20/03/1988

| HAP ng/m3 | P0,05 | MED | P0,95 | MOY | S | MAX | MIN |
|---|---|---|---|---|---|---|---|
| pyrène | 8,3 | 13,5 | 26,0 | 15,8 | 7,0 | 38,0 | 7,9 |
| fluoranthène | 10,7 | 17,5 | 33,0 | 20,4 | 8,7 | 49,2 | 10,0 |
| benzo (e) pyrène | 3,4 | 5,5 | 8,8 | 5,9 | 2,5 | 14,9 | 2,6 |
| benzo(b)fluoranthène | 4,2 | 8,3 | 13,2 | 8,9 | 4,0 | 23,6 | 4,2 |
| benzo(k)fluoranthène | 1,9 | 4,0 | 6,5 | 4,2 | 2,0 | 11,2 | 1,8 |
| benzo(a)pyrène | 1,4 | 3,6 | 8,0 | 4,6 | 3,4 | 17,6 | 0,8 |
| benzo(ghi)pérylène | 2,9 | 6,1 | 8,8 | 6,4 | 2,9 | 17,2 | 2,8 |
| indéno(1,2,3,c,d)pyrène | 1,5 | 3,0 | 4,7 | 3,3 | 1,6 | 9,2 | 1,5 |

Distribution of levels observed in Paris (LHVP site)
Autumn period : from 21/09 to 02/10/1987

| HAP ng/m3 | P0,05 | MED | P0,95 | MOY | S | MAX | MIN |
|---|---|---|---|---|---|---|---|
| pyrène | 4,6 | 7,4 | 14 | 8,2 | 3,1 | 17 | 4,5 |
| fluoranthène | 3,5 | 5,9 | 9,2 | 6,2 | 2,5 | 15 | 3,4 |
| benzo (e) pyrène | 0,35 | 1,2 | 2 | 1,1 | 0,6 | 2,8 | 0,3 |
| benzo(b)fluoranthène | 0,66 | 1,4 | 3,8 | 1,7 | 1 | 4,2 | 0,4 |
| benzo(k)fluoranthène | 0,25 | 0,54 | 1,5 | 0,67 | 0,4 | 1,8 | 0,1 |
| benzo(a)pyrène | 0,22 | 0,50 | 1,6 | 0,70 | 0,5 | 1,7 | 0,2 |
| benzo(ghi)pérylène | 0,78 | 1,1 | 3,2 | 1,8 | 2 | 12 | 0,8 |
| indéno(1,2,3,c,d)pyrène | 0,43 | 0,86 | 2,1 | 1,1 | 0,6 | 2,9 | 0,4 |

P 0,05 : valeur percentile 5, MED : valeur médiane, P0,95 : valeur percentile 95, MOY : valeur moyenne, S : écart type, MAX : valeur maximale, MIN : valeur minimale

LIMITS DEFINED BY THE DIRECTIVES RELATIVE TO AIR QUALITY
FOR COUNTRIES OF THE EUROPEAN ECONOMIC COMMUNITY

These values are considered to the limits defining acceptable air quality and must be not exceeded.

| Pollutants | Concentration in air (ug/m3) | Length of exposure | Observations |
|---|---|---|---|
| SULFURE DIOXIDE (S02) associated with suspended particules (PS) | S02 350<br>PS < 150<br>ou<br>S02 250<br>PS > 150 | 6 days per year<br><br><br>6 days per year | These levels are now very rarely exceeded in the Ile de France region, but may still be reached in industrial sectors. |
| | S02 180<br>PS < 60<br>ou<br>S02 130<br>PS > 60 | half of the days of the 6 month winter period<br><br>half of the days of the 6 month winter period | |
| | S02 120<br>PS < 40<br>ou<br>S02 80<br>PS > 40 | half of the days of the year<br><br>half of the days of the year | |
| NITROGEN DIOXIDE (N02) | 200 | 175 hours in the year | This level is exceeded in certains parts of the Paris area. |
| LEAD (Pb) | 2 | year | This level is not reached at any of the measuring sites of Paris. |

VALEURS GUIDES DE L ORGANISATION MONDIALE DE LA SANTE
EN MATIERE DE QUALITE DE L AIR

W.H.O AIR QUALITY GUIDELINES

**Below these exposure levels, no effect on health has been demonstrated.**

| Substance | NIVEAU D EXPOSITION<br>EXPOSURE LEVEL | DUREE D EXPOSITION<br>EXPOSURE TIME |
|---|---|---|
| Cadmium | 1- 5 ng/m$^3$ | 1 year (rural areas) |
| | 10-20 ng/m$^3$ | 1 year (urban areas) |
| Carbon disulfide | 100 $\mu$g/m$^3$ | 24 hours |
| Carbon monoxide | 100 mg/m$^3$ | 15 minutes |
| | 60 mg/m$^3$ | 30 minutes |
| | 30 mg/m$^3$ | 1 hour |
| | 10 mg/m$^3$ | 8 hours |
| 1,2-Dichloroethane | 0 7 mg/m$^3$ | 24 hours |
| Dichloromethane (Methylene chloride) | 3 mg/m$^3$ | 24 hours |
| Formaldehyde | 100 $\mu$g/m$^3$ | 30 minutes |
| Hydrogen sulfide | 150 $\mu$g/m$^3$ | 24 hours |
| Lead | 0.5-1.0 $\mu$g/m$^3$ | 1 year |
| Manganese | 1 $\mu$g/m$^3$ | 1 year [c] |
| Mercury | 1 $\mu$g/m$^3$ [d] (indoor air) | 1 year |
| Nitrogen dioxide | 400 $\mu$g/m$^3$ | 1 hour |
| | 150 $\mu$g/m$^3$ | 24 hours |
| Ozone | 150-200 $\mu$g/m$^3$ | 1 hour |
| | 100-120 $\mu$g/m$^3$ | 8 hours |
| Styrene | 800 $\mu$g/m$^3$ | 24 hours |
| Sulfur dioxide | 500 $\mu$g/m$^3$ | 10 minutes |
| | 350 $\mu$g/m$^3$ | 1 hour |
| Sulfuric acid | — [e] | — |
| Tetrachloroethylene | 5 mg/m$^3$ | 24 hours |
| Toluene | 8 mg/m$^3$ | 24 hours |
| Trichloroethylene | 1 mg/m$^3$ | 24 hours |
| Vanadium | 1 $\mu$g/m$^3$ | 24 hours |

**List of persons encountered in the course of the Air Quality measurement campaign carried out by AIRPARIF in Kuwait from 27 March to 4 April 1991.**

- **IBRAHIM M HADI : Secretary of the Environment Protection Council**

Director of the Environment Protection Departenement
Ministry of Public Health
P O BOX 24395 SAFAT KUWAIT

TEL : 2456835 / 2456836
FAX : 2421993

- **DR MOSTAFA EL-DESOUKY : Technical Advisor**

Ministry of Public Health
P O BOX 35035 AL-SHAAB KUWAIT

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FAX : 2421993

- **NABEEL M AL-KULAIFI : Geological Technician**

Environment Protection Departenement ; Air Pollution Part ;
Organic Chemistery

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P O BOX 35035 AL-SHAAB KUWAIT

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-**DR DANIEL TARANTOLA : World Health Organisation**

W.H.O Headquarters
Avenue APPIA 1211- GENEVA 27-CH

TEL : 7912706 / 7912111
FAX : 7910746

# KUWAIT STUDY

## 27 March to 4 April 1991

*ANNEX VI*

Results of analyses of light hydrocarbon,

polycyclic hydrocarbon and metals samples carried out by the

"Laboratoire d'Hygiène" of the City of Paris and French Institut of Petroleum

PRELIMINARY RESULTS OF MEASUREMENTS OF GASEOUS HYDROCARBONS(HC) AND POLYCYCLIC AROMATIC HYDROCARBONS CARRIED OUT BY THE "LABORATOIRE D'HYGIENE" OF THE CITY OF PARIS ON SAMPLES TAKEN IN KUWAIT DURING THE AIRPARIF MEASUREMENT CAMPAIGN

## I - METHODOLOGY

### Gaseous hydrocarbons (HC)

Te samples are taken by absorption on activated charcoal of plant origin (SKC,m = 150 mg).
The volumes of air sampled generally vary from 300 to 800 liters of air according to sampling.
The HC's are desorbed by carbon disulfide (2 ml) later subjected to chromatographic analyses.
The compounds are separated with the aid of a high resolution capillary column (L = 50m, d = 0,32mm phase methyl silicone) and detected by flame ionization (quantitative aspect) or by mass detection (qualitative aspect). The compounds were identified by mass sweeping in the field 33 to 450 ums in electronic impact mode.

### 1/ Polycyclic aromatic hydrocarbons

The level of polycyclic aromatic hydrocarbons (PAH) of the particulate phase was estimated from particles sampled on a cellulose filter (Whatman n° 1) on the basis of the black smoke index. 1 to 3 m3 of air was sampled for the samples analyzed. The PAH are extracted and analyzed following the recommendations of the standard AFNOR N° X 43-025. After ultrasonication of the filters by dichloromethane, the analyses are made by high performance liquid chromatography (HPLC) with detection by fluorescent emissions.

### 2/ Métals

The atmospheric particles sampled on cellulose nitrate filters (Satorius-SM 11305 d = 47 mm) are subjected to mineralisation by nitric acid, in a teflon spray.
The metallic elements are measured bu atomic absorption spectrophotometry with electrothermal atomization (no results available at present).

# RESULTS OF THE MEASUREMENTS OF A

## VOLATILE ORGANIC COMP

| N of Campaign and map indicator ( ) | PLACE | STARTING TIME AND DATE | ENDING TIME AND DATE | LENGTH OF TIME | AVERAGE HEPTANE | AVERAGE OCTANE | AVERAGE NONANE | AVERAGE DECANE | AVERAGE UNDECANE |
|---|---|---|---|---|---|---|---|---|---|
| (3) 3 | KOWEIT CITY Mansouriya (5 Minutes) | 29/3/91 11H35 | 30/3/91 17H05 | 5H30 | 4 | 2,3 | 1,7 | 2,8 | 2,6 |
| (2) 5 | KOWEIT CITY English School | 30/3/91 20H25 | 31/3/91 7H35 | 11H10 | 9,6 | 7,7 | 7 | 9,6 | 7,6 |
| (5) 6 | KOWEIT SUD Ahmadi Village | 31/3/91 11H00 | 31/3/91 17H05 | 6H05 | 57,8 | 43,9 | 38 | 31,2 | 19,4 |
| (2) 7 | KOWEIT CITY English School | 31/3/91 21H35 | 1/4/91 8H45 | 11H10 | 27,6 | 26,4 | 22,8 | 26,2 | 17,7 |
| (6) 8 | KOWEIT SUD Ahmadi Hopital | 1/4/91 12H25 | 1/4/91 17H40 | 5H15 | 9,5 | 6,7 | 5,1 | 6,7 | 4,9 |
| (2) 9 | KOWEIT CITY English School | 1/4/91 19H05 | 2/4/91 7H15 | 12H10 | 27,6 | 23,3 | 21,4 | 29,3 | 20,6 |
| (2) 10 | KOWEIT CITY English School | 2/4/91 17H25 | 3/4/91 8H15 | 14H50 | 7,5 | 5,3 | 7,1 | 13,3 | 10,7 |
| (7) 11 | KOWEIT SUD Ring 7 Airport | 3/4/91 10H15 | 3/4/91 18H05 | 7H50 | 40,4 | 51,6 | 55 | 58,6 | 44,4 |
| (2) 12 | KOWEIT CITY English School | 3/4/91 19H20 | 4/4/91 7H40 | 12H20 | 2,8 | 3,8 | 5,2 | 10,7 | 7,6 |
| (8) 13 | KOWEIT SUD AL MAQWA southern field | 4/4/91 11H05 | 4/4/91 17H00 | 5H55 | 15 | 17,7 | 22,5 | 35,7 | 41,5 |
| (2) 14 | KOWEIT CITY English School | 4/4/91 19H20 | 5/4/91 8H15 | 12H55 | 3,1 | 1,9 | 2,3 | 5,9 | 4 |
| | | | | | | | | | |
| MOYENNE DE L'ENSEMBLE DES CAMPAGNES | | | | | 18,6 | 17,3 | 17,1 | 20,9 | 16,4 |
| MAXIMUM SUR L'ENSEMBLE DES CAMPAGNES | | | | | 57,8 | 51,6 | 38 | 58,6 | 44,4 |

## ATMOSPHERIC POLLUTION IN KUWAIT

### POUNDS (in µg/m3)

| AVERAGE DODECANE | AVERAGE TRIDECANE | AVERAGE BENZENE | AVERAGE TOLUENE | AVERAGE ETHYLBENZENE | AVERAGE m+p XYLENE | AVERAGE o XYLENE | AVERAGE 1,2,4 TRIMETHYLBENZENE |
|---|---|---|---|---|---|---|---|
| 1,5 | 1,2 | 7,6 | 9,6 | 3,4 | 10,8 | 3,7 | 3,1 |
| 5,2 | 3,7 | 5,3 | 18,1 | 6,9 | 23,6 | 8,2 | 10,1 |
| 14,5 | 11 | 9,2 | 21,2 | 9,2 | 14,7 | 35,8 | 13,3 |
| 12,3 | 9 | 4,1 | 15.3 | 6,5 | 32,2 | 12,9 | 13,7 |
| 4,3 | 3,8 | 6,2 | 11,8 | 4,3 | 9 | 5,5 | 6,4 |
| 14,1 | 9,4 | 11,9 | 46,7 | 16,2 | 64 | 21,2 | 27,2 |
| 9,5 | 8,2 | 3,2 | 21,5 | 5 | 19 | 7,3 | 8,5 |
| 21,8 | 13,1 | 4 | 13,6 | 7,8 | 10 | 20,2 | 22,6 |
| 6,3 | 5,4 | 1,9 | 2,9 | 1,4 | 2,1 | 0,9 | 3,4 |
| 3,5 | 24,7 | 5,5 | 6,4 | 3,3 | 5,5 | 3,8 | 12,8 |
| 3,8 | 3,2 | 3,6 | 14,6 | 3,5 | 12,3 | 3,8 | 4,9 |
| | | | | | | | |
| 8.8 | 8,4 | 5,7 | 16.5 | 6,1 | 18,5 | 11,2 | 11,4 |
| 21,8 | 24,7 | 11,9 | 46.7 | 16,2 | 64 | 35,8 | 27,2 |

# RESULTS OF THE MEASUREMENTS OF

## AROMATIC POLYCYCLIC HY

*Samplings (cellulose support) analyse*

*High performance liqu*

*detection by f*

| N of Campaign and map indicator ( ) | PLACE | SARTING TIME AND DATE | ENDING TIME AND DATE | LENGHT OF DATE | AVERAGE ug/m3 SUSPENDED PARTICULES | VOLUME m3 | AVERAGE FLUORANTHENE | AVERAGE ANTHRACENE | A |
|---|---|---|---|---|---|---|---|---|---|
| (4) 4 | KOWEIT Northern Field | 30/3/91 14H00 | 30/3/91 15H00 | 1H00 | 360 | 1,091 | 7,9 | 4,3 | |
| (5) 6 | KOWEIT SUD Ahmadi Village | 31/3/91 14H00 | 31/3/91 15H00 | 1H00 | 827 | 0,938 | 9,0 | | |
| (6) 8 | KOWEIT SUD Ahmadi Hopital | 1/4/91 13H00 | 1/4/91 14H00 | 1H00 | 288 | 1,084 | 8,3 | | |
| (2) 9 | KOWEIT CITY English School | 1/4/91 23H00 | 1/4/91 24H00 | 1H00 | 109 | 1,084 | 7,6 | | |
| (2) 9 | KOWEIT CITY English School | 2/4/91 2H00 | 1/4/91 3H00 | 1H00 | 936 | 1,084 | 12,1 | | |
| (2) 10 | KOWEIT CITY English School | 3/4/91 1H00 | 3/4/91 2H00 | 1H00 | 507 | 1,171 | 17,4 | | |
| (2) 10 | KOWEIT CITY English School | 3/4/91 4H00 | 3/4/91 5H00 | 1H00 | 202 | 1,171 | 9,1 | 7,2 | |
| (7) 11 | KOWEIT SUD Ring 7 Airport | 3/4/91 17H00 | 3/4/91 18H00 | 1H00 | 1151 | 1,028 | 8,4 | | |
| (2) 12 | KOWEIT CITY English School | 3/4/91 23H00 | 4/4/91 00H00 | 1H00 | 185 | 1,171 | 5,2 | 2,6 | |
| (2) 12 | KOWEIT CITY English School | 4/4/91 6H00 | 4/4/91 7H00 | 1H00 | 638 | 1,171 | 8,9 | 3,4 | |
| (8) 13 | KOWEIT SUD AL MAQWA south field | 4/4/91 15H00 | 4/4/91 16H00 | 1H00 | 494 | 0,946 | 9,9 | | |
| MEAN OF ALL CAMPAIGNS | | | | | 518 | - | 9,4 | 4,4 | |
| MAXIMUM ON ALL CAMPAIGNS | | | | | 1151 | | 17,4 | 7,2 | |

## 'F ATMOSPHERIC POLLUTION IN KUWAIT

### IYDROCARBONS (in ng/m3)

lysed by French Institut of Petroleum

liquid chromatography

y fluorescence

| AVERAGE BENZO (a) ANTHRACENE | AVERAGE PYRENE | AVERAGE BENZO (b) FLUORANTHENE | AVERAGE BENZO (k) FLUORANTHENE | AVERAGE BENZO (a) PYRENE | AVERAGE DIBENZO (a,h) ANTHRACENE | AVERAGE BENZO (ghi) PERYLENE | AVERAGE INDENO PYRENE |
|---|---|---|---|---|---|---|---|
| 1.0 | 8,5 | 1,3 | 0,01 | 1,6 | 1,3 | 1,3 | 3,1 |
| 2,5 | | 6,1 | 2,0 | 3,8 | 6,2 | 23,1 | 40.0 |
| 2,6 | 9,6 | 3,7 | 1,4 | 2,7 | 3,0 | 8,0 | 11.2 |
| 1,6 | 7,1 | 4,3 | 1,4 | 3,9 | 4,1 | 9,7 | 11.4 |
| 4,2 | 10,2 | 7,5 | 2,9 | 6,0 | 9,2 | 10,7 | 13.3 |
| 5,4 | 12,7 | 9,6 | 4,5 | 5,7 | 15,4 | 23,5 | |
| | 9,3 | 3,2 | 1,3 | 2,3 | 3,8 | 2,9 | 11,9 |
| 1,6 | 6,3 | 3,95 | 1,7 | 4,0 | 4,3 | 2,1 | 4.6 |
| 1,6 | 6,3 | 1,4 | 0,7 | 0,9 | 1,4 | 4,2 | 8.5 |
| 0,7 | 4,9 | 2,7 | 1,8 | 1,7 | 4,2 | 5,3 | 6.4 |
| 3,7 | 8,6 | 4,8 | 2,2 | 3,9 | 6,2 | 1,3 | 9,2 |
| 2,5 | 8,4 | 4,4 | 1,8 | 3,3 | 5,4 | 8,4 | 12 |
| 5,4 | 12,7 | 9,6 | 4,5 | 6,0 | 15,4 | 23,5 | 40,0 |

# *RESULTS OF THE MEASUREMENTS OF ATMOSPHERIC POLLUTION IN KUWAIT*

## *AROMATIC POLYCYCLIC HYDROCARBONS (in ng/m3)*

*Samplings analysed by LHVP*

| N of Campaign and map indicator ( ) | PLACE | STARTING TIME AND DATE | ENDING TIME AND DATE | LENGHT OF TIME | AVERAGE FLUORANTHENE | AVERAGE BENZO (a) ANTHRACENE | AVERAGE BENZO (e) PYRENE | AVERAGE BENZO (b) FLUORANTHENE | AVERAGE BENZO (k) FLUORANTHENE | AVERAGE BENZO (a) PYRENE | AVERAGE DIBENZO (a,h) ANTHRACENE | AVERAGE BENZO (ghi) PERYLENE | AVERAGE INDENO (1,2,3,c,d) PYRENE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (2) 2 | KOWEIT CITY English school (1/4 hourly) | 28/3/91 23H00 | 29/3/91 1H00 | 2H | 24 | 1,4 | 9,3 | 7,4 | 3,6 | 4,9 | 0,4 | 8,3 | 15 |
| (5) 6 | KOWEIT South Ahmadi Village | 31/3/91 11H00 | 31/3/91 13H00 | 2H | 30 | 1,9 | 17 | 13 | 5,6 | 7,6 | 0,9 | 11 | 21 |
| (2) 9 | KOWEIT CITY English School | 1/4/91 20H00 | 1/4/91 22H00 | 2H | 5 | 0,7 | 3,5 | 2,9 | 1,2 | 3,4 | 0,01 | 4,1 | 5,7 |
| (7) 11 | KOWEIT Ring 7 Airport | 3/4/91 10H00 | 3/4/91 12H00 | 2H | 37 | 1,3 | 6,6 | 11 | 3,8 | 7,6 | 0,18 | 8,4 | 17 |
| (8) 13 | KOWEIT AL MAQWA South field | 4/4/91 11H00 | 4/4/91 14H00 | 3H | 110 | 3,8 | 26 | 20 | 12 | 30 | 0,6 | 26 | 41 |
| (7) 11* | KOWEIT SUD Ring 7 Airport | 3/4/91 11H00 | 3/4/91 18H00 | 7H | 19 | 5,6 | 4 | 3,3 | 1,8 | 5,8 | 0,2 | 3,8 | 5,8 |
| (7) 11** | KOWEIT SUD Ring 7 Airport | 3/4/91 11H00 | 3/4/91 18H00 | 7H | 17 | < 1 | < 0,1 | < 0,1 | < 0,1 | < 0,1 | < 0,1 | < 0,1 | < 0,1 |
| MEAN OF ALL CAMPAIGNS | | | | | 34,6 | 2,2 | 9,5 | 8,2 | 4,0 | 8,5 | 0,3 | 8,8 | 14,3 |
| MAXIMUM ON ALL CAMPAIGNS | | | | | 110 | 5,6 | 26 | 20 | 12 | 30 | 0,9 | 26 | 41 |

* particulate phase sampled on glass filter

** gazeous phase sampled on XAD2 resine

HYDROCABONS AND VOLATILE ORGANIC COMPOUNDS

AVERAGE LEVELS OBSERVED IN PARIS OR IN HABITATIONS

SOURCE : " LABORATOIRE D'HYGIENE " OF THE CITY OF P

MEASUREMENTS TAKEN IN SEPTEMBER/OCTOBER 1987

| SUBSTANCE | AMBIENT AIR | INDOOR AIR |
|---|---|---|
| ALKANES | 100 | 100 |
| HEXANE | | |
| HEPTANE | 25 | 10 |
| OCTANE | 11 | 5 |
| NONANE | 21 | 10 |
| DECANE | 20 | 20 |
| UNDECANE | 10 | 10 |
| DODECANE | 5 | 5 |
| TRIDECANE | 3 | 10 |
| TETRADECANE | 2 | 2 |
| PENTADECANE | 1 | 1 |
| HEXADECANE | 1 | 1 |
| CYCLOALKANES | | 25 |
| CYCLOHEXANE | | 10 |
| METHYL CYCLOHEXANE | | 10 |
| AROMATICS | 60 | 160 |
| BENZENE | 9 | 10 |
| TOLUENE | 23 | 80 |
| ETHYL BENZENE | 3 | 10 |
| M+P XYLENE | 10 | 20 |
| O XYLENE | 1 | 10 |

# *RESULTS OF THE MEASUREMENT OF ATMOSPHERIC POLLUTION IN KUWAIT*

## *METALS (in ng/m3)*

*Samplings analysed by LHVP*

| N of Campaign and map indicator ( ) | LIEU | SARTING TIME AND DATE | ENDING TIME AND DATE | LENGHT OF TIME | AVERAGE NICKEL | AVERAGE VANADIUM |
|---|---|---|---|---|---|---|
| (3) 3 | KOWEIT CITY Mansouriya (5 Minutes) | 29/3/91 14H00 | 30/3/91 17H00 | 3H00 | 20 | < 20 |
| (6) 8 | KOWEIT SUD Ahmadi Hospital | 1/4/91 15H00 | 1/4/91 16H00 | 1H00 | 150 | 60 |
| (6) 8 | KOWEIT SUD Ahmadi Hospital | 1/4/91 16H00 | 1/4/91 17H00 | 1H00 | 600 | 70 |
| (6) 8 | KOWEIT SUD Ahmadi Hospital | 1/4/91 17H00 | 1/4/91 18H00 | 1H00 | 200 | 70 |
| (7) 11 | KOWEIT SUD Ring 7 Airport | 3/4/91 11H00 | 3/4/91 12H00 | 1H00 | 400 | 200 |
| (7) 11 | KOWEIT SUD Ring 7 Airport | 3/4/91 17H00 | 3/4/91 18H00 | 1H00 | 330 | 200 |
| (8) 13 | KOWEIT SUD AL MAQWA south field | 4/4/91 12H00 | 4/4/91 13H00 | 1H00 | 20 | 20 |
| (8) 13 | KOWEIT SUD AL MAQWA south field | 4/4/91 13H00 | 4/4/91 14H00 | 1H00 | 50 | < 20 |
| | | | | | | |
| MEAN OF ALL CAMPAIGNS | | | | | 221 | 32 |
| MAXIMUN ON ALL CAMPAIGNS | | | | | 600 | 200 |

U.S. DEPARTMENT OF COMMERCE
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
Gaithersburg, MD 20899

# REPORT OF TEST
# FR 3985

June 20, 1991

Analysis of Smoke Samples from Oil Well fires in Kuwait

George W. Mulholland, Bruce A. Benner, Robert A. Fletcher,

Eric Steel, Stephen A. Wise, Willie E. May

Daniel Madrzykowski, and David Evans

Submitted to:

U.S. Department of Commerce
NOAA
Office of the Chief Scientist
Arabian Gulf Program Office
Rm. 6226

Report of Test on Analysis of Smoke Samples from Oil Well Fires in Kuwait

by

George W. Mulholland, Bruce A. Benner, Robert A. Fletcher,
Eric Steel, Stephen A. Wise, Willie E. May,
Daniel Madrzykowski, and David Evans

National Institute of Standards and Technology

## INTRODUCTION

This report describes results from a preliminary series of measurements concerning the smoke production from the Kuwait oil well fires. Detailed chemical analysis of the smoke is being carried out for determination of the fraction of ambient aerosol arising from the Kuwait oil well fires on a local, regional, and global scale. The overall goal is to characterize the amount of smoke particulate produced and its chemical makeup, as well as the amount of various gaseous species including $SO_x$ and PAHs from individual well fires. This information will be used together with the burning rates of a large number of oil well fires to estimate the total production of smoke and gases from all the fires in Kuwait. The source term information is essential for risk assessment in regard to health effects, environmental/climate impact, and visibility.

Smoke samples were collected in the Al Maqwa oil field in Kuwait on May 15, 1991 from two locations illustrated on the map (Fig. 1). The first set was collected about 3 meters above ground at an "ambient" location; that is, the sampling was not from a plume but was from the oil field region. These samples are indicated as ambient oil field samples. The second set of samples, denoted as plume samples, was collected in the plume of a combination jet-pool fire at a height of about 1 meter. The ground level plume consisted of whitish smoke, while black smoke was emanating from the flames (See Figure 2). It was the whitish smoke that we were sampling.

The particulate was collected on quartz filters, polytetrafluoroethylene (PTFE) filters, on stages of a cascade impactor, and on carbon coated transmission electron microscopy (TEM) grids. Volatile polycyclic aromatic hydrocarbons (PAHs) were collected downstream on XAD-2 sorbent and CO and $CO_2$ were collected in PTFE sampling bags. The sampling procedures are described in more detail below.

The smoke analysis included the determination of the mass of particulate on the filter, the relative amounts of organic and elemental carbon in the particulate, the PAH content of the particulate and gas, the chemical composition by laser microprobe mass spectroscopy (LMMS), and the particle size distribution by transmission electron microscopy and by cascade impactor. Gas chromatography was used to analyze the CO and $CO_2$ concentration in the gas samples.

## SMOKE SAMPLING

Smoke samples were collected on 47 mm diameter quartz fiber filters for thermal-optical analysis of organic versus elemental carbon content. Standard precautions were taken to avoid sample contamination before sample collection by heating the filter for two hours at 700°C to remove organic contaminant and also heating the aluminum foil used to line the sample containers to 500°C for several hours. All filters and impactor substrates were weighed and sealed with Teflon tape in Petri dishes lined with aluminum foil. As a further precaution, sets of filters were placed in plastic bags partially filled with filtered air. After the samples were collected, they were resealed with teflon tape in Petri dishes and maintained at about 5°C to avoid evaporation of the organic fraction until they were analyzed. The sample flow was maintained at 67

$cm^3/s$ (4 L/min.) using a battery operated pump (Gillian[1]), which contains a flow controller element to maintain constant flow with increasing pressure drop across the filter. A calibrated flowmeter was used to adjust the pump flow before collecting the smoke. A small fraction of the exhaust from the diaphragm pump, about 2 $cm^3/s$, was directed to a 5 L PTFE gas sampling bag for subsequent CO and $CO_2$ analysis.

The PAH sampling train was operated at a flow rate of 50 $cm^3/s$ (3 L/min) and contained a 37 mm filter holder followed by a 8 mm OD by 110 mm long sorbent tube filled with two sections of XAD-2. Analysis of the second section allows detection of PAH vapor breaking through the first section. The entire sampling train including disposable filter holders, sorbent tubes, connectors, and PTFE filers were obtained from one vendor, SKC. The sorbent tubes were covered with aluminum foil to minimize exposure of the PAH collected on the XAD-2 to sunlight. After collecting the samples, they were sealed and kept at about 5°C.

A six stage cascade impactor (Marple Personal Cascade Impactor), which provides size segregated samples, was used at a flow of 33 $cm^3/s$ (2 L/min). The ambient sample collected by this method was too small for gravimetric analysis, but the size segregated samples were useful for single particle analysis by LMMS. Samples were also collected directly on carbon coated TEM grids (3-mm diameter, 0.13 mm thick, and 200 mesh copper). Two grids were attached to the metal sampling housing with double stick tape in the case of the plume sample and to the side of the Van just below the roof in the case of the ambient sample.

## PARTICLE AND GAS ANALYSIS

### Smoke Concentration and Yield

The mass concentration of smoke was determined from the total volume of air sampled and the mass of smoke collected. The plume samples were collected for about 20 minutes and about 1 mg of smoke particulate was collected. This is a convenient sample size for gravimetric analysis with a 0.01 mg sensitivity microbalance. The Kuwait ambient sample was collected for thirty minutes resulting in the collection of about 0.05 mg of particulate matter. The time averaged mass concentrations (See Table 1) for the two plume samples are $21 \pm 1$ $mg/m^3$ and $15 \pm 1$ $mg/m^3$ and $0.05 \pm 0.03$ $mg/m^3$ for the Kuwait ambient sample.

The $CO_2$ concentration in the plume corresponding to the 21 $mg/m^3$ smoke concentration is 650 ± 20 ppm by volume and the concentration in the Kuwait ambient sample was 380 ±20 ppm as measured by gas chromatography (GC) equipped with a thermal conductivity detector operated at 200°C. The calibration of the GC was performed using NIST Standard Reference Material 2634, 789 ppm of $CO_2$ in nitrogen with an accuracy of ± 8 ppm. These values are to be compared with a reference ambient level of about 350 ppm in a pristine environment [1]. The CO concentration was below the detectable limit for the instrument (60 ppm).

From the measurement of the smoke collected on the filter and the $CO_2$ concentration, the smoke yield of whitish smoke in terms of grams of smoke per gram of fuel can be computed using the following equation [2]:

$$e = Y_c F_c \quad , \tag{1}$$

where $F_c$ is the mass fraction of carbon in the crude oil and $Y_s$ is the mass of smoke particulate divided by the mass of carbon in the combustion products including smoke and $CO_2$. We estimate $F_c$ as 0.86 based on elemental analysis for Arabian light crude and obtain $Y_c$ of 0.13 based on the smoke mass on the filter, the $CO_2$ concentration minus the background concentration, and the volume of gas sampled. Using Eq.(1), we obtain a smoke yield of 0.11 g smoke per gram of fuel consumed. This number is an upper bound, since the mass of carbon in the form of volatile hydrocarbons is not included.

---

[1] Certain materials and equipment are identified in this report in order to adequately specify the experimental procedure. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology.

Organic/Elemental Fraction

The organic/elemental carbon fractions were determined by Sunset Laboratory[1] using a method-defined analysis similar to that described by Johnson et al. [3]. The organic carbon was determined by measuring the carbon content of the vapors produced by heating the sample in a helium environment, and the elemental carbon fraction was determined by heating the residue in a mixture of 2% oxygen in helium. As indicated in Table 1, the organic content of the plume sample was found to be 92 ± 3 % and for the ambient sample was 72 ± 5 %.

PAH Analysis

Three PTFE filters (2 samples and 1 blank) and three XAD-2 cartridges (2 samples and 1 blank) were analyzed for polycyclic aromatic hydrocarbons (PAHs). The samples were fortified with perdeuterated derivatives of PAHs, which served as internal standards for the subsequent extractions and analyses. The samples were extracted with ultrasonic agitation in dichloromethane and the PAHs in the extract were measured using gas chromatography with mass spectrometric detection (GC-MS). Thirteen PAHs were measured in one of the PTFE filter samples (0.99 mg particulate loading, plume sample) whereas the other filter sample (approximately 0.05 mg particulate loading in the ambient sample) did not have detectable levels of the PAHs above the filter blank. Six PAHs were measured in extracts of XAD-2 cartridges collected downstream of a Teflon filter. Detectable levels of four of the six PAHs were observed on the downstream segment of one of the XAD-2 samples (each XAD-2 cartridge has two separate segments of the sorbent), suggesting that breakthrough occurred for those compounds on that cartridge. The details of the experimental procedure are described in the appendix.

Results of the PAH determinations of the filter and XAD-2 samples are shown in Tables 2 and 3, respectively. Except for a small phenanthrene contamination of 2.3 ng observed in the Teflon filter blank, the filter and XAD-2 blanks were free of PAHs. Significant concentrations of PAHs were observed in Filter 11 (plume sample) which was loaded with 0.99 mg of particulate matter (see Table 2). Detectable levels of PAHs were not observed in Filter 12 (ambient sample), which was composed of about 0.05 mg of collected particulate matter. A larger sample size would be needed to determine the PAH distribution in the Kuwait ambient. Results from the analysis of NIST SRM 1649, used in this study for analytical quality assurance (see Table 2), were in good agreement with concentrations listed in the SRM's Certificate.

Detectable levels of PAHs were observed in both the upstream and downstream XAD-2 segments of XAD-2 sample 11 (see Table 2). The PAHs measured on the downstream segment of XAD-2 sample 11 experienced breakthrough during sampling and may not have been collected quantitatively. Three PAHs were detected on the upstream segment of XAD-2 sample 12, with none detected on the downstream segment, suggesting that the PAHs were collected conservatively on the upstream XAD-2 segment.

As indicated in Table 4, the whitish plume smoke is more than a factor of five higher in the amount of benzo[a]pyrene, which is often used as an indicator of the health impact of PAHs, per gram of sample than either Alberta sweet crude oil or the urban dust standard; on the other hand, it is about a factor 10 lower than the black sooty smoke collected during the burning of Alberta sweet crude in the laboratory. This source information is one of the elements of a health effects analysis, which would also include the concentration of particulate to which individuals are exposed.

Laser Microprobe Mass Spectroscopy

The laser microprobe (LAMMA 500) is a time of flight mass spectrometer that utilizes a Nd:Yag pulsed laser as the ablation and ionization source [4]. LMMS has been used in a previous study on carbonaceous particles in regard to source identification of atmospheric soot [5]. Particulate was analyzed from quartz fiber filters and from the particulate deposited on the 2 μm cutoff size (sixth stage) of the impactor transferred to a quartz cover slip for the microprobe analysis. The negative ion spectra of the smoke particle is shown in Figure 3. The carbon clusters ranging in size from $C_2$ to $C_{10}$ is typical of all carbonaceous material. The peaks at 16 ($O^-$), 32, and 35 ($Cl^-$) may be characteristic of the smoke, but they also may arise from the fine ambient dust. LMMS analysis for possible PAHs was conducted by operating the laser at low power to gently desorb material from the smoke. The positive ion spectra (Figure 4) suggests the likely presence of PAH compounds. Peaks at m/z=252 could be the 5 ring benzo[a]pyrene, 276 and 302 could be six ring PAHs, and 326 could be a 7 ring PAH. There are peaks not shown on this plot extending out to m/z=450. Compared to the positive ion spectra for ambient samples collected in urban areas and to soot from the burning of acetylene, it appears that the Kuwait smoke results in larger PAH type structures. Such information may useful in source apportionment though additional analytical measurements may be needed on remote samples to distinguish the crude oil smoke from other combustion sources such as wood burning.

After examining the impactor sample by LMMS, the 2 μm sample was low temperature ashed in an oxygen plasma to remove carbon. The sample, viewed under light microscopy at 320X, revealed small dust or sand like particles. The laser microprobe analysis demonstrated that the particles are composed mostly of Si and have some Ba. Sand-like materials may be a significant portion of the aerosol.

Transmission Electron Microscopy

A TEM grid exposed to ambient smoke was analyzed with a JEOL 200 CX transmission electron microscope. Two smoke agglomerates were detected and their micrographs are shown on Figure 5. The larger agglomerate has an overall length of about 10 μm with primary particle diameters ranging from 0.05 μm to 0.2 μm. The smaller agglomerate has a length of about 1.5 μm with primary particle diameters ranging from 0.15 to 0.3 μm. Compared to soot observed in laboratory scale burns, the two smoke agglomerates collected in Kuwait seem to have larger, less well defined primary spherules.

## PRELIMINARY CONCLUSIONS/RECOMMENDATIONS

Limited data was obtained from one ambient site and one plume so that the conclusions we draw must be considered suggestive rather than definitive. Perhaps the greatest benefit of the measurements is to sharpen the focus of future studies in terms of the types of samples to be collected and the chemical analysis to be performed to allow quantitative characterization of the smoke source term for use in risk assessment.

1. The combination jet-pool fires produce a whitish ground level smoke that is primarily made up of organic carbon and a sooty plume emanating from the flames. Based on this observation and the high organic level of the ambient sample, we hypothesize that the whitish ground level smoke is the main component of the ambient aerosol in the local region (the country of Kuwait). To test this hypothesis, we recommend that a range of chemical measurements including organic/elemental carbon fraction be made in the whitish plume, in the sooty plume, and at several monitoring locations in Kuwait.

2. The carbon balance method indicates an upper bound of the white smoke yield as 0.11 g smoke per gram of fuel consumed. There is a need to include measurement of organic volatiles to obtain a more accurate estimate of the yield. Smoke yield measurements of both the black and white smoke need to be combined with burning rate information, wind velocity, and concentration for estimating the smoke emission from individual fires.

3. The benzo[a]pyrene in the whitish plume smoke for the one sample collected is mid range between that of soot from a laboratory crude oil burn and that of crude oil itself. It is recommended that the PAH analysis be made of the Kuwait crude oil, the whitish smoke, the black smoke, and of the ambient aerosol.

4. The LMMS spectra show potential for providing tracer information on a particle by particle basis for Kuwait smoke. It is recommended that smoke samples be collected from several wells together with samples of the crude oil. Single particle methods including LMMS, analytical electron microcopy, and Raman scattering should be applied to determine their applicability for source identification.

5. Transmission electron microscopy results, while very limited, suggest that the primary size of the smoke agglomerates is larger than is observed for laboratory scale burns. It is recommended that both electron microcopy and cascade impactors be used to quantify the size distribution and structure of the smoke from various well fires. The cascade impactor should also be used for collecting particulate smaller than 2.5 μm aerodynamic diameter for chemical analysis. Particles in this size range can penetrate deep into the respiratory tract and are of concern for their health impact.

6. Certified Reference Materials, when available, should be used as internal quality assurance tools by all laboratories involved in the Kuwait Oil Well Fire measurement activities. A listing of NIST Standard Reference Materials appropriate for the smoke related activities is available upon request.

ACKNOWLEDGEMENTS: James Brown measured the $CO_2$ concentration in the bag samples and Nelson Bryner and Randall Lawson assisted in the preparation of the smoke particulate and gas sampling equipment.

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Table Captions

| | |
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Figure 4 Positive Ion Mass Spectrum of Ambient Kuwait Smoke

Figure 5 Transmission Electron Micrographs of Ambient Kuwait Smoke. Left picture 6,000X, middle 20,000X of same agglomerate, Right 30,000X of second agglomerate.

**APPENDIX: PAH ANALYSIS**

The PTFE filters were transferred to 50 mL centrifuge tubes, spiked with 10 µL of a standard containing 7 perdeuterated PAHs and extracted ultrasonically in 25 mL dichloromethane (DCM) for 20 min. A particulate matter Standard Reference Material with known PAH concentrations (SRM 1649, Urban Dust/ Organics) was processed through the same procedure as the filter samples and served as a quality assurance sample. The filters were removed from the tubes and the extracts were centrifuged at approximately 10,000 g's for 1 min. This centrifugation did not clarify the extracts so they were concentrated under $N_2$ to < 2 mL and passed through a 0.2 µm pore syringe filter (Anotop 10). The filter and SRM extracts were finally concentrated to ≤ 100 µL in 4 mL amber vials prior to GC-MS quantification.

The upstream and downstream segments of each XAD-2 tube were processed separately to check for breakthrough of any PAHs collected in the vapor phase. The XAD-2 cartridges were scored above the upstream segment of sorbent and the different segments were spiked with the perdeuterated PAH standard described above and extracted ultrasonically for 15 min with 10 mL DCM in 15 mL centrifuge tubes. The XAD-2 extracts were transferred to other 15 mL tubes and concentrated under $N_2$ to ≤ 100 µL.

Two microliter volumes of each sample extract was injected onto the GC column. Details of both the GC and MS conditions are specified in Table 5. Each sample was analyzed one time, using a PAH standard solution (prepared at NIST) as a calibrant.

Table 1. Analysis of Smoke from Kuwait Oil Well Fires

| PROPERTY | PLUME | AMBIENT | LAB. SCALE[a] |
|---|---|---|---|
| PARTICULATE CONCENTRATION | $21 \pm 1$ mg/m$^3$<br>$15 \pm 1$ mg/m$^3$ [b] | $0.6 \pm 0.3$ mg/m$^3$ | 100-200 mg/m$^3$ |
| $CO_2$ Concentration | 650 ppm | 350 ppm | 1000-2000 ppm |
| Smoke Yield | 0.11 g smoke/g oil[c] | - | 0.09 - 0.15 g sm./g oil |
| Organic Fraction | $92 \pm 3$ %[d] | $72 \pm 5$ % | 14 - 21 % |

[a] Lab. Scale refers to data for Alberta sweet and Arabian light crude pool burns at the scale of 0.6 to 3 m in diameter [6,7].

[b] The error bounds are based on the uncertainty in the gravimetric determination of smoke particulate collected.

[c] This value represents an upperbound.

[d] The error bounds reflects the precision of the analysis.

Table 2. PAH Concentrations Observed in Kuwait Oil Fire Particulate Samples[a] (ng/mg unless noted otherwise)

| PAH | FILTER Blnk (ng) | PLUME [b] | AMBIENT(ng)[c] | SRM 1649[d] |
|---|---|---|---|---|
| phenanthrene | 2.3 | 100 | < 2.3 | 5.0 (4.5) |
| anthracene | < 1 | 30 | < 1 | 0.62 (0.6) |
| fluoranthene | < 1 | 76 | < 1 | 7.1 (7.1) |
| pyrene | < 1 | 84 | < 1 | 6.1 (7.2) |
| benz[a]anthracene | < 1 | 28 | < 1 | 2.7 (2.6) |
| chrysene | < 1 | 34 | < 1 | 3.3 (3.6) |
| benzo[b]fluoranthene | < 1 | 17 | < 1 | 5.8 (6.2) |
| benzo[k]fluoranthene | < 1 | 9.0 | < 1 | 2.0 (2.0) |
| benzo[e]pyrene | < 1 | 21 | < 1 | 3.6 (3.3) |
| benzo[a]pyrene | < 1 | 19 | < 1 | 2.7 (2.9) |
| perylene | < 1 | 5.8 | < 1 | 0.77 (0.8) |
| indeno[1,2,3-cd]pyrene | < 1 | 13 | < 1 | 3.1 (3.3) |
| benzo[ghi]perylene | < 1 | 15 | < 1 | 4.2 (4.5) |

[a] Uncertainties estimated from the measurement precision to be ± 10 % of the listed concentrations or masses.
[b] Plume sample - filter #11.
[c] Ambient sample - filter #12.
[d] Concentrations in parentheses are the assigned values for Standard Reference Material 1649 [Urban Dust/Organics], analyzed for quality control purposes.

Table 3. Masses of PAHs Observed in Kuwait XAD Samples[a]

| PAH | (ng) XAD BLANK | PL.XAD UP[b] | PL XAD DOWN[b] | AM. XAD UP[c] | AM. XAD DOWN[c] |
|---|---|---|---|---|---|
| phenanthrene | < 0.5 | 400 | 55 | 17 | < 0.5 |
| anthracene | < 0.5 | 50 | 4.4 | < 0.5 | < 0.5 |
| fluoranthene | < 0.5 | 32 | 2.3 | 0.69 | < 0.5 |
| pyrene | < 0.5 | 26 | 1.9 | 0.92 | < 0.5 |
| benz[a]anthracene | < 0.5 | 0.71 | < 0.5 | < 0.5 | < 0.5 |
| chrysene | < 0.5 | 0.78 | < 0.5 | < 0.5 | < 0.5 |

[a] Uncertainties estimated from the measurement precision to be ± 10 % of the listed masses.

[b] Plume XAD - Sample #11.

[c] Ambient XAD - Sample #12.

Table 4. Comparison of PAH Content of Smoke, Dust, and Oil[a]

| Sample | Total PAH/g sample[b] | benzo [a] pyrene/g sample |
|---|---|---|
| Kuwait whitish smoke | 490 μg, (16 μg/m$^3$)[c] | 19 μg, (0.3 μg/m$^3$) |
| Lab. Scale[d] | 4800-5200 μg | 180 - 240 μg |
| Alberta sweet crude | 1400 μg | less than 3 μg |
| urban dust standard | about 50 μg | 2.7 μg |

[a] Uncertainties estimated from the measurement precision to be ± 10 % of the listed masses.
[b] The total PAH refers to PAHs collected on the filter and does include the contribution of the volatile fraction listed in Table 3.
[c] The numbers in () refer to the mass concentrations of PAH in air.
[d] The results for the lab scale burns and the crude oil are taken from reference [6].

Table 5. Gas Chromatographic and Mass Spectrometric Conditions used for PAH Measurements of the Kuwait Samples

Gas Chromatography

Column: 25 m x 0.2 mm (0.15 μm phase) Smectic liquid crystalline phase
Carrier: He, 6 psi head pressure
Temperature Program: 37 °C (2 min hold), 30 °C/min, 200 °C, 3 °C/min, 270 °C (hold)
Injector: Cool on-column.
Detector Temperature: 270 °C.

Mass Spectrometry

Electron Multiplier Voltage: 2500 V.
Selected Ion Monitoring Program:

| Time (min) | Masses Monitored (amu) |
|---|---|
| 3 - 16 | 178, 188, 202, 212 |
| 16 - 26 | 228, 240 |
| 26 - 44 | 252, 264 |
| 44 - 65 | 276, 288 |

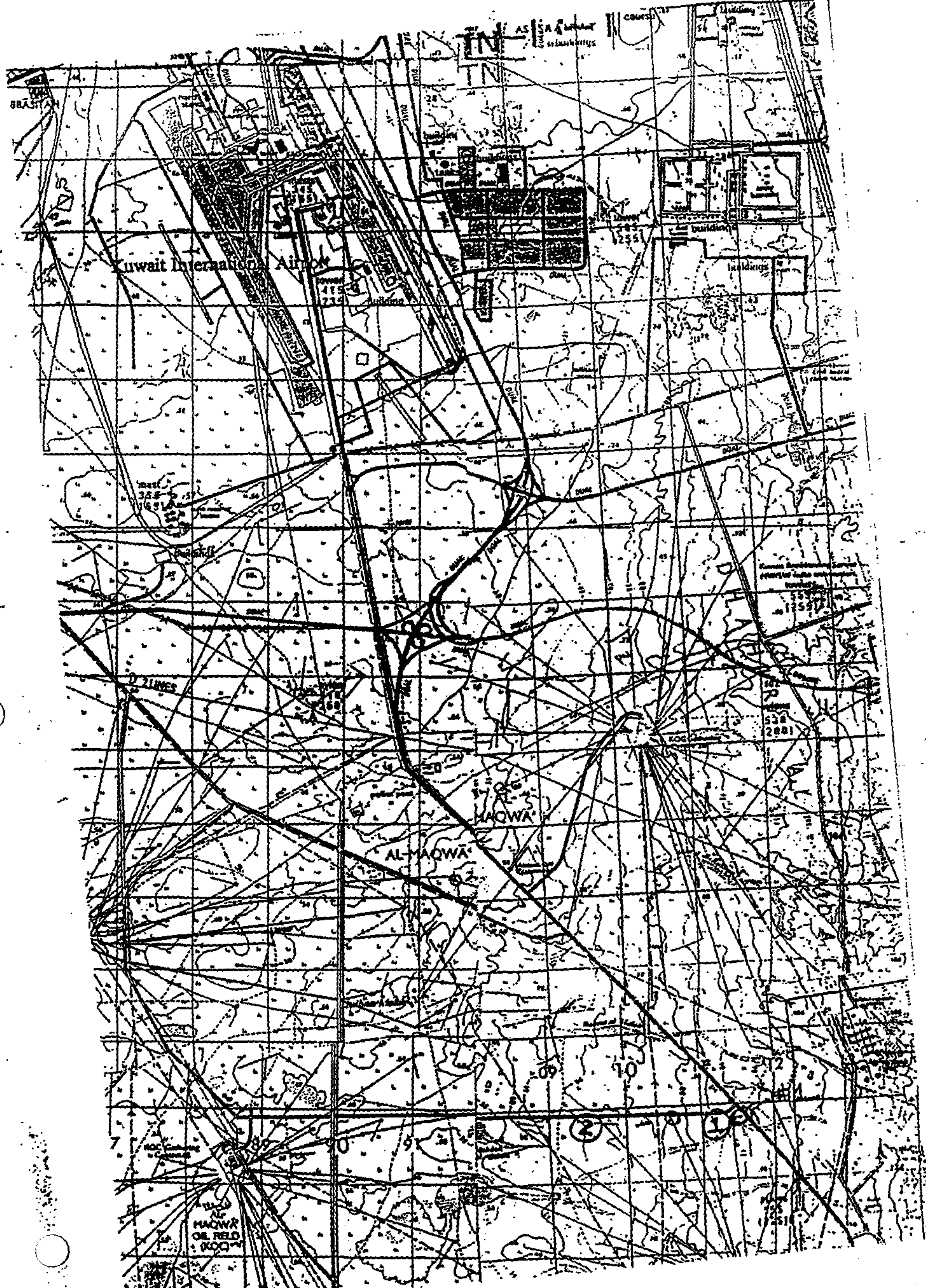

Kuwait International Airport
AL-MAQWA'
MAQWA'
MAQWA' OIL FIELD (KOC)

Figure 1.

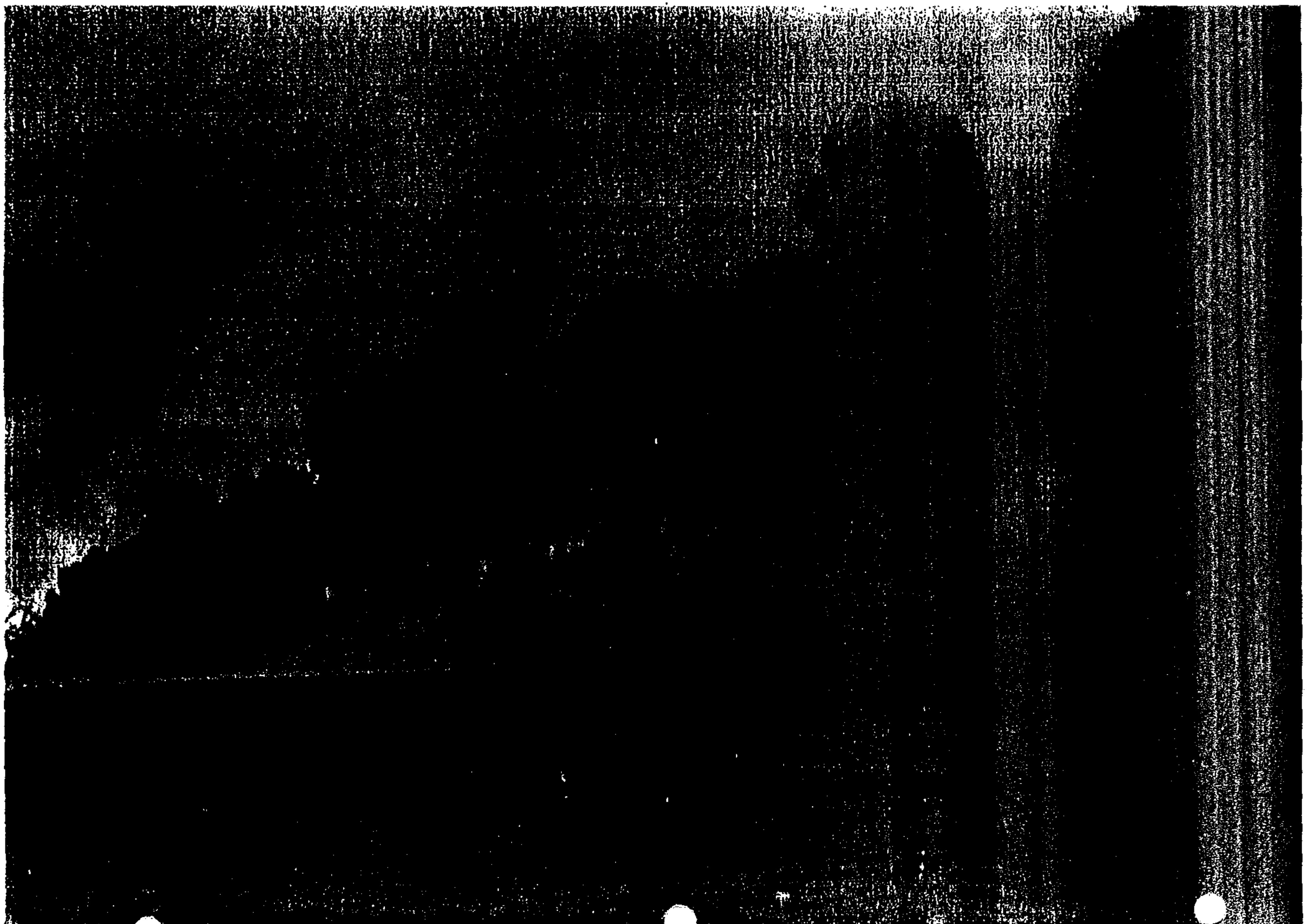
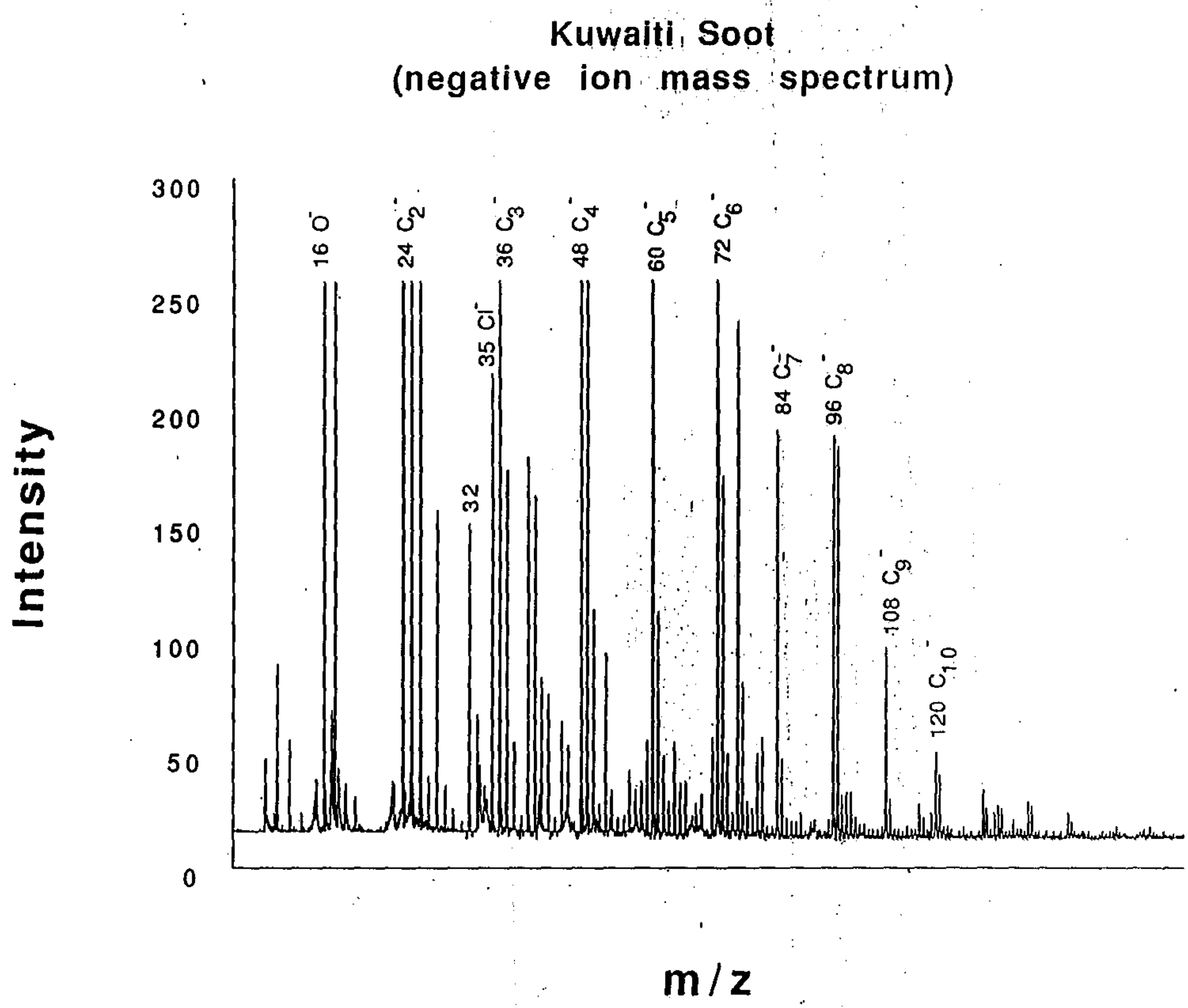


Figure 2.



Kuwaiti Soot
(negative ion mass spectrum)
Intensity
300
250
200
150
100
50
0
16 O⁻
24 C₂⁻
32
35 Cl⁻
36 C₃⁻
48 C₄⁻
60 C₅⁻
72 C₆⁻
84 C₇⁻
96 C₈⁻
108 C₉⁻
120 C₁₀⁻
m/z


Figure 3.

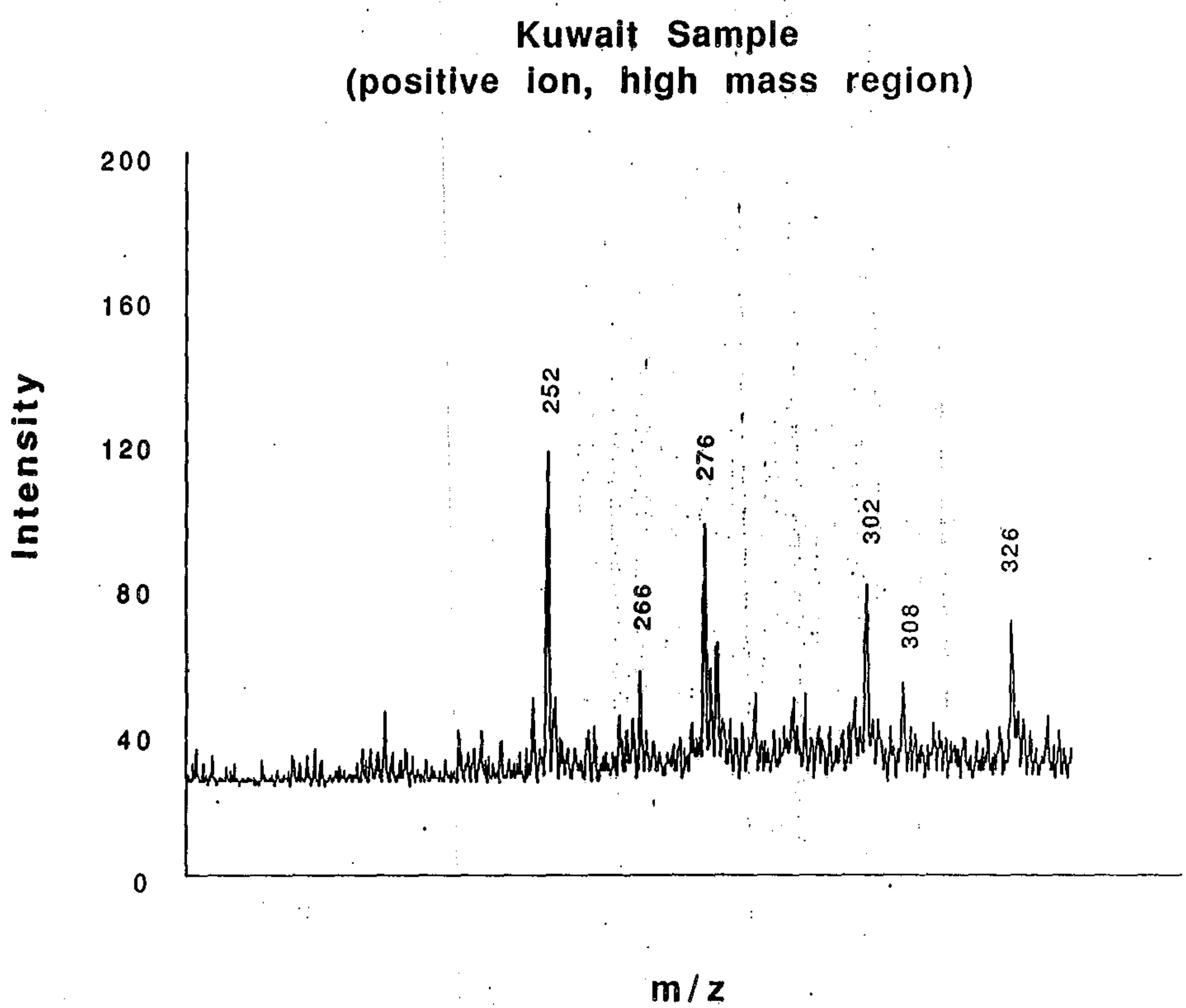

Kuwait Sample
(positive ion, high mass region)
Intensity
200
160
120
80
40
0
252
266
276
302
308
326
m/z

Figure 4.

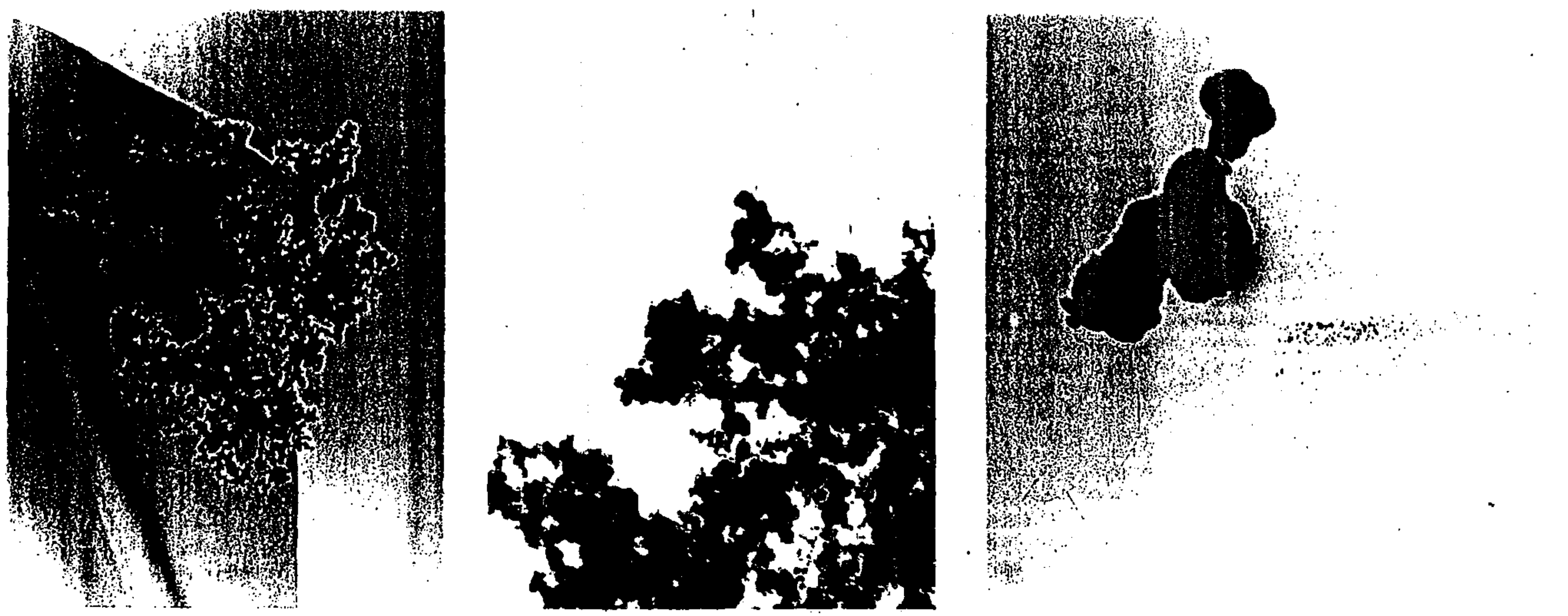


Figure 5.

NILU RR: 6/91

NILU RR : 6/91
REFERANSE : O-91042
DATO : JUNE 1991

# Air Quality Monitoring in Kuwait

*First NILU Mission, 5—12 June 1991*

B. Sivertsen
T. C. Berg

NILU

NORSK INSTITUTT FOR LUFTFORSKNING
**Norwegian Institute for Air Research**
POSTBOKS 64 — N-2001 LILLESTRØM — NORWAY

## CONTENTS

# AIR QUALITY MONITORING IN KUWAIT
# FIRST NILU MISSION, 5-12 JUNE 1991

## 1 INTRODUCTION

The Norwegian Institute for Air Research (NILU) has been asked by UNEP/WHO to plan and undertake air quality studies in Kuwait. The NILU tasks are part of the UN Inter-Agency Action Plan for the Gulf-region. The total Norwegian support amounts currently to 1 million USD, which has been transferred to UNEP in Nairobi. The Norwegian objective was to combat the destruction of the environment in Kuwait and the Gulf region through the contribution of 1 mill. USD to acquire the necessary air quality equipment.

NILU has submitted project proposals to several parts of the "Proposal for air pollution programme in connection with Kuwait oil field fires", presented by WHO on 13 May 1991. The latest versions of these proposals were:

- NILU monitoring stations for Kuwait (27 May 1991). Two permanent and one mobile station.
- NILU sampling stations for downwind support (27 May 1991).
- Use of dispersion models in an air quality surveillance and control programme for Kuwait (28 May 1991).

## 2 OBJECTIVES

The objectives of the first mission to Kuwait was to:

- Get acquianted with the existing air quality and meteorological monitoring systems already available.
- Present and discuss the NILU proposals with local authorities.
- Visit existing and planned sites for air quality monitoring.

- Visit to the NILU measurement site at the UNIKOM/NORMEDUNIT in Umm Quasr.

## 3 UNEP FUNDS AVAILABLE FOR NILU

In a meeting with Dr. David Mage in Geneva we were informed that from the 1 mill. USD transferred from Norway to UNEP in Nairobi, only 353.000 USD is available for the air quality monitoring in Kuwait to be performed by NILU. 375.000 USD was transferred to WMO, 72.000 USD went into UNEP (13% overhead), WHO has reserved 150.000 USD for the Heal-study and 50.000 USD were assigned for WHO services.

From the WMO transfer ~40.000 USD has been assigned for the "warning centre" and ~34.000 USD for the repair centre. Some of the money could be used for NILU work under the budget items mentioned. These matters have to be cleared with WMO.

## 4 VISIT TO UNIKOM-NORMEDUNIT IN UMM QUASR

After obtaining UN identification cards as UN representatives in Kuwait, we could visit the Norwegian NORMEDUNIT in Umm Quasr. The camp is located in the UN controlled zone within the old Iraqi territorium. Major Hoel and P.O. Vinjevold have been undertaking air quality measurements at the field hospital since 7 May 1991.

We inspected the NILU automatic air sampler (FK), the wind recorder (Woelfle) on a 2 m mast, and the PAH (PUF) sampler. All equipment have been operating perfect. Vinjevold is doing a professional job with the equipment.

The following data were obtained for analysis at NILU:

- Wind records, 7 May - 7 June 1991
- One PAH filter, 21 May 1991, 0700-1300 hrs (highly polluted)

- One FK-filter for analyses of soot, and microscopical analyses for identification of particles.

The plumes from the burning oil fields to the southwest have only rarely hit the hospital area. This is due to a predominant fairly strong north westerly flow during spring and summer. Conditions might be considerably worse during the fall season.

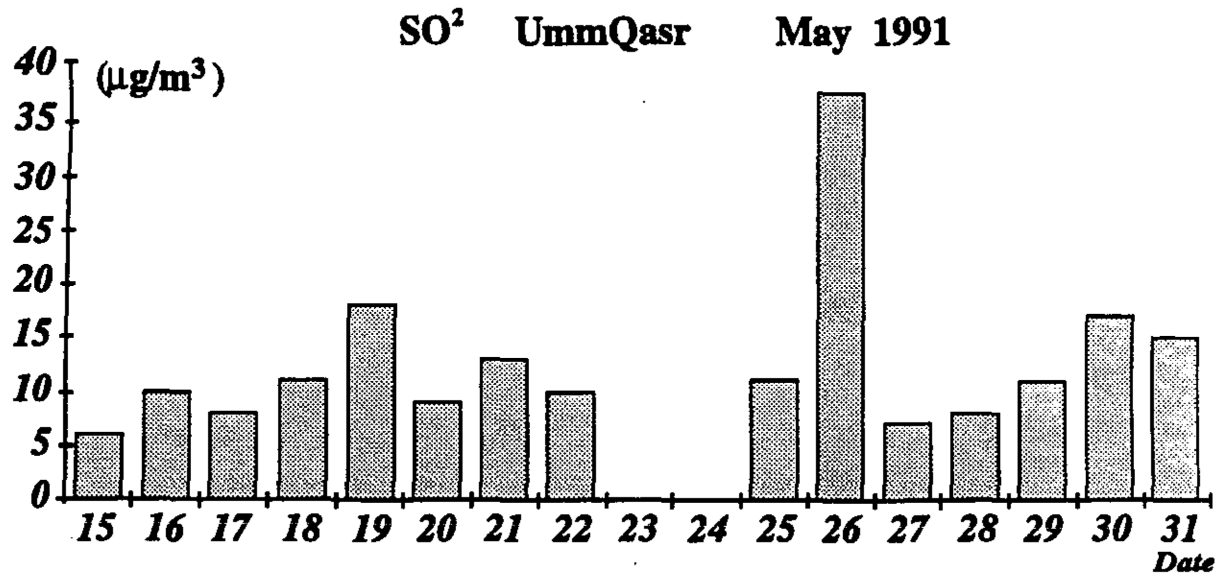
During one day on 16 to 27 May the smoke hit the Umm Quasar area. The 24 h average concentrations of $SO_2$ and soot were recorded to 36 $\mu g/m^3$ and 399 $\mu g/m^3$ respectively (see Figure 1).

The wind recorder is located in the middle of an open field (~100 x 60 $m^2$) with high trees 30 m to the east and south and low buildings to the north.

After discussions with Major T. Munkelien and T.M. Hoel its was decided that samples (filters and bottles) should be sent by personnel travelling between Kuwait and Norway every two week. We will prepare two NILU bags for this purpose. A test using DHL from NILU via the Norwegian embassy in Kuwait proved successful. A package of 15 kg reached the embassy in 5 days from NILU, and is being picked up by UN personnel in the Embassy.

## THE MONITORING STATIONS IN KUWAIT

We were informed by dr. Mostafa el Desouky about the monitoring network in Kuwait. Three stations; Mansoria, Rabia and Riqqa have been in operation for years (see map, Appendix C). Rabia has been used for repair and spare parts, which means that only two stations are operating at the moment. At these locations the following parameters are measured every 5 minute: $SO_2$, $H_2S$ (sulphate), NO, $NO_2$, $O_3$, CO, HC (NMHC), temperature, relative humidity, wind direction and speed. We also visited the station in Mansoria. (Fore a more detailed description of the site, see Appendix B). Data are collected on a cassette tape and printed out on a digital desk writer every 5 min. Manual calibration



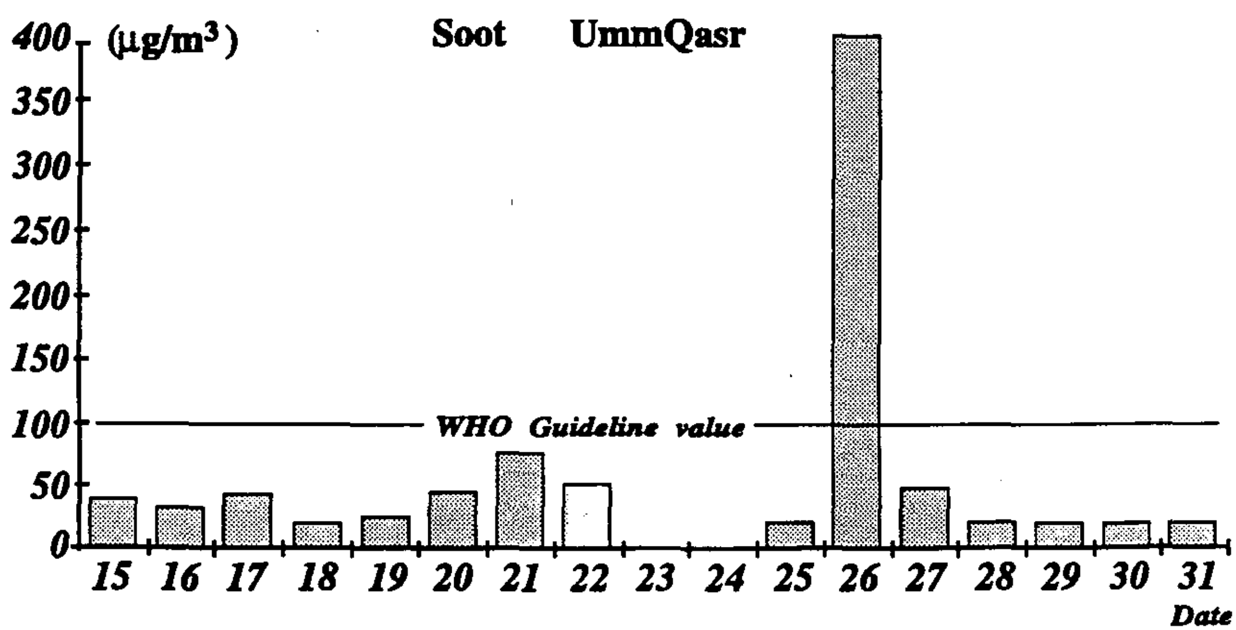




Figure 1: 24 h average concentrations of $SO_2$ and soot measured at the NORDMEDUNIT Hospital in Umm Quasr during 15-31 May 1991

and zero adjustment are carried out every 15 to 21 day. Automatic span cheque is performed every 25 h. Span gases have to be imported and are bought at fairly high concentrations. For $SO_2$ the concentration is 407 ppm, which is diluted in the instrument by a factor 1/1000.

The wind sensor is a Swiss made propeller (Gill type) with three axis. The bearing on the propeller is changed every 6 month to 1 year. The vertical propeller is not recorded at present. It might be possible to obtain a rough estimate of the one hour average $\sigma_w$-value.

Data on the cassettes are brought to the central computer at the Environmental Protection Department (EPD). Statistical evaluations are performed on a VAX main frame computer.

## 6 ENVIRONMENTAL PROTECTION DEPARTMENT (EPD)

In the EPD we had several meetings with dr. Ibrahim Hadi, dr. Mustafa el Desouky, dr. Mahmood Y. Abdulrahem, dr. Mohamed Abel and others. The EPD presents monthly and annual reports on the air quality monitoring programme. Some results are presented in Appendix C. Results from measurements performed after the war were also obtained. These are presented in Appendix D.

During the discussions we were told that several attempts have been made to estimate the emissions of gases and particles from the oil fires. None have been successful so far dr. Desouky claims. He indicated that 6 mill. barrels of oil burns every day at ~3000 $^0$F. About 5% (some claims up to 15%) of the oil is not burned. This means that ~40.000 tonnes of soot and smoke is produced every day. With an assumption of 4.1% S in the oil, ~65.000 tonnes of $SO_2$ and ~40.000 tonnes of $NO_2$ is released into the atmosphere every day. We also received a map showing the remaining oil wells on fire as of 9 June 1991 (Appendix E).

Some of the plumes are white, which as assumed to be caused by groundwater vapourized into the plume. This vapour plumes have not been verified by aeroplane measurements performed by American scientists.

High concentrations of $SO_2$ dr. Desouky claimed, have not been measured downwind from the oil fires. (This is not in agreement with French measurements performed in April). Two week averages of $PM_{10}$ have been measured at 400 to 460 $\mu g/m^3$. One day (on 9 April 1991) it was recorded 1160 $\mu g/m^3$ at a hi vol sampler in Addan hospital.

The meteorological conditions are at present beneficial for the air quality of Kuwait City. During a visit to the south of the city we could see the black clouds (~70 km from the city) darkening the sky making day into night. It is assumed that when the predominant strong winds from north east weakens during August and the winds become light and varying, the conditions get considerably worse for the larger part of the population living in Kuwait city.

Discussions with Mr. Yosi, responsible for computer operations at EPD, revealed that air quality data at present are collected every 4 day on cassette tapes. Data every 5 min are transferred to the Vax main frame computer (see Appendix F). The computer is a Vax 11/730 with VMS system version 4.4. and has no capacity for modelling purposes. NILU will have to provide a PC for data communication via modem (telephone lines) to the central.

## 7 THE LABORATORY IN SHUWAIKI

Dr. Mahmood Y. Abdulraheena, miss Sabah and others met with us at the laboratory in Shuwaiki. At the roof of one of the buildings we saw 2 Andersen type Hi-Vol samplers with filters and PUFs, one $SO_2$ bubbler for 24 h average concentrations (manually changed every morning) and a simple dustfall collector.

A semimobile lab (belonging to the University) was being built up again after the war. This isolated "container on weels" for pulling after a car was typically located for measurements during two weeks at each site.

The van had a cooled entrance room. In the air conditioned main lab. was one HC-analyzer (model 810 from Thermo-Environmental Inc.). Also the $NO/NO_x$ (mod. 14), and a $SO_2$ (mod. 43 A, UV-fluorescens) was from Thermo Environmental. A met-one wind system, a CO monitor with calibration unit, and a Sum X data-logger and printer for printouts every 5 min. was included in the van. Problems with some of the instruments are not yet solved. They have, however, planned to move the van to the south of Kuwait City to catch the center plumes from the burning oil wells.

Inside the lab we were presented to the analytical procedures and equipment. It was impressive to see how much this group has managed to keep away from the plundering and damaging during the war. Among the equipment was one SP 190 Automatic Absorption Spectrometre, Autoanalyzer (UV and IR), Perkin Elmer Sigma 115 Gas Chromatographs (some of the newer GCs were taken by the enemy), and one HP GCMS 5995.

Hi-Vol filters are devided into 4 parts, one analyzed for $SO_4$, $NO_3$, Cl, Na, K and Ca, the second for heavy metals and the last two for organic compounds. About 30 filters are analyzed each month. PAH are analyzed at present for 11 compounds on filter. An example chromatogram show a benzo(b)fluorethene + benzen c concentration of ~96 $pg/m^3$. The lab also uses Tenax tubes for VOC analyses. An example of a "fingerprint" of burning crude oil was presented (Apendix G). The laboratory also has used a Monostatic Sodar system from Aeroenvironment to estimate mixing heights and surface based inversion heights in Kuwait city (Appendix G B)).

## 8 VISIT TO THE NILU MONITORING SITES

Two sites for the NILU monitoring stations have been selected:

- Jahra, at the hospital 30 km west of EPD.
- Mina Al Zoor, at a power plant site, 80 km south south-east of EPD.

At Jahra the NILU station will be located at the roof of the hospital building (3 stories). Power is available a few metres from the site. Telephone lines can be obtained from the building. A truck with a lifting crane can move all the way into the building and place the NILU container on the top of the building.

At Mina Al Zoor the NILU container will be placed on the roof of a low building in the living quarter at the north western corner of the power plant site. Power is available. Telephone lines will be made available.

## 9 THE NOAA METEOROLOGICAL NETWORK

The US NOAA (National Oceanic & Atmospheric Administration) is at present locating 18 meteorological stations distributed all over Kuwait (see map Appendix H). In charge of the US team is William Pendergrass (NOAA, Oak Ridge) with whome we met. In addition to the meteorological network, US EPA has also brought in 9 $PM_{10}$ particle samplers. The locations of these samplers are presented in Appendix H B).

The meteorological stations are equipped with R M Young Campel type wind propellers on a wind vane for measurements of horizontal wind directions and wind speeds included estimates of standard deviations. Pressure, temperature and relative humidity is also recorded. The data are transferred via radio communication to the central CPB office every hour. A data file is created with 5 min, 15 min and 1 h average data on a IBM AT computer. Each station has also a local storage capacity of two days.

Data can be achieved from the IBM computer in ASCII-format. NOAA will create wind fields every hour in a 1 to 10 km grid. It should be no problem to establish an interface between the NOAA wind field output data, to the NILU dispersion modelling system (on HP Apollo). An example of a first temperature plot created at CPB on 9 June 1991 is shown in Appendix H C).

## 10 HEALTH INVESTIGATIONS

We were pleased to arrange a meeting between dr. Mustafa El Desouky and two Norwegian medical doctors; dr. Jens Holmboe, UNIKOM forces in Kuwait city and dr. Tor M. Hoel, NORMEDUNIT, Umm Quasr. Dr. Holmboe will spend one year in Kuwait, and is planning to perform a medical study (investigation) on a selection of one hundred persons highly exposed and less exposed to the plumes from the burning oil wells.

Dr. Holmboe briefly presented a first draft of a project proposal, where he indicated that a number of people would be followed every 2 month for the first half year and thereafter every 6 month. Several different types of chest studies and X-ray investigations will be undertaken.

During the discussions it was also mentioned that the Kuwait Health Department will perform a cohort investigation on ~500 persons in the Riqqa region. These are supposed to be followed up during the next 20 years. People selected from 11 clinics in Kuwait are also followed with various kind of "objective studies".

NILU pointed out the importance of establishing dose/response relationships. It was understood that also good air quality data and exposure estimates had to be available parallel to the health data.

## 11 WATER PROBLEMS

We briefly discussed other environmental problems in Kuwait. There is a comprehensive need for support in the field of water research. Kuwait needs "everything from simple pH-metres to research vessels". Drinking water quality problems have not been specified due to lack of instruments for bacterial counts etc. Atomic absorption instruments for analyses of water samples were destroyed during the war. Marine and sewage problems are also evident without enabling quantifying. Dr. Mahmood Y. Abdulrahmuna will visit Paris from 11 June 91 to "cry for help".

The Norwegian Institute for Water Research (NIVA) has been notified. A description of the problem, which was presented by dr. Mahmood, has been sent NIVA.

## 12 NORWEGIAN EMBASSY

We visited the Norwegian Embassy in Surra, Block 13, Street 13 where we met with mr. Jan Bråte, mr. Bjørn Bjerkås and mr. Bjørn Eriksen (Eksportrådet). Mr. Jan Bråte was informed about the NILU project plans, about the financial situation and about the results of discussions and site inspections in Kuwait.

## 13 PROTOCOL

A protocol with conclusions and agreements was established at the end of the visit to Kuwait. This protocol is presented in Appendix I.

# APPENDIX A

A) APPLICATION FOR VISUM TO KUWAIT

B) PEOPLE WE MET

WORLD HEALTH ORGANIZATION ORGANISATION MONDIALE DE LA SANTE

Téléphone Central/Exchange: 791.21.11
Direct: 791

Consulate General of the State of
Kuwait
GENEVA

In reply please refer to :
Prière de rappeler la référence: VISAS

05 June 1991

The World Health Organization in Geneva presents its compliments to the Consulate General of the State of Kuwait in Geneva and has the honour to submit to them the enclosed passport No G 0036655-7 issued to Mr Bjarne SIVERTSEN being of norwegian nationality who is travelling on official duty for the World Health Organization to Kuwait on 5 June 1991

The World Health Organization therefore requests that this document be endorsed with

an entry visa valid 1 week
within three months

The World Health Organization takes this opportunity of renewing to the Consulate General of the State of Kuwait its assurance of high esteem.

Annex : 1 laissez-passer
2 forms
2 photos

WORLD HEALTH ORGANIZATION · ORGANISATION MONDIALE DE LA SANTE

1211 GENEVA 27-SWITZERLAND Telegr.: UNISANTE-GENEVA Telex: 415416 OMS Fax 791.07.46 1211 GENEVE 27-SUISSE Télégr.:UNISANTE-GENEVE

## PEOPLE WE MET

Mr. Ibrahim M. Hadi, director EPD/secretary of EPC
Dr. Mostafa El Desouky, technical advisor, EPD
Dr. Mahmood Y. Abdulraheem, dep. dir., EPD

Mr. Yosi Malek, computer facility, EPD
Eng. (miss) Sabah Abd Al-Wa, responsible for monitoring stations, EPD-laboratory
Dr. Mohamed Abel, EPD laboratory
Mr. Ahmed Avorasiba, technical expert, EPD, head of workshop

Dr. Danny Foster, WMO representative
Mr. William R. Pendergrass, NOAA Oak Ridge, responsible for met. network

Mr. P.O. Vinjevoll, NORMEDUNIT, UNIKOM
Dr. Jens Holmboe, UNIKOM, health study, Kuwait city
Major Tor M. Hoel, NORMEDUNIT
Major Tor Munkelien, NORMEDUNIT, commander
Mr. Frøystein, NORMEDUNIT

Mr. Jan Bråte, Norske ambassade, Kuwait
Mr. Bjørn Bjerkås, Norske ambassade, Kuwait
Mr. Bjørn Eriksen, Eksportrådet, Ambassaden i Kuwait

ادارة حماية البيئة
وزارة الصحة العامة

دكتور
مصطفى الدسوقي
المستشار الفني

تلفون مكتب : ٢٤٥٦٨٣٢
فاكس : ٢٤٢١٩٩٣
منزل : ٥٧١٧٣٠٣

ص.ب : ٣٥٠٣٥
الشعب — الكويت
تلكس : ٤٦٤٠٨

Environment Protection Department
Ministry of Public Health

*Dr. Mostafa El-Desouky*
Technical Advisor

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Telex: 46408 EPCNCL KT.



د. محمود يوسف عبد الرحيم
نائب مدير ادارة حماية البيئة
وزارة الصحة

تلفون : ٢٤٥٦٨٣٣
٢٤٥٦٨٣٤
المنزل : ٥٣٨٦٣١٩

ص.ب : ٢٤٣٩٥ صفاة
كويت 13104
تلكس : ٤٦٤٠٨ EPCNCL
فاكس : ٢٤٢١٩٩٣

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سكرتير مجلس حماية البيئة
مدير ادارة حماية البيئة
وزارة الصحة العامة

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منزل ٥٣١٣٣٧٤ ـ ٥٣١٩٤٠٥

ص.ب ٢٤٣٩٥
صفاة ـ كويت
تلكس ٤٦٤٠٨ ـ كويت

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**UNITED NATIONS ENVIRONMENT PROGRAMME**
**UN INTER-AGENCY PLAN OF ACTION IN THE ROPME REGION**

**DR. PETER LITERATHY**
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# APPENDIX B

THE HORIBA STATION IN MANSOURIA

## HORIBA STATION MANSOURIA

The station is built up in a container with an entrance room as a working place for the maintenance assistant while inspecting the station. Between the foreroom and the instrument room is a sluice to prevent dust from entering the instrument room.

Cooling off the instrument room is performed by 2 air condition units "windowtype" in the end wall.

The central intake was a 10 cm stainless steel tube through the roof ending in a small fan. All monitors took sample air from this intake. The instrumentation was as follows:

1. Horiba model APHA-2010 Hydrocarbon monitor. The measuring principle is a flame ionization detector (FID), a partial combustion unit and a time controlled valve which gives signal out for total hydrocarbons (THC) and non-methane hydrocarbons (NMHC). The central data logger computes the content of $CH_4$.

2. Horiba model APNA-2010 Nitrous oxides monitor. The measuring principle is a single channel chemiluminescense detector. A time controlled valve gives NO and $NO_x$ as output. The data logger computes $NO_2$ as $NO_x$-NO.

3. Horiba model APOA-2010 Ozone monitor. The measuring principle is a chemiluminescense detector based on oxidizing of ethylene.

4. Horiba model APSA-2110 Sulphur monitor. The measuring principle is a flame photometer with a burning hydrogen flame. The monitor measures total sulphur (TS) which is defined as a sum of $H_2S$ and $SO_2$. A scrubber which removes the $H_2S$ is put into the sample input with a time controlled valve to produce an output of $SO_2$+$H_2S$=TS and $SO_2$ from the instrument. The $H_2S$ concentration is computed in the data logger.

5. Horiba model APMA-2010 Carbon monoxide monitor. The measuring principle is based on infrared absorption with reference to CO.

6. Meteorological instruments were mounted on a low mast at the roof. The instrumentation consists of:

   a) A 3 axis propeller anemometer, Swiss type.
   b) Temperature sensor based on termistor.
   c) Relative humidity sensor, Vaisala Electrochemical type.
   d) Pressure sensor
   e) Solar radiation
   f) Ultraviolet radiation

7. The particle concentration is measured with a "Digital Dust Indicator" (Aartac Inc., model P5) connected to the central intake. The principle is continuous measurement of 90 degrees scattered light.

8. All monitors, sensors and instruments are controlled by a data logger from the Swiss company ALCYON.

   The data logger is controlling daily span and zero check on all instruments based on 25 hours intervals. Data is computed every 5 minutes and recorded on a cassette tape and on a printer. Every hour is a simple maximum, minimum and sorting on wind direction and speed statistics printed on the printer as well.

   The calibration of the monitors is controlled manually every 21 days. This is performed by span gases with a dilution system of about 1:1000. Span gases for $SO_2$, NO, $CH_4$ and CO is used.

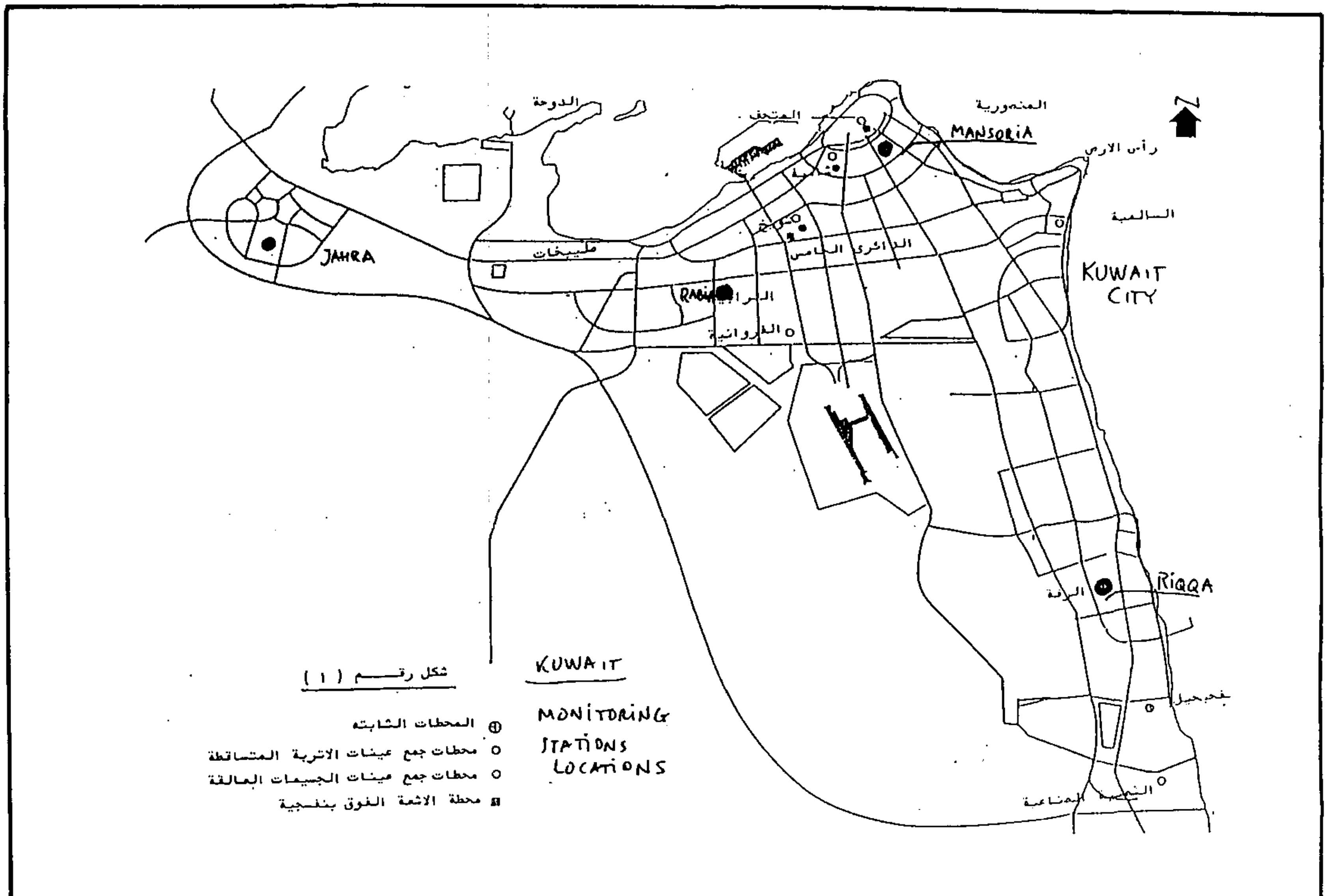
   The output to the tape and the printer is: Time, TS, $H_2S$, $SO_2$, THC, $CH_4$, $CH_4$, CO, $NH_3$, $NO_x$, $NO_2$, NO, $O_3$, temperature, humidity, Ws, Wa, pressure, solar, UVR and dust. The system has 2 spare channels for possible expansion. $NH_3$ is not measured on the Mansouria station, but on the other stations. The measuring principle is a converter connected to the $NO/NO_x$ monitor.

All systems are running on 110 Volt AC which requires a large 230/110 Volt transformer. The datalogger was equipped with a battery system for keeping the system clock undisturbed of mains failures.

The sample input to the monitors was protected with filters which had to be changed every week.

# APPENDIX C

AIR QUALITY DATA JUNE 1990


N
المنصورية
MANSORIA
رأس الارض
السالمية
KUWAIT CITY
الدوحة
المتحف
الدائري الخامس
مليبخات
JAHRA
RABIA
الرابية
الفروانية
RIQQA
الرقة
فنطاس
الصناعية
شكل رقم ( ١ )
KUWAIT
MONITORING STATIONS LOCATIONS
المحطات الثابته
محطات جمع عينات الاتربة المتساقطة
محطات جمع عينات الجسيمات العالقة
محطة الاشعة الفوق بنفسجية

جـــدول رقـم ( 1 )

MONTHLY MEAN CONCENTRATION OF THE GASES EXPRESSED AS PPM AND PPB
RECORDED BY THE AIR POLUTION MONITORING STATIONS TOGETHER WITH THE
MAXIMUM LEVEL AND THE PERCENTAGE DISTRIBUTION OF THE VALUES
EXCEEDING THE THRESHOLD LEVEL DURING
JUNE 1990

| GASES | LOCATIONS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | MANSORIA | | | RABIA | | | REQA | | |
| | MEAN | MAX | %EX. LIMIT | MEAN | MAX | %EX. LIMIT | MEAN | MAX | %EX. LIMIT |
| TS IN PPB | 2.765 | 85.000 | -- | 15.378 | 932.000 | -- | 1.873 | 21.000 | -- |
| H2S IN PPB | 1.251 | 84.000 | 5.5 | 12.463 | 863.000 | 16.5 | 0.253 | 20.000 | 1.3 |
| SO2 IN PPB | 1.431 | 12.000 | 0.0 | 2.953 | 142.000 | 1.2 | 1.284 | 3.000 | 0.0 |
| THC IN PPM | 2.116 | 8.060 | -- | 2.081 | 9.070 | -- | 2.138 | 9.410 | -- |
| NCH4 IN PPM | 0.342 | 6.130 | 49.9 | 0.650 | 4.250 | 87.1 | 0.357 | 7.690 | 39.2 |
| CH4 IN PPM | 1.772 | 4.520 | -- | 1.431 | 6.130 | -- | 1.780 | 4.600 | -- |
| NOX IN PPB | 26.224 | 460.000 | -- | 28.011 | 251.000 | -- | 33.533 | 540.000 | -- |
| NO IN PPB | 5.332 | 340.000 | 3.3 | 7.665 | 208.000 | 2.8 | 10.278 | 445.000 | 5.0 |
| NO2 IN PPB | 20.895 | 178.000 | 11.1 | 20.357 | 120.000 | 3.3 | 23.263 | 242.000 | 8.3 |
| CO IN PPM | 0.846 | 11.910 | 0.1 | 0.803 | 7.320 | 0.0 | 0.774 | 37.060 | 0.2 |
| O3 IN PPM | 0.013 | 0.137 | 0.4 | 0.010 | 0.066 | 0.0 | 0.012 | 0.053 | 0.0 |
| NH3 IN PPM | --- | --- | -- | --- | --- | -- | 0.063 | 1.580 | 10.8 |

جـدول رقـم ( 2 - 1 )

THE MEAN CONCENTRATION OF THE LEVEL OF SULFER COMPOUNDS
EXPRESSED IN PPB RECORDED AT MANSORIA, RABIA % REQA DURING
JUNE 1990 ACCORDING TO 3-HOUR INTERVAL OF THE DAY

| HOURS | TOTAL SULPHER | | | HYDROGENE SULPHIDE | | | SULPHER DIOXIDE | | |
|---|---|---|---|---|---|---|---|---|---|
| | MAN | RAB | REQ | MAN | RAB | REQ | MAN | RAB | REQ |
| 0-2 | 4.765 | 36.623 | 2.166 | 3.352 | 32.372 | 0.706 | 1.335 | 4.693 | 1.203 |
| 3-5 | 5.014 | 39.802 | 1.640 | 3.580 | 35.331 | 0.232 | 1.355 | 4.468 | 1.150 |
| 6-8 | 2.517 | 12.908 | 1.495 | 1.114 | 10.177 | 0.101 | 1.347 | 2.670 | 1.200 |
| 9-11 | 1.601 | 2.918 | 1.632 | 0.162 | 0.604 | 0.019 | 1.378 | 2.290 | 1.276 |
| 12-14 | 1.572 | 2.635 | 1.931 | 0.002 | 0.307 | 0.010 | 1.480 | 2.288 | 1.472 |
| 15-17 | 1.619 | 4.145 | 1.949 | 0.000 | 2.123 | 0.003 | 1.511 | 2.012 | 1.389 |
| 18-20 | 1.980 | 7.537 | 1.969 | 0.214 | 5.127 | 0.297 | 1.717 | 2.441 | 1.329 |
| 21-23 | 1.759 | 6.006 | 2.067 | 0.185 | 3.825 | 0.537 | 1.515 | 2.264 | 1.274 |

جدول رقم ( 2 - ب )

THE MEAN CONCENTRATION OF THE LEVEL OF HYDROCARBONS EXPRESSED IN PPM RECORDED AT MANSORIA, RABIA & REQA DURING JUNE 1990 ACCORDING TO 3-HOUR INTERVAL OF THE DAY

| HOURS | TOTAL HYDROCARBONS | | | NON-METHANE | | | METHANE | | |
|---|---|---|---|---|---|---|---|---|---|
| | MAN | RAB | REQ | MAN | RAB | REQ | MAN | RAB | REQ |
| 0-2 | 2.153 | 2.105 | 2.182 | 0.306 | 0.644 | 0.328 | 1.846 | 1.461 | 1.853 |
| 3-5 | 2.090 | 1.901 | 2.117 | 0.187 | 0.517 | 0.266 | 1.902 | 1.384 | 1.849 |
| 6-8 | 2.171 | 1.940 | 2.118 | 0.334 | 0.596 | 0.328 | 1.837 | 1.344 | 1.788 |
| 9-11 | 2.180 | 1.968 | 2.138 | 0.437 | 0.582 | 0.369 | 1.743 | 1.383 | 1.765 |
| 12-14 | 2.090 | 2.059 | 1.958 | 0.391 | 0.621 | 0.239 | 1.698 | 1.439 | 1.718 |
| 15-17 | 1.959 | 2.134 | 2.041 | 0.274 | 0.657 | 0.334 | 1.679 | 1.477 | 1.706 |
| 18-20 | 2.141 | 2.237 | 2.351 | 0.428 | 0.789 | 0.584 | 1.709 | 1.448 | 1.767 |
| 21-23 | 2.234 | 2.270 | 2.308 | 0.480 | 0.768 | 0.503 | 1.754 | 1.502 | 1.804 |

جدول رقم ( 2 - جـ )

THE MEAN CONCENTRATION OF THE LEVEL OF NITROGENE COMPS. EXPRESSED IN PPB RECORDED AT MANSORIA, RABIA & REQA DURING JUNE 1990 ACCORDING TO 3-HOUR INTERVAL OF THE DAY

| HOURS | TOTAL NITROGENE OXIDES | | | NITROGENE MONOXIDES | | | NITROGENE DIOXIDE | | |
|---|---|---|---|---|---|---|---|---|---|
| | MAN | RAB | REQ | MAN | RAB | REQ | MAN | RAB | REQ |
| 0-2 | 11.409 | 17.670 | 23.107 | 2.925 | 4.710 | 5.220 | 8.481 | 13.015 | 17.807 |
| 3-5 | 4.844 | 12.667 | 13.256 | 0.174 | 3.055 | 1.724 | 4.669 | 9.623 | 11.512 |
| 6-8 | 29.576 | 37.501 | 34.721 | 9.099 | 15.033 | 9.586 | 20.479 | 22.480 | 25.114 |
| 9-11 | 26.054 | 24.021 | 27.052 | 1.350 | 3.940 | 3.814 | 24.710 | 20.052 | 23.329 |
| 12-14 | 20.758 | 17.674 | 14.636 | 0.335 | 3.256 | 2.892 | 20.317 | 14.438 | 11.707 |
| 15-17 | 23.632 | 24.085 | 22.664 | 1.130 | 5.042 | 5.195 | 22.420 | 19.017 | 17.418 |
| 18-20 | 53.833 | 50.001 | 68.075 | 12.725 | 14.371 | 26.071 | 41.252 | 35.572 | 41.968 |
| 21-23 | 56.266 | 45.911 | 78.835 | 17.740 | 14.049 | 37.827 | 38.542 | 31.805 | 41.320 |

جـدول رقـم ( 2 - د )

THE MEAN CONCENTRATION OF THE LEVEL OF (CO, O3 AND NH3)
EXPRESSED IN PPM RECORDED AT MANSORIA, RABIA & REQA DURING
JUNE 1990 ACCORDING TO 3-HOUR INTERVAL OF THE DAY

| HOURS | CARBON MONOXIDE | | | OZON | | | AMONIA | | |
|---|---|---|---|---|---|---|---|---|---|
| | MAN | RAB | REQ | MAN | RAB | REQ | MAN | RAB | REQ |
| 0-2 | 0.382 | 0.460 | 0.433 | 0.008 | 0.011 | 0.010 | --- | --- | 0.055 |
| 3-5 | 0.251 | 0.339 | 0.275 | 0.007 | 0.010 | 0.010 | --- | --- | 0.034 |
| 6-8 | 0.921 | 0.918 | 0.681 | 0.007 | 0.007 | 0.008 | --- | --- | 0.045 |
| 9-11 | 1.085 | 0.818 | 0.645 | 0.010 | 0.012 | 0.015 | --- | --- | 0.045 |
| 12-14 | 0.772 | 0.563 | 0.399 | 0.018 | 0.015 | 0.021 | --- | --- | 0.056 |
| 15-17 | 0.701 | 0.738 | 0.582 | 0.023 | 0.014 | 0.018 | --- | --- | 0.061 |
| 18-20 | 1.586 | 1.516 | 1.833 | 0.017 | 0.007 | 0.006 | --- | --- | 0.091 |
| 21-23 | 1.580 | 1.384 | 1.723 | 0.011 | 0.006 | 0.004 | --- | --- | 0.121 |

جـدول رقـم ( 3 - 1 )

THE MEAN CONCENTRATION OF THE LEVEL OF SULFER COMPOUNDS
EXPRESSED IN PPB RECORDED AT MANSORIA, RABIA & REQA DURING
JUNE 1990 ACCORDING TO THE WIND DIRECTION

| WD | TOTAL SULPHER | | | HYDROGENE SULPHIDE | | | SULPHER DIOXIDE | | |
|---|---|---|---|---|---|---|---|---|---|
| | MAN | RAB | REQ | MAN | RAB | REQ | MAN | RAB | REQ |
| N | 1.477 | 7.207 | 1.937 | 0.018 | 5.080 | 0.360 | 1.376 | 2.174 | 1.264 |
| NE | 1.697 | 0.000 | 1.853 | 0.473 | 0.000 | 0.041 | 1.000 | 0.000 | 1.415 |
| E | 1.404 | 0.000 | 1.814 | 0.230 | 0.000 | 0.016 | 1.156 | 0.000 | 1.413 |
| SE | 1.062 | 0.000 | 1.815 | 0.075 | 0.000 | 0.007 | 0.960 | 0.000 | 1.323 |
| S | 2.907 | 10.480 | 1.813 | 1.241 | 7.306 | 0.020 | 1.598 | 3.167 | 1.278 |
| SW | 8.038 | 22.338 | 1.292 | 6.800 | 18.849 | 0.056 | 1.092 | 3.423 | 1.051 |
| W | 4.669 | 84.149 | 2.021 | 3.094 | 75.926 | 0.807 | 1.463 | 8.448 | 1.109 |
| NW | 1.601 | 3.332 | 1.783 | 0.026 | 1.220 | 0.328 | 1.525 | 2.053 | 1.224 |

جـدول رقـم ( 3 - ب )

THE MEAN CONCENTRATION OF THE LEVEL OF HYDROCARBONS
EXPRESSED IN PPM RECORDED AT MANSORIA, RABIA & REQA DURING
JUNE 1990 ACCORDING TO THE WIND DIRECTION

| WD | TOTAL HYDROCARBONS | | | NON-METHANE | | | METHANE | | |
|---|---|---|---|---|---|---|---|---|---|
| | MAN | RAB | REQ | MAN | RAB | REQ | MAN | RAB | REQ |
| N | 1.993 | 2.060 | 1.944 | 0.293 | 0.672 | 0.193 | 1.697 | 1.388 | 1.749 |
| NE | 2.277 | 0.000 | 1.883 | 0.606 | 0.000 | 0.149 | 1.663 | 0.000 | 1.733 |
| E | 2.839 | 0.000 | 2.194 | 1.016 | 0.000 | 0.439 | 1.822 | 0.000 | 1.754 |
| SE | 2.232 | 0.000 | 2.413 | 0.512 | 0.000 | 0.631 | 1.715 | 0.000 | 1.783 |
| S | 2.536 | 2.990 | 2.561 | 0.821 | 1.036 | 0.794 | 1.715 | 1.954 | 1.766 |
| SW | 2.523 | 2.039 | 2.745 | 0.584 | 0.545 | 0.910 | 1.940 | 1.494 | 1.836 |
| W | 2.128 | 1.691 | 2.946 | 0.278 | 0.597 | 1.010 | 1.849 | 1.105 | 1.935 |
| NW | 1.968 | 2.121 | 2.316 | 0.222 | 0.633 | 0.361 | 1.744 | 1.489 | 1.955 |

جـدول رقـم ( 3 - جـ )

THE MEAN CONCENTRATION OF THE LEVEL OF NITROGENE COMPS.
EXPRESSED IN PPB RECORDED AT MANSORIA, RABIA & REQA DURING
JUNE 1990 ACCORDING TO THE WIND DIRECTION

| WD | TOTAL NITROGENE OXIDES | | | NITROGENE MONOXIDES | | | NITROGENE DIOXIDE | | |
|---|---|---|---|---|---|---|---|---|---|
| | MAN | RAB | REQ | MAN | RAB | REQ | MAN | RAB | REQ |
| N | 24.665 | 25.451 | 30.580 | 3.266 | 6.333 | 8.858 | 21.355 | 19.119 | 21.717 |
| NE | 37.810 | 0.000 | 19.845 | 6.036 | 0.000 | 3.725 | 31.268 | 0.000 | 16.082 |
| E | 44.811 | 0.000 | 32.719 | 6.663 | 0.000 | 7.057 | 38.459 | 0.000 | 25.879 |
| SE | 44.015 | 0.000 | 25.796 | 5.952 | 0.000 | 5.221 | 38.070 | 0.000 | 20.568 |
| S | 91.935 | 47.902 | 44.808 | 41.594 | 13.252 | 11.524 | 50.382 | 34.543 | 33.309 |
| SW | 37.584 | 35.370 | 85.402 | 14.612 | 10.734 | 37.109 | 22.974 | 24.608 | 48.513 |
| W | 24.736 | 44.966 | 75.475 | 7.022 | 20.253 | 38.638 | 17.652 | 24.739 | 36.994 |
| NW | 18.361 | 23.696 | 23.331 | 1.754 | 5.178 | 5.322 | 16.630 | 18.547 | 17.961 |

جـدول رقم ( 3 - د )

THE MEAN CONCENTRATION OF THE LEVEL OF (CO, O3 AND NH3) EXPRESSED IN PPM RECORDED AT MANSORIA, RABIA & REQA DURING JUNE 1990 ACCORDING TO THE WIND DIRECTION

| WD | CARBON MONOXIDE | | | OZON | | | AMONIA | | |
|---|---|---|---|---|---|---|---|---|---|
| | MAN | RAB | REQ | MAN | RAB | REQ | MAN | RAB | REQ |
| N | 0.866 | 0.819 | 0.611 | 0.017 | 0.010 | 0.010 | --- | --- | 0.040 |
| NE | 1.203 | 0.000 | 0.489 | 0.011 | 0.000 | 0.013 | --- | --- | 0.034 |
| E | 1.333 | 0.000 | 0.818 | 0.015 | 0.000 | 0.019 | --- | --- | 0.043 |
| SE | 1.364 | 0.000 | 0.643 | 0.015 | 0.000 | 0.026 | --- | --- | 0.094 |
| S | 2.126 | 1.038 | 1.403 | 0.016 | 0.007 | 0.018 | --- | --- | 0.139 |
| SW | 0.914 | 0.838 | 2.429 | 0.004 | 0.013 | 0.005 | --- | --- | 0.282 |
| W | 0.756 | 0.970 | 1.607 | 0.006 | 0.009 | 0.003 | --- | --- | 0.122 |
| NW | 0.688 | 0.684 | 0.439 | 0.015 | 0.011 | 0.007 | --- | --- | 0.043 |

جـدول رقم ( 4 - ١ )

THE MEAN CONCENTRATION OF THE LEVEL OF SULFER COMPOUNDS EXPRESSED IN PPB RECORDED AT MANSORIA, RABIA & REQA DURING JUNE 1990 ACCORDING TO THE WIND SPEED IN m/s

| WS | TOTAL SULPHER | | | HYDROGENE SULPHIDE | | | SULPHER DIOXIDE | | |
|---|---|---|---|---|---|---|---|---|---|
| | MAN | RAB | REQ | MAN | RAB | REQ | MAN | RAB | REQ |
| 1m/s | 7.575 | 79.071 | 1.917 | 6.109 | 71.509 | 0.434 | 1.160 | 7.956 | 1.257 |
| 1-2 | 5.923 | 28.569 | 1.873 | 4.532 | 24.531 | 0.383 | 1.197 | 4.017 | 1.232 |
| 2-3 | 2.517 | 5.912 | 1.968 | 1.104 | 3.678 | 0.399 | 1.316 | 2.302 | 1.217 |
| 3-4 | 1.573 | 4.890 | 1.719 | 0.034 | 2.821 | 0.331 | 1.490 | 2.094 | 1.234 |
| 4-5 | 1.634 | 4.468 | 1.940 | 0.000 | 2.450 | 0.283 | 1.595 | 2.004 | 1.296 |
| 5-6 | 1.649 | 4.702 | 1.878 | 0.000 | 2.705 | 0.180 | 1.625 | 2.022 | 1.357 |
| 6-7 | 1.635 | 4.135 | 1.753 | 0.000 | 2.099 | 0.073 | 1.628 | 2.030 | 1.344 |
| 7-8 | 1.548 | 2.391 | 1.752 | 0.000 | 0.386 | 0.079 | 1.541 | 1.957 | 1.327 |
| 8-9 | 1.500 | 2.000 | 1.733 | 0.000 | 0.000 | 0.047 | 1.429 | 2.000 | 1.338 |
| 9-10 | 1.000 | 2.000 | 1.789 | 0.000 | 0.000 | 0.046 | 1.000 | 2.000 | 1.366 |
| 10+ | 0.000 | 0.000 | 1.794 | 0.000 | 0.000 | 0.009 | 0.000 | 0.000 | 1.411 |

جـدول رقم ( 4 - ب )

THE MEAN CONCENTRATION OF THE LEVEL OF HYDROCARBONS EXPRESSED IN PPM RECORDED AT MANSORIA, RABIA & REQA DURING JUNE 1990 ACCORDING TO THE WIND SPEED IN m/s

| WS | TOTAL HYDROCARBONS | | | NON-METHANE | | | METHANE | | |
|---|---|---|---|---|---|---|---|---|---|
| | MAN | RAB | REQ | MAN | RAB | REQ | MAN | RAB | REQ |
| 1m/s | 2.712 | 1.617 | 2.860 | 0.705 | 0.682 | 0.966 | 2.007 | 0.935 | 1.894 |
| 1-2 | 2.328 | 1.952 | 2.706 | 0.550 | 0.656 | 0.827 | 1.776 | 1.294 | 1.878 |
| 2-3 | 2.103 | 2.049 | 2.360 | 0.384 | 0.626 | 0.541 | 1.714 | 1.424 | 1.819 |
| 3-4 | 2.036 | 2.072 | 2.205 | 0.293 | 0.634 | 0.406 | 1.741 | 1.438 | 1.799 |
| 4-5 | 2.027 | 2.153 | 1.944 | 0.238 | 0.668 | 0.197 | 1.787 | 1.485 | 1.746 |
| 5-6 | 2.030 | 2.251 | 1.869 | 0.220 | 0.703 | 0.132 | 1.810 | 1.548 | 1.733 |
| 6-7 | 1.999 | 2.245 | 1.850 | 0.194 | 0.692 | 0.116 | 1.804 | 1.553 | 1.730 |
| 7-8 | 2.014 | 2.044 | 1.832 | 0.198 | 0.541 | 0.102 | 1.817 | 1.502 | 1.729 |
| 8-9 | 2.081 | 1.856 | 1.848 | 0.199 | 0.420 | 0.119 | 1.883 | 1.435 | 1.728 |
| 9-10 | 1.955 | 2.000 | 1.839 | 0.163 | 0.440 | 0.121 | 1.800 | 1.560 | 1.717 |
| 10+ | 0.000 | 0.000 | 1.800 | 0.000 | 0.000 | 0.094 | 0.000 | 0.000 | 1.705 |

جـدول رقم ( 4 - جـ )

THE MEAN CONCENTRATION OF THE LEVEL OF NITROGENE COMPS. EXPRESSED IN PPB RECORDED AT MANSORIA, RABIA & REQA DURING JUNE 1990 ACCORDING TO THE WIND SPEED IN m/s

| WS | TOTAL NITROGENE OXIDES | | | NITROGENE MONOXIDES | | | NITROGENE DIOXIDE | | |
|---|---|---|---|---|---|---|---|---|---|
| | MAN | RAB | REQ | MAN | RAB | REQ | MAN | RAB | REQ |
| 1m/s | 66.144 | 51.747 | 106.156 | 28.948 | 25.493 | 57.537 | 36.861 | 26.277 | 48.780 |
| 1-2 | 47.874 | 41.978 | 70.998 | 17.058 | 15.165 | 31.994 | 30.765 | 26.781 | 38.977 |
| 2-3 | 29.737 | 27.463 | 43.953 | 5.571 | 5.849 | 13.351 | 24.111 | 21.620 | 30.727 |
| 3-4 | 21.106 | 22.322 | 28.619 | 1.570 | 4.102 | 5.695 | 19.545 | 18.259 | 22.891 |
| 4-5 | 16.670 | 19.921 | 22.713 | 0.986 | 3.623 | 3.798 | 15.737 | 16.301 | 18.939 |
| 5-6 | 14.573 | 18.296 | 20.524 | 0.469 | 3.166 | 2.973 | 14.182 | 15.169 | 17.508 |
| 6-7 | 13.299 | 17.876 | 18.424 | 0.285 | 3.420 | 2.431 | 13.008 | 14.584 | 15.940 |
| 7-8 | 10.562 | 18.050 | 16.357 | 0.086 | 3.444 | 2.407 | 10.476 | 14.617 | 13.910 |
| 8-9 | 9.667 | 18.222 | 14.519 | 0.000 | 3.000 | 2.024 | 9.667 | 15.167 | 12.419 |
| 9-10 | 12.333 | 31.000 | 13.283 | 0.000 | 7.000 | 2.081 | 12.333 | 24.000 | 11.243 |
| 10+ | 0.000 | 0.000 | 13.278 | 0.000 | 0.000 | 1.926 | 0.000 | 0.000 | 11.380 |

جـدول رقم ( 4 - د )

THE MEAN CONCENTRATION OF THE LEVEL OF (CO, O3 AND NH3) EXPRESSED IN PPM RECORDED AT MANSORIA, RABIA & REQA DURING JUNE 1990 ACCORDING TO THE WIND SPEED IN m/s

| WS | CARBON MONOXIDE | | | OZON | | | AMONIA | | |
|---|---|---|---|---|---|---|---|---|---|
| | MAN | RAB | REQ | MAN | RAB | REQ | MAN | RAB | REG |
| 1m/s | 1.564 | 1.092 | 2.850 | 0.004 | 0.004 | 0.004 | --- | --- | 0.118 |
| 1-2 | 1.256 | 1.036 | 1.558 | 0.009 | 0.007 | 0.009 | --- | --- | 0.095 |
| 2-3 | 0.931 | 0.805 | 0.987 | 0.010 | 0.011 | 0.012 | --- | --- | 0.093 |
| 3-4 | 0.758 | 0.701 | 0.628 | 0.013 | 0.013 | 0.011 | --- | --- | 0.082 |
| 4-5 | 0.639 | 0.648 | 0.511 | 0.015 | 0.013 | 0.012 | --- | --- | 0.054 |
| 5-6 | 0.607 | 0.605 | 0.451 | 0.017 | 0.012 | 0.012 | --- | --- | 0.033 |
| 6-7 | 0.578 | 0.593 | 0.423 | 0.023 | 0.012 | 0.013 | --- | --- | 0.030 |
| 7-8 | 0.588 | 0.590 | 0.380 | 0.024 | 0.011 | 0.014 | --- | --- | 0.032 |
| 8-9 | 0.455 | 0.584 | 0.370 | 0.028 | 0.010 | 0.014 | --- | --- | 0.030 |
| 9-10 | 0.585 | 1.020 | 0.349 | 0.029 | 0.005 | 0.015 | --- | --- | 0.026 |
| 10+ | 0.750 | 0.000 | 0.367 | 0.004 | 0.000 | 0.015 | --- | --- | 0.022 |

جـدول رقم ( 5 - 1 )

Measurements of Ultraviolet Radiation (UVA), Recorded by International Light Detector, Mutzhas Meter, and Eplab UV Detector during June (1990), expressed in W/m^2

| Date | IL 442 Detector 320-400nm | Mutzhas Meter 330-380nm | Eplab UV-Detector 290-385nm | Date | IL 442 Detector 320-400nm | Mutzhas Meter 330-380nm | Eplab UV-Detector 290-385nm |
|---|---|---|---|---|---|---|---|
| 1 | ----- | ----- | 42.67 | 16 | 41.83 | 37.30 | 37.67 |
| 2 | 40.16 | 34.30 | 44.33 | 17 | 44.00 | 38.96 | ----- |
| 3 | 40.83 | 35.23 | 41.00 | 18 | 43.00 | 37.76 | 45.33 |
| 4 | 39.00 | 34.00 | 38.00 | 19 | 40.33 | 33.26 | 44.00 |
| 5 | 39.67 | 35.16 | 38.33 | 20 | 41.67 | 34.93 | 43.33 |
| 6 | 18.33 | 15.76 | 21.00 | 21 | 32.67 | 23.67 | 37.00 |
| 7 | 29.33 | 26.67 | 31.67 | 22 | ----- | ----- | 39.67 |
| 8 | ----- | ----- | 44.00 | 23 | 8.67 | 6.60 | 7.00 |
| 9 | 44.00 | 39.23 | 44.33 | 24 | 41.67 | 36.56 | 42.33 |
| 10 | 43.33 | 37.93 | 41.00 | 25 | 42.67 | 36.20 | 44.00 |
| 11 | 41.67 | 37.37 | ----- | 26 | 41.33 | 35.70 | 42.33 |
| 12 | 44.00 | 38.73 | ----- | 27 | 43.00 | 38.03 | 44.67 |
| 13 | 41.33 | 36.23 | ----- | 28 | 42.33 | 37.80 | 43.33 |
| 14 | 38.67 | 33.23 | 39.67 | 29 | ----- | ----- | 32.67 |
| 15 | ----- | ----- | 43.67 | 30 | ----- | ----- | 45.67 |

جـدول رقم ( 5 - ب )

Measurements of Ultraviolet Radiation (UVB) , Recorded by Polysulfone Films and International Light Detector during June (1990) , expressed in W/m^2

| Date | Polysulfone Film 280-320nm | IL 443 Detector 280-320nm | Date | Polysulfone Film 280-320nm | IL 443 Detector 280-320nm |
|---|---|---|---|---|---|
| 1 | ----- | ----- | 16 | 2.510 | 2.510 |
| 2 | 2.650 | 2.520 | 17 | 2.850 | 2.760 |
| 3 | 2.600 | 2.760 | 18 | 2.520 | 2.500 |
| 4 | 2.330 | 2.320 | 19 | 2.610 | 2.550 |
| 5 | 2.530 | 2.480 | 20 | 2.550 | 2.590 |
| 6 | 1.270 | 1.270 | 21 | 2.030 | 1.960 |
| 7 | 1.710 | 1.700 | 22 | ----- | ----- |
| 8 | ----- | ----- | 23 | 0.470 | 0.230 |
| 9 | 2.910 | 2.860 | 24 | 2.560 | 2.540 |
| 10 | 2.990 | 2.950 | 25 | 2.910 | 2.700 |
| 11 | 2.900 | 2.880 | 26 | 2.740 | 2.460 |
| 12 | 3.120 | 2.920 | 27 | 2.950 | 2.770 |
| 13 | 3.280 | 2.620 | 28 | 2.740 | 2.550 |
| 14 | 2.290 | 2.240 | 29 | ----- | ----- |
| 15 | ----- | ----- | 30 | ----- | ----- |

جـدول رقـم ( 5 - جـ )

Measurements of Solar Radiation recorded by Mansoria Station
during June (1990) expressed in W/m^2

| Hour | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Day | | | | | | | | | | | | | | | |
| 1 | | 121 | 329 | 539 | 737 | 887 | 975 | 1010 | 973 | 848 | 683 | 469 | 252 | 53 | |
| 2 | | 147 | 357 | 570 | 752 | 905 | 990 | 1029 | 989 | 866 | 693 | 485 | 263 | 62 | |
| 3 | | 136 | 344 | 549 | 733 | 888 | 976 | 997 | 959 | 836 | 666 | 465 | 251 | 50 | |
| 4 | | 125 | 317 | 530 | 700 | 845 | 944 | 990 | 931 | 796 | 640 | 457 | 226 | 54 | |
| 5 | | 134 | 351 | 553 | 746 | 898 | 990 | 985 | 975 | 850 | 663 | 459 | 234 | 52 | |
| 6 | | 128 | 320 | 527 | 704 | 830 | 781 | 663 | 768 | 737 | 591 | 425 | 236 | 58 | |
| 7 | | 158 | 386 | 607 | 799 | 916 | 1002 | 896 | 818 | 495 | 293 | 169 | 89 | 30 | |
| 8 | | 152 | 390 | 608 | 795 | 937 | 1018 | 1053 | 1010 | 898 | 732 | 530 | 300 | 71 | |
| 9 | | 155 | 363 | 564 | 779 | 950 | 1041 | 1078 | 1037 | 904 | 729 | 528 | 285 | 74 | |
| 10 | | 141 | 355 | 576 | 765 | 887 | 994 | 1010 | 936 | 851 | 687 | 487 | 264 | 66 | |
| *11 | | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | |
| *12 | | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | |
| *13 | | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | |
| *14 | | -- | -- | -- | -- | -- | 970 | 1007 | 960 | 841 | 675 | 416 | 236 | 67 | |
| 15 | | 142 | 356 | 577 | 767 | 926 | 1027 | 1053 | 1000 | 877 | 715 | 494 | 264 | 70 | |
| 16 | | 133 | 320 | 530 | 715 | 864 | 941 | 993 | 962 | 851 | 625 | 373 | 234 | 73 | |
| *17 | | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | |
| *18 | | -- | -- | -- | 802 | 892 | 1003 | 1051 | 987 | 884 | 713 | 493 | 278 | 89 | |
| 19 | | 141 | 348 | 559 | 761 | 890 | 997 | 1026 | 957 | 881 | 710 | 502 | 283 | 79 | |
| 20 | | 137 | 343 | 577 | 750 | 902 | 968 | 1026 | 1001 | 897 | 713 | 510 | 268 | 75 | |
| 21 | | 157 | 366 | 586 | 787 | 912 | 904 | 960 | 896 | 772 | 542 | 401 | 207 | 61 | |
| 22 | | 149 | 361 | 568 | 749 | 873 | 971 | 978 | 847 | 761 | 589 | 267 | 138 | 42 | |
| 23 | | 162 | 388 | 601 | 760 | 777 | 644 | 446 | 519 | 525 | 451 | 306 | 181 | 43 | |
| 24 | | 144 | 364 | 577 | 752 | 921 | 1015 | 1013 | 978 | 776 | 622 | 377 | 172 | 42 | |
| 25 | | 139 | 351 | 570 | 762 | 916 | 1007 | 1032 | 716 | 875 | 677 | 466 | 259 | 65 | |
| 26 | | 138 | 356 | 563 | 737 | 890 | 981 | 1021 | 986 | 849 | 662 | 467 | 255 | 65 | |
| 27 | | 151 | 364 | 579 | 766 | 909 | 1007 | 1039 | 986 | 879 | 708 | 489 | 263 | 42 | |
| 28 | | 164 | 386 | 617 | 819 | 953 | 1041 | 1040 | 1025 | 816 | 704 | 471 | 277 | 72 | |
| 29 | | 157 | 382 | 602 | 783 | 910 | 936 | 867 | 932 | 860 | 664 | 460 | 264 | 66 | |
| 30 | | 155 | 378 | 592 | 773 | 914 | 1010 | 1052 | 992 | 869 | 685 | 451 | 249 | 71 | |
| 31 | | | | | | | | | | | | | | | |

* Cut-Off Electricity

جـدول رقـم ( 6 - 1 )

Distribution of Settled Daily Dust
JUNE (1990)
(grams/square meter/day)

| Date | Locations | | | Daily Mean | Total No. of Sample |
|---|---|---|---|---|---|
| | Shuwaikh Industrial Area | Kuwait City | Al-Jahra | | |
| 1/ 6/90 | 0.478 | 0.458 | ----- | 0.468 | 2 |
| 2/ 6/90 | 0.826 | 0.756 | 0.687 | 0.756 | 3 |
| 3/ 6/90 | 3.613 | 3.065 | 8.877 | 5.185 | 3 |
| 4/ 6/90 | 5.245 | 4.723 | 18.650 | 9.539 | 3 |
| 5/ 6/90 | 3.394 | 3.658 | 13.057 | 6.703 | 3 |
| 6/ 6/90 | 20.232 | 20.740 | 60.150 | 33.707 | 3 |
| 7/ 6/90 | 25.527 | 34.131 | ----- | 29.829 | 2 |
| 8/ 6/90 | 0.587 | 0.736 | ----- | 0.662 | 2 |
| 9/ 6/90 | 0.816 | 0.677 | 1.035 | 0.843 | 3 |
| 10/ 6/90 | 2.189 | 1.270 | 3.115 | 2.191 | 3 |
| 11/ 6/90 | 0.627 | 0.577 | 1.334 | 0.846 | 3 |
| 12/ 6/90 | 0.916 | 0.846 | 1.234 | 0.999 | 3 |
| 13/ 6/90 | 0.557 | 0.468 | 1.015 | 0.680 | 3 |
| 14/ 6/90 | 4.498 | 2.816 | ----- | 3.657 | 2 |
| 15/ 6/90 | 1.065 | 0.806 | ----- | 0.936 | 2 |
| 16/ 6/90 | 1.334 | 1.373 | 1.483 | 1.397 | 3 |
| 17/ 6/90 | 1.509 | 1.015 | 2.185 | 1.570 | 3 |
| 18/ 6/90 | 0.876 | 0.587 | 1.980 | 1.148 | 3 |
| 19/ 6/90 | 2.787 | 2.249 | 1.821 | 2.286 | 3 |
| 20/ 6/90 | 2.528 | 1.742 | 6.071 | 3.447 | 3 |
| 21/ 6/90 | 6.747 | 5.792 | ----- | 6.270 | 2 |
| 22/ 6/90 | 10.251 | 12.749 | ----- | 11.500 | 2 |
| 23/ 6/90 | 31.349 | 47.829 | 98.499 | 59.226 | 3 |
| 24/ 6/90 | 2.757 | 2.249 | 5.892 | 3.633 | 3 |
| 25/ 6/90 | 0.796 | 0.617 | 1.921 | 1.111 | 3 |
| 26/ 6/90 | 0.587 | 0.518 | 0.969 | 0.691 | 3 |
| 27/ 6/90 | 0.806 | 0.717 | 1.188 | 0.762 | 3 |
| 28/ 6/90 | 5.304 | 4.429 | ----- | 4.867 | 2 |
| 29/ 6/90 | 6.081 | 7.583 | ----- | 6.832 | 2 |
| 30/ 6/90 | 0.916 | 0.766 | ----- | 0.841 | 2 |
| 31/ 6/90 | ----- | ----- | ----- | ----- | - |
| Mean | 4.840 | 5.531 | 11.558 | 6.779 | 80 |
| S.D.± | 7.583 | 10.691 | 24.444 | 14.648 | |

جـدول رقـم ( 6 - ب )

Distribution of Sulphates and Nitrates in Monthly
Dust fall out samples
May (1990)

| Location | Monthly Dust fall out (Tons/Km2) | Weight and Percentage | | | |
|---|---|---|---|---|---|
| | | Sulphate | | Nitrate | |
| | | Wt. | % | Wt. | % |
| 1.Kuwait City | 040.194 | 01.477 | 03.675 | 0.029 | 0.072 |
| 2.Shamiah | 021.739 | 00.973 | 04.476 | 0.009 | 0.041 |
| 3.Sulaibikhat | 032.113 | 05.648 | 17.588 | 0.023 | 0.072 |
| 4.Mutlaa | 254.971 | 31.283 | 12.269 | 0.115 | 0.045 |
| 5.Farwaniah | 033.396 | 02.155 | 06.453 | 0.006 | 0.018 |
| 6.Shuaibah | 005.628 | 01.224 | 21.748 | 0.060 | 1.066 |
| 7.Salmiah | 126.385 | 15.300 | 12.106 | 0.097 | 0.077 |
| 8.Fahaheel | 009.155 | 00.612 | 06.685 | 0.050 | 0.546 |
| 9.Shuwaikh | 175.593 | 25.200 | 14.351 | 0.040 | 0.023 |
| 10.Khiran | 059.262 | 11.250 | 18.983 | 0.097 | 0.164 |
| Monthly Mean | 075.844 | 09.512 | 11.833 | 0.053 | 0.212 |
| S.D.± | 083.104 | 11.111 | 06.371 | 0.039 | 0.338 |

جـدول رقـم ( 7 - 1 )

Concentration of Suspended Particulate Matter in daily samples
June (1990)
(micrograms/cubic meter)

| Date | Locations | | | | Daily Mean | Total Samples |
|---|---|---|---|---|---|---|
| | Shuwaikh | Kuwait City | Shamiah | Al-Jahra | | |
| 1/ 6/90 | ----- | ----- | ----- | ----- | ----- | - |
| 2/ 6/90 | ----- | ----- | ----- | ----- | ----- | - |
| 3/ 6/90 | ----- | ----- | 616.9 | 1089.1 | 853.0 | 2 |
| 4/ 6/90 | 903.1 | 710.3 | ----- | ----- | 806.7 | 2 |
| 5/ 6/90 | ----- | ----- | 606.9 | 753.3 | 680.1 | 2 |
| 6/ 6/90 | ----- | 1355.2 | ----- | ----- | 1355.2 | 1 |
| 7/ 6/90 | ----- | ----- | 2228.3 | 1780.6 | 2004.5 | 2 |
| 8/ 6/90 | 328.0 | 235.2 | ----- | ----- | 281.6 | 2 |
| 9/ 6/90 | ----- | ----- | 229.1 | 456.1 | 342.6 | 2 |
| 10/ 6/90 | 323.9 | 302.2 | ----- | ----- | 313.1 | 2 |
| 11/ 6/90 | ----- | ----- | 235.4 | 297.6 | 266.5 | 2 |
| 12/ 6/90 | 382.7 | 226.9 | ----- | ----- | 304.8 | 2 |
| 13/ 6/90 | ----- | ----- | 214.0 | 318.3 | 266.2 | 2 |
| 14/ 6/90 | 447.4 | 387.6 | ----- | ----- | 417.5 | 2 |
| 15/ 6/90 | ----- | ----- | 304.9 | 374.6 | 339.8 | 2 |
| 16/ 6/90 | 552.5 | 390.3 | ----- | ----- | 471.4 | 2 |
| 17/ 6/90 | ----- | ----- | 288.0 | 365.3 | 326.7 | 2 |
| 18/ 6/90 | ----- | ----- | ----- | ----- | ----- | - |
| 19/ 6/90 | ----- | ----- | 345.9 | 356.7 | 351.3 | 2 |
| 20/ 6/90 | 492.0 | 349.7 | ----- | ----- | 420.9 | 2 |
| 21/ 6/90 | ----- | ----- | 796.8 | 730.8 | 763.8 | 2 |
| 22/ 6/90 | 1375.4 | 1266.9 | ----- | ----- | 1321.2 | 2 |
| 23/ 6/90 | ----- | ----- | 1443.5 | 1853.3 | 1648.4 | 2 |
| 24/ 6/90 | 887.7 | 767.2 | ----- | ----- | 827.5 | 2 |
| 25/ 6/90 | ----- | ----- | 261.4 | 360.5 | 310.9 | 2 |
| 26/ 6/90 | 408.9 | 310.9 | ----- | ----- | 359.9 | 2 |
| 27/ 6/90 | ----- | ----- | ----- | ----- | ----- | - |
| 28/ 6/90 | ----- | ----- | ----- | ----- | ----- | - |
| 29/ 6/90 | ----- | ----- | 1042.9 | ----- | 1042.9 | 1 |
| 30/ 6/90 | 432.9 | 353.8 | ----- | ----- | 393.4 | 2 |
| Mean | 594.0 | 554.7 | 662.6 | 728.0 | 636.3 | 48 |
| S.D.$\pm$ | 327.8 | 391.7 | 600.7 | 560.9 | 478.6 | |

جـدول رقم ( 7 - ب )

Size Distribution of Suspended Particulate Matter
June (1990)

| Particle Size | Size Range (micron) | Shuwaikh (n=2) | | | kuwait City (n=3) | | | Shamiah (n=3) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean Conc. ug/m3 | % in Size Range | Cumul Freq. % | Mean Conc. ug/m3 | % in Size Range | Cumul Freq. % | Mean Conc. ug/m3 | % in Size Range | Cumul Freq. % |
| R E S P I R A B L E | 0.1-1.1 | 282.7 | 30.3 | 30.3 | 793.9 | 50.6 | 50.6 | 273.6 | 31.82 | 31.8 |
| | 1.1-2.0 | 57.8 | 6.2 | 36.5 | 75.6 | 4.8 | 55.4 | 43.0 | 05.00 | 36.8 |
| | 2.0-3.3 | 107.0 | 11.4 | 47.9 | 126.7 | 8.1 | 63.5 | 97.4 | 11.33 | 48.2 |
| | 3.3-7.0 | 162.1 | 17.4 | 65.3 | 158.8 | 10.1 | 73.6 | 129.3 | 15.04 | 63.2 |
| Non Re-spirable | > 7.0 | 323.9 | 34.7 | 100.0 | 413.7 | 26.4 | 100.0 | 316.5 | 36.81 | 100.0 |
| T o t a l | | 933.5 | 100.0 | — | 1568.7 | 100.0 | — | 859.8 | 100.0 | — |

# APPENDIX D

AIR QUALITY DATA APRIL 1991

جدول رقم( 1 )

MON..LY MEAN CONCENTRATION OF THE GASES EXPRESSED AS PPM AND PPB RECORDED BY THE AIR POLUTION MONITORING STATIONS TOGETHER WITH THE MAXIMUM LEVEL AND THE PERCENTAGE DISTRIBUTION OF THE VALUES EXCEEDING THE THRESHOLD LEVEL DURING APRIL 1991

| GASES | LOCATIONS | | | | | |
|---|---|---|---|---|---|---|
| | MANSORIA | | | REQA | | |
| | MEAN | MAX | %EX. LIMIT | MEAN | MAX | %EX. LIMIT |
| TS IN PPB | 3.124 | 40.000 | — | 1.823 | 27.000 | -- |
| H2S IN PPB | 0.087 | 11.000 | 0.1 | 0.050 | 6.000 | 0.1 |
| SO2 IN PPB | 3.016 | 38.000 | 2.6 | .1.603 | 22.000 | 0.0 |
| THC IN PPM | 6.347 | 18.950 | — | 2.626 | 8.980 | — |
| NCH4 IN PPM | 1.742 | 13.140 | 76.4 | 0.781 | 6.150 | 62.0 |
| CH4 IN PPM | 4.596 | 18.950 | -- | 1.845 | 3.760 | -- |
| NOX IN PPB | 20.264 | 742.000 | — | 58.848 | 1011.000 | — |
| NO IN PPB | 8.032 | 341.000 | 5.1 | 39.096 | 1006.000 | 10.1 |
| NO2 IN PPB | 12.226 | 496.000 | 2.3 | 19.731 | 167.000 | 6.3 |
| CO IN PPM | 0.643 | 7.280 | 0.0 | 0.492 | 32.370 | 0.0 |
| O3 IN PPM | 0.003 | 0.015 | 0.0 | 0.017 | 0.161 | 2.9 |
| NH3 IN PPM | --- | --- | — | 0.011 | 1.560 | 1.3 |

جدول رقم ( 2 )

Daily average of measurements at:
Mansoriya Apr 1991

| Day | SO2 ppm | CH4 ppm | NCH4 ppm | NO ppm | NO2 ppm | CO ppm | O3 ppm |
|---|---|---|---|---|---|---|---|
| 1 | .0021 | 3.928 | .1147 | .0406 | .0258 | 1.479 | .0002 |
| 2 | .0021 | 3.223 | .1561 | .0330 | .0325 | 1.541 | .0004 |
| 3 | .0020 | 2.856 | .1277 | .0120 | .0268 | .7198 | .0002 |
| 4 | .0020 | 3.692 | .6543 | .0101 | .0197 | .8816 | .0034 |
| 5 | .0020 | 2.637 | .2930 | .0096 | .0086 | .6355 | .0017 |
| 6 | .0020 | 3.500 | .5097 | .0043 | .0102 | .6048 | .0016 |
| 7 | .0020 | 1.918 | .4141 | 0.000 | .0025 | .3225 | .0032 |
| 8 | .0020 | 2.291 | .1829 | .0054 | .0155 | .5953 | .0026 |
| 9 | .0021 | 2.604 | 1.123 | .0088 | .0109 | .5268 | .0046 |
| 10 | .0020 | 2.570 | .2177 | .0364 | .0185 | 1.344 | .0032 |
| 11 | .0020 | 3.793 | .9982 | .0037 | .0088 | .4991 | .0034 |
| 12 | .0019 | 5.119 | 2.930 | 0.000 | .0016 | .2669 | .0085 |
| 13 | .0018 | 5.228 | 2.916 | 0.000 | .0005 | .3212 | .0039 |
| 14 | .0020 | 5.426 | 2.255 | 0.000 | .0035 | .3620 | .0039 |
| 15 | .0020 | 4.640 | 1.082 | .0237 | .0172 | 1.030 | .0019 |
| 16 | .0199 | 4.071 | 1.337 | .0042 | .0156 | .6454 | .0010 |
| 17 | .0082 | 5.016 | 2.924 | .0001 | .0136 | .4661 | .0043 |
| 18 | .0020 | 3.233 | 1.359 | .0034 | .0095 | .6012 | .0023 |
| 19 | .0020 | 3.589 | 1.668 | .0154 | .0144 | .8082 | .0041 |
| 20 | .0020 | 3.079 | .9405 | .0002 | .0126 | .5026 | .0035 |
| 21 | .0020 | 4.008 | 1.653 | .0002 | .0067 | .4534 | .0045 |
| 22 | .0020 | 5.068 | 2.284 | .0000 | .0047 | .3523 | .0012 |
| 23 | .0020 | 11.26 | 1.755 | 0.000 | .0021 | .3520 | .0000 |
| 24 | .0024 | 6.762 | 2.145 | .0018 | .0162 | .5536 | .0018 |
| 25 | .0042 | 3.269 | 1.036 | .0013 | .0089 | .3202 | .0004 |
| 29 | .0019 | 4.584 | 2.892 | .0001 | .0083 | .4402 | .0053 |
| 30 | .0018 | 5.049 | 1.077 | .0061 | .0162 | .6440 | .0034 |
| TOTA | .0030 | 4.596 | 1.742 | .0080 | .0122 | .6430 | .0028 |

جدول رقم ( 2 ب )

Daily average of measurements at:
Reqa Apr 1991

| Day | SO2 ppm | CH4 ppm | NCH4 ppm | NO ppm | NO2 ppm | CO ppm | O3 ppm |
|---|---|---|---|---|---|---|---|
| 7 | .0012 | . | . | | | .4984 | .0065 |
| 8 | .0013 | 1.843 | 1.087 | . | . | .6016 | .0055 |
| 9 | .0011 | 1.833 | .9289 | . | . | .4732 | .0061 |
| 10 | .0014 | 1.889 | .6418 | .0178 | .0158 | .8068 | .0097 |
| 11 | .0018 | 2.040 | 1.303 | .0044 | .0069 | .5283 | .0098 |
| 12 | .0017 | 1.834 | .0993 | . | . | .3483 | .0114 |
| 13 | .0014 | 1.867 | .0923 | . | . | .3763 | .0118 |
| 14 | .0010 | 1.864 | .1610 | . | . | .4117 | .0120 |
| 15 | .0011 | 1.969 | 1.098 | . | . | .5096 | .0094 |
| 16 | .0011 | 1.877 | 1.932 | . | . | .5058 | .0107 |
| 17 | .0015 | 1.921 | 1.314 | .0039 | .0142 | .5207 | .0178 |
| 18 | .0013 | 1.826 | .9252 | .0015 | .0130 | .4697 | .0173 |
| 19 | .0018 | 1.811 | .9210 | .0048 | .0161 | .5571 | .0175 |
| 20 | .0011 | 1.831 | .6204 | .0048 | .0215 | .6478 | .0154 |
| 21 | .0020 | 1.792 | .1792 | .0000 | .0093 | .3217 | .0201 |
| 22 | .0018 | 1.760 | .5374 | .0025 | .0164 | .5819 | .0199 |
| 23 | .0018 | 1.762 | .2054 | .0003 | .0132 | .3686 | .0210 |
| 24 | .0020 | 1.824 | .6971 | .0018 | .0174 | .5034 | .0203 |
| 25 | .0027 | 2.012 | 1.688 | .0255 | .0402 | 1.493 | .0062 |
| 26 | .0021 | 1.780 | .8114 | .0027 | .0398 | .3454 | .0093 |
| 27 | .0020 | 1.648 | .1872 | .0267 | .0218 | .3207 | .0188 |
| 28 | .0020 | 1.676 | .0622 | .0121 | .0128 | .2911 | .0195 |
| 29 | .0020 | . | . | .2132 | .0173 | .1933 | .0599 |
| 30 | . | . | . | .2279 | .0235 | .1510 | .1250 |
| TOTA | .0016 | 1.845 | .7811 | .0391 | .0197 | .4922 | .0172 |

جدول رقم ( 3 أ )

THE MEAN CONCENTRATION OF THE LEVEL OF SULFER COMPOUNDS
EXPRESSED IN PPB RECORDED AT MANSORIA, RABIA & REQA DURING
APRIL 1991 ACCORDING TO 3-HOUR INTERVAL OF THE DAY

| HOURS | TOTAL SULPHER | | | HYDROGENE SULPHIDE | | | SULPHER DIOXIDE | | |
|---|---|---|---|---|---|---|---|---|---|
| | MAN | RAB | REQ | MAN | RAB | REQ | MAN | RAB | REQ |
| 0-2 | 3.197 | ******* | 1.777 | 0.194 | ******* | 0.064 | 2.998 | ******* | 1.575 |
| 3-5 | 2.862 | ******* | 1.830 | 0.033 | ******* | 0.082 | 2.796 | ******* | 1.616 |
| 6-8 | 2.367 | ******* | 2.172 | 0.017 | ******* | 0.152 | 2.329 | ******* | 1.837 |
| 9-11 | 3.402 | ******* | 1.805 | 0.111 | ******* | 0.047 | 3.255 | ******* | 1.607 |
| 12-14 | 3.602 | ******* | 1.746 | 0.094 | ******* | 0.008 | 3.474 | ******* | 1.578 |
| 15-17 | 3.226 | ******* | 1.711 | 0.092 | ******* | 0.008 | 3.117 | ******* | 1.477 |
| 18-20 | 3.079 | ******* | 1.780 | 0.068 | ******* | 0.026 | 2.998 | ******* | 1.578 |
| 21-23 | 3.095 | ******* | 1.829 | 0.058 | ******* | 0.033 | 3.029 | ******* | 1.617 |

جدول رقم ( 3 ب)

THE MEAN CONCENTRATION OF THE LEVEL OF HYDROCARBONS EXPRESSED IN PPM RECORDED AT MANSORIA, RABIA & REQA DURING APRIL 1991 ACCORDING TO 3-HOUR INTERVAL OF THE DAY

| HOURS | TOTAL HYDROCARBONS | | | NON-METHANE | | | METHANE | | |
|---|---|---|---|---|---|---|---|---|---|
| | MAN | RAB | REQ | MAN | RAB | REQ | MAN | RAB | REQ |
| 0-2 | 6.620 | ******* | 2.687 | 1.819 | ******* | 0.786 | 4.801 | ******* | 1.901 |
| 3-5 | 6.113 | ******* | 2.678 | 1.341 | ******* | 0.803 | 4.771 | ******* | 1.876 |
| 6-8 | 6.441 | ******* | 2.753 | 1.550 | ******* | 0.908 | 4.891 | ******* | 1.846 |
| 9-11 | 6.377 | ******* | 2.504 | 1.950 | ******* | 0.700 | 4.413 | ******* | 1.805 |
| 12-14 | 6.304 | ******* | 2.260 | 2.059 | ******* | 0.496 | 4.205 | ******* | 1.760 |
| 15-17 | 6.395 | ******* | 2.356 | 1.880 | ******* | 0.594 | 4.495 | ******* | 1.762 |
| 18-20 | 5.893 | ******* | 2.863 | 1.607 | ******* | 0.978 | 4.285 | ******* | 1.885 |
| 21-23 | 6.062 | ******* | 2.853 | 1.590 | ******* | 0.962 | 4.472 | ******* | 1.891 |

جدول رقم ( 3 ج)

THE MEAN CONCENTRATION OF THE LEVEL OF NITROGENE COMPS. EXPRESSED IN PPB RECORDED AT MANSORIA, RABIA & REQA DURING APRIL 1991 ACCORDING TO 3-HOUR INTERVAL OF THE DAY

| HOURS | TOTAL NITROGENE OXIDES | | | NITROGENE MONOXIDES | | | NITROGENE DIOXIDE | | |
|---|---|---|---|---|---|---|---|---|---|
| | MAN | RAB | REQ | MAN | RAB | REQ | MAN | RAB | REQ |
| 0-2 | 21.187 | ******* | 79.809 | 11.723 | ******* | 57.159 | 9.717 | ******* | 22.371 |
| 3-5 | 7.704 | ******* | 59.267 | 2.542 | ******* | 46.853 | 5.144 | ******* | 12.125 |
| 6-8 | 7.547 | ******* | 43.167 | 1.450 | ******* | 30.607 | 6.091 | ******* | 13.455 |
| 9-11 | 14.948 | ******* | 25.494 | 3.366 | ******* | 9.970 | 11.572 | ******* | 15.548 |
| 12-14 | 11.222 | ******* | 20.255 | 0.966 | ******* | 9.476 | 10.241 | ******* | 10.770 |
| 15-17 | 21.150 | ******* | 35.485 | 5.282 | ******* | 21.096 | 15.720 | ******* | 14.360 |
| 18-20 | 33.221 | ******* | 103.900 | 12.944 | ******* | 67.073 | 20.261 | ******* | 36.827 |
| 21-23 | 42.565 | ******* | 109.605 | 22.710 | ******* | 77.176 | 19.943 | ******* | 31.771 |

جدول رقم ( 3 د)

THE MEAN CONCENTRATION OF THE LEVEL OF (CO, O3 AND NH3) EXPRESSED IN PPM RECORDED AT MANSORIA, RABIA & REGA DURING APRIL 1991 ACCORDING TO 3-HOUR INTERVAL OF THE DAY

| HOURS | CARBON MONOXIDE | | | OZON | | | AMONIA | | |
|---|---|---|---|---|---|---|---|---|---|
| | MAN | RAB | REG | MAN | RAB | REG | MAN | RAB | REG |
| 0-2 | 0.633 | ******* | 0.437 | 0.002 | ******* | 0.017 | --- | ******* | 0.010 |
| 3-5 | 0.308 | ******* | 0.280 | 0.003 | ******* | 0.020 | --- | ******* | 0.010 |
| 6-8 | 0.327 | ******* | 0.337 | 0.003 | ******* | 0.018 | --- | ******* | 0.006 |
| 9-11 | 0.617 | ******* | 0.454 | 0.002 | ******* | 0.016 | --- | ******* | 0.006 |
| 12-14 | 0.511 | ******* | 0.397 | 0.003 | ******* | 0.016 | --- | ******* | 0.009 |
| 15-17 | 0.671 | ******* | 0.456 | 0.004 | ******* | 0.018 | --- | ******* | 0.015 |
| 18-20 | 0.953 | ******* | 0.869 | 0.002 | ******* | 0.017 | --- | ******* | 0.018 |
| 21-23 | 1.161 | ******* | 0.803 | 0.002 | ******* | 0.017 | --- | ******* | 0.023 |

Apr 1991

جدول رقم ( 4 ا)

THE MEAN CONCENTRATION OF THE LEVEL OF SULFER COMPOUNDS EXPRESSED IN PPB RECORDED AT MANSORIA, RABIA & REGA DURING APRIL 1991 ACCORDING TO THE WIND DIRECTION

| WD | TOTAL SULPHER | | | HYDROGENE SULPHIDE | | | SULPHER DIOXIDE | | |
|---|---|---|---|---|---|---|---|---|---|
| | MAN | RAB | REG | MAN | RAB | REG | MAN | RAB | REG |
| N | 2.043 | ******* | 1.756 | 0.006 | ******* | 0.023 | 2.032 | ******* | 1.623 |
| NE | 2.989 | ******* | 1.729 | 0.089 | ******* | 0.043 | 2.878 | ******* | 1.558 |
| E | 5.284 | ******* | 1.829 | 0.213 | ******* | 0.050 | 5.049 | ******* | 1.499 |
| SE | 6.873 | ******* | 1.683 | 0.236 | ******* | 0.067 | 6.611 | ******* | 1.442 |
| S | 3.486 | ******* | 2.092 | 0.085 | ******* | 0.092 | 3.389 | ******* | 1.776 |
| SW | 3.047 | ******* | 1.896 | 0.104 | ******* | 0.019 | 2.930 | ******* | 1.595 |
| W | 2.245 | ******* | 2.056 | 0.109 | ******* | 0.130 | 2.116 | ******* | 1.677 |
| NW | 1.997 | ******* | 1.991 | 0.001 | ******* | 0.198 | 1.955 | ******* | 1.608 |

جدول رقم ( 4 ب)

THE MEAN CONCENTRATION OF THE LEVEL OF HYDROCARBONS EXPRESSED IN PPM RECORDED AT MANSORIA, RABIA & REGA DURING APRIL 1991 ACCORDING TO THE WIND DIRECTION

| WD | TOTAL HYDROCARBONS | | | NON-METHANE | | | METHANE | | |
|---|---|---|---|---|---|---|---|---|---|
| | MAN | RAB | REG | MAN | RAB | REG | MAN | RAB | REG |
| N | 4.507 | ******* | 2.275 | 1.066 | ******* | 0.455 | 3.441 | ******* | 1.820 |
| NE | 3.592 | ******* | 2.159 | 0.736 | ******* | 0.381 | 2.825 | ******* | 1.778 |
| E | 3.511 | ******* | 2.541 | 0.608 | ******* | 0.730 | 2.890 | ******* | 1.807 |
| SE | 6.977 | ******* | 2.667 | 2.229 | ******* | 0.868 | 4.748 | ******* | 1.800 |
| S | 5.456 | ******* | 3.030 | 1.498 | ******* | 1.188 | 3.957 | ******* | 1.842 |
| SW | 5.077 | ******* | 3.043 | 1.245 | ******* | 1.120 | 3.831 | ******* | 1.924 |
| W | 6.588 | ******* | 3.632 | 1.702 | ******* | 1.643 | 4.877 | ******* | 1.990 |
| NW | 7.781 | ******* | 4.338 | 2.293 | ******* | 2.299 | 5.472 | ******* | 2.039 |

جدول رقم ( 4 ح)

THE MEAN CONCENTRATION OF THE LEVEL OF NITROGENE COMPS. EXPRESSED IN PPB RECORDED AT MANSORIA, RABIA & REGA DURING APRIL 1991 ACCORDING TO THE WIND DIRECTION

| WD | TOTAL NITROGENE OXIDES | | | NITROGENE MONOXIDES | | | NITROGENE DIOXIDE | | |
|---|---|---|---|---|---|---|---|---|---|
| | MAN | RAB | REG | MAN | RAB | REG | MAN | RAB | REG |
| N | 14.109 | ******* | 66.524 | 5.574 | ******* | 46.572 | 8.711 | ******* | 20.073 |
| NE | 20.294 | ******* | 29.269 | 6.433 | ******* | 12.745 | 13.694 | ******* | 16.529 |
| E | 27.676 | ******* | 37.819 | 8.646 | ******* | 25.925 | 18.959 | ******* | 11.822 |
| SE | 25.572 | ******* | 28.025 | 4.660 | ******* | 11.038 | 20.908 | ******* | 16.987 |
| S | 46.738 | ******* | 38.202 | 21.072 | ******* | 10.528 | 25.671 | ******* | 27.444 |
| SW | 46.240 | ******* | 41.360 | 28.155 | ******* | 11.084 | 18.060 | ******* | 30.252 |
| W | 20.815 | ******* | 90.560 | 11.005 | ******* | 58.519 | 9.750 | ******* | 31.681 |
| NW | 6.395 | ******* | 223.084 | 1.076 | ******* | 200.661 | 5.310 | ******* | 20.289 |

جدول رقم ( 4 د)

THE MEAN CONCENTRATION OF THE LEVEL OF (CO, O3 AND NH3) EXPRESSED IN PPM RECORDED AT MANSORIA, RABIA & REGA DURING APRIL 1991 ACCORDING TO THE WIND DIRECTION

| WD | CARBON MONOXIDE | | | OZON | | | AMONIA | | |
|---|---|---|---|---|---|---|---|---|---|
| | MAN | RAB | REG | MAN | RAB | REG | MAN | RAB | REG |
| N | 0.592 | ******* | 0.387 | 0.004 | ******* | 0.018 | --- | ******* | 0.009 |
| NE | 0.662 | ******* | 0.372 | 0.003 | ******* | 0.016 | --- | ******* | 0.006 |
| E | 0.782 | ******* | 0.510 | 0.002 | ******* | 0.020 | --- | ******* | 0.006 |
| SE | 0.670 | ******* | 0.587 | 0.002 | ******* | 0.015 | --- | ******* | 0.012 |
| S | 1.004 | ******* | 0.752 | 0.001 | ******* | 0.012 | --- | ******* | 0.024 |
| SW | 1.081 | ******* | 0.672 | 0.001 | ******* | 0.012 | --- | ******* | 0.016 |
| W | 0.666 | ******* | 1.280 | 0.003 | ******* | 0.010 | --- | ******* | 0.038 |
| NW | 0.395 | ******* | 0.350 | 0.004 | ******* | 0.033 | --- | ******* | 0.010 |

جدول رقم ( 5 أ)

THE MEAN CONCENTRATION OF THE LEVEL OF SULFER COMPOUNDS EXPRESSED IN PPB RECORDED AT MANSORIA, RABIA & REGA DURING APRIL 1991 ACCORDING TO THE WIND SPEED IN m/s

| WS | TOTAL SULPHER | | | HYDROGENE SULPHIDE | | | SULPHER DIOXIDE | | |
|---|---|---|---|---|---|---|---|---|---|
| | MAN | RAB | REG | MAN | RAB | REG | MAN | RAB | REG |
| 1m/s | 2.943 | ******* | 2.238 | 0.080 | ******* | 0.147 | 2.849 | ******* | 1.824 |
| 1-2 | 2.730 | ******* | 1.745 | 0.099 | ******* | 0.072 | 2.619 | ******* | 1.468 |
| 2-3 | 3.038 | ******* | 1.715 | 0.082 | ******* | 0.047 | 2.941 | ******* | 1.470 |
| 3-4 | 3.996 | ******* | 1.792 | 0.098 | ******* | 0.035 | 3.858 | ******* | 1.567 |
| 4-5 | 3.714 | ******* | 1.862 | 0.094 | ******* | 0.050 | 3.582 | ******* | 1.666 |
| 5-6 | 2.492 | ******* | 1.883 | 0.021 | ******* | 0.020 | 2.446 | ******* | 1.763 |
| 6-7 | 2.000 | ******* | 1.829 | 0.000 | ******* | 0.018 | 1.977 | ******* | 1.753 |
| 7-8 | 2.000 | ******* | 1.873 | 0.000 | ******* | 0.026 | 1.962 | ******* | 1.828 |
| 8-9 | 2.000 | ******* | 1.857 | 0.000 | ******* | 0.000 | 2.000 | ******* | 1.839 |
| 9-10 | 2.000 | ******* | 2.000 | 0.000 | ******* | 0.000 | 2.000 | ******* | 2.000 |
| 10+ | 2.000 | ******* | 2.500 | 0.000 | ******* | 0.000 | 2.000 | ******* | 2.500 |

جدول رقم ( 5 ب)

THE MEAN CONCENTRATION OF THE LEVEL OF HYDROCARBONS EXPRESSED IN PPM RECORDED AT MANSORIA, RABIA & REGA DURING APRIL 1991 ACCORDING TO THE WIND SPEED IN m/s

| WS | TOTAL HYDROCARBONS | | | NON-METHANE | | | METHANE | | |
|---|---|---|---|---|---|---|---|---|---|
| | MAN | RAB | REG | MAN | RAB | REG | MAN | RAB | REG |
| 1m/s | 4.630 | ******* | 3.539 | 0.805 | ******* | 1.611 | 3.810 | ******* | 1.928 |
| 1-2 | 5.113 | ******* | 3.133 | 1.136 | ******* | 1.224 | 3.971 | ******* | 1.909 |
| 2-3 | 6.402 | ******* | 2.668 | 1.614 | ******* | 0.789 | 4.787 | ******* | 1.880 |
| 3-4 | 7.291 | ******* | 2.475 | 2.156 | ******* | 0.645 | 5.111 | ******* | 1.831 |
| 4-5 | 7.838 | ******* | 2.377 | 2.758 | ******* | 0.568 | 5.064 | ******* | 1.805 |
| 5-6 | 7.647 | ******* | 2.094 | 2.887 | ******* | 0.344 | 4.760 | ******* | 1.749 |
| 6-7 | 6.065 | ******* | 1.929 | 1.795 | ******* | 0.216 | 4.271 | ******* | 1.713 |
| 7-8 | 4.717 | ******* | 1.838 | 1.120 | ******* | 0.129 | 3.594 | ******* | 1.708 |
| 8-9 | 0.000 | ******* | 1.798 | 0.000 | ******* | 0.087 | 0.000 | ******* | 1.711 |
| 9-10 | 0.000 | ******* | 1.796 | 0.000 | ******* | 0.083 | 0.000 | ******* | 1.715 |
| 10+ | 0.000 | ******* | 1.790 | 0.000 | ******* | 0.052 | 0.000 | ******* | 1.735 |

جدول رقم ( 5 ج)

THE MEAN CONCENTRATION OF THE LEVEL OF NITROGENE COMPS. EXPRESSED IN PPB RECORDED AT MANSORIA, RABIA & REGA DURING APRIL 1991 ACCORDING TO THE WIND SPEED IN m/s

| WS | TOTAL NITROGENE OXIDES | | | NITROGENE MONOXIDES | | | NITROGENE DIOXIDE | | |
|---|---|---|---|---|---|---|---|---|---|
| | MAN | RAB | REQ | MAN | RAB | REQ | MAN | RAB | REQ |
| 1m/s | 65.460 | ******* | 162.777 | 40.718 | ******* | 124.087 | 24.832 | ******* | 38.712 |
| 1-2 | 23.812 | ******* | 90.177 | 9.086 | ******* | 60.496 | 14.659 | ******* | 29.581 |
| 2-3 | 10.314 | ******* | 61.959 | 1.366 | ******* | 39.829 | 8.955 | ******* | 21.970 |
| 3-4 | 8.230 | ******* | 51.884 | 0.553 | ******* | 36.030 | 7.629 | ******* | 16.160 |
| 4-5 | 7.861 | ******* | 35.706 | 0.417 | ******* | 20.280 | 7.412 | ******* | 15.326 |
| 5-6 | 10.078 | ******* | 28.451 | 0.672 | ******* | 14.952 | 9.414 | ******* | 13.509 |
| 6-7 | 12.833 | ******* | 34.008 | 1.253 | ******* | 20.502 | 11.648 | ******* | 13.560 |
| 7-8 | 12.038 | ******* | 28.767 | 1.154 | ******* | 15.736 | 10.808 | ******* | 12.851 |
| 8-9 | 15.429 | ******* | 22.760 | 1.714 | ******* | 12.120 | 13.714 | ******* | 10.680 |
| 9-10 | 23.000 | ******* | 18.824 | 2.000 | ******* | 5.765 | 21.000 | ******* | 13.000 |
| 10+ | 11.000 | ******* | 10.750 | 1.000 | ******* | 3.000 | 9.000 | ******* | 7.750 |

جدول رقم ( 5د )

THE MEAN CONCENTRATION OF THE LEVEL OF (CO, O3 AND NH3) EXPRESSED IN PPM RECORDED AT MANSORIA, RABIA & REGA DURING APRIL 1991 ACCORDING TO THE WIND SPEED IN m/s

| WS | CARBON MONOXIDE | | | OZON | | | AMONIA | | |
|---|---|---|---|---|---|---|---|---|---|
| | MAN | RAB | REQ | MAN | RAB | REQ | MAN | RAB | REQ |
| 1m/s | 1.585 | ******* | 1.442 | 0.002 | ******* | 0.017 | --- | ******* | 0.035 |
| 1-2 | 0.706 | ******* | 0.748 | 0.002 | ******* | 0.013 | --- | ******* | 0.017 |
| 2-3 | 0.428 | ******* | 0.456 | 0.003 | ******* | 0.016 | --- | ******* | 0.014 |
| 3-4 | 0.405 | ******* | 0.353 | 0.003 | ******* | 0.019 | --- | ******* | 0.010 |
| 4-5 | 0.387 | ******* | 0.317 | 0.004 | ******* | 0.018 | --- | ******* | 0.005 |
| 5-6 | 0.390 | ******* | 0.301 | 0.003 | ******* | 0.019 | --- | ******* | 0.003 |
| 6-7 | 0.403 | ******* | 0.285 | 0.003 | ******* | 0.019 | --- | ******* | 0.002 |
| 7-8 | 0.404 | ******* | 0.281 | 0.002 | ******* | 0.018 | --- | ******* | 0.002 |
| 8-9 | 0.357 | ******* | 0.279 | 0.001 | ******* | 0.018 | --- | ******* | 0.002 |
| 9-10 | 0.480 | ******* | 0.284 | 0.001 | ******* | 0.019 | --- | ******* | 0.000 |
| 10+ | 0.140 | ******* | 0.260 | 0.000 | ******* | 0.022 | --- | ******* | 0.000 |

Suspended Particulate Matter Measurements
Using High Volume Sampler During
MARCH & APRIL 1991

FARWANIA HOSPITAL

| Date | Total Conc. ug/m3 | Filter Shade | Concentration of Elements ug/m3 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Na | Ca | Fa | Ni | Pb | V | Al |
| 16/ 3/91 | 168.3 | Gray | 2.073 | 28.121 | 4:737 | 0.055 | 0.189 | 0.013 | ---- |
| 20/ 3/91 | 99.5 | Black | 2.350 | 11.750 | 1.427 | 0.039 | 0.197 | 0.024 | ---- |
| 25/ 3/91 | 75.1 | Gray | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| 30/ 3/91 | 93.5 | Black | 2.538 | 11.766 | 2.193 | 0.039 | 0.395 | 0.007 | ---- |
| 2/ 4/91 | 382.4 | Black | 2.149 | 26.766 | 2.168 | 0.051 | 0.161 | 0.073 | ---- |
| 7/ 4/91 | 140.3 | Gray | 2.600 | 6.030 | 3.660 | 0.046 | 0.145 | 0.021 | ---- |
| 15/ 4/91 | 278.3 | Gray | 2.215 | 27.685 | 9.999 | 0.054 | 0.372 | 0.030 | ---- |
| 18/ 4/91 | 174.0 | Black | 2.760 | 27.601 | 4.190 | 0.038 | 0.298 | 0.022 | ---- |
| 23/ 4/91 | 142.8 | Gray | 2.002 | 21.722 | 4.574 | 0.024 | 0.156 | 0.012 | ---- |
| 26/ 4/91 | 195.2 | Black | 1.352 | 5.981 | 4.359 | 0.026 | 0.144 | 0.024 | ---- |

Suspended Particulate Matter Measurements
Using High Volume Sampler During
MARCH & APRIL 1991

MUBARAK HOSPITAL

| Date | Total Conc. ug/m3 | Filter Shade | Concentration of Elements ug/m3 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Na | Ca | Fa | Ni | Pb | V | Al |
| 18/ 3/91 | 117.7 | Black | 2.204 | 11.023 | 1.384 | 0.036 | 0.317 | 0.020 | ---- |
| 26/ 3/91 | 124.9 | Black | 2.442 | 15.852 | 1.840 | 0.029 | 0.456 | 0.010 | ---- |
| 31/ 3/91 | 154.2 | Black | 2.832 | 6.572 | 3.566 | 0.022 | 0.441 | 0.028 | ---- |
| 3/ 4/91 | 263.9 | Black | 2.080 | 14.481 | 7.192 | 0.069 | 0.209 | 0.041 | ---- |
| 8/ 4/91 | 735.3 | Sandwish | 2.084 | 18.032 | 50.085 | 0.123 | 0.346 | 0.042 | ---- |
| 13/ 4/91 | 176.1 | Black | 2.421 | 14.721 | 3.696 | 0.032 | 0.188 | 0.027 | ---- |
| 16/ 4/91 | 212.6 | Black | 1.840 | 23.001 | 6.109 | 0.055 | 0.199 | 0.035 | ---- |
| 20/ 4/91 | 132.3 | Black | 2.088 | 26.109 | 2.199 | 0.034 | 0.226 | 0.019 | ---- |
| 24/ 4/91 | 282.8 | Black | 2.364 | 27.415 | 4.329 | 0.045 | 0.329 | 0.045 | ---- |
| 27/ 4/91 | 418.3 | Gray | 2.616 | 33.961 | 11.872 | 0.093 | 0.244 | 0.043 | ---- |

Suspended Particulate Matter Measurements
Using High Volume Sampler During
MARCH & APRIL 1991

ADDAN HOSPITAL

| Date | Total Conc. ug/m3 | Filter Shade | Concentration of Elements ug/m3 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Na | Ca | Fa | Ni | Pb | V | Al |
| 19/ 3/91 | 128.4 | Gray | 2.192 | 29.732 | 2.697 | 0.059 | 0.257 | 0.023 | ---- |
| 24/ 3/91 | 242.0 | Black | 2.370 | 17.743 | 5.134 | 0.052 | 0.313 | 0.034 | ---- |
| 27/ 3/91 | 182.0 | Black | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| 1/ 4/91 | 327.7 | Black | 2.912 | 36.400 | 2.004 | 0.056 | 0.279 | 0.040 | ---- |
| 6/ 4/91 | 142.8 | Gray | 2.387 | 11.936 | 5.026 | 0.039 | 0.143 | 0.015 | ---- |
| 9/ 4/91 | 1159.7 | Sandwish | 2.594 | 42.121 | 22.123 | 0.145 | 0.115 | 0.075 | ---- |
| 14/ 4/91 | 196.3 | Black | 2.698 | 31.300 | 2.636 | 0.055 | 0.210 | 0.028 | ---- |
| 17/ 4/91 | 353.5 | Black | 2.617 | 42.503 | 10.522 | 0.073 | 0.175 | 0.064 | ---- |
| 22/ 4/91 | 276.4 | Black | 2.873 | 33.324 | 6.800 | 0.073 | 0.288 | 0.035 | ---- |
| 25/ 4/91 | 189.5 | Black | 2.366 | 5.917 | 3.546 | 0.052 | 0.256 | 0.038 | ---- |

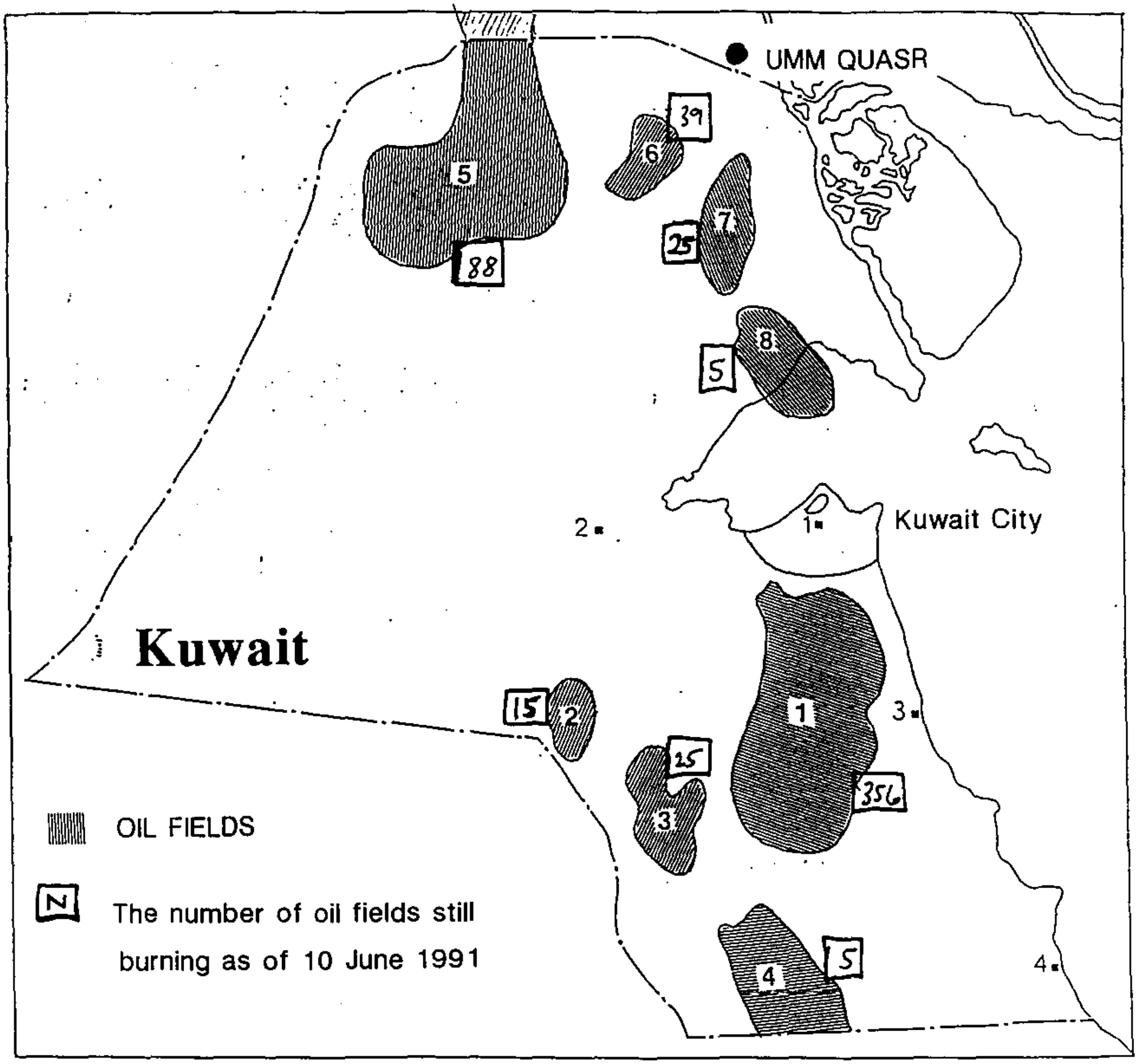
# Microbiological Examination of Coastal Water

## APRIL / 1991

| Location | Sampling Date | Air Temp C | Water Temp. C | No.of Indicator Bacteria/100 ml | | |
|---|---|---|---|---|---|---|
| | | | | Total Coliform | Faecal Coliform | Streptococcus Faecal Bacteria |
| Al-Salam Beach | 29/ 4/91 | 32 | 22 | 2360 | 290 | 660 |
| Benaid Al-Gar | 29/ 4/91 | 32 | 22 | 1540 | 14 | 10 |
| Al-Messila | 29/ 4/91 | 34 | 22 | 580 | 171 | 180 |
| Al-Beda'a | 29/ 4/91 | 34 | 22 | 1100 | 140 | 290 |

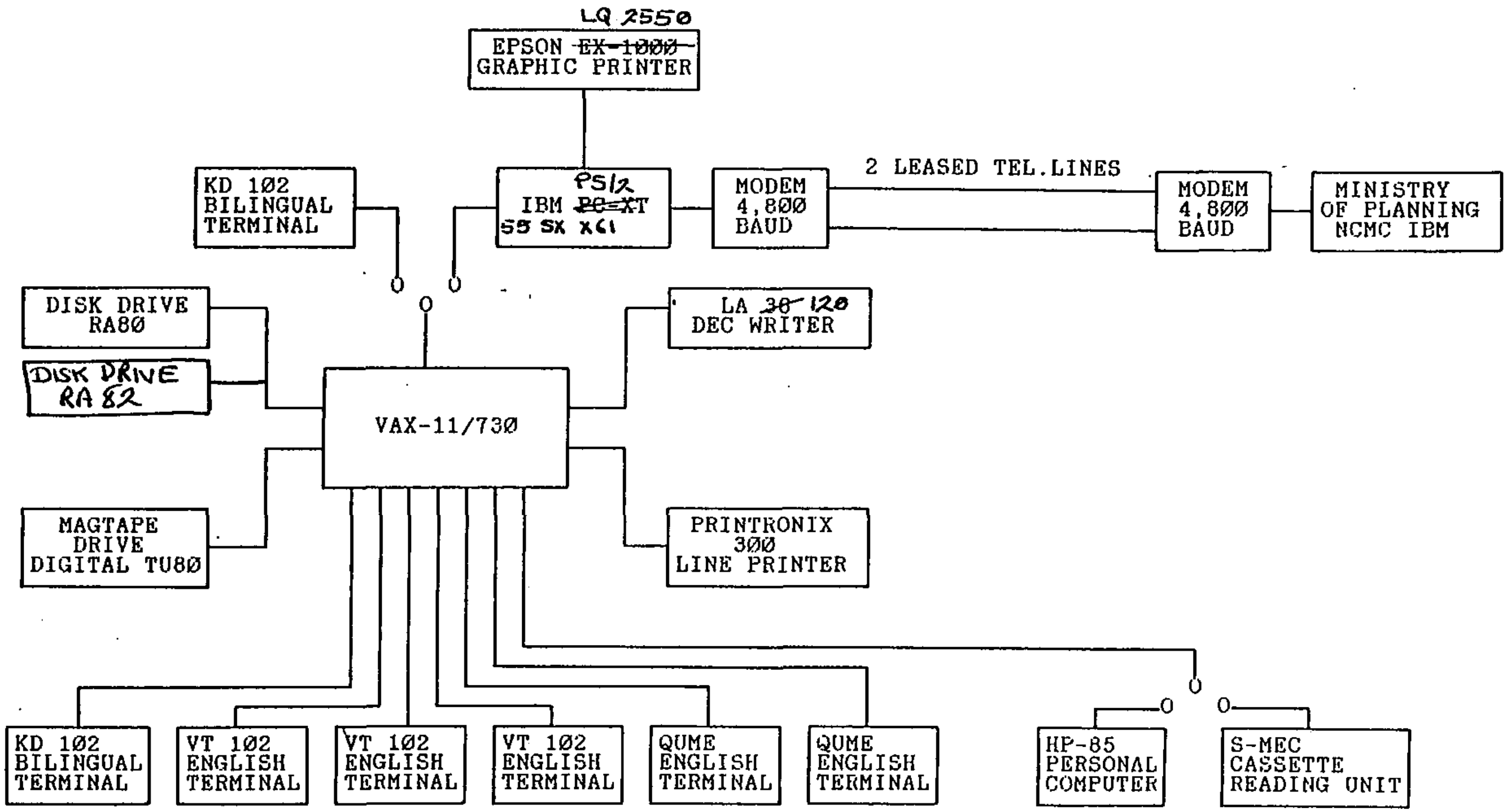
# APPENDIX E

OIL WELLS BURNING IN KUWAIT
AS OF 10 JUNE 1991


UMM QUASR
Kuwait City
Kuwait
5
88
6
39
7
25
8
5
2
1
3
4
1
356
2
15
3
25
4
5
OIL FIELDS
N
The number of oil fields still burning as of 10 June 1991

# APPENDIX F

COMPUTER SYSTEM AT EPD




Hardware Configuaration Of Computer System At EPD Location

# APPENDIX G

A) "FINGERPRINT" OF CRUDE OIL ANALYSES

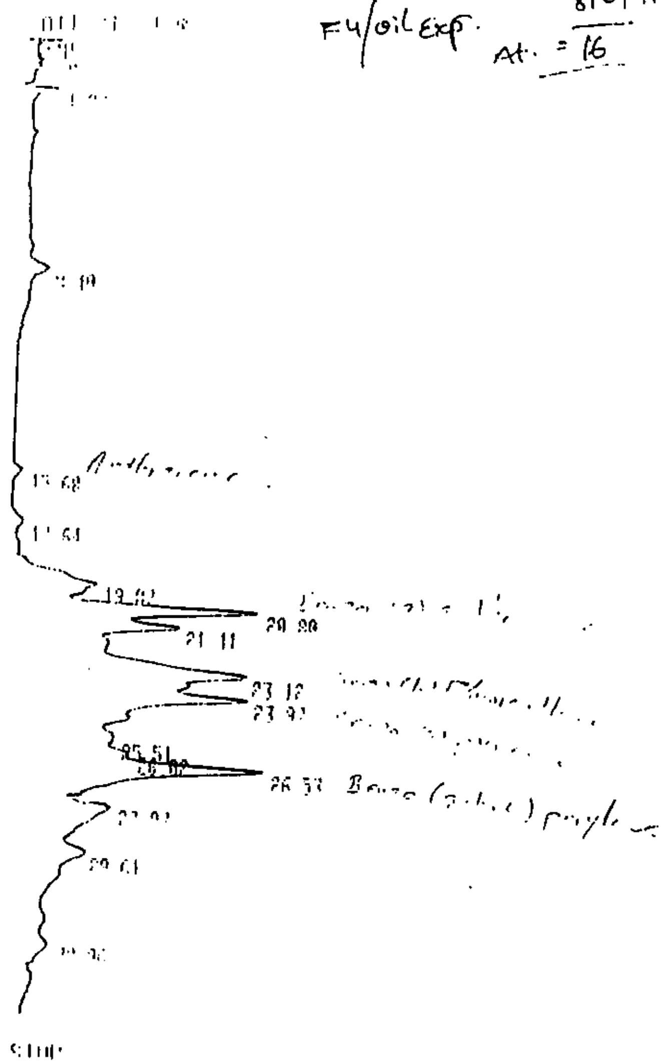
B) HEIGHT OF GROUND BASED INVERSION AS MEASURED BY A MONOSTATIC SODAR

pressure start 54 bar

a)

F4/oil Exp. At. = 16 8/6/91

Fingerprint of crude oil burning




RUN # 16

AREA%

| RT | AREA | TYPE | | |
|---|---|---|---|---|
| 1.92 | 362420 | PP | [illegible] | |
| 19.87 | 547190 | PV | [illegible] | |
| 20.80 | 1190000 | VV | [illegible] | [illegible] |
| 21.41 | 560990 | VV | [illegible] | [illegible] |
| 23.12 | 1234300 | PV | [illegible] | [illegible] |
| 23.97 | 1213000 | VV | [illegible] | [illegible] |
| 25.51 | 277420 | VV | [illegible] | [illegible] |
| 26.02 | 263040 | VV | [illegible] | [illegible] |
| 26.53 | 1691400 | VP | [illegible] | [illegible] |
| 27.97 | 625030 | PV | [illegible] | [illegible] |
| 29.61 | 472250 | VP | [illegible] | [illegible] |
| 32.96 | 186770 | VP | [illegible] | [illegible] |

TOTAL AREA= 8628700
MUL FACTOR= 1.0000E+00

Report : Groundbased inversions in Kuwait.
by Dr. M. El Aeroaly
Eng Sabah Abd Al-Wahhab.

1981-84 data from 1983'.

b)



Table (II.2)

The mean and s.d. of the height of the ground based thermal inversion detected by the sonic radar in Kuwait in the period covered by the study in the various hours of the day according to the season.

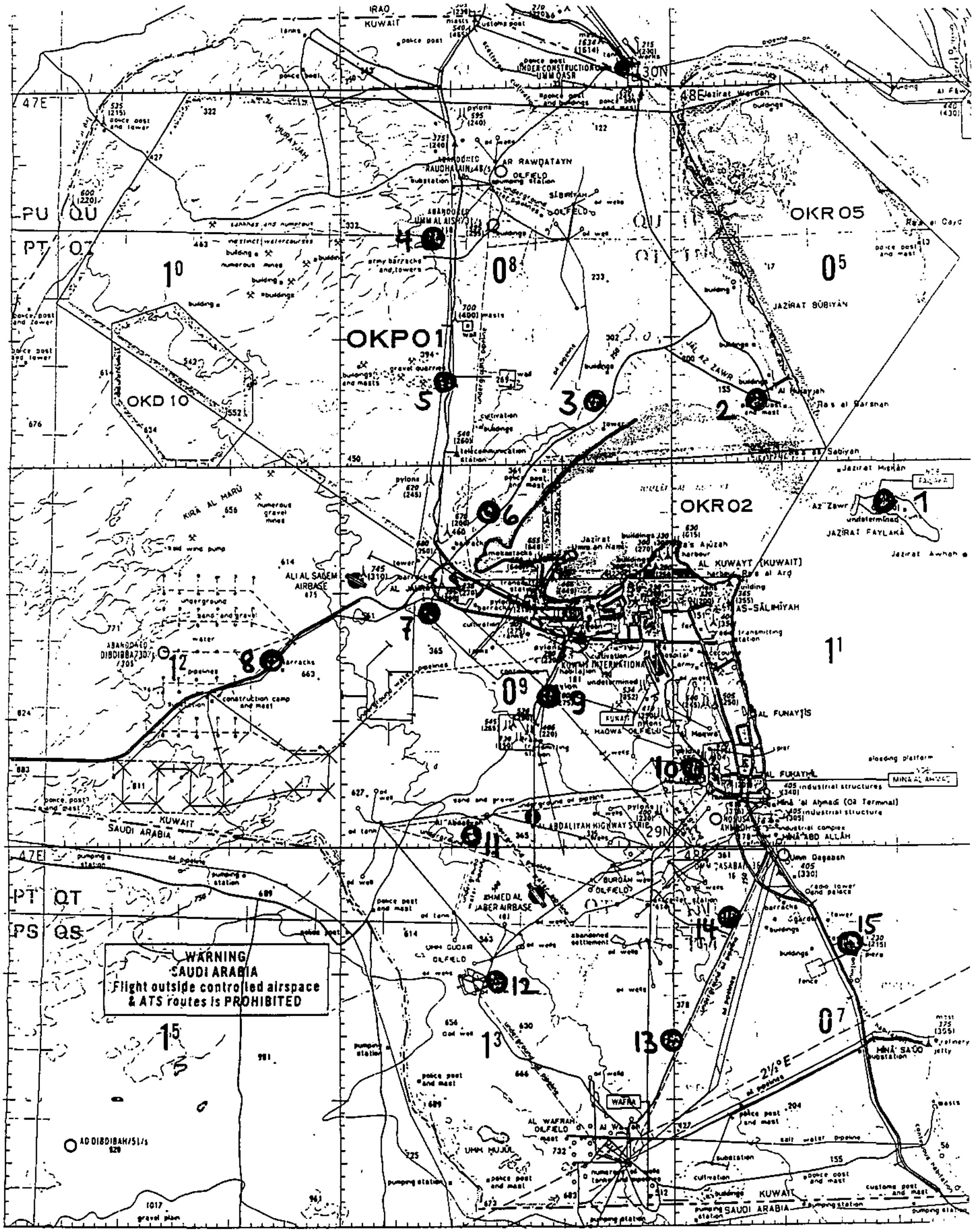
| Hour of the day | Height in Meters | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Autumn | | | Winter | | | Spring | | | Summer | | |
| | Mean | S.d. | N | Mean | S.d. | N | Mean | S.d. | N | Mean | S.d. | N |
| 0 | 140.0 | 42.2 | 54 | 147.1 | 40.9 | 34 | 146.7 | 36.1 | 42 | 201.1 | 35.9 | 37 |
| 1 | 142.8 | 41.6 | 58 | 149.9 | 42.7 | 35 | 141.9 | 35.0 | 42 | 204.3 | 38.9 | 37 |
| 2 | 143.2 | 42.9 | 57 | 154.1 | 42.5 | 34 | 138.1 | 39.2 | 41 | 219.5 | 40.4 | 37 |
| 3 | 146.3 | 42.6 | 57 | 155.3 | 38.5 | 34 | 141.0 | 34.2 | 40 | 228.6 | 49.8 | 37 |
| 4 | 149.1 | 39.0 | 55 | 156.6 | 38.7 | 35 | 142.5 | 37.9 | 40 | 235.0 | 50.2 | 35 |
| 5 | 152.3 | 39.1 | 57 | 156.6 | 41.9 | 35 | 146.1 | 41.1 | 36 | 230.4 | 44.0 | 25 |
| 6 | 148.3 | 38.4 | 58 | 157.8 | 37.0 | 36 | 142.7 | 40.9 | 37 | 232.0 | 17.9 | 5 |
| 7 | 146.3 | 37.2 | 41 | 155.2 | 41.8 | 33 | 150.8 | 34.5 | 26 | - | - | - |
| 8 | 170.0 | 30.3 | 6 | 168.6 | 41.4 | 7 | 158.0 | 30.5 | 10 | - | - | - |
| 9 | - | - | - | - | - | - | - | - | - | - | - | - |
| 10 | - | - | - | - | - | - | - | - | - | - | - | - |
| 11 | - | - | - | - | - | - | - | - | - | - | - | - |
| 12 | - | - | - | - | - | - | - | - | - | - | - | - |
| 13 | - | - | - | - | - | - | - | - | - | - | - | - |
| 14 | - | - | - | - | - | - | - | - | - | - | - | - |
| 15 | 190.0 | - | 2 | 166.7 | 30.6 | 3 | 200.0 | - | 1 | 200.0 | 28.3 | 2 |
| 16 | 144.0 | 15.8 | 10 | 153.3 | 32.7 | 6 | 168.0 | 48.2 | 5 | 197.8 | 18.6 | 9 |
| 17 | 136.5 | 23.9 | 23 | 142.2 | 21.1 | 9 | 169.1 | 38.3 | 11 | 186.7 | 27.4 | 18 |
| 18 | 133.5 | 25.9 | 34 | 133.8 | 27.1 | 16 | 157.0 | 36.9 | 20 | 182.5 | 20.7 | 24 |
| 19 | 138.0 | 29.3 | 40 | 140.0 | 31.4 | 18 | 153.3 | 34.6 | 30 | 175.2 | 30.0 | 33 |
| 20 | 139.0 | 29.2 | 46 | 145.2 | 35.3 | 23 | 152.2 | 36.2 | 36 | 174.3 | 34.5 | 35 |
| 21 | 139.6 | 30.4 | 55 | 145.0 | 33.8 | 28 | 152.6 | 30.7 | 35 | 184.0 | 34.6 | 35 |
| 22 | 139.3 | 31.8 | 57 | 144.0 | 37.3 | 30 | 154.7 | 34.1 | 38 | 185.0 | 25.5 | 36 |
| 23 | 140.3 | 34.1 | 59 | 148.8 | 36.6 | 32 | 153.5 | 38.8 | 40 | 180.5 | 33.9 | 37 |

# APPENDIX H

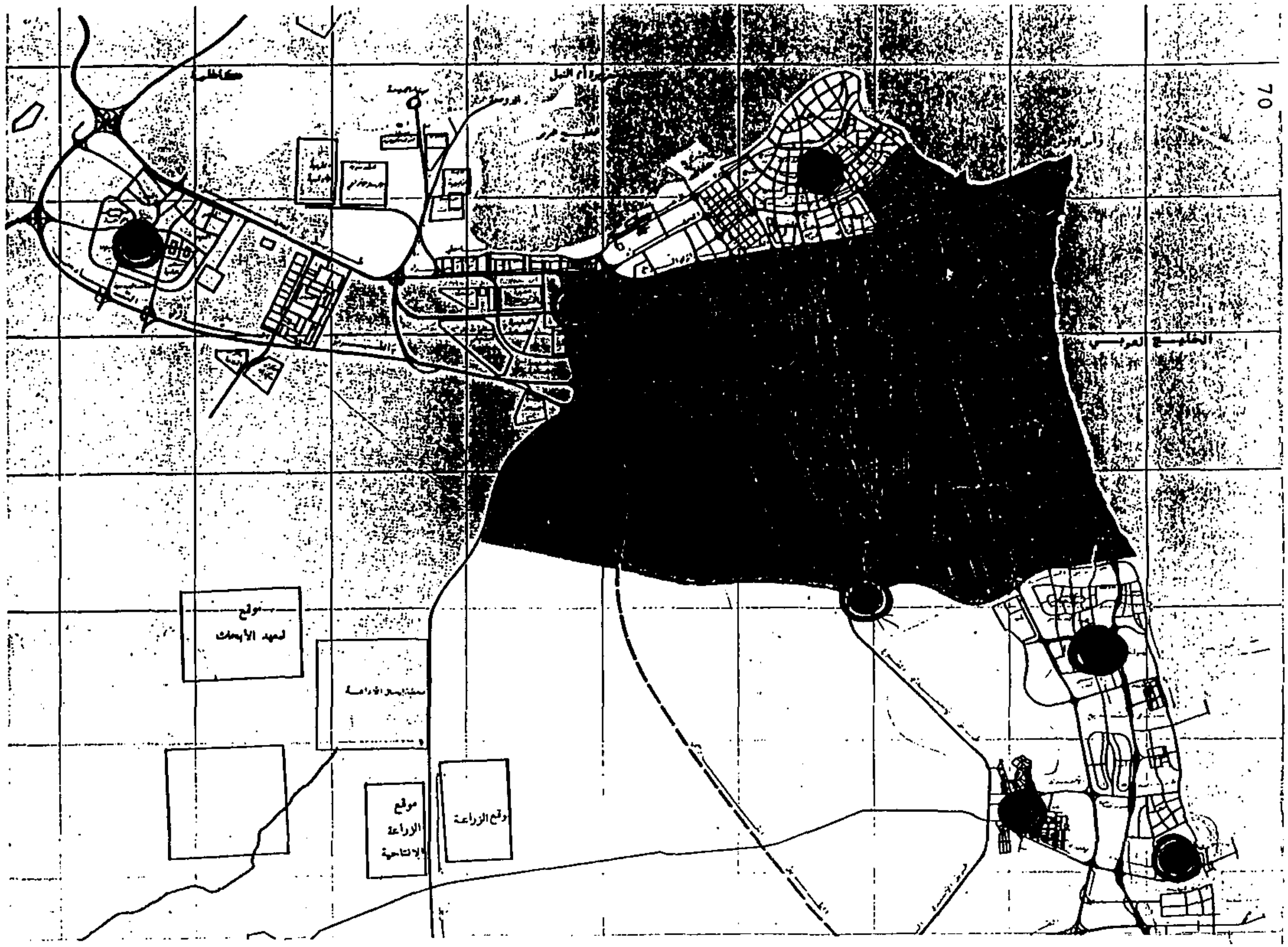
A) LOCATION OF NOAA METEOROLOGICAL STATIONS

B) LOCATION OF $PM_{10}$ SAMPLERS (FROM US EPA)

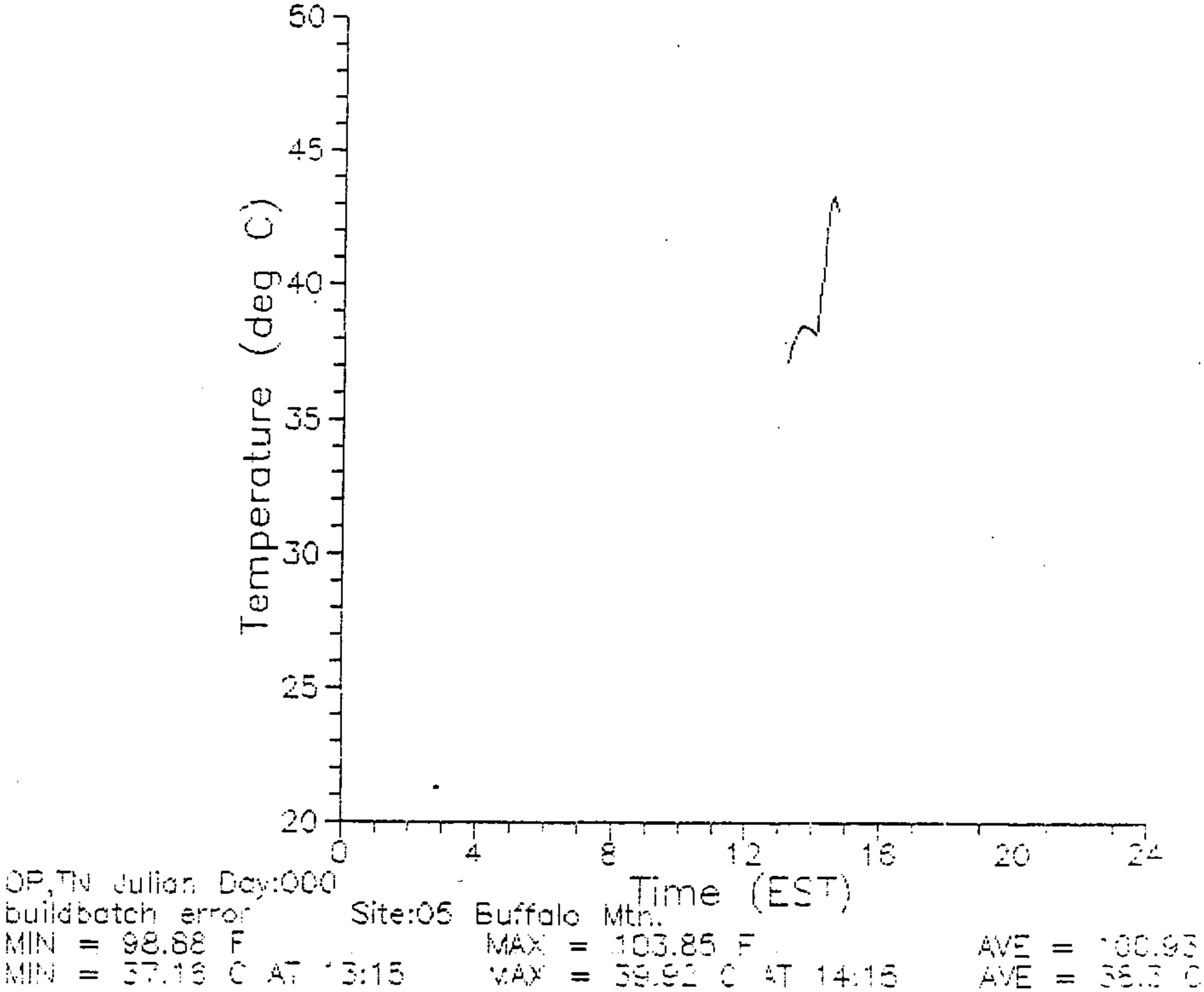
C) EXAMPLE PLOT OF TEMPERATURE




A) Location of NOAA meterological stations




H 5) Location of EPA $PM_{10}$ samplers.




11c) Temperature plot from NOAA station in Kuwait.

# APPENDIX I

## PROTOCOL OF VISIT IN KUWAIT 7-12 JUNE 1991

NORWEGIAN INSTITUTE FOR AIR RESEARCH (NILU)
Our ref.: BS/SBH/O-91042/26 June 1991

NILU

# PROTOCOL OF VISIT IN KUWAIT 7-12 JUNE 1991

The following conclusions have been drawn from discussions with representatives from the Environment Protection Department (EPD) and site visits in Kuwait 7-12 June 1991:

1. Two fixed air quality monitoring stations will be delivered from NILU, Norway to Kuwait. Instruments will be placed in isolated and air conditioned containers, size: 4.1 m x 2,0 m, height 2,3 m, weight included instruments approximately 2.200 kg.

2. Locations of the two stations will be:

   a) Jahra, 30 km west of EPD centre in Kuwait city.
   b) Mina Al Zoor, at the north western corner of the power plant site, 80 km SSE of the EPD centre.

   At both locations the containers will be placed at the roof of low, flat buildings. Standard 3 phase power and telephone lines will be made available at both sites. Power requirements: 20 kW.

3. First priority air pollutants and parameters

   The Norwegian contribution of 1 mill. USD has by UNEP been divided into administration, WMO and WHO contributions. The amount left for AQ stations from NILU is at present 350.000 USD. We therefore have divided the AQ instrument package into first and second priority. Only first priority can be delivered within the 350.000 USD.

   First priority monitors are:

   $SO_2$ (by Monitor Lab.), $PM_{10}$ (by TEOM), $NO/NO_x$ (by Monitor Lab), meteorology (wind speed and direction, temperatures, radiation) by Aanderaa Instruments. The stations will be automatic on telephone line. Local calibration and maintenance will be undertaken once a week.

4. Second priority A.Q. parameters

If funds are available, the following parameters can be added to the NILU stations:

1. Dustfall (NILU international standard collectors)
2. Ozone (by Monitor Lab, UV absorption)
3. $H_2S$ (by Monitor Lab)
4. CO (by Monitor Lab, infrared absorption)
5. THC (not decided, SIMRAD Optronics? .....)
6. PAH (NILU PUF sampler)
7. Soot/$SO_2$ (NILU sequential 24 h sampler)

5. Data transmission

All data from the NILU AQ station (first priority) will be transmitted via good quality public telephone lines for data transmission, up to 2400 baud (see flow chart). Three switched lines and five dedicated lines have to be prepared by Kuwait. These includes also data transmission from the EPD Horiba AQ-stations, where NILU provides 3 logger/transmission systems included 6 modems.

6. Warning centre at EPD

To obtain printouts of concentrations and meteorological variables from all 5 AQ stations (2 NILU + 3 EPD) NILU will provide a data logger and a printer. To transfer data to the VAX main frame computer, Norway will also provide a PC with floppy disc. (The format available every 5 min is indicated on page 7).

7. Modelling for warning purpose

No money is at present available for modelling. However, it will be possible to establish the NILU modelling system, provided that a HP Apollo work station with at least 8 MB RAM and preferably 300 MB disc capacity will be available. Wind field data from the NOAA meteorological network can be transferred to the HP computer as input to the dispersion/statistical model. Further details on displays and possible applications have to be discussed later.

8. Optional information and warning centre

Based upon the NILU experience from planning and performance of tracer experiments and from information system for air quality in Oslo, NILU can provide training of local personnel for air quality information and warning in Kuwait.

9. Future possibilities

During the discussions, several aspects were indicated as possible future co-operations:

a) NILU is responsible for intercalibration and intercomparisons of chemical analyses in EMEP (European Monitoring and Evaluation Programme). Possibilities for participatation by the EPD will be discussed by NILU experts.

b) Remote sensing of various air pollutants is being performed and further developed in Scandinavia. Some of these instruments can be included in the present network if funds are made available:

- DOAS (differential optical absorption spectroscopy) is at present used by NILU in Oslo.
- New HC instruments based upon IR spectroscopy are available in Norway for high concentration ranges.

- Development of new diode laser based absorption spectroscopy is being developed by NILU/NEO. These instruments for HC and other gases can be used in future programmes.

c) NILUs experience with doppler sodars for measurements of wind and turbulence profiles from the surface to 1000 m can be transferred to Kuwait if requested.

10. NILU samplers

NILU will provide 5 dustfall buckets (international standard), and one stand within the first priority delivery to the EPD laboratory in Kuwait.

NILU will also estimate costs and prepare PAH samplers (NILU PUF) for installation in the two NILU stations. Three additional PUF samplers will be delivered as a kit for building into existing stations.

11. Draft cost estimate

The first priority monitoring equipment, installation and operation is estimated to 402.900 USD, consisting of the folowing items:

| | | | |
|---|---|---|---|
| One NILU monitoring station | | | |
| Container | USD 12.0 | | |
| $SO_2$ | " 15.4 | | |
| TEOM | " 25.4 | | |
| $NO_x$ | " 16.0 | | |
| Wind | " 9.2 | | |
| Data logging* | " 14.1 | | |
| 2 set span gas | " 9.1 | | |
| | USD 101.2 | | |
| Two NILU stations | | | USD 202.4 |
| EPD warning centre | | | |
| 2 modems | USD 1.8 | | |
| Ram memory logger | " 12.3 | | |
| Modem out | " 0.9 | | |
| Printer | " 3.1 | | |
| PC + disc | " 3.7 | | |
| | | | USD 21.8 |
| Horiba stations | | | |
| Site logger and modem | 5.5x3 | USD 16.6 | |
| Central modem | | " 2.8 | |
| | | | USD 19.4 |
| Operations | | | |
| Transport | | USD 18.5 | |
| Site inspections | | " 21.2 | |
| Preparation | | " 15.4 | |
| Start up | | " 47.2 | |
| Inspections | | " 31.0 | |
| Follow up (telephone), man power | | USD 26.0 | |
| | | | USD 159.3 |
| | | | USD 402.9 |

Not included:
- Sparepart kit and extras
- Electric power and telephone lines
- Transport, handling, lifting in Kuwait
- Local inspections

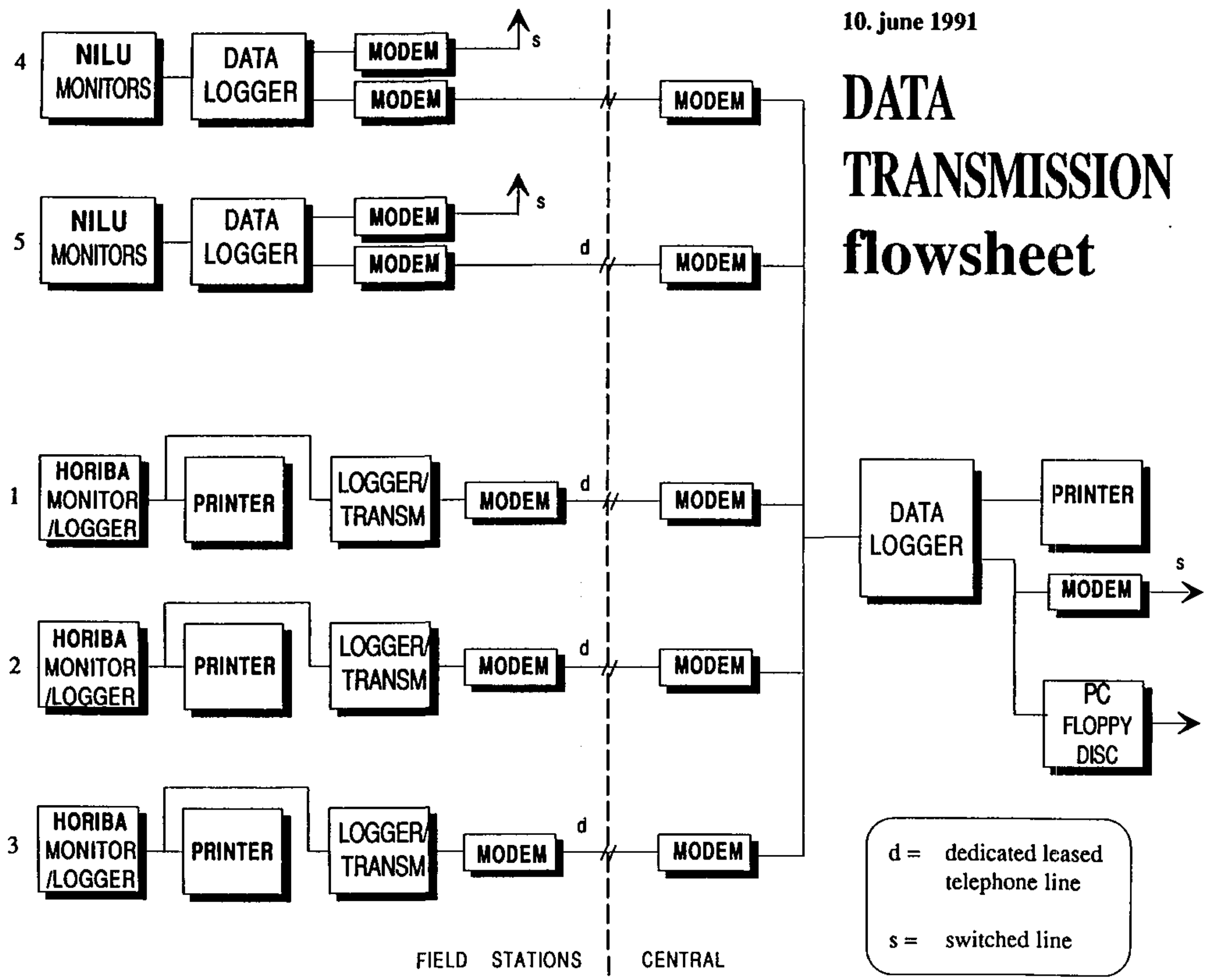
Tickets, accomodation in Kuwait and local transportation can be made available from Kuwait. A total cost for these services was estimated to ~35.000 USD.

In reference to chapter 7, modelling for warning purpose,these tasks have been estimated to:

Modelling/interface/work station ~ 100.000 USD

10. june 1991

# DATA TRANSMISSION flowsheet



Format available on printout every five minute at EPD warning centre in Kuwait.

PRINTER FORMAT CENTRAL

ALTERNATIVE 1

| ST | DATE | INST | TS | H2S | SO2 | THC | etc |
|---|---|---|---|---|---|---|---|
| 01 | 910608 | 1005 | 0001 | 0000 | 0002 | 0600 | |
| 02 | 910608 | 1005 | 0000 | 0010 | 0001 | 0590 | |
| 03 | 910608 | 1005 | 0003 | 0005 | 0003 | 0430 | |
| 04 | 910608 | 1005 | - | - | 0003 | - | |
| 05 | 910608 | 1005 | - | - | 0006 | - | |
| ST | DATE | INST | TS | H2S | SO2 | THC | etc |

ALTERNATIVE 2

| ST | DATE | INST | TS | H2S | SO2 | THC | etc |
|---|---|---|---|---|---|---|---|
| 1 | 910608 | 1005 | 1 | 0 | 2 | 600 | |
| 2 | 910608 | 1005 | 0 | 10 | 1 | 590 | |
| 3 | 910608 | 1005 | 3 | 5 | 3 | 430 | |
| 4 | 910608 | 1005 | - | - | 3 | - | |
| 5 | 910608 | 1005 | - | - | 6 | - | |
| ST | DATE | INST | TS | H2S | SO2 | THC | etc |

NILU TR: 6/91

NILU TR : 6/91
REFERENCE : O-91042
DATE : JULY 1991
ISBN : 82-425-0262-5

# Air Quality Measurements at Nordmedunit, Umm Quasr, Iraq

B. Sivertsen

NILU

NORSK INSTITUTT FOR LUFTFORSKNING
Norwegian Institute for Air Research
POSTBOKS 64 — N-2001 LILLESTRØM — NORWAY

## CONTENTS

# AIR QUALITY MEASUREMENTS AT NORDMEDUNIT, UMM QUASR, IRAQ

## 1 INTRODUCTION

The Norwegian Institute for Air Research (NILU) was asked by the Norwegian army field hospital (UNIKOM/NORDMEDUNIT) in Umm Quasr to provide instruments for air quality measurements. The objectives of these measurements were to daily collect air samples to quantify the air pollution impact at the hospital. The health personnel consists of 50 Norwegians. Some of these persons will be located in the area for up to 12 months. A selection of persons will be followed up through medical tests. Information about air quality is thus needed for explanatory reasons. The concern about potential health effects was also mentioned in the request to NILU.

## 2 INSTRUMENTATION

The following instruments are being used at the Umm Quasr site:

- One automatic 24 h sampler (NILU-FK) for $SO_2$ and soot measurements (filter and absorption solution).

- One NILU PUF sampler for PAH sampling on filter and on polyurethane foam (filters can also be used for analyses of heavy metals).

- One analog wind recorder (Woelfle) mounted on a 2 m mast, located in an open field.

Temperatures are also measured at 01, 07, 13 and 19 hrs every day.

## 3 LOCATION

The monitoring site is located near Umm Quasr in the UN controlled zone at the border between Kuwait and Iraq (see map, Figure 1). The area is located 20-50 km north and north east of some of the burning oil fields in the north of Kuwait. The distance from the larger part of the burning oil field is about 100 km.

## 4 WIND DIRECTIONS

The predominant winds in May and June have been from around north and north-west (roughly 80% of the time). This means that smoke from the fires only rarely has been blown directly from the fire areas towards Umm Quasr. One such period was, however, observed between 26 and 27 May 1991. In the morning of 27 May weak winds (0.5 m/s) from south and west were observed in Umm Quasr.

## 5 THE FIRST RESULTS

The 24 h average $SO_2$ concentrations in May and June 1991 varied between 5 and 36 $\mu g/m^3$. The average concentration was 11.5 $\pm$6.4 $\mu g/m^3$. The highest concentration, 36 $\mu g/m^3$, was measured on 26-27 May 1991.

The measured 24 h average soot concentrations were between 8 and 400 $\mu g/m^3$. The average concentration was 43.3 $\pm$ 71.5 $\mu g/m^3$.

The WHO air quality guideline value for black smoke (reflectance method), which is 125 $\mu g/m^3$ as a 24 h average, was exceeded on two occations. On 26-27 May 1991 the measured concentration was more than 3 times the WHO guideline value. On 14-15 June 1991 the soot concentration was 156 $\mu g/m^3$.

Four PAH samples have been analyzed so far. The total PAH concentrations varied between 207 and 412 ng/$m^3$. Naphtalene alone accounted for between 45 and 60%. The naphtalene concentrations in air were probably considerably higher. At high temperatures the sampling efficiencies of naphtalene and other volatile PAH-components are usually poor.

The average total PAH concentration of (296 ± 87) ng/$m^3$ is rather low, and much lower than the concentrations measured in some of the industrialized areas in Norway or in streets with high traffic.

## 6 CONCLUSIONS

Strong conclusions cannot be drawn based on these rather limited data, collected during a period with favourable weather conditions with little air quality impact on the location in Umm Quasr. However, during winds from south and south west, the concentrations of black smoke (soot) at the border between Kuwait and Iraq exceeded the WHO air quality guideline value by a factor of 3. The $SO_2$ concentrations were surprisingly low and not higher than 36 μg/$m^3$.

Also the total PAH concentrations were rather low. The most volatile compounds might, however, have been considerably higher than measured by the methods used.

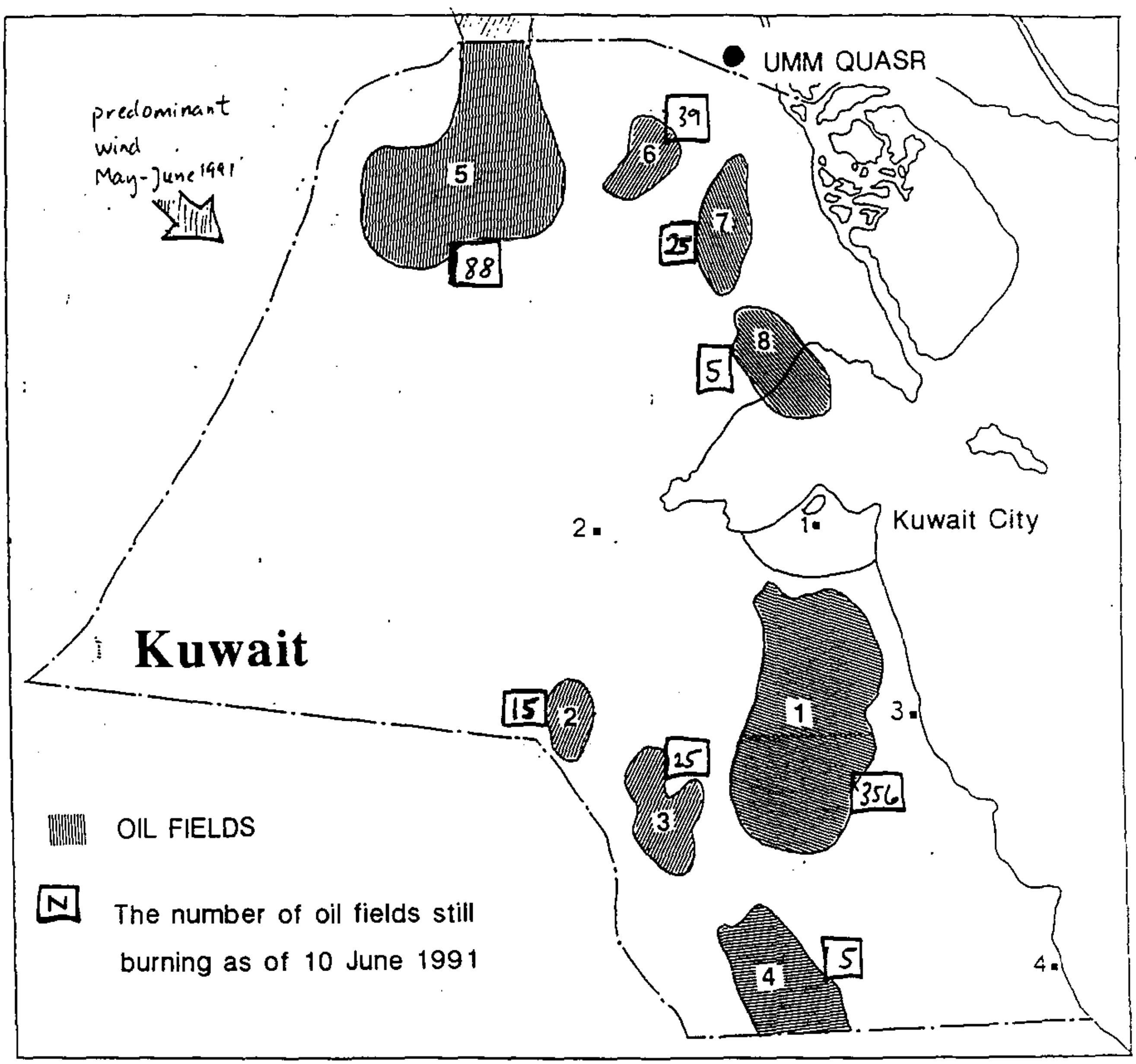
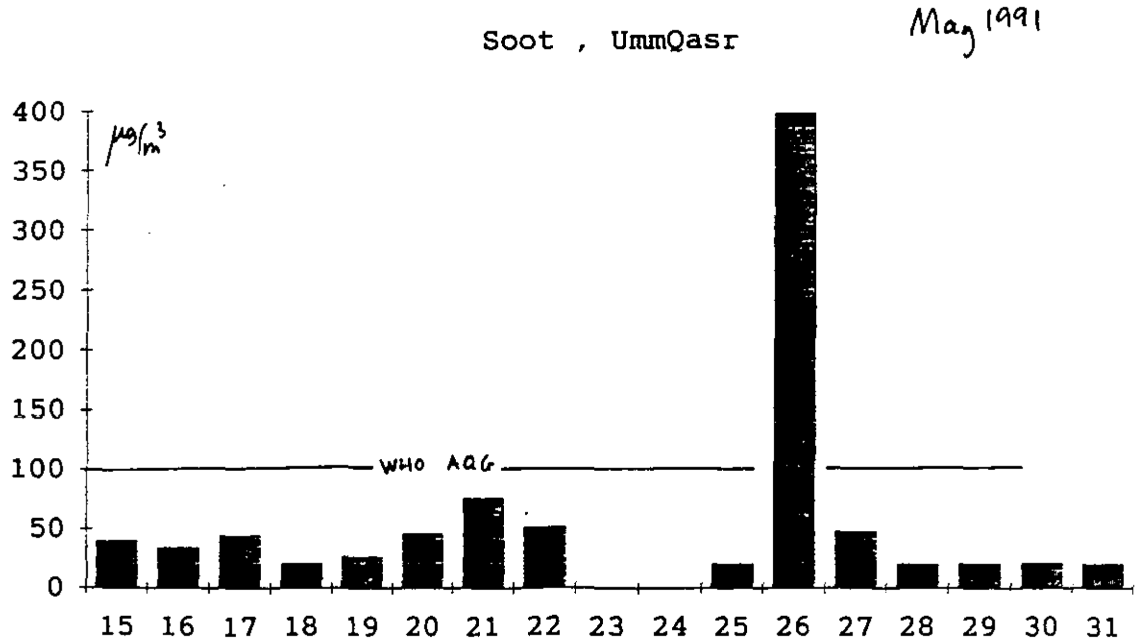



Figure 1: Burning oil fields and location of monitoring site in Umm Quasr.



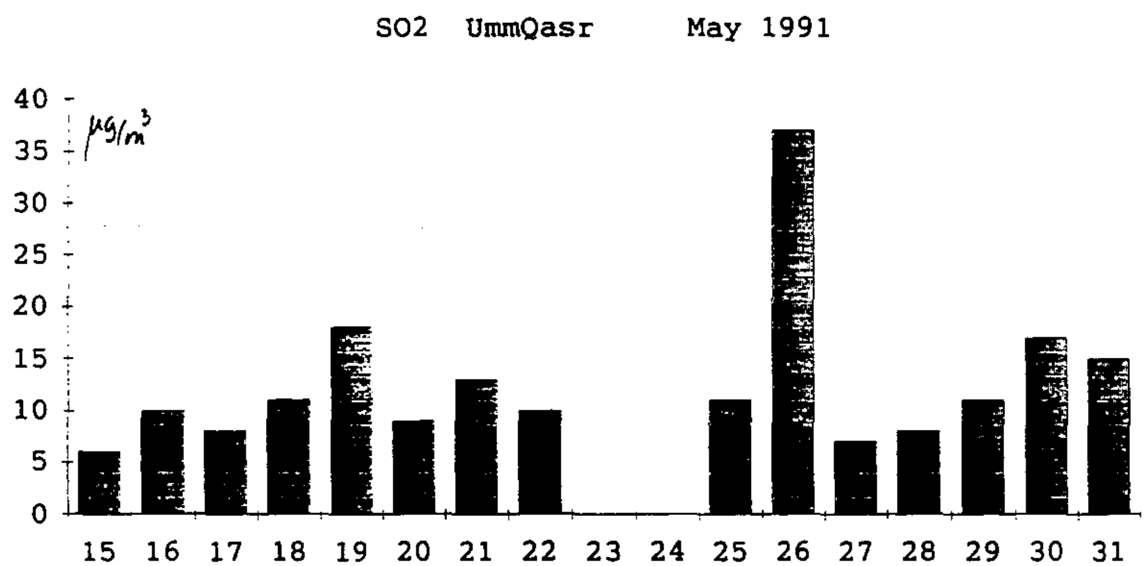
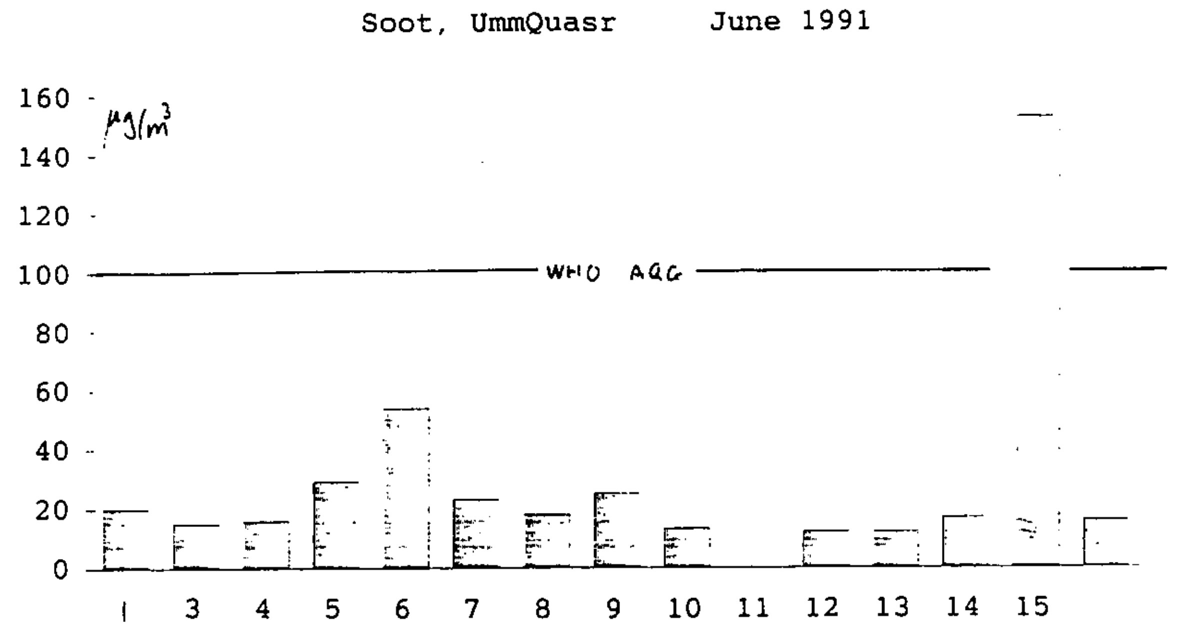




Figure 2: 24 h average concentrations of $SO_2$ and soot (black smoke) in Umm Quasr at the border between Kuwait and Iraq (May 1991).



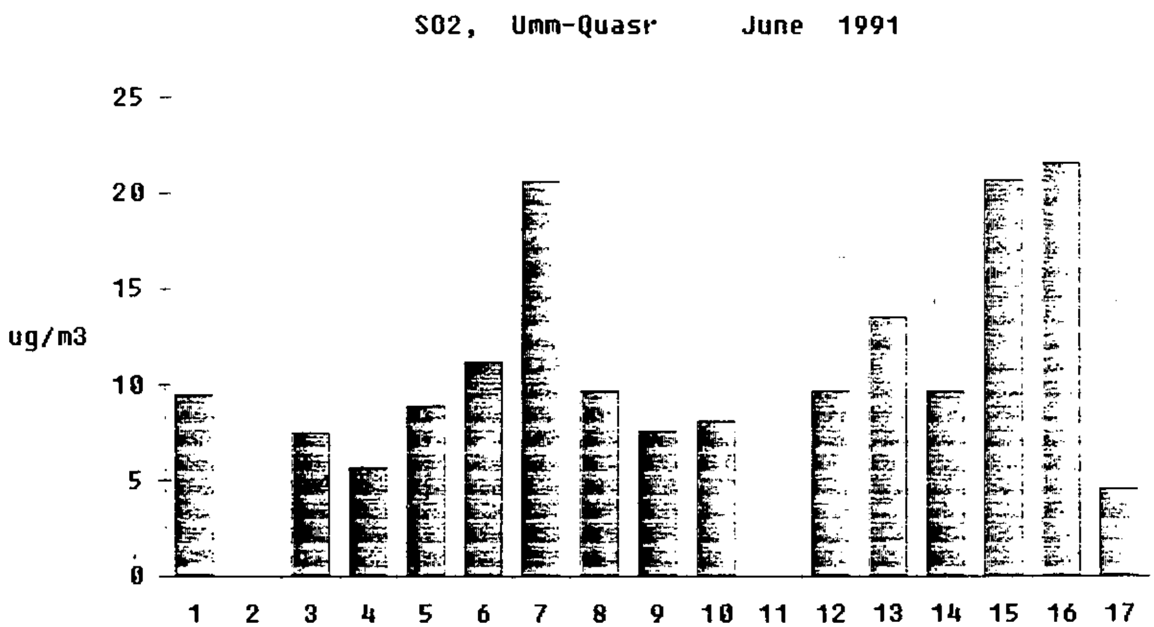




Figure 3: 24 h average concentrations of $SO_2$ and soot (black smoke) in Umm Quasr at the border between Kuwait and Iraq (June 1991).

Table 1: Concentration of PAH in air (ng/m$^3$) Umm Quasr, Kuwait

| PAH | 21.5.1991 Total | 27.5.1991 Total | 14-15.6.1991 Total | 15.6.1991 Total |
|---|---|---|---|---|
| Naphtalene | 228 | 94.4 | 184 | 132 |
| 2-methylnaphthalene | 8.8 | 4.5 | 7.2 | 9.3 |
| 1-methylnaphthalene | 4.6 | 2.1 | 4.2 | 5.6 |
| Biphenyl | 5.0 | 2.1 | 7.4 | 17.4 |
| Acenaphthylene | | 1.4 | | |
| Acenapthene | | | | |
| Dibenzofuran | 5.7 | | | |
| Fluorene | 15.4 | 7.2 | 17.6 | 34.8 |
| Dibenzothiophene | 26.6 | 12.2 | 2.7 | 5.5 |
| Phenanthrene | 48.7 | 31.7 | 33.2 | 22.3 |
| Anthracene | 10.8 | 4.5 | 6.1 | 10.4 |
| 2-methylphenanthrene | 11.4 | 3.4 | 2.5 | 3.0 |
| 2-metylanthracene | | | | |
| 1-methylphenanthrene | | | | |
| Fluoranthene | 17.3 | 11.5 | 15.3 | 6.6 |
| Pyrene | 16.1 | 11.3 | 9.6 | 6.1 |
| Benzo(a)fluorene | | | | |
| Retene | | | | |
| Benzo(b)fluorene | | | | |
| Benzo(g,h,i)fluoranthene | | 1.4 | 0.5 | |
| Cyklopenta(cd)pyrene | (2.9) | (2.7) | (2.0) | (1.7) |
| Benz(a)anthracene | 1.3 | 1.0 | 1.3 | ~0.4 |
| Chrysene/Thriphenylene | 4.6 | 2.4 | 1.9 | 1.1 |
| Benzo(b,j,k)fluoranthenes | 2.7 | 5.9 | 2.9 | 1.4 |
| Benzo(e)pyrene | ~0.8 | 1.3 | 1.2 | 0.6 |
| Benzo(a)pyrene | ~0.8 | 0.3 | 1.0 | 0.5 |
| Perylene | | | | |
| Inden-(1,2,3-c,d)pyrene | | 1.8 | 0.7 | 0.7 |
| Dibenzo(ac/ah)anthraces | | | | |
| Benzo(g,h,i)perylene | | 1.8 | 1.1 | 1.0 |
| Anthanthrene | | | | |
| Coronene | | 2.0 | 1.0 | |
| 1,2,4,5-dibenzopyrene | | | | |
| Total | 412 | 207 | 303 | 260 |

**NORSK INSTITUTT FOR LUFTFORSKNING (NILU)**
**NORWEGIAN INSTITUTE FOR AIR RESEARCH**
**POSTBOKS 64, N-2001 LILLESTRØM**

| | | | |
|---|---|---|---|
| RAPPORTTYPE<br>TEKNISK RAPPORT | RAPPORTNR. TR 6/91 | ISBN-82-425-0262-5 | |
| DATO<br>JULY 1991 | ANSV. SIGN. | ANT. SIDER<br>8 | PRIS<br>NOK 15,- |
| TITTEL<br>Air quality measurements at NORDMEDUNIT, Umm Quasr, Iraq | | PROSJEKTLEDER<br>B. Sivertsen | |
| | | NILU PROSJEKT NR.<br>O-91042 | |
| FORFATTER(E)<br>B. Sivertsen | | TILGJENGELIGHET *<br>A | |
| | | OPPDRAGSGIVERS REF. | |
| OPPDRAGSGIVER (NAVN OG ADRESSE)<br>Norsk institutt for luftforskning | | | |
| STIKKORD<br>Partikler | Svoveldioksid | PAH | |
| REFERAT | | | |

| |
|---|
| TITLE |

ABSTRACT

The first results of air quality measurements performed by NILU in Umm Quasr, at the border of Kuwait and Iraq show high concentrations of black smoke, and rather low concentrations of $SO_2$ and PAH.

* Kategorier: Åpen - kan bestilles fra NILU A
Må bestilles gjennom oppdragsgiver B
Kan ikke utleveres C

[April – May]

DRAFT

# AMBIENT AIR MONITORING DATA
# Dammam

Meteorology and Environmental Protection Administration
Kingdom of Saudi Arabia

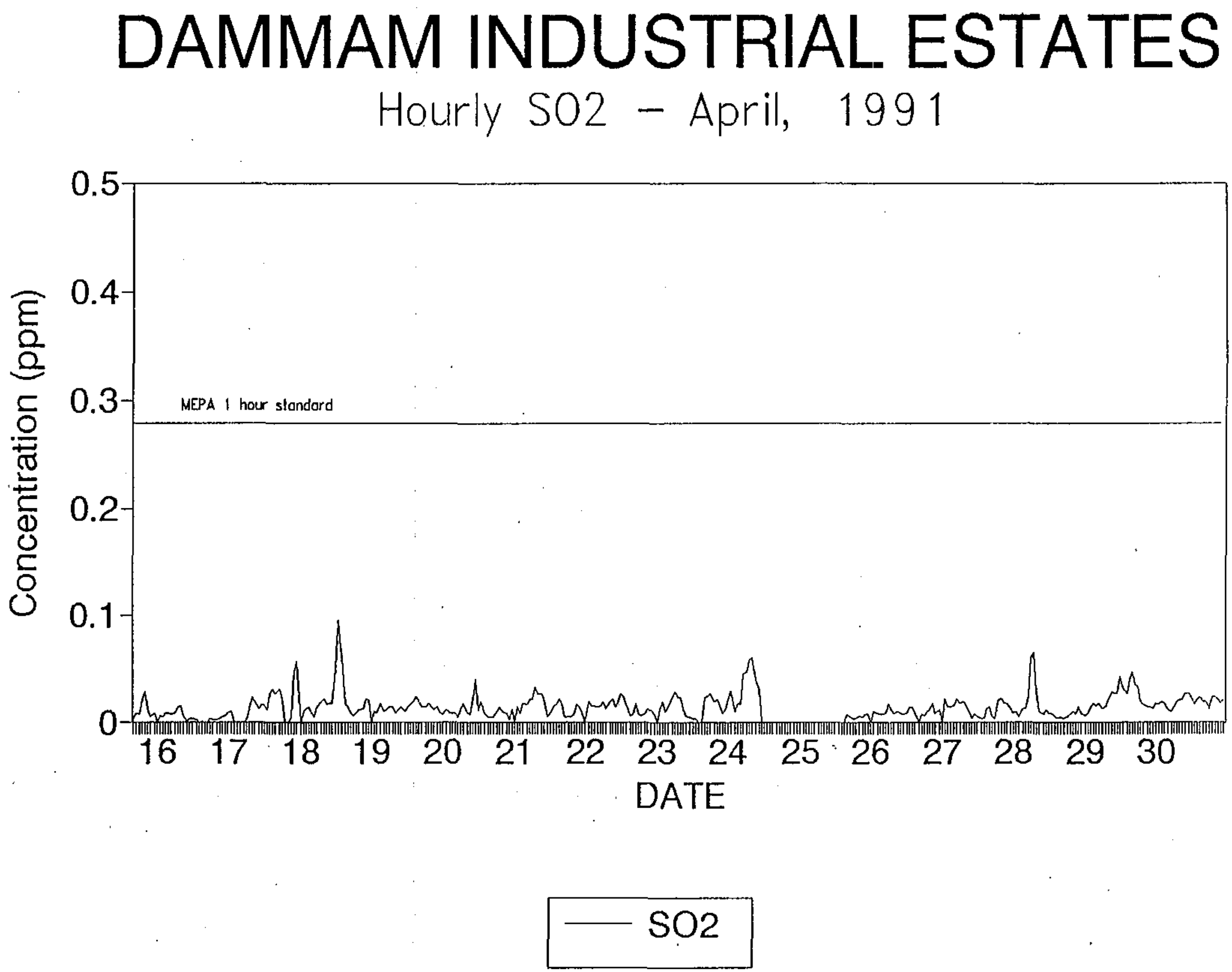
MEPA - Dammam Industrial Estates
April 1991
Hourly Averages for SO2 in ppm

| Day \ Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 2 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 3 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 4 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 5 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 8 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 9 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 10 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 11 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 12 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 13 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 14 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 15 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.002 | 0.009 | 0.007 | 0.020 | 0.028 | 0.012 | 0.005 | 0.008 | 0.0114 |
| 16 | ND | 0.006 | 0.004 | 0.009 | 0.008 | 0.007 | 0.009 | 0.013 | 0.015 | 0.006 | 0.001 | 0.003 | 0.003 | 0.002 | 0.000 | 0.001 | 0.000 | 0.000 | 0.003 | 0.002 | 0.002 | 0.003 | 0.005 | 0.006 | 0.0047 |
| 17 | 0.009 | 0.010 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.012 | 0.023 | 0.019 | 0.012 | 0.016 | 0.015 | 0.011 | 0.026 | 0.030 | 0.026 | 0.031 | 0.020 | 0.000 | 0.000 | 0.004 | 0.046 | 0.057 | 0.0154 |
| 18 | ND | 0.010 | 0.012 | 0.013 | 0.008 | 0.004 | 0.013 | 0.019 | 0.022 | 0.016 | 0.017 | 0.018 | 0.049 | 0.096 | 0.061 | 0.016 | 0.014 | 0.009 | 0.006 | 0.008 | 0.011 | 0.012 | 0.021 | 0.020 | 0.0207 |
| 19 | ND | 0.010 | 0.009 | 0.017 | 0.010 | 0.011 | 0.014 | 0.013 | 0.009 | 0.011 | 0.013 | 0.010 | 0.013 | 0.016 | 0.019 | 0.024 | 0.019 | 0.014 | 0.014 | 0.018 | 0.014 | 0.011 | 0.013 | 0.009 | 0.0135 |
| 20 | 0.007 | 0.011 | 0.008 | 0.009 | 0.008 | 0.004 | 0.011 | 0.017 | 0.008 | 0.007 | 0.021 | 0.039 | 0.011 | 0.019 | 0.009 | 0.004 | 0.004 | 0.005 | 0.010 | 0.013 | 0.010 | 0.008 | 0.002 | 0.011 | 0.0107 |
| 21 | ND | 0.014 | 0.009 | 0.018 | 0.016 | 0.021 | 0.021 | 0.032 | 0.027 | 0.027 | 0.021 | 0.004 | 0.008 | 0.015 | 0.016 | 0.022 | 0.018 | 0.004 | 0.004 | 0.004 | 0.007 | 0.016 | 0.014 | 0.008 | 0.0150 |
| 22 | ND | 0.019 | 0.015 | 0.015 | 0.014 | 0.015 | 0.019 | 0.012 | 0.019 | 0.021 | 0.014 | 0.019 | 0.027 | 0.024 | 0.016 | 0.006 | 0.007 | 0.018 | 0.007 | 0.006 | 0.007 | 0.012 | 0.011 | 0.007 | 0.0143 |
| 23 | ND | 0.012 | 0.019 | 0.010 | 0.013 | 0.024 | 0.028 | 0.023 | 0.023 | 0.012 | 0.006 | 0.004 | 0.003 | 0.003 | CAL | CAL | 0.023 | 0.024 | 0.027 | 0.019 | 0.021 | 0.015 | 0.008 | 0.011 | 0.0156 |
| 24 | 0.020 | 0.029 | 0.010 | 0.018 | 0.016 | 0.045 | 0.046 | 0.058 | 0.061 | 0.040 | 0.030 | ND | 0.080 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.0378 |
| 25 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | CAL | CAL | CAL | CAL | CAL | 0.007 | 0.005 | 0.003 | 0.003 | 0.006 | 0.004 | 0.007 | 0.007 | 0.0053 |
| 26 | ND | 0.010 | 0.009 | 0.007 | 0.007 | 0.009 | 0.016 | 0.011 | 0.009 | 0.010 | 0.008 | 0.007 | 0.009 | 0.014 | 0.013 | 0.009 | CAL | 0.007 | 0.006 | 0.010 | 0.011 | 0.018 | 0.009 | 0.011 | 0.0100 |
| 27 | ND | 0.021 | 0.014 | 0.013 | 0.015 | 0.021 | 0.018 | 0.019 | 0.014 | 0.010 | 0.003 | 0.007 | 0.004 | 0.003 | 0.003 | 0.012 | 0.014 | 0.005 | 0.003 | 0.020 | 0.022 | 0.017 | 0.018 | 0.012 | 0.0125 |
| 28 | 0.008 | 0.010 | 0.005 | 0.012 | 0.012 | 0.024 | 0.061 | 0.065 | 0.028 | 0.010 | 0.007 | 0.011 | 0.009 | 0.009 | 0.005 | 0.003 | 0.004 | 0.003 | 0.004 | 0.007 | 0.010 | 0.007 | 0.014 | 0.008 | 0.0140 |
| 29 | 0.006 | 0.008 | 0.013 | 0.018 | 0.015 | 0.017 | 0.012 | 0.013 | 0.021 | 0.028 | 0.026 | 0.027 | 0.042 | 0.032 | 0.027 | 0.039 | 0.046 | 0.035 | 0.033 | 0.019 | 0.016 | 0.013 | 0.013 | 0.012 | 0.0221 |
| 30 | 0.018 | 0.016 | 0.019 | 0.018 | 0.011 | 0.010 | 0.014 | 0.019 | 0.020 | 0.020 | 0.026 | 0.027 | 0.021 | 0.016 | 0.020 | 0.023 | 0.019 | 0.019 | 0.012 | 0.023 | 0.023 | 0.020 | 0.017 | 0.020 | 0.0188 |
| Monthly Average = | | | | | | | | | | | | | | | | | | | | | | | | | 0.0150 |

Maximum Hourly Average was 0.096 at Hour 14 on Day 18 with 1 occurences and there were no Hourly Violations
Maximum Daily Average was 0.0378 on Day 24 with 1 occurences and there were no Daily Violations
Operating Efficiency = 46.8 percent
ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data
[CEM 1990]

MEPA - Dammam Industrial Estates
April 1991
Frequency Distribution
Hourly Averages for $SO_2$ in ppm

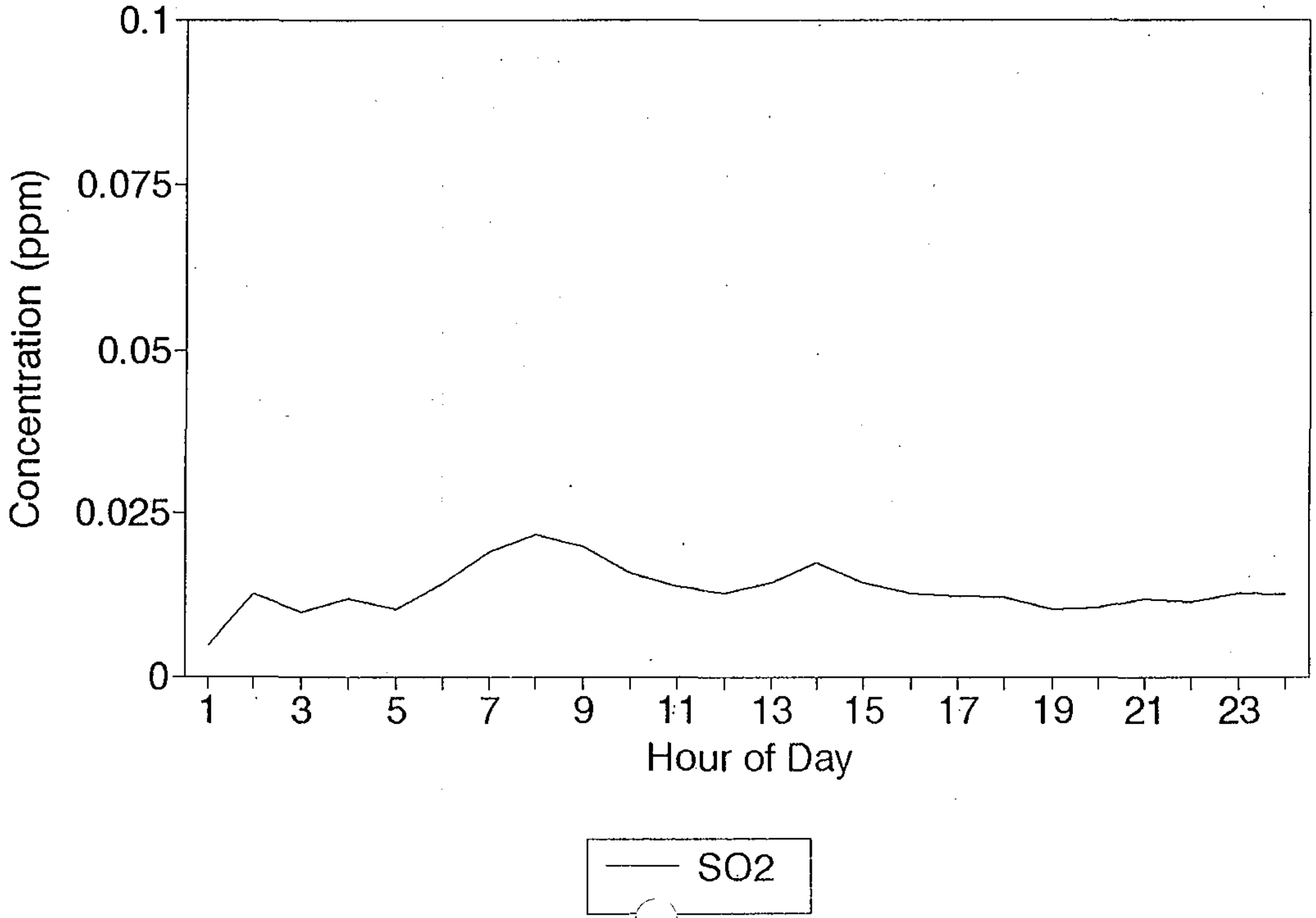
| Concentration | # of Hours | Percentage |
|---|---|---|
| 0.000 - 0.020 | 263 | 79.9 |
| 0.021 - 0.060 | 60 | 18.2 |
| 0.061 - 0.110 | 6 | 1.8 |
| 0.111 - 0.170 | 0 | 0.0 |
| 0.171 - 0.340 | 0 | 0.0 |
| 0.341+ | 0 | 0.0 |



DAMMAM INDUSTRIAL ESTATES
Hourly SO2 - April, 1991
Concentration (ppm)
0.5
0.4
0.3
0.2
0.1
0
MEPA 1 hour standard
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
DATE
SO2

# DAMMAM INDUSTRIAL ESTATES

Diurnal SO2 - April, 1991



MEPA - Dammam Industrial Estates
April 1991
Hourly Averages for NOx in ppm

| Day \ Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 2 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 3 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 4 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 5 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 8 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 9 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 10 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 11 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 12 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 13 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 14 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 15 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.047 | 0.027 | 0.047 | 0.032 | 0.050 | 0.068 | 0.080 | 0.056 | 0.0509 |
| 16 | ND | 0.049 | 0.035 | 0.061 | 0.058 | 0.046 | 0.080 | 0.100 | 0.032 | 0.024 | 0.014 | 0.018 | 0.012 | 0.013 | 0.014 | 0.017 | 0.019 | 0.024 | 0.088 | 0.086 | 0.053 | 0.052 | 0.052 | 0.091 | 0.0451 |
| 17 | 0.113 | 0.085 | 0.038 | 0.022 | 0.038 | 0.030 | 0.053 | 0.060 | 0.038 | 0.030 | 0.025 | 0.041 | 0.031 | 0.028 | 0.026 | 0.028 | 0.048 | 0.039 | 0.056 | 0.060 | 0.064 | 0.058 | 0.143 | 0.050 | 0.0502 |
| 18 | ND | 0.016 | 0.018 | 0.020 | 0.039 | 0.037 | 0.058 | 0.045 | 0.087 | 0.063 | 0.045 | 0.042 | 0.036 | 0.035 | 0.036 | 0.036 | 0.052 | 0.068 | 0.097 | 0.081 | 0.088 | 0.195 | 0.134 | 0.124 | 0.0631 |
| 19 | ND | 0.051 | 0.045 | 0.042 | 0.055 | 0.053 | 0.074 | 0.050 | 0.023 | 0.021 | 0.017 | 0.017 | 0.015 | 0.018 | 0.026 | 0.040 | 0.037 | 0.071 | 0.114 | 0.105 | 0.078 | 0.076 | 0.087 | 0.066 | 0.0513 |
| 20 | 0.052 | 0.028 | 0.027 | 0.021 | 0.030 | 0.028 | 0.038 | 0.063 | 0.033 | 0.038 | 0.036 | 0.032 | 0.026 | 0.027 | 0.039 | 0.040 | 0.051 | 0.068 | 0.039 | 0.063 | 0.097 | 0.072 | 0.030 | 0.027 | 0.0419 |
| 21 | ND | 0.019 | 0.019 | 0.017 | 0.014 | 0.024 | 0.038 | 0.085 | 0.061 | 0.047 | 0.037 | CAL | CAL | 0.069 | 0.038 | 0.044 | 0.059 | 0.058 | 0.064 | 0.060 | 0.068 | 0.097 | 0.083 | 0.057 | 0.0504 |
| 22 | ND | 0.019 | 0.015 | 0.014 | 0.014 | 0.021 | 0.045 | 0.054 | 0.049 | 0.045 | 0.035 | 0.040 | 0.043 | 0.026 | 0.029 | 0.035 | 0.057 | 0.061 | 0.067 | 0.090 | 0.086 | 0.121 | 0.081 | 0.046 | 0.0475 |
| 23 | ND | 0.017 | 0.017 | 0.010 | 0.013 | 0.017 | 0.038 | 0.053 | 0.047 | 0.035 | 0.024 | 0.025 | 0.029 | 0.030 | 0.027 | 0.048 | 0.046 | 0.100 | 0.102 | 0.111 | 0.117 | 0.066 | 0.048 | 0.043 | 0.0462 |
| 24 | 0.025 | 0.021 | 0.014 | 0.016 | 0.015 | 0.024 | 0.058 | 0.113 | 0.072 | 0.045 | 0.038 | 0.043 | 0.037 | 0.034 | 0.033 | 0.041 | 0.049 | 0.052 | 0.066 | 0.090 | 0.108 | 0.118 | 0.100 | 0.086 | 0.0541 |
| 25 | ND | 0.073 | 0.063 | 0.045 | 0.046 | 0.051 | 0.086 | 0.091 | 0.087 | 0.054 | 0.043 | 0.041 | 0.053 | 0.038 | 0.025 | 0.020 | 0.032 | 0.038 | 0.067 | 0.086 | 0.120 | 0.149 | 0.152 | 0.096 | 0.0677 |
| 26 | ND | 0.066 | 0.109 | 0.073 | 0.050 | 0.037 | 0.045 | 0.024 | 0.017 | CAL | CAL | CAL | CAL | CAL | 0.027 | 0.032 | 0.034 | 0.050 | 0.072 | 0.120 | 0.219 | 0.154 | 0.081 | 0.071 | 0.0712 |
| 27 | ND | 0.045 | 0.041 | 0.032 | 0.019 | 0.036 | 0.062 | 0.055 | 0.045 | 0.036 | 0.028 | 0.027 | 0.020 | 0.024 | 0.024 | 0.038 | 0.059 | 0.060 | 0.056 | 0.053 | 0.057 | 0.051 | 0.044 | 0.030 | 0.0410 |
| 28 | 0.019 | 0.019 | 0.020 | 0.020 | 0.020 | 0.030 | 0.058 | 0.079 | 0.041 | 0.030 | 0.032 | 0.029 | 0.026 | 0.029 | 0.028 | 0.028 | 0.040 | 0.046 | 0.059 | 0.060 | 0.071 | 0.074 | 0.100 | 0.079 | 0.0432 |
| 29 | 0.063 | 0.032 | 0.019 | 0.015 | 0.016 | 0.027 | 0.055 | 0.074 | 0.064 | 0.060 | 0.053 | 0.050 | 0.073 | 0.070 | 0.052 | 0.056 | 0.078 | 0.107 | 0.122 | 0.111 | 0.108 | 0.105 | 0.096 | 0.098 | 0.0668 |
| 30 | 0.083 | 0.048 | 0.040 | 0.028 | 0.027 | 0.037 | 0.069 | 0.105 | 0.064 | 0.066 | 0.048 | 0.048 | 0.043 | 0.047 | 0.043 | 0.044 | 0.046 | 0.064 | 0.100 | 0.114 | 0.146 | 0.141 | 0.155 | 0.093 | 0.0708 |
| | | | | | | | | | | | | | | | | | | | | | | Monthly Average = | | | 0.0537 |

Maximum Hourly Average was 0.219 at Hour 21 on Day 26 with 1 occurences and there were no Hourly Violations
Maximum Daily Average was 0.0712 on Day 26 with 1 occurences and there were no Daily Violations
Operating Efficiency = 49.9 percent
ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data
[CEM 1990]

MEPA - Dammam Industrial Estates
April 1991
Frequency Distribution
Hourly Averages for NOx in ppm

| Concentration | # of Hours | Percentage |
|---|---|---|
| 0.000 - 0.050 | 197 | 56.0 |
| 0.051 - 0.110 | 132 | 37.5 |
| 0.111 - 0.210 | 22 | 6.2 |
| 0.211+ | 1 | 0.3 |

MEPA - Dammam Industrial Estates
April 1991
Hourly Averages for NO2 in ppm

| Day \ Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 2 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 3 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 4 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 5 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 8 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 9 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 10 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 11 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 12 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 13 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 14 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 15 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.041 | 0.026 | 0.044 | 0.031 | 0.044 | 0.051 | 0.053 | 0.045 | 0.0419 |
| 16 | ND | 0.040 | 0.033 | 0.039 | 0.038 | 0.037 | 0.038 | 0.041 | 0.024 | 0.019 | 0.011 | 0.016 | 0.011 | 0.012 | 0.012 | 0.015 | 0.017 | 0.023 | 0.042 | 0.041 | 0.043 | 0.045 | 0.046 | 0.045 | 0.0299 |
| 17 | 0.047 | 0.042 | 0.030 | 0.021 | 0.037 | 0.028 | 0.039 | 0.041 | 0.029 | 0.024 | 0.021 | 0.034 | 0.026 | 0.025 | 0.025 | 0.026 | 0.043 | 0.035 | 0.043 | 0.045 | 0.049 | 0.047 | 0.050 | 0.044 | 0.0355 |
| 18 | ND | 0.016 | 0.018 | 0.019 | 0.032 | 0.031 | 0.040 | 0.033 | 0.038 | 0.037 | 0.032 | 0.034 | 0.033 | 0.032 | 0.034 | 0.033 | 0.044 | 0.049 | 0.054 | 0.058 | 0.055 | 0.054 | 0.050 | 0.049 | 0.0380 |
| 19 | ND | 0.039 | 0.036 | 0.037 | 0.037 | 0.035 | 0.037 | 0.032 | 0.020 | 0.018 | 0.015 | 0.015 | 0.014 | 0.017 | 0.024 | 0.034 | 0.030 | 0.046 | 0.048 | 0.049 | 0.047 | 0.043 | 0.041 | 0.043 | 0.0329 |
| 20 | 0.043 | 0.028 | 0.027 | 0.020 | 0.026 | 0.021 | 0.028 | 0.042 | 0.025 | 0.028 | 0.028 | 0.025 | 0.022 | 0.024 | 0.033 | 0.033 | 0.038 | 0.045 | 0.033 | 0.047 | 0.047 | 0.041 | 0.029 | 0.025 | 0.0316 |
| 21 | ND | 0.018 | 0.018 | 0.016 | 0.013 | 0.021 | 0.032 | 0.047 | 0.040 | 0.033 | 0.028 | CAL | CAL | 0.029 | 0.033 | 0.037 | 0.044 | 0.042 | 0.045 | 0.047 | 0.050 | 0.055 | 0.047 | 0.041 | 0.0350 |
| 22 | ND | 0.018 | 0.014 | 0.013 | 0.013 | 0.018 | 0.029 | 0.031 | 0.033 | 0.030 | 0.027 | 0.030 | 0.033 | 0.022 | 0.023 | 0.028 | 0.039 | 0.041 | 0.042 | 0.044 | 0.043 | 0.044 | 0.039 | 0.034 | 0.0299 |
| 23 | ND | 0.016 | 0.016 | 0.010 | 0.012 | 0.015 | 0.027 | 0.034 | 0.033 | 0.027 | 0.020 | 0.020 | 0.023 | 0.024 | 0.023 | 0.037 | 0.038 | 0.055 | 0.054 | 0.055 | 0.053 | 0.050 | 0.043 | 0.039 | 0.0315 |
| 24 | 0.023 | 0.020 | 0.013 | 0.015 | 0.014 | 0.018 | 0.033 | 0.042 | 0.045 | 0.035 | 0.030 | 0.030 | 0.028 | 0.027 | 0.028 | 0.033 | 0.040 | 0.039 | 0.042 | 0.046 | 0.047 | 0.048 | 0.044 | 0.047 | 0.0328 |
| 25 | ND | 0.042 | 0.038 | 0.036 | 0.037 | 0.035 | 0.044 | 0.042 | 0.050 | 0.039 | 0.036 | 0.034 | 0.043 | 0.033 | 0.024 | 0.019 | 0.028 | 0.033 | 0.050 | 0.053 | 0.059 | 0.058 | 0.071 | 0.060 | 0.0419 |
| 26 | ND | 0.048 | 0.046 | 0.042 | 0.040 | 0.032 | 0.034 | 0.020 | 0.015 | CAL | CAL | CAL | CAL | CAL | 0.025 | 0.028 | 0.029 | 0.047 | 0.067 | 0.066 | 0.078 | 0.074 | 0.061 | 0.056 | 0.0449 |
| 27 | ND | 0.042 | 0.039 | 0.031 | 0.019 | 0.028 | 0.037 | 0.035 | 0.029 | 0.025 | 0.020 | 0.020 | 0.016 | 0.019 | 0.019 | 0.029 | 0.040 | 0.045 | 0.047 | 0.044 | 0.048 | 0.045 | 0.039 | 0.029 | 0.0324 |
| 28 | 0.018 | 0.018 | 0.019 | 0.019 | 0.019 | 0.026 | 0.031 | 0.039 | 0.030 | 0.022 | 0.023 | 0.021 | 0.018 | 0.022 | 0.021 | 0.020 | 0.028 | 0.031 | 0.039 | 0.045 | 0.049 | 0.053 | 0.050 | 0.045 | 0.0294 |
| 29 | 0.044 | 0.029 | 0.017 | 0.014 | 0.015 | 0.023 | 0.037 | 0.040 | 0.036 | 0.037 | 0.039 | 0.037 | 0.047 | 0.049 | 0.042 | 0.046 | 0.052 | 0.052 | 0.051 | 0.047 | 0.048 | 0.048 | 0.052 | 0.045 | 0.0395 |
| 30 | 0.040 | 0.039 | 0.032 | 0.024 | 0.024 | 0.030 | 0.039 | 0.047 | 0.040 | 0.046 | 0.037 | 0.035 | 0.032 | 0.035 | 0.034 | 0.035 | 0.035 | 0.044 | 0.052 | 0.059 | 0.059 | 0.052 | 0.054 | 0.048 | 0.0405 |
| Monthly Average = | | | | | | | | | | | | | | | | | | | | | | | | | 0.0351 |

Maximum Hourly Average was 0.078 at Hour 21 on Day 26 with 1 occurences and there were no Hourly Violations
Maximum Daily Average was 0.0449 on Day 26 with 1 occurences and there were no Daily Violations
Operating Efficiency = 49.9 percent
ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data
[CEM 1990]

MEPA - Dammam Industrial Estates
April 1991
Frequency Distribution
Hourly Averages for $NO_2$ in ppm

| Concentration | # of Hours | Percentage |
|---|---|---|
| 0.000 - 0.050 | 320 | 90.9 |
| 0.051 - 0.110 | 32 | 9.1 |
| 0.111 - 0.210 | 0 | 0.0 |
| 0.211+ | 0 | 0.0 |

MEPA - Dammam Industrial Estates
April 1991
Hourly Averages for NO in ppm

| Hour / Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 2 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 3 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 4 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 5 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 8 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 9 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 10 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 11 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 12 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 13 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 14 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 15 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.006 | 0.002 | 0.004 | 0.001 | 0.006 | 0.018 | 0.028 | 0.011 | 0.0095 |
| 16 | ND | 0.010 | 0.002 | 0.022 | 0.020 | 0.009 | 0.043 | 0.060 | 0.009 | 0.006 | 0.003 | 0.002 | 0.001 | 0.002 | 0.002 | 0.002 | 0.001 | 0.001 | 0.047 | 0.046 | 0.010 | 0.007 | 0.007 | 0.047 | 0.0156 |
| 17 | 0.067 | 0.043 | 0.008 | 0.001 | 0.001 | 0.003 | 0.014 | 0.019 | 0.010 | 0.006 | 0.004 | 0.007 | 0.005 | 0.003 | 0.002 | 0.002 | 0.005 | 0.004 | 0.013 | 0.015 | 0.016 | 0.011 | 0.094 | 0.006 | 0.0150 |
| 18 | ND | 0.000 | 0.000 | 0.001 | 0.007 | 0.006 | 0.019 | 0.012 | 0.050 | 0.026 | 0.013 | 0.009 | 0.004 | 0.004 | 0.002 | 0.003 | 0.008 | 0.020 | 0.045 | 0.023 | 0.033 | 0.143 | 0.085 | 0.076 | 0.0256 |
| 19 | ND | 0.012 | 0.009 | 0.005 | 0.018 | 0.019 | 0.037 | 0.019 | 0.003 | 0.003 | 0.002 | 0.002 | 0.001 | 0.001 | 0.002 | 0.006 | 0.007 | 0.026 | 0.067 | 0.057 | 0.031 | 0.034 | 0.046 | 0.023 | 0.0187 |
| 20 | 0.009 | 0.001 | 0.001 | 0.001 | 0.005 | 0.006 | 0.010 | 0.022 | 0.008 | 0.010 | 0.009 | 0.007 | 0.004 | 0.004 | 0.006 | 0.007 | 0.013 | 0.024 | 0.006 | 0.017 | 0.051 | 0.031 | 0.001 | 0.003 | 0.0107 |
| 21 | ND | 0.001 | 0.001 | 0.001 | 0.001 | 0.003 | 0.006 | 0.038 | 0.021 | 0.014 | 0.009 | CAL | CAL | 0.040 | 0.006 | 0.007 | 0.015 | 0.016 | 0.020 | 0.014 | 0.019 | 0.042 | 0.037 | 0.017 | 0.0156 |
| 22 | ND | 0.001 | 0.001 | 0.001 | 0.001 | 0.004 | 0.016 | 0.023 | 0.016 | 0.016 | 0.009 | 0.011 | 0.010 | 0.005 | 0.006 | 0.007 | 0.018 | 0.020 | 0.025 | 0.047 | 0.044 | 0.079 | 0.043 | 0.012 | 0.0180 |
| 23 | ND | 0.001 | 0.001 | 0.000 | 0.000 | 0.002 | 0.012 | 0.019 | 0.015 | 0.008 | 0.005 | 0.005 | 0.006 | 0.006 | 0.004 | 0.011 | 0.008 | 0.045 | 0.048 | 0.056 | 0.065 | 0.017 | 0.006 | 0.004 | 0.0150 |
| 24 | 0.002 | 0.002 | 0.001 | 0.002 | 0.002 | 0.006 | 0.025 | 0.072 | 0.028 | 0.010 | 0.009 | 0.012 | 0.010 | 0.007 | 0.005 | 0.008 | 0.010 | 0.014 | 0.025 | 0.044 | 0.062 | 0.071 | 0.057 | 0.040 | 0.0218 |
| 25 | ND | 0.032 | 0.025 | 0.009 | 0.010 | 0.016 | 0.042 | 0.049 | 0.037 | 0.015 | 0.008 | 0.007 | 0.010 | 0.006 | 0.002 | 0.001 | 0.004 | 0.005 | 0.018 | 0.033 | 0.062 | 0.093 | 0.082 | 0.037 | 0.0262 |
| 26 | ND | 0.019 | 0.063 | 0.032 | 0.011 | 0.006 | 0.011 | 0.004 | 0.002 | CAL | CAL | CAL | CAL | CAL | 0.002 | 0.004 | 0.006 | 0.003 | 0.005 | 0.054 | 0.143 | 0.082 | 0.021 | 0.015 | 0.0268 |
| 27 | ND | 0.003 | 0.002 | 0.001 | 0.001 | 0.008 | 0.025 | 0.020 | 0.016 | 0.010 | 0.008 | 0.007 | 0.004 | 0.005 | 0.005 | 0.009 | 0.019 | 0.016 | 0.010 | 0.009 | 0.010 | 0.006 | 0.004 | 0.002 | 0.0087 |
| 28 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.004 | 0.027 | 0.040 | 0.012 | 0.008 | 0.009 | 0.008 | 0.007 | 0.007 | 0.007 | 0.007 | 0.012 | 0.016 | 0.020 | 0.015 | 0.022 | 0.021 | 0.050 | 0.035 | 0.0138 |
| 29 | 0.020 | 0.003 | 0.002 | 0.001 | 0.001 | 0.004 | 0.018 | 0.034 | 0.028 | 0.023 | 0.014 | 0.013 | 0.026 | 0.021 | 0.010 | 0.010 | 0.027 | 0.056 | 0.072 | 0.064 | 0.061 | 0.058 | 0.045 | 0.054 | 0.0277 |
| 30 | 0.044 | 0.010 | 0.007 | 0.004 | 0.003 | 0.007 | 0.031 | 0.058 | 0.025 | 0.020 | 0.010 | 0.013 | 0.011 | 0.013 | 0.009 | 0.010 | 0.011 | 0.021 | 0.048 | 0.056 | 0.088 | 0.090 | 0.102 | 0.045 | 0.0307 |
| Monthly Average = | | | | | | | | | | | | | | | | | | | | | | | | | 0.0190 |

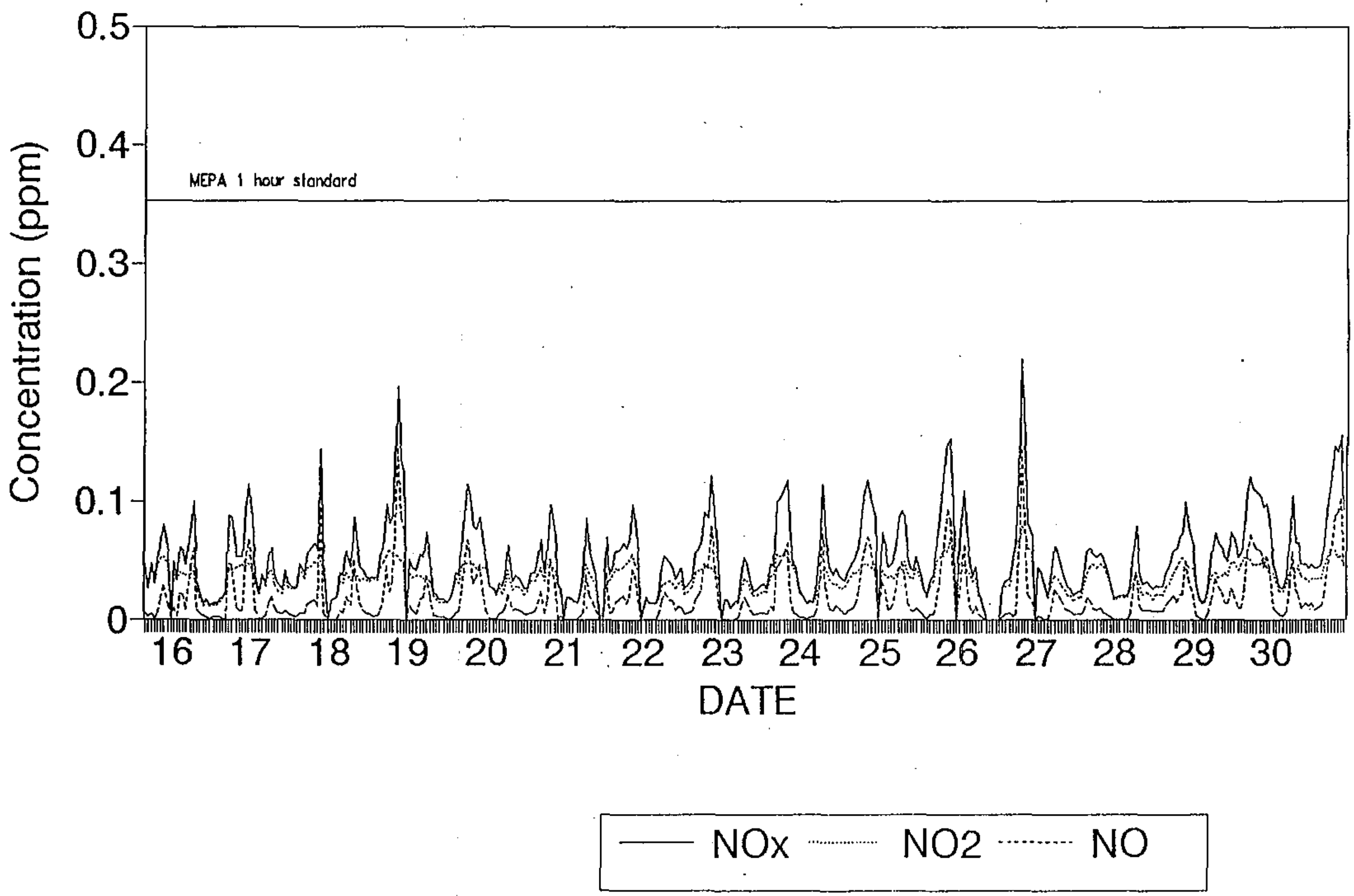
Maximum Hourly Average was 0.143 at Hour 22 on Day 18 with 2 occurences and there were no Hourly Violations
Maximum Daily Average was 0.0307 on Day 30 with 1 occurences and there were no Daily Violations
Operating Efficiency = 49.9 percent
ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data
[CEM 1990]

MEPA - Dammam Industrial Estates
April 1991
Frequency Distribution
Hourly Averages for NO in ppm

| Concentration | # of Hours | Percentage |
|---|---|---|
| 0.000 - 0.050 | 318 | 90.3 |
| 0.051 - 0.110 | 32 | 9.1 |
| 0.111 - 0.210 | 2 | 0.6 |
| 0.211+ | 0 | 0.0 |

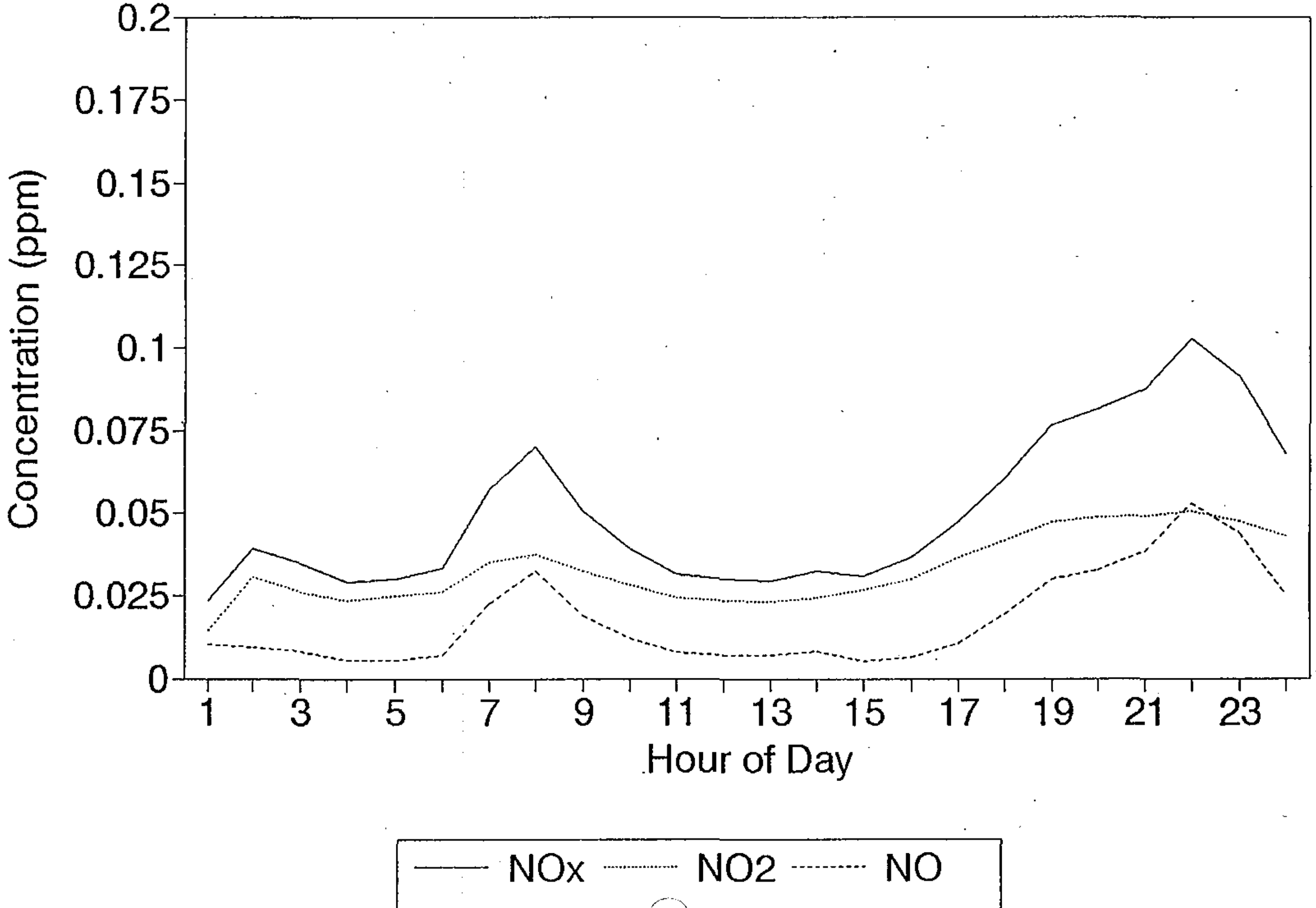
# DAMMAM INDUSTRIAL ESTATES

Hourly NOx/NO2/NO – April, 1991



# DAMMAM INDUSTRIAL ESTATES

Diurnal NOx/NO2/NO - April, 1991



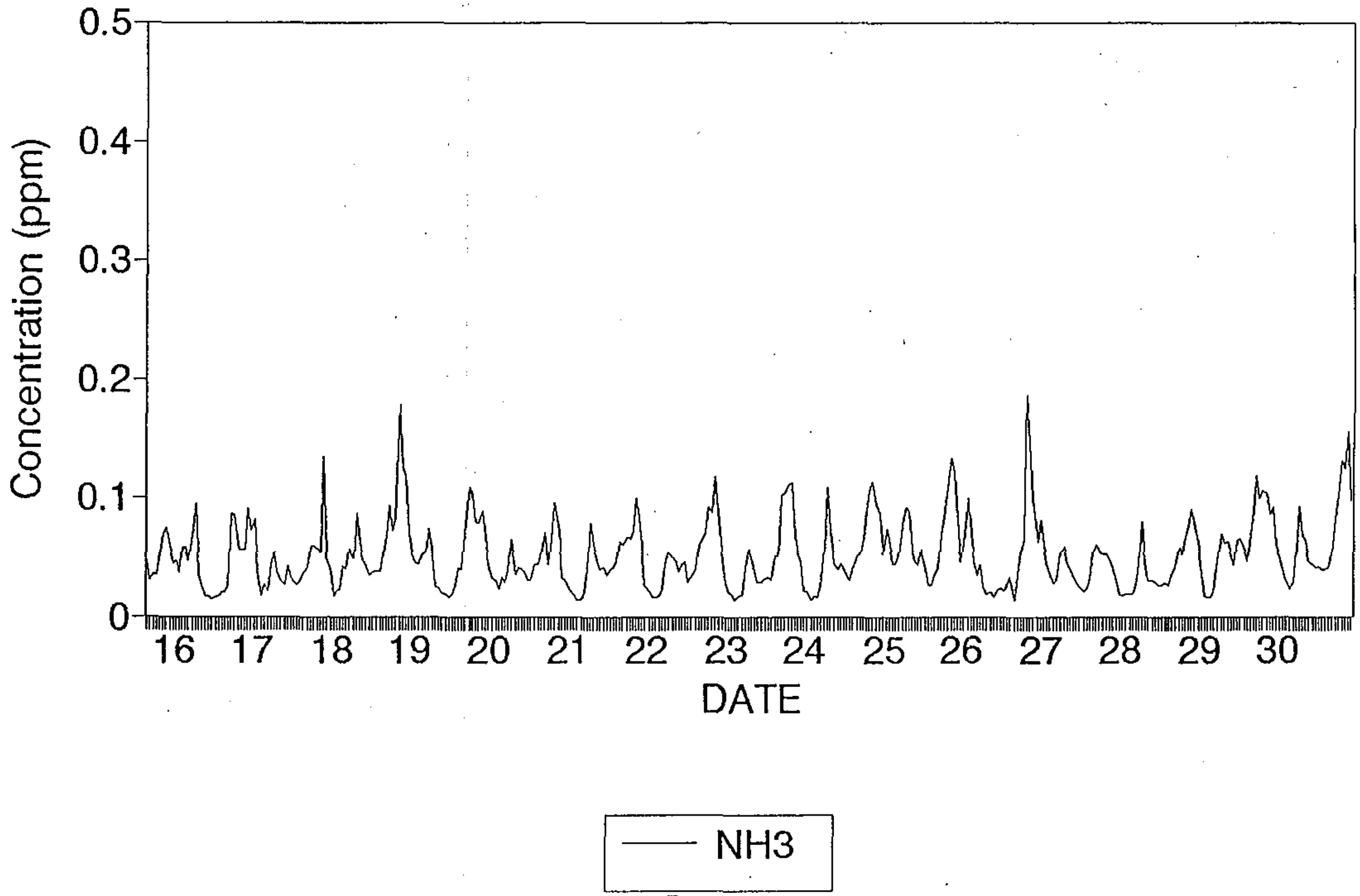
MEPA - Dammam Industrial Estates
April 1991
Hourly Averages for $NH_3$ in ppm

| Day \ Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 2 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 3 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 4 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 5 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 8 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 9 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 10 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 11 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 12 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 13 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 14 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 15 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.048 | 0.030 | 0.036 | 0.035 | 0.053 | 0.069 | 0.075 | 0.055 | 0.0501 |
| 16 | 0.045 | 0.048 | 0.037 | 0.058 | 0.058 | 0.047 | 0.074 | 0.094 | 0.034 | 0.026 | 0.018 | 0.018 | 0.015 | 0.016 | 0.018 | 0.020 | 0.020 | 0.027 | 0.087 | 0.085 | 0.055 | 0.055 | 0.055 | 0.090 | 0.0458 |
| 17 | 0.072 | 0.081 | 0.037 | 0.018 | 0.026 | 0.022 | 0.044 | 0.054 | 0.037 | 0.030 | 0.026 | 0.042 | 0.032 | 0.029 | 0.027 | 0.029 | 0.036 | 0.041 | 0.059 | 0.059 | 0.056 | 0.054 | 0.134 | 0.050 | 0.0456 |
| 18 | 0.038 | 0.018 | 0.022 | 0.023 | 0.042 | 0.040 | 0.057 | 0.049 | 0.087 | 0.063 | 0.047 | 0.043 | 0.035 | 0.037 | 0.038 | 0.038 | 0.053 | 0.067 | 0.093 | 0.072 | 0.081 | 0.178 | 0.125 | 0.117 | 0.0610 |
| 19 | 0.069 | 0.053 | 0.046 | 0.043 | 0.052 | 0.054 | 0.074 | 0.051 | 0.025 | 0.024 | 0.020 | 0.019 | 0.016 | 0.019 | 0.027 | 0.041 | 0.039 | 0.071 | 0.109 | 0.102 | 0.080 | 0.079 | 0.089 | 0.067 | 0.0529 |
| 20 | 0.044 | 0.032 | 0.030 | 0.023 | 0.033 | 0.029 | 0.040 | 0.064 | 0.036 | 0.041 | 0.040 | 0.037 | 0.030 | 0.031 | 0.043 | 0.044 | 0.055 | 0.071 | 0.043 | 0.066 | 0.096 | 0.072 | 0.032 | 0.030 | 0.0442 |
| 21 | 0.025 | 0.021 | 0.019 | 0.014 | 0.013 | 0.020 | 0.039 | 0.079 | 0.061 | 0.048 | 0.039 | 0.041 | 0.034 | 0.040 | 0.041 | 0.048 | 0.063 | 0.061 | 0.067 | 0.065 | 0.072 | 0.100 | 0.084 | 0.061 | 0.0481 |
| 22 | 0.027 | 0.021 | 0.016 | 0.016 | 0.017 | 0.023 | 0.045 | 0.054 | 0.050 | 0.047 | 0.038 | 0.044 | 0.046 | 0.029 | 0.033 | 0.039 | 0.061 | 0.066 | 0.071 | 0.092 | 0.088 | 0.118 | 0.080 | 0.048 | 0.0487 |
| 23 | 0.028 | 0.020 | 0.019 | 0.013 | 0.016 | 0.019 | 0.041 | 0.056 | 0.050 | 0.038 | 0.029 | 0.029 | 0.032 | 0.033 | 0.030 | 0.051 | 0.051 | 0.102 | 0.103 | 0.111 | 0.112 | 0.067 | 0.053 | 0.046 | 0.0479 |
| 24 | 0.022 | 0.021 | 0.014 | 0.017 | 0.016 | 0.025 | 0.056 | 0.109 | 0.072 | 0.045 | 0.040 | 0.045 | 0.039 | 0.034 | 0.031 | 0.040 | 0.051 | 0.053 | 0.066 | 0.089 | 0.106 | 0.113 | 0.094 | 0.086 | 0.0535 |
| 25 | 0.052 | 0.073 | 0.061 | 0.045 | 0.045 | 0.051 | 0.083 | 0.091 | 0.088 | 0.056 | 0.046 | 0.043 | 0.056 | 0.040 | 0.027 | 0.026 | 0.035 | 0.041 | 0.069 | 0.084 | 0.109 | 0.133 | 0.121 | 0.082 | 0.0649 |
| 26 | 0.046 | 0.062 | 0.100 | 0.069 | 0.046 | 0.035 | 0.043 | 0.025 | 0.019 | 0.020 | 0.016 | 0.022 | 0.024 | 0.022 | 0.027 | 0.033 | 0.013 | 0.035 | 0.055 | 0.065 | 0.186 | 0.147 | 0.100 | 0.063 | 0.0530 |
| 27 | 0.081 | 0.060 | 0.045 | 0.037 | 0.028 | 0.031 | 0.054 | 0.059 | 0.045 | 0.039 | 0.034 | 0.029 | 0.025 | 0.022 | 0.024 | 0.032 | 0.054 | 0.060 | 0.055 | 0.052 | 0.052 | 0.049 | 0.042 | 0.031 | 0.0433 |
| 28 | 0.019 | 0.018 | 0.019 | 0.019 | 0.019 | 0.027 | 0.045 | 0.080 | 0.046 | 0.030 | 0.031 | 0.029 | 0.027 | 0.027 | 0.028 | 0.026 | 0.035 | 0.042 | 0.058 | 0.053 | 0.067 | 0.076 | 0.090 | 0.080 | 0.0413 |
| 29 | 0.059 | 0.036 | 0.018 | 0.016 | 0.016 | 0.022 | 0.048 | 0.069 | 0.062 | 0.063 | 0.051 | 0.044 | 0.064 | 0.066 | 0.055 | 0.048 | 0.070 | 0.089 | 0.119 | 0.100 | 0.106 | 0.103 | 0.087 | 0.091 | 0.0626 |
| 30 | 0.061 | 0.050 | 0.039 | 0.031 | 0.024 | 0.029 | 0.056 | 0.093 | 0.068 | 0.064 | 0.048 | 0.043 | 0.041 | 0.042 | 0.040 | 0.040 | 0.041 | 0.053 | 0.083 | 0.102 | 0.132 | 0.125 | 0.157 | 0.098 | 0.0650 |
| | | | | | | | | | | | | | | | | | | | | | | Monthly Average = | | | 0.0518 |

Maximum Hourly Average was 0.186 at Hour 21 on Day 26 with 1 occurences and there were no Hourly Violations
Maximum Daily Average was 0.0650 on Day 30 with 1 occurences and there were no Daily Violations
Operating Efficiency = 51.1 percent
ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data
[CEM 1990]

# DAMMAM INDUSTRIAL ESTATES

Hourly NH3 – April, 1991



MEPA - Dammam Industrial Estates
April 1991
Hourly Averages for O3 in ppm

| Hour / Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 2 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 3 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 4 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 5 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 8 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 9 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 10 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 11 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 12 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 13 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 14 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 15 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.014 | 0.023 | 0.008 | 0.015 | 0.005 | 0.001 | 0.001 | 0.004 | 0.0089 |
| 16 | ND | 0.003 | 0.005 | 0.002 | 0.001 | 0.003 | 0.004 | 0.003 | 0.014 | 0.018 | 0.024 | 0.024 | 0.026 | 0.025 | 0.023 | 0.021 | 0.020 | 0.016 | 0.004 | 0.002 | 0.004 | 0.004 | 0.002 | 0.002 | 0.0109 |
| 17 | 0.001 | 0.001 | 0.006 | 0.013 | 0.009 | 0.010 | 0.006 | 0.005 | 0.015 | 0.022 | 0.024 | 0.020 | 0.031 | 0.033 | 0.039 | 0.032 | 0.020 | 0.011 | 0.005 | 0.004 | 0.003 | 0.002 | 0.001 | 0.004 | 0.0132 |
| 18 | ND | 0.020 | 0.016 | 0.013 | 0.003 | 0.003 | 0.004 | 0.006 | 0.004 | 0.008 | 0.012 | 0.021 | 0.034 | 0.037 | 0.032 | 0.022 | 0.010 | 0.005 | 0.001 | 0.005 | 0.006 | 0.001 | 0.001 | 0.001 | 0.0115 |
| 19 | ND | 0.003 | 0.003 | 0.002 | 0.005 | 0.001 | 0.002 | 0.007 | 0.018 | 0.021 | 0.024 | 0.025 | 0.027 | 0.025 | 0.019 | 0.013 | 0.013 | 0.003 | 0.001 | 0.001 | 0.002 | 0.002 | 0.001 | 0.001 | 0.0095 |
| 20 | 0.001 | 0.006 | 0.008 | 0.011 | 0.008 | 0.008 | 0.007 | 0.007 | 0.017 | 0.015 | 0.015 | 0.019 | 0.022 | 0.022 | 0.014 | 0.013 | 0.007 | 0.003 | 0.010 | 0.002 | 0.001 | 0.002 | 0.010 | 0.012 | 0.0100 |
| 21 | ND | 0.015 | 0.014 | 0.017 | 0.018 | 0.014 | 0.008 | 0.002 | 0.008 | 0.014 | 0.020 | CAL | CAL | 0.014 | 0.015 | 0.013 | 0.007 | 0.007 | 0.004 | 0.004 | 0.002 | 0.002 | 0.001 | 0.001 | 0.0095 |
| 22 | ND | 0.016 | 0.018 | 0.018 | 0.017 | 0.014 | 0.007 | 0.007 | 0.010 | 0.015 | 0.019 | 0.017 | 0.017 | 0.020 | 0.017 | 0.012 | 0.004 | 0.002 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.0103 |
| 23 | ND | 0.012 | 0.013 | 0.017 | 0.016 | 0.014 | 0.009 | 0.009 | 0.013 | 0.021 | 0.025 | 0.024 | 0.022 | 0.021 | 0.023 | 0.011 | 0.012 | 0.002 | 0.001 | 0.001 | 0.001 | 0.001 | 0.002 | 0.005 | 0.0120 |
| 24 | 0.017 | 0.017 | 0.017 | 0.016 | 0.016 | 0.011 | 0.003 | 0.002 | 0.008 | 0.019 | 0.024 | 0.020 | 0.019 | 0.021 | 0.021 | 0.012 | 0.009 | 0.006 | 0.003 | 0.002 | 0.001 | 0.001 | 0.001 | 0.001 | 0.0111 |
| 25 | ND | 0.001 | 0.001 | 0.002 | 0.001 | 0.003 | 0.003 | 0.003 | 0.008 | 0.016 | 0.020 | 0.024 | 0.019 | 0.027 | 0.037 | 0.035 | 0.020 | 0.015 | 0.004 | 0.002 | 0.001 | 0.001 | 0.001 | 0.001 | 0.0107 |
| 26 | ND | 0.003 | 0.001 | 0.001 | 0.002 | 0.005 | 0.009 | 0.019 | 0.025 | 0.029 | 0.036 | 0.040 | 0.046 | 0.046 | CAL | CAL | CAL | CAL | 0.007 | 0.008 | 0.001 | 0.002 | 0.001 | 0.001 | 0.0148 |
| 27 | ND | 0.007 | 0.004 | 0.008 | 0.018 | 0.009 | 0.006 | 0.012 | 0.015 | 0.020 | 0.023 | 0.023 | 0.028 | 0.023 | 0.022 | 0.015 | 0.006 | 0.005 | 0.004 | 0.005 | 0.003 | 0.004 | 0.006 | 0.011 | 0.0120 |
| 28 | 0.017 | 0.016 | 0.015 | 0.013 | 0.012 | 0.006 | 0.004 | 0.004 | 0.016 | 0.019 | 0.018 | 0.020 | 0.021 | 0.018 | 0.016 | 0.017 | 0.012 | 0.009 | 0.006 | 0.005 | 0.002 | 0.003 | 0.001 | 0.001 | 0.0113 |
| 29 | 0.001 | 0.011 | 0.017 | 0.021 | 0.021 | 0.012 | 0.002 | 0.002 | 0.006 | 0.010 | 0.014 | 0.012 | 0.004 | 0.007 | 0.016 | 0.014 | 0.005 | 0.002 | 0.001 | 0.001 | 0.002 | 0.001 | 0.001 | 0.001 | 0.0077 |
| 30 | 0.001 | 0.002 | 0.006 | 0.012 | 0.014 | 0.009 | 0.004 | 0.003 | 0.011 | 0.016 | 0.023 | 0.020 | 0.020 | 0.018 | 0.020 | 0.016 | 0.012 | 0.006 | 0.001 | 0.006 | 0.003 | 0.001 | 0.001 | 0.001 | 0.0094 |
| | | | | | | | | | | | | | | | | | | | | | | | | Monthly Average = | 0.0108 |

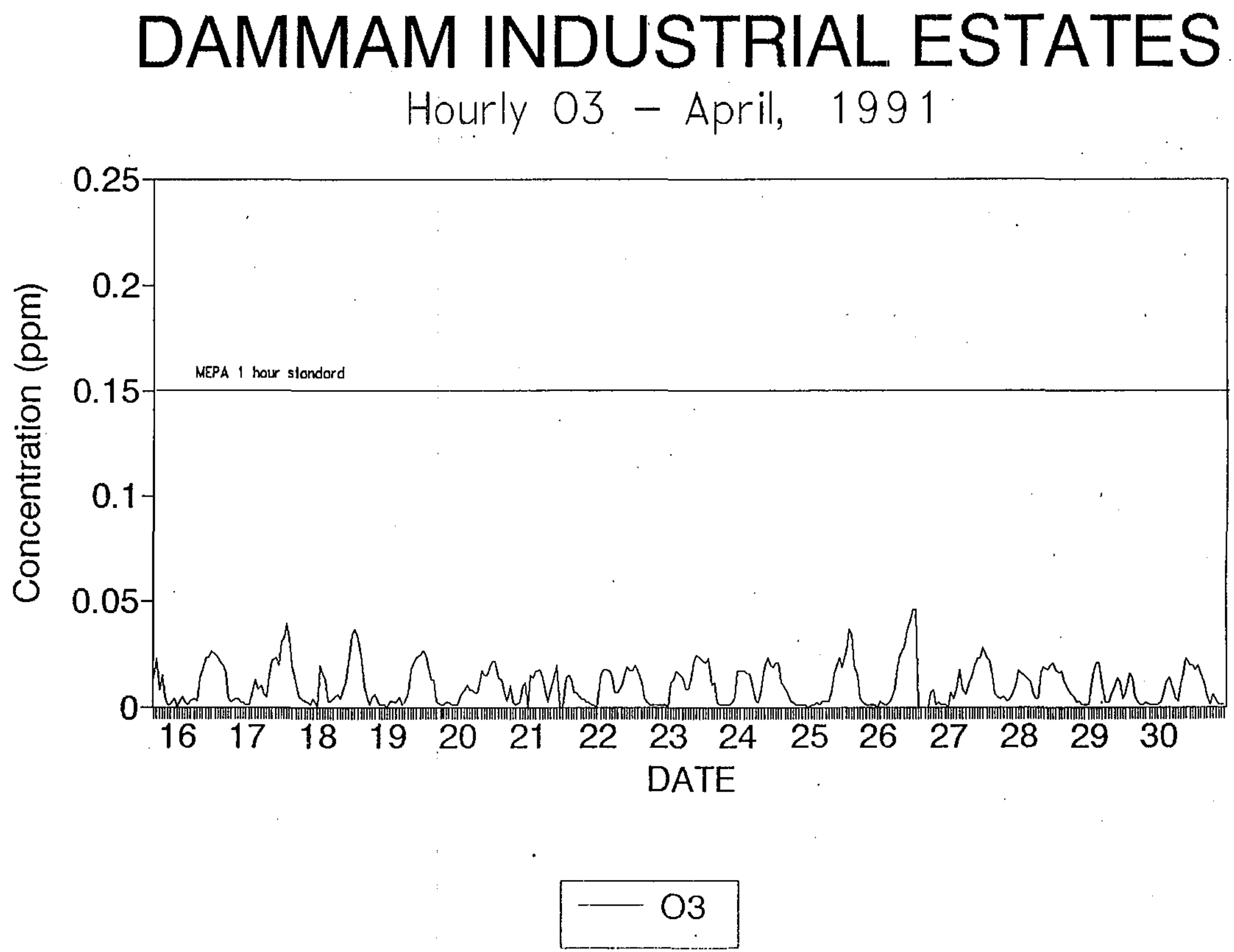
Maximum Hourly Average was 0.046 at Hour 13 on Day 26 with 2 occurences and there were no Hourly Violations

Maximum Daily Average was 0.0148 on Day 26 with 1 occurences and there were no Daily Violations

Operating Efficiency = 49.9 percent

ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data

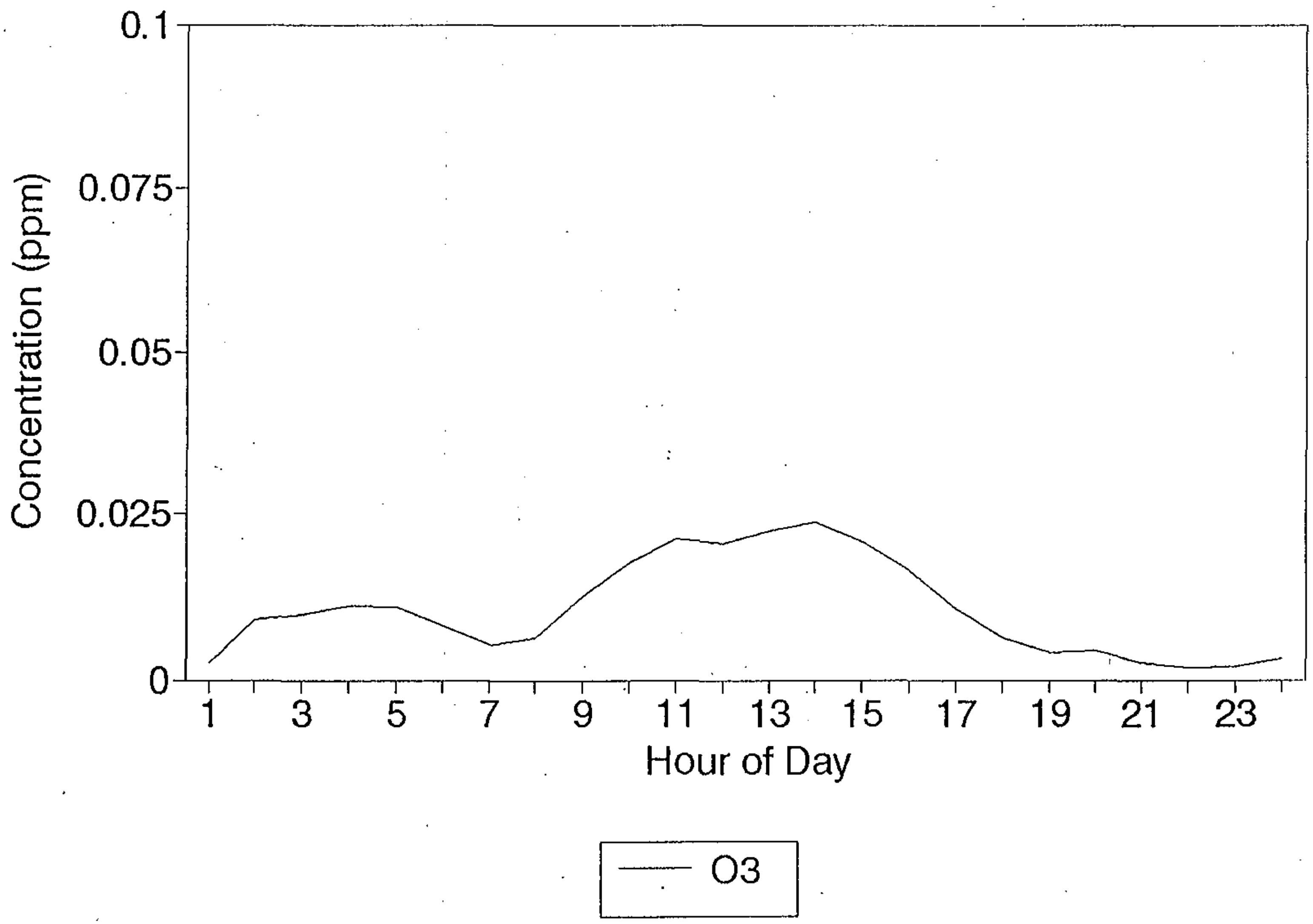
[CEM 1990]



DAMMAM INDUSTRIAL ESTATES
Hourly O3 - April, 1991
Concentration (ppm)
0.25
0.2
0.15
0.1
0.05
0
MEPA 1 hour standard
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
DATE
O3

# DAMMAM INDUSTRIAL ESTATES

Diurnal O3 - April, 1991



MEPA - Dammam Industrial Estates
April 1991
Hourly Averages for Carbon Monoxide in ppm

| Day \ Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 2 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 3 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 4 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 5 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 8 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 9 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 10 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 11 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 12 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 13 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 14 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 15 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.6 | 0.6 | 0.9 | 0.6 | 0.8 | 1.0 | 1.0 | 0.4 | 0.74 |
| 16 | ND | 0.5 | 0.5 | 0.9 | 0.9 | 0.7 | 0.9 | 1.2 | 0.6 | 0.5 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.5 | 0.9 | 1.0 | 0.8 | 1.0 | 1.1 | 1.4 | 0.70 |
| 17 | 1.6 | 1.3 | 0.9 | 0.5 | 0.6 | 0.6 | 1.2 | 1.0 | 0.8 | 0.6 | 0.6 | 0.8 | 0.7 | 0.6 | 0.7 | 0.6 | 0.7 | 0.7 | 0.9 | 1.0 | 0.9 | 1.0 | 1.8 | 0.9 | 0.88 |
| 18 | ND | 0.4 | 0.5 | 0.5 | 0.8 | 0.8 | 0.8 | 0.7 | 1.0 | 1.0 | 0.9 | 1.0 | 1.0 | 0.9 | 0.8 | 0.8 | 0.9 | 1.1 | 1.4 | 1.2 | 1.4 | 2.6 | 1.8 | 1.5 | 1.03 |
| 19 | ND | 0.7 | 0.9 | 0.7 | 0.9 | 0.8 | 1.0 | 0.8 | 0.7 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.7 | 0.8 | 1.1 | 1.6 | 1.5 | 1.5 | 1.7 | 1.4 | 1.3 | 0.94 |
| 20 | 1.3 | 0.7 | 0.7 | 0.6 | 0.5 | 0.6 | 0.9 | 1.4 | 1.0 | 1.1 | 0.9 | 0.8 | 0.8 | 0.8 | 0.8 | 0.9 | 1.1 | 1.4 | 1.1 | 1.3 | 1.4 | 1.0 | 0.7 | 0.6 | 0.93 |
| 21 | ND | 0.4 | 0.4 | 0.4 | 0.3 | 0.5 | 0.7 | 1.5 | 1.1 | 1.0 | 1.1 | CAL | CAL | 0.7 | 1.0 | 0.9 | 1.1 | 1.3 | 1.2 | 1.1 | 1.6 | 2.2 | 1.3 | 0.7 | 0.98 |
| 22 | ND | 0.4 | 0.4 | 0.4 | 0.4 | 0.5 | 0.9 | 1.0 | 1.0 | 0.9 | 0.9 | 1.0 | 1.0 | 0.8 | 0.8 | 0.9 | 1.2 | 1.3 | 1.3 | 1.5 | 1.9 | 2.2 | 1.2 | 0.8 | 0.99 |
| 23 | ND | 0.5 | 0.4 | 0.4 | 0.4 | 0.5 | 0.9 | 1.2 | 1.0 | 0.8 | 0.7 | 0.9 | CAL | CAL | CAL | 1.7 | 1.6 | 2.4 | 2.3 | 2.5 | 1.8 | 1.2 | 1.1 | 1.1 | 1.17 |
| 24 | 0.9 | 0.9 | 0.8 | 0.8 | 0.8 | 1.0 | 1.6 | 2.5 | 2.0 | 1.7 | 1.4 | 1.5 | 1.5 | 1.4 | 1.5 | 1.8 | 1.9 | 2.0 | 2.2 | 2.6 | 2.5 | 2.6 | 2.4 | 1.9 | 1.67 |
| 25 | ND | 1.7 | 1.6 | 1.3 | 1.2 | 1.4 | 1.9 | 1.8 | 2.3 | 2.0 | 1.7 | 1.5 | 1.5 | 1.4 | 0.7 | 0.5 | 0.6 | 0.9 | 1.1 | 1.4 | 1.8 | 1.8 | 1.8 | 1.5 | 1.45 |
| 26 | ND | 1.0 | 1.4 | 1.1 | 0.9 | 0.7 | 0.6 | 0.4 | 0.4 | 0.4 | 0.4 | 0.6 | 0.6 | 0.5 | 0.6 | 0.6 | CAL | CAL | 1.2 | 2.0 | 3.3 | 2.0 | 1.0 | 1.0 | 0.99 |
| 27 | ND | 0.7 | 0.5 | 0.3 | 0.2 | 0.5 | 1.1 | 1.1 | 0.7 | 0.7 | 0.5 | 0.4 | 0.2 | 0.4 | 0.4 | 0.5 | 0.7 | 0.9 | 0.8 | 0.8 | 0.9 | 0.9 | 0.7 | 0.5 | 0.63 |
| 28 | 0.3 | 0.2 | 0.2 | 0.2 | 0.2 | 0.3 | 1.0 | 1.4 | 0.9 | 0.7 | 0.6 | 0.6 | 0.6 | 0.5 | 0.6 | 0.7 | 0.9 | 1.0 | 1.1 | 1.0 | 1.2 | 1.6 | 1.3 | 0.9 | 0.75 |
| 29 | 0.5 | 0.3 | 0.2 | 0.1 | 0.1 | 0.3 | 0.8 | 1.1 | 0.8 | 0.8 | 0.8 | 0.7 | 1.0 | 0.9 | 0.7 | 0.8 | 1.1 | 1.6 | 1.7 | 1.8 | 2.0 | 1.8 | 1.9 | 1.3 | 0.96 |
| 30 | 0.8 | 0.4 | 0.3 | 0.2 | 0.6 | 0.4 | 0.8 | 1.3 | 0.8 | 1.1 | 0.8 | 0.6 | 0.4 | 0.3 | 0.5 | 0.7 | 0.9 | 1.2 | 1.5 | 1.6 | 1.6 | 2.2 | 2.8 | 1.6 | 0.98 |
| | | | | | | | | | | | | | | | | | | | | | | | | Monthly Average = | 1.00 |

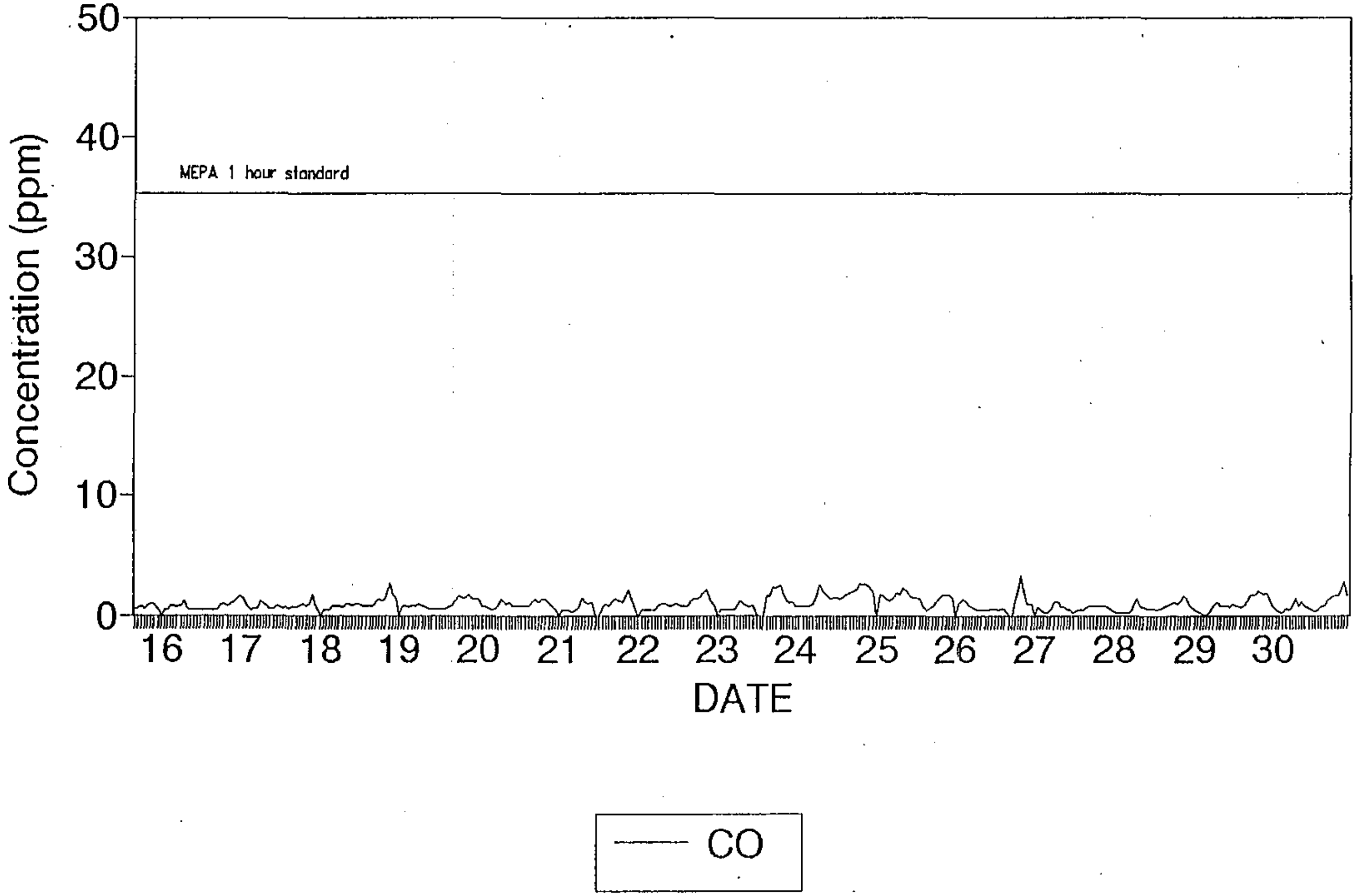
Maximum Hourly Average was 3.3 at Hour 21 on Day 26 with 1 occurences and there were no Hourly Violations
Maximum Daily Average was 1.67 on Day 24 with 1 occurences and there were no Daily Violations
Operating Efficiency = 49.9 percent
ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data
[CEM 1990]

MEPA - Dammam Industrial Estates
April 1991
Frequency Distribution
Hourly Averages for Carbon Monoxide in ppm

| Concentration | # of Hours | Percentage |
|---|---|---|
| 0.0 - 5.0 | 352 | 100.0 |
| 5.1 - 10.0 | 0 | 0.0 |
| 10.1 - 30.0 | 0 | 0.0 |
| 30.1 - 50.0 | 0 | 0.0 |
| 50.1+ | 0 | 0.0 |

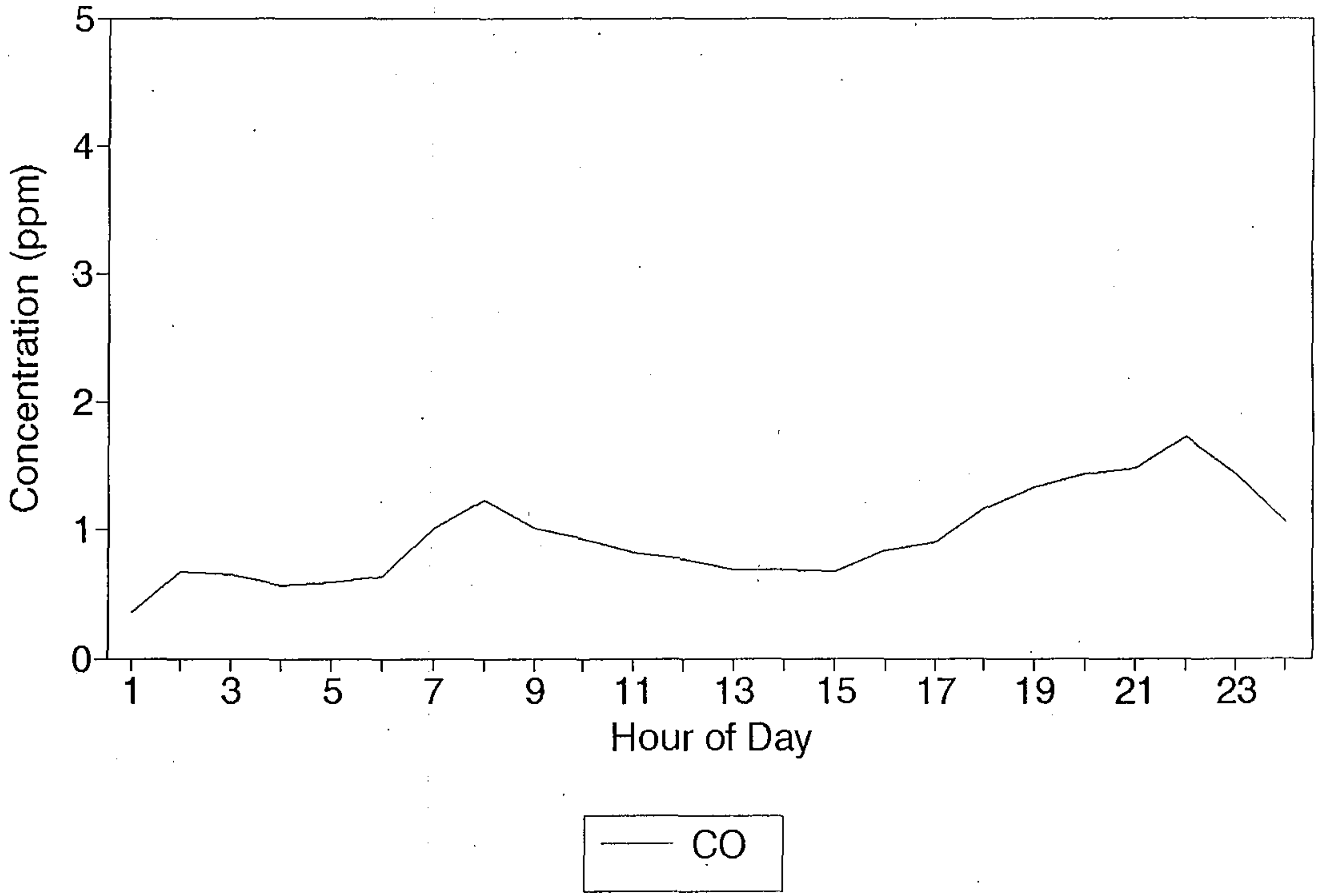
# DAMMAM INDUSTRIAL ESTATES

Hourly CO - April, 1991



# DAMMAM INDUSTRIAL ESTATES

Diurnal CO - April, 1991



MEPA - Dammam Industrial Estates
May 1991
Hourly Averages for SO2 in ppm

| Hour / Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ND | 0.011 | 0.016 | 0.023 | 0.009 | 0.009 | 0.014 | 0.021 | 0.012 | 0.010 | 0.007 | 0.037 | 0.051 | 0.039 | 0.020 | 0.018 | 0.023 | 0.021 | 0.029 | 0.048 | 0.046 | 0.055 | 0.046 | 0.030 | 0.0259 |
| 2 | 0.026 | 0.018 | 0.020 | 0.024 | 0.017 | 0.015 | 0.033 | 0.027 | 0.032 | 0.027 | 0.043 | 0.026 | 0.020 | 0.017 | 0.020 | 0.019 | 0.024 | 0.011 | 0.015 | 0.009 | 0.006 | 0.008 | 0.009 | 0.008 | 0.0197 |
| 3 | ND | 0.016 | 0.036 | 0.070 | 0.072 | 0.064 | 0.060 | 0.058 | 0.024 | 0.017 | 0.015 | 0.012 | 0.010 | 0.006 | 0.005 | 0.009 | 0.009 | 0.008 | 0.007 | 0.004 | 0.003 | 0.001 | 0.003 | 0.010 | 0.0226 |
| 4 | ND | 0.008 | 0.005 | 0.013 | 0.013 | 0.026 | 0.039 | 0.052 | 0.051 | 0.044 | 0.036 | 0.017 | 0.009 | 0.011 | 0.014 | 0.011 | 0.007 | 0.003 | 0.001 | 0.002 | 0.007 | 0.009 | 0.011 | 0.009 | 0.0173 |
| 5 | 0.009 | 0.004 | 0.009 | 0.012 | 0.010 | 0.013 | 0.017 | 0.016 | 0.011 | 0.012 | 0.008 | 0.005 | 0.006 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.0102 |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.010 | 0.016 | 0.017 | 0.018 | 0.0153 |
| 7 | ND | 0.005 | 0.007 | 0.015 | 0.017 | 0.013 | 0.013 | 0.009 | 0.017 | 0.018 | 0.020 | 0.018 | 0.020 | 0.010 | 0.012 | 0.008 | 0.013 | 0.022 | 0.012 | 0.013 | 0.019 | 0.016 | 0.013 | 0.018 | 0.0143 |
| 8 | ND | 0.021 | 0.018 | 0.014 | 0.008 | 0.007 | 0.013 | 0.012 | 0.012 | 0.010 | CAL | CAL | 0.007 | 0.006 | 0.004 | 0.009 | 0.008 | 0.012 | 0.017 | 0.021 | 0.026 | 0.030 | 0.034 | 0.063 | 0.0168 |
| 9 | ND | 0.013 | 0.009 | 0.005 | 0.005 | 0.004 | 0.007 | 0.013 | 0.011 | 0.011 | 0.010 | 0.011 | 0.015 | 0.019 | 0.025 | 0.015 | 0.009 | 0.014 | 0.025 | 0.025 | 0.024 | 0.028 | 0.033 | 0.028 | 0.0156 |
| 10 | ND | 0.034 | 0.025 | 0.023 | 0.027 | 0.025 | 0.021 | 0.013 | 0.008 | 0.024 | 0.021 | 0.004 | 0.002 | 0.009 | 0.002 | 0.001 | 0.000 | 0.000 | 0.000 | 0.001 | 0.005 | 0.004 | 0.002 | 0.003 | 0.0110 |
| 11 | 0.007 | 0.008 | 0.007 | 0.006 | 0.002 | 0.008 | 0.008 | 0.018 | 0.030 | 0.036 | 0.055 | 0.046 | 0.023 | 0.011 | 0.005 | 0.008 | 0.010 | 0.013 | 0.006 | 0.007 | 0.008 | 0.013 | 0.016 | 0.009 | 0.0150 |
| 12 | 0.009 | 0.004 | 0.010 | 0.005 | 0.005 | 0.006 | 0.008 | 0.011 | 0.014 | 0.019 | 0.010 | 0.008 | 0.006 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.0088 |
| 13 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.011 | 0.016 | 0.012 | 0.008 | 0.007 | 0.008 | 0.006 | 0.005 | 0.011 | 0.019 | 0.0103 |
| 14 | ND | 0.011 | 0.011 | 0.010 | 0.019 | 0.018 | 0.010 | 0.013 | 0.010 | 0.007 | 0.007 | 0.005 | 0.005 | 0.004 | 0.009 | 0.014 | 0.010 | 0.012 | 0.008 | 0.009 | 0.012 | 0.025 | 0.013 | 0.018 | 0.0113 |
| 15 | 0.020 | 0.022 | 0.016 | 0.014 | 0.016 | 0.017 | 0.015 | 0.011 | 0.011 | 0.012 | CAL | 0.010 | 0.009 | 0.009 | 0.010 | 0.010 | 0.007 | 0.011 | 0.010 | 0.011 | 0.010 | 0.012 | 0.037 | 0.021 | 0.0140 |
| 16 | ND | 0.011 | 0.009 | 0.009 | 0.009 | 0.007 | 0.010 | 0.010 | 0.010 | 0.009 | 0.007 | 0.006 | 0.005 | 0.004 | 0.007 | 0.006 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.004 | 0.003 | 0.001 | 0.0062 |
| 17 | ND | 0.007 | 0.010 | 0.008 | 0.004 | 0.002 | 0.005 | 0.013 | 0.011 | 0.005 | 0.003 | 0.004 | 0.004 | 0.004 | 0.003 | 0.003 | 0.002 | 0.000 | 0.000 | 0.001 | 0.001 | 0.001 | 0.000 | 0.001 | 0.0040 |
| 18 | ND | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.002 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.004 | 0.008 | 0.005 | 0.0010 |
| 19 | ND | 0.007 | 0.006 | 0.005 | 0.004 | 0.005 | 0.007 | 0.003 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.002 | 0.000 | 0.001 | 0.001 | 0.001 | 0.003 | 0.001 | 0.006 | 0.015 | 0.007 | 0.003 | 0.0036 |
| 20 | 0.004 | 0.002 | 0.003 | 0.004 | 0.004 | 0.011 | 0.021 | 0.040 | 0.040 | 0.029 | 0.012 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.0155 |
| 21 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 22 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 23 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 24 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 25 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 26 | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.018 | 0.008 | 0.007 | 0.003 | 0.010 | 0.003 | 0.002 | 0.002 | 0.003 | 0.005 | 0.006 | 0.009 | 0.009 | 0.010 | 0.008 | 0.0069 |
| 27 | ND | 0.008 | 0.005 | 0.002 | 0.003 | 0.004 | 0.004 | 0.007 | 0.009 | 0.008 | 0.004 | 0.004 | 0.003 | 0.005 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.003 | 0.002 | 0.007 | 0.005 | 0.0047 |
| 28 | 0.004 | 0.004 | 0.013 | 0.013 | 0.009 | 0.015 | 0.016 | 0.004 | 0.003 | ND | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.005 | 0.007 | 0.004 | 0.0044 |
| 29 | 0.005 | 0.004 | 0.002 | 0.005 | 0.005 | 0.009 | 0.010 | 0.002 | 0.000 | 0.000 | 0.005 | CAL | CAL | CAL | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.0043 |
| 30 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 31 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |

Monthly Average = 0.0117

Maximum Hourly Average was 0.072 at Hour 5 on Day 3 with 1 occurences and there were no Hourly Violations

Maximum Daily Average was 0.0259 on Day 1 with 1 occurences and there were no Daily Violations

Operating Efficiency = 63.7 percent

ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data

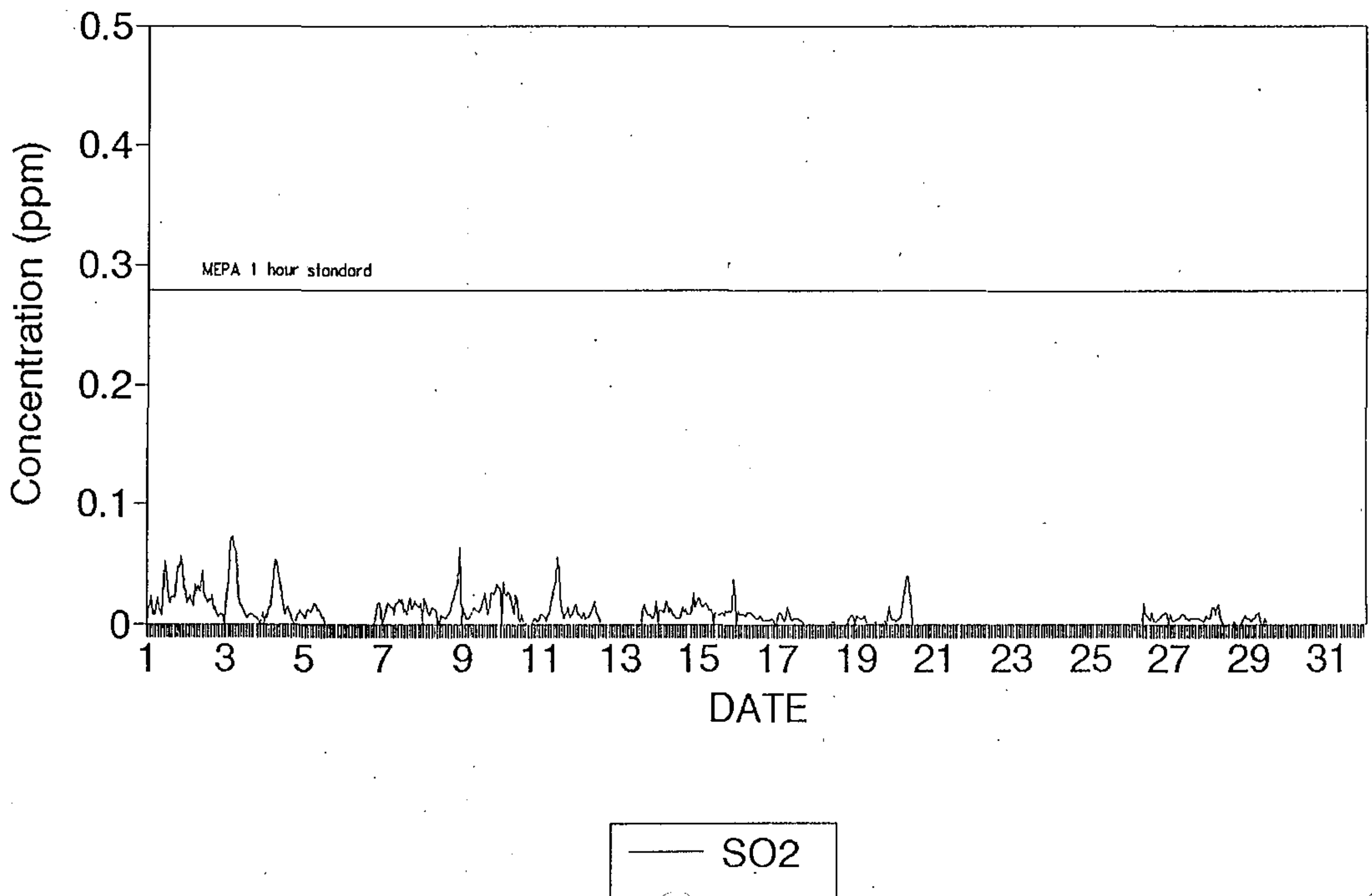
[CEM 1990]

MEPA - Dammam Industrial Estates
May 1991
Frequency Distribution
Hourly Averages for $SO_2$ in ppm

| Concentration | # of Hours | Percentage |
|---|---|---|
| 0.000 - 0.020 | 398 | 85.0 |
| 0.021 - 0.060 | 66 | 14.1 |
| 0.061 - 0.110 | 4 | 0.9 |
| 0.111 - 0.170 | 0 | 0.0 |
| 0.171 - 0.340 | 0 | 0.0 |
| 0.341+ | 0 | 0.0 |

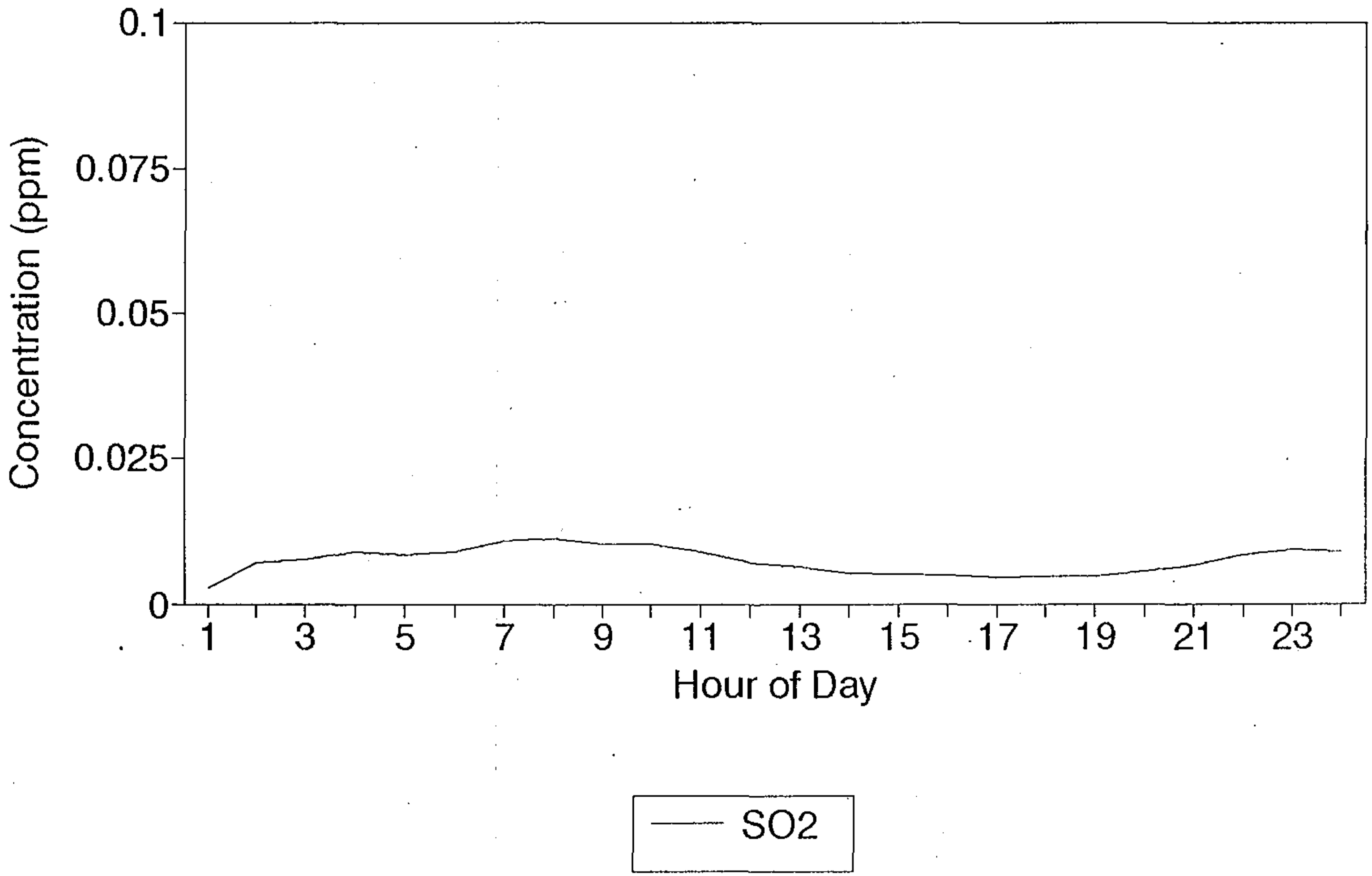
# DAMMAM INDUSTRIAL ESTATES

Hourly SO2 – May, 1991



# DAMMAM INDUSTRIAL ESTATES

Diurnal SO2 – May, 1991



MEPA - Dammam Industrial Estates

May 1991

Hourly Averages for NOx in ppm

| Hour / Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ND | 0.045 | 0.047 | 0.045 | 0.021 | 0.032 | 0.061 | 0.074 | 0.057 | 0.046 | 0.055 | 0.053 | 0.056 | 0.062 | 0.055 | 0.072 | 0.124 | 0.241 | 0.277 | 0.275 | 0.332 | 0.264 | 0.208 | 0.107 | 0.1134 |
| 2 | 0.054 | 0.056 | 0.071 | 0.074 | 0.052 | 0.060 | 0.103 | 0.070 | 0.085 | 0.102 | 0.060 | 0.040 | 0.035 | 0.030 | 0.028 | 0.031 | 0.052 | 0.045 | 0.052 | 0.053 | 0.055 | 0.082 | 0.067 | 0.027 | 0.0577 |
| 3 | ND | 0.020 | 0.018 | 0.016 | 0.019 | 0.021 | 0.019 | 0.019 | 0.024 | 0.030 | 0.015 | 0.015 | 0.017 | 0.018 | 0.017 | 0.019 | 0.021 | 0.040 | 0.055 | 0.048 | 0.050 | 0.035 | 0.036 | 0.029 | 0.0261 |
| 4 | ND | 0.014 | 0.017 | 0.017 | 0.021 | 0.025 | 0.044 | 0.068 | 0.058 | 0.047 | 0.050 | 0.045 | 0.030 | 0.030 | 0.035 | 0.037 | 0.035 | 0.041 | 0.049 | 0.052 | 0.060 | 0.074 | 0.093 | 0.084 | 0.0446 |
| 5 | 0.051 | 0.024 | 0.024 | 0.020 | 0.017 | 0.025 | 0.050 | 0.072 | 0.057 | 0.060 | 0.046 | 0.034 | 0.024 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.0388 |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.098 | 0.075 | 0.096 | 0.098 | 0.0917 |
| 7 | ND | 0.037 | 0.036 | 0.043 | 0.035 | 0.046 | 0.070 | 0.072 | 0.075 | 0.062 | 0.039 | 0.033 | 0.051 | 0.031 | 0.033 | 0.049 | 0.077 | 0.069 | 0.125 | 0.191 | 0.148 | 0.164 | 0.247 | 0.078 | 0.0787 |
| 8 | ND | 0.047 | 0.037 | 0.036 | 0.026 | 0.033 | 0.065 | 0.072 | 0.058 | 0.043 | 0.029 | 0.079 | 0.027 | 0.036 | 0.041 | 0.045 | 0.073 | 0.150 | 0.129 | 0.163 | 0.309 | 0.469 | 0.298 | 0.256 | 0.1096 |
| 9 | ND | 0.077 | 0.035 | 0.021 | 0.031 | 0.030 | 0.060 | 0.061 | 0.062 | 0.071 | 0.117 | 0.069 | 0.051 | 0.056 | 0.080 | 0.059 | 0.099 | 0.252 | 0.449 | 0.256 | 0.244 | 0.244 | 0.192 | 0.083 | 0.1173 |
| 10 | ND | 0.033 | 0.026 | 0.038 | 0.047 | 0.040 | 0.036 | 0.027 | 0.019 | 0.021 | 0.019 | 0.014 | 0.016 | 0.018 | 0.015 | 0.020 | 0.025 | 0.032 | 0.040 | 0.050 | 0.072 | 0.073 | 0.058 | 0.042 | 0.0340 |
| 11 | 0.031 | 0.017 | 0.012 | 0.016 | 0.014 | 0.045 | 0.051 | 0.080 | 0.069 | 0.060 | 0.077 | 0.062 | 0.046 | 0.036 | 0.039 | 0.049 | 0.070 | 0.082 | 0.110 | 0.099 | 0.097 | 0.112 | 0.107 | 0.055 | 0.0598 |
| 12 | 0.038 | 0.034 | 0.020 | 0.018 | 0.015 | 0.025 | 0.067 | 0.075 | 0.052 | 0.051 | 0.040 | 0.041 | 0.038 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.0395 |
| 13 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.033 | 0.039 | 0.042 | 0.047 | 0.075 | 0.099 | 0.095 | 0.092 | 0.087 | 0.112 | 0.0721 |
| 14 | ND | 0.047 | 0.032 | 0.032 | 0.049 | 0.058 | 0.063 | 0.081 | 0.078 | 0.045 | 0.031 | 0.035 | 0.033 | 0.040 | 0.038 | 0.068 | 0.069 | 0.090 | 0.086 | 0.133 | 0.137 | 0.142 | 0.181 | 0.198 | 0.0768 |
| 15 | 0.161 | 0.118 | 0.073 | 0.053 | 0.056 | 0.064 | 0.070 | 0.062 | 0.048 | 0.035 | 0.079 | 0.035 | 0.032 | 0.041 | 0.055 | 0.069 | 0.072 | 0.090 | 0.121 | 0.135 | 0.101 | 0.112 | 0.180 | 0.235 | 0.0874 |
| 16 | ND | 0.142 | 0.106 | 0.065 | 0.067 | 0.051 | 0.074 | 0.081 | 0.056 | 0.046 | 0.042 | 0.035 | 0.053 | 0.070 | 0.071 | 0.064 | 0.109 | 0.071 | 0.069 | 0.053 | 0.053 | 0.049 | 0.027 | 0.021 | 0.0641 |
| 17 | ND | 0.017 | 0.012 | 0.011 | 0.012 | 0.011 | 0.020 | 0.032 | 0.027 | 0.023 | 0.018 | 0.018 | 0.019 | 0.020 | 0.019 | 0.022 | 0.023 | 0.028 | 0.028 | 0.039 | 0.028 | 0.029 | 0.021 | 0.021 | 0.0217 |
| 18 | ND | 0.010 | 0.008 | 0.008 | 0.007 | 0.011 | 0.021 | 0.029 | 0.028 | 0.030 | 0.032 | 0.028 | 0.023 | 0.018 | 0.020 | 0.024 | 0.028 | 0.039 | 0.042 | 0.048 | 0.048 | 0.057 | 0.043 | 0.044 | 0.0281 |
| 19 | ND | 0.021 | 0.016 | 0.015 | 0.015 | 0.020 | 0.032 | 0.038 | 0.032 | 0.035 | 0.026 | 0.031 | 0.027 | 0.025 | 0.023 | 0.031 | 0.047 | 0.051 | 0.047 | 0.059 | 0.063 | 0.058 | 0.049 | 0.041 | 0.0349 |
| 20 | 0.039 | 0.019 | 0.014 | 0.012 | 0.011 | 0.014 | 0.044 | 0.096 | 0.076 | 0.048 | 0.032 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.0368 |
| 21 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 22 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 23 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 24 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 25 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 26 | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.037 | 0.023 | 0.058 | 0.026 | 0.034 | 0.039 | 0.039 | 0.060 | 0.071 | 0.122 | 0.134 | 0.160 | 0.149 | 0.152 | 0.180 | 0.0856 |
| 27 | ND | 0.063 | 0.032 | 0.027 | 0.039 | 0.063 | 0.079 | 0.078 | 0.055 | 0.051 | 0.027 | 0.023 | 0.025 | 0.039 | 0.035 | 0.040 | 0.043 | 0.065 | 0.082 | 0.116 | 0.127 | 0.094 | 0.129 | 0.129 | 0.0635 |
| 28 | 0.095 | 0.024 | 0.018 | 0.022 | 0.024 | 0.017 | 0.029 | 0.032 | 0.031 | ND | 0.024 | 0.032 | 0.027 | 0.021 | 0.023 | 0.030 | 0.025 | 0.031 | 0.040 | 0.041 | 0.036 | 0.033 | 0.038 | 0.029 | 0.0314 |
| 29 | 0.020 | 0.011 | 0.009 | 0.009 | 0.013 | 0.028 | 0.046 | 0.042 | 0.028 | 0.022 | 0.021 | 0.035 | 0.043 | 0.015 | 0.019 | 0.032 | 0.041 | 0.041 | 0.042 | 0.050 | 0.038 | 0.045 | 0.047 | 0.042 | 0.0308 |
| 30 | 0.051 | 0.027 | 0.021 | 0.019 | 0.019 | 0.022 | 0.025 | 0.028 | 0.019 | 0.020 | 0.020 | 0.023 | 0.020 | 0.019 | 0.013 | 0.012 | 0.021 | 0.022 | 0.037 | 0.035 | 0.036 | 0.031 | 0.034 | 0.030 | 0.0252 |
| 31 | ND | 0.016 | 0.011 | 0.009 | 0.007 | 0.009 | 0.012 | 0.011 | 0.010 | 0.010 | 0.009 | 0.010 | 0.010 | 0.010 | 0.011 | 0.013 | 0.018 | 0.025 | 0.039 | 0.037 | 0.037 | 0.044 | 0.056 | 0.043 | 0.0199 |

Monthly Average = 0.0564

Maximum Hourly Average was 0.469 at Hour 22 on Day 8 with 1 occurences and there were no Hourly Violations

Maximum Daily Average was 0.1173 on Day 9 with 1 occurences and there were no Daily Violations

Operating Efficiency = 71.4 percent

ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data

[CEM 1990]

MEPA - Dammam Industrial Estates
May 1991
Frequency Distribution
Hourly Averages for NOx in ppm

| Concentration | # of Hours | Percentage |
|---|---|---|
| 0.000 - 0.050 | 329 | 62.0 |
| 0.051 - 0.110 | 151 | 28.4 |
| 0.111 - 0.210 | 35 | 6.6 |
| 0.211+ | 16 | 3.0 |

MEPA - Dammam Industrial Estates
May 1991
Hourly Averages for NO2 in ppm

| Hour / Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ND | 0.039 | 0.038 | 0.032 | 0.019 | 0.025 | 0.041 | 0.041 | 0.036 | 0.035 | 0.043 | 0.039 | 0.044 | 0.045 | 0.042 | 0.049 | 0.058 | 0.063 | 0.071 | 0.071 | 0.064 | 0.059 | 0.062 | 0.054 | 0.0465 |
| 2 | 0.045 | 0.044 | 0.045 | 0.044 | 0.039 | 0.039 | 0.049 | 0.040 | 0.050 | 0.065 | 0.050 | 0.035 | 0.031 | 0.026 | 0.025 | 0.028 | 0.044 | 0.038 | 0.044 | 0.043 | 0.042 | 0.055 | 0.050 | 0.025 | 0.0415 |
| 3 | ND | 0.019 | 0.017 | 0.015 | 0.017 | 0.019 | 0.017 | 0.017 | 0.020 | 0.025 | 0.013 | 0.013 | 0.014 | 0.015 | 0.015 | 0.017 | 0.019 | 0.035 | 0.049 | 0.042 | 0.045 | 0.033 | 0.033 | 0.027 | 0.0233 |
| 4 | ND | 0.012 | 0.016 | 0.016 | 0.020 | 0.021 | 0.033 | 0.041 | 0.039 | 0.033 | 0.038 | 0.036 | 0.025 | 0.024 | 0.028 | 0.030 | 0.029 | 0.034 | 0.040 | 0.044 | 0.050 | 0.055 | 0.051 | 0.048 | 0.0332 |
| 5 | 0.040 | 0.018 | 0.018 | 0.014 | 0.012 | 0.018 | 0.033 | 0.039 | 0.029 | 0.038 | 0.031 | 0.024 | 0.018 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.0255 |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.056 | 0.056 | 0.055 | 0.051 | 0.0545 |
| 7 | ND | 0.032 | 0.030 | 0.036 | 0.030 | 0.037 | 0.042 | 0.037 | 0.044 | 0.043 | 0.030 | 0.024 | 0.039 | 0.025 | 0.027 | 0.036 | 0.037 | 0.046 | 0.056 | 0.059 | 0.063 | 0.059 | 0.059 | 0.047 | 0.0408 |
| 8 | ND | 0.037 | 0.030 | 0.029 | 0.021 | 0.027 | 0.043 | 0.042 | 0.035 | 0.029 | 0.020 | 0.020 | 0.022 | 0.028 | 0.030 | 0.036 | 0.049 | 0.056 | 0.058 | 0.057 | 0.051 | 0.043 | 0.053 | 0.052 | 0.0377 |
| 9 | ND | 0.038 | 0.028 | 0.020 | 0.027 | 0.021 | 0.036 | 0.037 | 0.038 | 0.038 | 0.050 | 0.041 | 0.032 | 0.035 | 0.043 | 0.049 | 0.051 | 0.052 | 0.056 | 0.052 | 0.048 | 0.052 | 0.049 | 0.033 | 0.0403 |
| 10 | ND | 0.029 | 0.025 | 0.034 | 0.040 | 0.029 | 0.023 | 0.017 | 0.014 | 0.017 | 0.015 | 0.011 | 0.013 | 0.014 | 0.012 | 0.015 | 0.019 | 0.024 | 0.030 | 0.035 | 0.041 | 0.045 | 0.047 | 0.037 | 0.0255 |
| 11 | 0.030 | 0.016 | 0.011 | 0.015 | 0.013 | 0.035 | 0.037 | 0.039 | 0.037 | 0.035 | 0.047 | 0.045 | 0.036 | 0.029 | 0.031 | 0.037 | 0.047 | 0.052 | 0.054 | 0.058 | 0.060 | 0.058 | 0.052 | 0.045 | 0.0383 |
| 12 | 0.035 | 0.032 | 0.018 | 0.016 | 0.013 | 0.019 | 0.043 | 0.045 | 0.035 | 0.037 | 0.031 | 0.032 | 0.031 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.0298 |
| 13 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.025 | 0.030 | 0.032 | 0.036 | 0.047 | 0.053 | 0.048 | 0.051 | 0.052 | 0.050 | 0.0424 |
| 14 | ND | 0.039 | 0.027 | 0.024 | 0.033 | 0.035 | 0.035 | 0.039 | 0.041 | 0.029 | 0.023 | 0.027 | 0.025 | 0.030 | 0.028 | 0.041 | 0.042 | 0.045 | 0.043 | 0.047 | 0.047 | 0.044 | 0.045 | 0.051 | 0.0365 |
| 15 | 0.049 | 0.044 | 0.041 | 0.037 | 0.035 | 0.036 | 0.036 | 0.032 | 0.030 | 0.026 | 0.016 | 0.029 | 0.028 | 0.033 | 0.045 | 0.056 | 0.060 | 0.067 | 0.059 | 0.055 | 0.048 | 0.059 | 0.057 | 0.054 | 0.0430 |
| 16 | ND | 0.059 | 0.058 | 0.050 | 0.048 | 0.038 | 0.040 | 0.041 | 0.035 | 0.035 | 0.033 | 0.029 | 0.046 | 0.064 | 0.065 | 0.059 | 0.102 | 0.067 | 0.062 | 0.050 | 0.049 | 0.041 | 0.026 | 0.019 | 0.0485 |
| 17 | ND | 0.015 | 0.010 | 0.009 | 0.010 | 0.008 | 0.016 | 0.022 | 0.021 | 0.015 | 0.014 | 0.014 | 0.015 | 0.016 | 0.016 | 0.018 | 0.020 | 0.025 | 0.024 | 0.029 | 0.022 | 0.024 | 0.017 | 0.018 | 0.0173 |
| 18 | ND | 0.008 | 0.006 | 0.006 | 0.005 | 0.009 | 0.017 | 0.022 | 0.021 | 0.022 | 0.024 | 0.022 | 0.018 | 0.014 | 0.016 | 0.020 | 0.024 | 0.032 | 0.036 | 0.041 | 0.041 | 0.048 | 0.039 | 0.040 | 0.0231 |
| 19 | ND | 0.019 | 0.014 | 0.013 | 0.013 | 0.017 | 0.026 | 0.029 | 0.026 | 0.026 | 0.021 | 0.024 | 0.021 | 0.020 | 0.019 | 0.024 | 0.034 | 0.039 | 0.039 | 0.047 | 0.048 | 0.049 | 0.045 | 0.038 | 0.0283 |
| 20 | 0.037 | 0.017 | 0.012 | 0.010 | 0.009 | 0.011 | 0.036 | 0.047 | 0.046 | 0.033 | 0.025 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.0257 |
| 21 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 22 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 23 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 24 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 25 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 26 | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.031 | 0.019 | 0.044 | 0.023 | 0.028 | 0.032 | 0.033 | 0.046 | 0.050 | 0.057 | 0.058 | 0.058 | 0.056 | 0.055 | 0.057 | 0.0431 |
| 27 | ND | 0.043 | 0.026 | 0.023 | 0.031 | 0.042 | 0.044 | 0.039 | 0.033 | 0.030 | 0.018 | 0.018 | 0.018 | 0.033 | 0.029 | 0.031 | 0.035 | 0.045 | 0.050 | 0.048 | 0.044 | 0.047 | 0.049 | 0.045 | 0.0357 |
| 28 | 0.036 | 0.022 | 0.016 | 0.020 | 0.022 | 0.014 | 0.022 | 0.024 | 0.022 | ND | 0.018 | 0.023 | 0.020 | 0.016 | 0.017 | 0.023 | 0.020 | 0.025 | 0.034 | 0.034 | 0.031 | 0.030 | 0.034 | 0.027 | 0.0239 |
| 29 | 0.018 | 0.009 | 0.007 | 0.008 | 0.010 | 0.023 | 0.032 | 0.029 | 0.022 | 0.017 | 0.016 | 0.009 | 0.010 | 0.011 | 0.015 | 0.022 | 0.029 | 0.031 | 0.035 | 0.040 | 0.033 | 0.041 | 0.040 | 0.036 | 0.0226 |
| 30 | 0.042 | 0.024 | 0.018 | 0.017 | 0.016 | 0.018 | 0.018 | 0.020 | 0.015 | 0.015 | 0.015 | 0.017 | 0.015 | 0.015 | 0.010 | 0.009 | 0.018 | 0.019 | 0.031 | 0.030 | 0.030 | 0.027 | 0.029 | 0.027 | 0.0206 |
| 31 | ND | 0.014 | 0.009 | 0.007 | 0.005 | 0.007 | 0.009 | 0.008 | 0.007 | 0.007 | 0.007 | 0.007 | 0.007 | 0.007 | 0.008 | 0.010 | 0.014 | 0.022 | 0.033 | 0.033 | 0.034 | 0.039 | 0.042 | 0.037 | 0.0162 |
| | | | | | | | | | | | | | | | | | | | | | Monthly Average = | | | | 0.0325 |

Maximum Hourly Average was 0.102 at Hour 17 on Day 16 with 1 occurences and there were no Hourly Violations

Maximum Daily Average was 0.0545 on Day 6 with 1 occurences and there were no Daily Violations

Operating Efficiency = 71.4 percent

ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data

[CEM 1990]

MEPA - Dammam Industrial Estates
May 1991
Frequency Distribution
Hourly Averages for $NO_2$ in ppm

| Concentration | # of Hours | Percentage |
|---|---|---|
| 0.000 - 0.050 | 467 | 87.9 |
| 0.051 - 0.110 | 64 | 12.1 |
| 0.111 - 0.210 | 0 | 0.0 |
| 0.211+ | 0 | 0.0 |

MEPA - Dammam Industrial Estates
May 1991
Hourly Averages for NO in ppm

| Day \ Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ND | 0.006 | 0.009 | 0.013 | 0.002 | 0.007 | 0.020 | 0.033 | 0.021 | 0.012 | 0.011 | 0.013 | 0.012 | 0.018 | 0.013 | 0.023 | 0.067 | 0.180 | 0.208 | 0.205 | 0.270 | 0.206 | 0.147 | 0.053 | 0.0673 |
| 2 | 0.010 | 0.013 | 0.026 | 0.030 | 0.013 | 0.021 | 0.054 | 0.030 | 0.035 | 0.037 | 0.010 | 0.005 | 0.005 | 0.004 | 0.003 | 0.003 | 0.008 | 0.007 | 0.009 | 0.010 | 0.013 | 0.027 | 0.017 | 0.002 | 0.0163 |
| 3 | ND | 0.001 | 0.001 | 0.001 | 0.002 | 0.002 | 0.003 | 0.003 | 0.004 | 0.005 | 0.002 | 0.002 | 0.003 | 0.003 | 0.002 | 0.002 | 0.002 | 0.004 | 0.006 | 0.006 | 0.005 | 0.002 | 0.003 | 0.002 | 0.0029 |
| 4 | ND | 0.001 | 0.001 | 0.001 | 0.001 | 0.005 | 0.011 | 0.028 | 0.019 | 0.014 | 0.013 | 0.010 | 0.005 | 0.006 | 0.006 | 0.007 | 0.006 | 0.008 | 0.009 | 0.008 | 0.010 | 0.019 | 0.042 | 0.037 | 0.0116 |
| 5 | 0.010 | 0.006 | 0.006 | 0.007 | 0.005 | 0.007 | 0.017 | 0.034 | 0.028 | 0.022 | 0.015 | 0.010 | 0.006 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.0133 |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.043 | 0.020 | 0.042 | 0.047 | 0.0380 |
| 7 | ND | 0.005 | 0.006 | 0.007 | 0.004 | 0.009 | 0.029 | 0.035 | 0.032 | 0.019 | 0.009 | 0.009 | 0.012 | 0.005 | 0.006 | 0.014 | 0.041 | 0.023 | 0.070 | 0.133 | 0.086 | 0.106 | 0.189 | 0.031 | 0.0383 |
| 8 | ND | 0.009 | 0.007 | 0.007 | 0.005 | 0.007 | 0.023 | 0.031 | 0.024 | 0.015 | 0.009 | 0.059 | 0.004 | 0.008 | 0.011 | 0.009 | 0.025 | 0.094 | 0.072 | 0.107 | 0.261 | 0.437 | 0.246 | 0.206 | 0.0729 |
| 9 | ND | 0.039 | 0.007 | 0.001 | 0.004 | 0.008 | 0.024 | 0.025 | 0.024 | 0.033 | 0.068 | 0.028 | 0.020 | 0.022 | 0.038 | 0.010 | 0.048 | 0.202 | 0.402 | 0.206 | 0.198 | 0.193 | 0.144 | 0.050 | 0.0780 |
| 10 | ND | 0.004 | 0.002 | 0.004 | 0.007 | 0.011 | 0.013 | 0.010 | 0.005 | 0.004 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.005 | 0.006 | 0.008 | 0.011 | 0.015 | 0.031 | 0.028 | 0.011 | 0.005 | 0.0085 |
| 11 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.010 | 0.015 | 0.041 | 0.032 | 0.026 | 0.030 | 0.017 | 0.010 | 0.007 | 0.008 | 0.012 | 0.024 | 0.031 | 0.057 | 0.042 | 0.037 | 0.055 | 0.055 | 0.011 | 0.0219 |
| 12 | 0.003 | 0.002 | 0.002 | 0.002 | 0.002 | 0.006 | 0.025 | 0.031 | 0.017 | 0.014 | 0.009 | 0.009 | 0.008 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.0100 |
| 13 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.007 | 0.010 | 0.010 | 0.012 | 0.029 | 0.047 | 0.048 | 0.042 | 0.036 | 0.063 | 0.0304 |
| 14 | ND | 0.008 | 0.005 | 0.007 | 0.017 | 0.024 | 0.028 | 0.043 | 0.038 | 0.017 | 0.007 | 0.008 | 0.009 | 0.010 | 0.010 | 0.028 | 0.027 | 0.046 | 0.044 | 0.088 | 0.090 | 0.100 | 0.137 | 0.149 | 0.0409 |
| 15 | 0.113 | 0.074 | 0.032 | 0.016 | 0.021 | 0.028 | 0.034 | 0.030 | 0.018 | 0.010 | 0.064 | 0.006 | 0.005 | 0.008 | 0.011 | 0.014 | 0.012 | 0.024 | 0.063 | 0.082 | 0.054 | 0.054 | 0.124 | 0.182 | 0.0450 |
| 16 | ND | 0.084 | 0.048 | 0.016 | 0.021 | 0.014 | 0.035 | 0.041 | 0.022 | 0.012 | 0.009 | 0.006 | 0.007 | 0.006 | 0.007 | 0.006 | 0.008 | 0.005 | 0.007 | 0.003 | 0.005 | 0.008 | 0.002 | 0.002 | 0.0163 |
| 17 | ND | 0.002 | 0.002 | 0.002 | 0.002 | 0.003 | 0.005 | 0.010 | 0.006 | 0.008 | 0.004 | 0.004 | 0.004 | 0.005 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.010 | 0.007 | 0.006 | 0.003 | 0.003 | 0.0046 |
| 18 | ND | 0.002 | 0.002 | 0.002 | 0.002 | 0.003 | 0.005 | 0.007 | 0.007 | 0.008 | 0.008 | 0.007 | 0.006 | 0.004 | 0.004 | 0.005 | 0.005 | 0.008 | 0.007 | 0.008 | 0.007 | 0.009 | 0.005 | 0.004 | 0.0054 |
| 19 | ND | 0.002 | 0.002 | 0.002 | 0.002 | 0.003 | 0.006 | 0.009 | 0.007 | 0.009 | 0.006 | 0.008 | 0.006 | 0.005 | 0.004 | 0.007 | 0.013 | 0.012 | 0.009 | 0.013 | 0.016 | 0.009 | 0.005 | 0.003 | 0.0069 |
| 20 | 0.003 | 0.002 | 0.002 | 0.002 | 0.002 | 0.003 | 0.008 | 0.050 | 0.031 | 0.015 | 0.007 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.0114 |
| 21 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 22 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 23 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 24 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 25 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 26 | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.007 | 0.005 | 0.014 | 0.004 | 0.006 | 0.007 | 0.006 | 0.014 | 0.021 | 0.066 | 0.077 | 0.103 | 0.094 | 0.098 | 0.124 | 0.0431 |
| 27 | ND | 0.020 | 0.007 | 0.004 | 0.008 | 0.022 | 0.036 | 0.039 | 0.022 | 0.021 | 0.009 | 0.005 | 0.007 | 0.007 | 0.006 | 0.009 | 0.008 | 0.020 | 0.032 | 0.069 | 0.083 | 0.048 | 0.082 | 0.084 | 0.0282 |
| 28 | 0.060 | 0.003 | 0.002 | 0.002 | 0.002 | 0.003 | 0.007 | 0.008 | 0.008 | ND | 0.007 | 0.009 | 0.008 | 0.005 | 0.006 | 0.007 | 0.005 | 0.006 | 0.007 | 0.007 | 0.005 | 0.004 | 0.004 | 0.002 | 0.0077 |
| 29 | 0.002 | 0.002 | 0.002 | 0.002 | 0.003 | 0.005 | 0.014 | 0.013 | 0.007 | 0.005 | 0.005 | 0.026 | 0.033 | 0.004 | 0.005 | 0.010 | 0.012 | 0.011 | 0.007 | 0.010 | 0.005 | 0.005 | 0.007 | 0.006 | 0.0084 |
| 30 | 0.009 | 0.003 | 0.004 | 0.003 | 0.003 | 0.004 | 0.008 | 0.008 | 0.005 | 0.005 | 0.005 | 0.006 | 0.005 | 0.005 | 0.003 | 0.003 | 0.004 | 0.004 | 0.006 | 0.005 | 0.006 | 0.004 | 0.004 | 0.003 | 0.0048 |
| 31 | ND | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.003 | 0.003 | 0.003 | 0.003 | 0.002 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.005 | 0.004 | 0.007 | 0.005 | 0.004 | 0.005 | 0.014 | 0.007 | 0.0039 |
| | | | | | | | | | | | | | | | | | | | | | | | | Monthly Average = | 0.0243 |

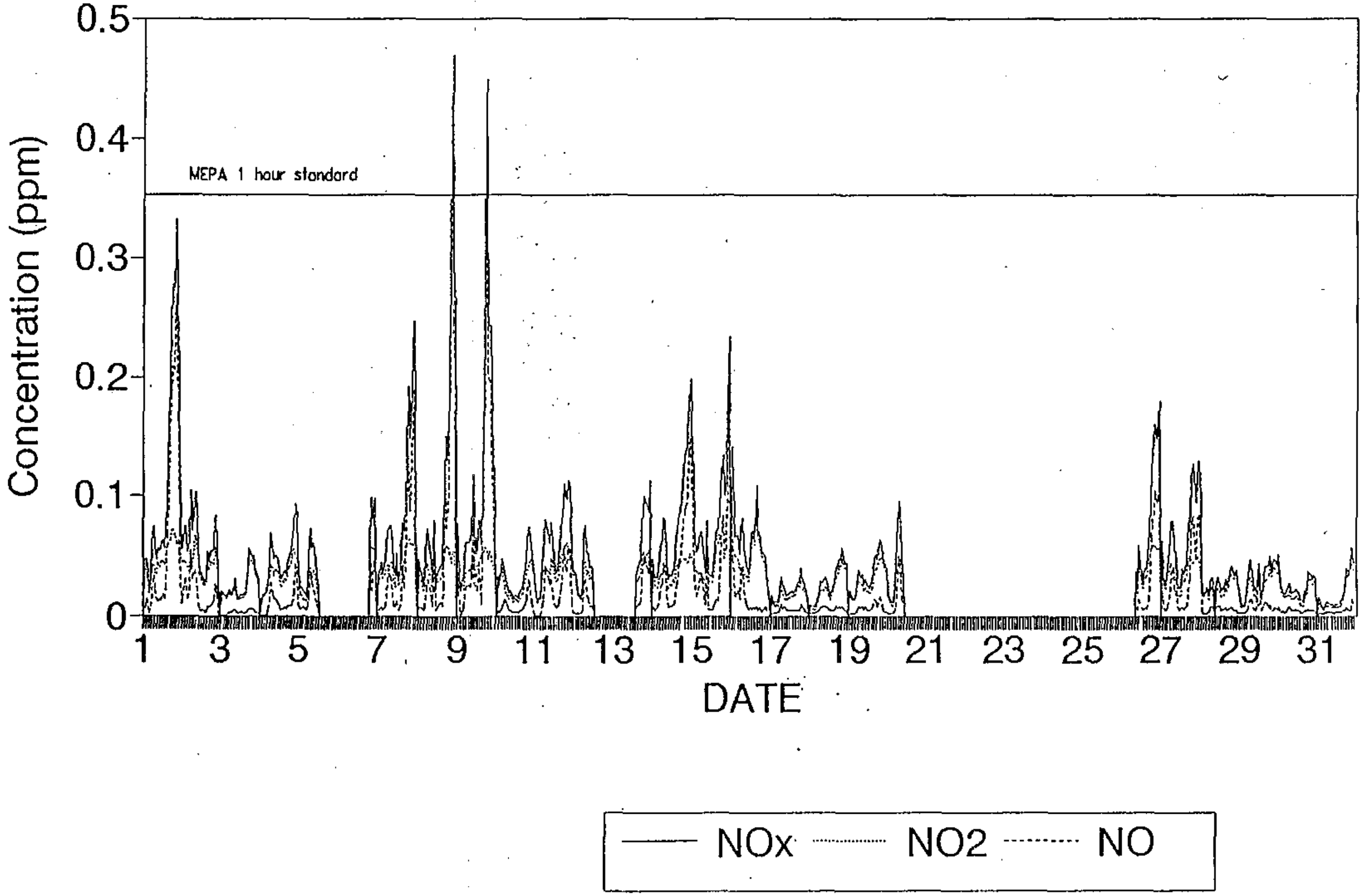
Maximum Hourly Average was 0.437 at Hour 22 on Day 8 with 1 occurences and there were no Hourly Violations
Maximum Daily Average was 0.0780 on Day 9 with 1 occurences and there were no Daily Violations
Operating Efficiency = 71.4 percent
ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data
[CEM 1990]

MEPA - Dammam Industrial Estates
May 1991
Frequency Distribution
Hourly Averages for NO in ppm

| Concentration | # of Hours | Percentage |
|---|---|---|
| 0.000 - 0.050 | 472 | 88.9 |
| 0.051 - 0.110 | 35 | 6.6 |
| 0.111 - 0.210 | 19 | 3.6 |
| 0.211+ | 5 | 0.9 |

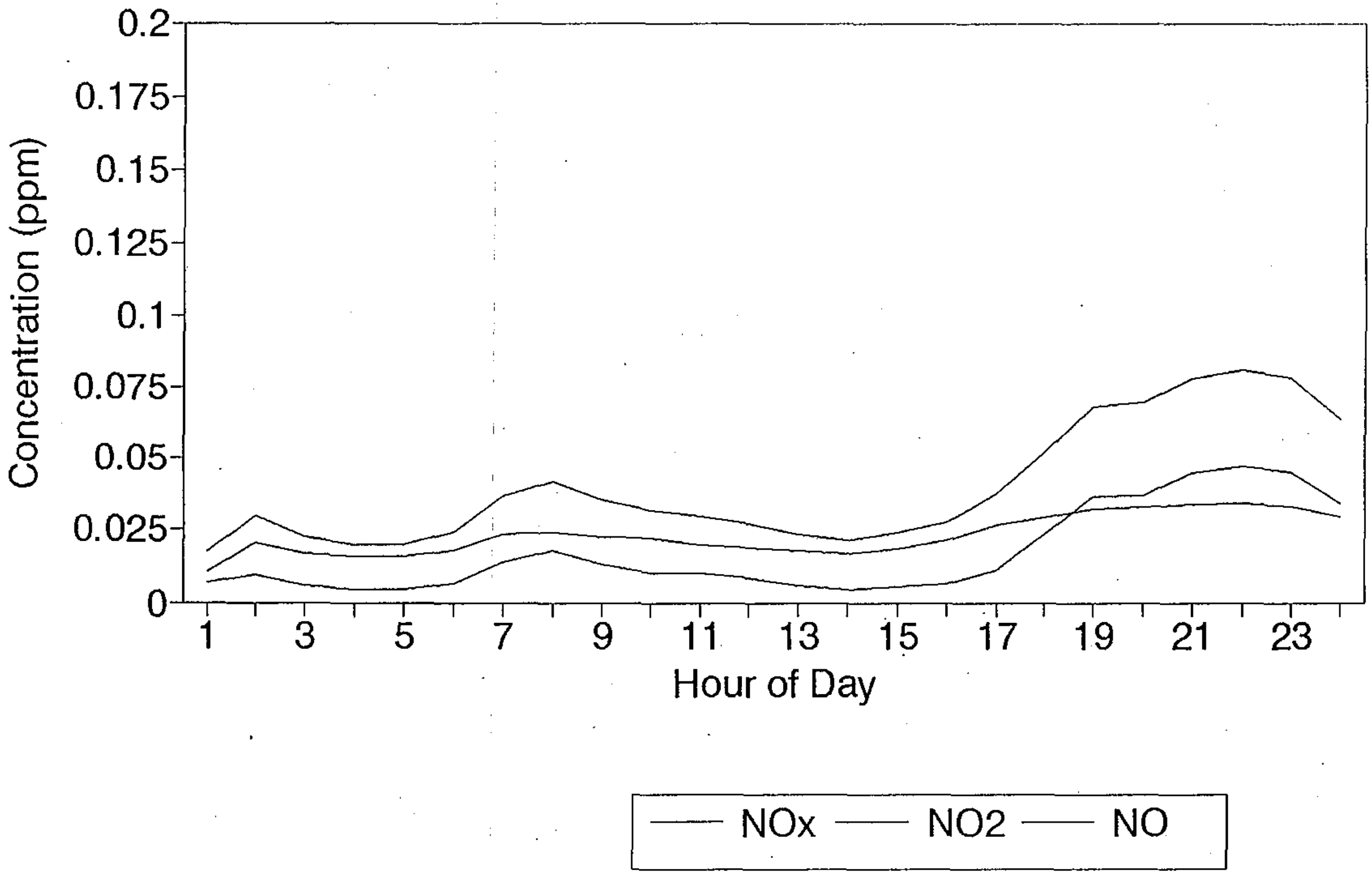
# DAMMAM INDUSTRIAL ESTATES

Hourly NOx/NO2/NO - May, 1991



# DAMMAM INDUSTRIAL ESTATES

Diurnal NOx/NO2/NO - May, 1991



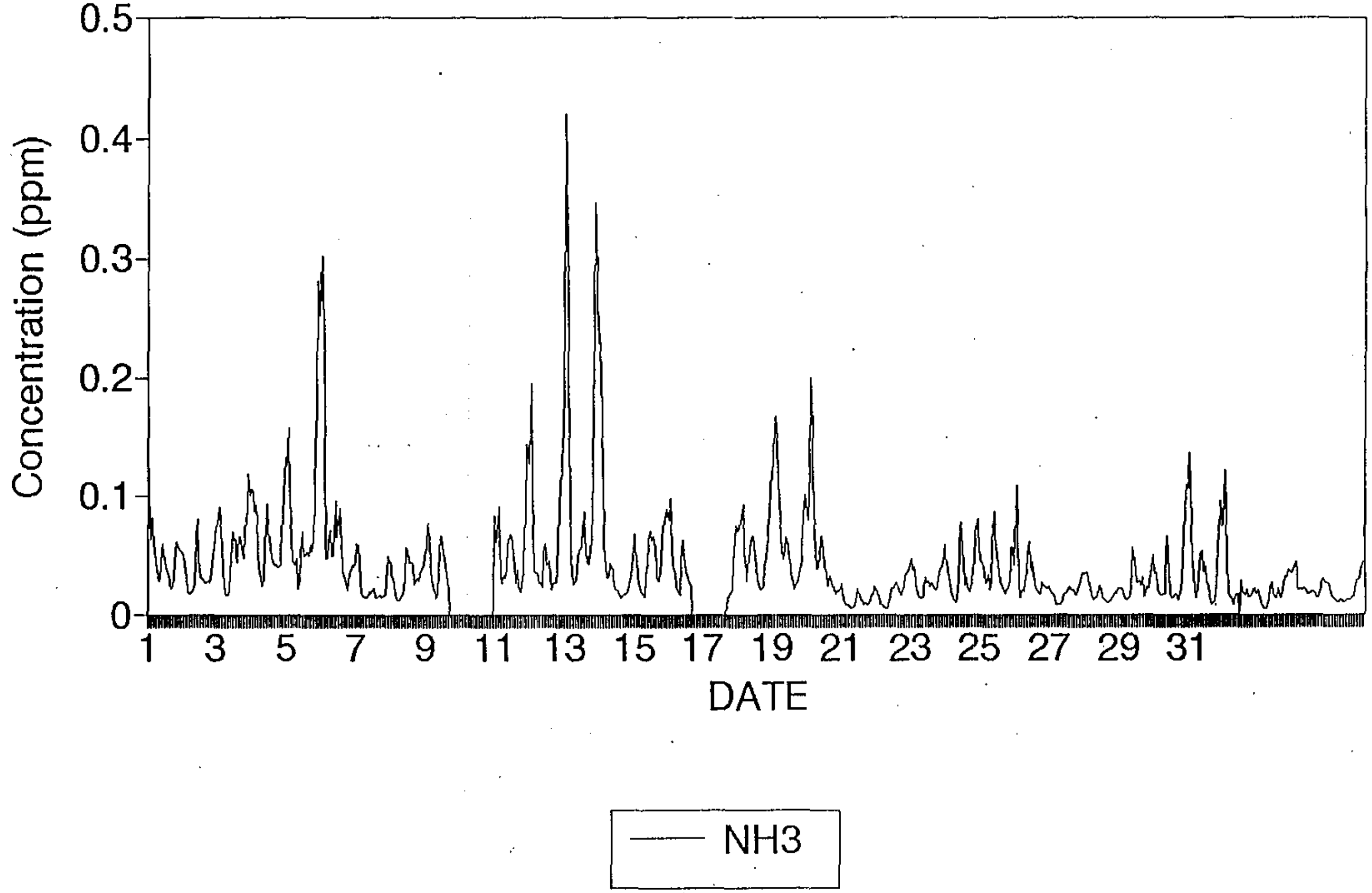
MEPA - Dammam Industrial Estates
May 1991
Hourly Averages for NH3 in ppm

| Day \ Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.063 | 0.045 | 0.041 | 0.046 | 0.021 | 0.026 | 0.053 | 0.070 | 0.062 | 0.049 | 0.050 | 0.052 | 0.050 | 0.059 | 0.052 | 0.062 | 0.105 | 0.184 | 0.281 | 0.252 | 0.302 | 0.275 | 0.206 | 0.135 | 0.1059 |
| 2 | 0.047 | 0.047 | 0.062 | 0.071 | 0.049 | 0.050 | 0.096 | 0.064 | 0.078 | 0.089 | 0.059 | 0.036 | 0.030 | 0.024 | 0.021 | 0.020 | 0.035 | 0.036 | 0.041 | 0.040 | 0.043 | 0.059 | 0.058 | 0.028 | 0.0493 |
| 3 | 0.017 | 0.015 | 0.015 | 0.013 | 0.015 | 0.019 | 0.018 | 0.017 | 0.020 | 0.022 | 0.013 | 0.013 | 0.015 | 0.016 | 0.014 | 0.015 | 0.016 | 0.028 | 0.049 | 0.044 | 0.044 | 0.033 | 0.032 | 0.025 | 0.0220 |
| 4 | 0.018 | 0.012 | 0.012 | 0.014 | 0.016 | 0.018 | 0.031 | 0.057 | 0.054 | 0.043 | 0.044 | 0.042 | 0.026 | 0.025 | 0.028 | 0.030 | 0.028 | 0.034 | 0.038 | 0.041 | 0.050 | 0.057 | 0.076 | 0.066 | 0.0358 |
| 5 | 0.037 | 0.023 | 0.021 | 0.016 | 0.014 | 0.017 | 0.037 | 0.065 | 0.065 | 0.051 | 0.047 | 0.033 | 0.021 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.0344 |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.082 | 0.061 | 0.066 | 0.090 | 0.0748 |
| 7 | 0.032 | 0.026 | 0.028 | 0.033 | 0.031 | 0.038 | 0.059 | 0.064 | 0.067 | 0.061 | 0.040 | 0.026 | 0.037 | 0.023 | 0.019 | 0.025 | 0.036 | 0.044 | 0.083 | 0.144 | 0.134 | 0.126 | 0.194 | 0.101 | 0.0613 |
| 8 | 0.036 | 0.035 | 0.034 | 0.025 | 0.026 | 0.023 | 0.051 | 0.059 | 0.052 | 0.041 | 0.042 | 0.045 | 0.020 | 0.025 | 0.026 | 0.026 | 0.038 | 0.087 | 0.112 | 0.118 | 0.193 | 0.420 | 0.330 | 0.257 | 0.0884 |
| 9 | 0.199 | 0.101 | 0.047 | 0.025 | 0.026 | 0.029 | 0.049 | 0.054 | 0.055 | 0.059 | 0.087 | 0.065 | 0.043 | 0.042 | 0.058 | 0.047 | 0.062 | 0.143 | 0.346 | 0.327 | 0.228 | 0.237 | 0.206 | 0.119 | 0.1106 |
| 10 | 0.058 | 0.040 | 0.030 | 0.032 | 0.042 | 0.040 | 0.037 | 0.031 | 0.022 | 0.020 | 0.019 | 0.015 | 0.014 | 0.016 | 0.016 | 0.017 | 0.020 | 0.025 | 0.032 | 0.039 | 0.057 | 0.067 | 0.054 | 0.048 | 0.0330 |
| 11 | 0.030 | 0.021 | 0.018 | 0.017 | 0.015 | 0.033 | 0.042 | 0.062 | 0.069 | 0.062 | 0.066 | 0.055 | 0.039 | 0.030 | 0.028 | 0.031 | 0.044 | 0.065 | 0.079 | 0.088 | 0.083 | 0.079 | 0.097 | 0.057 | 0.0504 |
| 12 | 0.040 | 0.035 | 0.023 | 0.019 | 0.016 | 0.017 | 0.045 | 0.062 | 0.050 | 0.036 | 0.033 | 0.027 | 0.024 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.0328 |
| 13 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.014 | 0.017 | 0.018 | 0.022 | 0.043 | 0.062 | 0.075 | 0.070 | 0.072 | 0.083 | 0.0476 |
| 14 | 0.091 | 0.052 | 0.034 | 0.028 | 0.042 | 0.044 | 0.056 | 0.065 | 0.066 | 0.050 | 0.029 | 0.025 | 0.020 | 0.022 | 0.023 | 0.041 | 0.048 | 0.064 | 0.074 | 0.088 | 0.120 | 0.113 | 0.154 | 0.167 | 0.0632 |
| 15 | 0.148 | 0.113 | 0.078 | 0.053 | 0.046 | 0.054 | 0.064 | 0.059 | 0.048 | 0.041 | 0.033 | 0.027 | 0.022 | 0.025 | 0.027 | 0.033 | 0.037 | 0.045 | 0.082 | 0.101 | 0.085 | 0.079 | 0.120 | 0.199 | 0.0675 |
| 16 | 0.157 | 0.119 | 0.089 | 0.053 | 0.038 | 0.039 | 0.060 | 0.065 | 0.054 | 0.039 | 0.034 | 0.024 | 0.032 | 0.026 | 0.024 | 0.019 | 0.023 | 0.017 | 0.020 | 0.019 | 0.021 | 0.025 | 0.011 | 0.009 | 0.0424 |
| 17 | 0.009 | 0.008 | 0.006 | 0.006 | 0.006 | 0.007 | 0.011 | 0.022 | 0.019 | 0.017 | 0.012 | 0.011 | 0.009 | 0.010 | 0.008 | 0.009 | 0.012 | 0.016 | 0.016 | 0.023 | 0.020 | 0.018 | 0.015 | 0.015 | 0.0127 |
| 18 | 0.009 | 0.008 | 0.006 | 0.006 | 0.005 | 0.008 | 0.014 | 0.022 | 0.022 | 0.024 | 0.026 | 0.023 | 0.020 | 0.016 | 0.017 | 0.019 | 0.023 | 0.032 | 0.034 | 0.038 | 0.041 | 0.046 | 0.037 | 0.039 | 0.0223 |
| 19 | 0.024 | 0.018 | 0.014 | 0.014 | 0.013 | 0.015 | 0.023 | 0.030 | 0.027 | 0.028 | 0.023 | 0.027 | 0.024 | 0.022 | 0.020 | 0.024 | 0.035 | 0.038 | 0.039 | 0.044 | 0.058 | 0.046 | 0.045 | 0.036 | 0.0286 |
| 20 | 0.027 | 0.019 | 0.014 | 0.011 | 0.010 | 0.013 | 0.029 | 0.077 | 0.067 | 0.042 | 0.024 | 0.030 | 0.028 | 0.022 | 0.019 | 0.026 | 0.037 | 0.043 | 0.068 | 0.080 | 0.070 | 0.045 | 0.043 | 0.039 | 0.0368 |
| 21 | 0.027 | 0.026 | 0.033 | 0.027 | 0.020 | 0.027 | 0.059 | 0.087 | 0.066 | 0.050 | 0.034 | 0.026 | 0.023 | 0.020 | 0.018 | 0.020 | 0.022 | 0.029 | 0.044 | 0.055 | 0.057 | 0.041 | 0.082 | 0.108 | 0.0417 |
| 22 | 0.025 | 0.014 | 0.020 | 0.019 | 0.027 | 0.035 | 0.051 | 0.061 | 0.040 | 0.034 | 0.043 | 0.025 | 0.022 | 0.019 | 0.018 | 0.017 | 0.027 | 0.024 | 0.023 | 0.022 | 0.023 | 0.020 | 0.018 | 0.018 | 0.0269 |
| 23 | 0.014 | 0.009 | 0.008 | 0.008 | 0.008 | 0.009 | 0.012 | 0.016 | 0.017 | 0.019 | 0.020 | 0.023 | 0.020 | 0.020 | 0.017 | 0.016 | 0.021 | 0.022 | 0.024 | 0.029 | 0.035 | 0.033 | 0.035 | 0.035 | 0.0196 |
| 24 | 0.028 | 0.021 | 0.016 | 0.012 | 0.013 | 0.013 | 0.018 | 0.021 | 0.024 | 0.021 | 0.014 | 0.012 | 0.011 | 0.010 | 0.010 | 0.011 | 0.013 | 0.015 | 0.019 | 0.018 | 0.022 | 0.022 | 0.021 | 0.021 | 0.0169 |
| 25 | 0.021 | 0.015 | 0.012 | 0.012 | 0.013 | 0.015 | 0.035 | 0.055 | 0.045 | 0.027 | 0.026 | 0.028 | 0.024 | 0.030 | 0.017 | 0.015 | 0.018 | 0.023 | 0.022 | 0.033 | 0.039 | 0.049 | 0.035 | 0.034 | 0.0268 |
| 26 | 0.021 | 0.018 | 0.016 | 0.016 | 0.018 | 0.018 | 0.033 | 0.065 | 0.051 | 0.017 | 0.014 | 0.014 | 0.016 | 0.017 | 0.012 | 0.014 | 0.021 | 0.029 | 0.066 | 0.090 | 0.110 | 0.106 | 0.117 | 0.136 | 0.0431 |
| 27 | 0.073 | 0.043 | 0.020 | 0.014 | 0.022 | 0.031 | 0.051 | 0.052 | 0.036 | 0.039 | 0.027 | 0.024 | 0.014 | 0.013 | 0.009 | 0.010 | 0.011 | 0.024 | 0.040 | 0.071 | 0.096 | 0.073 | 0.077 | 0.121 | 0.0413 |
| 28 | 0.047 | 0.018 | 0.013 | 0.013 | 0.014 | 0.008 | 0.012 | 0.016 | 0.016 | ND | 0.028 | 0.019 | 0.018 | 0.016 | 0.020 | 0.015 | 0.015 | 0.017 | 0.020 | 0.021 | 0.019 | 0.018 | 0.020 | 0.017 | 0.0183 |
| 29 | 0.010 | 0.007 | 0.005 | 0.005 | 0.007 | 0.012 | 0.023 | 0.027 | 0.017 | 0.013 | 0.013 | 0.015 | 0.021 | 0.015 | 0.013 | 0.020 | 0.027 | 0.032 | 0.031 | 0.037 | 0.036 | 0.035 | 0.038 | 0.039 | 0.0207 |
| 30 | 0.044 | 0.035 | 0.022 | 0.020 | 0.022 | 0.020 | 0.021 | 0.022 | 0.018 | 0.017 | 0.017 | 0.019 | 0.019 | 0.017 | 0.014 | 0.014 | 0.016 | 0.022 | 0.027 | 0.028 | 0.029 | 0.027 | 0.026 | 0.025 | 0.0225 |
| 31 | 0.020 | 0.015 | 0.013 | 0.012 | 0.011 | 0.010 | 0.012 | 0.012 | 0.011 | 0.010 | 0.010 | 0.011 | 0.012 | 0.012 | 0.012 | 0.013 | 0.015 | 0.020 | 0.028 | 0.029 | 0.029 | 0.034 | 0.042 | 0.043 | 0.0182 |
| | | | | | | | | | | | | | | | | | | | | | | Monthly Average = | | | 0.0417 |

Maximum Hourly Average was 0.420 at Hour 22 on Day 8 with 1 occurences and there were no Hourly Violations
Maximum Daily Average was 0.1106 on Day 9 with 1 occurences and there were no Daily Violations
Operating Efficiency = 92.3 percent
ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data
[CEM 1990]

# DAMMAM INDUSTRIAL ESTATES

Hourly NH3 - May, 1991



MEPA - Dammam Industrial Estates
May 1991
Hourly Averages for O3 in ppm

| Hour / Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ND | 0.002 | 0.003 | 0.006 | 0.014 | 0.013 | 0.005 | 0.007 | 0.015 | 0.019 | 0.017 | 0.013 | 0.010 | 0.008 | 0.012 | 0.007 | 0.002 | 0.001 | 0.002 | 0.006 | 0.006 | 0.007 | 0.006 | 0.002 | 0.0080 |
| 2 | 0.001 | 0.001 | 0.001 | 0.001 | 0.002 | 0.002 | 0.004 | 0.005 | 0.007 | 0.010 | 0.024 | 0.036 | 0.034 | 0.036 | 0.050 | 0.039 | 0.020 | 0.015 | 0.009 | 0.008 | 0.006 | 0.005 | 0.005 | 0.011 | 0.0138 |
| 3 | ND | 0.012 | 0.013 | 0.014 | 0.016 | 0.017 | 0.019 | 0.021 | 0.021 | 0.017 | 0.031 | 0.032 | 0.032 | 0.031 | 0.029 | 0.028 | 0.026 | 0.014 | 0.005 | 0.008 | 0.007 | 0.015 | 0.015 | 0.018 | 0.0192 |
| 4 | ND | 0.025 | 0.021 | 0.021 | 0.017 | 0.016 | 0.007 | 0.004 | 0.008 | 0.014 | 0.014 | 0.019 | 0.026 | 0.023 | 0.021 | 0.021 | 0.021 | 0.018 | 0.012 | 0.010 | 0.006 | 0.002 | 0.001 | 0.003 | 0.0143 |
| 5 | 0.005 | 0.023 | 0.023 | 0.026 | 0.025 | 0.019 | 0.008 | 0.002 | 0.007 | 0.011 | 0.017 | 0.026 | 0.032 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.0172 |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.001 | 0.007 | 0.004 | 0.003 | 0.0038 |
| 7 | ND | 0.008 | 0.012 | 0.008 | 0.015 | 0.009 | 0.003 | 0.005 | 0.009 | 0.017 | 0.024 | 0.026 | 0.025 | 0.029 | 0.023 | 0.018 | 0.013 | 0.006 | 0.001 | 0.001 | 0.004 | 0.002 | 0.001 | 0.006 | 0.0115 |
| 8 | ND | 0.008 | 0.014 | 0.014 | 0.017 | 0.014 | 0.007 | 0.010 | 0.016 | 0.023 | CAL | CAL | 0.033 | 0.025 | 0.021 | 0.018 | 0.006 | 0.001 | 0.002 | 0.002 | 0.004 | 0.002 | 0.008 | 0.003 | 0.0118 |
| 9 | ND | 0.001 | 0.005 | 0.011 | 0.007 | 0.007 | 0.002 | 0.002 | 0.004 | 0.004 | 0.003 | 0.007 | 0.007 | 0.005 | 0.004 | 0.014 | 0.002 | 0.001 | 0.002 | 0.002 | 0.001 | 0.002 | 0.001 | 0.001 | 0.0041 |
| 10 | ND | 0.003 | 0.005 | 0.003 | 0.001 | 0.004 | 0.006 | 0.013 | 0.016 | 0.017 | 0.019 | 0.021 | 0.021 | 0.019 | 0.019 | 0.016 | 0.013 | 0.011 | 0.008 | 0.003 | 0.002 | 0.001 | 0.003 | 0.011 | 0.0102 |
| 11 | 0.013 | 0.020 | 0.023 | 0.014 | 0.017 | 0.005 | 0.005 | 0.003 | 0.006 | 0.007 | 0.008 | 0.014 | 0.018 | 0.022 | 0.019 | 0.015 | 0.008 | 0.005 | 0.002 | 0.001 | 0.002 | 0.001 | 0.001 | 0.003 | 0.0097 |
| 12 | 0.009 | 0.012 | 0.021 | 0.021 | 0.022 | 0.018 | 0.006 | 0.007 | 0.015 | 0.019 | 0.024 | 0.024 | 0.025 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.0172 |
| 13 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.021 | 0.015 | 0.013 | 0.011 | 0.004 | 0.003 | 0.001 | 0.001 | 0.002 | 0.001 | 0.0072 |
| 14 | ND | 0.002 | 0.006 | 0.007 | 0.003 | 0.003 | 0.003 | 0.004 | 0.005 | 0.013 | 0.022 | 0.021 | 0.019 | 0.013 | 0.017 | 0.004 | 0.003 | 0.002 | 0.003 | 0.004 | 0.004 | 0.002 | 0.001 | 0.001 | 0.0070 |
| 15 | 0.001 | 0.001 | 0.001 | 0.002 | 0.002 | 0.002 | 0.002 | 0.005 | 0.011 | 0.014 | CAL | 0.023 | 0.023 | 0.022 | 0.015 | 0.013 | 0.013 | 0.006 | 0.003 | 0.002 | 0.004 | 0.005 | 0.002 | 0.001 | 0.0075 |
| 16 | ND | 0.001 | 0.001 | 0.002 | 0.001 | 0.003 | 0.004 | 0.005 | 0.012 | 0.018 | 0.026 | 0.032 | 0.038 | 0.041 | 0.036 | 0.029 | 0.025 | 0.027 | 0.028 | 0.021 | 0.012 | 0.011 | 0.018 | 0.022 | 0.0180 |
| 17 | ND | 0.022 | 0.025 | 0.024 | 0.026 | 0.027 | 0.021 | 0.015 | 0.012 | 0.023 | 0.025 | 0.027 | 0.029 | 0.027 | 0.032 | 0.035 | 0.033 | 0.029 | 0.027 | 0.015 | 0.016 | 0.014 | 0.022 | 0.021 | 0.0238 |
| 18 | ND | 0.031 | 0.031 | 0.032 | 0.034 | 0.031 | 0.025 | 0.024 | 0.024 | 0.024 | 0.026 | 0.028 | 0.025 | 0.027 | 0.026 | 0.023 | 0.023 | 0.016 | 0.014 | 0.010 | 0.010 | 0.006 | 0.011 | 0.008 | 0.0221 |
| 19 | ND | 0.022 | 0.024 | 0.025 | 0.026 | 0.025 | 0.020 | 0.020 | 0.025 | 0.026 | 0.027 | 0.023 | 0.026 | 0.028 | 0.028 | 0.023 | 0.017 | 0.013 | 0.013 | 0.006 | 0.008 | 0.005 | 0.006 | 0.009 | 0.0193 |
| 20 | 0.012 | 0.022 | 0.026 | 0.028 | 0.028 | 0.026 | 0.012 | 0.002 | 0.005 | 0.016 | 0.024 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.0183 |
| 21 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 22 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 23 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 24 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 25 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 26 | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.031 | 0.034 | 0.020 | 0.026 | 0.022 | 0.020 | 0.020 | 0.010 | 0.007 | 0.002 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.0131 |
| 27 | ND | 0.004 | 0.012 | 0.013 | 0.008 | 0.004 | 0.003 | 0.005 | 0.011 | 0.016 | 0.028 | 0.034 | 0.035 | 0.036 | 0.028 | 0.019 | 0.018 | 0.007 | 0.003 | 0.001 | 0.001 | 0.001 | 0.002 | 0.001 | 0.0126 |
| 28 | 0.001 | 0.013 | 0.021 | 0.016 | 0.012 | 0.016 | 0.013 | 0.015 | 0.017 | ND | 0.024 | 0.021 | 0.022 | 0.025 | 0.024 | 0.020 | 0.022 | 0.017 | 0.012 | 0.011 | 0.013 | 0.014 | 0.011 | 0.015 | 0.0163 |
| 29 | 0.022 | 0.026 | 0.026 | 0.026 | 0.025 | 0.013 | 0.009 | 0.014 | 0.023 | 0.028 | 0.029 | CAL | CAL | CAL | 0.024 | 0.017 | 0.013 | 0.012 | 0.010 | 0.005 | 0.011 | 0.010 | 0.005 | 0.006 | 0.0169 |
| 30 | 0.004 | 0.015 | 0.016 | 0.017 | 0.018 | 0.018 | 0.019 | 0.019 | 0.026 | 0.026 | 0.026 | 0.025 | 0.026 | 0.026 | 0.027 | 0.027 | 0.020 | 0.016 | 0.012 | 0.010 | 0.009 | 0.012 | 0.011 | 0.012 | 0.0182 |
| 31 | ND | 0.020 | 0.023 | 0.025 | 0.026 | 0.025 | 0.023 | 0.025 | 0.026 | 0.028 | 0.029 | 0.033 | 0.032 | 0.031 | 0.031 | 0.029 | 0.025 | 0.018 | 0.010 | 0.011 | 0.011 | 0.007 | 0.003 | 0.006 | 0.0216 |
| | | | | | | | | | | | | | | | | | | | | | | | | Monthly Average = | 0.0143 |

Maximum Hourly Average was 0.050 at Hour 15 on Day 2 with 1 occurences and there were no Hourly Violations

Maximum Daily Average was 0.0238 on Day 17 with 1 occurences and there were no Daily Violations

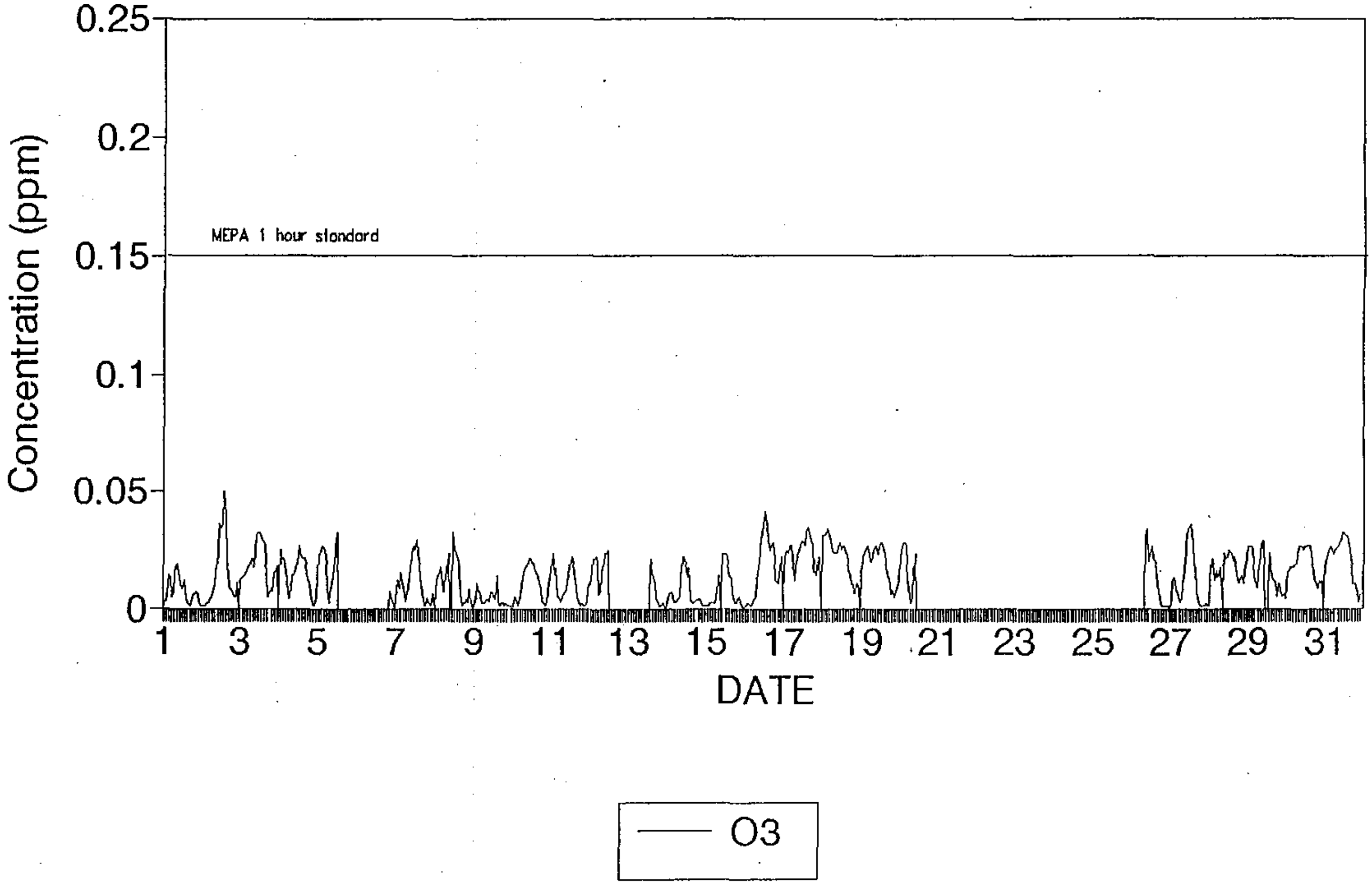
Operating Efficiency = 71.4 percent

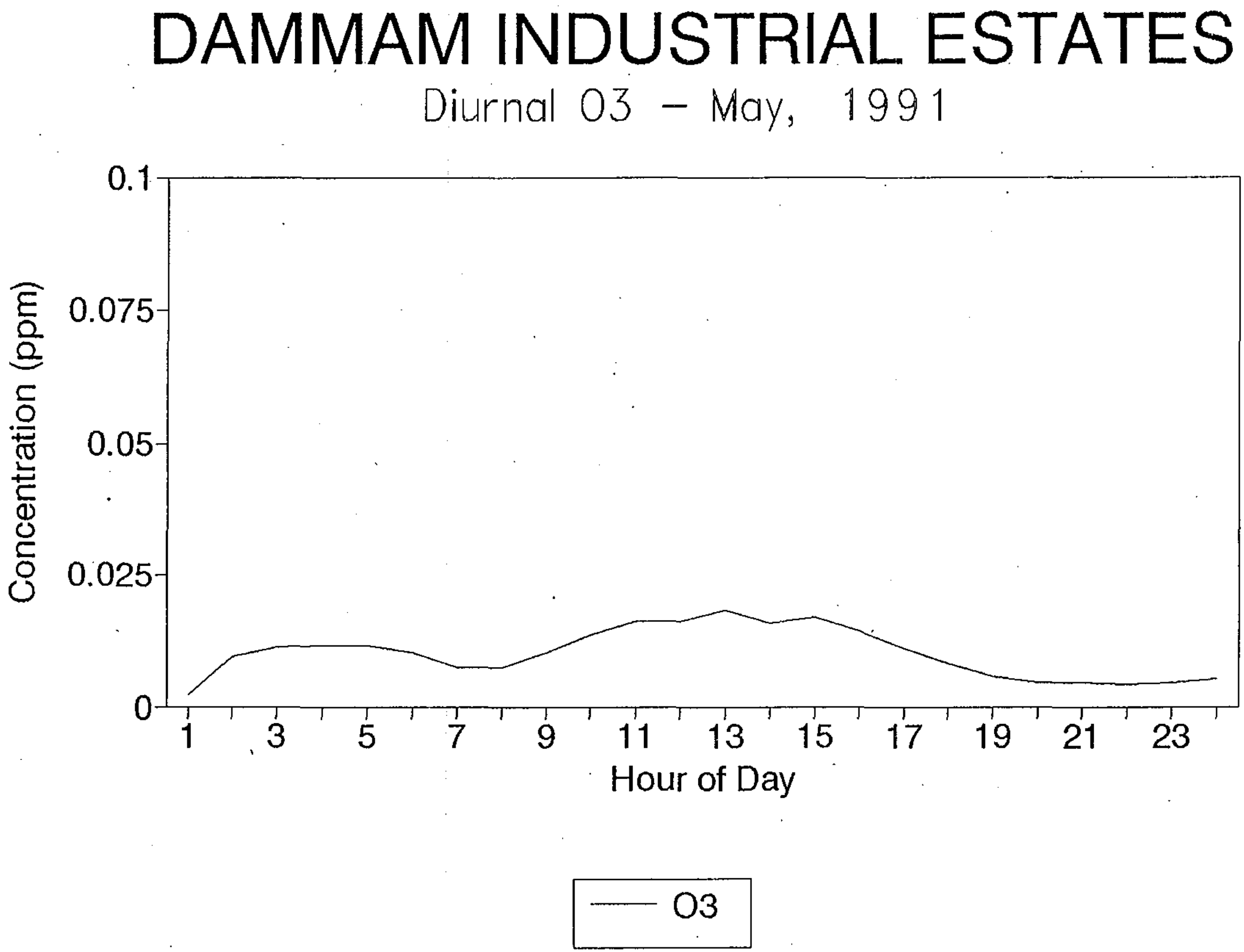
ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data

[CEM 1990]

# DAMMAM INDUSTRIAL ESTATES

Hourly O3 - May, 1991





DAMMAM INDUSTRIAL ESTATES
Diurnal O3 - May, 1991
Concentration (ppm)
0.1
0.075
0.05
0.025
0
1
3
5
7
9
11
13
15
17
19
21
23
Hour of Day
O3

MEPA - Dammam Industrial Estates
May 1991
Hourly Averages for Carbon Monoxide in ppm

| Hour / Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ND | 0.6 | 0.4 | 0.3 | 0.2 | 0.2 | 0.6 | 0.7 | 0.6 | 0.7 | 1.1 | 1.0 | 1.1 | 0.8 | 0.8 | 1.3 | 2.0 | 3.4 | 3.7 | 3.9 | 4.1 | 3.3 | 2.3 | 1.1 | 1.49 |
| 2 | 0.4 | 0.4 | 0.4 | 0.4 | 0.2 | 0.3 | 0.6 | 0.6 | 1.1 | 1.5 | 1.0 | 0.7 | 0.4 | 0.3 | 0.3 | 0.4 | 0.8 | 0.9 | 0.9 | 1.0 | 1.1 | 1.4 | 1.2 | 0.6 | 0.70 |
| 3 | ND | 0.4 | 0.4 | 0.4 | 0.4 | 0.3 | 0.3 | 0.3 | 0.3 | 0.2 | 0.2 | 0.2 | 0.2 | 0.1 | 0.2 | 0.2 | 0.3 | 0.4 | 0.5 | 0.7 | 0.7 | 0.6 | 0.5 | 0.3 | 0.35 |
| 4 | ND | 0.1 | 0.1 | 0.0 | 0.1 | 0.2 | 0.6 | 1.0 | 0.7 | 0.7 | 0.6 | 0.5 | 0.4 | 0.5 | 0.6 | 0.7 | 0.7 | 0.7 | 0.8 | 0.8 | 0.8 | 1.2 | 0.8 | 0.4 | 0.57 |
| 5 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 0.6 | 0.2 | 0.4 | 0.5 | 0.4 | 0.2 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.22 |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 1.3 | 0.8 | 1.2 | 1.1 | 1.10 |
| 7 | ND | 0.3 | 0.3 | 0.2 | 0.2 | 0.2 | 0.3 | 0.4 | 0.6 | 0.4 | 0.3 | 0.3 | 0.5 | 0.4 | 0.5 | 0.7 | 1.1 | 1.0 | 1.8 | 2.3 | 1.6 | 2.9 | 3.7 | 0.7 | 0.90 |
| 8 | ND | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.3 | 0.2 | 0.2 | CAL | CAL | 1.0 | 1.0 | 1.0 | 1.3 | 1.7 | 2.9 | 3.0 | 3.2 | 4.7 | 7.1 | 4.5 | 4.6 | 1.76 |
| 9 | ND | 1.0 | 0.6 | 0.5 | 0.7 | 0.7 | 0.9 | 0.9 | 0.9 | 1.2 | 2.4 | 1.7 | 1.1 | 1.2 | 1.3 | 1.3 | 1.9 | 3.9 | 7.2 | 5.6 | 5.5 | 4.4 | 2.5 | 1.1 | 2.11 |
| 10 | ND | 0.6 | 0.6 | 0.5 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.7 | 0.7 | 0.8 | 0.9 | 0.8 | 0.7 | 0.8 | 0.9 | 1.0 | 1.1 | 1.3 | 1.6 | 1.7 | 1.4 | 1.3 | 0.89 |
| 11 | 1.0 | 0.7 | 0.6 | 0.6 | 0.6 | 0.8 | 0.9 | 1.4 | 1.0 | 1.1 | 1.4 | 1.4 | 1.2 | 1.0 | 1.1 | 1.4 | 1.6 | 1.7 | 2.2 | 2.0 | 2.1 | 2.3 | 1.4 | 0.7 | 1.26 |
| 12 | 0.6 | 0.6 | 0.5 | 0.5 | 0.5 | 0.6 | 1.1 | 1.0 | 0.9 | 1.1 | 1.0 | 1.0 | 1.0 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.80 |
| 13 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 1.0 | 1.1 | 1.1 | 1.3 | 1.7 | 2.0 | 1.8 | 1.7 | 1.5 | 1.8 | 1.50 |
| 14 | ND | 0.8 | 0.7 | 0.6 | 0.6 | 0.7 | 1.0 | 1.3 | 1.2 | 0.9 | 0.9 | 0.9 | 0.9 | 1.0 | 1.0 | 1.2 | 1.2 | 1.4 | 1.3 | 1.8 | 1.6 | 1.8 | 2.1 | 1.9 | 1.17 |
| 15 | 1.7 | 1.1 | 0.8 | 0.6 | 0.5 | 0.6 | 0.7 | 0.8 | 0.7 | 0.7 | CAL | 1.0 | 1.1 | 1.1 | 1.3 | 1.4 | 1.5 | 1.4 | 1.7 | 1.9 | 1.7 | 1.6 | 2.4 | 2.5 | 1.25 |
| 16 | ND | 1.6 | 1.5 | 1.0 | 0.8 | 0.8 | 1.0 | 1.2 | 1.0 | 0.9 | 0.9 | 0.8 | 1.0 | 1.0 | 0.9 | 0.8 | 0.9 | 0.9 | 1.0 | 1.2 | 1.4 | 1.1 | 0.9 | 0.7 | 1.01 |
| 17 | ND | 0.6 | 0.5 | 0.4 | 0.4 | 0.4 | 0.5 | 0.6 | 0.4 | 0.5 | 0.6 | 0.6 | 0.7 | 0.8 | 0.9 | 0.9 | 0.8 | 0.9 | 0.8 | 0.8 | 0.7 | 0.7 | 0.5 | 0.5 | 0.63 |
| 18 | ND | 0.3 | 0.3 | 0.3 | 0.4 | 0.4 | 0.6 | 0.8 | 0.8 | 0.8 | 0.8 | 0.7 | 0.7 | 0.6 | 0.6 | 0.7 | 0.7 | 0.8 | 0.9 | 0.9 | 0.9 | 1.1 | 0.9 | 0.6 | 0.68 |
| 19 | ND | 0.3 | 0.3 | 0.3 | 0.3 | 0.4 | 0.7 | 1.0 | 0.8 | 0.6 | 0.6 | 0.7 | 0.6 | 0.6 | 0.5 | 0.7 | 0.9 | 0.9 | 0.9 | 1.1 | 1.4 | 1.1 | 0.7 | 0.5 | 0.69 |
| 20 | 0.5 | 0.2 | 0.1 | 0.1 | 0.1 | 0.3 | 0.7 | 1.5 | 1.2 | 0.9 | 0.8 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.58 |
| 21 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 22 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 23 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 24 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 25 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 26 | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.7 | 0.5 | 1.0 | 0.5 | 0.6 | 0.9 | 0.8 | 1.1 | 1.2 | 1.8 | 1.8 | 1.9 | 2.0 | 2.9 | 2.8 | 1.37 |
| 27 | ND | 0.4 | 0.0 | 0.1 | 0.0 | 0.2 | 0.3 | 0.5 | 0.4 | 0.5 | 0.4 | 0.4 | 0.4 | 0.7 | 0.5 | 0.5 | 0.7 | 0.9 | 1.1 | 1.8 | 1.9 | 1.3 | 2.3 | 2.0 | 0.75 |
| 28 | 1.1 | 0.2 | 0.1 | 0.1 | 0.1 | 0.3 | 0.6 | 0.8 | 0.8 | ND | 0.4 | 0.7 | 0.7 | 0.5 | 0.6 | 0.6 | 0.5 | 0.5 | 0.6 | 0.6 | 0.5 | 0.4 | 0.5 | 0.3 | 0.50 |
| 29 | 0.2 | 0.0 | 0.1 | 0.1 | 0.1 | 0.4 | 0.8 | 0.8 | 0.6 | 0.4 | 0.5 | CAL | CAL | CAL | 0.9 | 1.1 | 1.2 | 1.2 | 1.3 | 1.5 | 1.3 | 1.4 | 1.3 | 0.9 | 0.77 |
| 30 | 1.1 | 0.7 | 0.5 | 0.5 | 0.6 | 0.6 | 0.7 | 1.0 | 0.9 | 0.9 | 1.0 | 0.9 | 0.8 | 0.8 | 0.7 | 0.7 | 0.8 | 0.8 | 1.1 | 1.0 | 0.9 | 0.8 | 0.8 | 0.8 | 0.81 |
| 31 | ND | 0.6 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.7 | 0.6 | 0.6 | 0.7 | 0.7 | 0.8 | 1.0 | 0.9 | 1.0 | 1.0 | 1.1 | 0.8 | 0.70 |
| | | | | | | | | | | | | | | | | | | | | | Monthly Average = | | | | 0.94 |

Maximum Hourly Average was 7.2 at Hour 19 on Day 9 with 1 occurences and there were no Hourly Violations

Maximum Daily Average was 2.11 on Day 9 with 1 occurences and there were no Daily Violations

Operating Efficiency = 71.4 percent

ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data

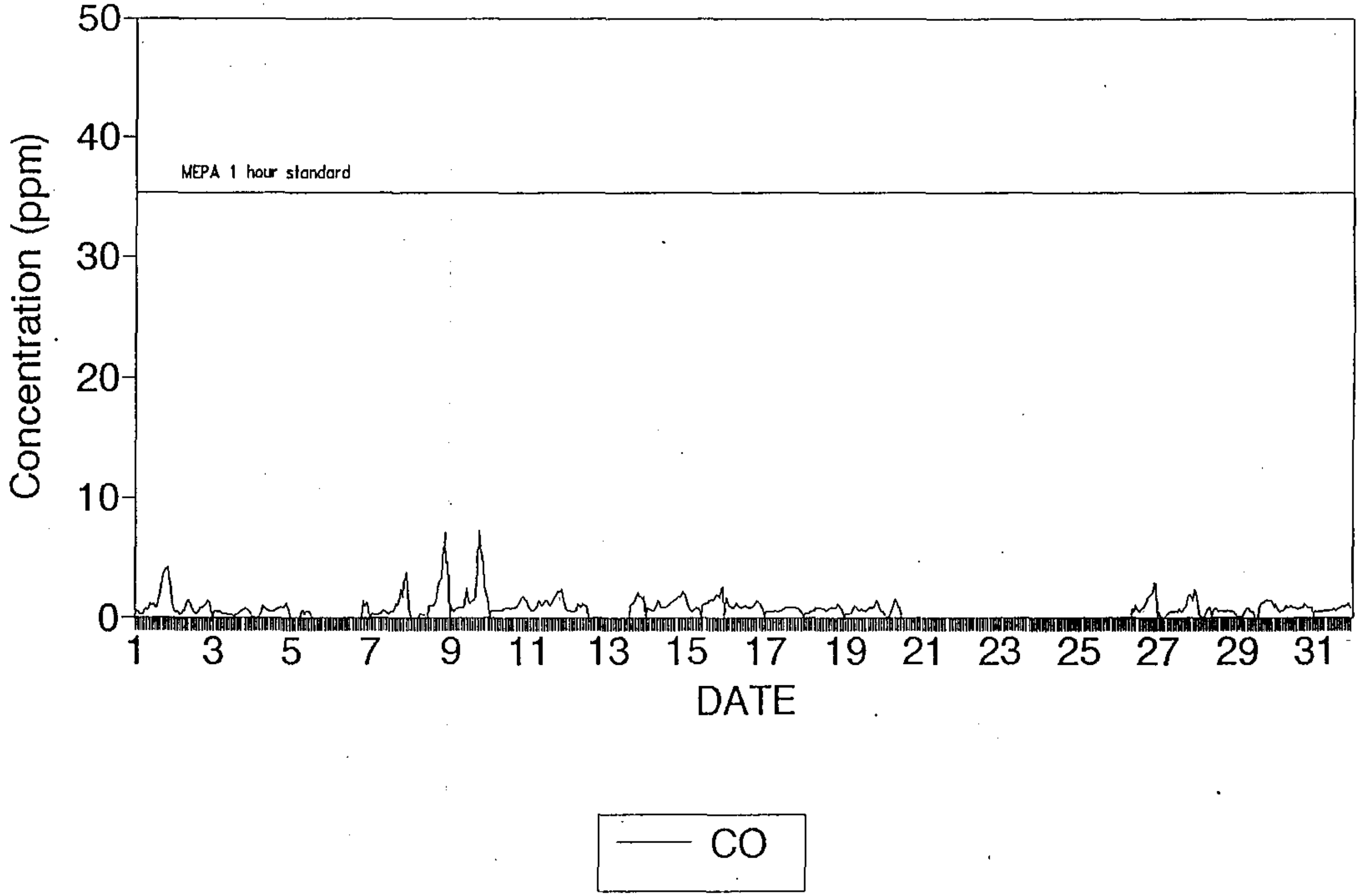
[CEM 1990]

MEPA - Dammam Industrial Estates
May 1991
Frequency Distribution
Hourly Averages for Carbon Monoxide in ppm

| Concentration | # of Hours | Percentage |
|---|---|---|
| 0.0 - 5.0 | 521 | 99.2 |
| 5.1 - 10.0 | 4 | 0.8 |
| 10.1 - 30.0 | 0 | 0.0 |
| 30.1 - 50.0 | 0 | 0.0 |
| 50.1+ | 0 | 0.0 |

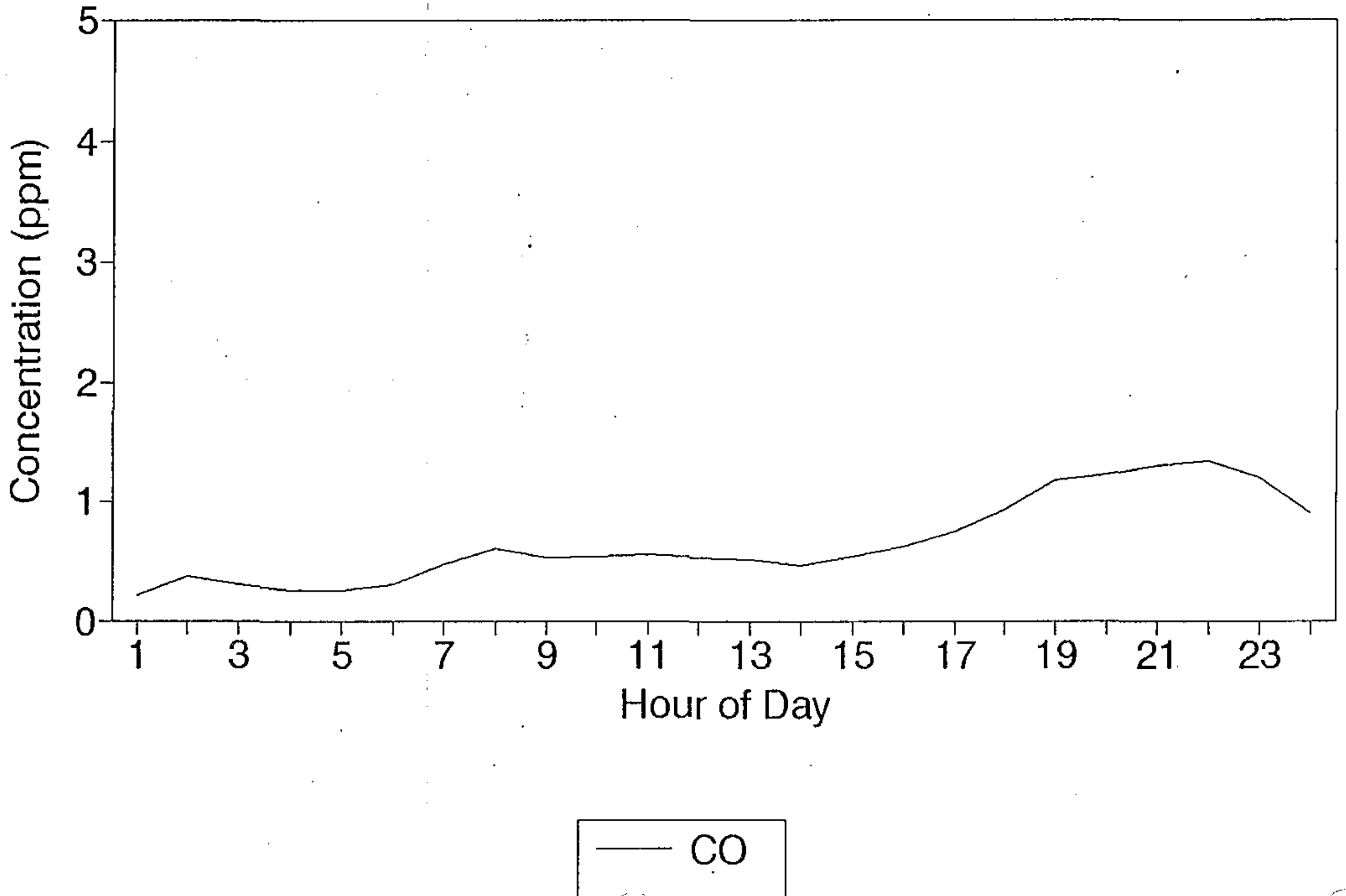
# DAMMAM INDUSTRIAL ESTATES

Hourly CO – May, 1991



# DAMMAM INDUSTRIAL ESTATES

Diurnal CO – May, 1991



[ April, May, June ]

# DRAFT

# AMBIENT AIR MONITORING DATA
## Kuwait

Meteorology and Environmental Protection Administration
Kingdom of Saudi Arabia

MEPA - Kuwait
April 1991
Hourly Averages for Direction(degrees)

| Hour / Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | *** |
| 2 | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | *** |
| 3 | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | *** |
| 4 | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | *** |
| 5 | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | *** |
| 6 | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | *** |
| 7 | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | *** |
| 8 | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | *** |
| 9 | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | *** |
| 10 | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | *** |
| 11 | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | *** |
| 12 | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | *** |
| 13 | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | *** |
| 14 | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | *** |
| 15 | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | *** |
| 16 | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | *** |
| 17 | ** | ** | ** | ** | ** | ** | ** | 148 | 144 | 0 | 129 | 110 | 119 | 113 | 133 | 146 | 156 | 149 | 153 | 155 | 154 | 157 | 164 | 161 | 141.03 |
| 18 | 277 | 331 | 351 | 19 | 32 | 54 | 58 | 59 | 69 | 58 | 59 | 56 | 71 | 83 | 30 | 20 | 79 | 259 | 50 | 173 | 7 | 5 | 152 | 200 | 44.28 |
| 19 | 188 | 313 | 294 | 289 | 297 | 319 | 248 | 256 | 0 | 0 | 333 | 322 | 6 | 22 | 18 | 17 | 19 | 91 | 110 | 181 | 277 | 303 | 330 | 340 | 328.09 |
| 20 | 332 | 336 | 311 | 331 | 303 | 310 | 327 | 321 | 330 | 341 | 326 | 349 | 336 | 6 | 35 | 55 | 47 | 7 | 5 | 5 | 355 | 325 | 299 | 297 | 340.81 |
| 21 | 286 | 293 | 315 | 307 | 301 | 318 | 291 | 290 | 304 | 0 | 317 | 338 | 338 | 340 | 339 | 350 | 12 | 13 | 14 | 12 | 359 | 330 | 304 | 286 | 327.10 |
| 22 | 272 | 268 | 262 | 258 | 260 | 269 | 283 | 272 | 274 | 308 | 308 | 313 | 328 | 34 | 355 | 336 | 340 | 338 | 351 | 4 | 4 | 354 | 337 | 332 | 314.01 |
| 23 | 314 | 304 | 305 | 315 | 308 | 308 | 322 | 325 | 335 | 0 | 2 | 345 | 337 | 341 | 338 | 341 | 349 | 348 | 334 | 313 | 314 | 305 | 304 | 294 | 325.79 |
| 24 | 294 | 282 | 272 | 271 | 265 | 270 | 272 | 275 | 319 | 7 | 8 | 22 | 21 | 38 | 64 | 85 | 125 | 138 | 143 | 152 | 165 | 168 | 185 | 226 | 269.60 |
| 25 | 250 | 256 | 241 | 245 | 254 | 242 | 235 | 231 | 227 | 109 | 109 | 112 | 112 | 113 | 104 | 117 | 137 | 141 | 115 | 139 | 143 | 155 | 169 | 192 | 168.89 |
| 26 | 201 | 206 | 221 | 257 | 270 | 259 | 261 | 291 | 302 | 0 | 312 | 314 | 316 | 315 | 324 | 326 | 332 | 346 | 335 | 342 | 336 | 332 | 331 | 330 | 305.68 |
| 27 | 332 | 331 | 336 | 344 | 356 | 351 | 338 | 334 | 338 | 334 | 337 | 334 | 341 | 348 | 342 | 340 | 341 | 343 | 337 | 333 | 334 | 330 | 326 | 316 | 337.34 |
| 28 | 307 | 316 | 317 | 318 | 327 | 325 | 327 | 327 | 325 | 0 | 327 | 329 | 335 | 0 | 333 | 333 | 331 | 0 | 328 | 279 | 274 | 312 | 322 | 326 | 325.14 |
| 29 | 311 | 309 | 318 | 313 | 310 | 310 | 315 | 312 | 330 | 322 | 315 | 307 | 321 | 321 | 321 | 320 | 320 | 316 | 301 | 303 | 293 | 15 | 252 | 261 | 311.68 |
| 30 | 265 | 269 | 270 | 263 | 264 | 265 | 263 | 276 | 301 | 310 | 311 | 321 | 0 | 26 | 44 | 36 | 61 | 36 | 316 | 331 | 330 | 306 | 288 | 280 | 310.43 |

Monthly Average = 325

Operating Efficiency for Wind Direction = 45.7 percent

** = missing or no data

Last Instrument Calibration Date - unknown

[CEM]

MEPA - Kuwait

April 1991

Hourly Averages for Wind Speed(meters/sec)

| Day \ Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | **** |
| 2 | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | **** |
| 3 | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | **** |
| 4 | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | **** |
| 5 | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | **** |
| 6 | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | **** |
| 7 | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | **** |
| 8 | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | **** |
| 9 | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | **** |
| 10 | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | **** |
| 11 | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | **** |
| 12 | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | **** |
| 13 | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | **** |
| 14 | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | **** |
| 15 | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | **** |
| 16 | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | **** |
| 17 | ** | ** | ** | ** | ** | ** | ** | 4.6 | 5.0 | 0.0 | 2.7 | 2.3 | 1.7 | 2.6 | 4.7 | 4.1 | 4.7 | 4.0 | 5.4 | 5.4 | 5.5 | 5.7 | 6.1 | 2.8 | 3.96 |
| 18 | 1.2 | 2.5 | 4.3 | 6.0 | 4.8 | 5.6 | 4.7 | 3.0 | 3.1 | 4.0 | 4.3 | 3.9 | 2.3 | 1.3 | 1.5 | 1.4 | 1.9 | 1.2 | 0.8 | 1.9 | 2.4 | 2.4 | 1.5 | 1.7 | 2.82 |
| 19 | 2.2 | 4.0 | 2.0 | 2.9 | 1.6 | 0.5 | 1.3 | 4.6 | 0.0 | 0.0 | 2.8 | 2.4 | 2.4 | 3.9 | 4.4 | 4.4 | 3.2 | 1.1 | 0.7 | 0.9 | 0.4 | 1.5 | 1.6 | 1.8 | 2.11 |
| 20 | 2.2 | 2.1 | 2.1 | 2.1 | 3.0 | 2.6 | 1.9 | 1.0 | 2.0 | 2.0 | 1.9 | 2.8 | 2.7 | 3.3 | 3.5 | 3.0 | 1.8 | 0.5 | 2.1 | 2.6 | 2.2 | 0.7 | 1.3 | 1.7 | 2.13 |
| 21 | 2.0 | 1.9 | 1.2 | 1.7 | 2.1 | 1.6 | 2.3 | 2.8 | 3.3 | 0.0 | 4.5 | 3.9 | 3.7 | 4.0 | 3.8 | 3.5 | 4.7 | 4.5 | 2.9 | 2.7 | 1.0 | 0.8 | 0.9 | 1.8 | 2.57 |
| 22 | 2.2 | 2.3 | 2.9 | 3.2 | 3.4 | 3.4 | 2.7 | 3.3 | 4.5 | 3.5 | 4.5 | 6.1 | 4.9 | 4.0 | 3.9 | 5.0 | 4.9 | 4.4 | 3.4 | 4.1 | 4.0 | 3.3 | 2.8 | 2.6 | 3.72 |
| 23 | 2.4 | 3.4 | 2.9 | 3.4 | 3.4 | 2.6 | 2.7 | 3.3 | 3.6 | 0.0 | 3.9 | 5.0 | 5.7 | 6.0 | 6.3 | 5.2 | 4.3 | 3.7 | 2.9 | 2.2 | 2.5 | 3.7 | 3.8 | 2.9 | 3.57 |
| 24 | 2.4 | 2.7 | 2.3 | 2.8 | 3.0 | 3.0 | 3.0 | 3.0 | 1.9 | 3.1 | 3.9 | 4.5 | 3.6 | 3.9 | 4.5 | 3.9 | 4.2 | 4.2 | 3.2 | 3.1 | 3.4 | 3.9 | 3.2 | 3.1 | 3.33 |
| 25 | 3.2 | 3.8 | 4.9 | 3.7 | 3.4 | 4.0 | 3.8 | 3.4 | 2.1 | 1.0 | 1.3 | 2.1 | 3.4 | 4.1 | 2.7 | 3.5 | 3.6 | 3.8 | 2.2 | 1.5 | 1.4 | 2.2 | 2.3 | 2.8 | 2.93 |
| 26 | 2.8 | 2.3 | 1.8 | 2.4 | 3.6 | 3.7 | 3.2 | 4.6 | 4.0 | 0.0 | 4.8 | 5.3 | 5.6 | 6.4 | 5.4 | 6.0 | 5.0 | 4.5 | 3.4 | 2.4 | 2.2 | 3.4 | 3.4 | 3.6 | 3.74 |
| 27 | 4.1 | 3.5 | 3.9 | 4.4 | 4.8 | 3.6 | 3.3 | 3.6 | 4.8 | 4.9 | 4.7 | 6.3 | 5.3 | 5.1 | 5.7 | 5.9 | 5.6 | 4.8 | 5.0 | 5.3 | 5.4 | 4.8 | 4.2 | 4.2 | 4.72 |
| 28 | 6.1 | 4.7 | 4.1 | 3.8 | 4.5 | 4.6 | 5.8 | 6.4 | 6.4 | 0.0 | 6.9 | 6.7 | 7.2 | 0.0 | 7.3 | 5.8 | 5.6 | 0.0 | 4.3 | 2.5 | 3.1 | 3.4 | 2.6 | 2.8 | 4.36 |
| 29 | 3.5 | 4.5 | 3.5 | 3.7 | 4.2 | 3.7 | 3.5 | 4.4 | 3.9 | 4.4 | 5.3 | 6.1 | 5.3 | 5.3 | 5.6 | 5.2 | 5.6 | 3.5 | 2.6 | 1.3 | 0.8 | 0.1 | 0.2 | 1.4 | 3.65 |
| 30 | 2.5 | 2.5 | 2.5 | 2.7 | 2.9 | 3.2 | 3.7 | 3.1 | 3.6 | 3.0 | 2.7 | 2.4 | 0.0 | 3.0 | 2.8 | 2.1 | 0.2 | 0.0 | 0.2 | 1.8 | 1.8 | 1.5 | 1.6 | 2.1 | 2.16 |
| | | | | | | | | | | | | | | | | | | | | | | Monthly Average = | | | 3.25 |

Maximum Hourly Average Wind Speed was 7.3 meters/sec at Hour 15 on Day 28

Maximum Daily Average Wind Speed was 4.72 meters/sec on Day 27

Operating Efficiency for Wind Speed = 45.7 percent ** = missing or no data

Last Instrument Calibration Date - unknown

[CEM]

MEPA - Kuwait

April 1991

Hourly Averages for Wind Speed(meters/sec) and Direction

| Day \ Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ****** |
| 2 | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ****** |
| 3 | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ****** |
| 4 | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ****** |
| 5 | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ****** |
| 6 | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ****** |
| 7 | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ****** |
| 8 | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ****** |
| 9 | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ****** |
| 10 | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ****** |
| 11 | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ****** |
| 12 | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ****** |
| 13 | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ****** |
| 14 | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ****** |
| 15 | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ****** |
| 16 | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ****** |
| 17 | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | ** ** | 5SSE | 5SE | 0N | 3SE | 2ESE | 2ESE | 3ESE | 5SE | 4SE | 5SSE | 4SSE | 5SSE | 5SSE | 6SSE | 6SSE | 6SSE | 3SSE | 4SE |
| 18 | 1W | 2NNW | 4N | 6NNE | 5NNE | 6NE | 5ENE | 3ENE | 3ENE | 4ENE | 4ENE | 4NE | 2ENE | 1E | 2NNE | 1NNE | 2E | 1W | 1NE | 2S | 2N | 2N | 2SSE | 2SSW | 3NE |
| 19 | 2S | 4NW | 2WNW | 3WNW | 2WNW | 0NW | 1WSW | 5WSW | 0N | 0N | 3NNW | 2NW | 2N | 4NNE | 4NNE | 4NNE | 3NNE | 1E | 1ESE | 1S | 0W | 2WNW | 2NNW | 2NNW | 2NNW |
| 20 | 2NNW | 2NNW | 2NW | 2NNW | 3WNW | 3NW | 2NNW | 1NW | 2NNW | 2NNW | 2NW | 3N | 3NNW | 3N | 4NE | 3NE | 2NE | 0N | 2N | 3N | 2N | 1NW | 1WNW | 2WNW | 2NNW |
| 21 | 2WNW | 2WNW | 1NW | 2NW | 2WNW | 2NW | 2WNW | 3WNW | 3NW | 0N | 4NW | 4NNW | 4NNW | 4NNW | 4NNW | 4N | 5NNE | 4NNE | 3NNE | 3NNE | 1N | 1NNW | 1NW | 2WNW | 3NNW |
| 22 | 2W | 2W | 3W | 3WSW | 3W | 3W | 3WNW | 3W | 4W | 4NW | 4NW | 6NW | 5NNW | 4NE | 4N | 5NNW | 5NNW | 4NNW | 3N | 4N | 4N | 3N | 3NNW | 3NNW | 4NW |
| 23 | 2NW | 3NW | 3NW | 3NW | 3NW | 3NW | 3NW | 3NW | 4NNW | 0N | 4N | 5NNW | 6NNW | 6NNW | 6NNW | 5NNW | 4N | 4NNW | 3NNW | 2NW | 2NW | 4NW | 4NW | 3WNW | 4NW |
| 24 | 2WNW | 3WNW | 2W | 3W | 3W | 3W | 3W | 3W | 2NW | 3N | 4N | 4NNE | 4NNE | 4NE | 4ENE | 4E | 4SE | 4SE | 3SE | 3SSE | 3SSE | 4SSE | 3S | 3SW | 3W |
| 25 | 3WSW | 4WSW | 5WSW | 4WSW | 3WSW | 4WSW | 4SW | 3SW | 2SW | 1ESE | 1ESE | 2ESE | 3ESE | 4ESE | 3ESE | 4ESE | 4SE | 4SE | 2ESE | 2SE | 1SE | 2SSE | 2S | 3SSW | 3S |
| 26 | 3SSW | 2SSW | 2SW | 2WSW | 4W | 4W | 3W | 5WNW | 4WNW | 0N | 5NW | 5NW | 6NW | 6NW | 5NW | 6NW | 5NNW | 4NNW | 3NNW | 2NNW | 2NNW | 3NNW | 3NNW | 4NNW | 4NW |
| 27 | 4NNW | 4NNW | 4NNW | 4NNW | 5N | 4N | 3NNW | 4NNW | 5NNW | 5NNW | 5NNW | 6NNW | 5NNW | 5NNW | 6NNW | 6NNW | 6NNW | 5NNW | 5NNW | 5NNW | 5NNW | 5NNW | 4NW | 4NW | 5NNW |
| 28 | 6NW | 5NW | 4NW | 4NW | 4NNW | 5NW | 6NNW | 6NNW | 6NW | 0N | 7NNW | 7NNW | 7NNW | 0N | 7NNW | 6NNW | 6NNW | 0N | 4NNW | 2W | 3W | 3NW | 3NW | 3NW | 4NW |
| 29 | 4NW | 4NW | 4NW | 4NW | 4NW | 4NW | 4NW | 4NW | 4NNW | 4NW | 5NW | 6NW | 5NW | 5NW | 6NW | 5NW | 6NW | 4NW | 3WNW | 1WNW | 1WNW | 0NNE | 0WSW | 1W | 4NW |
| 30 | 2W | 2W | 2W | 3W | 3W | 3W | 4W | 3W | 4WNW | 3NW | 3NW | 2NW | 0N | 3NNE | 3NE | 2NE | 0ENE | 0NE | 0NW | 2NNW | 2NNW | 2NW | 2WNW | 2W | 2NW |

Monthly Average = 3NW

Maximum Hourly Average Wind Speed was 7 meters/sec at Hour 15 on Day 28 and Wind Direction was from the NNW.

Maximum Daily Average Wind Speed was 5 meters/sec on Day 27 and Wind Direction was from the NNW

Operating Efficiency for Wind Speed = 45.7 percent

Operating Efficiency for Wind Direction = 45.7 percent

** = missing or no data

Last Instrument Calibration Date - unknown

[CEM]

MEPA - Kuwait

April 1991

Hourly Averages for Pressure in millibars

| Day \ Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 2 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 3 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 4 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 5 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 8 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 9 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 10 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 11 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 12 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 13 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 14 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 15 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 16 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 17 | ND | ND | ND | ND | ND | ND | ND | 1003 | 1004 | ND | 1005 | 1001 | 1008 | 1008 | 1010 | 1009 | 1008 | 1002 | 1008 | 1009 | 1009 | 1008 | 1008 | 1008 | 1006.8 |
| 18 | 1008 | 1008 | 1008 | 1008 | 1008 | 1008 | 1007 | ND | 1007 | 1007 | 1008 | 1009 | 1009 | 1010 | 1010 | 1010 | 1009 | 1009 | 1009 | 1009 | 1008 | 1008 | 1008 | 1008 | 1008.4 |
| 19 | 1008 | 1008 | 1008 | 1008 | 1008 | 1008 | 1008 | 1008 | ND | ND | 1013 | 1014 | 1016 | 1017 | 1020 | 1020 | 1020 | 1017 | 1014 | 1012 | 1013 | 1011 | 1010 | 1010 | 1012.3 |
| 20 | 1010 | 1009 | 1009 | 1009 | 1009 | 1008 | 1008 | 1008 | 1008 | 1008 | 1010 | 1014 | 1018 | 1025 | 1026 | 1025 | 1022 | 1015 | 1010 | 1008 | 1007 | 1007 | 1007 | 1007 | 1012.0 |
| 21 | 1007 | 1007 | 1007 | 1008 | 1008 | 1008 | 1007 | 1008 | 1012 | ND | 1021 | 1022 | 1017 | 1017 | 1018 | 1017 | 1015 | 1011 | 1008 | 1008 | 1008 | 1009 | 1009 | 1010 | 1011.4 |
| 22 | 1008 | 1006 | 1006 | 1006 | 1006 | 1006 | 1007 | 1007 | 1017 | 1022 | 1025 | 1026 | 1029 | 1035 | 1040 | 1041 | 1036 | 1031 | 1025 | 1021 | 1017 | 1012 | 1009 | 1007 | 1018.5 |
| 23 | 1007 | 1007 | 1007 | 1007 | 1007 | 1007 | 1007 | 1007 | 1011 | ND | 1010 | 1013 | 1012 | 1013 | 1013 | 1012 | 1012 | 1012 | 1011 | 1009 | 1008 | 1007 | 1007 | 1008 | 1009.3 |
| 24 | 1006 | 1005 | 1005 | 1005 | 1005 | 1005 | 1005 | 1005 | 1006 | 1008 | 1009 | 1014 | 1020 | 1026 | 1023 | 1019 | 1016 | 1013 | 1008 | 1007 | 1007 | 1006 | 1006 | 1007 | 1009.8 |
| 25 | 1009 | 1008 | 1008 | 1009 | 1009 | 1009 | 1010 | 1011 | 1011 | 1012 | 1011 | 1012 | 1013 | 1010 | 1011 | 1011 | 1009 | 1008 | 1008 | 1008 | 1008 | 1009 | 1009 | 1008 | 1009.6 |
| 26 | 1008 | 1007 | 1007 | 1007 | 1007 | 1006 | 1007 | 1006 | 1007 | ND | 1012 | 1012 | 1012 | 1014 | 1016 | 1016 | 1016 | 1013 | 1010 | 1007 | 1007 | 1007 | 1009 | 1007 | 1009.6 |
| 27 | 1006 | 1006 | 1005 | 1005 | 1006 | 1007 | 1007 | 1008 | 1007 | 1009 | 1016 | 1015 | 1013 | 1013 | 1011 | 1009 | 1007 | 1006 | 1006 | 1006 | 1006 | 1007 | 1007 | 1006 | 1008.1 |
| 28 | 1005 | 1005 | 1005 | 1005 | 1005 | 1005 | 1005 | 1005 | 1007 | ND | 1013 | 1016 | 1020 | ND | 1025 | 1028 | 1026 | ND | 1020 | 1015 | 1013 | 1011 | 1010 | 1007 | 1012.0 |
| 29 | 1006 | 1005 | 1005 | 1006 | 1006 | 1006 | 1006 | 1006 | 1008 | 1011 | 1015 | 1018 | 1021 | 1024 | 1024 | ND | 1017 | 1013 | 1009 | 1006 | 1003 | 1002 | 1001 | 1001 | 1009.5 |
| 30 | 1002 | 1005 | 1006 | 1006 | 1006 | 1006 | 1006 | 1005 | 1006 | 1009 | 1010 | 1011 | ND | 1015 | 1017 | 1015 | 1013 | 1011 | 1009 | 1007 | 1006 | 1004 | 1003 | 1002 | 1007.8 |

Monthly Average = 1010.4

Maximum Hourly Average was 1041 at Hour 16 on Day 22 with 1 occurences

Maximum Daily Average was 1018.5 on Day 22 with 1 occurences

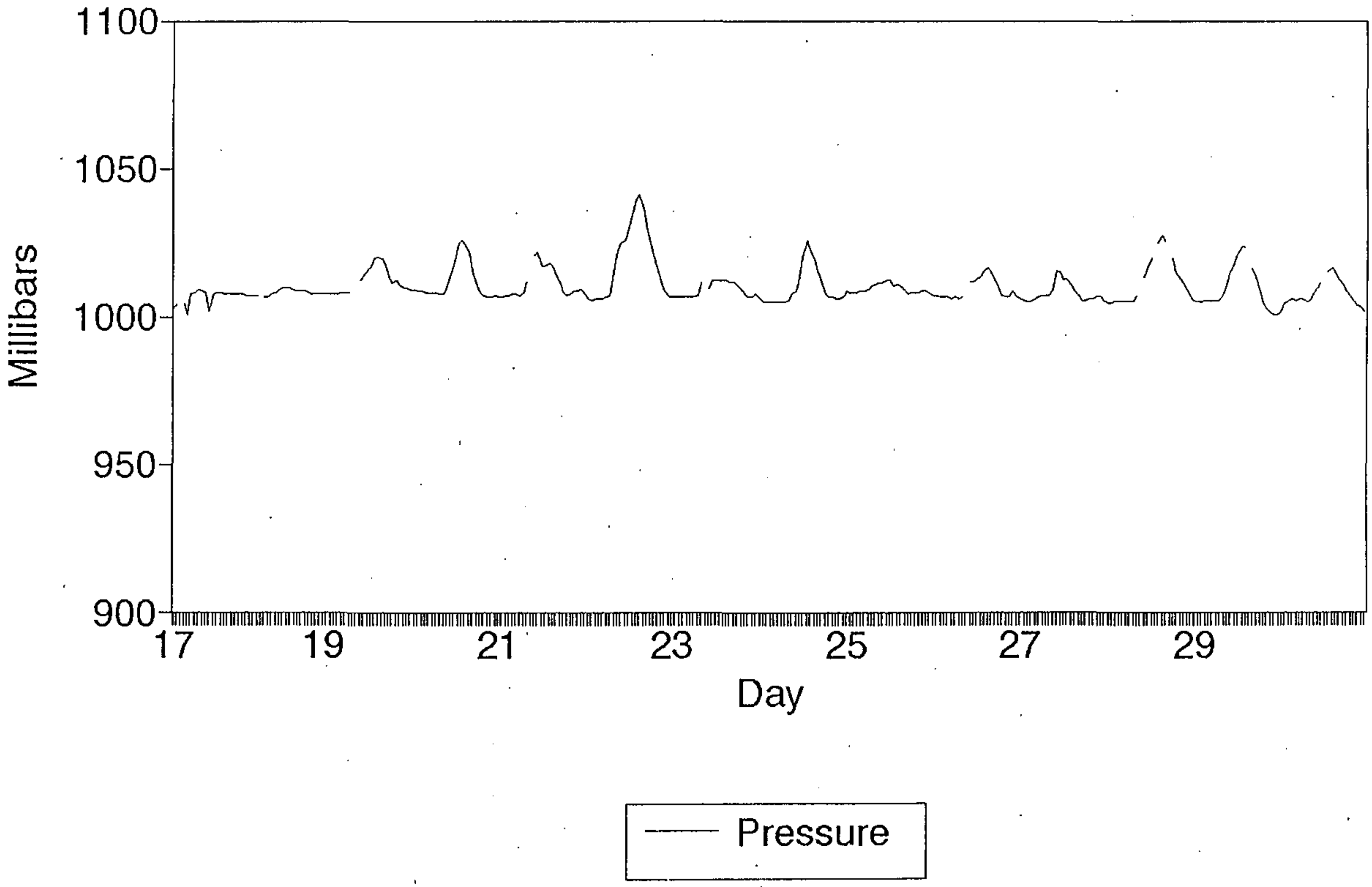
Operating Efficiency = 44.0 percent

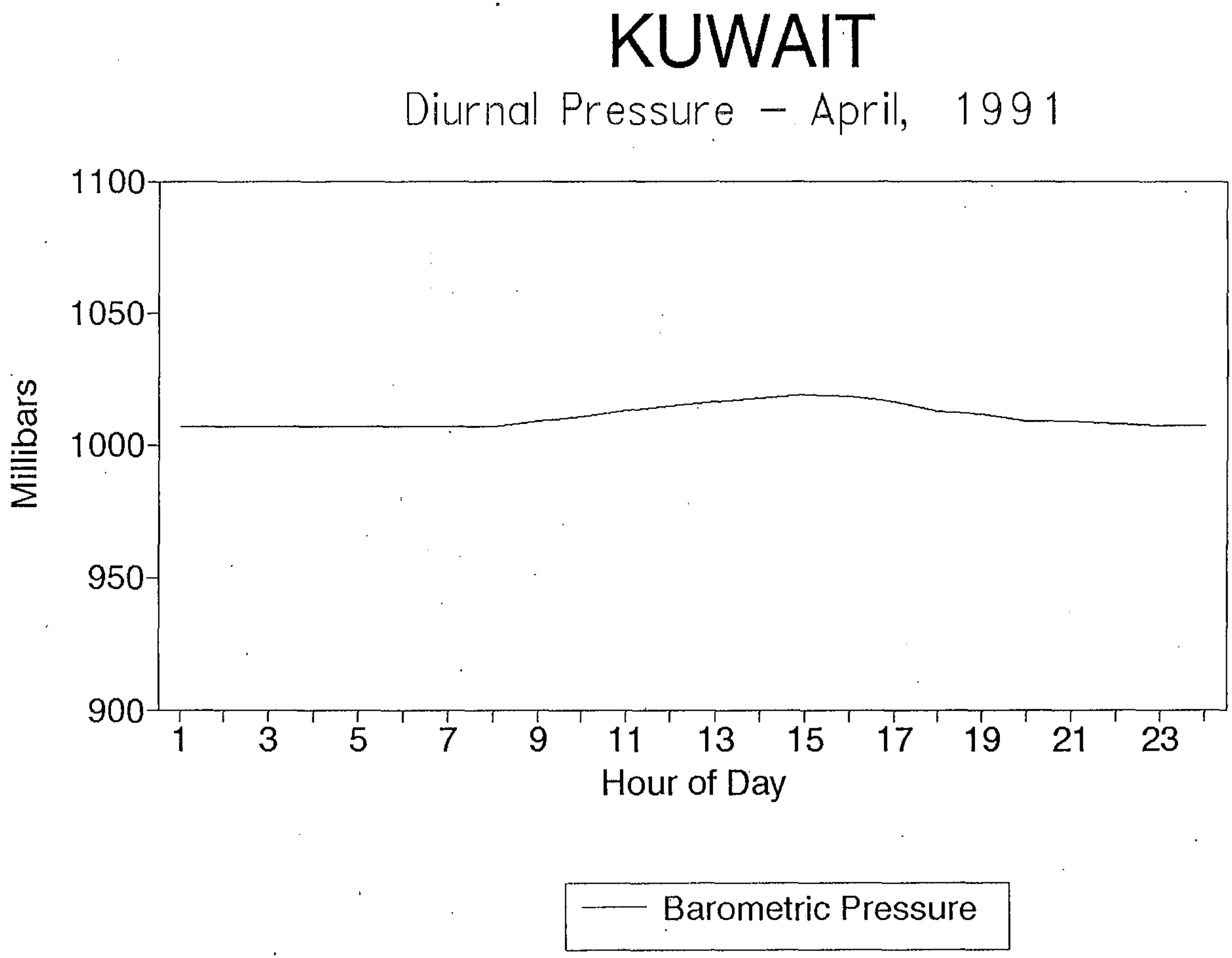
ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data

[CEM 1990]

# KUWAIT

Hourly Barometric Press – April, 1991




KUWAIT
Diurnal Pressure - April, 1991
1100
1050
1000
950
900
Millibars
1
3
5
7
9
11
13
15
17
19
21
23
Hour of Day
Barometric Pressure

MEPA - Kuwait

April 1991

Hourly Averages for Solar Radiation in Watts/ M2

| Hour / Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 2 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 3 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 4 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 5 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 8 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 9 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 10 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 11 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 12 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 13 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 14 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 15 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 16 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 17 | ND | ND | ND | ND | ND | ND | ND | 14 | 32 | ND | 61 | 194 | 155 | 5 | 17 | 77 | 9 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 35.6 |
| 18 | 0 | 0 | 0 | 0 | 0 | 2 | 20 | 38 | 89 | 299 | 359 | 126 | 29 | 63 | 9 | 36 | 27 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 45.8 |
| 19 | 0 | 0 | 0 | 0 | 0 | 1 | 40 | 65 | ND | ND | 356 | 295 | 389 | 506 | 445 | 299 | 121 | 22 | 0 | 0 | 0 | 0 | 0 | 0 | 115.4 |
| 20 | 0 | 0 | 0 | 0 | 0 | 3 | 27 | 23 | 48 | 116 | 264 | 494 | 590 | 556 | 469 | 347 | 201 | 55 | 1 | 1 | 0 | 0 | 0 | 0 | 133.1 |
| 21 | 0 | 0 | 0 | 0 | 0 | 29 | 50 | 78 | 345 | ND | 713 | 543 | 664 | 619 | 378 | 300 | 128 | 35 | 0 | 0 | 0 | 0 | 0 | 0 | 168.8 |
| 22 | 0 | 0 | 0 | 0 | 0 | 19 | 67 | 135 | 452 | 553 | 641 | 699 | 663 | 606 | 528 | 397 | 233 | 72 | 2 | 0 | 0 | 0 | 0 | 0 | 211.1 |
| 23 | 0 | 0 | 0 | 0 | 0 | 11 | 46 | 98 | 422 | ND | 595 | 547 | 476 | 324 | 246 | 156 | 76 | 25 | 1 | 0 | 0 | 0 | 0 | 0 | 131.4 |
| 24 | 0 | 0 | 0 | 0 | 0 | 7 | 39 | 32 | 304 | 508 | 577 | 609 | 553 | 570 | 484 | 366 | 224 | 66 | 2 | 0 | 0 | 0 | 0 | 0 | 180.9 |
| 25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 39 | 141 | 170 | 168 | 192 | 179 | 252 | 63 | 38 | 1 | 1 | 0 | 0 | 0 | 0 | 51.9 |
| 26 | 0 | 0 | 0 | 0 | 0 | 6 | 55 | 129 | 341 | ND | 539 | 420 | 482 | 580 | 479 | 387 | 154 | 61 | 3 | 0 | 0 | 0 | 0 | 0 | 158.1 |
| 27 | 0 | 0 | 0 | 0 | 0 | 9 | 52 | 87 | 317 | 348 | 341 | 302 | 217 | 306 | 187 | 111 | 66 | 31 | 1 | 0 | 0 | 0 | 0 | 0 | 99.0 |
| 28 | 0 | 0 | 0 | 0 | 0 | 12 | 64 | 99 | 391 | ND | 626 | 620 | 573 | ND | 556 | 352 | 149 | ND | 3 | 0 | 0 | 0 | 0 | 0 | 164.0 |
| 29 | 0 | 0 | 0 | 0 | 0 | 17 | 74 | 86 | 448 | 568 | 646 | 688 | 666 | 539 | 437 | 403 | 254 | 91 | 5 | 0 | 0 | 0 | 0 | 0 | 205.1 |
| 30 | 0 | 0 | 0 | 0 | 0 | 15 | 63 | 120 | 383 | 219 | 176 | 211 | ND | 275 | 240 | 116 | 61 | 39 | 1 | 0 | 0 | 0 | 0 | 0 | 83.4 |

Monthly Average = 129.3

Maximum Hourly Average was 713 at Hour 11 on Day 21 with 1 occurences

Maximum Daily Average was 211.1 on Day 22 with 1 occurences

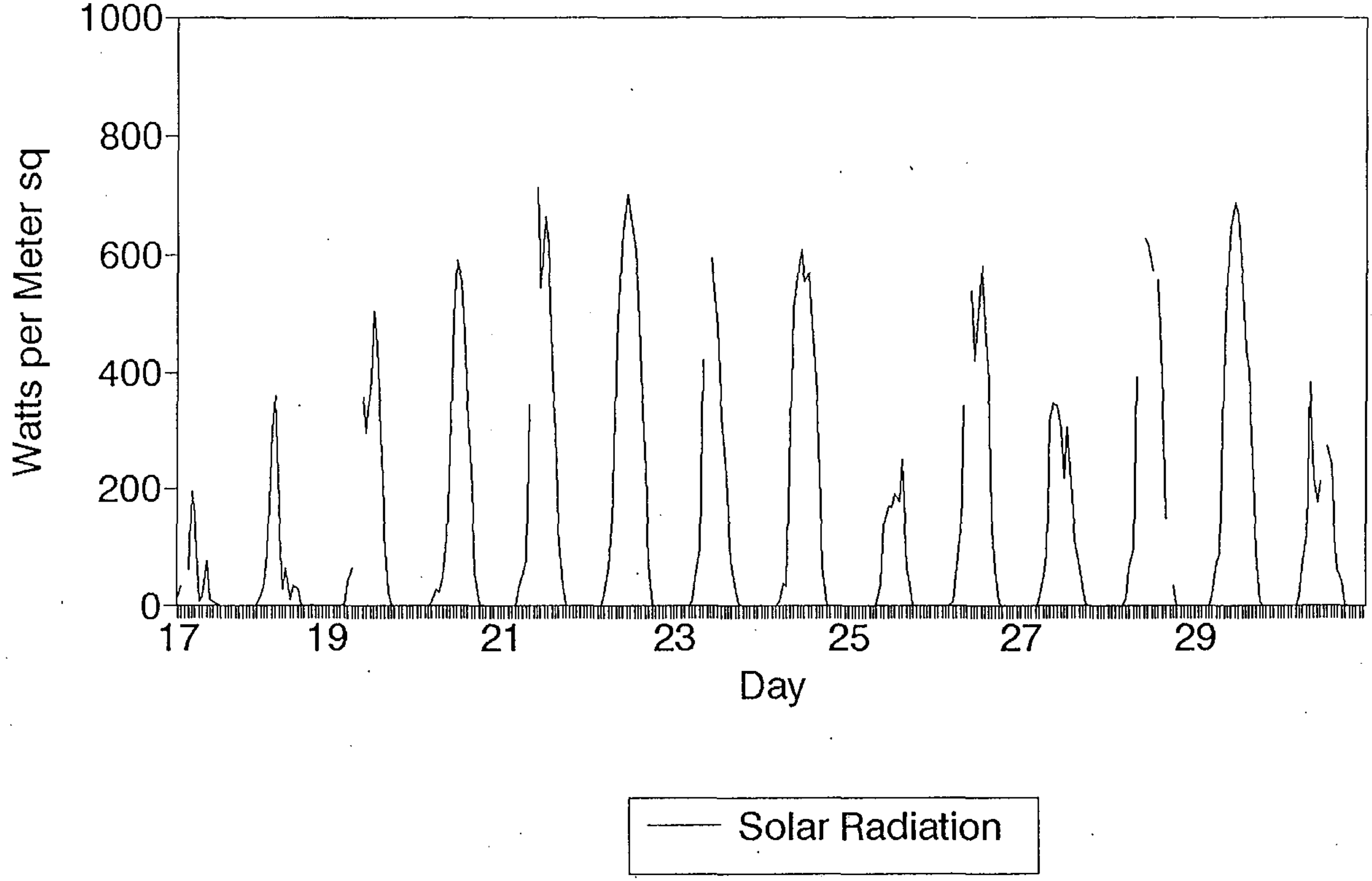
Operating Efficiency = 44.3 percent

ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data

[CEM 1990]

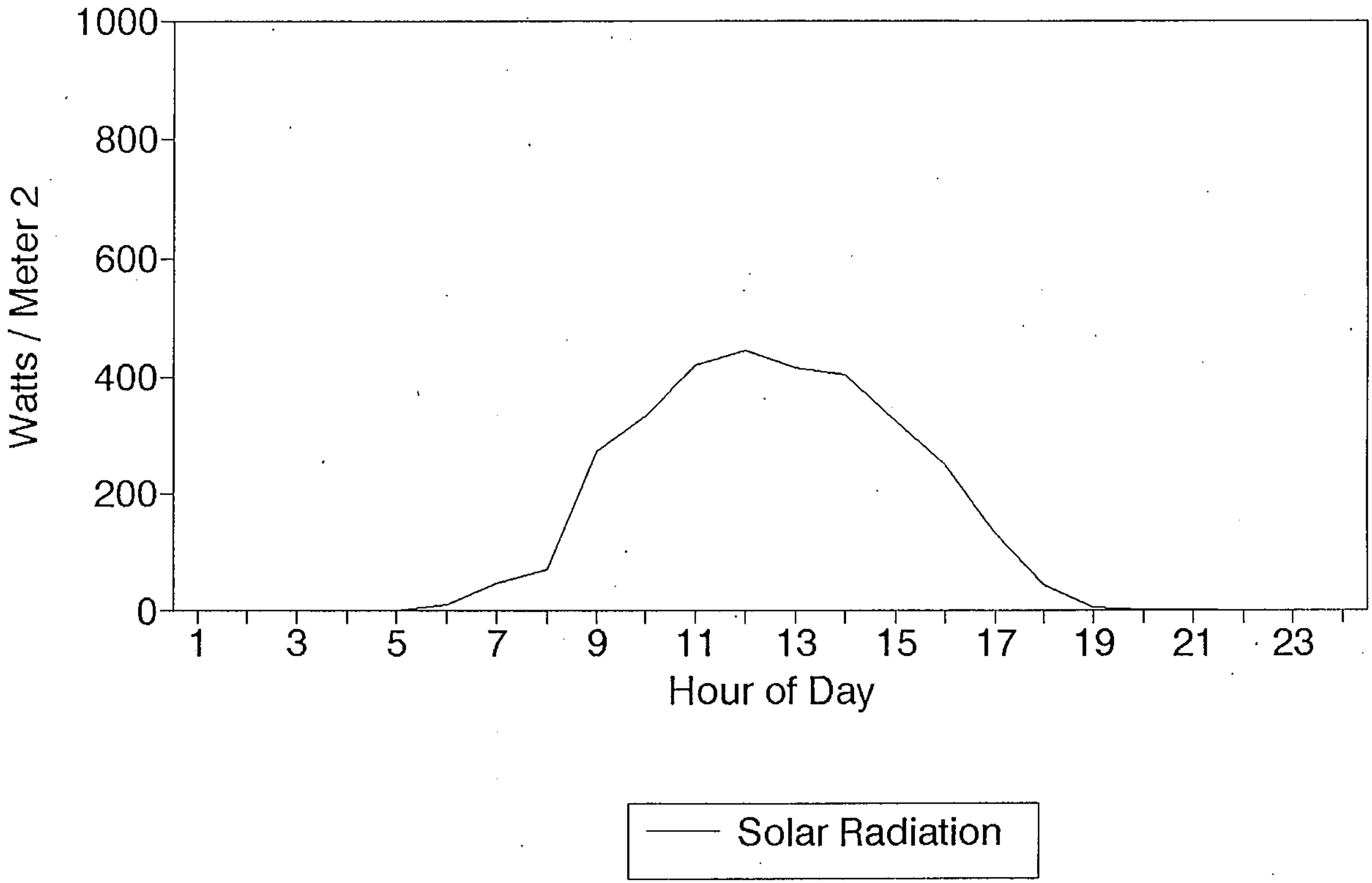
# KUWAIT

Hourly Solar Radiation – April, 1991



# KUWAIT

Diurnal Radiation – April, 1991



MEPA - Kuwait

April 1991

Hourly Averages for Relative Humidity in Per Cent

| Hour / Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 2 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 3 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 4 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 5 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 8 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 9 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 10 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 11 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 12 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 13 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 14 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 15 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 16 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 17 | ND | ND | ND | ND | ND | ND | ND | 77.4 | 85.4 | ND | 87.1 | 80.9 | 72.5 | 75.4 | 74.5 | 66.6 | 58.1 | 45.6 | 45.5 | 39.4 | 35.7 | 40.6 | 34.9 | 30.3 | 59.37 |
| 18 | 26.6 | 34.7 | 52.1 | 57.8 | 61.8 | 77.9 | 84.2 | 84.8 | 85.1 | 80.9 | 75.1 | 66.6 | 57.1 | 49.7 | 51.6 | 66.3 | 65.2 | 69.5 | 85.1 | 77.0 | 66.6 | 53.7 | 52.5 | 52.1 | 63.92 |
| 19 | 43.3 | 56.2 | 57.5 | 53.6 | 61.2 | 64.6 | 59.4 | 53.7 | ND | ND | 44.6 | 38.9 | 30.4 | 27.3 | 25.7 | 24.0 | 23.9 | 30.1 | 35.7 | 40.1 | 38.3 | 39.4 | 38.2 | 35.4 | 41.89 |
| 20 | 30.4 | 27.0 | 27.9 | 30.5 | 31.0 | 30.9 | 31.2 | 33.5 | 34.6 | 30.4 | 26.6 | 20.4 | 16.1 | 14.0 | 13.6 | 14.2 | 14.3 | 15.0 | 16.3 | 14.9 | 14.3 | 15.6 | 16.8 | 18.3 | 22.41 |
| 21 | 19.8 | 21.0 | 22.8 | 26.1 | 27.6 | 28.6 | 26.9 | 22.0 | 17.2 | ND | 13.5 | 13.2 | 12.4 | 11.3 | 11.0 | 11.1 | 12.2 | 13.0 | 15.1 | 17.7 | 18.7 | 18.8 | 19.3 | 19.5 | 18.21 |
| 22 | 21.0 | 21.3 | 22.0 | 23.6 | 24.3 | 24.3 | 24.0 | 20.7 | 17.4 | 15.9 | 14.7 | 14.1 | 13.1 | 12.9 | 11.6 | 10.1 | 10.1 | 10.3 | 11.7 | 12.8 | 13.9 | 13.5 | 13.7 | 15.0 | 16.33 |
| 23 | 16.0 | 17.7 | 19.2 | 19.4 | 20.4 | 20.5 | 21.5 | 19.7 | 16.7 | ND | 14.0 | 11.9 | 10.1 | 10.0 | 10.0 | 10.0 | 10.4 | 11.8 | 13.2 | 14.4 | 14.9 | 15.4 | 15.3 | 15.6 | 15.13 |
| 24 | 16.5 | 16.9 | 18.0 | 17.8 | 17.5 | 17.6 | 17.7 | 17.5 | 16.3 | 15.0 | 13.4 | 12.1 | 11.1 | 10.5 | 10.7 | 12.6 | 14.0 | 14.1 | 14.3 | 15.0 | 15.4 | 14.7 | 14.0 | 14.2 | 14.87 |
| 25 | 14.6 | 15.4 | 15.0 | 14.3 | 14.2 | 14.2 | 13.6 | 13.2 | 13.2 | 20.5 | 24.2 | 22.0 | 23.5 | 26.1 | 24.8 | 22.3 | 23.0 | 21.6 | 22.9 | 29.4 | 27.0 | 24.3 | 21.9 | 19.9 | 20.05 |
| 26 | 17.5 | 17.4 | 17.7 | 17.4 | 18.6 | 18.8 | 19.1 | 18.8 | 18.4 | ND | 14.8 | 12.1 | 10.6 | 10.0 | 10.1 | 10.1 | 10.1 | 10.0 | 10.1 | 11.1 | 12.1 | 13.0 | 14.6 | 16.4 | 14.30 |
| 27 | 18.3 | 19.7 | 20.2 | 19.3 | 18.0 | 18.0 | 18.4 | 18.2 | 17.4 | 15.9 | 15.1 | 14.4 | 14.0 | 13.5 | 13.2 | 13.1 | 13.5 | 14.2 | 15.1 | 15.9 | 16.8 | 18.0 | 18.7 | 19.2 | 16.59 |
| 28 | 19.3 | 19.6 | 20.5 | 20.5 | 21.1 | 21.7 | 22.3 | 20.9 | 18.7 | ND | 16.0 | 14.6 | 13.3 | ND | 11.8 | 10.7 | 11.2 | ND | 12.0 | 12.3 | 12.2 | 12.4 | 13.3 | 13.5 | 16.09 |
| 29 | 13.4 | 13.3 | 14.0 | 14.2 | 14.2 | 14.2 | 14.3 | 14.1 | 13.5 | 12.5 | 11.3 | 10.2 | 10.1 | 10.1 | 10.1 | 10.1 | 10.1 | 10.0 | 10.0 | 10.0 | 10.2 | 11.1 | 11.8 | 11.9 | 11.86 |
| 30 | 11.9 | 11.9 | 12.3 | 12.8 | 12.9 | 13.4 | 13.8 | 13.6 | 13.0 | 13.2 | 13.5 | 13.6 | ND | 12.0 | 11.9 | 11.9 | 12.0 | 12.7 | 13.2 | 13.3 | 13.0 | 13.9 | 14.3 | 15.1 | 13.01 |
| | | | | | | | | | | | | | | | | | | | | | Monthly Average = | | | | 23.79 |

Maximum Hourly Average was 87.1 at Hour 11 on Day 17 with 1 occurences

Maximum Daily Average was 63.92 on Day 18 with 1 occurences

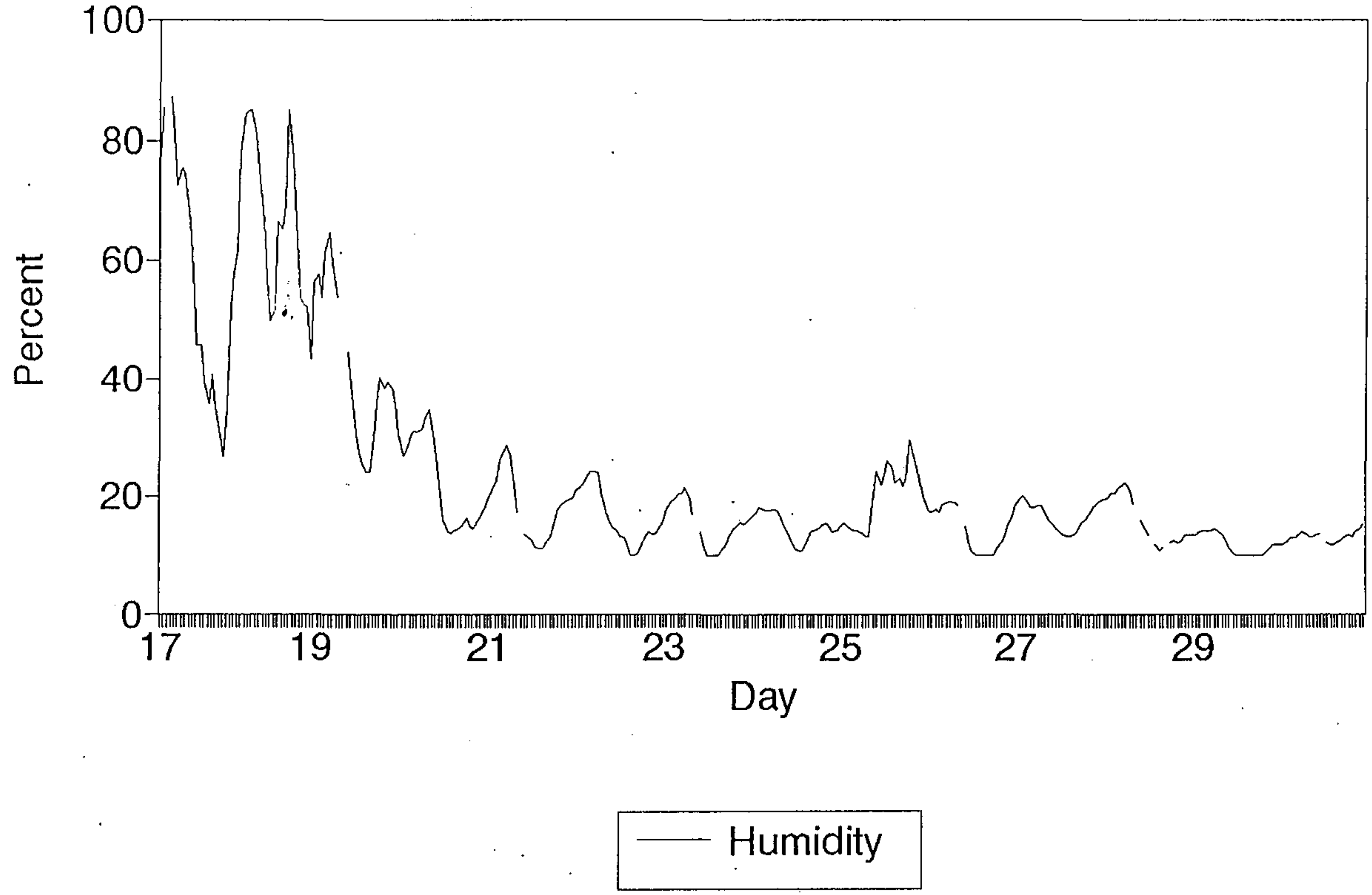
Operating Efficiency = 44.3 percent

ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data

[CEM 1990]

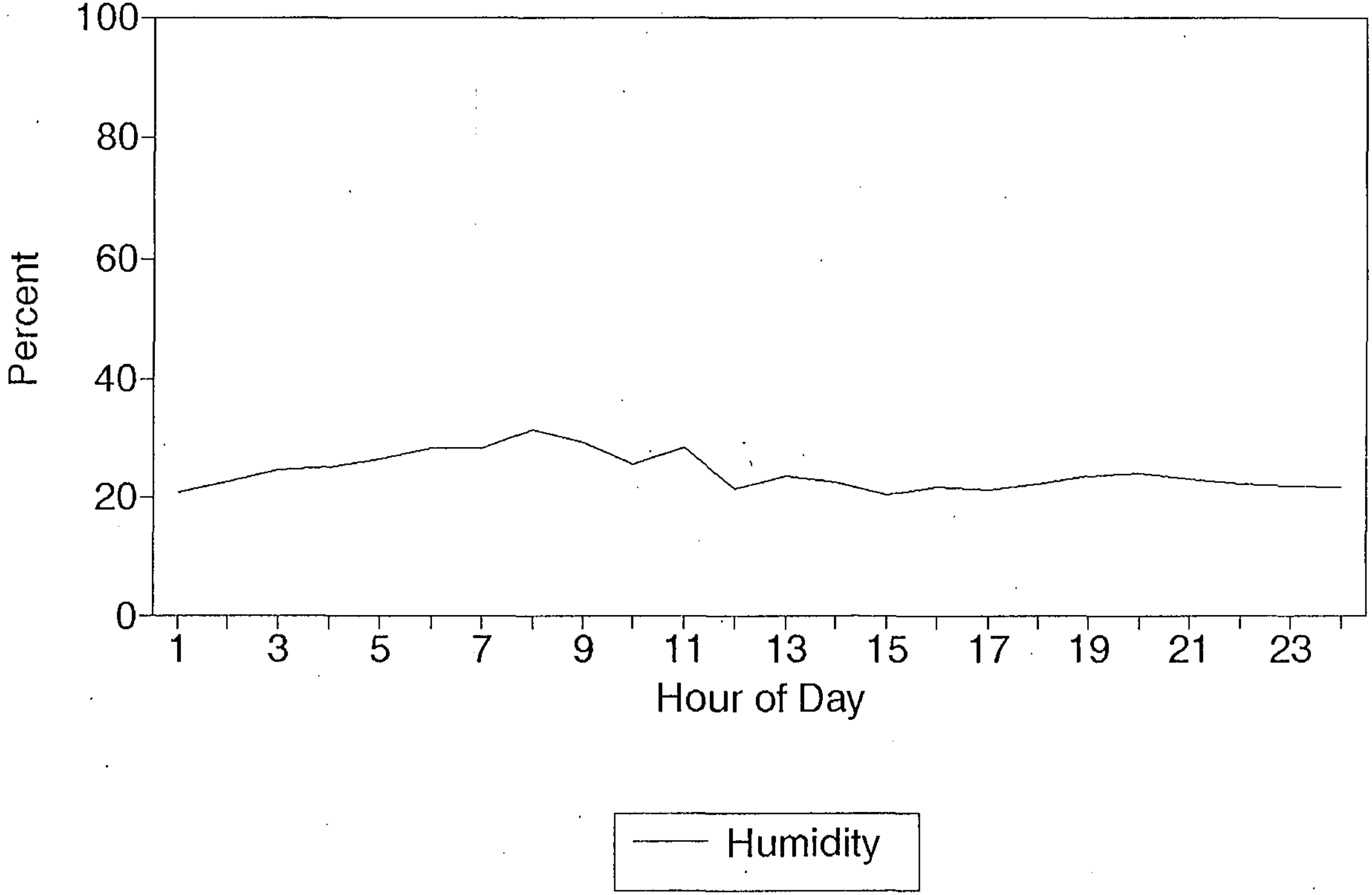
# KUWAIT

## Hourly Humidity - April, 1991



# KUWAIT

## Diurnal Humidity – April, 1991



MEPA - Kuwait

April 1991

Hourly Averages for Temperature in Degrees C

| Day \ Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 2 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 3 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 4 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 5 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 8 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 9 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 10 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 11 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 12 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 13 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 14 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 15 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 16 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 17 | ND | ND | ND | ND | ND | ND | ND | 21.8 | 21.4 | ND | 22.1 | 23.4 | 24.4 | 23.7 | 23.4 | 24.1 | 24.4 | 21.2 | 24.8 | 25.2 | 25.4 | 24.5 | 24.7 | 25.3 | 23.74 |
| 18 | 26.4 | 25.8 | 24.5 | 23.4 | 23.1 | 21.9 | 21.3 | 21.3 | 21.5 | 22.9 | 24.0 | 23.8 | 23.7 | 24.2 | 23.9 | 23.4 | 23.1 | 22.7 | 21.5 | 22.0 | 22.7 | 23.8 | 23.8 | 23.7 | 23.27 |
| 19 | 24.6 | 24.0 | 24.0 | 24.3 | 23.4 | 23.2 | 23.9 | 24.7 | ND | ND | 28.5 | 29.6 | 31.8 | 33.7 | 34.3 | 34.4 | 33.5 | 30.5 | 28.8 | 27.6 | 27.6 | 27.2 | 27.1 | 26.9 | 27.89 |
| 20 | 26.9 | 26.5 | 25.6 | 24.7 | 24.6 | 24.4 | 24.2 | 23.8 | 23.8 | 25.3 | 27.5 | 31.7 | 35.0 | 36.3 | 36.3 | 34.9 | 34.7 | 33.5 | 31.3 | 30.1 | 29.0 | 27.3 | 26.6 | 25.7 | 28.74 |
| 21 | 25.1 | 24.7 | 23.8 | 23.2 | 22.8 | 22.8 | 24.4 | 28.0 | 31.0 | ND | 35.8 | 36.4 | 38.0 | 38.9 | 38.2 | 38.1 | 35.9 | 33.9 | 32.0 | 31.0 | 30.3 | 29.8 | 29.6 | 29.5 | 30.57 |
| 22 | 28.2 | 27.4 | 26.4 | 25.7 | 25.3 | 25.3 | 26.9 | 31.0 | 34.5 | 37.3 | 39.2 | 40.2 | 41.5 | 41.5 | 41.8 | 41.5 | 40.4 | 38.3 | 36.0 | 34.6 | 33.1 | 32.6 | 31.5 | 30.3 | 33.77 |
| 23 | 29.2 | 28.3 | 27.5 | 27.4 | 26.8 | 26.2 | 26.8 | 30.3 | 33.4 | ND | 36.9 | 38.2 | 38.8 | 38.4 | 38.1 | 37.6 | 36.7 | 35.2 | 33.7 | 32.5 | 32.3 | 31.8 | 31.4 | 30.3 | 32.51 |
| 24 | 29.4 | 28.6 | 27.7 | 27.7 | 27.0 | 26.6 | 27.3 | 27.6 | 32.5 | 36.0 | 38.0 | 39.4 | 41.0 | 41.5 | 40.9 | 38.2 | 36.3 | 34.8 | 33.0 | 31.9 | 31.4 | 31.9 | 32.1 | 31.6 | 33.02 |
| 25 | 30.8 | 30.0 | 30.6 | 31.1 | 30.9 | 30.9 | 32.5 | 32.7 | 32.7 | 30.5 | 31.0 | 32.1 | 31.3 | 30.7 | 31.5 | 32.6 | 31.1 | 30.6 | 29.2 | 27.1 | 27.8 | 28.4 | 29.4 | 29.7 | 30.63 |
| 26 | 30.6 | 30.1 | 29.9 | 30.2 | 28.9 | 28.8 | 29.6 | 32.1 | 34.8 | ND | 40.0 | 41.0 | 41.2 | 42.0 | 42.3 | 41.7 | 39.7 | 37.9 | 36.4 | 35.0 | 34.1 | 33.5 | 32.4 | 31.3 | 34.93 |
| 27 | 30.3 | 29.5 | 29.4 | 29.7 | 30.6 | 29.9 | 30.3 | 31.9 | 33.9 | 35.5 | 36.0 | 37.1 | 37.4 | 38.3 | 38.2 | 37.3 | 36.8 | 35.8 | 34.6 | 33.6 | 32.6 | 31.6 | 30.9 | 30.3 | 33.40 |
| 28 | 29.9 | 29.0 | 28.4 | 28.5 | 28.0 | 27.6 | 28.4 | 30.0 | 32.4 | ND | 35.6 | 37.0 | 38.3 | ND | 39.0 | 38.5 | 37.2 | ND | 35.0 | 33.1 | 32.3 | 32.1 | 31.1 | 30.4 | 32.47 |
| 29 | 30.3 | 29.8 | 29.1 | 28.6 | 28.1 | 27.9 | 29.1 | 31.0 | 33.7 | 36.2 | 37.5 | 38.2 | 39.5 | 39.3 | 39.2 | 39.5 | 38.8 | 37.4 | 35.4 | 33.4 | 31.5 | 29.7 | 28.3 | 27.6 | 33.30 |
| 30 | 26.9 | 26.0 | 25.4 | 25.1 | 24.7 | 24.1 | 25.2 | 29.0 | 32.3 | 33.0 | 33.7 | 35.3 | ND | 37.3 | 36.7 | 35.8 | 34.7 | 33.9 | 32.3 | 32.0 | 31.1 | 30.0 | 29.2 | 28.4 | 30.53 |
| | | | | | | | | | | | | | | | | | | | | | | Monthly Average = | | | 30.78 |

Maximum Hourly Average was 42.3 at Hour 15 on Day 26 with 1 occurences

Maximum Daily Average was 34.93 on Day 26 with 1 occurences

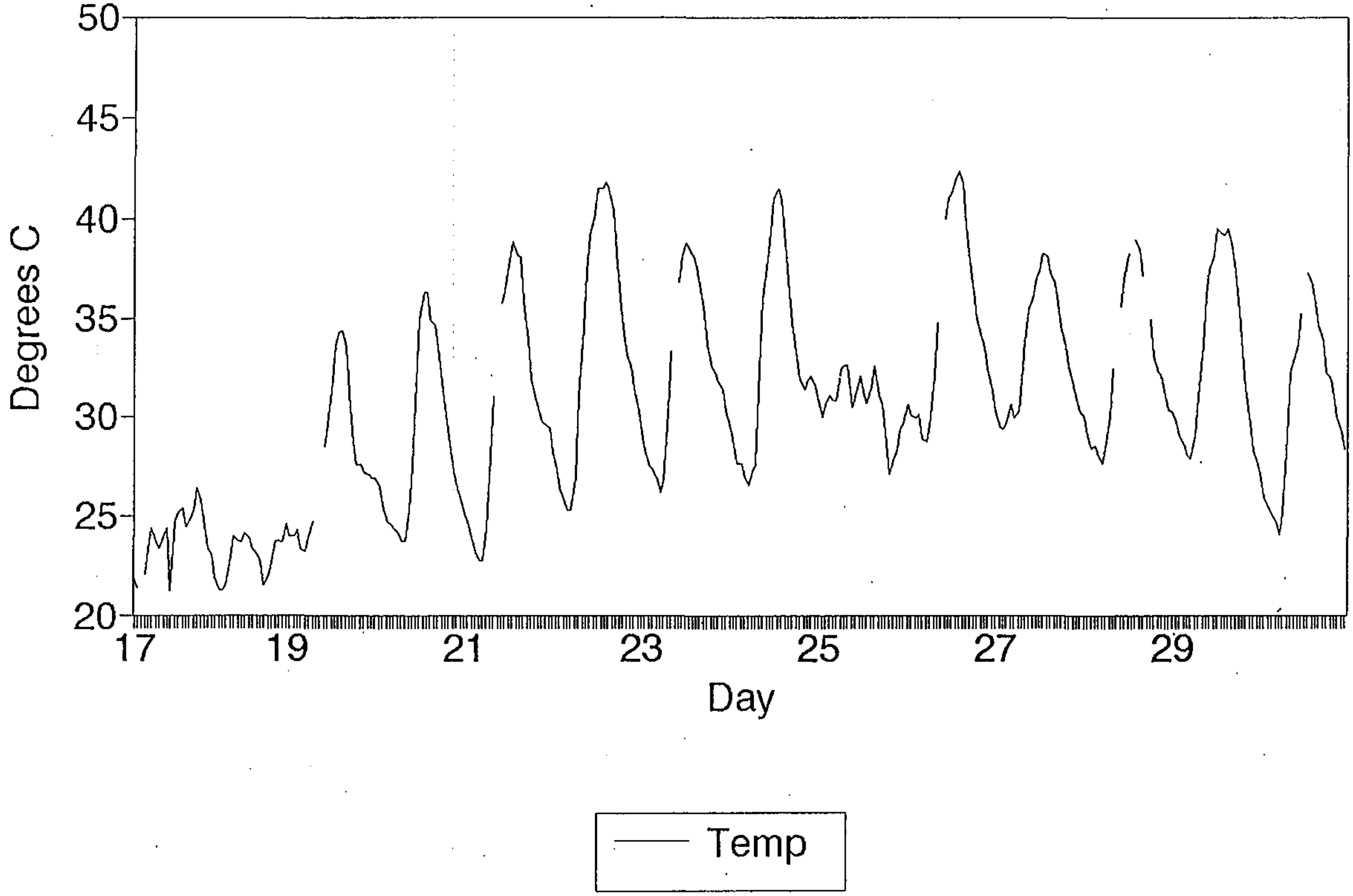
Operating Efficiency = 44.3 percent

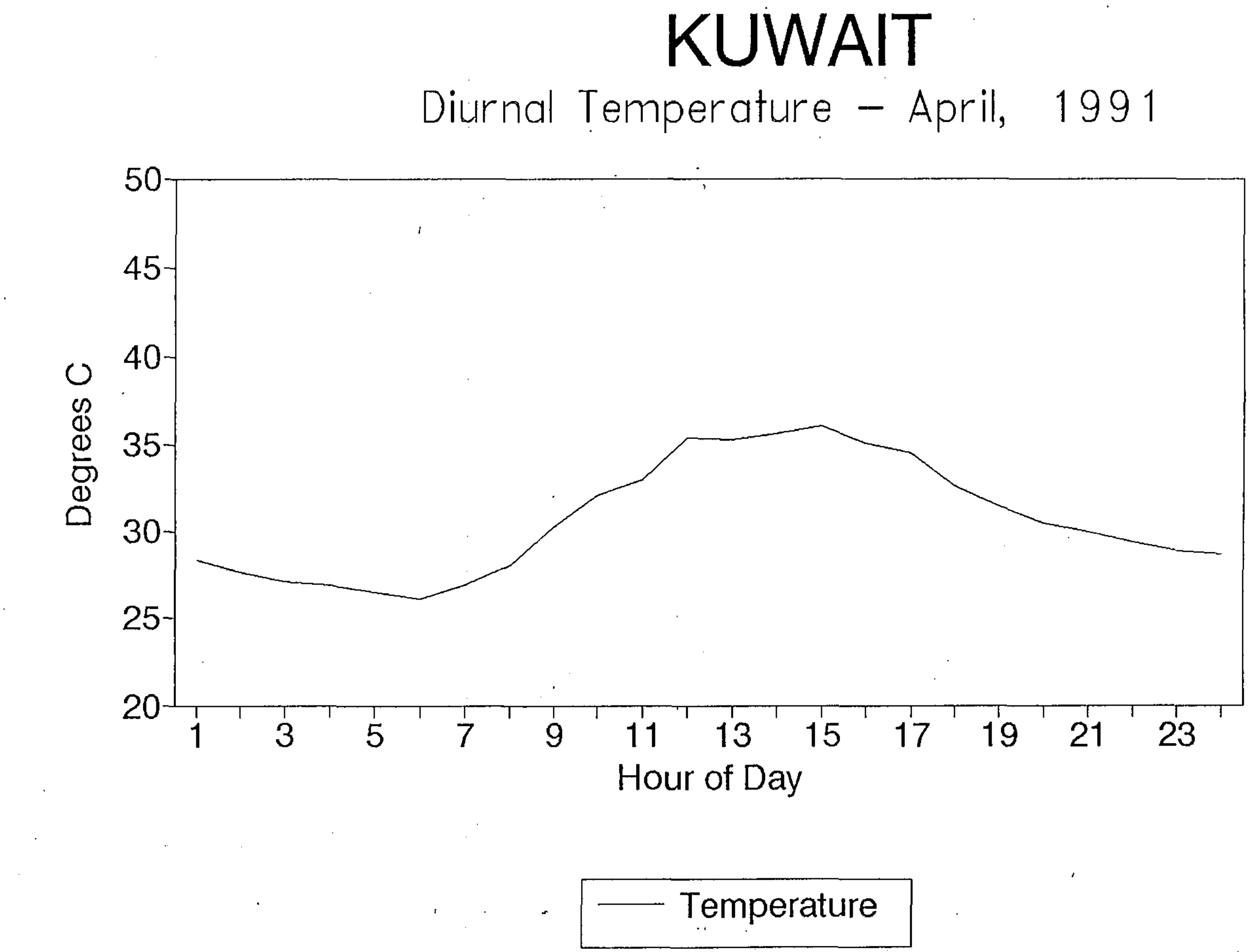
ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data

[CEM 1990]

# KUWAIT

Hourly Temperature – April, 1991




KUWAIT
Diurnal Temperature – April, 1991
Degrees C
50
45
40
35
30
25
20
1
3
5
7
9
11
13
15
17
19
21
23
Hour of Day
Temperature

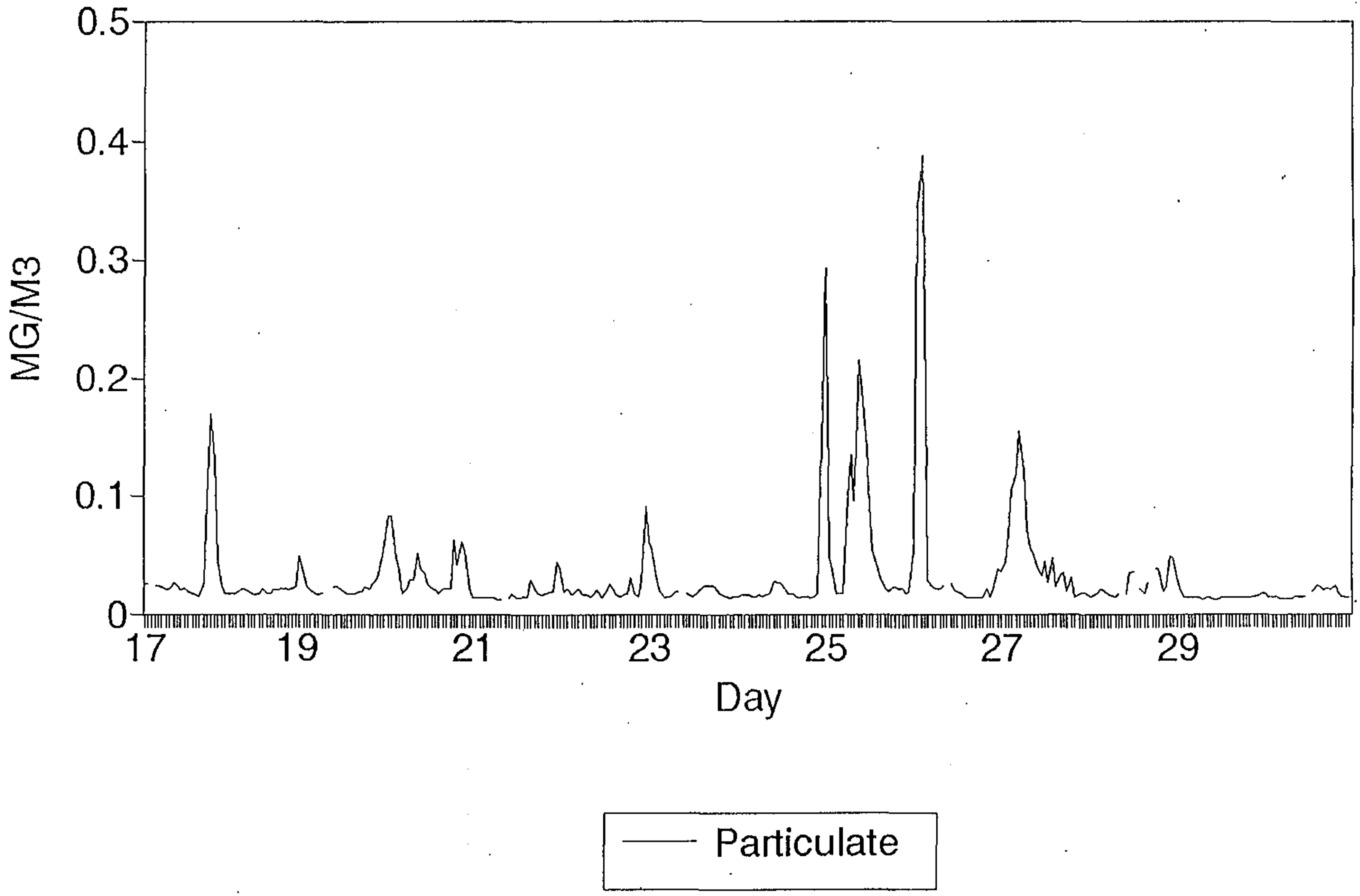
MEPA - Kuwait
April 1991
Hourly Averages for Total Particulate in MG/M3

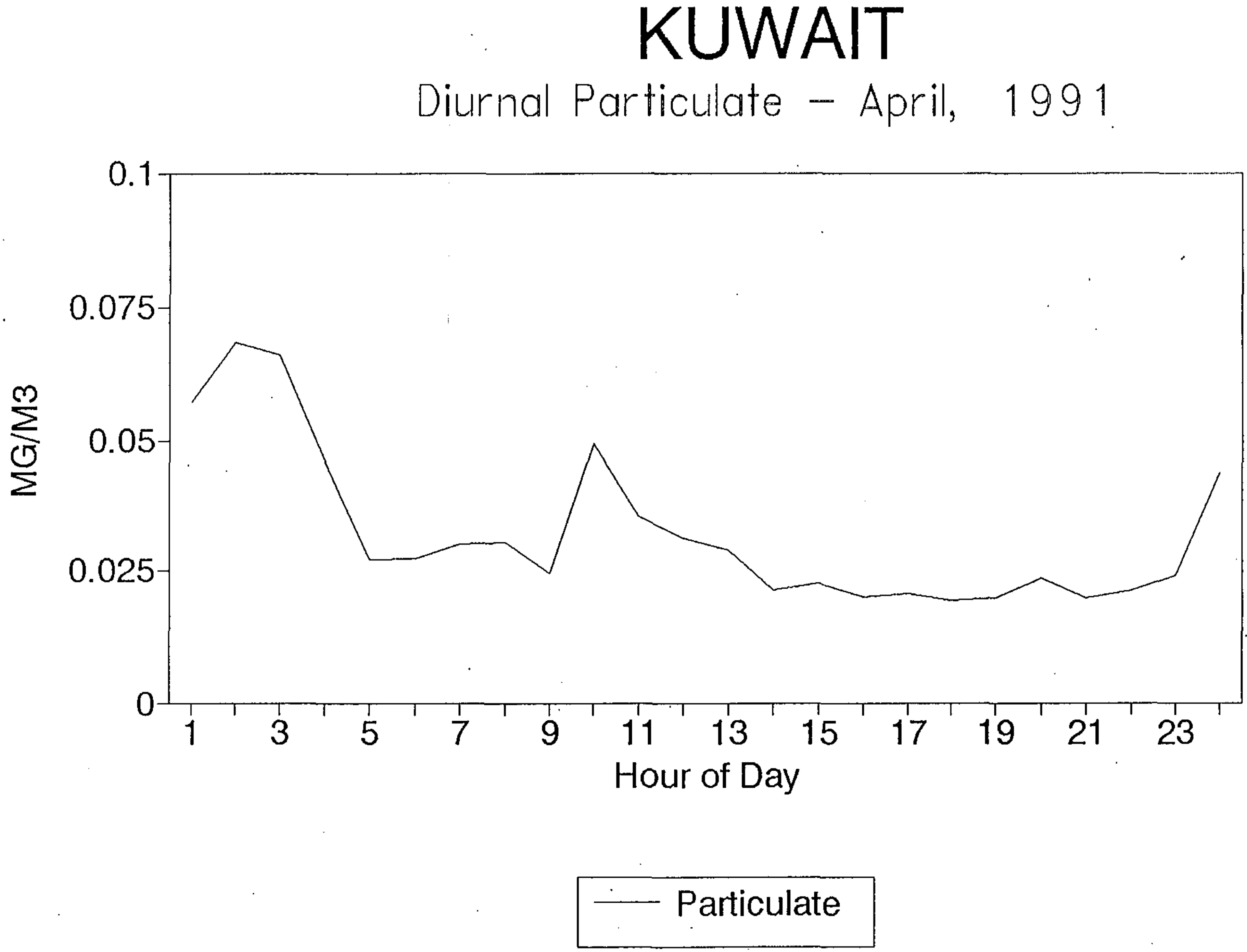
| Hour / Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 2 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 3 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 4 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 5 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 8 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 9 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 10 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 11 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 12 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 13 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 14 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 15 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 16 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 17 | ND | ND | ND | ND | ND | ND | ND | 0.025 | 0.025 | ND | 0.024 | 0.024 | 0.023 | 0.020 | 0.021 | 0.026 | 0.024 | 0.020 | 0.022 | 0.019 | 0.017 | 0.016 | 0.015 | 0.026 | 0.0217 |
| 18 | 0.096 | 0.169 | 0.131 | 0.044 | 0.024 | 0.018 | 0.018 | 0.018 | 0.018 | 0.020 | 0.021 | 0.019 | 0.018 | 0.016 | 0.018 | 0.021 | 0.018 | 0.017 | 0.020 | 0.020 | 0.021 | 0.022 | 0.020 | 0.021 | 0.0345 |
| 19 | 0.023 | 0.049 | 0.032 | 0.023 | 0.020 | 0.018 | 0.016 | 0.018 | ND | ND | 0.023 | 0.024 | 0.020 | 0.019 | 0.018 | 0.018 | 0.018 | 0.019 | 0.019 | 0.023 | 0.021 | 0.025 | 0.031 | 0.042 | 0.0236 |
| 20 | 0.054 | 0.083 | 0.082 | 0.048 | 0.038 | 0.018 | 0.021 | 0.029 | 0.029 | 0.051 | 0.038 | 0.035 | 0.025 | 0.022 | 0.020 | 0.017 | 0.021 | 0.021 | 0.021 | 0.062 | 0.041 | 0.060 | 0.052 | 0.021 | 0.0379 |
| 21 | 0.014 | 0.014 | 0.014 | 0.013 | 0.014 | 0.013 | 0.013 | 0.012 | 0.012 | ND | 0.013 | 0.017 | 0.014 | 0.014 | 0.015 | 0.015 | 0.029 | 0.020 | 0.017 | 0.016 | 0.017 | 0.019 | 0.019 | 0.043 | 0.0168 |
| 22 | 0.038 | 0.019 | 0.021 | 0.016 | 0.019 | 0.022 | 0.016 | 0.016 | 0.015 | 0.018 | 0.020 | 0.014 | 0.017 | 0.025 | 0.021 | 0.016 | 0.015 | 0.016 | 0.018 | 0.031 | 0.017 | 0.015 | 0.028 | 0.090 | 0.0226 |
| 23 | 0.060 | 0.054 | 0.028 | 0.019 | 0.014 | 0.015 | 0.015 | 0.019 | 0.019 | ND | 0.017 | 0.016 | 0.015 | 0.017 | 0.022 | 0.024 | 0.024 | 0.024 | 0.023 | 0.018 | 0.016 | 0.015 | 0.014 | 0.015 | 0.0219 |
| 24 | 0.015 | 0.016 | 0.016 | 0.016 | 0.015 | 0.015 | 0.016 | 0.015 | 0.016 | 0.017 | 0.028 | 0.026 | 0.026 | 0.022 | 0.017 | 0.017 | 0.015 | 0.014 | 0.015 | 0.015 | 0.014 | 0.015 | 0.017 | 0.177 | 0.0240 |
| 25 | 0.293 | 0.048 | 0.038 | 0.017 | 0.017 | 0.017 | 0.098 | 0.135 | 0.096 | 0.215 | 0.189 | 0.140 | 0.091 | 0.053 | 0.040 | 0.031 | 0.021 | 0.019 | 0.021 | 0.023 | 0.022 | 0.021 | 0.018 | 0.019 | 0.0701 |
| 26 | 0.054 | 0.346 | 0.388 | 0.254 | 0.028 | 0.023 | 0.022 | 0.021 | 0.024 | ND | 0.025 | 0.020 | 0.019 | 0.017 | 0.015 | 0.014 | 0.013 | 0.013 | 0.013 | 0.014 | 0.021 | 0.014 | 0.022 | 0.038 | 0.0617 |
| 27 | 0.036 | 0.044 | 0.067 | 0.104 | 0.118 | 0.154 | 0.120 | 0.071 | 0.056 | 0.049 | 0.038 | 0.032 | 0.043 | 0.027 | 0.047 | 0.023 | 0.033 | 0.035 | 0.019 | 0.031 | 0.014 | 0.016 | 0.018 | 0.017 | 0.0505 |
| 28 | 0.014 | 0.015 | 0.016 | 0.020 | 0.019 | 0.016 | 0.015 | 0.014 | 0.016 | ND | 0.017 | 0.035 | 0.036 | ND | 0.022 | 0.017 | 0.026 | ND | 0.038 | 0.038 | 0.019 | 0.024 | 0.049 | 0.047 | 0.0244 |
| 29 | 0.031 | 0.019 | 0.014 | 0.013 | 0.014 | 0.014 | 0.013 | 0.012 | 0.013 | 0.013 | 0.012 | 0.012 | 0.013 | 0.013 | 0.014 | 0.014 | 0.013 | 0.013 | 0.013 | 0.013 | 0.013 | 0.015 | 0.015 | 0.017 | 0.0144 |
| 30 | 0.018 | 0.014 | 0.013 | 0.013 | 0.012 | 0.012 | 0.012 | 0.012 | 0.013 | 0.013 | 0.013 | 0.013 | ND | 0.019 | 0.024 | 0.023 | 0.020 | 0.021 | 0.020 | 0.024 | 0.018 | 0.015 | 0.014 | 0.013 | 0.0160 |
| | | | | | | | | | | | | | | | | | | | | | | | Monthly Average = | | 0.0318 |

Maximum Hourly Average was 0.388 at Hour 3 on Day 26 with 1 occurences
Maximum Daily Average was 0.0701 on Day 25 with 1 occurences
Operating Efficiency = 44.3 percent
ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data
[CEM 1990]

# KUWAIT

Hourly Particulate – April, 1991




KUWAIT
Diurnal Particulate - April, 1991
MG/M3
0.1
0.075
0.05
0.025
0
1
3
5
7
9
11
13
15
17
19
21
23
Hour of Day
Particulate

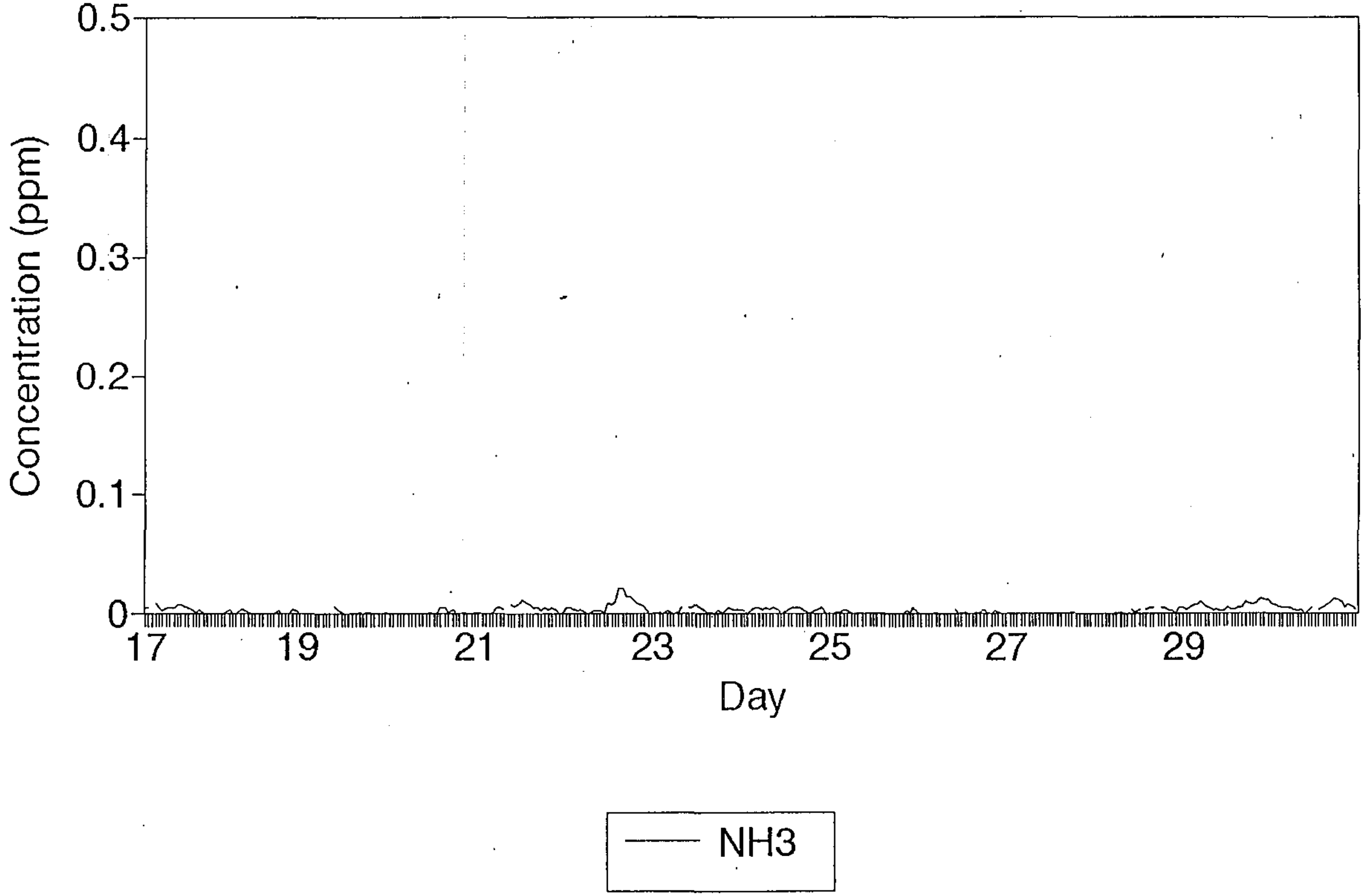
MEPA - Kuwait
April 1991
Hourly Averages for NH3 in ppm

| Day \ Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 2 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 3 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 4 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 5 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 8 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 9 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 10 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 11 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 12 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 13 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 14 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 15 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 16 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 17 | ND | ND | ND | ND | ND | ND | ND | 0.005 | 0.004 | CAL | 0.009 | 0.005 | 0.002 | 0.004 | 0.005 | 0.005 | 0.007 | 0.007 | 0.006 | 0.004 | 0.002 | 0.001 | 0.003 | 0.000 | 0.0043 |
| 18 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.003 | 0.000 | 0.000 | 0.003 | 0.003 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.000 | 0.000 | 0.000 | 0.003 | 0.0007 |
| 19 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | CAL | CAL | 0.006 | 0.003 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.001 | 0.001 | 0.000 | 0.000 | 0.000 | 0.0007 |
| 20 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.001 | 0.004 | 0.005 | 0.001 | 0.003 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.0007 |
| 21 | 0.001 | 0.001 | 0.000 | 0.000 | 0.000 | 0.001 | 0.004 | 0.004 | 0.003 | CAL | 0.007 | 0.006 | 0.009 | 0.011 | 0.008 | 0.007 | 0.004 | 0.004 | 0.002 | 0.005 | 0.003 | 0.005 | 0.003 | 0.000 | 0.0038 |
| 22 | 0.001 | 0.005 | 0.004 | 0.003 | 0.002 | 0.003 | 0.001 | 0.000 | 0.002 | 0.002 | 0.002 | 0.001 | 0.009 | 0.007 | 0.010 | 0.020 | 0.020 | 0.013 | 0.013 | 0.011 | 0.008 | 0.007 | 0.006 | 0.000 | 0.0062 |
| 23 | 0.000 | 0.001 | 0.001 | 0.000 | 0.002 | 0.001 | 0.000 | 0.001 | 0.004 | CAL | 0.005 | 0.005 | 0.007 | 0.005 | 0.003 | 0.001 | 0.001 | 0.000 | 0.002 | 0.001 | 0.002 | 0.004 | 0.003 | 0.003 | 0.0023 |
| 24 | 0.003 | 0.002 | 0.000 | 0.003 | 0.004 | 0.004 | 0.003 | 0.004 | 0.003 | 0.004 | 0.003 | 0.000 | 0.001 | 0.003 | 0.005 | 0.005 | 0.005 | 0.003 | 0.001 | 0.001 | 0.002 | 0.003 | 0.004 | 0.000 | 0.0028 |
| 25 | 0.000 | 0.000 | 0.001 | 0.001 | 0.002 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.001 | 0.005 | 0.0006 |
| 26 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | ND | 0.003 | 0.000 | 0.001 | 0.001 | 0.000 | 0.000 | 0.001 | 0.001 | 0.003 | 0.001 | 0.000 | 0.002 | 0.001 | 0.000 | 0.0007 |
| 27 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.003 | 0.000 | 0.000 | 0.000 | 0.000 | 0.0002 |
| 28 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | CAL | 0.003 | 0.001 | 0.003 | ND | 0.003 | 0.004 | 0.005 | ND | 0.004 | 0.004 | 0.002 | 0.002 | 0.001 | 0.004 | 0.0018 |
| 29 | 0.005 | 0.003 | 0.004 | 0.007 | 0.007 | 0.010 | 0.006 | 0.004 | 0.002 | 0.003 | 0.002 | 0.002 | 0.004 | 0.003 | 0.003 | 0.005 | 0.005 | 0.010 | 0.008 | 0.007 | 0.009 | 0.012 | 0.011 | 0.011 | 0.0060 |
| 30 | 0.008 | 0.007 | 0.006 | 0.004 | 0.005 | 0.004 | 0.003 | 0.002 | 0.003 | 0.000 | 0.002 | 0.004 | ND | 0.003 | 0.004 | 0.007 | 0.008 | 0.012 | 0.011 | 0.010 | 0.005 | 0.007 | 0.006 | 0.003 | 0.0054 |
| | | | | | | | | | | | | | | | | | | | | | | Monthly Average = | | | 0.0025 |

Maximum Hourly Average was 0.020 at Hour 16 on Day 22 with 2 occurences
Maximum Daily Average was 0.0062 on Day 22 with 1 occurences
Operating Efficiency = 45.1 percent
ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data
[CEM 1990]

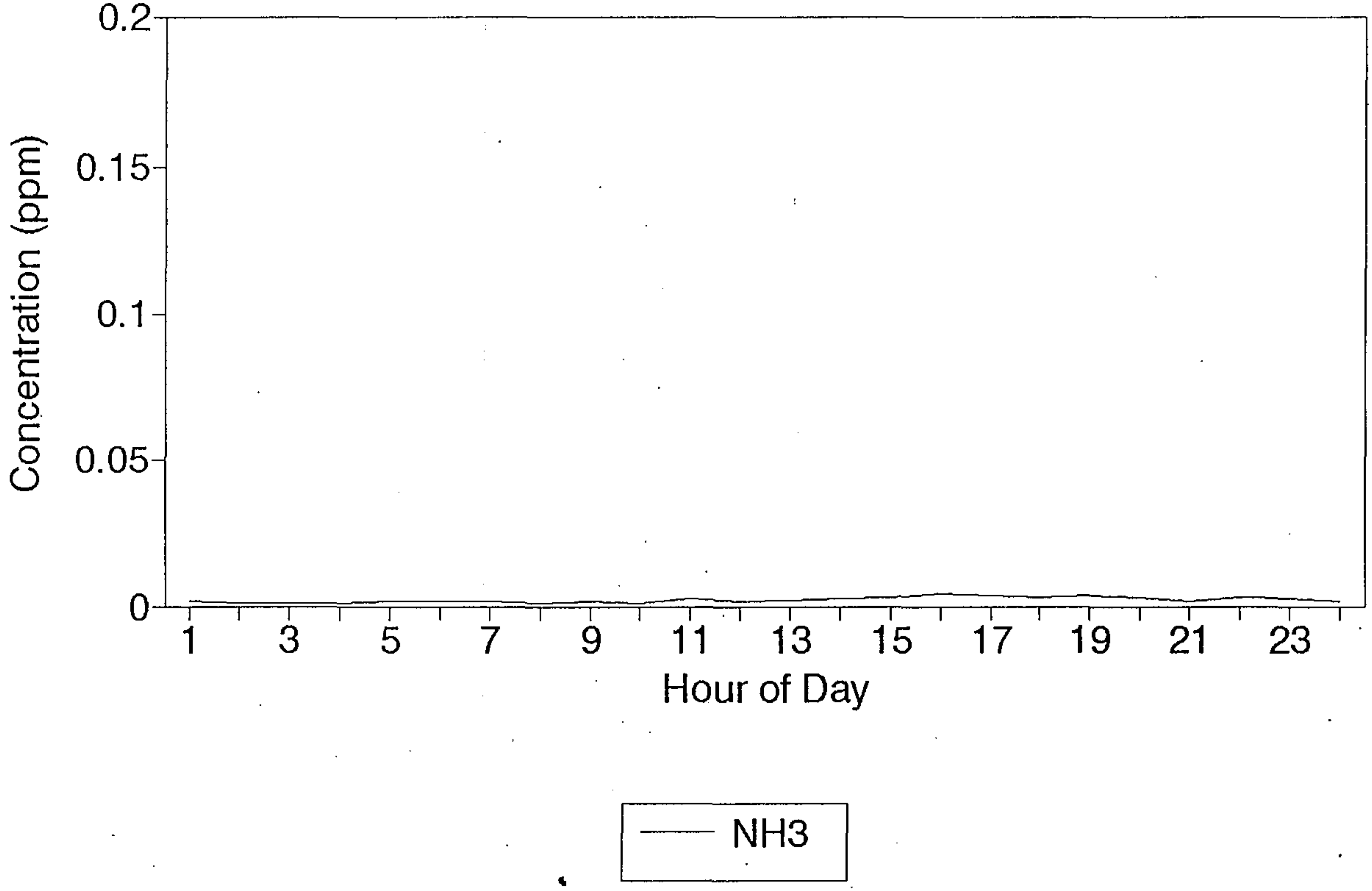
# KUWAIT

## Hourly NH3 - April, 1991



# KUWAIT

## Diurnal NH3 - April, 1991



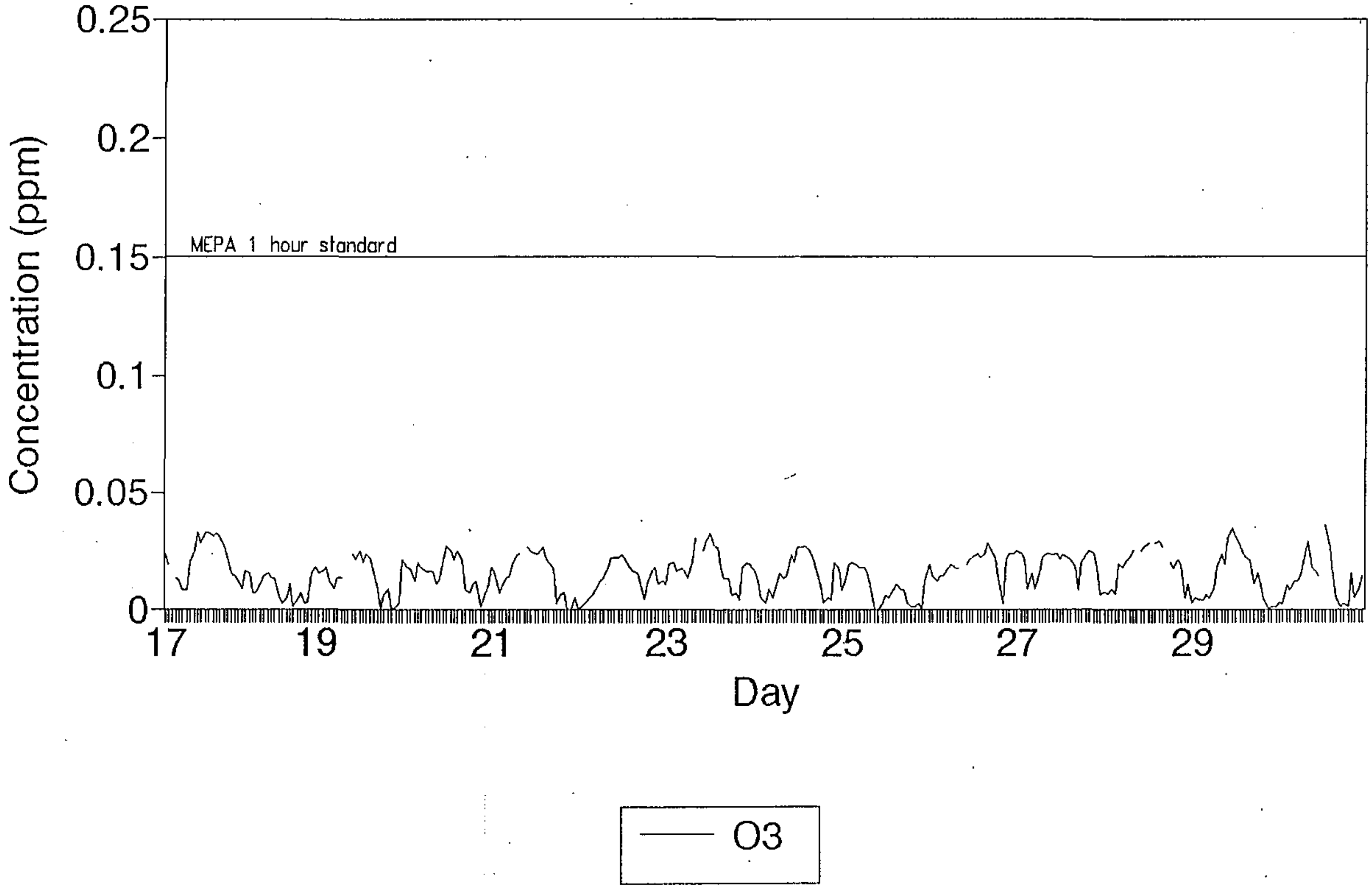
MEPA - Kuwait
April 1991
Hourly Averages for O3 in ppm

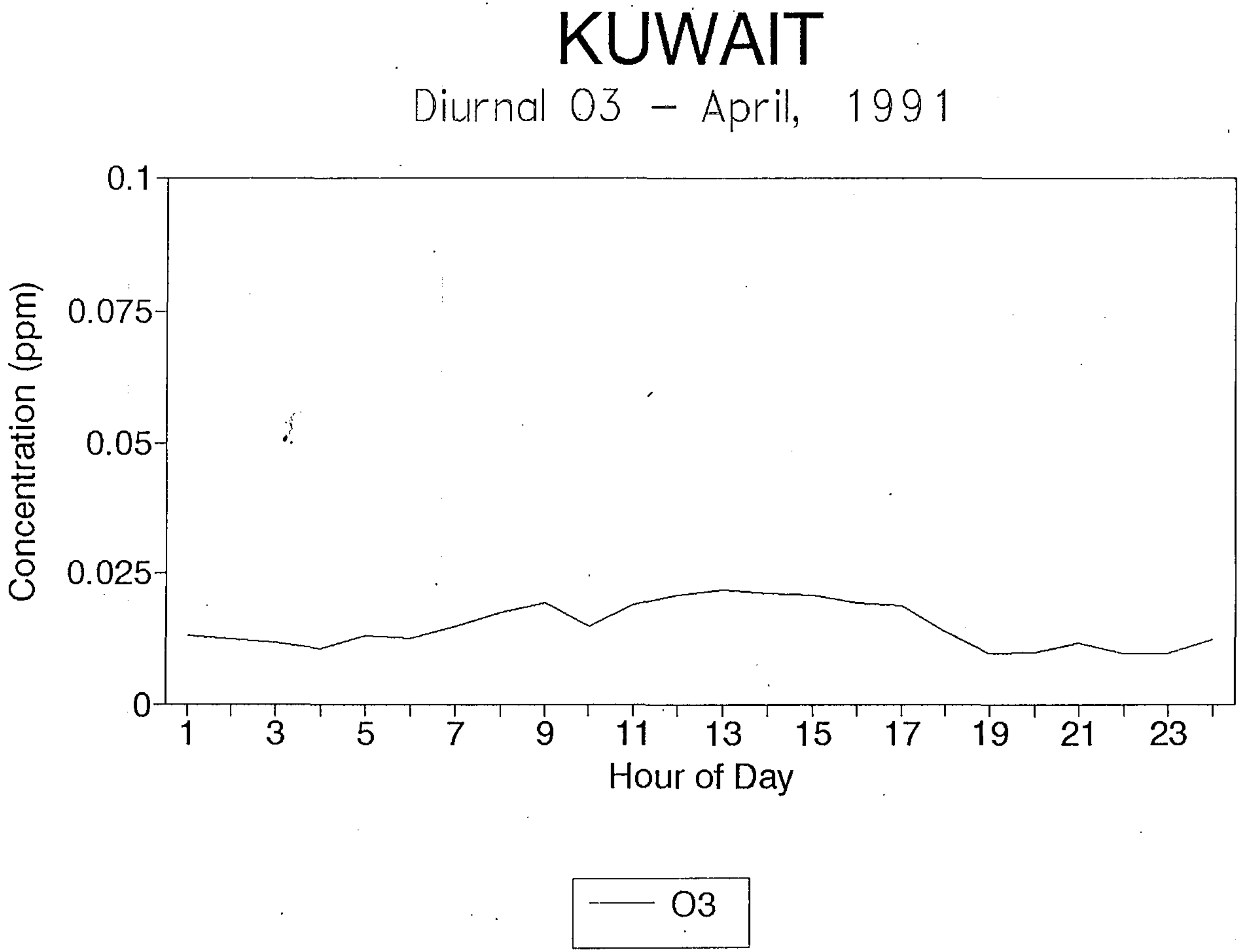
| Day \ Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 2 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 3 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 4 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 5 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 8 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 9 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 10 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 11 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 12 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 13 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 14 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 15 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 16 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 17 | ND | ND | ND | ND | ND | ND | ND | 0.024 | 0.019 | CAL | 0.013 | 0.012 | 0.008 | 0.008 | 0.020 | 0.025 | 0.033 | 0.028 | 0.033 | 0.033 | 0.031 | 0.032 | 0.031 | 0.026 | 0.0235 |
| 18 | 0.022 | 0.015 | 0.014 | 0.012 | 0.009 | 0.016 | 0.015 | 0.007 | 0.007 | 0.011 | 0.014 | 0.015 | 0.013 | 0.013 | 0.005 | 0.002 | 0.005 | 0.011 | 0.001 | 0.004 | 0.007 | 0.002 | 0.003 | 0.015 | 0.0099 |
| 19 | 0.018 | 0.015 | 0.016 | 0.018 | 0.012 | 0.009 | 0.013 | 0.013 | CAL | CAL | 0.024 | 0.021 | 0.025 | 0.020 | 0.024 | 0.022 | 0.015 | 0.009 | 0.000 | 0.006 | 0.009 | 0.000 | 0.001 | 0.003 | 0.0133 |
| 20 | 0.021 | 0.018 | 0.017 | 0.012 | 0.020 | 0.018 | 0.016 | 0.016 | 0.016 | 0.011 | 0.013 | 0.021 | 0.027 | 0.025 | 0.021 | 0.025 | 0.021 | 0.009 | 0.007 | 0.011 | 0.012 | 0.001 | 0.005 | 0.011 | 0.0156 |
| 21 | 0.018 | 0.015 | 0.007 | 0.010 | 0.013 | 0.014 | 0.020 | 0.023 | 0.024 | CAL | 0.026 | 0.025 | 0.024 | 0.024 | 0.026 | 0.022 | 0.020 | 0.017 | 0.002 | 0.006 | 0.007 | 0.000 | 0.000 | 0.005 | 0.0151 |
| 22 | 0.000 | 0.001 | 0.002 | 0.005 | 0.006 | 0.008 | 0.012 | 0.013 | 0.018 | 0.022 | 0.022 | 0.022 | 0.023 | 0.020 | 0.018 | 0.016 | 0.015 | 0.010 | 0.004 | 0.011 | 0.015 | 0.018 | 0.011 | 0.012 | 0.0127 |
| 23 | 0.010 | 0.019 | 0.020 | 0.016 | 0.017 | 0.016 | 0.013 | 0.020 | 0.030 | CAL | 0.025 | 0.029 | 0.032 | 0.027 | 0.026 | 0.018 | 0.013 | 0.013 | 0.006 | 0.007 | 0.004 | 0.018 | 0.020 | 0.019 | 0.0182 |
| 24 | 0.016 | 0.012 | 0.005 | 0.003 | 0.009 | 0.005 | 0.011 | 0.015 | 0.013 | 0.014 | 0.023 | 0.020 | 0.026 | 0.026 | 0.027 | 0.025 | 0.022 | 0.018 | 0.010 | 0.003 | 0.005 | 0.004 | 0.020 | 0.017 | 0.0145 |
| 25 | 0.008 | 0.013 | 0.019 | 0.020 | 0.019 | 0.018 | 0.018 | 0.015 | 0.010 | 0.000 | 0.000 | 0.002 | 0.006 | 0.005 | 0.008 | 0.011 | 0.008 | 0.008 | 0.003 | 0.001 | 0.001 | 0.002 | 0.000 | 0.012 | 0.0086 |
| 26 | 0.019 | 0.014 | 0.012 | 0.014 | 0.014 | 0.017 | 0.019 | 0.017 | 0.017 | ND | 0.019 | 0.021 | 0.022 | 0.024 | 0.022 | 0.023 | 0.028 | 0.025 | 0.022 | 0.013 | 0.002 | 0.021 | 0.024 | 0.024 | 0.0188 |
| 27 | 0.025 | 0.024 | 0.021 | 0.009 | 0.015 | 0.009 | 0.015 | 0.022 | 0.023 | 0.024 | 0.023 | 0.024 | 0.021 | 0.023 | 0.022 | 0.021 | 0.018 | 0.008 | 0.020 | 0.023 | 0.025 | 0.024 | 0.017 | 0.006 | 0.0193 |
| 28 | 0.007 | 0.006 | 0.008 | 0.006 | 0.019 | 0.017 | 0.020 | 0.022 | 0.025 | CAL | 0.025 | 0.026 | 0.028 | ND | 0.028 | 0.029 | 0.026 | ND | 0.020 | 0.017 | 0.021 | 0.019 | 0.005 | 0.011 | 0.0183 |
| 29 | 0.003 | 0.005 | 0.004 | 0.004 | 0.006 | 0.005 | 0.009 | 0.018 | 0.024 | 0.019 | 0.030 | 0.035 | 0.031 | 0.027 | 0.024 | 0.022 | 0.021 | 0.011 | 0.015 | 0.010 | 0.004 | 0.000 | 0.001 | 0.001 | 0.0137 |
| 30 | 0.003 | 0.002 | 0.010 | 0.008 | 0.012 | 0.012 | 0.014 | 0.024 | 0.029 | 0.018 | 0.016 | 0.014 | ND | 0.036 | 0.026 | 0.014 | 0.005 | 0.001 | 0.002 | 0.001 | 0.015 | 0.005 | 0.009 | 0.014 | 0.0126 |
| | | | | | | | | | | | | | | | | | | | | | | Monthly Average = | | | 0.0151 |

Maximum Hourly Average was 0.036 at Hour 14 on Day 30 with 1 occurences and there were no Hourly Violations
Maximum Daily Average was 0.0235 on Day 17 with 1 occurences and there were no Daily Violations
Operating Efficiency = 45.1 percent
ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data
[CEM 1990]

# KUWAIT

## Hourly O3 - April, 1991




KUWAIT
Diurnal 03 - April, 1991
Concentration (ppm)
0.1
0.075
0.05
0.025
0
1
3
5
7
9
11
13
15
17
19
21
23
Hour of Day
O3

MEPA - Kuwait
April 1991
Hourly Averages for NOx in ppm

| Day \ Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 2 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 3 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 4 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 5 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 8 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 9 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 10 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 11 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 12 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 13 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 14 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 15 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 16 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 17 | ND | ND | ND | ND | ND | ND | ND | 0.010 | 0.014 | CAL | 0.027 | 0.029 | 0.041 | 0.041 | 0.028 | 0.030 | 0.025 | 0.035 | 0.026 | 0.023 | 0.023 | 0.023 | 0.018 | 0.021 | 0:0259 |
| 18 | 0.036 | 0.051 | 0.030 | 0.060 | 0.069 | 0.024 | 0.022 | 0.043 | 0.038 | 0.031 | 0.026 | 0.028 | 0.043 | 0.044 | 0.069 | 0.090 | 0.066 | 0.046 | 0.110 | 0.065 | 0.049 | 0.081 | 0.055 | 0.024 | 0.0500 |
| 19 | 0.022 | 0.028 | 0.035 | 0.028 | 0.045 | 0.048 | 0.034 | 0.061 | CAL | CAL | 0.032 | 0.024 | 0.026 | 0.057 | 0.045 | 0.050 | 0.064 | 0.054 | 0.085 | 0.059 | 0.065 | 0.087 | 0.077 | 0.095 | 0.0510 |
| 20 | 0.020 | 0.032 | 0.036 | 0.042 | 0.017 | 0.024 | 0.034 | 0.038 | 0.036 | 0.060 | 0.047 | 0.038 | 0.023 | 0.029 | 0.038 | 0.015 | 0.022 | 0.050 | 0.049 | 0.045 | 0.065 | 0.109 | 0.063 | 0.047 | 0.0408 |
| 21 | 0.027 | 0.032 | 0.063 | 0.051 | 0.047 | 0.036 | 0.015 | 0.015 | 0.023 | CAL | 0.023 | 0.017 | 0.015 | 0.014 | 0.011 | 0.021 | 0.027 | 0.027 | 0.063 | 0.060 | 0.065 | 0.132 | 0.140 | 0.070 | 0.0432 |
| 22 | 0.115 | 0.101 | 0.093 | 0.077 | 0.087 | 0.067 | 0.028 | 0.057 | 0.036 | 0.022 | 0.027 | 0.027 | 0.022 | 0.025 | 0.023 | 0.021 | 0.021 | 0.034 | 0.053 | 0.032 | 0.022 | 0.028 | 0.052 | 0.032 | 0.0459 |
| 23 | 0.044 | 0.013 | 0.016 | 0.044 | 0.041 | 0.036 | 0.053 | 0.042 | 0.025 | CAL | 0.042 | 0.024 | 0.016 | 0.026 | 0.029 | 0.048 | 0.053 | 0.056 | 0.079 | 0.069 | 0.087 | 0.025 | 0.020 | 0.019 | 0.0394 |
| 24 | 0.025 | 0.038 | 0.088 | 0.103 | 0.033 | 0.046 | 0.034 | 0.021 | 0.045 | 0.062 | 0.040 | 0.060 | 0.040 | 0.039 | 0.016 | 0.013 | 0.018 | 0.028 | 0.040 | 0.057 | 0.060 | 0.063 | 0.019 | 0.023 | 0.0421 |
| 25 | 0.047 | 0.014 | 0.006 | 0.005 | 0.005 | 0.007 | 0.016 | 0.025 | 0.034 | 0.089 | 0.073 | 0.051 | 0.028 | 0.025 | 0.034 | 0.027 | 0.032 | 0.036 | 0.053 | 0.104 | 0.132 | 0.086 | 0.062 | 0.028 | 0.0425 |
| 26 | 0.015 | 0.029 | 0.033 | 0.025 | 0.012 | 0.007 | 0.009 | 0.011 | 0.023 | ND | 0.037 | 0.035 | 0.033 | 0.028 | 0.034 | 0.031 | 0.019 | 0.027 | 0.031 | 0.051 | 0.085 | 0.022 | 0.014 | 0.012 | 0.0271 |
| 27 | 0.009 | 0.010 | 0.018 | 0.055 | 0.037 | 0.054 | 0.043 | 0.020 | 0.022 | 0.025 | 0.023 | 0.024 | 0.031 | 0.033 | 0.034 | 0.033 | 0.032 | 0.054 | 0.027 | 0.017 | 0.011 | 0.011 | 0.035 | 0.089 | 0.0311 |
| 28 | 0.076 | 0.087 | 0.073 | 0.085 | 0.025 | 0.026 | 0.014 | 0.017 | 0.022 | CAL | 0.029 | 0.024 | 0.017 | ND | 0.022 | 0.020 | 0.018 | ND | 0.033 | 0.028 | 0.019 | 0.033 | 0.119 | 0.077 | 0.0411 |
| 29 | 0.138 | 0.116 | 0.124 | 0.131 | 0.120 | 0.121 | 0.098 | 0.056 | 0.040 | 0.041 | 0.036 | 0.025 | 0.031 | 0.035 | 0.038 | 0.039 | 0.045 | 0.083 | 0.064 | 0.068 | 0.081 | 0.110 | 0.088 | 0.068 | 0.0748 |
| 30 | 0.049 | 0.053 | 0.027 | 0.030 | 0.024 | 0.027 | 0.028 | 0.019 | 0.024 | 0.060 | 0.070 | 0.078 | ND | 0.075 | 0.040 | 0.073 | 0.084 | 0.135 | 0.104 | 0.091 | 0.047 | 0.084 | 0.066 | 0.034 | 0.0575 |

Monthly Average = .0.0442

Maximum Hourly Average was 0.140 at Hour 23 on Day 21 with 1 occurences and there were no Hourly Violations
Maximum Daily Average was 0.0748 on Day 29 with 1 occurences and there were no Daily Violations
Operating Efficiency = 45.1 percent
ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data
[CEM 1990]

MEPA - Kuwait
April 1991
Frequency Distribution
Hourly Averages for NOx in ppm

| Concentration | # of Hours | Percentage |
|---|---|---|
| 0.000 - 0.050 | 218 | 68.3 |
| 0.051 - 0.110 | 89 | 27.9 |
| 0.111 - 0.210 | 12 | 3.8 |
| 0.211+ | 0 | 0.0 |

MEPA - Kuwait
April 1991
Hourly Averages for NO2 in ppm

| Day \ Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 2 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 3 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 4 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 5 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 8 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 9 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 10 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 11 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 12 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 13 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 14 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 15 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 16 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 17 | ND | ND | ND | ND | ND | ND | ND | 0.008 | 0.010 | CAL | 0.020 | 0.023 | 0.031 | 0.032 | 0.025 | 0.026 | 0.022 | 0.030 | 0.023 | 0.021 | 0.021 | 0.022 | 0.017 | 0.019 | 0.0219 |
| 18 | 0.028 | 0.037 | 0.023 | 0.030 | 0.035 | 0.019 | 0.017 | 0.031 | 0.027 | 0.021 | 0.016 | 0.022 | 0.032 | 0.036 | 0.050 | 0.056 | 0.048 | 0.035 | 0.049 | 0.046 | 0.039 | 0.053 | 0.047 | 0.021 | 0.0341 |
| 19 | 0.021 | 0.019 | 0.022 | 0.018 | 0.027 | 0.032 | 0.023 | 0.033 | CAL | CAL | 0.017 | 0.019 | 0.019 | 0.036 | 0.029 | 0.030 | 0.042 | 0.043 | 0.055 | 0.052 | 0.046 | 0.057 | 0.056 | 0.055 | 0.0341 |
| 20 | 0.018 | 0.026 | 0.027 | 0.029 | 0.013 | 0.018 | 0.025 | 0.028 | 0.028 | 0.042 | 0.037 | 0.030 | 0.019 | 0.023 | 0.029 | 0.013 | 0.018 | 0.041 | 0.046 | 0.043 | 0.043 | 0.062 | 0.052 | 0.039 | 0.0312 |
| 21 | 0.024 | 0.027 | 0.038 | 0.032 | 0.024 | 0.022 | 0.012 | 0.011 | 0.019 | CAL | 0.015 | 0.012 | 0.010 | 0.010 | 0.008 | 0.017 | 0.021 | 0.023 | 0.052 | 0.049 | 0.041 | 0.060 | 0.058 | 0.048 | 0.0275 |
| 22 | 0.058 | 0.048 | 0.043 | 0.032 | 0.034 | 0.028 | 0.018 | 0.031 | 0.020 | 0.014 | 0.021 | 0.021 | 0.019 | 0.020 | 0.021 | 0.021 | 0.019 | 0.029 | 0.043 | 0.029 | 0.021 | 0.025 | 0.038 | 0.028 | 0.0284 |
| 23 | 0.030 | 0.012 | 0.011 | 0.022 | 0.025 | 0.025 | 0.032 | 0.027 | 0.019 | CAL | 0.029 | 0.019 | 0.014 | 0.022 | 0.025 | 0.039 | 0.041 | 0.042 | 0.050 | 0.044 | 0.051 | 0.022 | 0.019 | 0.018 | 0.0277 |
| 24 | 0.023 | 0.029 | 0.046 | 0.053 | 0.030 | 0.038 | 0.030 | 0.018 | 0.031 | 0.039 | 0.030 | 0.038 | 0.029 | 0.029 | 0.013 | 0.010 | 0.014 | 0.024 | 0.036 | 0.050 | 0.046 | 0.048 | 0.016 | 0.020 | 0.0308 |
| 25 | 0.037 | 0.012 | 0.005 | 0.004 | 0.003 | 0.006 | 0.014 | 0.022 | 0.026 | 0.037 | 0.039 | 0.034 | 0.023 | 0.019 | 0.022 | 0.020 | 0.026 | 0.030 | 0.043 | 0.048 | 0.052 | 0.052 | 0.049 | 0.024 | 0.0270 |
| 26 | 0.013 | 0.025 | 0.031 | 0.023 | 0.010 | 0.006 | 0.007 | 0.009 | 0.014 | ND | 0.024 | 0.022 | 0.021 | 0.019 | 0.020 | 0.020 | 0.014 | 0.023 | 0.027 | 0.040 | 0.054 | 0.020 | 0.013 | 0.009 | 0.0202 |
| 27 | 0.007 | 0.008 | 0.014 | 0.037 | 0.029 | 0.037 | 0.029 | 0.017 | 0.016 | 0.020 | 0.017 | 0.019 | 0.025 | 0.024 | 0.028 | 0.026 | 0.025 | 0.040 | 0.022 | 0.016 | 0.009 | 0.009 | 0.019 | 0.038 | 0.0221 |
| 28 | 0.034 | 0.037 | 0.033 | 0.039 | 0.014 | 0.015 | 0.008 | 0.010 | 0.014 | CAL | 0.018 | 0.016 | 0.012 | ND | 0.016 | 0.018 | 0.015 | ND | 0.023 | 0.027 | 0.017 | 0.023 | 0.051 | 0.044 | 0.0230 |
| 29 | 0.060 | 0.056 | 0.060 | 0.059 | 0.056 | 0.056 | 0.050 | 0.034 | 0.026 | 0.028 | 0.025 | 0.019 | 0.022 | 0.025 | 0.025 | 0.027 | 0.031 | 0.047 | 0.038 | 0.043 | 0.055 | 0.061 | 0.060 | 0.046 | 0.0420 |
| 30 | 0.041 | 0.041 | 0.025 | 0.027 | 0.023 | 0.024 | 0.023 | 0.015 | 0.020 | 0.041 | 0.043 | 0.051 | ND | 0.040 | 0.032 | 0.052 | 0.067 | 0.082 | 0.080 | 0.068 | 0.042 | 0.058 | 0.047 | 0.032 | 0.0423 |

Monthly Average = 0.0297

Maximum Hourly Average was 0.082 at Hour 18 on Day 30 with 1 occurences and there were no Hourly Violations
Maximum Daily Average was 0.0423 on Day 30 with 1 occurences and there were no Daily Violations
Operating Efficiency = 45.1 percent
ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data
[CEM 1990]

MEPA - Kuwait
April 1991
Frequency Distribution
Hourly Averages for NO2 in ppm

| Concentration | # of Hours | Percentage |
|---|---|---|
| 0.000 - 0.050 | 284 | 89.0 |
| 0.051 - 0.110 | 35 | 11.0 |
| 0.111 - 0.210 | 0 | 0.0 |
| 0.211+ | 0 | 0.0 |

MEPA - Kuwait

April 1991

Hourly Averages for NO in ppm

| Day \ Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 2 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 3 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 4 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 5 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 8 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 9 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 10 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 11 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 12 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 13 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 14 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 15 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 16 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 17 | ND | ND | ND | ND | ND | ND | ND | 0.002 | 0.003 | CAL | 0.007 | 0.006 | 0.010 | 0.009 | 0.003 | 0.005 | 0.003 | 0.005 | 0.003 | 0.003 | 0.002 | 0.002 | 0.001 | 0.002 | 0.0041 |
| 18 | 0.008 | 0.014 | 0.007 | 0.029 | 0.034 | 0.005 | 0.005 | 0.012 | 0.011 | 0.009 | 0.009 | 0.007 | 0.011 | 0.008 | 0.020 | 0.034 | 0.018 | 0.011 | 0.061 | 0.019 | 0.011 | 0.029 | 0.009 | 0.003 | 0.0160 |
| 19 | 0.002 | 0.010 | 0.013 | 0.010 | 0.018 | 0.016 | 0.011 | 0.028 | CAL | CAL | 0.015 | 0.006 | 0.007 | 0.021 | 0.017 | 0.020 | 0.021 | 0.011 | 0.029 | 0.017 | 0.019 | 0.030 | 0.022 | 0.040 | 0.0174 |
| 20 | 0.002 | 0.006 | 0.009 | 0.013 | 0.004 | 0.006 | 0.008 | 0.010 | 0.008 | 0.018 | 0.010 | 0.080 | 0.004 | 0.006 | 0.009 | 0.002 | 0.004 | 0.009 | 0.004 | 0.002 | 0.022 | 0.046 | 0.011 | 0.009 | 0.0126 |
| 21 | 0.004 | 0.005 | 0.002 | 0.016 | 0.023 | 0.014 | 0.003 | 0.003 | 0.004 | CAL | 0.009 | 0.004 | 0.005 | 0.004 | 0.003 | 0.004 | 0.006 | 0.004 | 0.011 | 0.012 | 0.024 | 0.072 | 0.082 | 0.022 | 0.0146 |
| 22 | 0.056 | 0.052 | 0.051 | 0.045 | 0.052 | 0.039 | 0.011 | 0.027 | 0.016 | 0.007 | 0.006 | 0.006 | 0.002 | 0.004 | 0.002 | 0.001 | 0.002 | 0.004 | 0.011 | 0.003 | 0.001 | 0.003 | 0.013 | 0.004 | 0.0174 |
| 23 | 0.015 | 0.001 | 0.005 | 0.021 | 0.016 | 0.011 | 0.020 | 0.015 | 0.006 | CAL | 0.013 | 0.005 | 0.002 | 0.005 | 0.004 | 0.009 | 0.012 | 0.014 | 0.029 | 0.025 | 0.035 | 0.003 | 0.001 | 0.001 | 0.0117 |
| 24 | 0.002 | 0.009 | 0.042 | 0.050 | 0.004 | 0.008 | 0.004 | 0.002 | 0.014 | 0.023 | 0.010 | 0.022 | 0.011 | 0.010 | 0.003 | 0.003 | 0.003 | 0.004 | 0.004 | 0.007 | 0.013 | 0.015 | 0.003 | 0.004 | 0.0113 |
| 25 | 0.009 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.002 | 0.003 | 0.008 | 0.052 | 0.033 | 0.017 | 0.005 | 0.006 | 0.012 | 0.007 | 0.006 | 0.006 | 0.010 | 0.056 | 0.080 | 0.034 | 0.013 | 0.004 | 0.0153 |
| 26 | 0.002 | 0.003 | 0.002 | 0.002 | 0.002 | 0.001 | 0.001 | 0.002 | 0.008 | ND | 0.013 | 0.013 | 0.012 | 0.010 | 0.013 | 0.011 | 0.005 | 0.004 | 0.004 | 0.011 | 0.031 | 0.003 | 0.002 | 0.002 | 0.0068 |
| 27 | 0.007 | 0.008 | 0.014 | 0.037 | 0.029 | 0.037 | 0.029 | 0.003 | 0.006 | 0.005 | 0.005 | 0.005 | 0.006 | 0.008 | 0.007 | 0.007 | 0.007 | 0.014 | 0.005 | 0.002 | 0.001 | 0.002 | 0.016 | 0.051 | 0.0130 |
| 28 | 0.042 | 0.049 | 0.039 | 0.046 | 0.011 | 0.011 | 0.005 | 0.007 | 0.009 | CAL | 0.010 | 0.009 | 0.005 | ND | 0.006 | 0.002 | 0.002 | ND | 0.010 | 0.001 | 0.002 | 0.010 | 0.067 | 0.033 | 0.0179 |
| 29 | 0.077 | 0.059 | 0.064 | 0.072 | 0.063 | 0.064 | 0.048 | 0.022 | 0.014 | 0.013 | 0.011 | 0.005 | 0.009 | 0.010 | 0.013 | 0.012 | 0.014 | 0.035 | 0.024 | 0.025 | 0.026 | 0.048 | 0.028 | 0.022 | 0.0324 |
| 30 | 0.007 | 0.012 | 0.002 | 0.003 | 0.001 | 0.003 | 0.005 | 0.004 | 0.004 | 0.019 | 0.027 | 0.027 | ND | 0.035 | 0.008 | 0.021 | 0.018 | 0.054 | 0.024 | 0.023 | 0.005 | 0.026 | 0.019 | 0.002 | 0.0152 |
| | | | | | | | | | | | | | | | | | | | | | | Monthly Average = | | | 0.0149 |

Maximum Hourly Average was 0.082 at Hour 23 on Day 21 with 1 occurences and there were no Hourly Violations

Maximum Daily Average was 0.0324 on Day 29 with 1 occurences and there were no Daily Violations

Operating Efficiency = 45.1 percent

ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data

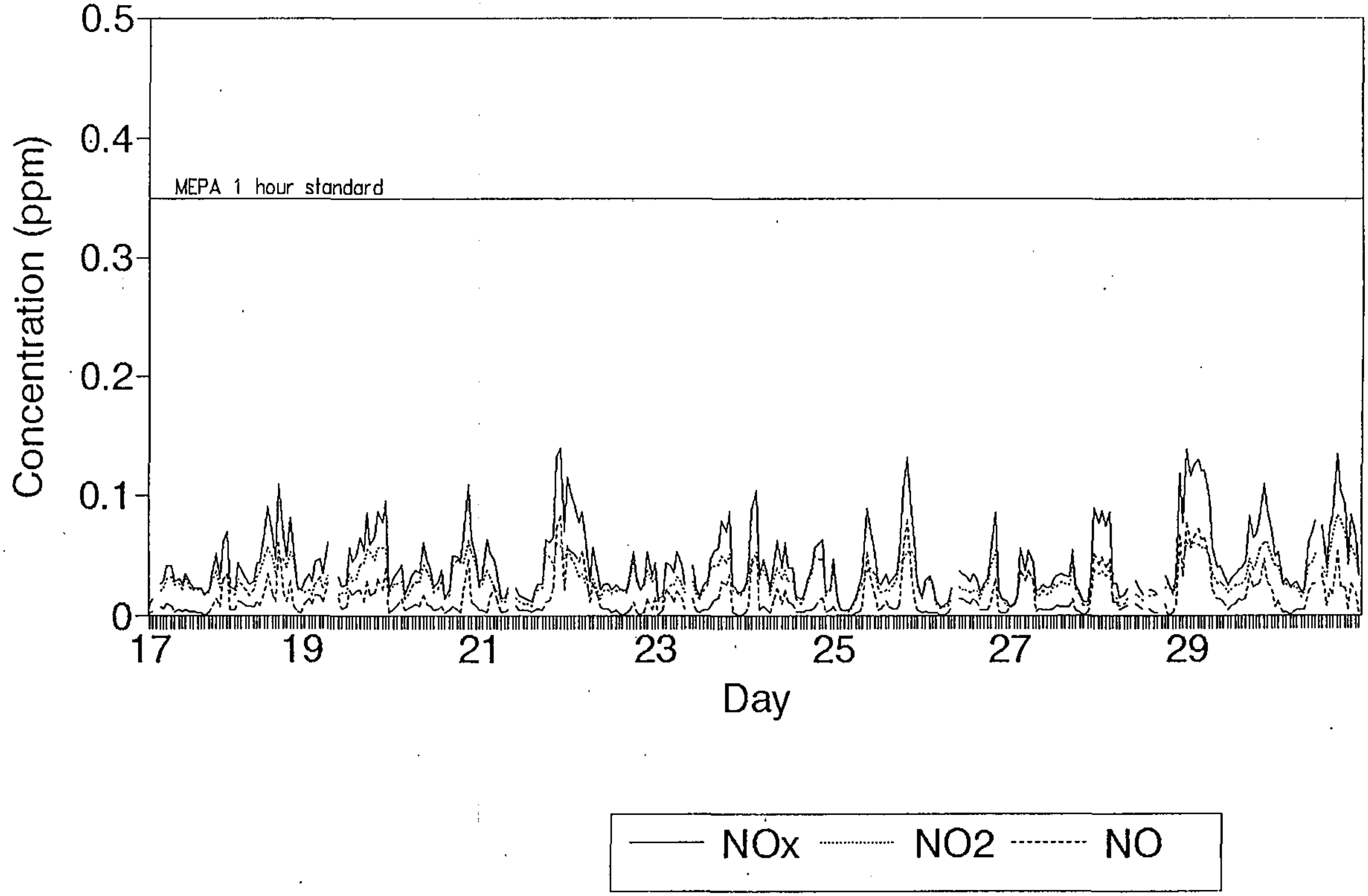
[CEM 1990]

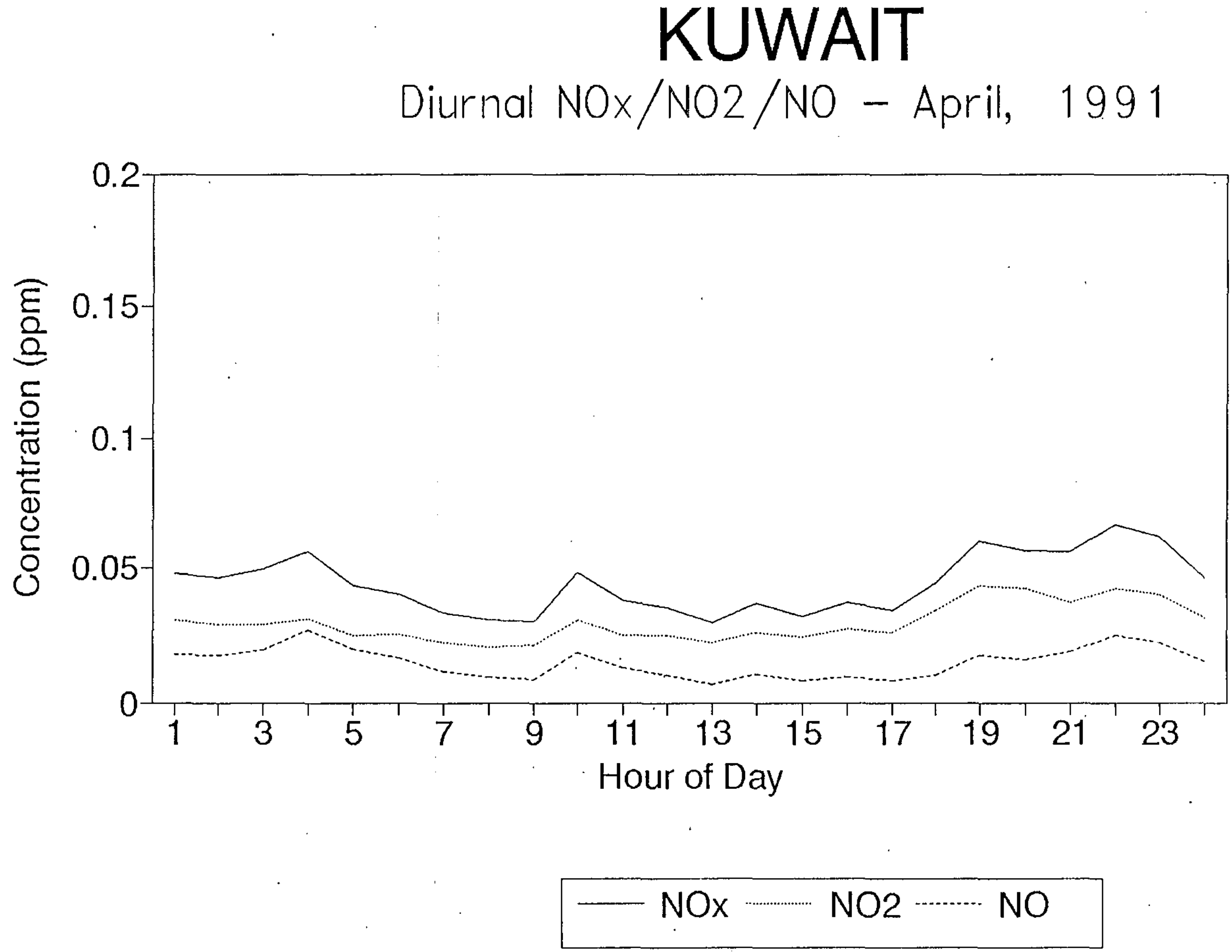
MEPA - Kuwait
April 1991
Frequency Distribution
Hourly Averages for NO in ppm

| Concentration | # of Hours | Percentage |
|---|---|---|
| 0.000 - 0.050 | 299 | 93.7 |
| 0.051 - 0.110 | 20 | 6.3 |
| 0.111 - 0.210 | 0 | 0.0 |
| 0.211+ | 0 | 0.0 |

# KUWAIT

## Hourly NOx/NO2/NO - April, 1991



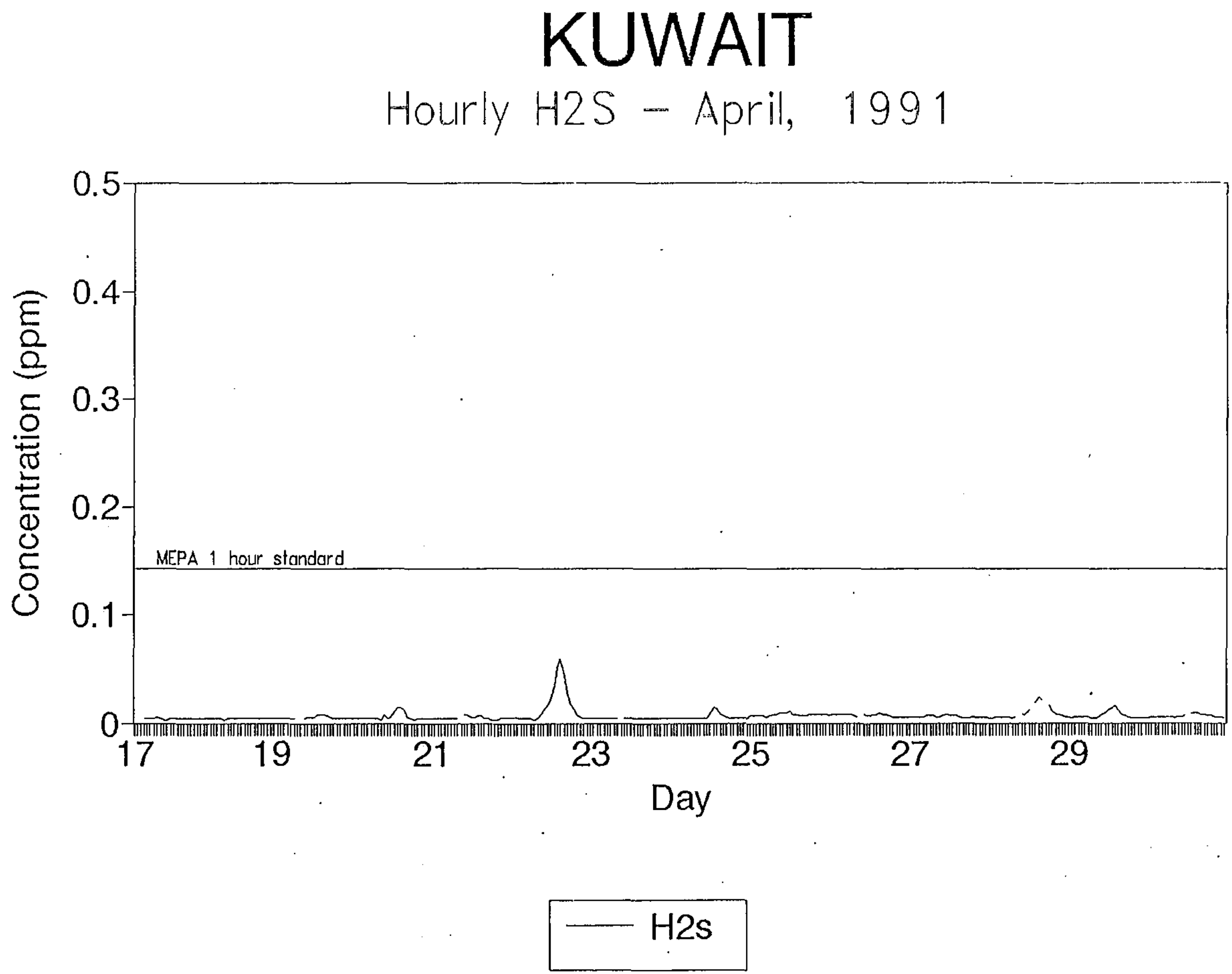

KUWAIT
Diurnal NOx/NO2/NO - April, 1991
Concentration (ppm)
0.2
0.15
0.1
0.05
0
1
3
5
7
9
11
13
15
17
19
21
23
Hour of Day
NOx
NO2
NO

MEPA - Kuwait
April 1991
Hourly Averages for H2S in ppm

| Hour / Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 2 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 3 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 4 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 5 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 8 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 9 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 10 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 11 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 12 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 13 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 14 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 15 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 16 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 17 | ND | ND | ND | ND | ND | ND | ND | 0.000 | 0.000 | CAL | 0.004 | 0.004 | 0.004 | 0.005 | 0.006 | 0.005 | 0.003 | 0.003 | 0.004 | 0.005 | 0.004 | 0.004 | 0.004 | 0.004 | 0.0037 |
| 18 | 0.004 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.004 | 0.004 | 0.003 | 0.004 | 0.005 | 0.004 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.0047 |
| 19 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.005 | 0.004 | 0.005 | CAL | CAL | 0.005 | 0.006 | 0.006 | 0.006 | 0.008 | 0.009 | 0.008 | 0.007 | 0.006 | 0.004 | 0.005 | 0.005 | 0.005 | 0.005 | 0.0054 |
| 20 | 0.005 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.003 | 0.008 | 0.004 | 0.006 | 0.011 | 0.015 | 0.015 | 0.012 | 0.006 | 0.004 | 0.003 | 0.004 | 0.004 | 0.004 | 0.004 | 0.0058 |
| 21 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.004 | 0.004 | CAL | 0.008 | 0.008 | 0.006 | 0.006 | 0.007 | 0.007 | 0.005 | 0.004 | 0.003 | 0.003 | 0.003 | 0.004 | 0.004 | 0.004 | 0.0050 |
| 22 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.003 | 0.005 | 0.008 | 0.011 | 0.018 | 0.022 | 0.034 | 0.051 | 0.059 | 0.043 | 0.028 | 0.018 | 0.013 | 0.008 | 0.006 | 0.005 | 0.005 | 0.0152 |
| 23 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | CAL | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.005 | 0.005 | 0.005 | 0.004 | 0.004 | 0.004 | 0.004 | 0.0045 |
| 24 | 0.004 | 0.005 | 0.005 | 0.005 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.005 | 0.009 | 0.015 | 0.013 | 0.009 | 0.007 | 0.006 | 0.004 | 0.005 | 0.005 | 0.004 | 0.004 | 0.005 | 0.0057 |
| 25 | 0.007 | 0.007 | 0.007 | 0.007 | 0.007 | 0.006 | 0.007 | 0.008 | 0.009 | 0.010 | 0.010 | 0.010 | 0.011 | 0.009 | 0.008 | 0.007 | 0.007 | 0.007 | 0.008 | 0.008 | 0.009 | 0.009 | 0.008 | 0.008 | 0.0081 |
| 26 | 0.007 | 0.008 | 0.009 | 0.009 | 0.009 | 0.008 | 0.008 | 0.007 | 0.006 | ND | 0.008 | 0.007 | 0.007 | 0.008 | 0.009 | 0.010 | 0.009 | 0.008 | 0.007 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.0076 |
| 27 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.007 | 0.007 | 0.007 | 0.006 | 0.006 | 0.007 | 0.008 | 0.007 | 0.007 | 0.007 | 0.006 | 0.005 | 0.005 | 0.005 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.0063 |
| 28 | 0.005 | 0.005 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.005 | 0.006 | CAL | 0.008 | 0.009 | 0.012 | ND | 0.019 | 0.024 | 0.022 | ND | 0.016 | 0.011 | 0.009 | 0.008 | 0.007 | 0.006 | 0.0096 |
| 29 | 0.006 | 0.005 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.005 | 0.005 | 0.006 | 0.008 | 0.010 | 0.012 | 0.015 | 0.016 | 0.012 | 0.009 | 0.007 | 0.006 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.0074 |
| 30 | 0.005 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.005 | 0.006 | 0.006 | 0.007 | ND | 0.010 | 0.010 | 0.010 | 0.009 | 0.008 | 0.007 | 0.007 | 0.006 | 0.006 | 0.006 | 0.005 | 0.0067 |

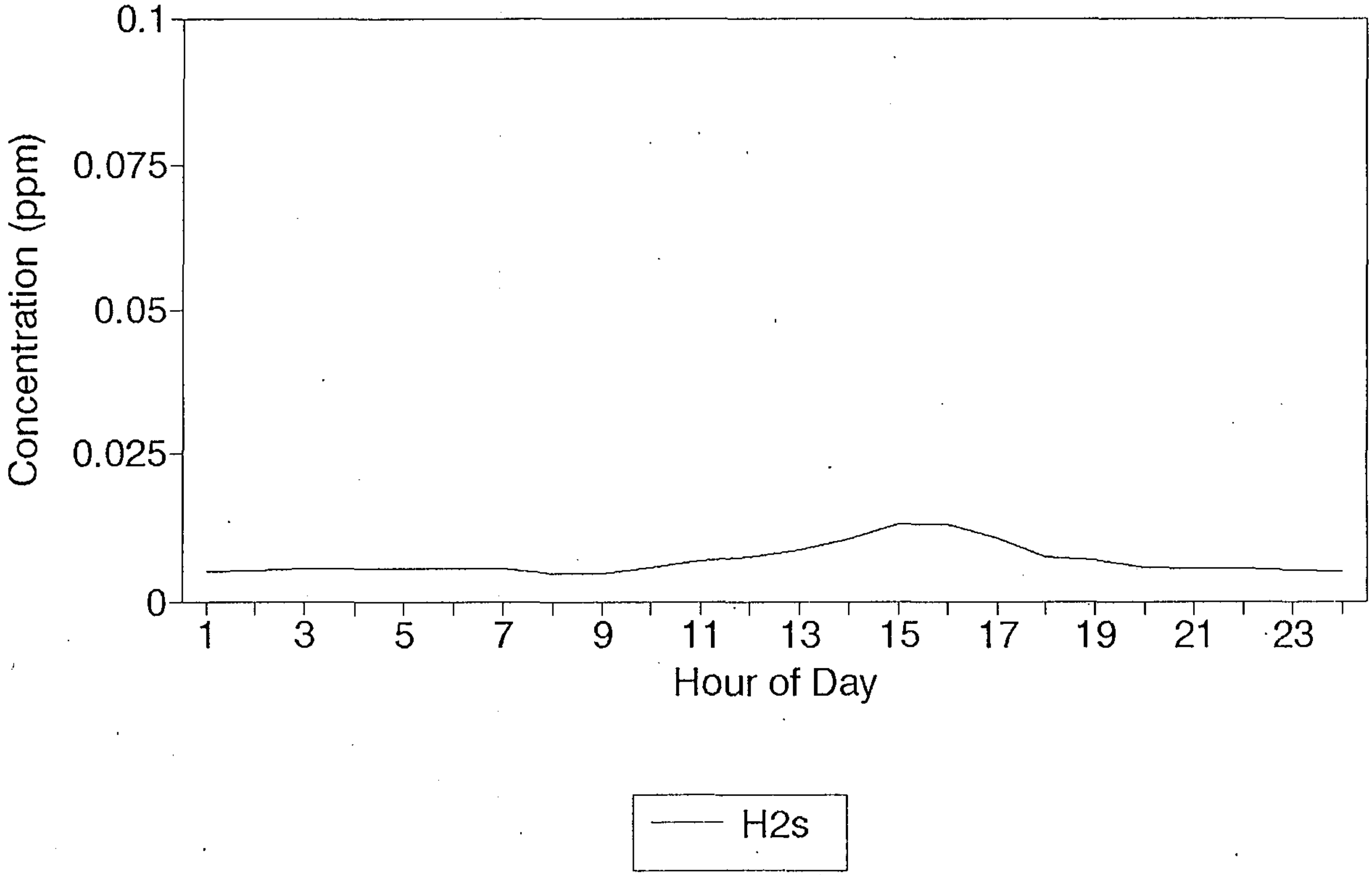
Monthly Average = 0.0069

Maximum Hourly Average was 0.059 at Hour 16 on Day 22 with 1 occurences and there were no Hourly Violations
Maximum Daily Average was 0.0152 on Day 22 with 1 occurences and there were no Daily Violations
Operating Efficiency = 45.1 percent
ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data
[CEM 1990]


KUWAIT
Hourly H2S - April, 1991
Concentration (ppm)
0.5
0.4
0.3
0.2
0.1
0
MEPA 1 hour standard
17
19
21
23
25
27
29
Day
H2s

# KUWAIT

Diurnal H2S - April, 1991



MEPA - Kuwait
April 1991
Hourly Averages for SO2 in ppm

| Day \ Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 2 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 3 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 4 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 5 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 8 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 9 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 10 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 11 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 12 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 13 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 14 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 15 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 16 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 17 | ND | ND | ND | ND | ND | ND | ND | 0.008 | 0.006 | CAL | 0.007 | 0.007 | 0.008 | 0.006 | 0.006 | 0.005 | 0.006 | 0.010 | 0.012 | 0.017 | 0.020 | 0.017 | 0.021 | 0.039 | 0.0122 |
| 18 | 0.108 | 0.145 | 0.083 | 0.040 | 0.030 | 0.011 | 0.009 | 0.009 | 0.008 | 0.008 | 0.011 | 0.013 | 0.014 | 0.014 | 0.019 | 0.015 | 0.014 | 0.015 | 0.014 | 0.014 | 0.016 | 0.017 | 0.016 | 0.015 | 0.0274 |
| 19 | 0.017 | 0.032 | 0.026 | 0.017 | 0.015 | 0.016 | 0.012 | 0.019 | CAL | CAL | 0.018 | 0.015 | 0.011 | 0.020 | 0.019 | 0.019 | 0.020 | 0.010 | 0.007 | 0.008 | 0.013 | 0.015 | 0.016 | 0.032 | 0.0171 |
| 20 | 0.036 | 0.053 | 0.056 | 0.041 | 0.027 | 0.012 | 0.015 | 0.023 | 0.021 | 0.036 | 0.026 | 0.021 | 0.018 | 0.018 | 0.019 | 0.008 | 0.007 | 0.007 | 0.009 | 0.047 | 0.030 | 0.048 | 0.041 | 0.017 | 0.0265 |
| 21 | 0.007 | 0.006 | 0.018 | 0.016 | 0.014 | 0.013 | 0.004 | 0.004 | 0.006 | CAL | 0.012 | 0.005 | 0.004 | 0.004 | 0.003 | 0.004 | 0.019 | 0.008 | 0.006 | 0.006 | 0.008 | 0.022 | 0.030 | 0.028 | 0.0107 |
| 22 | 0.032 | 0.022 | 0.021 | 0.019 | 0.023 | 0.021 | 0.009 | 0.016 | 0.011 | 0.016 | 0.011 | 0.027 | 0.015 | 0.025 | 0.033 | 0.035 | 0.022 | 0.012 | 0.009 | 0.012 | 0.001 | 0.001 | 0.014 | 0.049 | 0.0190 |
| 23 | 0.040 | 0.027 | 0.013 | 0.014 | 0.010 | 0.010 | 0.012 | 0.010 | 0.005 | CAL | 0.007 | 0.003 | 0.001 | 0.004 | 0.009 | 0.019 | 0.022 | 0.021 | 0.021 | 0.013 | 0.016 | 0.001 | 0.001 | 0.002 | 0.0122 |
| 24 | 0.002 | 0.005 | 0.015 | 0.018 | 0.002 | 0.003 | 0.003 | 0.002 | 0.004 | 0.008 | 0.018 | 0.026 | 0.021 | 0.018 | 0.004 | 0.001 | 0.001 | 0.000 | 0.001 | 0.005 | 0.006 | 0.002 | 0.003 | 0.133 | 0.0125 |
| 25 | 0.269 | 0.053 | 0.039 | 0.010 | 0.001 | 0.002 | 0.089 | 0.148 | 0.107 | 0.098 | 0.120 | 0.109 | 0.077 | 0.044 | 0.035 | 0.026 | 0.010 | 0.006 | 0.007 | 0.008 | 0.014 | 0.013 | 0.011 | 0.010 | 0.0544 |
| 26 | 0.035 | 0.270 | 0.326 | 0.247 | 0.041 | 0.017 | 0.012 | 0.009 | 0.009 | ND | 0.025 | 0.011 | 0.010 | 0.003 | 0.009 | 0.007 | 0.003 | 0.002 | 0.002 | 0.004 | 0.016 | 0.001 | 0.008 | 0.030 | 0.0477 |
| 27 | 0.027 | 0.036 | 0.071 | 0.138 | 0.126 | 0.151 | 0.139 | 0.074 | 0.040 | 0.043 | 0.025 | 0.006 | 0.018 | 0.014 | 0.021 | 0.017 | 0.016 | 0.008 | 0.002 | 0.009 | 0.001 | 0.000 | 0.008 | 0.022 | 0.0422 |
| 28 | 0.016 | 0.020 | 0.017 | 0.025 | 0.008 | 0.007 | 0.001 | 0.011 | 0.002 | CAL | 0.006 | 0.004 | 0.003 | ND | 0.007 | 0.008 | 0.006 | ND | 0.005 | 0.002 | 0.001 | 0.003 | 0.022 | 0.012 | 0.0089 |
| 29 | 0.029 | 0.025 | 0.028 | 0.030 | 0.028 | 0.028 | 0.023 | 0.011 | 0.008 | 0.008 | 0.009 | 0.006 | 0.007 | 0.008 | 0.016 | 0.014 | 0.012 | 0.016 | 0.009 | 0.006 | 0.008 | 0.005 | 0.004 | 0.003 | 0.0142 |
| 30 | 0.003 | 0.003 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.011 | 0.013 | 0.016 | ND | 0.025 | 0.010 | 0.013 | 0.003 | 0.012 | 0.013 | 0.014 | 0.004 | 0.009 | 0.009 | 0.002 | 0.0070 |
| | | | | | | | | | | | | | | | | | | | | | | Monthly Average = | | | 0.0227 |

Maximum Hourly Average was 0.326 at Hour 3 on Day 26 with 1 occurences and the Number of Hourly Violations were 1

Maximum Daily Average was 0.0544 on Day 25 with 1 occurences and there were no Daily Violations

Operating Efficiency = 45.1 percent

ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data

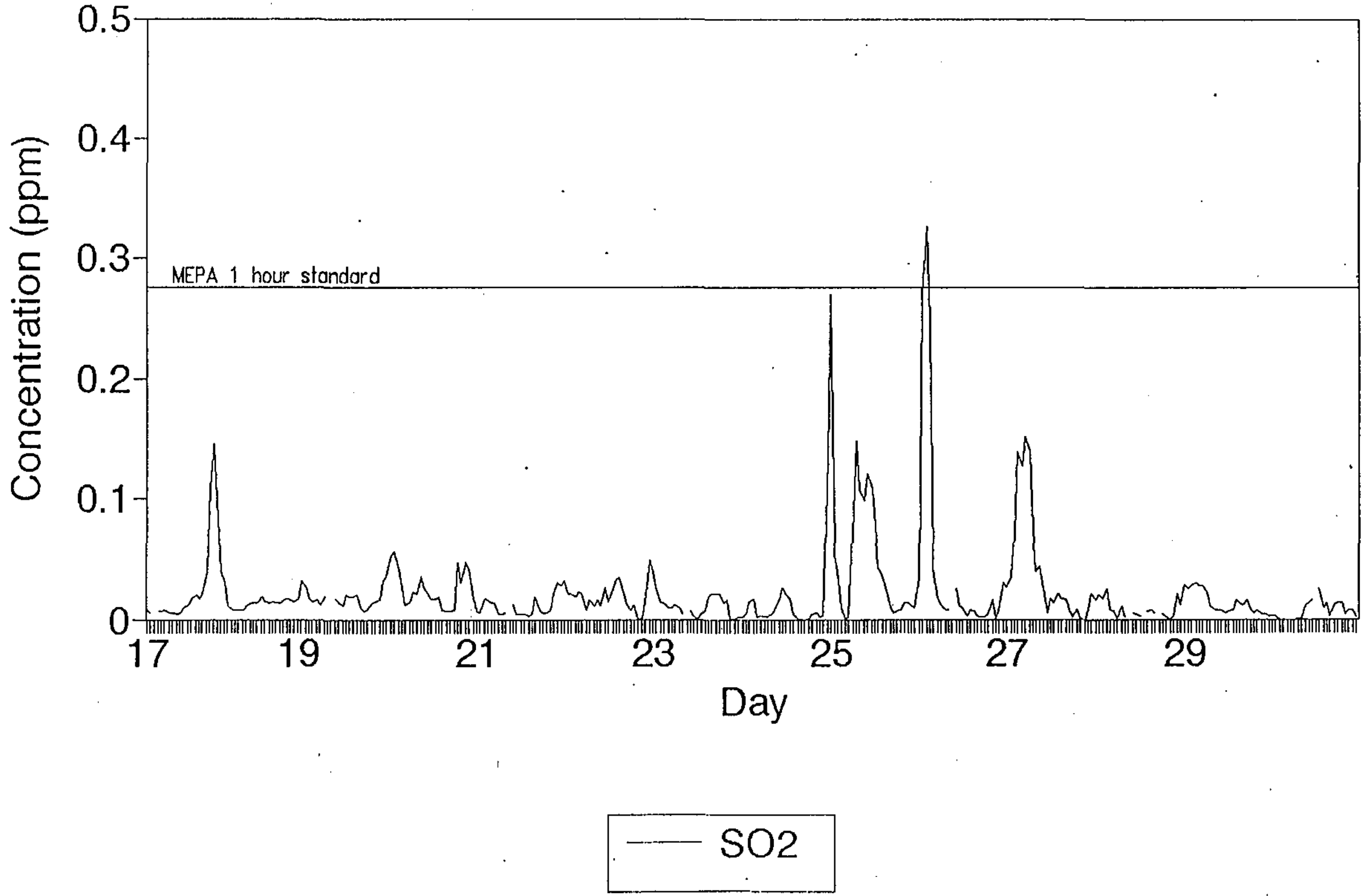
[CEM 1990]

MEPA - Kuwait
April 1991
Frequency Distribution
Hourly Averages for SO2 in ppm

| Concentration | # of Hours | Percentage |
|---|---|---|
| 0.000 - 0.020 | 230 | 72.1 |
| 0.021 - 0.060 | 68 | 21.3 |
| 0.061 - 0.110 | 9 | 2.8 |
| 0.111 - 0.170 | 8 | 2.5 |
| 0.171 - 0.340 | 4 | 1.3 |
| 0.341+ | 0 | 0.0 |

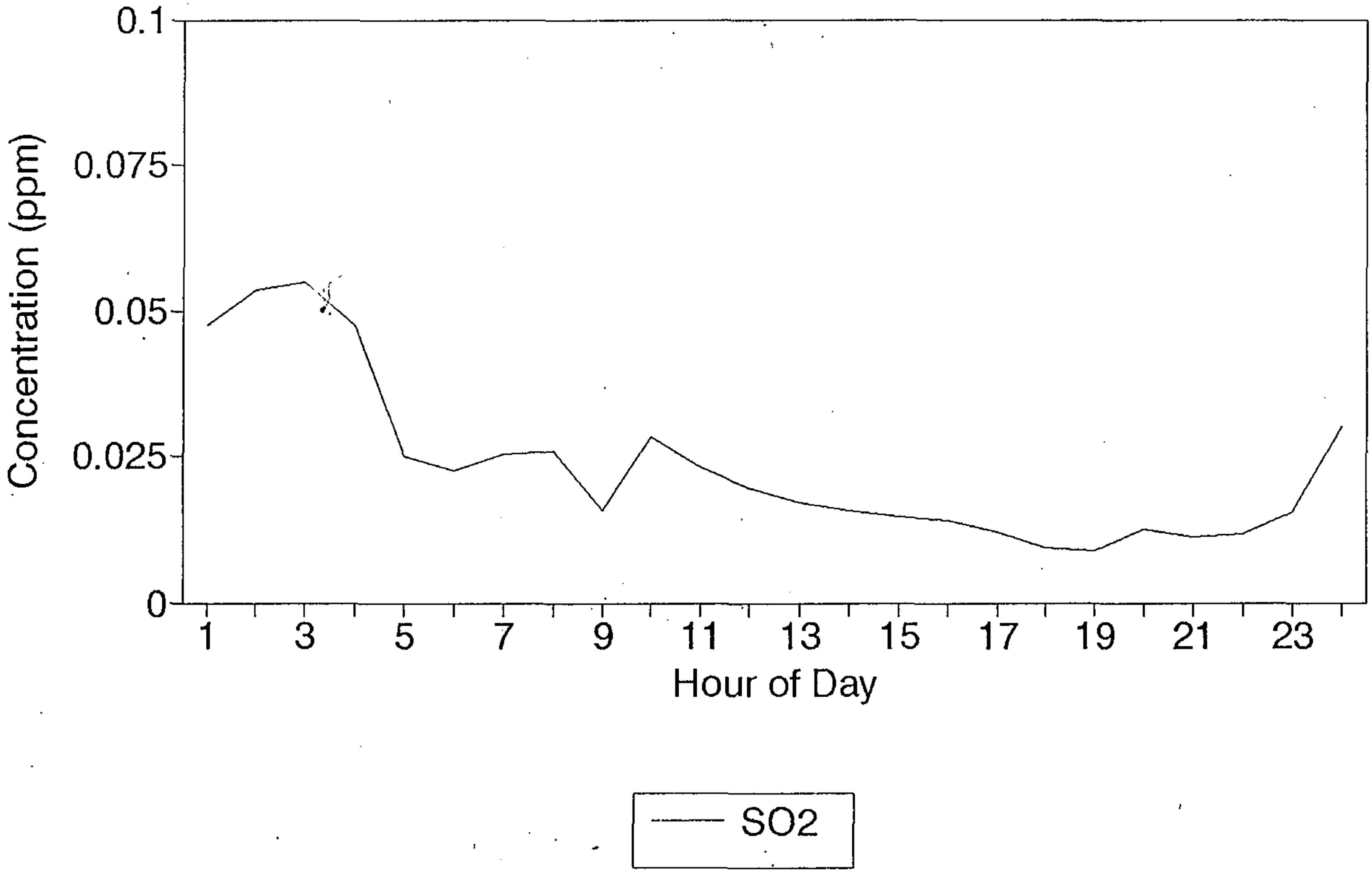
# KUWAIT

Hourly SO2 - April, 1991



# KUWAIT

Diurnal SO2 - April, 1991



MEPA - Kuwait

May 1991

Hourly Averages for Direction(degrees)

| Hour / Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 282 | 277 | 284 | 287 | 286 | 278 | 272 | 279 | 294 | 312 | 340 | 333 | 338 | 349 | 74 | 94 | 126 | 0 | 0 | 354 | 11 | 329 | 278 | 284 | 316.70 |
| 2 | 240 | 241 | 241 | 238 | 253 | 255 | 254 | 269 | 283 | 306 | 307 | 328 | 355 | 301 | 298 | 317 | 329 | 330 | 328 | 322 | 316 | 310 | 311 | 315 | 294.47 |
| 3 | 318 | 325 | 328 | 329 | 329 | 326 | 329 | 331 | 332 | 0 | 334 | 332 | 330 | 331 | 338 | 335 | 333 | 333 | 343 | 334 | 328 | 315 | 304 | 320 | 329.86 |
| 4 | 325 | 322 | 324 | 329 | 330 | 318 | 308 | 313 | 312 | 314 | 312 | 306 | 307 | 308 | 311 | 312 | 323 | 318 | 321 | 328 | 307 | 287 | 280 | 271 | 312.12 |
| 5 | 284 | 295 | 273 | 268 | 270 | 279 | 284 | 282 | 289 | 302 | 0 | 309 | 311 | 316 | 310 | 311 | 314 | 313 | 313 | 311 | 298 | 273 | 290 | 292 | 297.43 |
| 6 | 283 | 264 | 258 | 264 | 268 | 269 | 275 | 277 | 292 | 304 | 310 | 308 | 314 | 309 | 305 | 308 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 311.46 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 299 | 218 | 172 | 99 | 130 | 147 | 162 | 172 | 213 | 229 | 243 | 251 | 340.27 |
| 9 | 242 | 268 | 276 | 276 | 272 | 288 | 304 | 322 | 358 | 9 | 0 | 22 | 56 | 73 | 87 | 115 | 125 | 146 | 149 | 189 | 203 | 208 | 230 | 244 | 264.97 |
| 10 | 246 | 249 | 270 | 306 | 315 | 312 | 315 | 308 | 308 | 0 | 313 | 328 | 329 | 326 | 321 | 323 | 319 | 324 | 325 | 332 | 330 | 330 | 317 | 284 | 313.15 |
| 11 | 265 | 277 | 285 | 258 | 276 | 298 | 304 | 309 | 312 | 315 | 315 | 311 | 315 | 315 | 314 | 317 | 326 | 328 | 332 | 333 | 330 | 326 | 325 | 308 | 308.55 |
| 12 | 278 | 281 | 259 | 265 | 271 | 277 | 286 | 316 | 341 | 0 | 314 | 315 | 306 | 308 | 309 | 316 | 335 | 332 | 349 | 106 | 50 | 45 | 91 | 114 | 318.94 |
| 13 | 227 | 266 | 264 | 260 | 256 | 259 | 269 | 269 | 282 | 321 | 347 | 349 | 330 | 325 | 290 | 198 | 107 | 85 | 230 | 245 | 254 | 267 | 276 | 248 | 272.39 |
| 14 | 265 | 261 | 262 | 262 | 249 | 240 | 248 | 252 | 261 | 262 | 294 | 319 | 80 | 72 | 107 | 123 | 124 | 147 | 153 | 156 | 168 | 179 | 206 | 237 | 217.51 |
| 15 | 240 | 248 | 239 | 247 | 250 | 241 | 241 | 255 | 253 | 0 | 358 | 43 | 47 | 47 | 66 | 75 | 90 | 101 | 119 | 133 | 151 | 160 | 124 | 108 | 145.60 |
| 16 | 109 | 114 | 124 | 144 | 184 | 205 | 196 | 330 | 140 | 337 | 339 | 345 | 345 | 340 | 343 | 346 | 348 | 339 | 336 | 351 | 346 | 333 | 334 | 327 | 345.96 |
| 17 | 328 | 330 | 335 | 333 | 334 | 332 | 333 | 330 | 0 | 337 | 339 | 345 | 345 | 349 | 343 | 346 | 348 | 339 | 336 | 351 | 346 | 335 | 334 | 327 | 338.94 |
| 18 | 328 | 330 | 335 | 333 | 334 | 332 | 333 | 328 | 339 | 338 | 335 | 337 | 338 | 333 | 336 | 338 | 332 | 334 | 335 | 336 | 333 | 331 | 329 | 326 | 333.46 |
| 19 | 324 | 321 | 320 | 306 | 295 | 294 | 312 | 324 | 330 | 329 | 0 | 333 | 330 | 333 | 336 | 340 | 342 | 344 | 344 | 341 | 344 | 329 | 324 | 315 | 328.00 |
| 20 | 304 | 305 | 310 | 301 | 272 | 266 | 270 | 285 | 305 | 319 | 310 | 311 | 317 | 334 | 335 | 336 | 341 | 12 | 8 | 8 | 3 | 353 | 328 | 292 | 319.23 |
| 21 | 282 | 278 | 260 | 253 | 245 | 239 | 245 | 263 | 274 | 0 | 39 | 111 | 73 | 101 | 127 | 137 | 140 | 144 | 151 | 129 | 199 | 223 | 286 | 297 | 216.37 |
| 22 | 288 | 284 | 291 | 306 | 330 | 332 | 334 | 339 | 347 | 352 | 352 | 359 | 6 | 8 | 11 | 11 | 12 | 11 | 355 | 345 | 11 | 9 | 357 | 344 | 345.85 |
| 23 | 349 | 8 | 7 | 352 | 338 | 316 | 355 | 345 | 10 | 8 | 359 | 0 | 335 | 343 | 339 | 324 | 320 | 321 | 324 | 333 | 320 | 338 | 341 | 306 | 341.30 |
| 24 | 286 | 279 | 280 | 279 | 276 | 279 | 318 | 321 | 323 | 355 | 347 | 336 | 331 | 332 | 333 | 337 | 337 | 342 | 353 | 345 | 335 | 326 | 322 | 325 | 321.34 |
| 25 | 321 | 323 | 318 | 310 | 312 | 318 | 326 | 325 | 314 | 0 | 320 | 311 | 317 | 327 | 324 | 326 | 334 | 333 | 333 | 344 | 337 | 318 | 304 | 309 | 323.41 |
| 26 | 313 | 321 | 305 | 289 | 272 | 274 | 282 | 301 | 311 | 317 | 322 | 337 | 348 | 330 | 348 | 63 | 103 | 104 | 124 | 139 | 167 | 196 | 226 | 252 | 302.09 |
| 27 | 251 | 242 | 245 | 242 | 234 | 233 | 225 | 225 | 262 | 0 | 319 | 312 | 319 | 321 | 0 | 0 | 321 | 314 | 317 | 319 | 311 | 312 | 315 | 311 | 294.20 |
| 28 | 319 | 320 | 317 | 323 | 321 | 320 | 325 | 326 | 330 | 335 | 336 | 332 | 326 | 326 | 327 | 331 | 335 | 334 | 335 | 333 | 333 | 332 | 327 | 328 | 327.96 |
| 29 | 329 | 328 | 329 | 332 | 329 | 329 | 329 | 329 | 330 | 0 | 328 | 331 | 325 | 329 | 332 | 339 | 343 | 344 | 340 | 339 | 344 | 329 | 327 | 328 | 333.37 |
| 30 | 329 | 329 | 330 | 329 | 330 | 328 | 326 | 315 | 319 | 334 | 337 | 332 | 333 | 333 | 341 | 347 | 352 | 359 | 333 | 352 | 346 | 336 | 328 | 328 | 334.38 |
| 31 | 327 | 327 | 339 | 357 | 342 | 337 | 344 | 334 | 336 | 343 | 350 | 350 | 355 | 0 | 1 | 356 | 351 | 345 | 332 | 325 | 327 | 324 | 326 | 328 | 340.65 |

Monthly Average = 321

Operating Efficiency for Wind Direction = 100.0 percent

** = missing or no data

Last Instrument Calibration Date - unknown

[CEM]

MEPA - Kuwait

May 1991

Hourly Averages for Wind Speed(meters/sec)

| Day \ Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2.7 | 2.4 | 2.7 | 2.4 | 3.0 | 2.5 | 2.4 | 2.6 | 2.6 | 2.2 | 2.4 | 2.5 | 1.3 | 1.4 | 0.9 | 1.1 | 1.5 | 0.0 | 0.0 | 0.0 | 0.7 | 0.9 | 0.8 | 0.0 | 1.63 |
| 2 | 0.4 | 0.4 | 0.9 | 0.6 | 1.0 | 2.2 | 3.0 | 3.0 | 3.6 | 4.2 | 1.3 | 2.3 | 2.7 | 1.9 | 2.2 | 3.3 | 4.8 | 6.3 | 4.9 | 4.5 | 4.3 | 5.7 | 6.2 | 5.6 | 3.14 |
| 3 | 5.5 | 4.9 | 5.6 | 6.3 | 6.2 | 6.1 | 6.5 | 6.7 | 7.1 | 0.0 | 5.0 | 6.8 | 6.8 | 7.1 | 6.2 | 6.3 | 6.2 | 4.8 | 3.8 | 3.5 | 2.9 | 2.5 | 4.0 | 3.5 | 5.18 |
| 4 | 3.8 | 3.1 | 3.4 | 4.5 | 4.6 | 3.7 | 4.8 | 4.7 | 6.0 | 5.9 | 7.0 | 7.6 | 7.1 | 7.2 | 7.2 | 6.6 | 5.5 | 4.5 | 3.3 | 2.8 | 2.2 | 2.3 | 2.5 | 2.3 | 4.69 |
| 5 | 3.1 | 3.4 | 2.9 | 2.3 | 2.2 | 2.9 | 3.8 | 4.0 | 4.6 | 4.9 | 0.0 | 6.5 | 6.4 | 5.7 | 5.8 | 6.2 | 5.8 | 4.7 | 3.1 | 2.5 | 2.5 | 2.1 | 2.3 | 1.8 | 3.73 |
| 6 | 2.4 | 2.7 | 2.9 | 3.5 | 3.7 | 3.7 | 4.4 | 3.9 | 4.6 | 5.9 | 6.5 | 6.2 | 5.3 | 5.1 | 5.7 | 4.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.95 |
| 7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.00 |
| 8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.5 | 1.0 | 2.4 | 4.2 | 4.1 | 4.3 | 3.2 | 3.8 | 3.0 | 3.3 | 3.2 | 3.0 | 1.54 |
| 9 | 3.8 | 3.7 | 2.4 | 1.8 | 1.9 | 2.1 | 1.9 | 1.6 | 1.8 | 2.4 | 1.8 | 2.7 | 3.3 | 4.1 | 3.8 | 3.3 | 3.7 | 3.3 | 3.0 | 4.1 | 4.0 | 3.9 | 3.9 | 5.1 | 3.06 |
| 10 | 4.7 | 4.9 | 6.6 | 6.1 | 4.7 | 6.0 | 5.0 | 7.3 | 7.9 | 0.0 | 6.4 | 6.5 | 6.5 | 6.9 | 6.7 | 6.8 | 5.7 | 4.7 | 4.2 | 3.5 | 3.9 | 3.4 | 2.6 | 2.4 | 5.14 |
| 11 | 2.3 | 2.6 | 3.3 | 2.2 | 2.8 | 3.9 | 4.8 | 4.6 | 6.2 | 6.1 | 7.6 | 7.9 | 7.7 | 8.1 | 7.4 | 7.2 | 6.5 | 6.4 | 5.9 | 4.5 | 4.0 | 3.5 | 2.7 | 3.1 | 5.05 |
| 12 | 2.1 | 2.5 | 2.9 | 2.8 | 2.6 | 2.5 | 3.6 | 4.2 | 3.8 | 0.0 | 4.3 | 5.3 | 6.0 | 6.4 | 5.8 | 5.3 | 4.6 | 4.4 | 2.5 | 1.1 | 1.3 | 1.7 | 0.8 | 0.3 | 3.20 |
| 13 | 1.3 | 2.3 | 3.1 | 3.2 | 3.2 | 3.4 | 3.3 | 3.4 | 2.9 | 2.0 | 1.9 | 2.5 | 2.3 | 2.6 | 3.0 | 3.5 | 2.9 | 2.7 | 2.3 | 2.4 | 2.0 | 1.9 | 1.7 | 1.6 | 2.56 |
| 14 | 2.4 | 3.2 | 3.3 | 3.1 | 3.3 | 3.6 | 3.7 | 3.5 | 4.6 | 3.4 | 2.9 | 2.7 | 3.8 | 4.2 | 3.9 | 4.4 | 5.5 | 4.7 | 3.6 | 3.1 | 3.6 | 2.3 | 0.2 | 2.6 | 3.40 |
| 15 | 2.4 | 2.4 | 3.4 | 3.2 | 3.0 | 2.5 | 3.5 | 3.3 | 2.1 | 0.0 | 2.1 | 3.6 | 5.0 | 5.6 | 5.9 | 5.3 | 4.7 | 4.4 | 3.7 | 2.9 | 2.4 | 1.8 | 1.4 | 1.8 | 3.18 |
| 16 | 1.7 | 0.5 | 0.4 | 0.6 | 1.3 | 2.5 | 2.1 | 7.0 | 2.7 | 7.7 | 7.4 | 6.7 | 6.9 | 7.2 | 6.8 | 6.6 | 6.0 | 5.6 | 4.7 | 4.2 | 3.8 | 4.2 | 3.7 | 3.7 | 4.33 |
| 17 | 3.6 | 3.8 | 4.6 | 3.7 | 3.7 | 4.1 | 4.6 | 7.0 | 0.0 | 7.7 | 7.4 | 6.7 | 6.9 | 7.2 | 6.8 | 6.6 | 6.0 | 5.6 | 4.7 | 4.2 | 3.8 | 4.2 | 3.7 | 3.7 | 5.01 |
| 18 | 3.6 | 3.8 | 4.6 | 3.7 | 3.7 | 4.1 | 4.6 | 5.0 | 5.7 | 8.3 | 7.4 | 7.8 | 8.3 | 8.1 | 7.9 | 7.7 | 6.8 | 6.1 | 5.2 | 5.1 | 4.7 | 4.7 | 4.2 | 4.2 | 5.64 |
| 19 | 4.3 | 3.8 | 3.7 | 3.6 | 3.3 | 4.0 | 5.5 | 6.0 | 6.5 | 7.1 | 0.0 | 8.6 | 8.6 | 8.8 | 8.1 | 8.0 | 7.9 | 7.0 | 5.2 | 4.2 | 3.4 | 3.7 | 3.3 | 3.0 | 5.32 |
| 20 | 3.9 | 4.5 | 4.3 | 4.0 | 3.2 | 3.8 | 3.8 | 5.0 | 5.6 | 6.0 | 6.3 | 6.2 | 6.3 | 5.9 | 6.1 | 6.1 | 5.6 | 5.0 | 4.8 | 3.3 | 2.8 | 1.9 | 1.2 | 1.8 | 4.47 |
| 21 | 1.9 | 2.3 | 3.3 | 3.8 | 4.1 | 4.2 | 4.2 | 4.1 | 4.4 | 0.0 | 2.8 | 4.4 | 4.6 | 5.6 | 6.1 | 6.2 | 5.7 | 4.9 | 4.1 | 1.6 | 1.0 | 2.0 | 2.2 | 2.0 | 3.56 |
| 22 | 1.6 | 0.6 | 1.4 | 2.6 | 3.1 | 3.8 | 3.6 | 3.9 | 4.4 | 5.1 | 5.1 | 5.4 | 6.5 | 6.5 | 6.6 | 7.0 | 6.3 | 5.9 | 3.9 | 4.5 | 4.3 | 3.3 | 3.0 | 3.3 | 4.24 |
| 23 | 2.7 | 2.5 | 2.1 | 1.6 | 1.7 | 2.1 | 3.5 | 4.1 | 4.9 | 4.8 | 4.9 | 0.0 | 4.8 | 5.2 | 5.4 | 5.8 | 5.5 | 5.7 | 4.7 | 3.9 | 3.1 | 3.2 | 1.8 | 2.0 | 3.58 |
| 24 | 2.8 | 2.9 | 3.2 | 2.7 | 2.4 | 2.6 | 2.4 | 2.8 | 3.0 | 2.3 | 4.2 | 5.8 | 6.9 | 7.2 | 7.8 | 7.2 | 7.0 | 5.8 | 4.9 | 4.3 | 4.2 | 3.6 | 3.6 | 3.7 | 4.30 |
| 25 | 3.7 | 3.6 | 3.5 | 4.0 | 4.3 | 4.3 | 5.5 | 5.2 | 6.6 | 0.0 | 7.9 | 8.3 | 8.6 | 7.5 | 7.2 | 6.5 | 5.9 | 5.2 | 3.7 | 3.0 | 3.2 | 2.5 | 3.2 | 3.1 | 4.85 |
| 26 | 2.4 | 2.2 | 2.5 | 2.5 | 2.4 | 3.2 | 3.6 | 4.1 | 3.9 | 4.4 | 4.6 | 4.6 | 4.1 | 4.5 | 4.3 | 4.5 | 3.5 | 2.0 | 2.1 | 2.0 | 1.4 | 2.1 | 2.1 | 3.2 | 3.17 |
| 27 | 3.4 | 4.2 | 3.5 | 3.8 | 3.6 | 3.8 | 3.9 | 4.2 | 4.4 | 0.0 | 5.6 | 5.6 | 6.0 | 6.4 | 0.0 | 0.0 | 7.0 | 6.5 | 5.4 | 4.9 | 6.1 | 6.3 | 5.7 | 6.0 | 4.43 |
| 28 | 5.1 | 4.6 | 5.1 | 4.5 | 4.3 | 4.6 | 4.9 | 5.0 | 5.8 | 6.8 | 7.9 | 8.1 | 7.8 | 8.1 | 8.0 | 7.1 | 7.4 | 6.3 | 5.7 | 4.7 | 4.2 | 4.6 | 5.1 | 5.5 | 5.88 |
| 29 | 5.7 | 5.8 | 5.5 | 5.0 | 4.6 | 5.0 | 5.9 | 6.8 | 6.7 | 0.0 | 7.9 | 7.9 | 8.1 | 7.3 | 7.7 | 6.8 | 6.5 | 5.8 | 5.2 | 4.8 | 3.2 | 2.6 | 3.2 | 4.7 | 5.53 |
| 30 | 5.0 | 5.1 | 5.6 | 4.7 | 4.3 | 4.3 | 3.9 | 4.3 | 4.2 | 5.0 | 6.7 | 7.2 | 6.9 | 7.3 | 7.4 | 7.1 | 5.9 | 5.1 | 5.2 | 5.4 | 4.4 | 4.1 | 3.8 | 4.1 | 5.29 |
| 31 | 4.7 | 5.0 | 5.0 | 4.9 | 4.1 | 4.0 | 3.4 | 5.7 | 5.8 | 5.0 | 5.4 | 4.9 | 5.2 | 5.6 | 5.6 | 5.0 | 4.3 | 3.5 | 3.1 | 3.7 | 3.8 | 3.1 | 3.6 | 3.7 | 4.50 |
| | | | | | | | | | | | | | | | | | | | | | | Monthly Average = | | | 3.95 |

Maximum Hourly Average Wind Speed was 8.8 meters/sec at Hour 14 on Day 19

Maximum Daily Average Wind Speed was 5.88 meters/sec on Day 28

Operating Efficiency for Wind Speed = 100.0 percent ** = missing or no data

Last Instrument Calibration Date - unknown

[CEM]

MEPA - Kuwait

May 1991

Hourly Averages for Wind Speed(meters/sec) and Direction

| Day \ Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3WNW | 2W | 3WNW | 2WNW | 3WNW | 2W | 2W | 3W | 3WNW | 2NW | 2NNW | 2NNW | 1NNW | 1N | 1ENE | 1E | 2SE | 0N | 0N | 0N | 1N | 1NNW | 1W | 0WNW | 2NW |
| 2 | 0WSW | 0WSW | 1WSW | 1WSW | 1WSW | 2WSW | 3WSW | 3W | 4WNW | 4NW | 1NW | 2NNW | 3N | 2WNW | 2WNW | 3NW | 5NNW | 6NNW | 5NNW | 4NW | 4NW | 6NW | 6NW | 6NW | 3WNW |
| 3 | 6NW | 5NW | 6NNW | 6NNW | 6NNW | 6NW | 6NNW | 7NNW | 7NNW | 0N | 5NNW | 7NNW | 7NNW | 7NNW | 6NNW | 6NNW | 6NNW | 5NNW | 4NNW | 4NNW | 3NNW | 2NW | 4NW | 4NW | 5NNW |
| 4 | 4NW | 3NW | 3NW | 4NNW | 5NNW | 4NW | 5NW | 5NW | 6NW | 6NW | 7NW | 8NW | 7NW | 7NW | 7NW | 7NW | 6NW | 4NW | 3NW | 3NNW | 2NW | 2WNW | 2W | 2W | 5NW |
| 5 | 3WNW | 3WNW | 3W | 2W | 2W | 3W | 4WNW | 4WNW | 5WNW | 5WNW | 0N | 6NW | 6NW | 6NW | 6NW | 6NW | 6NW | 5NW | 3NW | 2NW | 2WNW | 2W | 2WNW | 2WNW | 4WNW |
| 6 | 2WNW | 3W | 3WSW | 4W | 4W | 4W | 4W | 4W | 5WNW | 6NW | 6NW | 6NW | 5NW | 5NW | 6NW | 4NW | 0N | 0N | 0N | 0N | 0N | 0N | 0N | 0N | 3NW |
| 7 | 0N | 0N | 0N | 0N | 0N | 0N | 0N | 0N | 0N | 0N | 0N | 0N | 0N | 0N | 0N | 0N | 0N | 0N | 0N | 0N | 0N | 0N | 0N | 0N | 0N |
| 8 | 0N | 0N | 0N | 0N | 0N | 0N | 0N | 0N | 0N | 0N | 0N | 0N | 2WNW | 1SW | 2S | 4E | 4SE | 4SSE | 3SSE | 4S | 3SSW | 3SW | 3WSW | 3WSW | 2NNW |
| 9 | 4WSW | 4W | 2W | 2W | 2W | 2WNW | 2NW | 2NW | 2N | 2N | 2N | 3NNE | 3NE | 4ENE | 4E | 3ESE | 4SE | 3SE | 3SSE | 4S | 4SSW | 4SSW | 4SW | 5WSW | 3W |
| 10 | 5WSW | 5WSW | 7W | 6NW | 5NW | 6NW | 5NW | 7NW | 8NW | 0N | 6NW | 6NNW | 6NNW | 7NW | 7NW | 7NW | 6NW | 5NW | 4NW | 4NNW | 4NNW | 3NNW | 3NW | 2WNW | 5NW |
| 11 | 2W | 3W | 3WNW | 2WSW | 3W | 4WNW | 5NW | 5NW | 6NW | 6NW | 8NW | 8NW | 8NW | 8NW | 7NW | 7NW | 6NW | 6NNW | 6NNW | 4NNW | 4NNW | 4NW | 3NW | 3NW | 5NW |
| 12 | 2W | 2W | 3W | 3W | 3W | 2W | 4WNW | 4NW | 4NNW | 0N | 4NW | 5NW | 6NW | 6NW | 6NW | 5NW | 5NNW | 4NNW | 2N | 1ESE | 1NE | 2NE | 1E | 0ESE | 3NW |
| 13 | 1SW | 2W | 3W | 3W | 3WSW | 3W | 3W | 3W | 3WNW | 2NW | 2NNW | 2N | 2NNW | 3NW | 3WNW | 4SSW | 3ESE | 3E | 2SW | 2WSW | 2WSW | 2W | 2W | 2WSW | 3W |
| 14 | 2W | 3W | 3W | 3W | 3WSW | 4WSW | 4WSW | 4WSW | 5W | 3W | 3WNW | 3NW | 4E | 4ENE | 4ESE | 4ESE | 6SE | 5SSE | 4SSE | 3SSE | 4SSE | 2S | 0SSW | 3WSW | 3SW |
| 15 | 2WSW | 2WSW | 3WSW | 3WSW | 3WSW | 2WSW | 4WSW | 3WSW | 2WSW | 0N | 2N | 4NE | 5NE | 6NE | 6ENE | 5ENE | 5E | 4E | 4ESE | 3SE | 2SSE | 2SSE | 1SE | 2ESE | 3SE |
| 16 | 2ESE | 0ESE | 0SE | 1SE | 1S | 2SSW | 2SSW | 7NNW | 3SE | 8NNW | 7NNW | 7NNW | 7NNW | 7NNW | 7NNW | 7NNW | 6NNW | 6NNW | 5NNW | 4N | 4NNW | 4NNW | 4NNW | 4NNW | 4NNW |
| 17 | 4NNW | 4NNW | 5NNW | 4NNW | 4NNW | 4NNW | 5NNW | 7NNW | 0N | 8NNW | 7NNW | 7NNW | 7NNW | 7N | 7NNW | 7NNW | 6NNW | 6NNW | 5NNW | 4N | 4NNW | 4NNW | 4NNW | 4NNW | 5NNW |
| 18 | 4NNW | 4NNW | 5NNW | 4NNW | 4NNW | 4NNW | 5NNW | 5NNW | 6NNW | 8NNW | 7NNW | 8NNW | 8NNW | 8NNW | 8NNW | 8NNW | 7NNW | 6NNW | 5NNW | 5NNW | 5NNW | 5NNW | 4NNW | 4NW | 6NNW |
| 19 | 4NW | 4NW | 4NW | 4NW | 3WNW | 4WNW | 6NW | 6NW | 6NNW | 7NNW | 0N | 9NNW | 9NNW | 9NNW | 8NNW | 8NNW | 8NNW | 7NNW | 5NNW | 4NNW | 3NNW | 4NNW | 3NW | 3NW | 5NNW |
| 20 | 4NW | 4NW | 4NW | 4WNW | 3W | 4W | 4W | 5WNW | 6NW | 6NW | 6NW | 6NW | 6NW | 6NNW | 6NNW | 6NNW | 6NNW | 5NNE | 5N | 3N | 3N | 2N | 1NNW | 2WNW | 4NW |
| 21 | 2WNW | 2W | 3W | 4WSW | 4WSW | 4WSW | 4WSW | 4W | 4W | 0N | 3NE | 4ESE | 5ENE | 6E | 6SE | 6SE | 6SE | 5SE | 4SSE | 2SE | 1SSW | 2SW | 2WNW | 2WNW | 4SW |
| 22 | 2WNW | 1WNW | 1WNW | 3NW | 3NNW | 4NNW | 4NNW | 4NNW | 4NNW | 5N | 5N | 5N | 6N | 6N | 7N | 7N | 6NNE | 6N | 4N | 4NNW | 4N | 3N | 3N | 3NNW | 4NNW |
| 23 | 3N | 2N | 2N | 2N | 2NNW | 2NW | 4N | 4NNW | 5N | 5N | 5N | 0N | 5NNW | 5NNW | 5NNW | 6NW | 6NW | 6NW | 5NW | 4NNW | 3NW | 3NNW | 2NNW | 2NW | 4NNW |
| 24 | 3WNW | 3W | 3W | 3W | 2W | 3W | 2NW | 3NW | 3NW | 2N | 4NNW | 6NNW | 7NNW | 7NNW | 8NNW | 7NNW | 7NNW | 6NNW | 5N | 4NNW | 4NNW | 4NW | 4NW | 4NW | 4NW |
| 25 | 4NW | 4NW | 4NW | 4NW | 4NW | 4NW | 6NW | 5NW | 7NW | 0N | 8NW | 8NW | 9NW | 8NNW | 7NW | 6NW | 6NNW | 5NNW | 4NNW | 3NNW | 3NNW | 2NW | 3NW | 3NW | 5NW |
| 26 | 2NW | 2NW | 2NW | 2WNW | 2W | 3W | 4WNW | 4WNW | 4NW | 4NW | 5NW | 5NNW | 4NNW | 4NNW | 4NNW | 4ENE | 4ESE | 2ESE | 2SE | 2SE | 1SSE | 2SSW | 2SW | 3WSW | 3WNW |
| 27 | 3WSW | 4WSW | 4WSW | 4WSW | 4SW | 4SW | 4SW | 4SW | 4W | 0N | 6NW | 6NW | 6NW | 6NW | 0N | 0N | 7NW | 6NW | 5NW | 5NW | 6NW | 6NW | 6NW | 6NW | 4WNW |
| 28 | 5NW | 5NW | 5NW | 4NW | 4NW | 5NW | 5NW | 5NW | 6NNW | 7NNW | 8NNW | 8NNW | 8NW | 8NW | 8NNW | 7NNW | 7NNW | 6NNW | 6NNW | 5NNW | 4NNW | 5NNW | 5NNW | 6NNW | 6NNW |
| 29 | 6NNW | 6NNW | 6NNW | 5NNW | 5NNW | 5NNW | 6NNW | 7NNW | 7NNW | 0N | 8NNW | 8NNW | 8NW | 7NNW | 8NNW | 7NNW | 6NNW | 6NNW | 5NNW | 5NNW | 3NNW | 3NNW | 3NNW | 5NNW | 6NNW |
| 30 | 5NNW | 5NNW | 6NNW | 5NNW | 4NNW | 4NNW | 4NW | 4NW | 4NW | 5NNW | 7NNW | 7NNW | 7NNW | 7NNW | 7NNW | 7NNW | 6N | 5N | 5NNW | 5N | 4NNW | 4NNW | 4NNW | 4NNW | 5NNW |
| 31 | 5NNW | 5NNW | 5NNW | 5N | 4NNW | 4NNW | 3NNW | 6NNW | 6NNW | 5NNW | 5N | 5N | 5N | 6N | 6N | 5N | 4N | 4NNW | 3NNW | 4NW | 4NNW | 3NW | 4NW | 4NNW | 5NNW |

Monthly Average = 4NW

Maximum Hourly Average Wind Speed was 9 meters/sec at Hour 14 on Day 19 and Wind Direction was from the NNW.

Maximum Daily Average Wind Speed was 6 meters/sec on Day 28 and Wind Direction was from the NNW

Operating Efficiency for Wind Speed = 100.0 percent  Operating Efficiency for Wind Direction = 100.0 percent  ** = missing or no data.

Last Instrument Calibration Date - unknown

[CEM]

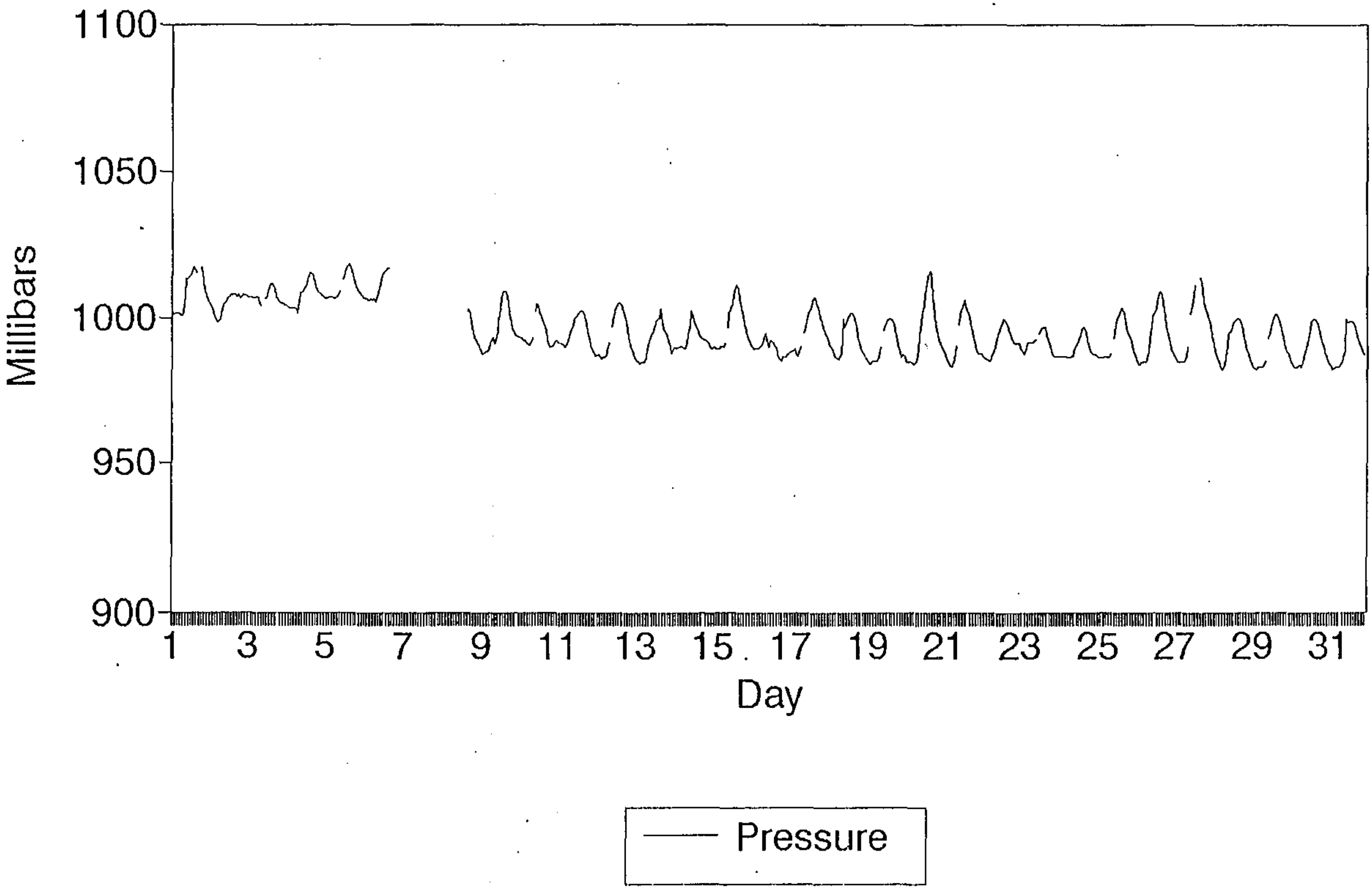
MEPA - Kuwait
May 1991
Hourly Averages for Pressure in millibars

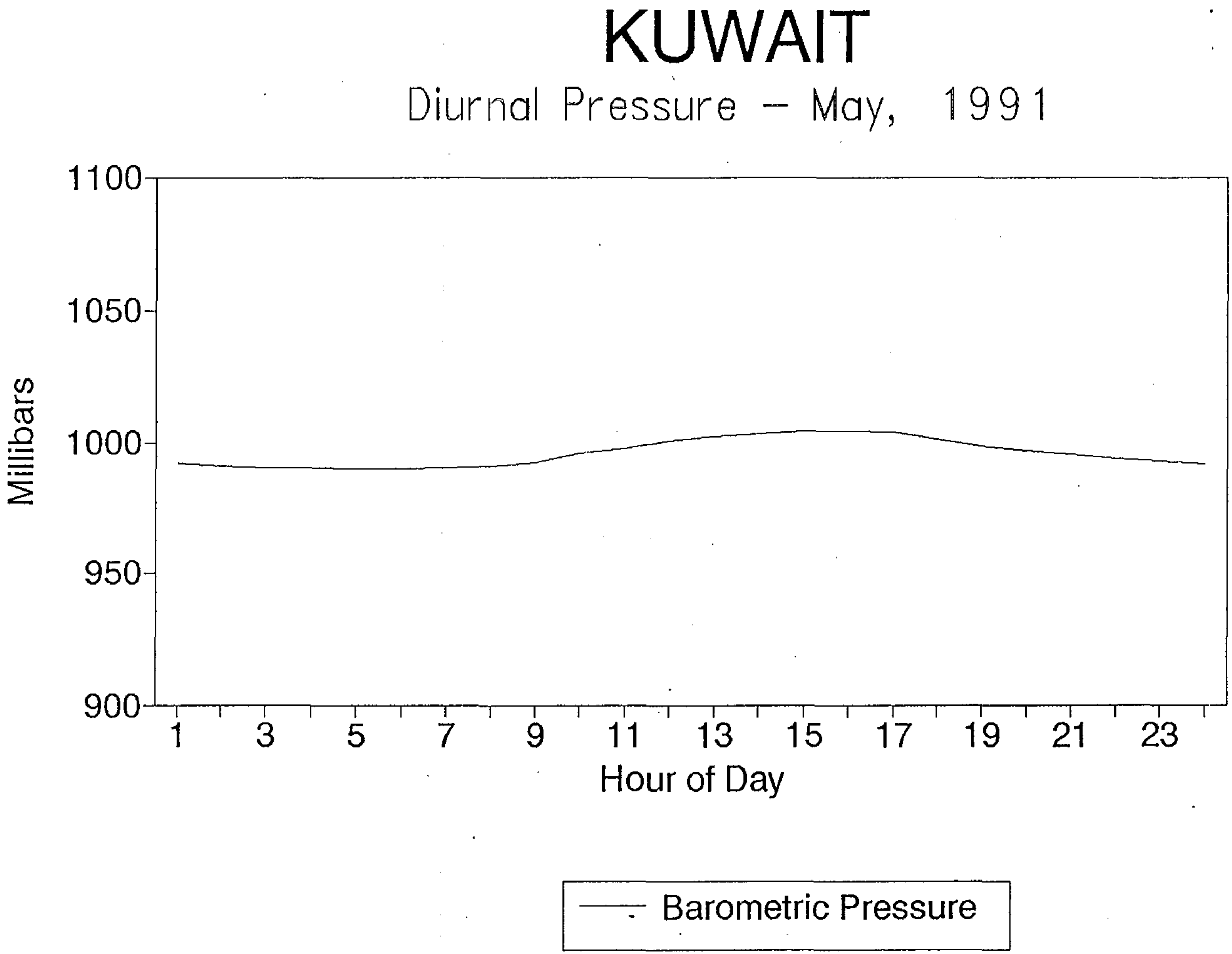
| Day \ Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1003 | 1001 | 1001 | 1001 | 1001 | 1001 | 1001 | 1001 | 1002 | 1008 | 1014 | 1014 | 1014 | 1016 | 1018 | 1017 | 1016 | ND | ND | 1018 | 1013 | 1010 | 1008 | 1006 | 1008.4 |
| 2 | 1005 | 1004 | 1003 | 1002 | 1000 | 999 | 999 | 1000 | 1002 | 1005 | 1006 | 1007 | 1007 | 1008 | 1008 | 1008 | 1008 | 1007 | 1008 | 1007 | 1007 | 1008 | 1008 | 1008 | 1005.2 |
| 3 | 1008 | 1007 | 1007 | 1007 | 1007 | 1007 | 1007 | 1005 | 1004 | ND | 1007 | 1007 | 1008 | 1011 | 1011 | 1012 | 1011 | 1010 | 1008 | 1006 | 1005 | 1005 | 1005 | 1005 | 1007.4 |
| 4 | 1004 | 1004 | 1004 | 1004 | 1003 | 1004 | 1003 | 1002 | 1006 | 1009 | 1009 | 1010 | 1012 | 1014 | 1015 | 1016 | 1015 | 1014 | 1011 | 1009 | 1009 | 1008 | 1008 | 1007 | 1008.3 |
| 5 | 1007 | 1007 | 1007 | 1007 | 1007 | 1007 | 1007 | 1007 | 1008 | 1009 | ND | 1013 | 1016 | 1017 | 1018 | 1019 | 1018 | 1016 | 1014 | 1011 | 1009 | 1009 | 1008 | 1007 | 1010.8 |
| 6 | 1007 | 1007 | 1006 | 1006 | 1007 | 1006 | 1007 | 1006 | 1007 | 1009 | 1012 | 1014 | 1015 | 1016 | 1017 | 1017 | ND | ND | ND | ND | ND | ND | ND | ND | 1009.9 |
| 7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 8 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 1002 | 1003 | 1002 | 998 | 995 | 994 | 993 | 992 | 990 | 996.6 |
| 9 | 989 | 987 | 988 | 989 | 989 | 989 | 991 | 994 | 991 | 992 | 995 | 1000 | 1004 | 1007 | 1009 | 1010 | 1009 | 1006 | 1002 | 998 | 996 | 995 | 995 | 994 | 996.6 |
| 10 | 994 | 993 | 992 | 993 | 992 | 991 | 991 | 992 | 993 | ND | 1003 | 1005 | 1005 | 1002 | 1001 | 999 | 996 | 993 | 990 | 990 | 990 | 991 | 992 | 993 | 994.8 |
| 11 | 992 | 992 | 992 | 991 | 991 | 990 | 991 | 993 | 997 | 998 | 1000 | 1000 | 1001 | 1002 | 1003 | 1003 | 1002 | 1001 | 998 | 995 | 993 | 991 | 989 | 988 | 995.5 |
| 12 | 987 | 987 | 987 | 986 | 986 | 987 | 987 | 990 | 992 | ND | 997 | 1001 | 1003 | 1004 | 1005 | 1005 | 1005 | 1003 | 1000 | 996 | 993 | 991 | 989 | 988 | 994.3 |
| 13 | 986 | 986 | 985 | 985 | 985 | 985 | 985 | 986 | 990 | 992 | 995 | 995 | 997 | 999 | 1000 | 1000 | 1003 | 999 | 996 | 995 | 995 | 992 | 990 | 988 | 992.0 |
| 14 | 990 | 990 | 990 | 990 | 990 | 990 | 990 | 990 | 992 | 994 | 998 | 1003 | 1001 | 998 | 997 | 997 | 995 | 993 | 994 | 993 | 992 | 992 | 991 | 990 | 993.3 |
| 15 | 990 | 990 | 990 | 990 | 990 | 990 | 990 | 990 | 992 | ND | 997 | 1002 | 1005 | 1008 | 1011 | 1012 | 1010 | 1007 | 1003 | 1001 | 998 | 996 | 994 | 993 | 997.8 |
| 16 | 991 | 990 | 990 | 990 | 990 | 990 | 991 | 992 | 994 | 995 | 993 | 990 | 993 | 992 | 992 | 991 | 990 | 988 | 986 | 985 | 987 | 987 | 988 | 988 | 990.1 |
| 17 | 988 | 989 | 989 | 989 | 988 | 987 | 989 | 990 | ND | 995 | 997 | 1000 | 1002 | 1004 | 1006 | 1007 | 1007 | 1005 | 1002 | 1000 | 998 | 997 | 996 | 994 | 996.5 |
| 18 | 993 | 991 | 990 | 989 | 988 | 986 | 986 | 987 | 988 | 1000 | 997 | 999 | 1000 | 1001 | 1002 | 1002 | 1002 | 1000 | 997 | 994 | 992 | 990 | 988 | 987 | 993.7 |
| 19 | 986 | 985 | 985 | 985 | 985 | 985 | 985 | 958 | 987 | 990 | ND | 996 | 997 | 998 | 1000 | 1000 | 1000 | 998 | 996 | 993 | 991 | 989 | 987 | 988 | 989.7 |
| 20 | 987 | 985 | 985 | 985 | 985 | 985 | 984 | 986 | 990 | 995 | 999 | 1002 | 1005 | 1008 | 1012 | 1015 | 1016 | 1013 | 1007 | 1002 | 998 | 995 | 993 | 991 | 996.8 |
| 21 | 989 | 988 | 986 | 985 | 984 | 983 | 984 | 986 | 991 | ND | 998 | 1002 | 1003 | 1004 | 1006 | 1004 | 1001 | 998 | 995 | 993 | 991 | 989 | 988 | 988 | 992.9 |
| 22 | 988 | 987 | 987 | 986 | 986 | 986 | 986 | 987 | 989 | 993 | 995 | 996 | 997 | 998 | 1000 | 999 | 998 | 996 | 994 | 993 | 992 | 991 | 991 | 991 | 991.9 |
| 23 | 991 | 989 | 987 | 989 | 991 | 992 | 992 | 992 | 992 | 992 | 993 | ND | 995 | 996 | 997 | 997 | 997 | 994 | 992 | 989 | 987 | 987 | 987 | 987 | 991.5 |
| 24 | 987 | 987 | 987 | 987 | 987 | 987 | 987 | 987 | 987 | 987 | 989 | 991 | 993 | 995 | 996 | 997 | 997 | 995 | 992 | 990 | 989 | 988 | 988 | 988 | 989.9 |
| 25 | 987 | 987 | 987 | 987 | 987 | 987 | 987 | 987 | 988 | ND | 993 | 996 | 1000 | 1001 | 1002 | 1004 | 1003 | 1001 | 999 | 995 | 993 | 991 | 989 | 987 | 993.0 |
| 26 | 986 | 985 | 984 | 985 | 985 | 985 | 985 | 986 | 989 | 993 | 997 | 1001 | 1004 | 1006 | 1009 | 1010 | 1008 | 1005 | 1001 | 998 | 994 | 992 | 990 | 988 | 994.4 |
| 27 | 988 | 986 | 985 | 985 | 985 | 985 | 985 | 987 | 990 | ND | 1001 | 1005 | 1008 | 1011 | ND | ND | 1014 | 1014 | 1010 | 1006 | 1003 | 1000 | 997 | 994 | 997.1 |
| 28 | 991 | 989 | 987 | 986 | 984 | 983 | 983 | 984 | 987 | 990 | 995 | 996 | 997 | 999 | 1000 | 1000 | 1000 | 998 | 996 | 993 | 991 | 989 | 987 | 986 | 991.3 |
| 29 | 985 | 983 | 983 | 983 | 983 | 984 | 984 | 984 | 985 | ND | 994 | 995 | 997 | 999 | 1001 | 1002 | 1002 | 1000 | 998 | 996 | 993 | 991 | 989 | 988 | 991.3 |
| 30 | 986 | 985 | 984 | 983 | 983 | 984 | 984 | 983 | 985 | 987 | 989 | 991 | 993 | 996 | 999 | 1000 | 1000 | 998 | 997 | 994 | 992 | 990 | 989 | 987 | 990.0 |
| 31 | 986 | 984 | 983 | 982 | 983 | 984 | 983 | 984 | 985 | 987 | 989 | 1000 | 998 | 999 | 999 | 999 | 998 | 997 | 995 | 993 | 991 | 990 | 989 | 988 | 990.3 |
| | | | | | | | | | | | | | | | | | | | | | | Monthly Average = | | | 996.2 |

Maximum Hourly Average was 1019 at Hour 16 on Day 5 with 1 occurences
Maximum Daily Average was 1010.8 on Day 5 with 1 occurences
Operating Efficiency = 91.5 percent
ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data
[CEM 1990]

# KUWAIT

## Hourly Barometric Pressure – May, 1991



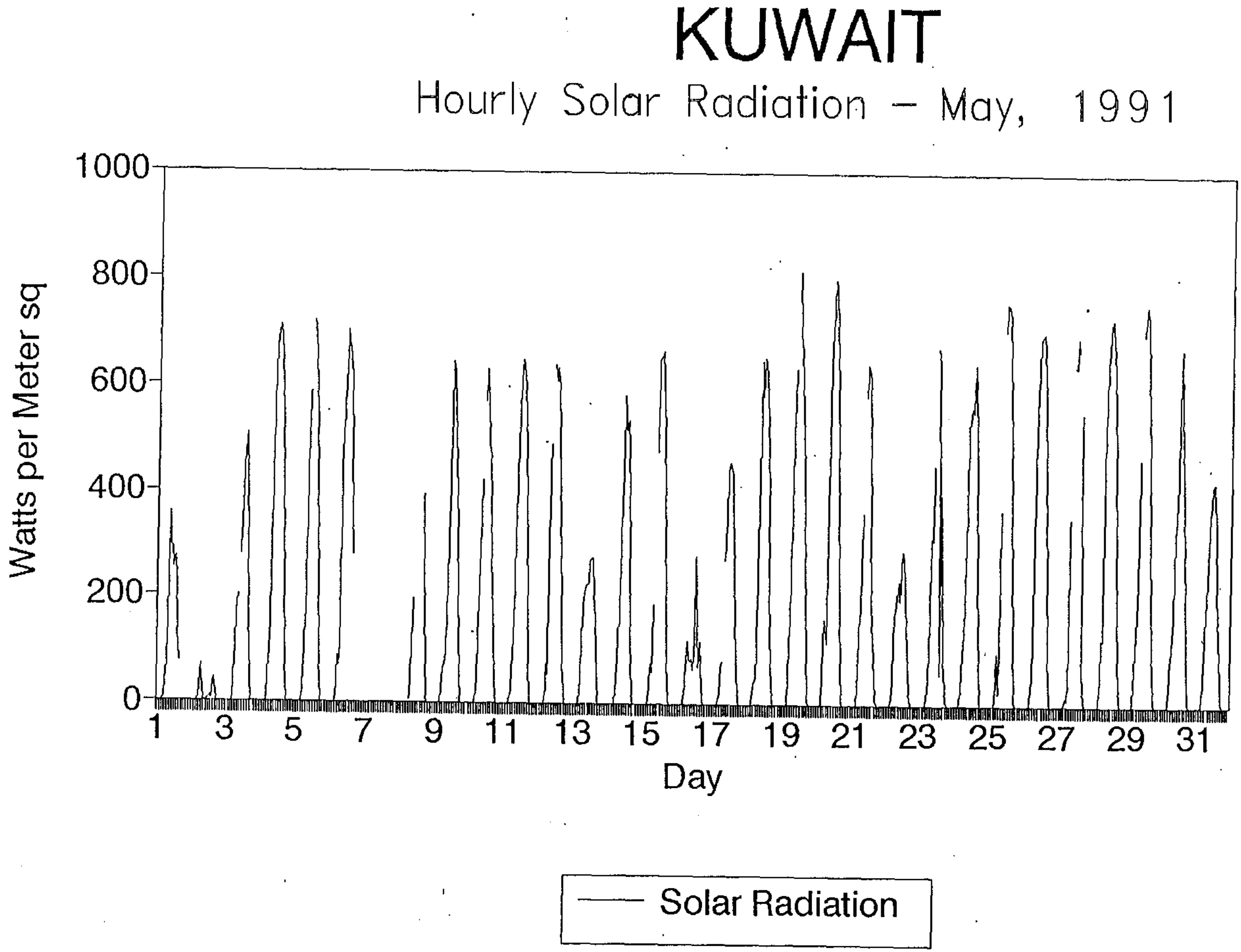

KUWAIT
Diurnal Pressure - May, 1991
Millibars
1100
1050
1000
950
900
1
3
5
7
9
11
13
15
17
19
21
23
Hour of Day
Barometric Pressure

MEPA - Kuwait
May 1991
Hourly Averages for Solar Radiation in Watts/ M2.

| Hour / Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 8 | 39 | 72 | 134 | 357 | 293 | 289 | 250 | 270 | 239 | 129 | 75 | ND | ND | 0 | 0 | 0 | 0 | 0 | 98.0 |
| 2 | 0 | 0 | 0 | 0 | 0 | 7 | 30 | 70 | 41 | 0 | 0 | 1 | 6 | 10 | 4 | 34 | 44 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 10.9 |
| 3 | 0 | 0 | 0 | 0 | 1 | 45 | 105 | 165 | 202 | ND | 277 | 383 | 449 | 496 | 508 | 317 | 157 | 42 | 1 | 0 | 0 | 0 | 0 | 0 | 136.9 |
| 4 | 0 | 0 | 0 | 0 | 1 | 58 | 97 | 126 | 434 | 568 | 670 | 710 | 693 | 645 | 549 | 403 | 235 | 72 | 1 | 0 | 0 | 0 | 0 | 0 | 219.3 |
| 5 | 0 | 0 | 0 | 0 | 2 | 59 | 117 | 178 | 440 | 585 | ND | 717 | 696 | 647 | 549 | 408 | 241 | 74 | 1 | 0 | 0 | 0 | 0 | 0 | 205.0 |
| 6 | 0 | 0 | 0 | 0 | 5 | 86 | 68 | 108 | 464 | 551 | 634 | 701 | 667 | 618 | 458 | 276 | ND | ND | ND | ND | ND | ND | ND | ND | 289.8 |
| 7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 8 | ND | ND | ND | ND | ND | ND | ND | 3 | 108 | 195 | ND | 326 | 357 | 325 | 361 | 393 | 242 | 85 | 4 | 0 | 0 | 0 | 0 | 0 | 149.9 |
| 9 | 0 | 0 | 0 | 0 | 1 | 29 | 60 | 92 | 221 | 299 | 540 | 642 | 621 | 553 | 454 | 333 | 190 | 52 | 1 | 0 | 0 | 0 | 0 | 0 | 170.3 |
| 10 | 0 | 0 | 0 | 0 | 4 | 45 | 136 | 272 | 423 | ND | 571 | 629 | 571 | 487 | 469 | 268 | 118 | 36 | 2 | 0 | 0 | 0 | 0 | 0 | 175.3 |
| 11 | 0 | 0 | 0 | 0 | 4 | 25 | 64 | 123 | 427 | 540 | 609 | 649 | 638 | 597 | 483 | 374 | 219 | 54 | 1 | 0 | 0 | 0 | 0 | 0 | 200.3 |
| 12 | 0 | 0 | 0 | 0 | 4 | 76 | 52 | 443 | 491 | ND | 637 | 606 | 633 | 597 | 417 | 346 | 208 | 71 | 1 | 0 | 0 | 0 | 0 | 0 | 199.2 |
| 13 | 0 | 0 | 0 | 0 | 2 | 49 | 129 | 175 | 209 | 223 | 224 | 268 | 273 | 271 | 205 | 157 | 101 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 95.3 |
| 14 | 0 | 0 | 0 | 0 | 0 | 24 | 69 | 141 | 153 | 320 | 452 | 582 | 516 | 533 | 485 | 298 | 115 | 24 | 0 | 0 | 0 | 0 | 0 | 0 | 154.7 |
| 15 | 0 | 0 | 0 | 0 | 5 | 46 | 75 | 59 | 185 | ND | 476 | 644 | 663 | 618 | 516 | 390 | 222 | 77 | 4 | 0 | 0 | 0 | 0 | 0 | 173.0 |
| 16 | 0 | 0 | 0 | 0 | 2 | 37 | 84 | 118 | 83 | 80 | 85 | 63 | 124 | 278 | 145 | 68 | 118 | 65 | 5 | 0 | 0 | 0 | 0 | 0 | 56.5 |
| 17 | 0 | 0 | 0 | 0 | 0 | 18 | 50 | 80 | ND | 272 | 342 | 439 | 456 | 438 | 363 | 257 | 150 | 54 | 3 | 0 | 0 | 0 | 0 | 0 | 127.0 |
| 18 | 0 | 0 | 0 | 0 | 1 | 37 | 51 | 103 | 408 | 649 | 581 | 653 | 649 | 582 | 540 | 409 | 205 | 72 | 5 | 0 | 0 | 0 | 0 | 0 | 206.0 |
| 19 | 0 | 0 | 0 | 0 | 2 | 63 | 153 | 236 | 528 | 632 | ND | 815 | 701 | 666 | 614 | 446 | 260 | 104 | 6 | 0 | 0 | 0 | 0 | 0 | 227.2 |
| 20 | 0 | 0 | 0 | 0 | 3 | 70 | 160 | 115 | 538 | 669 | 746 | 799 | 778 | 709 | 610 | 455 | 257 | 74 | 4 | 0 | 0 | 0 | 0 | 0 | 249.5 |
| 21 | 0 | 0 | 0 | 0 | 5 | 66 | 147 | 181 | 362 | ND | 580 | 640 | 633 | 613 | 356 | 187 | 52 | 10 | 1 | 0 | 0 | 0 | 0 | 0 | 166.7 |
| 22 | 0 | 0 | 0 | 0 | 1 | 14 | 60 | 168 | 190 | 233 | 197 | 256 | 290 | 276 | 229 | 148 | 63 | 22 | 2 | 0 | 0 | 0 | 0 | 0 | 89.5 |
| 23 | 0 | 0 | 0 | 0 | 2 | 18 | 47 | 159 | 315 | 311 | 454 | ND | 674 | 652 | 57 | 398 | 238 | 88 | 6 | 0 | 0 | 0 | 0 | 0 | 148.7 |
| 24 | 0 | 0 | 0 | 0 | 5 | 29 | 98 | 134 | 203 | 375 | 525 | 562 | 556 | 642 | 590 | 432 | 225 | 68 | 3 | 0 | 0 | 0 | 0 | 0 | 185.3 |
| 25 | 0 | 0 | 0 | 0 | 12 | 97 | 22 | 103 | 367 | ND | 709 | 757 | 755 | 734 | 654 | 507 | 356 | 137 | 10 | 0 | 0 | 0 | 0 | 0 | 227.0 |
| 26 | 0 | 0 | 0 | 0 | 2 | 39 | 48 | 141 | 434 | 548 | 636 | 693 | 703 | 672 | 585 | 428 | 262 | 89 | 5 | 0 | 0 | 0 | 0 | 0 | 220.2 |
| 27 | 0 | 0 | 0 | 0 | 2 | 16 | 13 | 98 | 355 | ND | 640 | 637 | 695 | 669 | ND | ND | 551 | 62 | 9 | 0 | 0 | 0 | 0 | 0 | 178.4 |
| 28 | 0 | 0 | 0 | 0 | 3 | 52 | 122 | 124 | 453 | 588 | 634 | 704 | 728 | 715 | 636 | 482 | 271 | 80 | 5 | 0 | 0 | 0 | 0 | 0 | 233.2 |
| 29 | 0 | 0 | 0 | 0 | 8 | 71 | 172 | 202 | 470 | ND | 699 | 749 | 754 | 712 | 629 | 484 | 291 | 105 | 7 | 0 | 0 | 0 | 0 | 0 | 232.7 |
| 30 | 0 | 0 | 0 | 0 | 2 | 34 | 91 | 110 | 153 | 270 | 356 | 429 | 561 | 675 | 559 | 376 | 193 | 51 | 4 | 0 | 0 | 0 | 0 | 0 | 161.0 |
| 31 | 0 | 0 | 0 | 0 | 2 | 20 | 82 | 142 | 273 | 366 | 382 | 420 | 424 | 386 | 338 | 213 | 125 | 52 | 6 | 0 | 0 | 0 | 0 | 0 | 134.6 |

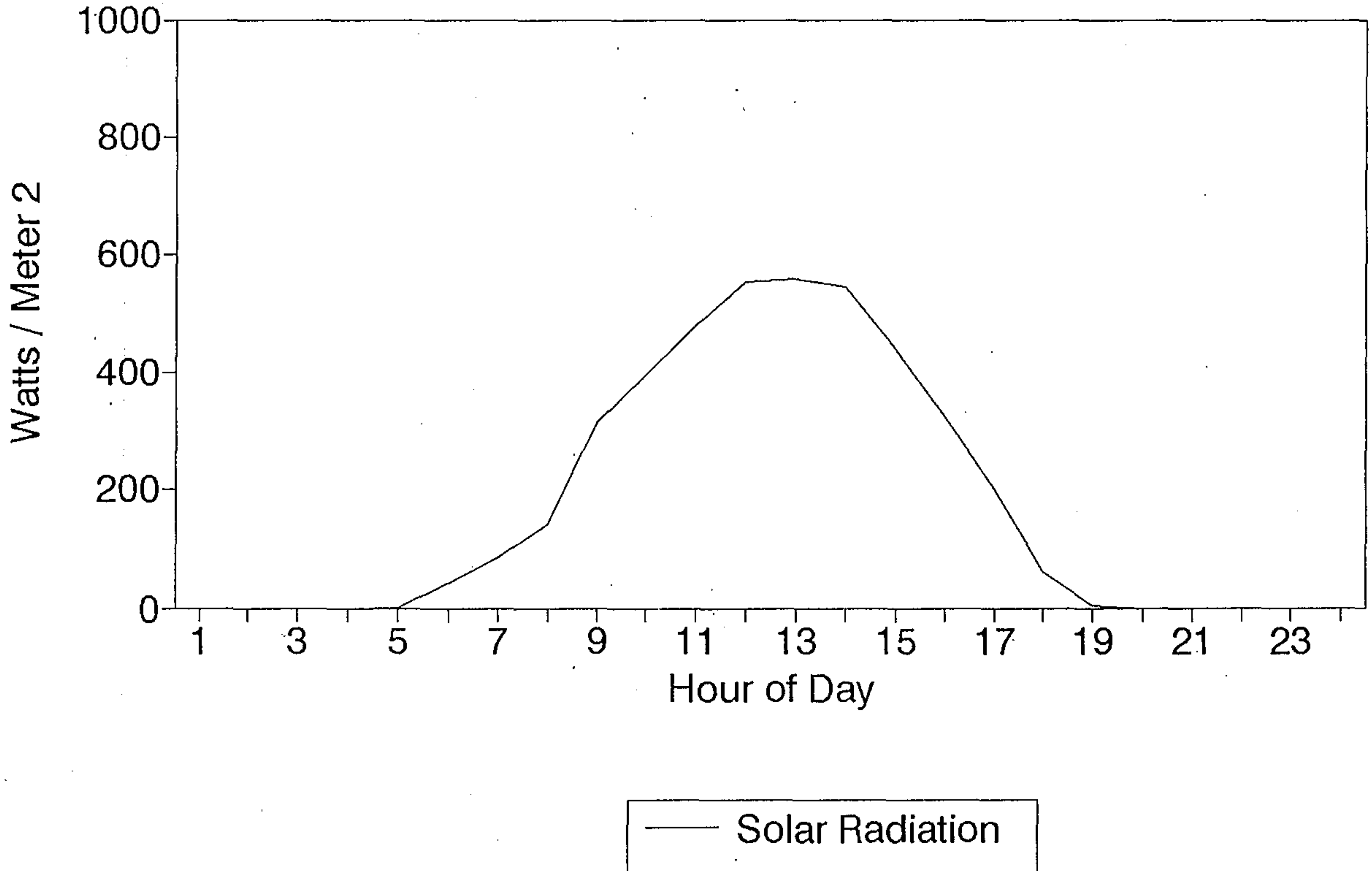
Monthly Average = 169.5

Maximum Hourly Average was 815 at Hour 12 on Day 19 with 1 occurences
Maximum Daily Average was 289.8 on Day 6 with 1 occurences
Operating Efficiency = 92.5 percent
ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data
[CEM 1990]


KUWAIT
Hourly Solar Radiation - May, 1991
Watts per Meter sq
1000
800
600
400
200
0
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Day
Solar Radiation

# KUWAIT

Diurnal Radiation – May, 1991



MEPA - Kuwait

May 1991

Hourly Averages for Relative Humidity in Per Cent

| Hour / Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 15.1 | 15.6 | 16.5 | 17.8 | 18.9 | 19.7 | 20.2 | 19.8 | 19.2 | 17.7 | 15.3 | 14.5 | 14.0 | 13.1 | 12.9 | 13.3 | 14.2 | ND | ND | 16.3 | 15.9 | 15.3 | 16.6 | 17.6 | 16.34 |
| 2 | 18.2 | 18.6 | 18.3 | 18.2 | 18.2 | 18.2 | 18.0 | 17.6 | 17.5 | 17.6 | 18.4 | 20.2 | 21.4 | 22.6 | 24.6 | 25.4 | 26.4 | 28.2 | 30.3 | 31.2 | 29.9 | 28.2 | 27.6 | 27.8 | 22.61 |
| 3 | 28.0 | 28.0 | 27.4 | 27.3 | 29.5 | 31.1 | 30.9 | 29.9 | 29.1 | ND | 27.5 | 24.5 | 21.8 | 18.8 | 17.0 | 17.0 | 18.0 | 18.3 | 19.5 | 20.2 | 21.2 | 21.7 | 21.3 | 21.9 | 23.91 |
| 4 | 22.9 | 23.7 | 25.4 | 25.9 | 24.9 | 25.1 | 24.0 | 22.8 | 20.9 | 18.5 | 16.7 | 15.3 | 14.2 | 12.9 | 11.9 | 11.3 | 11.0 | 11.9 | 13.4 | 15.3 | 16.5 | 16.6 | 16.2 | 16.1 | 18.06 |
| 5 | 16.5 | 16.6 | 16.9 | 17.8 | 18.6 | 18.8 | 18.1 | 17.0 | 15.8 | 14.6 | ND | 12.7 | 11.9 | 11.1 | 10.2 | 10.1 | 10.1 | 10.2 | 11.4 | 13.1 | 13.5 | 13.6 | 13.9 | 14.9 | 14.23 |
| 6 | 15.4 | 15.8 | 16.2 | 16.7 | 17.3 | 17.6 | 17.2 | 16.5 | 15.1 | 14.1 | 13.6 | 13.1 | 12.6 | 12.0 | 11.6 | 11.6 | ND | ND | ND | ND | ND | ND | ND | ND | 14.78 |
| 7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 8 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 2.9 | 2.6 | 1.4 | 4.2 | 12.9 | 13.3 | 13.6 | 14.1 | 14.6 | 14.2 | 14.6 | 15.0 | 15.4 | 10.68 |
| 9 | 15.6 | 15.9 | 16.1 | 16.5 | 17.1 | 17.4 | 17.8 | 18.5 | 18.5 | 17.2 | 15.3 | 13.6 | 12.8 | 13.3 | 14.4 | 15.2 | 14.8 | 14.7 | 14.9 | 15.2 | 15.1 | 15.0 | 14.9 | 14.7 | 15.60 |
| 10 | 14.3 | 14.0 | 13.5 | 15.1 | 17.3 | 17.3 | 17.1 | 16.0 | 14.6 | ND | 13.9 | 13.6 | 12.6 | 12.0 | 11.3 | 11.1 | 11.6 | 12.3 | 12.7 | 13.1 | 13.3 | 13.6 | 14.0 | 14.2 | 13.85 |
| 11 | 14.2 | 14.2 | 14.2 | 14.4 | 14.8 | 15.5 | 16.4 | 16.5 | 15.2 | 13.8 | 12.9 | 12.1 | 11.5 | 11.1 | 11.0 | 10.6 | 10.6 | 11.7 | 13.2 | 13.8 | 14.2 | 14.8 | 14.9 | 15.2 | 13.62 |
| 12 | 15.8 | 16.2 | 16.5 | 16.7 | 17.0 | 17.1 | 16.5 | 15.0 | 14.5 | ND | 13.2 | 12.6 | 12.4 | 12.0 | 12.0 | 12.0 | 12.1 | 12.5 | 13.4 | 20.9 | 22.9 | 22.3 | 22.5 | 22.6 | 16.03 |
| 13 | 22.9 | 23.2 | 22.2 | 21.2 | 21.1 | 20.6 | 19.6 | 18.4 | 18.1 | 17.3 | 16.7 | 16.6 | 16.5 | 16.3 | 16.0 | 17.1 | 17.8 | 17.9 | 18.3 | 19.3 | 19.7 | 19.9 | 20.2 | 21.3 | 19.09 |
| 14 | 21.6 | 21.8 | 21.8 | 21.9 | 21.9 | 21.7 | 21.3 | 20.2 | 19.1 | 18.2 | 16.3 | 15.6 | 18.9 | 18.0 | 18.1 | 18.3 | 18.4 | 19.0 | 19.2 | 19.5 | 19.6 | 19.5 | 19.9 | 20.2 | 19.58 |
| 15 | 20.4 | 20.8 | 21.2 | 21.5 | 21.6 | 21.6 | 21.6 | 21.6 | 20.9 | ND | 18.1 | 15.8 | 15.2 | 14.9 | 15.4 | 15.9 | 16.1 | 19.2 | 21.7 | 20.8 | 21.7 | 22.1 | 21.5 | 21.5 | 19.61 |
| 16 | 22.2 | 23.4 | 24.4 | 24.9 | 24.2 | 23.6 | 22.3 | 20.5 | 19.5 | 23.9 | 26.4 | 28.8 | 29.0 | 35.9 | 37.8 | 42.6 | 41.2 | 39.2 | 35.7 | 35.3 | 33.6 | 31.4 | 31.4 | 34.1 | 29.64 |
| 17 | 49.4 | 56.9 | 54.8 | 51.4 | 49.7 | 41.0 | 32.4 | 29.6 | ND | 22.4 | 20.8 | 18.2 | 16.9 | 16.0 | 15.3 | 15.0 | 15.3 | 16.4 | 18.9 | 20.8 | 22.0 | 21.7 | 23.5 | 23.3 | 28.33 |
| 18 | 24.0 | 25.2 | 27.1 | 28.5 | 20.1 | 21.0 | 30.8 | 29.7 | 26.3 | 16.4 | 19.8 | 18.2 | 16.4 | 15.2 | 14.6 | 14.6 | 14.6 | 14.8 | 15.8 | 15.9 | 16.6 | 17.1 | 17.5 | 18.6 | 19.95 |
| 19 | 19.7 | 21.4 | 22.5 | 22.8 | 22.3 | 22.0 | 21.1 | 20.1 | 18.7 | 17.8 | ND | 14.4 | 13.1 | 12.8 | 12.6 | 13.0 | 13.1 | 12.9 | 13.5 | 14.0 | 15.5 | 17.3 | 18.3 | 18.5 | 17.28 |
| 20 | 18.2 | 18.3 | 19.3 | 19.8 | 20.2 | 20.2 | 19.5 | 17.9 | 16.6 | 15.8 | 15.3 | 14.5 | 13.0 | 11.9 | 11.5 | 11.5 | 11.7 | 13.4 | 14.3 | 15.4 | 15.6 | 16.0 | 16.1 | 16.3 | 15.93 |
| 21 | 17.4 | 18.2 | 18.6 | 19.1 | 19.2 | 18.8 | 17.7 | 16.4 | 15.3 | ND | 13.4 | 14.1 | 13.7 | 14.8 | 16.5 | 19.1 | 20.2 | 20.5 | 19.3 | 17.9 | 17.6 | 17.7 | 19.2 | 19.5 | 17.57 |
| 22 | 19.5 | 19.6 | 19.8 | 19.8 | 19.8 | 19.6 | 19.5 | 20.2 | 20.6 | 21.1 | 20.8 | 19.6 | 18.7 | 17.6 | 17.0 | 18.4 | 19.3 | 20.2 | 20.0 | 19.1 | 20.2 | 21.2 | 21.2 | 20.7 | 19.73 |
| 23 | 21.0 | 21.6 | 22.9 | 24.2 | 24.6 | 26.2 | 27.3 | 27.0 | 25.6 | 25.5 | 23.5 | ND | 19.6 | 18.3 | 18.2 | 17.8 | 17.5 | 17.3 | 17.8 | 18.9 | 19.2 | 20.0 | 22.0 | 23.3 | 21.71 |
| 24 | 25.3 | 23.1 | 22.9 | 23.6 | 24.4 | 25.0 | 26.9 | 26.2 | 25.5 | 23.4 | 20.5 | 18.6 | 17.7 | 17.0 | 16.5 | 16.3 | 16.7 | 17.1 | 18.0 | 18.5 | 19.4 | 19.8 | 20.2 | 21.5 | 21.00 |
| 25 | 22.4 | 22.8 | 23.3 | 23.3 | 23.6 | 23.2 | 20.5 | 18.9 | 17.4 | ND | 13.6 | 12.1 | 10.2 | 10.1 | 10.1 | 10.1 | 10.1 | 10.2 | 11.3 | 12.0 | 12.5 | 15.0 | 16.8 | 16.3 | 15.90 |
| 26 | 17.1 | 19.1 | 19.8 | 19.4 | 19.2 | 19.4 | 19.0 | 18.1 | 16.8 | 15.3 | 13.9 | 12.5 | 11.4 | 10.5 | 10.1 | 10.7 | 13.9 | 14.3 | 14.4 | 15.1 | 15.8 | 16.2 | 16.3 | 16.5 | 15.62 |
| 27 | 16.5 | 16.4 | 16.3 | 16.2 | 15.9 | 15.6 | 15.4 | 14.9 | 13.5 | ND | 11.9 | 11.7 | 11.6 | 11.3 | ND | ND | 11.3 | 12.9 | 13.7 | 15.1 | 15.4 | 16.3 | 18.0 | 19.2 | 14.72 |
| 28 | 20.1 | 21.0 | 21.7 | 22.0 | 22.1 | 22.4 | 22.5 | 22.0 | 20.3 | 18.7 | 17.4 | 16.3 | 15.3 | 14.3 | 13.7 | 13.7 | 14.0 | 14.7 | 15.9 | 16.5 | 17.0 | 18.0 | 18.8 | 19.7 | 18.25 |
| 29 | 20.4 | 20.9 | 22.0 | 23.3 | 24.3 | 24.3 | 23.2 | 21.5 | 20.3 | ND | 16.7 | 15.3 | 14.1 | 13.0 | 12.6 | 12.6 | 12.7 | 13.0 | 13.4 | 14.2 | 14.8 | 15.4 | 16.9 | 17.8 | 17.51 |
| 30 | 18.3 | 19.1 | 19.6 | 10.8 | 21.9 | 22.8 | 23.2 | 22.3 | 21.4 | 19.4 | 17.1 | 16.3 | 15.5 | 14.0 | 13.3 | 13.9 | 14.4 | 15.0 | 15.3 | 15.3 | 15.7 | 16.5 | 17.7 | 18.7 | 17.40 |
| 31 | 19.3 | 20.6 | 22.3 | 22.3 | 23.0 | 23.1 | 23.0 | 22.0 | 19.5 | 17.4 | 16.6 | 15.9 | 14.5 | 13.7 | 13.8 | 13.9 | 13.9 | 14.4 | 14.7 | 14.5 | 15.2 | 15.6 | 15.9 | 16.8 | 17.58 |

Monthly Average = 18.38

Maximum Hourly Average was 56.9 at Hour 2 on Day 17 with 1 occurences

Maximum Daily Average was 29.64 on Day 16 with 1 occurences

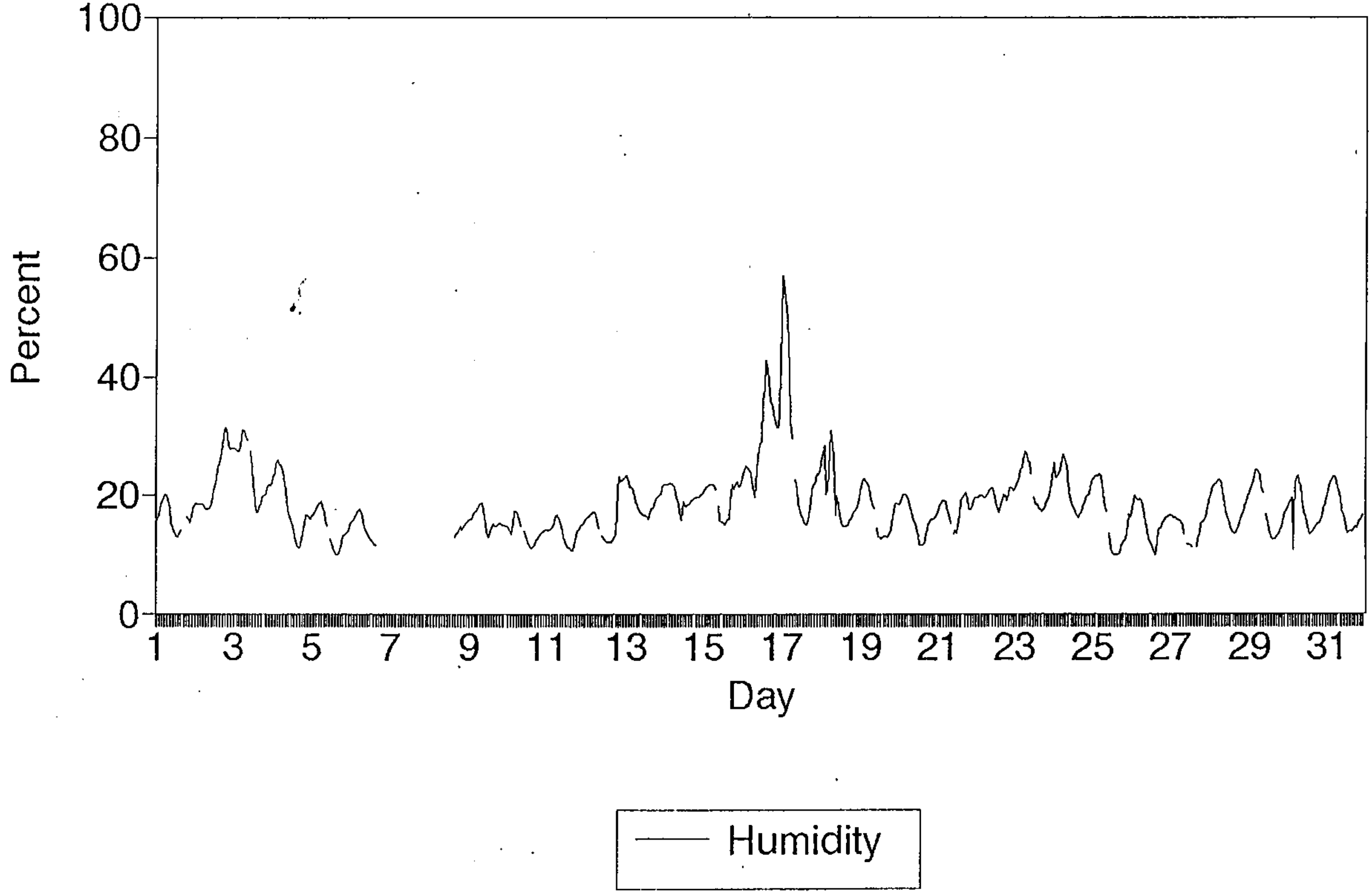
Operating Efficiency = 92.1 percent

ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data

[CEM 1990]

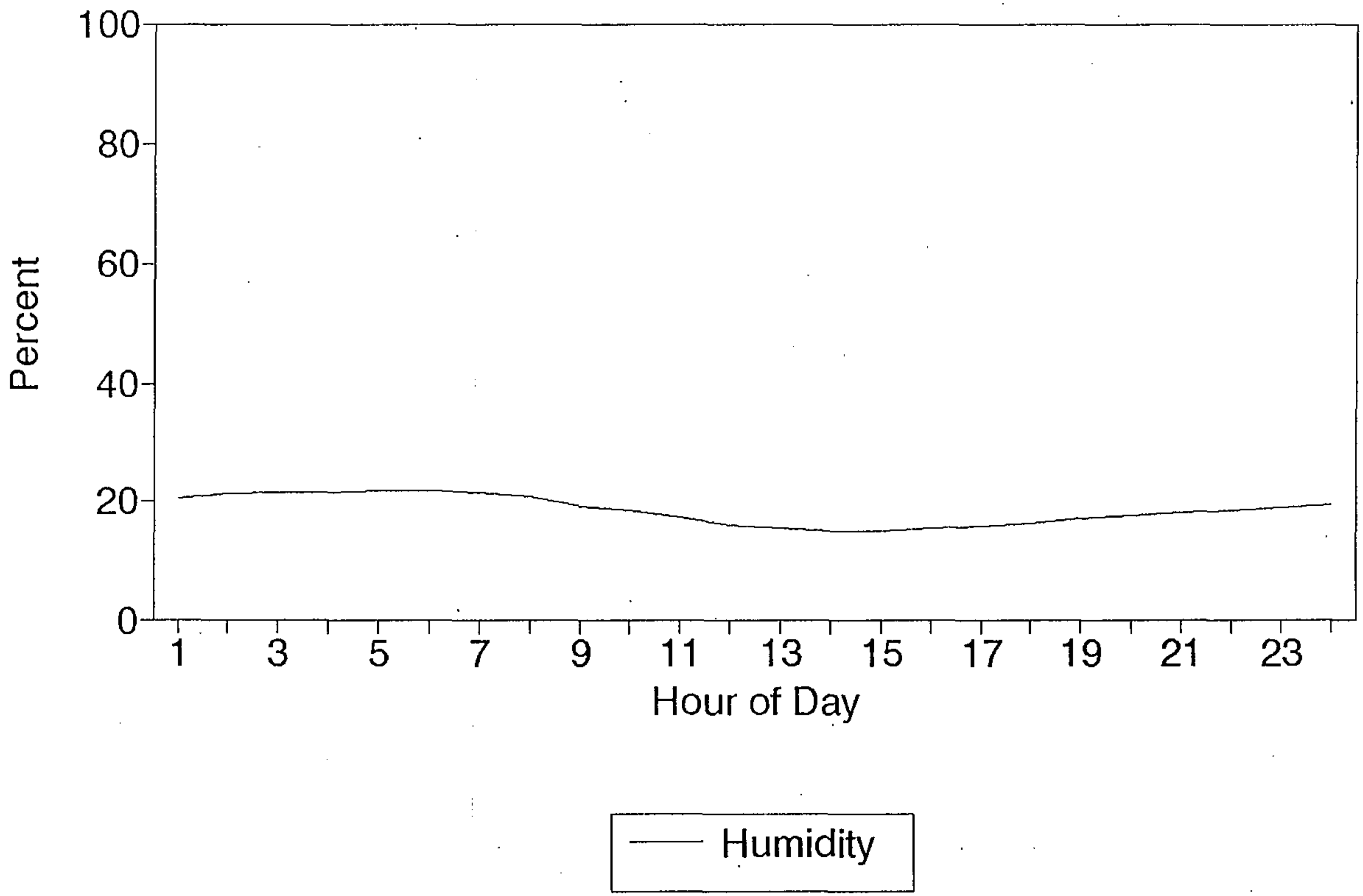
# KUWAIT

## Hourly Humidity - May, 1991



# KUWAIT

Diurnal Humidity - May, 1991



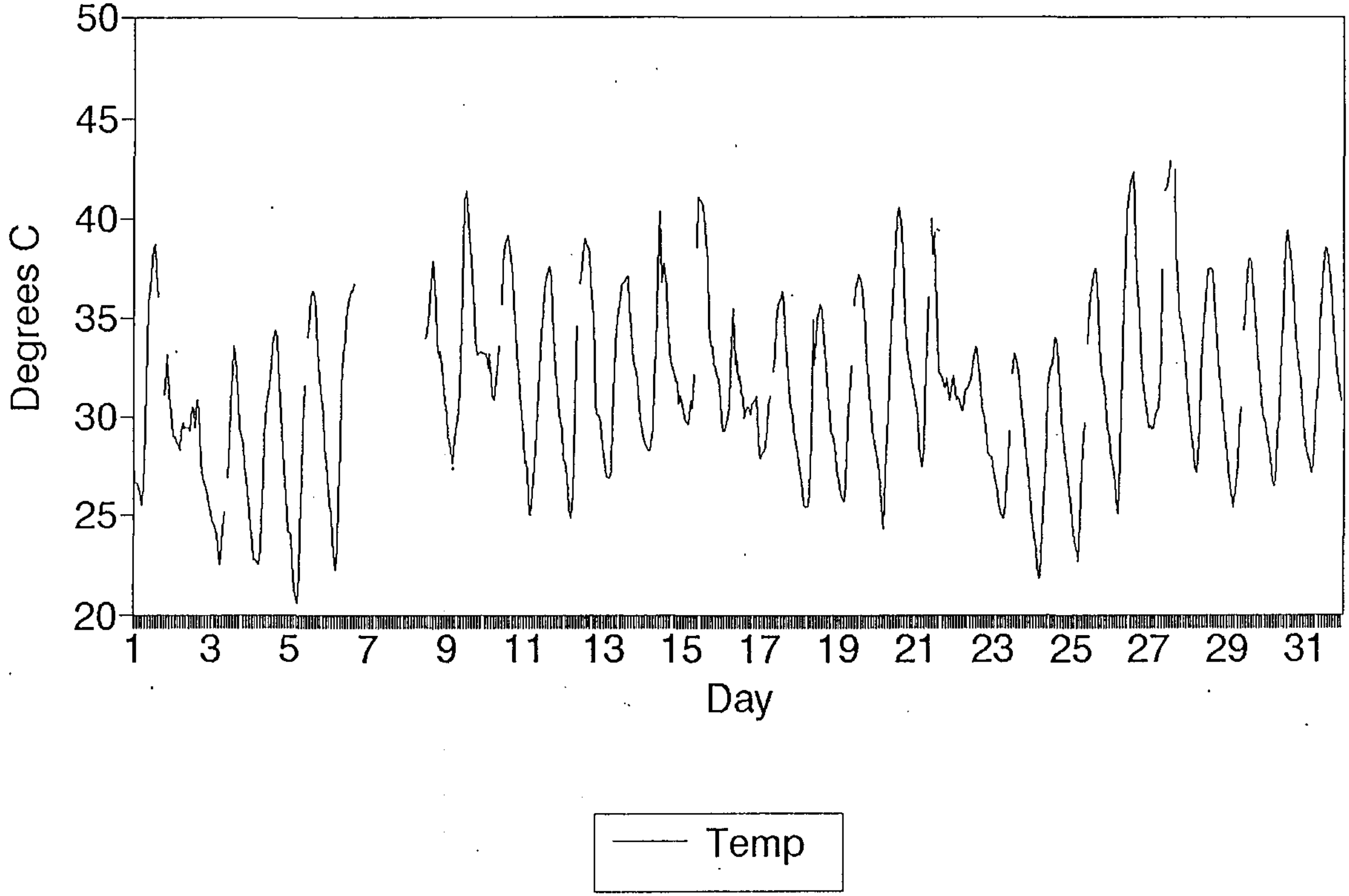
MEPA - Kuwait
May 1991
Hourly Averages for Temperature in Degrees C

| Hour / Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 27.9 | 26.7 | 26.7 | 26.6 | 26.2 | 25.5 | 25.7 | 27.6 | 29.6 | 33.5 | 35.8 | 36.5 | 37.2 | 38.5 | 38.7 | 37.3 | 36.0 | ND | ND | 31.1 | 32.3 | 33.1 | 31.1 | 30.6 | 31.55 |
| 2 | 29.7 | 29.0 | 29.0 | 28.8 | 28.6 | 28.3 | 29.2 | 29.7 | 29.4 | 29.5 | 29.5 | 29.3 | 30.5 | 30.4 | 29.5 | 30.9 | 30.9 | 29.3 | 27.7 | 26.9 | 26.5 | 26.4 | 26.0 | 25.5 | 28.77 |
| 3 | 25.1 | 24.7 | 24.4 | 24.0 | 22.9 | 22.5 | 23.5 | 24.4 | 25.2 | ND | 26.9 | 28.9 | 30.7 | 32.2 | 33.6 | 33.1 | 32.1 | 30.8 | 29.4 | 28.6 | 27.5 | 26.8 | 26.2 | 25.2 | 27.33 |
| 4 | 24.4 | 23.6 | 22.8 | 22.8 | 22.6 | 22.5 | 23.3 | 24.9 | 26.8 | 29.1 | 30.6 | 31.6 | 32.7 | 33.6 | 34.2 | 34.4 | 34.0 | 32.6 | 30.9 | 29.3 | 28.2 | 26.7 | 26.0 | 24.2 | 27.99 |
| 5 | 24.2 | 24.0 | 22.7 | 21.2 | 20.6 | 21.9 | 24.2 | 26.8 | 29.4 | 31.6 | ND | 34.1 | 35.2 | 36.1 | 36.4 | 36.3 | 35.7 | 34.4 | 32.7 | 31.3 | 30.2 | 28.5 | 27.7 | 27.0 | 29.23 |
| 6 | 25.6 | 25.1 | 23.7 | 22.6 | 22.3 | 23.4 | 26.0 | 28.3 | 31.5 | 33.2 | 33.9 | 34.9 | 35.8 | 36.4 | 36.3 | 36.7 | ND | ND | ND | ND | ND | ND | ND | ND | 29.73 |
| 7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 8 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 34.0 | 34.1 | 34.8 | 36.7 | 37.8 | 37.3 | 35.7 | 33.8 | 33.0 | 33.4 | 32.6 | 31.9 | 30.8 | 34.30 |
| 9 | 30.2 | 29.1 | 28.6 | 28.3 | 27.7 | 28.4 | 29.3 | 30.3 | 32.8 | 34.5 | 38.5 | 40.9 | 41.4 | 40.7 | 39.1 | 37.9 | 37.1 | 35.3 | 33.8 | 33.1 | 33.2 | 33.3 | 33.3 | 33.2 | 33.75 |
| 10 | 33.2 | 32.4 | 33.2 | 32.0 | 31.0 | 30.9 | 31.3 | 32.3 | 33.6 | ND | 35.7 | 37.7 | 38.7 | 38.8 | 39.1 | 38.4 | 37.1 | 35.7 | 34.4 | 33.1 | 32.2 | 31.1 | 30.1 | 29.0 | 33.96 |
| 11 | 27.7 | 27.8 | 27.1 | 25.0 | 25.0 | 26.2 | 26.8 | 28.4 | 31.3 | 33.4 | 34.3 | 35.2 | 36.4 | 37.0 | 37.4 | 37.6 | 37.0 | 35.2 | 33.3 | 32.3 | 31.4 | 30.6 | 29.8 | 29.4 | 31.48 |
| 12 | 27.9 | 27.5 | 26.3 | 25.3 | 24.9 | 26.1 | 27.8 | 33.1 | 34.6 | ND | 36.7 | 37.5 | 38.2 | 39.0 | 38.6 | 38.6 | 38.3 | 36.8 | 35.0 | 30.6 | 30.2 | 30.1 | 29.7 | 29.1 | 32.26 |
| 13 | 28.1 | 27.8 | 27.0 | 27.0 | 26.9 | 27.3 | 29.9 | 32.3 | 33.7 | 35.0 | 36.0 | 36.6 | 36.8 | 36.9 | 37.0 | 37.1 | 35.5 | 34.5 | 33.4 | 32.6 | 32.4 | 32.0 | 30.5 | 29.9 | 32.34 |
| 14 | 29.3 | 29.0 | 28.7 | 28.3 | 28.3 | 28.7 | 29.4 | 31.8 | 33.3 | 35.5 | 39.0 | 40.3 | 36.8 | 37.7 | 37.3 | 36.6 | 34.9 | 33.3 | 32.8 | 32.1 | 31.8 | 31.7 | 30.6 | 31.0 | 32.84 |
| 15 | 30.8 | 30.3 | 29.9 | 29.7 | 29.6 | 30.1 | 30.8 | 30.4 | 32.1 | ND | 38.5 | 41.1 | 40.8 | 40.6 | 39.6 | 38.8 | 37.8 | 34.7 | 33.6 | 33.6 | 32.7 | 32.4 | 32.1 | 31.9 | 34.00 |
| 16 | 31.4 | 30.0 | 29.3 | 29.3 | 29.9 | 30.5 | 32.4 | 34.7 | 35.5 | 32.7 | 33.2 | 31.9 | 32.1 | 31.2 | 31.0 | 29.9 | 30.3 | 30.5 | 30.5 | 30.2 | 30.6 | 30.9 | 31.0 | 30.0 | 31.21 |
| 17 | 28.0 | 27.9 | 28.2 | 28.3 | 28.6 | 29.5 | 30.6 | 31.0 | ND | 32.3 | 33.1 | 34.8 | 35.7 | 36.0 | 36.3 | 35.7 | 34.5 | 32.9 | 31.6 | 30.8 | 30.3 | 30.0 | 28.9 | 28.7 | 31.47 |
| 18 | 28.2 | 27.7 | 27.1 | 26.3 | 25.6 | 25.4 | 25.5 | 26.3 | 28.8 | 34.9 | 32.6 | 33.9 | 34.9 | 35.4 | 35.7 | 35.4 | 34.5 | 33.3 | 32.0 | 31.1 | 30.1 | 29.3 | 28.9 | 28.1 | 30.46 |
| 19 | 27.4 | 26.8 | 26.1 | 26.0 | 25.7 | 25.8 | 27.9 | 29.7 | 31.1 | 32.6 | ND | 35.6 | 36.5 | 36.9 | 37.2 | 36.8 | 35.8 | 34.5 | 32.9 | 32.0 | 31.1 | 30.2 | 29.3 | 28.7 | 31.16 |
| 20 | 28.2 | 27.8 | 27.2 | 26.4 | 24.8 | 24.3 | 27.1 | 30.2 | 32.8 | 34.6 | 35.9 | 37.1 | 38.9 | 40.0 | 40.5 | 40.2 | 39.4 | 36.9 | 35.0 | 33.6 | 33.0 | 32.7 | 32.1 | 31.6 | 32.93 |
| 21 | 30.7 | 30.0 | 28.5 | 27.8 | 27.5 | 28.4 | 30.9 | 33.7 | 36.0 | ND | 40.0 | 38.2 | 39.3 | 37.0 | 34.2 | 32.3 | 32.0 | 31.6 | 31.5 | 32.0 | 31.4 | 30.9 | 31.4 | 32.1 | 32.50 |
| 22 | 31.8 | 30.9 | 31.0 | 30.9 | 30.6 | 30.3 | 30.4 | 31.3 | 31.4 | 31.8 | 31.9 | 32.7 | 33.1 | 33.5 | 33.4 | 32.5 | 31.5 | 30.5 | 30.1 | 29.9 | 28.9 | 28.2 | 28.1 | 28.0 | 30.95 |
| 23 | 27.6 | 27.0 | 26.2 | 25.6 | 25.2 | 25.0 | 24.9 | 25.6 | 26.9 | 27.7 | 29.3 | ND | 32.2 | 33.2 | 32.9 | 32.6 | 32.0 | 31.1 | 29.7 | 28.8 | 28.1 | 27.3 | 26.1 | 25.3 | 28.27 |
| 24 | 24.4 | 23.9 | 23.3 | 22.4 | 21.8 | 22.0 | 24.2 | 26.0 | 26.6 | 29.0 | 31.6 | 32.5 | 32.7 | 33.8 | 34.0 | 33.6 | 32.5 | 31.2 | 29.8 | 29.0 | 28.3 | 27.6 | 26.8 | 26.1 | 28.05 |
| 25 | 25.4 | 24.6 | 23.7 | 23.1 | 22.7 | 24.6 | 27.4 | 28.4 | 29.7 | ND | 33.7 | 34.7 | 36.2 | 36.8 | 37.2 | 37.5 | 37.2 | 35.6 | 33.6 | 32.2 | 31.5 | 30.0 | 29.4 | 29.0 | 30.62 |
| 26 | 28.3 | 27.7 | 27.5 | 26.7 | 25.3 | 25.1 | 27.8 | 30.6 | 33.5 | 35.9 | 38.0 | 40.3 | 41.9 | 42.0 | 42.3 | 40.5 | 37.1 | 36.3 | 35.3 | 33.6 | 31.9 | 31.0 | 30.7 | 30.0 | 33.30 |
| 27 | 29.5 | 29.6 | 29.4 | 29.5 | 30.2 | 30.5 | 31.2 | 33.1 | 37.4 | ND | 41.4 | 41.6 | 42.2 | 42.9 | ND | ND | 42.4 | 38.2 | 37.0 | 35.5 | 34.8 | 33.7 | 32.4 | 31.4 | 34.95 |
| 28 | 30.4 | 29.8 | 29.1 | 28.2 | 27.4 | 27.2 | 28.0 | 29.6 | 32.1 | 33.5 | 34.5 | 35.5 | 36.8 | 37.4 | 37.5 | 37.3 | 36.2 | 34.6 | 33.0 | 32.1 | 31.3 | 30.5 | 29.6 | 28.9 | 32.10 |
| 29 | 28.2 | 27.4 | 26.5 | 25.8 | 25.4 | 26.3 | 27.6 | 29.4 | 30.5 | ND | 34.4 | 35.4 | 36.4 | 37.8 | 38.0 | 37.8 | 37.1 | 35.6 | 34.1 | 33.1 | 32.1 | 31.3 | 30.2 | 29.7 | 31.74 |
| 30 | 29.2 | 28.6 | 28.0 | 27.2 | 26.6 | 26.5 | 27.5 | 29.2 | 29.9 | 32.1 | 34.1 | 35.4 | 37.5 | 39.2 | 39.4 | 38.2 | 37.1 | 35.4 | 34.0 | 33.2 | 32.5 | 32.0 | 30.9 | 29.8 | 32.23 |
| 31 | 29.1 | 28.3 | 27.9 | 27.8 | 27.2 | 27.2 | 28.4 | 30.1 | 32.2 | 34.7 | 36.0 | 37.0 | 38.1 | 38.5 | 38.4 | 37.9 | 37.0 | 35.8 | 34.4 | 33.5 | 32.7 | 31.9 | 31.4 | 30.8 | 32.76 |
| | | | | | | | | | | | | | | | | | | | | | | Monthly Average = | | | 31.44 |

Maximum Hourly Average was 42.9 at Hour 14 on Day 27 with 1 occurences
Maximum Daily Average was 34.95 on Day 27 with 1 occurences
Operating Efficiency = 92.1 percent
ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data
[CEM 1990]

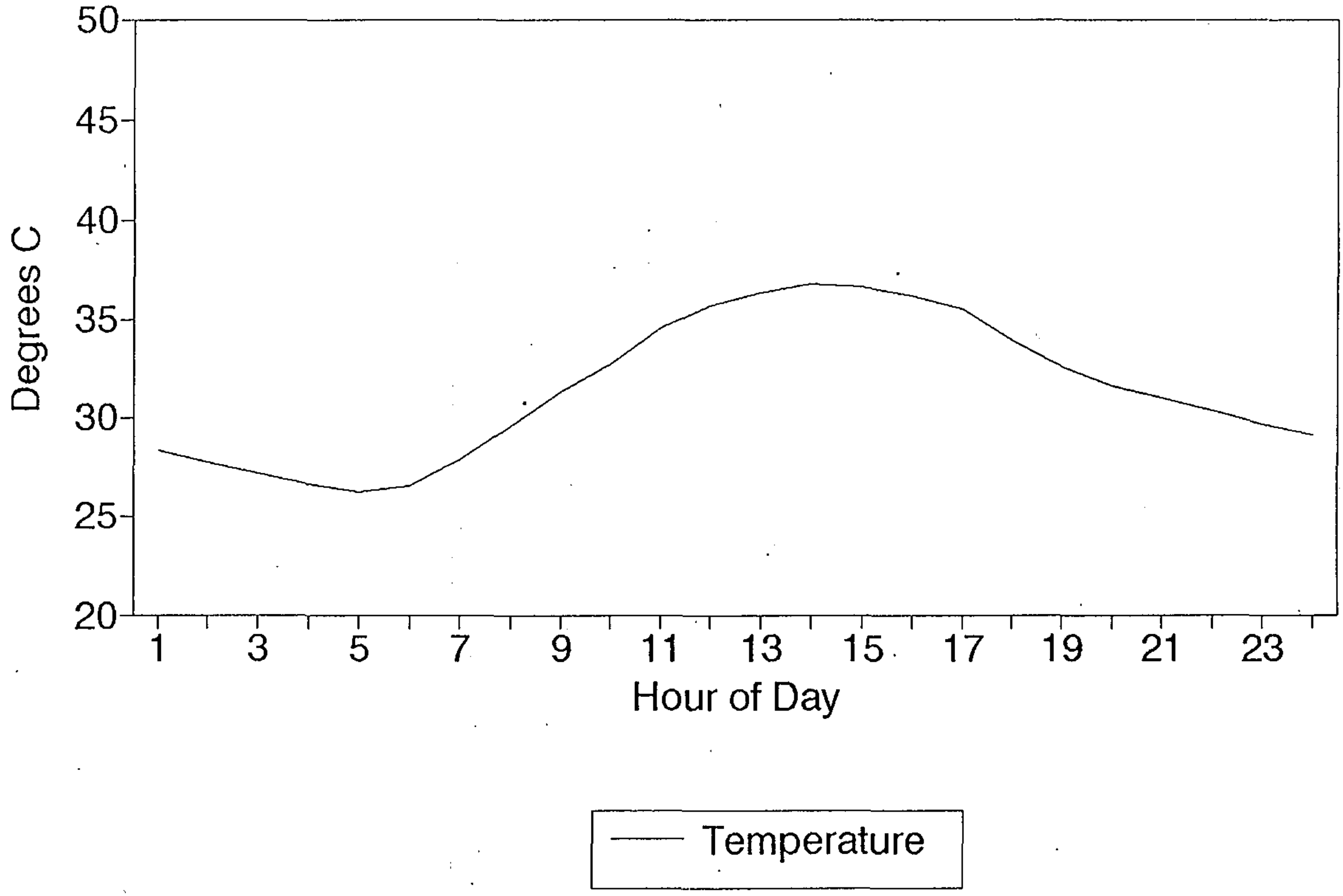
# KUWAIT

## Hourly Temperature – May, 1991



# KUWAIT

Diurnal Temperature - May, 1991



MEPA - Kuwait

May 1991

Hourly Averages for Total Particulate in MG/M3

| Day \ Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.014 | 0.013 | 0.014 | 0.014 | 0.016 | 0.017 | 0.015 | 0.015 | 0.015 | 0.018 | 0.013 | 0.012 | 0.013 | 0.015 | 0.017 | 0.018 | 0.019 | ND | ND | 0.022 | 0.017 | 0.019 | 0.044 | 0.041 | 0.0182 |
| 2 | 0.056 | 0.070 | 0.057 | 0.066 | 0.091 | 0.045 | 0.051 | 0.016 | 0.070 | 0.096 | 0.100 | 0.055 | 0.036 | 0.038 | 0.059 | 0.056 | 0.043 | 0.041 | 0.045 | 0.052 | 0.063 | 0.070 | 0.042 | 0.020 | 0.0558 |
| 3 | 0.024 | 0.025 | 0.025 | 0.025 | 0.028 | 0.031 | 0.030 | 0.031 | 0.031 | CAL | 0.088 | 0.060 | 0.035 | 0.026 | 0.024 | 0.031 | 0.044 | 0.043 | 0.033 | 0.033 | 0.033 | 0.034 | 0.025 | 0.017 | 0.0337 |
| 4 | 0.016 | 0.015 | 0.015 | 0.018 | 0.025 | 0.029 | 0.027 | 0.027 | 0.030 | 0.028 | 0.022 | 0.018 | 0.018 | 0.016 | 0.016 | 0.017 | 0.017 | 0.016 | 0.015 | 0.015 | 0.016 | 0.013 | 0.014 | 0.020 | 0.0193 |
| 5 | 0.015 | 0.014 | 0.014 | 0.015 | 0.016 | 0.017 | 0.020 | 0.022 | 0.023 | 0.021 | CAL | 0.013 | 0.012 | 0.013 | 0.013 | 0.013 | 0.013 | 0.013 | 0.014 | 0.014 | 0.015 | 0.014 | 0.015 | 0.014 | 0.0153 |
| 6 | 0.018 | 0.017 | 0.017 | 0.018 | 0.015 | 0.013 | 0.012 | 0.013 | 0.013 | 0.012 | 0.012 | 0.011 | 0.012 | 0.011 | 0.012 | 0.011 | ND | ND | ND | ND | ND | ND | ND | ND | 0.0136 |
| 7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.015 | 0.010 | 0.010 | 0.010 | 0.015 | 0.015 | 0.017 | 0.014 | 0.016 | 0.030 | CAL | 0.020 | 0.020 | 0.026 | 0.0168 |
| 8 | 0.037 | 0.080 | 0.022 | 0.017 | 0.052 | 0.052 | 0.033 | 0.038 | 0.028 | 0.016 | CAL | CAL | 0.015 | 0.018 | 0.019 | 0.019 | 0.017 | 0.017 | 0.017 | 0.017 | 0.045 | 0.248 | 0.123 | 0.087 | 0.0462 |
| 9 | 0.060 | 0.034 | 0.050 | 0.044 | 0.034 | 0.031 | 0.030 | 0.028 | 0.025 | 0.019 | 0.018 | 0.019 | 0.018 | 0.020 | 0.021 | 0.019 | 0.017 | 0.017 | 0.016 | 0.057 | 0.205 | 0.307 | 0.258 | 0.065 | 0.0588 |
| 10 | 0.034 | 0.022 | 0.031 | 0.050 | 0.083 | 0.090 | 0.108 | 0.102 | 0.079 | CAL | 0.066 | 0.036 | 0.024 | 0.022 | 0.020 | 0.022 | 0.019 | 0.018 | 0.020 | 0.018 | 0.017 | 0.018 | 0.019 | 0.018 | 0.0407 |
| 11 | 0.016 | 0.016 | 0.015 | 0.015 | 0.015 | 0.017 | 0.023 | 0.032 | 0.038 | 0.041 | 0.038 | 0.032 | 0.026 | 0.021 | 0.019 | 0.019 | 0.019 | 0.024 | 0.022 | 0.016 | 0.020 | 0.028 | 0.027 | 0.019 | 0.0232 |
| 12 | 0.016 | 0.015 | 0.014 | 0.014 | 0.014 | 0.013 | 0.130 | 0.023 | 0.027 | CAL | 0.022 | 0.018 | 0.017 | 0.017 | 0.017 | 0.017 | 0.018 | 0.018 | 0.021 | 0.024 | 0.023 | 0.023 | 0.023 | 0.023 | 0.0238 |
| 13 | 0.026 | 0.030 | 0.065 | 0.057 | 0.057 | 0.026 | 0.035 | 0.028 | 0.022 | 0.019 | 0.018 | 0.017 | 0.013 | 0.017 | 0.015 | 0.047 | 0.051 | 0.030 | 0.028 | 0.035 | 0.023 | 0.019 | 0.015 | 0.035 | 0.0303 |
| 14 | 0.104 | 0.054 | 0.038 | 0.036 | 0.041 | 0.032 | 0.027 | 0.300 | 0.048 | 0.037 | 0.023 | 0.024 | 0.028 | 0.025 | 0.033 | 0.036 | 0.029 | 0.025 | 0.022 | 0.018 | 0.021 | 0.025 | 0.070 | 0.244 | 0.0558 |
| 15 | 0.233 | 0.195 | 0.098 | 0.039 | 0.400 | 0.036 | 0.068 | 0.034 | 0.029 | CAL | 0.025 | 0.020 | 0.018 | 0.017 | 0.017 | 0.160 | 0.016 | 0.018 | 0.018 | 0.019 | 0.021 | 0.021 | 0.023 | 0.020 | 0.0672 |
| 16 | 0.019 | 0.019 | 0.019 | 0.018 | 0.018 | 0.028 | 0.057 | 0.021 | 0.021 | 0.027 | 0.025 | 0.024 | 0.023 | 0.023 | 0.023 | 0.022 | 0.022 | 0.021 | 0.020 | 0.021 | 0.020 | 0.020 | 0.021 | 0.021 | 0.0230 |
| 17 | 0.021 | 0.018 | 0.018 | 0.018 | 0.020 | 0.048 | 0.173 | 0.230 | CAL | 0.178 | 0.189 | 0.161 | 0.145 | 0.127 | 0.106 | 0.107 | 0.090 | 0.081 | 0.095 | 0.079 | 0.047 | 0.036 | 0.034 | 0.033 | 0.0893 |
| 18 | 0.024 | 0.018 | 0.020 | 0.043 | 0.038 | 0.044 | 0.061 | 0.053 | 0.042 | 0.039 | 0.034 | 0.035 | 0.039 | 0.039 | 0.029 | 0.025 | 0.020 | 0.019 | 0.018 | 0.018 | 0.019 | 0.023 | 0.021 | 0.020 | 0.0309 |
| 19 | 0.022 | 0.024 | 0.020 | 0.017 | 0.015 | 0.016 | 0.015 | 0.014 | 0.014 | 0.014 | CAL | 0.017 | 0.020 | 0.025 | 0.023 | 0.025 | 0.320 | 0.022 | 0.022 | 0.028 | 0.032 | 0.039 | 0.042 | 0.028 | 0.0354 |
| 20 | 0.022 | 0.019 | 0.019 | 0.014 | 0.014 | 0.015 | 0.014 | 0.014 | 0.014 | 0.016 | 0.016 | 0.016 | 0.015 | 0.015 | 0.016 | 0.016 | 0.017 | 0.020 | 0.016 | 0.015 | 0.015 | 0.016 | 0.019 | 0.022 | 0.0165 |
| 21 | 0.041 | 0.026 | 0.041 | 0.018 | 0.019 | 0.022 | 0.028 | 0.020 | 0.023 | CAL | 0.026 | 0.023 | 0.021 | 0.017 | 0.017 | 0.020 | 0.026 | 0.024 | 0.018 | 0.017 | 0.018 | 0.017 | 0.019 | 0.034 | 0.0233 |
| 22 | 0.044 | 0.039 | 0.038 | 0.044 | 0.046 | 0.063 | 0.083 | 0.089 | 0.098 | 0.122 | 0.147 | 0.188 | 0.195 | 0.162 | 0.128 | 0.145 | 0.138 | 0.122 | 0.115 | 0.131 | 0.115 | 0.105 | 0.107 | 0.117 | 0.1075 |
| 23 | 0.108 | 0.121 | 0.113 | 0.133 | 0.128 | 0.086 | 0.047 | 0.033 | 0.027 | 0.027 | 0.024 | CAL | 0.019 | 0.020 | 0.025 | 0.030 | 0.027 | 0.028 | 0.027 | 0.023 | 0.021 | 0.025 | 0.036 | 0.055 | 0.0514 |
| 24 | 0.029 | 0.020 | 0.020 | 0.020 | 0.018 | 0.023 | 0.030 | 0.049 | 0.057 | 0.029 | 0.020 | 0.019 | 0.020 | 0.020 | 0.022 | 0.022 | 0.026 | 0.025 | 0.023 | 0.037 | 0.027 | 0.018 | 0.020 | 0.019 | 0.0255 |
| 25 | 0.018 | 0.018 | 0.018 | 0.017 | 0.015 | 0.014 | 0.013 | 0.013 | 0.014 | CAL | 0.014 | 0.014 | 0.014 | 0.013 | 0.013 | 0.015 | 0.015 | 0.016 | 0.013 | 0.016 | 0.022 | 0.021 | 0.016 | 0.018 | 0.0157 |
| 26 | 0.018 | 0.018 | 0.018 | 0.024 | 0.023 | 0.023 | 0.017 | 0.016 | 0.015 | 0.016 | 0.015 | 0.015 | 0.015 | 0.015 | 0.017 | 0.020 | 0.020 | 0.018 | 0.018 | 0.020 | 0.018 | 0.017 | 0.056 | 0.097 | 0.0229 |
| 27 | 0.054 | 0.036 | 0.020 | 0.017 | 0.032 | 0.063 | 0.159 | 0.131 | 0.031 | CAL | 0.021 | 0.020 | 0.019 | 0.019 | ND | ND | 0.019 | 0.048 | 0.063 | 0.083 | 0.053 | 0.043 | 0.035 | 0.031 | 0.0475 |
| 28 | 0.036 | 0.031 | 0.032 | 0.026 | 0.019 | 0.019 | 0.021 | 0.025 | 0.031 | 0.029 | 0.025 | 0.023 | 0.022 | 0.019 | 0.020 | 0.022 | 0.024 | 0.027 | 0.031 | 0.031 | 0.033 | 0.032 | 0.026 | 0.023 | 0.0261 |
| 29 | 0.019 | 0.017 | 0.016 | 0.014 | 0.015 | 0.016 | 0.017 | 0.019 | 0.019 | CAL | 0.016 | 0.016 | 0.016 | 0.016 | 0.017 | 0.021 | 0.020 | 0.021 | 0.021 | 0.021 | 0.024 | 0.030 | 0.022 | 0.018 | 0.0187 |
| 30 | 0.016 | 0.015 | 0.015 | 0.025 | 0.027 | 0.040 | 0.044 | 0.050 | 0.024 | 0.014 | 0.015 | 0.015 | 0.015 | 0.015 | 0.019 | 0.032 | 0.027 | 0.025 | 0.026 | 0.039 | 0.048 | 0.042 | 0.021 | 0.015 | 0.0260 |
| 31 | 0.015 | 0.017 | 0.058 | 0.211 | 0.182 | 0.296 | 0.162 | 0.076 | 0.020 | 0.030 | 0.037 | 0.029 | 0.030 | 0.028 | 0.024 | 0.026 | 0.023 | 0.019 | 0.019 | 0.018 | 0.015 | 0.015 | 0.014 | 0.015 | 0.0575 |

Monthly Average = 0.0372

Maximum Hourly Average was 0.400 at Hour 5 on Day 15 with 1 occurences

Maximum Daily Average was 0.1075 on Day 22 with 1 occurences

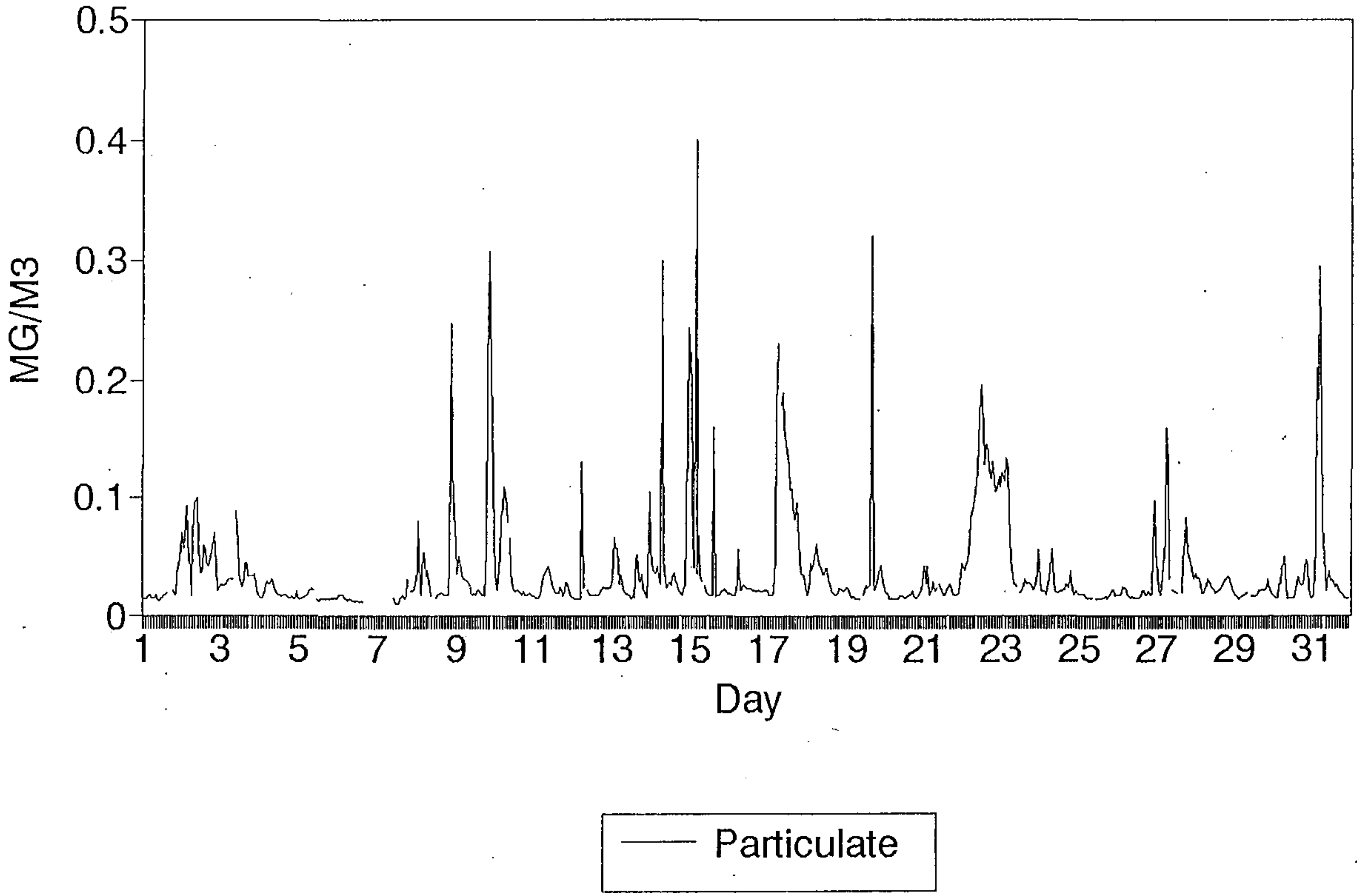
Operating Efficiency = 97.0 percent

ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data

[CEM 1990]

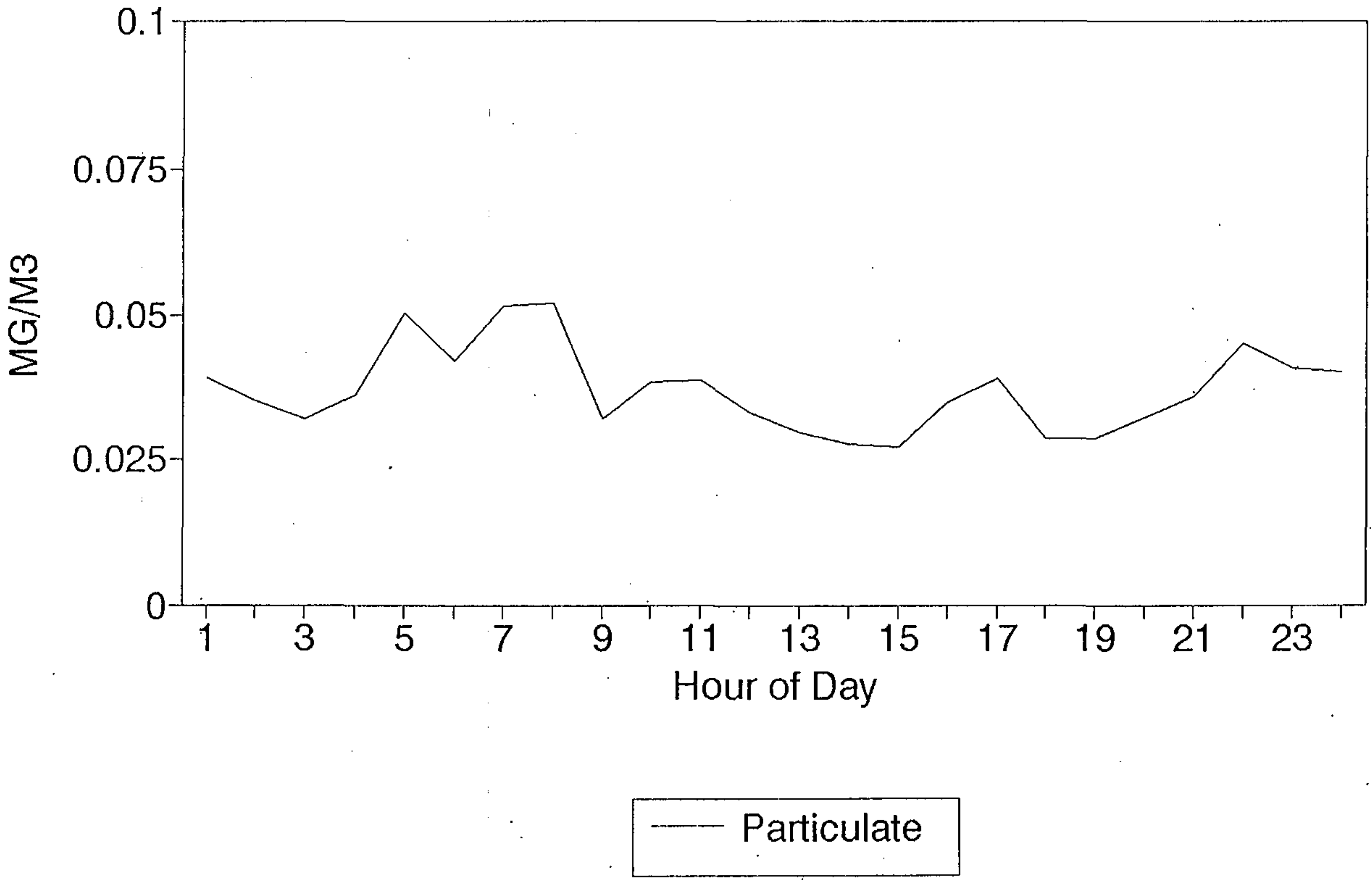
# KUWAIT

Hourly Particulate - May, 1991



# KUWAIT

Diurnal Particulate - May, 1991



MEPA - Kuwait
May 1991
Hourly Averages for NH3 in ppm

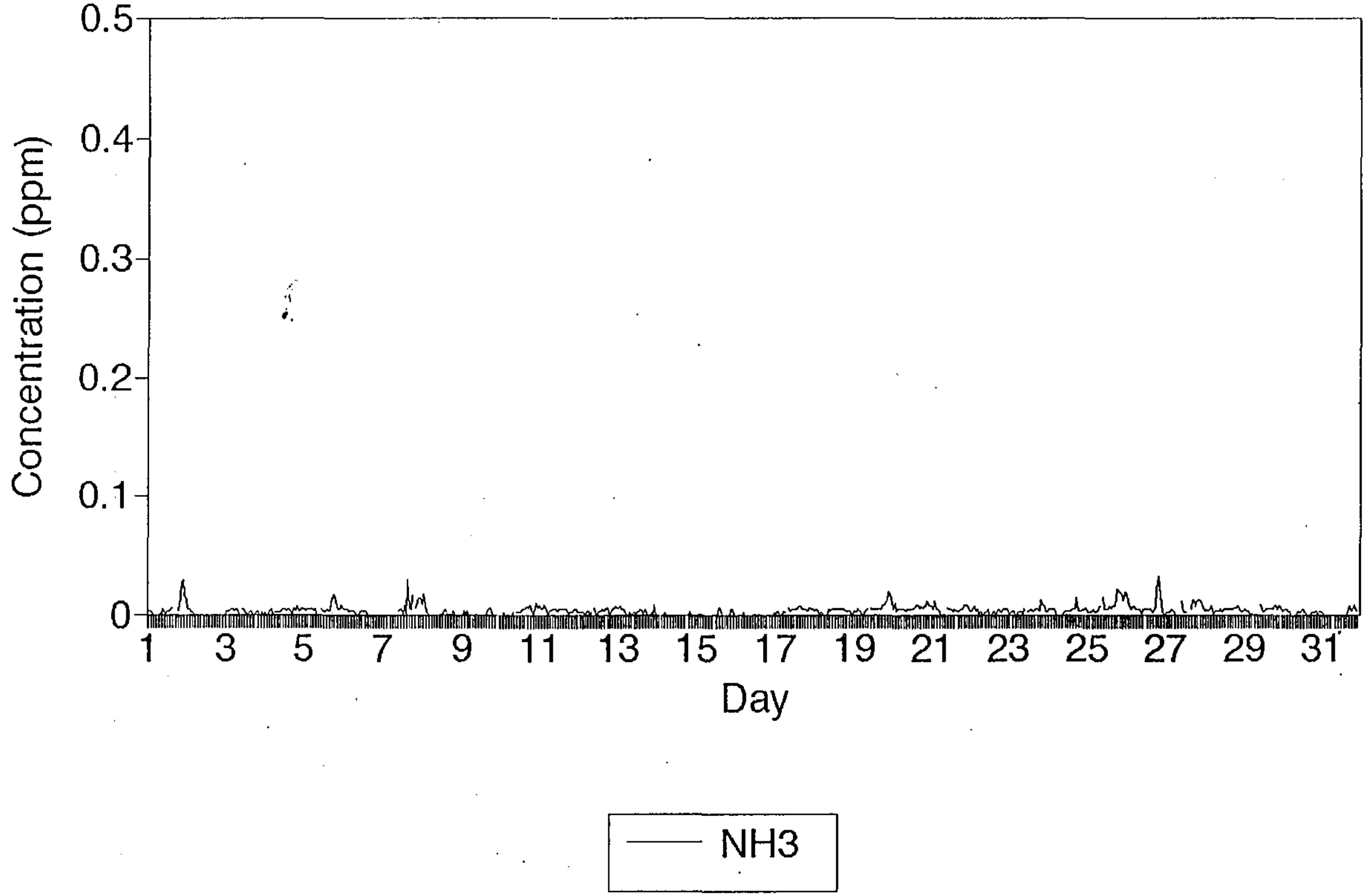
| Hour / Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.003 | 0.003 | 0.003 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.004 | 0.002 | 0.001 | 0.003 | 0.003 | 0.004 | 0.006 | ND | ND | 0.003 | 0.014 | 0.026 | 0.029 | 0.016 | 0.0056 |
| 2 | 0.012 | 0.005 | 0.004 | 0.003 | 0.002 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.0011 |
| 3 | 0.000 | 0.003 | 0.003 | 0.004 | 0.004 | 0.003 | 0.004 | 0.005 | 0.001 | CAL | 0.005 | 0.004 | 0.002 | 0.001 | 0.001 | 0.002 | 0.003 | 0.001 | 0.000 | 0.003 | 0.001 | 0.000 | 0.002 | 0.000 | 0.0023 |
| 4 | 0.002 | 0.000 | 0.000 | 0.003 | 0.005 | 0.000 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.004 | 0.004 | 0.003 | 0.004 | 0.004 | 0.002 | 0.001 | 0.006 | 0.003 | 0.007 | 0.003 | 0.003 | 0.006 | 0.0029 |
| 5 | 0.004 | 0.005 | 0.003 | 0.004 | 0.004 | 0.004 | 0.003 | 0.004 | 0.001 | 0.000 | CAL | 0.005 | 0.003 | 0.003 | 0.003 | 0.004 | 0.003 | 0.004 | 0.013 | 0.017 | 0.007 | 0.004 | 0.004 | 0.009 | 0.0048 |
| 6 | 0.006 | 0.004 | 0.004 | 0.004 | 0.002 | 0.003 | 0.003 | 0.003 | 0.002 | 0.000 | 0.001 | 0.002 | 0.003 | 0.003 | 0.003 | 0.000 | ND | ND | ND | ND | ND | ND | ND | ND | 0.0027 |
| 7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.003 | 0.004 | 0.005 | 0.001 | 0.008 | 0.000 | 0.029 | 0.006 | 0.005 | 0.016 | CAL | 0.006 | 0.014 | 0.014 | 0.0085 |
| 8 | 0.009 | 0.017 | 0.008 | 0.002 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | CAL | CAL | 0.001 | 0.001 | 0.005 | 0.001 | 0.000 | 0.001 | 0.001 | 0.003 | 0.000 | 0.000 | 0.000 | 0.000 | 0.0023 |
| 9 | 0.000 | 0.000 | 0.003 | 0.001 | 0.003 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.004 | 0.006 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.0009 |
| 10 | 0.000 | 0.000 | 0.002 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.002 | CAL | 0.002 | 0.002 | 0.002 | 0.002 | 0.004 | 0.005 | 0.007 | 0.006 | 0.008 | 0.004 | 0.001 | 0.002 | 0.010 | 0.006 | 0.0029 |
| 11 | 0.008 | 0.006 | 0.004 | 0.008 | 0.007 | 0.003 | 0.001 | 0.003 | 0.005 | 0.004 | 0.005 | 0.003 | 0.004 | 0.004 | 0.004 | 0.005 | 0.005 | 0.005 | 0.001 | 0.002 | 0.002 | 0.002 | 0.004 | 0.004 | 0.0041 |
| 12 | 0.002 | 0.002 | 0.002 | 0.002 | 0.001 | 0.003 | 0.003 | 0.001 | 0.002 | CAL | 0.006 | 0.001 | 0.001 | 0.003 | 0.003 | 0.004 | 0.003 | 0.005 | 0.006 | 0.000 | 0.002 | 0.005 | 0.006 | 0.007 | 0.0030 |
| 13 | 0.006 | 0.006 | 0.007 | 0.005 | 0.004 | 0.002 | 0.000 | 0.000 | 0.002 | 0.000 | 0.002 | 0.001 | 0.002 | 0.003 | 0.004 | 0.003 | 0.001 | 0.005 | 0.002 | 0.000 | 0.000 | 0.002 | 0.000 | 0.008 | 0.0027 |
| 14 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.000 | 0.000 | 0.000 | 0.0002 |
| 15 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | CAL | 0.000 | 0.000 | 0.001 | 0.000 | 0.006 | 0.006 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.004 | 0.005 | 0.0011 |
| 16 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.0003 |
| 17 | 0.002 | 0.001 | 0.003 | 0.000 | 0.000 | 0.001 | 0.003 | 0.002 | CAL | 0.006 | 0.003 | 0.004 | 0.004 | 0.005 | 0.006 | 0.007 | 0.007 | 0.004 | 0.005 | 0.004 | 0.003 | 0.004 | 0.006 | 0.004 | 0.0037 |
| 18 | 0.005 | 0.003 | 0.004 | 0.003 | 0.001 | 0.002 | 0.000 | 0.000 | 0.000 | 0.005 | 0.003 | 0.004 | 0.005 | 0.004 | 0.005 | 0.004 | 0.005 | 0.005 | 0.004 | 0.004 | 0.003 | 0.003 | 0.003 | 0.001 | 0.0032 |
| 19 | 0.001 | 0.003 | 0.002 | 0.005 | 0.003 | 0.002 | 0.000 | 0.001 | 0.003 | 0.004 | CAL | 0.006 | 0.005 | 0.005 | 0.005 | 0.005 | 0.004 | 0.005 | 0.007 | 0.009 | 0.010 | 0.012 | 0.019 | 0.017 | 0.0058 |
| 20 | 0.010 | 0.005 | 0.010 | 0.003 | 0.004 | 0.004 | 0.004 | 0.004 | 0.003 | 0.005 | 0.004 | 0.004 | 0.005 | 0.005 | 0.006 | 0.009 | 0.009 | 0.006 | 0.007 | 0.006 | 0.007 | 0.007 | 0.011 | 0.008 | 0.0061 |
| 21 | 0.007 | 0.005 | 0.011 | 0.004 | 0.005 | 0.003 | 0.000 | 0.000 | 0.001 | CAL | 0.006 | 0.004 | 0.005 | 0.004 | 0.003 | 0.004 | 0.003 | 0.003 | 0.005 | 0.004 | 0.009 | 0.008 | 0.008 | 0.006 | 0.0047 |
| 22 | 0.003 | 0.003 | 0.006 | 0.007 | 0.003 | 0.004 | 0.001 | 0.003 | 0.000 | 0.002 | 0.002 | 0.004 | 0.000 | 0.000 | 0.001 | 0.003 | 0.001 | 0.002 | 0.004 | 0.003 | 0.002 | 0.005 | 0.005 | 0.005 | 0.0029 |
| 23 | 0.004 | 0.001 | 0.003 | 0.003 | 0.000 | 0.000 | 0.002 | 0.002 | 0.003 | 0.001 | 0.004 | CAL | 0.002 | 0.003 | 0.004 | 0.003 | 0.003 | 0.004 | 0.004 | 0.003 | 0.012 | 0.009 | 0.007 | 0.002 | 0.0034 |
| 24 | 0.002 | 0.005 | 0.004 | 0.004 | 0.005 | 0.004 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.003 | 0.003 | 0.003 | 0.003 | 0.004 | 0.004 | 0.004 | 0.014 | 0.003 | 0.003 | 0.003 | 0.005 | 0.005 | 0.0034 |
| 25 | 0.006 | 0.003 | 0.002 | 0.003 | 0.004 | 0.002 | 0.003 | 0.005 | 0.007 | CAL | 0.015 | 0.005 | 0.004 | 0.005 | 0.007 | 0.006 | 0.007 | 0.007 | 0.008 | 0.022 | 0.019 | 0.018 | 0.012 | 0.019 | 0.0082 |
| 26 | 0.019 | 0.012 | 0.008 | 0.005 | 0.007 | 0.007 | 0.004 | 0.004 | 0.004 | 0.004 | 0.001 | 0.004 | 0.004 | 0.005 | 0.005 | 0.005 | 0.002 | 0.003 | 0.007 | 0.022 | 0.032 | 0.016 | 0.008 | 0.000 | 0.0078 |
| 27 | 0.000 | 0.002 | 0.002 | 0.002 | 0.004 | 0.002 | 0.000 | 0.000 | 0.000 | CAL | 0.011 | 0.002 | 0.002 | 0.002 | ND | ND | 0.005 | 0.012 | 0.012 | 0.007 | 0.012 | 0.012 | 0.008 | 0.006 | 0.0049 |
| 28 | 0.003 | 0.005 | 0.003 | 0.004 | 0.007 | 0.001 | 0.002 | 0.003 | 0.003 | 0.003 | 0.004 | 0.002 | 0.005 | 0.004 | 0.005 | 0.004 | 0.005 | 0.004 | 0.006 | 0.006 | 0.007 | 0.006 | 0.003 | 0.002 | 0.0040 |
| 29 | 0.003 | 0.004 | 0.003 | 0.003 | 0.001 | 0.001 | 0.000 | 0.001 | 0.000 | CAL | 0.008 | 0.004 | 0.002 | 0.003 | 0.004 | 0.005 | 0.004 | 0.004 | 0.004 | 0.007 | 0.008 | 0.004 | 0.009 | 0.004 | 0.0037 |
| 30 | 0.003 | 0.005 | 0.004 | 0.003 | 0.003 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.003 | 0.002 | 0.003 | 0.004 | 0.003 | 0.001 | 0.000 | 0.000 | 0.002 | 0.002 | 0.002 | 0.003 | 0.000 | 0.002 | 0.0019 |
| 31 | 0.003 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.004 | 0.007 | 0.003 | 0.004 | 0.008 | 0.005 | 0.003 | 0.0016 |

Monthly Average = 0.0035

Maximum Hourly Average was 0.032 at Hour 21 on Day 26 with 1 occurences
Maximum Daily Average was 0.0085 on Day 7 with 1 occurences
Operating Efficiency = 97.0 percent
ND = no data, ZS = zero/span, CAL = calibration, 1R = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data
[CEM 1990]

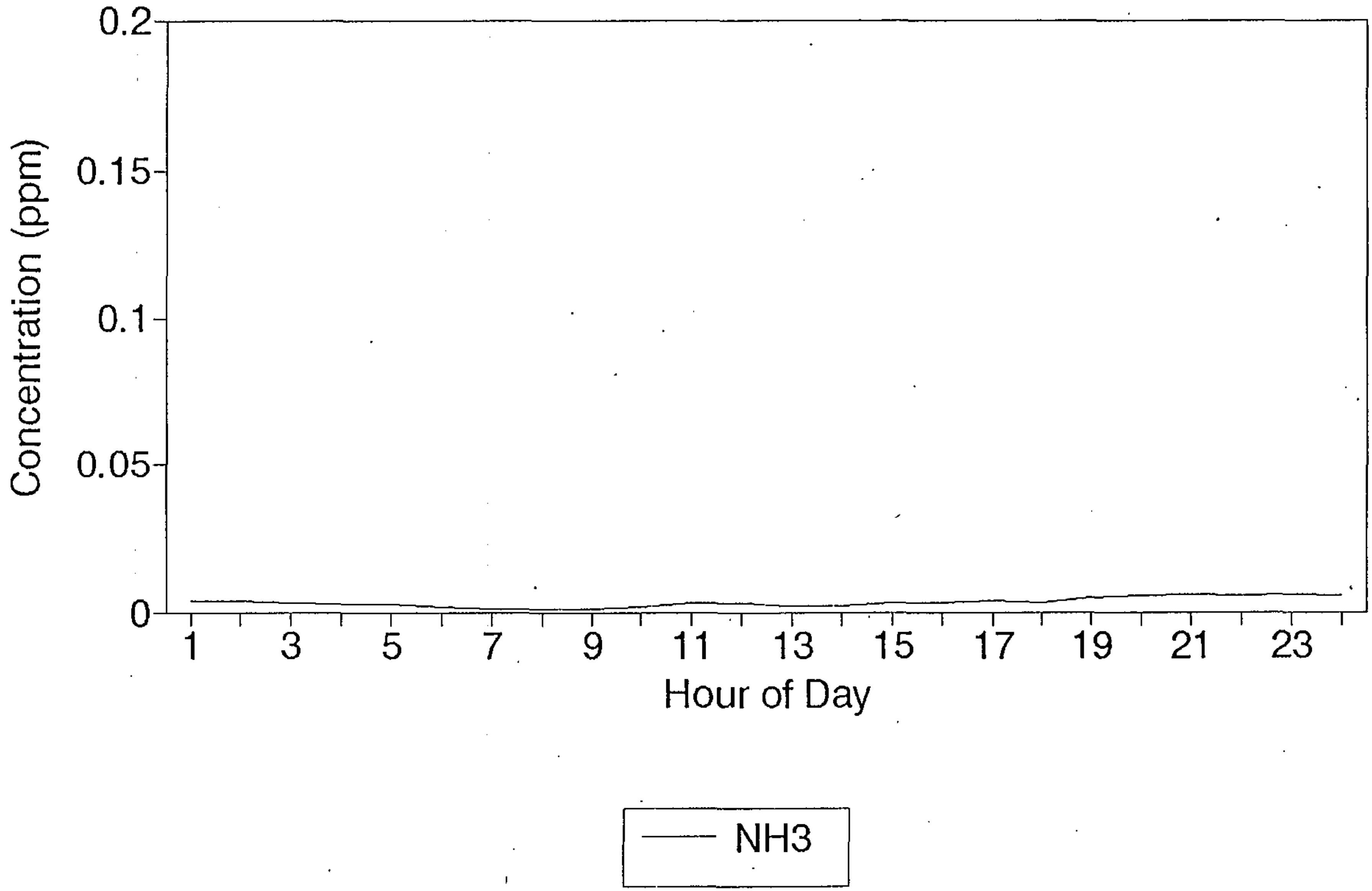
# KUWAIT

## Hourly NH3 - May, 1991



# KUWAIT

Diurnal NH3 - May, 1991



MEPA - Kuwait
May 1991
Hourly Averages for O3 in ppm

| Day \ Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.013 | 0.012 | 0.020 | 0.022 | 0.023 | 0.020 | 0.012 | 0.017 | 0.019 | 0.027 | 0.032 | 0.028 | 0.026 | 0.025 | 0.031 | 0.029 | 0.013 | ND | ND | 0.033 | 0.029 | 0.006 | 0.000 | 0.001 | 0.0199 |
| 2 | 0.001 | 0.002 | 0.012 | 0.014 | 0.012 | 0.010 | 0.014 | 0.009 | 0.003 | 0.001 | 0.000 | 0.000 | 0.001 | 0.003 | 0.000 | 0.001 | 0.008 | 0.017 | 0.014 | 0.010 | 0.009 | 0.010 | 0.013 | 0.018 | 0.0076 |
| 3 | 0.019 | 0.028 | 0.031 | 0.033 | 0.035 | 0.033 | 0.033 | 0.034 | 0.034 | CAL | 0.032 | 0.030 | 0.033 | 0.034 | 0.034 | 0.034 | 0.032 | 0.029 | 0.013 | 0.023 | 0.024 | 0.012 | 0.016 | 0.012 | 0.0277 |
| 4 | 0.021 | 0.015 | 0.019 | 0.034 | 0.034 | 0.025 | 0.029 | 0.025 | 0.031 | 0.035 | 0.037 | 0.037 | 0.034 | 0.035 | 0.035 | 0.036 | 0.029 | 0.020 | 0.009 | 0.021 | 0.010 | 0.021 | 0.021 | 0.015 | 0.0262 |
| 5 | 0.021 | 0.023 | 0.018 | 0.013 | 0.022 | 0.020 | 0.026 | 0.028 | 0.029 | 0.029 | CAL | 0.036 | 0.037 | 0.033 | 0.035 | 0.031 | 0.026 | 0.019 | 0.000 | 0.001 | 0.014 | 0.014 | 0.015 | 0.007 | 0.0216 |
| 6 | 0.011 | 0.022 | 0.019 | 0.018 | 0.016 | 0.017 | 0.027 | 0.029 | 0.035 | 0.038 | 0.037 | 0.038 | 0.039 | 0.035 | 0.036 | 0.020 | ND | ND | ND | ND | ND | ND | ND | ND | 0.0273 |
| 7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.030 | 0.006 | 0.027 | 0.030 | 0.025 | 0.007 | 0.018 | 0.009 | 0.001 | 0.013 | CAL | 0.001 | 0.002 | 0.002 | 0.0132 |
| 8 | 0.001 | 0.011 | 0.010 | 0.010 | 0.021 | 0.019 | 0.022 | 0.015 | 0.030 | 0.018 | CAL | CAL | 0.029 | 0.022 | 0.029 | 0.035 | 0.033 | 0.029 | 0.007 | 0.014 | 0.022 | 0.014 | 0.008 | 0.007 | 0.0185 |
| 9 | 0.008 | 0.009 | 0.002 | 0.002 | 0.009 | 0.007 | 0.005 | 0.002 | 0.003 | 0.010 | 0.030 | 0.033 | 0.038 | 0.039 | 0.036 | 0.034 | 0.029 | 0.014 | 0.003 | 0.011 | 0.018 | 0.013 | 0.011 | 0.011 | 0.0157 |
| 10 | 0.015 | 0.015 | 0.017 | 0.008 | 0.003 | 0.008 | 0.010 | 0.022 | 0.026 | CAL | 0.025 | 0.028 | 0.031 | 0.028 | 0.020 | 0.021 | 0.015 | 0.018 | 0.013 | 0.032 | 0.034 | 0.028 | 0.006 | 0.016 | 0.0191 |
| 11 | 0.010 | 0.016 | 0.026 | 0.010 | 0.015 | 0.026 | 0.018 | 0.014 | 0.021 | 0.024 | 0.034 | 0.036 | 0.033 | 0.033 | 0.030 | 0.023 | 0.030 | 0.031 | 0.034 | 0.035 | 0.034 | 0.016 | 0.016 | 0.021 | 0.0244 |
| 12 | 0.019 | 0.025 | 0.017 | 0.012 | 0.012 | 0.021 | 0.030 | 0.028 | 0.017 | CAL | 0.034 | 0.031 | 0.034 | 0.031 | 0.027 | 0.027 | 0.025 | 0.028 | 0.010 | 0.003 | 0.002 | 0.000 | 0.000 | 0.000 | 0.0188 |
| 13 | 0.000 | 0.000 | 0.005 | 0.015 | 0.014 | 0.021 | 0.017 | 0.021 | 0.031 | 0.028 | 0.028 | 0.026 | 0.026 | 0.012 | 0.017 | 0.028 | 0.021 | 0.030 | 0.018 | 0.023 | 0.020 | 0.016 | 0.010 | 0.000 | 0.0178 |
| 14 | 0.000 | 0.003 | 0.010 | 0.013 | 0.016 | 0.023 | 0.021 | 0.021 | 0.019 | 0.020 | 0.029 | 0.035 | 0.055 | 0.033 | 0.032 | 0.033 | 0.025 | 0.015 | 0.003 | 0.000 | 0.006 | 0.007 | 0.003 | 0.006 | 0.0178 |
| 15 | 0.005 | 0.010 | 0.010 | 0.013 | 0.014 | 0.016 | 0.012 | 0.009 | 0.008 | CAL | 0.016 | 0.027 | 0.028 | 0.024 | 0.028 | 0.027 | 0.023 | 0.015 | 0.008 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.0128 |
| 16 | 0.000 | 0.003 | 0.000 | 0.000 | 0.000 | 0.015 | 0.018 | 0.018 | 0.011 | 0.025 | 0.023 | 0.023 | 0.025 | 0.025 | 0.026 | 0.024 | 0.025 | 0.025 | 0.020 | 0.019 | 0.017 | 0.022 | 0.025 | 0.025 | 0.0173 |
| 17 | 0.030 | 0.033 | 0.031 | 0.028 | 0.028 | 0.027 | 0.025 | 0.018 | CAL | 0.025 | 0.023 | 0.023 | 0.025 | 0.025 | 0.026 | 0.024 | 0.025 | 0.025 | 0.020 | 0.019 | 0.017 | 0.022 | 0.025 | 0.025 | 0.0247 |
| 18 | 0.030 | 0.033 | 0.031 | 0.028 | 0.028 | 0.027 | 0.025 | 0.022 | 0.024 | 0.032 | 0.030 | 0.029 | 0.032 | 0.032 | 0.033 | 0.034 | 0.033 | 0.031 | 0.030 | 0.028 | 0.030 | 0.034 | 0.040 | 0.029 | 0.0302 |
| 19 | 0.020 | 0.009 | 0.011 | 0.016 | 0.029 | 0.029 | 0.022 | 0.021 | 0.029 | 0.031 | CAL | 0.033 | 0.032 | 0.034 | 0.033 | 0.035 | 0.030 | 0.022 | 0.013 | 0.003 | 0.002 | 0.019 | 0.007 | 0.000 | 0.0209 |
| 20 | 0.012 | 0.018 | 0.004 | 0.023 | 0.024 | 0.022 | 0.026 | 0.032 | 0.030 | 0.023 | 0.027 | 0.032 | 0.030 | 0.030 | 0.028 | 0.024 | 0.022 | 0.013 | 0.007 | 0.003 | 0.003 | 0.006 | 0.000 | 0.001 | 0.0183 |
| 21 | 0.001 | 0.005 | 0.005 | 0.012 | 0.016 | 0.022 | 0.022 | 0.023 | 0.039 | CAL | 0.041 | 0.051 | 0.051 | 0.036 | 0.038 | 0.033 | 0.024 | 0.020 | 0.021 | 0.006 | 0.000 | 0.005 | 0.001 | 0.003 | 0.0207 |
| 22 | 0.003 | 0.000 | 0.001 | 0.003 | 0.012 | 0.015 | 0.013 | 0.012 | 0.010 | 0.015 | 0.017 | 0.019 | 0.023 | 0.027 | 0.027 | 0.025 | 0.022 | 0.018 | 0.015 | 0.019 | 0.015 | 0.015 | 0.026 | 0.010 | 0.0151 |
| 23 | 0.024 | 0.022 | 0.026 | 0.021 | 0.024 | 0.011 | 0.022 | 0.023 | 0.029 | 0.027 | 0.035 | CAL | 0.036 | 0.038 | 0.034 | 0.035 | 0.032 | 0.029 | 0.030 | 0.031 | 0.007 | 0.019 | 0.015 | 0.014 | 0.0254 |
| 24 | 0.023 | 0.021 | 0.023 | 0.021 | 0.022 | 0.014 | 0.017 | 0.017 | 0.020 | 0.028 | 0.036 | 0.035 | 0.035 | 0.035 | 0.035 | 0.035 | 0.033 | 0.029 | 0.025 | 0.013 | 0.022 | 0.025 | 0.020 | 0.024 | 0.0253 |
| 25 | 0.020 | 0.026 | 0.013 | 0.019 | 0.012 | 0.021 | 0.032 | 0.026 | 0.028 | CAL | CAL | 0.040 | 0.043 | 0.043 | 0.043 | 0.038 | 0.037 | 0.035 | 0.021 | 0.000 | 0.002 | 0.003 | 0.007 | 0.006 | 0.0234 |
| 26 | 0.003 | 0.009 | 0.014 | 0.021 | 0.008 | 0.015 | 0.025 | 0.033 | 0.032 | 0.032 | 0.032 | 0.035 | 0.035 | 0.038 | 0.037 | 0.034 | 0.031 | 0.025 | 0.005 | 0.000 | 0.000 | 0.000 | 0.011 | 0.012 | 0.0203 |
| 27 | 0.017 | 0.024 | 0.026 | 0.027 | 0.030 | 0.026 | 0.025 | 0.026 | 0.031 | CAL | 0.025 | 0.026 | 0.028 | 0.025 | ND | ND | 0.026 | 0.016 | 0.010 | 0.005 | 0.002 | 0.002 | 0.004 | 0.005 | 0.0193 |
| 28 | 0.011 | 0.008 | 0.007 | 0.019 | 0.016 | 0.015 | 0.015 | 0.017 | 0.025 | 0.032 | 0.033 | 0.032 | 0.030 | 0.028 | 0.028 | 0.028 | 0.032 | 0.026 | 0.023 | 0.022 | 0.019 | 0.021 | 0.030 | 0.034 | 0.0230 |
| 29 | 0.035 | 0.032 | 0.031 | 0.030 | 0.029 | 0.029 | 0.029 | 0.028 | 0.004 | CAL | 0.034 | 0.035 | 0.032 | 0.029 | 0.032 | 0.032 | 0.028 | 0.017 | 0.014 | 0.012 | 0.011 | 0.013 | 0.013 | 0.031 | 0.0252 |
| 30 | 0.034 | 0.033 | 0.036 | 0.033 | 0.030 | 0.023 | 0.014 | 0.013 | 0.012 | 0.021 | 0.026 | 0.028 | 0.031 | 0.030 | 0.030 | 0.030 | 0.023 | 0.016 | 0.014 | 0.017 | 0.006 | 0.010 | 0.026 | 0.023 | 0.0233 |
| 31 | 0.033 | 0.033 | 0.023 | 0.027 | 0.005 | 0.013 | 0.014 | 0.023 | 0.030 | 0.026 | 0.037 | 0.035 | 0.036 | 0.037 | 0.032 | 0.022 | 0.010 | 0.010 | 0.016 | 0.010 | 0.003 | 0.014 | 0.020 | 0.014 | 0.0218 |
| Monthly Average = | | | | | | | | | | | | | | | | | | | | | | | | | 0.0208 |

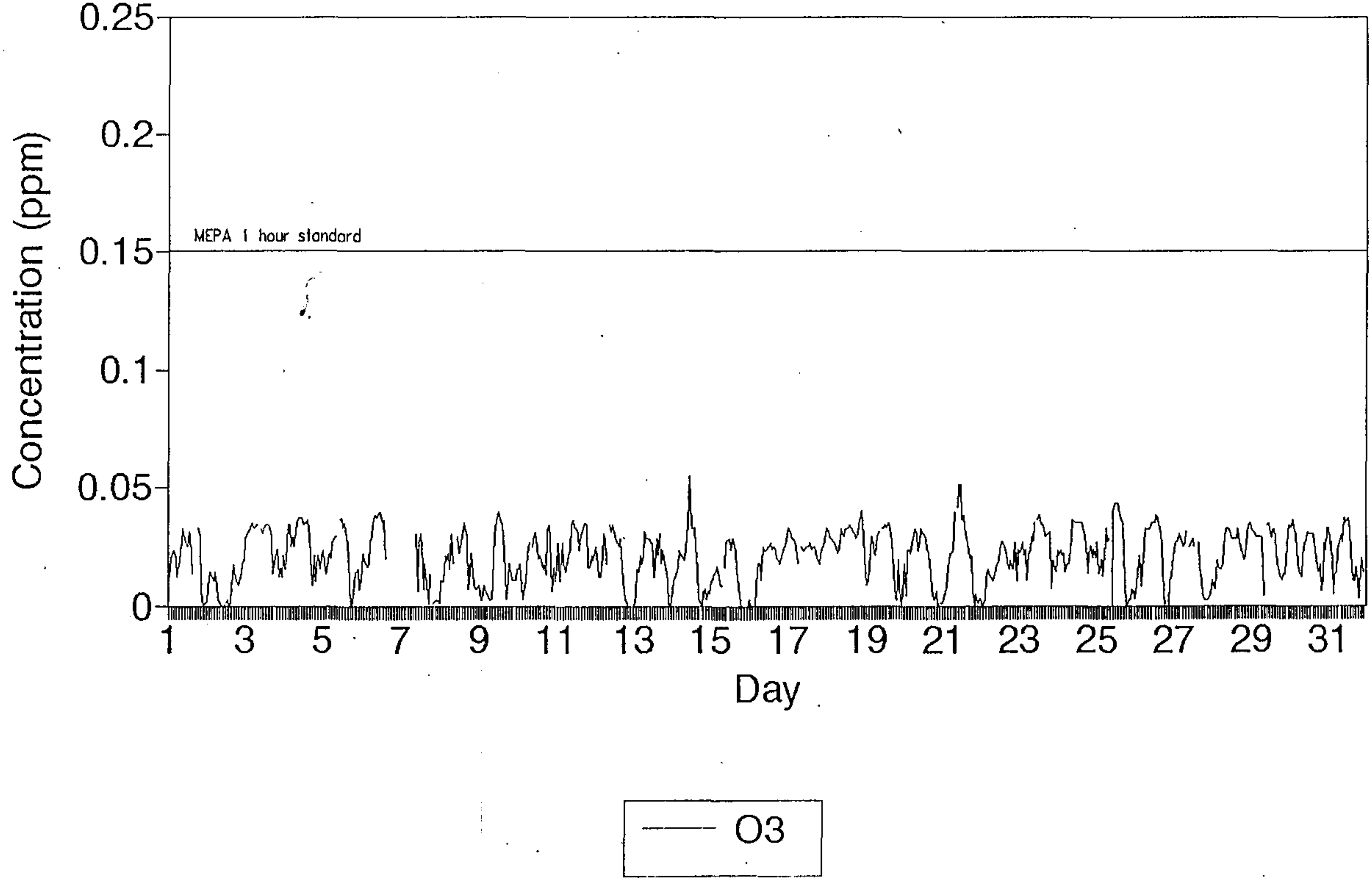
Maximum Hourly Average was 0.055 at Hour 13 on Day 14 with 1 occurences and there were no Hourly Violations

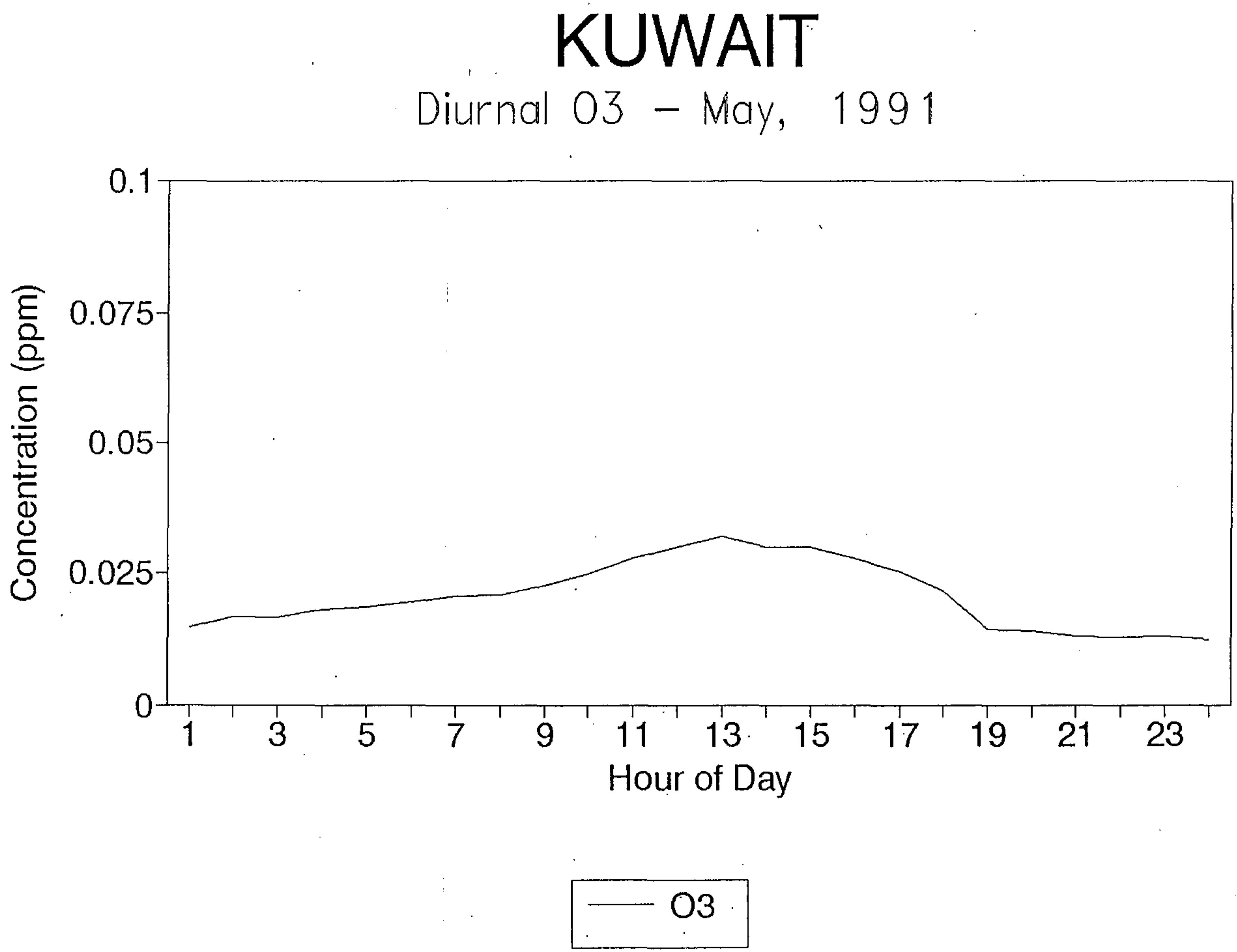
Maximum Daily Average was 0.0302 on Day 18 with 1 occurences and there were no Daily Violations

Operating Efficiency = 97.0 percent

# KUWAIT

Hourly O3 - May, 1991




KUWAIT
Diurnal O3 - May, 1991
Concentration (ppm)
0.1
0.075
0.05
0.025
0
1
3
5
7
9
11
13
15
17
19
21
23
Hour of Day
O3

MEPA - Kuwait
May 1991
Hourly Averages for NOx in ppm

| Hour / Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.036 | 0.033 | 0.022 | 0.021 | 0.013 | 0.018 | 0.032 | 0.032 | 0.030 | 0.031 | 0.024 | 0.030 | 0.033 | 0.033 | 0.041 | 0.034 | 0.099 | ND | ND | 0.197 | 0.084 | 0.156 | 0.182 | 0.139 | 0.0600 |
| 2 | 0.102 | 0.042 | 0.016 | 0.012 | 0.015 | 0.014 | 0.011 | 0.022 | 0.035 | 0.051 | 0.063 | 0.085 | 0.085 | 0.077 | 0.052 | 0.072 | 0.038 | 0.013 | 0.028 | 0.053 | 0.065 | 0.066 | 0.064 | 0.051 | 0.0472 |
| 3 | 0.044 | 0.016 | 0.008 | 0.007 | 0.004 | 0.006 | 0.006 | 0.005 | 0.010 | CAL | 0.016 | 0.011 | 0.015 | 0.013 | 0.015 | 0.012 | 0.011 | 0.017 | 0.054 | 0.032 | 0.027 | 0.059 | 0.045 | 0.074 | 0.0220 |
| 4 | 0.035 | 0.053 | 0.038 | 0.005 | 0.004 | 0.022 | 0.012 | 0.025 | 0.022 | 0.002 | 0.019 | 0.014 | 0.016 | 0.014 | 0.020 | 0.021 | 0.039 | 0.055 | 0.106 | 0.046 | 0.088 | 0.027 | 0.024 | 0.027 | 0.0306 |
| 5 | 0.014 | 0.013 | 0.015 | 0.020 | 0.005 | 0.015 | 0.010 | 0.011 | 0.014 | 0.023 | CAL | 0.020 | 0.019 | 0.030 | 0.025 | 0.036 | 0.048 | 0.069 | 0.169 | 0.182 | 0.057 | 0.034 | 0.035 | 0.093 | 0.0416 |
| 6 | 0.025 | 0.013 | 0.011 | 0.012 | 0.020 | 0.019 | 0.006 | 0.008 | 0.012 | 0.022 | 0.024 | 0.019 | 0.015 | 0.026 | 0.022 | 0.020 | ND | ND | ND | ND | ND | ND | ND | ND | 0.0171 |
| 7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.025 | 0.061 | 0.024 | 0.010 | 0.010 | 0.044 | 0.024 | 0.065 | 0.057 | 0.095 | CAL | 0.063 | 0.132 | 0.108 | 0.0552 |
| 8 | 0.073 | 0.030 | 0.015 | 0.008 | 0.005 | 0.005 | 0.007 | 0.022 | 0.015 | 0.034 | CAL | CAL | 0.027 | 0.045 | 0.021 | 0.011 | 0.015 | 0.022 | 0.077 | 0.045 | 0.034 | 0.052 | 0.080 | 0.088 | 0.0332 |
| 9 | 0.076 | 0.089 | 0.075 | 0.078 | 0.097 | 0.028 | 0.058 | 0.084 | 0.111 | 0.090 | 0.044 | 0.049 | 0.028 | 0.015 | 0.013 | 0.013 | 0.017 | 0.047 | 0.072 | 0.055 | 0.026 | 0.041 | 0.052 | 0.057 | 0.0548 |
| 10 | 0.049 | 0.051 | 0.042 | 0.073 | 0.111 | 0.081 | 0.068 | 0.025 | 0.031 | CAL | 0.036 | 0.035 | 0.025 | 0.033 | 0.061 | 0.057 | 0.076 | 0.066 | 0.090 | 0.021 | 0.017 | 0.027 | 0.128 | 0.055 | 0.0547 |
| 11 | 0.073 | 0.039 | 0.021 | 0.070 | 0.049 | 0.018 | 0.050 | 0.070 | 0.060 | 0.056 | 0.030 | 0.028 | 0.035 | 0.037 | 0.042 | 0.061 | 0.039 | 0.030 | 0.013 | 0.016 | 0.023 | 0.066 | 0.065 | 0.056 | 0.0436 |
| 12 | 0.030 | 0.019 | 0.026 | 0.031 | 0.034 | 0.026 | 0.017 | 0.041 | 0.012 | CAL | 0.033 | 0.037 | 0.028 | 0.032 | 0.036 | 0.034 | 0.031 | 0.024 | 0.061 | 0.059 | 0.061 | 0.081 | 0.087 | 0.083 | 0.0401 |
| 13 | 0.075 | 0.078 | 0.036 | 0.012 | 0.012 | 0.009 | 0.027 | 0.037 | 0.018 | 0.029 | 0.035 | 0.031 | 0.039 | 0.037 | 0.040 | 0.025 | 0.031 | 0.036 | 0.029 | 0.017 | 0.018 | 0.015 | 0.045 | 0.087 | 0.0341 |
| 14 | 0.060 | 0.027 | 0.015 | 0.012 | 0.010 | 0.004 | 0.006 | 0.010 | 0.023 | 0.034 | 0.016 | 0.022 | 0.025 | 0.012 | 0.011 | 0.014 | 0.018 | 0.032 | 0.062 | 0.080 | 0.053 | 0.056 | 0.055 | 0.041 | 0.0291 |
| 15 | 0.036 | 0.014 | 0.009 | 0.005 | 0.006 | 0.005 | 0.009 | 0.012 | 0.027 | CAL | 0.061 | 0.031 | 0.018 | 0.027 | 0.009 | 0.008 | 0.016 | 0.025 | 0.035 | 0.065 | 0.084 | 0.085 | 0.133 | 0.104 | 0.0358 |
| 16 | 0.074 | 0.054 | 0.067 | 0.060 | 0.082 | 0.020 | 0.014 | 0.013 | 0.049 | 0.089 | 0.069 | 0.038 | 0.022 | 0.016 | 0.015 | 0.013 | 0.020 | 0.023 | 0.027 | 0.023 | 0.022 | 0.027 | 0.040 | 0.049 | 0.0386 |
| 17 | 0.013 | 0.016 | 0.011 | 0.021 | 0.050 | 0.034 | 0.007 | 0.010 | CAL | 0.012 | 0.016 | 0.020 | 0.018 | 0.016 | 0.016 | 0.022 | 0.021 | 0.021 | 0.024 | 0.024 | 0.310 | 0.025 | 0.130 | 0.210 | 0.0455 |
| 18 | 0.110 | 0.006 | 0.009 | 0.008 | 0.007 | 0.007 | 0.013 | 0.026 | 0.028 | 0.015 | 0.014 | 0.022 | 0.015 | 0.017 | 0.017 | 0.012 | 0.017 | 0.016 | 0.016 | 0.019 | 0.015 | 0.017 | 0.014 | 0.032 | 0.0197 |
| 19 | 0.063 | 0.107 | 0.090 | 0.085 | 0.016 | 0.017 | 0.046 | 0.051 | 0.026 | 0.025 | CAL | 0.022 | 0.026 | 0.019 | 0.020 | 0.016 | 0.028 | 0.044 | 0.063 | 0.095 | 0.101 | 0.048 | 0.130 | 0.165 | 0.0567 |
| 20 | 0.090 | 0.049 | 0.132 | 0.028 | 0.011 | 0.012 | 0.012 | 0.011 | 0.027 | 0.055 | 0.039 | 0.025 | 0.028 | 0.021 | 0.021 | 0.026 | 0.025 | 0.053 | 0.047 | 0.052 | 0.050 | 0.058 | 0.098 | 0.078 | 0.0437 |
| 21 | 0.073 | 0.035 | 0.029 | 0.013 | 0.003 | 0.002 | 0.007 | 0.015 | 0.013 | CAL | 0.046 | 0.032 | 0.029 | 0.014 | 0.015 | 0.020 | 0.031 | 0.040 | 0.042 | 0.074 | 0.096 | 0.067 | 0.074 | 0.063 | 0.0362 |
| 22 | 0.055 | 0.059 | 0.071 | 0.073 | 0.026 | 0.026 | 0.033 | 0.031 | 0.039 | 0.024 | 0.023 | 0.017 | 0.017 | 0.020 | 0.029 | 0.029 | 0.032 | 0.039 | 0.049 | 0.038 | 0.052 | 0.054 | 0.022 | 0.060 | 0.0382 |
| 23 | 0.028 | 0.029 | 0.015 | 0.020 | 0.017 | 0.062 | 0.027 | 0.029 | 0.025 | 0.036 | 0.023 | CAL | 0.200 | 0.013 | 0.020 | 0.022 | 0.033 | 0.040 | 0.037 | 0.048 | 0.112 | 0.053 | 0.057 | 0.056 | 0.0436 |
| 24 | 0.018 | 0.019 | 0.015 | 0.011 | 0.012 | 0.029 | 0.040 | 0.044 | 0.036 | 0.024 | 0.017 | 0.021 | 0.019 | 0.020 | 0.019 | 0.015 | 0.018 | 0.026 | 0.028 | 0.056 | 0.036 | 0.031 | 0.052 | 0.040 | 0.0269 |
| 25 | 0.062 | 0.038 | 0.072 | 0.051 | 0.079 | 0.047 | 0.022 | 0.042 | 0.043 | CAL | 0.095 | 0.021 | 0.019 | 0.016 | 0.017 | 0.029 | 0.028 | 0.030 | 0.054 | 0.134 | 0.111 | 0.156 | 0.089 | 0.132 | 0.0603 |
| 26 | 0.151 | 0.110 | 0.079 | 0.023 | 0.051 | 0.035 | 0.016 | 0.024 | 0.043 | 0.042 | 0.041 | 0.036 | 0.034 | 0.017 | 0.013 | 0.015 | 0.020 | 0.028 | 0.073 | 0.173 | 0.181 | 0.107 | 0.044 | 0.022 | 0.0574 |
| 27 | 0.009 | 0.004 | 0.002 | 0.003 | 0.002 | 0.008 | 0.016 | 0.016 | 0.014 | CAL | 0.077 | 0.029 | 0.030 | 0.041 | ND | ND | 0.032 | 0.115 | 0.118 | 0.121 | 0.127 | 0.126 | 0.097 | 0.092 | 0.0514 |
| 28 | 0.066 | 0.077 | 0.082 | 0.040 | 0.025 | 0.052 | 0.051 | 0.052 | 0.038 | 0.024 | 0.019 | 0.020 | 0.023 | 0.030 | 0.029 | 0.031 | 0.019 | 0.025 | 0.031 | 0.031 | 0.036 | 0.034 | 0.021 | 0.019 | 0.0365 |
| 29 | 0.014 | 0.013 | 0.013 | 0.013 | 0.016 | 0.016 | 0.023 | 0.024 | 0.004 | CAL | 0.023 | 0.019 | 0.026 | 0.032 | 0.022 | 0.017 | 0.026 | 0.051 | 0.054 | 0.056 | 0.061 | 0.051 | 0.096 | 0.016 | 0.0298 |
| 30 | 0.010 | 0.013 | 0.002 | 0.004 | 0.004 | 0.020 | 0.052 | 0.057 | 0.064 | 0.042 | 0.034 | 0.026 | 0.023 | 0.020 | 0.020 | 0.021 | 0.033 | 0.042 | 0.042 | 0.034 | 0.078 | 0.057 | 0.026 | 0.021 | 0.0310 |
| 31 | 0.011 | 0.008 | 0.026 | 0.016 | 0.082 | 0.053 | 0.051 | 0.027 | 0.020 | 0.038 | 0.019 | 0.021 | 0.019 | 0.013 | 0.010 | 0.019 | 0.037 | 0.071 | 0.050 | 0.040 | 0.054 | 0.102 | 0.044 | 0.023 | 0.0356 |

Monthly Average = 0.0402

Maximum Hourly Average was 0.310 at Hour 21 on Day 17 with 1 occurences and there were no Hourly Violations
Maximum Daily Average was 0.0603 on Day 25 with 1 occurences and there were no Daily Violations
Operating Efficiency = 97.0 percent
ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data
[CEM 1990]

MEPA - Kuwait
May 1991
Frequency Distribution
Hourly Averages for NOx in ppm

| Concentration | # of Hours | Percentage |
|---|---|---|
| 0.000 - 0.050 | 509 | 72.0 |
| 0.051 - 0.110 | 167 | 23.6 |
| 0.111 - 0.210 | 30 | 4.2 |
| 0.211+ | 1 | 0.1 |

MEPA - Kuwait

May 1991

Hourly Averages for NO2 in ppm

| Day \ Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.034 | 0.031 | 0.021 | 0.020 | 0.012 | 0.016 | 0.028 | 0.028 | 0.027 | 0.027 | 0.020 | 0.024 | 0.029 | 0.028 | 0.038 | 0.031 | 0.064 | ND | ND | 0.082 | 0.057 | 0.064 | 0.080 | 0.078 | 0.0381 |
| 2 | 0.061 | 0.033 | 0.014 | 0.010 | 0.013 | 0.013 | 0.009 | 0.018 | 0.030 | 0.038 | 0.037 | 0.041 | 0.052 | 0.050 | 0.037 | 0.039 | 0.024 | 0.011 | 0.020 | 0.030 | 0.038 | 0.039 | 0.039 | 0.033 | 0.0304 |
| 3 | 0.030 | 0.012 | 0.006 | 0.005 | 0.003 | 0.006 | 0.004 | 0.004 | 0.008 | CAL | 0.013 | 0.008 | 0.011 | 0.010 | 0.011 | 0.010 | 0.009 | 0.014 | 0.042 | 0.027 | 0.022 | 0.038 | 0.030 | 0.042 | 0.0159 |
| 4 | 0.024 | 0.033 | 0.024 | 0.003 | 0.003 | 0.016 | 0.009 | 0.018 | 0.017 | 0.016 | 0.014 | 0.011 | 0.012 | 0.011 | 0.015 | 0.017 | 0.029 | 0.041 | 0.060 | 0.038 | 0.051 | 0.027 | 0.024 | 0.026 | 0.0225 |
| 5 | 0.013 | 0.012 | 0.014 | 0.020 | 0.005 | 0.014 | 0.008 | 0.008 | 0.011 | 0.016 | CAL | 0.014 | 0.014 | 0.021 | 0.018 | 0.024 | 0.032 | 0.042 | 0.072 | 0.072 | 0.039 | 0.031 | 0.030 | 0.045 | 0.0250 |
| 6 | 0.023 | 0.013 | 0.011 | 0.011 | 0.019 | 0.016 | 0.004 | 0.006 | 0.010 | 0.016 | 0.018 | 0.014 | 0.012 | 0.019 | 0.017 | 0.036 | ND | ND | ND | ND | ND | ND | ND | ND | 0.0153 |
| 7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.027 | 0.047 | 0.029 | 0.016 | 0.007 | 0.029 | 0.028 | 0.000 | 0.046 | 0.062 | CAL | 0.057 | 0.068 | 0.066 | 0.0371 |
| 8 | 0.049 | 0.028 | 0.014 | 0.007 | 0.004 | 0.004 | 0.005 | 0.017 | 0.015 | 0.023 | CAL | CAL | 0.021 | 0.028 | 0.015 | 0.010 | 0.013 | 0.020 | 0.059 | 0.042 | 0.025 | 0.037 | 0.044 | 0.043 | 0.0238 |
| 9 | 0.038 | 0.038 | 0.036 | 0.036 | 0.041 | 0.023 | 0.036 | 0.048 | 0.059 | 0.058 | 0.035 | 0.040 | 0.023 | 0.014 | 0.012 | 0.012 | 0.016 | 0.043 | 0.058 | 0.039 | 0.023 | 0.033 | 0.036 | 0.031 | 0.0345 |
| 10 | 0.027 | 0.026 | 0.023 | 0.030 | 0.044 | 0.037 | 0.033 | 0.016 | 0.019 | CAL | 0.021 | 0.024 | 0.018 | 0.023 | 0.039 | 0.034 | 0.047 | 0.041 | 0.048 | 0.019 | 0.015 | 0.021 | 0.056 | 0.034 | 0.0302 |
| 11 | 0.040 | 0.025 | 0.015 | 0.034 | 0.028 | 0.014 | 0.030 | 0.040 | 0.038 | 0.038 | 0.021 | 0.019 | 0.023 | 0.025 | 0.028 | 0.039 | 0.026 | 0.023 | 0.012 | 0.015 | 0.020 | 0.043 | 0.043 | 0.033 | 0.0280 |
| 12 | 0.029 | 0.018 | 0.024 | 0.028 | 0.032 | 0.023 | 0.016 | 0.028 | 0.008 | CAL | 0.022 | 0.025 | 0.019 | 0.021 | 0.023 | 0.022 | 0.023 | 0.017 | 0.045 | 0.047 | 0.049 | 0.060 | 0.058 | 0.062 | 0.0304 |
| 13 | 0.057 | 0.050 | 0.029 | 0.011 | 0.012 | 0.008 | 0.021 | 0.029 | 0.015 | 0.023 | 0.031 | 0.026 | 0.029 | 0.027 | 0.074 | 0.093 | 0.085 | 0.065 | 0.045 | 0.038 | 0.031 | 0.021 | 0.020 | 0.049 | 0.0370 |
| 14 | 0.035 | 0.020 | 0.014 | 0.011 | 0.008 | 0.004 | 0.005 | 0.008 | 0.019 | 0.025 | 0.012 | 0.018 | 0.023 | 0.010 | 0.009 | 0.012 | 0.016 | 0.028 | 0.052 | 0.054 | 0.044 | 0.042 | 0.042 | 0.032 | 0.0226 |
| 15 | 0.027 | 0.012 | 0.007 | 0.004 | 0.005 | 0.004 | 0.006 | 0.010 | 0.018 | CAL | 0.041 | 0.022 | 0.013 | 0.016 | 0.007 | 0.007 | 0.014 | 0.021 | 0.031 | 0.048 | 0.058 | 0.061 | 0.063 | 0.061 | 0.0242 |
| 16 | 0.056 | 0.047 | 0.053 | 0.051 | 0.057 | 0.017 | 0.012 | 0.005 | 0.034 | 0.010 | 0.013 | 0.016 | 0.015 | 0.013 | 0.015 | 0.020 | 0.019 | 0.019 | 0.022 | 0.022 | 0.027 | 0.022 | 0.012 | 0.014 | 0.0246 |
| 17 | 0.009 | 0.004 | 0.008 | 0.006 | 0.006 | 0.005 | 0.009 | 0.005 | CAL | 0.010 | 0.013 | 0.016 | 0.015 | 0.013 | 0.015 | 0.020 | 0.019 | 0.019 | 0.022 | 0.022 | 0.027 | 0.022 | 0.012 | 0.014 | 0.0135 |
| 18 | 0.009 | 0.004 | 0.008 | 0.006 | 0.006 | 0.005 | 0.009 | 0.016 | 0.022 | 0.012 | 0.011 | 0.017 | 0.012 | 0.013 | 0.014 | 0.011 | 0.014 | 0.015 | 0.016 | 0.018 | 0.014 | 0.016 | 0.013 | 0.025 | 0.0128 |
| 19 | 0.036 | 0.052 | 0.044 | 0.039 | 0.014 | 0.013 | 0.028 | 0.031 | 0.016 | 0.016 | CAL | 0.015 | 0.018 | 0.014 | 0.016 | 0.013 | 0.023 | 0.038 | 0.050 | 0.066 | 0.064 | 0.039 | 0.058 | 0.066 | 0.0334 |
| 20 | 0.044 | 0.029 | 0.053 | 0.018 | 0.010 | 0.011 | 0.010 | 0.008 | 0.018 | 0.033 | 0.025 | 0.017 | 0.020 | 0.015 | 0.015 | 0.020 | 0.021 | 0.040 | 0.042 | 0.047 | 0.047 | 0.046 | 0.061 | 0.056 | 0.0294 |
| 21 | 0.052 | 0.031 | 0.026 | 0.012 | 0.002 | 0.001 | 0.005 | 0.012 | 0.009 | CAL | 0.026 | 0.028 | 0.026 | 0.013 | 0.014 | 0.018 | 0.029 | 0.037 | 0.041 | 0.067 | 0.077 | 0.060 | 0.063 | 0.052 | 0.0305 |
| 22 | 0.048 | 0.048 | 0.044 | 0.036 | 0.022 | 0.021 | 0.027 | 0.024 | 0.027 | 0.019 | 0.018 | 0.014 | 0.014 | 0.016 | 0.022 | 0.021 | 0.025 | 0.031 | 0.040 | 0.033 | 0.039 | 0.039 | 0.021 | 0.046 | 0.0290 |
| 23 | 0.022 | 0.020 | 0.012 | 0.017 | 0.014 | 0.037 | 0.024 | 0.023 | 0.016 | 0.025 | 0.019 | CAL | 0.015 | 0.010 | 0.016 | 0.017 | 0.026 | 0.031 | 0.028 | 0.036 | 0.064 | 0.041 | 0.044 | 0.038 | 0.0259 |
| 24 | 0.018 | 0.019 | 0.015 | 0.011 | 0.010 | 0.026 | 0.026 | 0.030 | 0.026 | 0.019 | 0.015 | 0.016 | 0.015 | 0.015 | 0.015 | 0.012 | 0.016 | 0.024 | 0.026 | 0.045 | 0.032 | 0.026 | 0.034 | 0.027 | 0.0216 |
| 25 | 0.036 | 0.027 | 0.042 | 0.030 | 0.044 | 0.030 | 0.018 | 0.029 | 0.030 | CAL | 0.019 | 0.015 | 0.012 | 0.012 | 0.014 | 0.024 | 0.025 | 0.027 | 0.048 | 0.085 | 0.076 | 0.070 | 0.059 | 0.050 | 0.0357 |
| 26 | 0.061 | 0.053 | 0.044 | 0.022 | 0.035 | 0.028 | 0.014 | 0.021 | 0.032 | 0.032 | 0.032 | 0.027 | 0.026 | 0.014 | 0.011 | 0.013 | 0.019 | 0.027 | 0.057 | 0.076 | 0.076 | 0.074 | 0.038 | 0.020 | 0.0355 |
| 27 | 0.008 | 0.003 | 0.002 | 0.002 | 0.002 | 0.006 | 0.015 | 0.016 | 0.012 | CAL | 0.039 | 0.022 | 0.020 | 0.027 | ND | ND | 0.023 | 0.076 | 0.062 | 0.060 | 0.061 | 0.056 | 0.047 | 0.046 | 0.0288 |
| 28 | 0.036 | 0.039 | 0.040 | 0.023 | 0.030 | 0.029 | 0.029 | 0.030 | 0.025 | 0.018 | 0.014 | 0.015 | 0.016 | 0.018 | 0.019 | 0.022 | 0.016 | 0.022 | 0.028 | 0.030 | 0.034 | 0.033 | 0.019 | 0.018 | 0.0251 |
| 29 | 0.012 | 0.012 | 0.012 | 0.012 | 0.014 | 0.013 | 0.016 | 0.017 | 0.002 | CAL | 0.016 | 0.013 | 0.018 | 0.021 | 0.015 | 0.014 | 0.022 | 0.041 | 0.045 | 0.046 | 0.045 | 0.037 | 0.040 | 0.013 | 0.0216 |
| 30 | 0.008 | 0.009 | 0.002 | 0.004 | 0.004 | 0.014 | 0.031 | 0.036 | 0.041 | 0.034 | 0.027 | 0.020 | 0.017 | 0.014 | 0.016 | 0.017 | 0.028 | 0.038 | 0.040 | 0.031 | 0.050 | 0.043 | 0.022 | 0.018 | 0.0235 |
| 31 | 0.010 | 0.006 | 0.001 | 0.015 | 0.049 | 0.037 | 0.037 | 0.022 | 0.017 | 0.030 | 0.016 | 0.017 | 0.017 | 0.012 | 0.010 | 0.017 | 0.031 | 0.049 | 0.045 | 0.033 | 0.040 | 0.049 | 0.033 | 0.019 | 0.0255 |
| | | | | | | | | | | | | | | | | | | | | | | | Monthly Average = | | 0.0268 |

Maximum Hourly Average was 0.093 at Hour 16 on Day 13 with 1 occurences and there were no Hourly Violations

Maximum Daily Average was 0.0381 on Day 1 with 1 occurences and there were no Daily Violations

Operating Efficiency = 97.0 percent

ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data

[CEM 1990]

MEPA - Kuwait

May 1991

Frequency Distribution

Hourly Averages for $NO_2$ in ppm

| Concentration | # of Hours | Percentage |
|---|---|---|
| 0.000 - 0.050 | 638 | 90.2 |
| 0.051 - 0.110 | 69 | 9.8 |
| 0.111 - 0.210 | 0 | 0.0 |
| 0.211+ | 0 | 0.0 |

MEPA - Kuwait
May 1991
Hourly Averages for NO in ppm

| Hour / Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.002 | 0.002 | 0.002 | 0.001 | 0.001 | 0.002 | 0.004 | 0.004 | 0.003 | 0.004 | 0.004 | 0.007 | 0.005 | 0.005 | 0.005 | 0.003 | 0.035 | ND | ND | 0.115 | 0.028 | 0.092 | 0.102 | 0.061 | 0.0221 |
| 2 | 0.041 | 0.009 | 0.001 | 0.002 | 0.002 | 0.001 | 0.001 | 0.004 | 0.005 | 0.013 | 0.026 | 0.044 | 0.033 | 0.027 | 0.015 | 0.033 | 0.014 | 0.002 | 0.009 | 0.022 | 0.027 | 0.027 | 0.025 | 0.018 | 0.0167 |
| 3 | 0.014 | 0.004 | 0.003 | 0.002 | 0.001 | 0.001 | 0.002 | 0.001 | 0.002 | CAL | 0.003 | 0.003 | 0.004 | 0.004 | 0.003 | 0.002 | 0.002 | 0.003 | 0.012 | 0.005 | 0.005 | 0.021 | 0.015 | 0.032 | 0.0063 |
| 4 | 0.011 | 0.020 | 0.014 | 0.002 | 0.001 | 0.006 | 0.003 | 0.001 | 0.004 | 0.006 | 0.005 | 0.003 | 0.004 | 0.003 | 0.004 | 0.005 | 0.009 | 0.014 | 0.046 | 0.008 | 0.037 | 0.001 | 0.001 | 0.001 | 0.0087 |
| 5 | 0.001 | 0.000 | 0.001 | 0.001 | 0.000 | 0.001 | 0.002 | 0.002 | 0.003 | 0.007 | CAL | 0.005 | 0.005 | 0.009 | 0.007 | 0.012 | 0.016 | 0.027 | 0.097 | 0.109 | 0.017 | 0.003 | 0.005 | 0.048 | 0.0164 |
| 6 | 0.002 | 0.001 | 0.000 | 0.001 | 0.001 | 0.003 | 0.002 | 0.001 | 0.002 | 0.006 | 0.006 | 0.005 | 0.004 | 0.007 | 0.005 | 0.018 | ND | ND | ND | ND | ND | ND | ND | ND | 0.0040 |
| 7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.015 | 0.024 | 0.001 | 0.007 | 0.007 | 0.015 | 0.000 | 0.000 | 0.004 | 0.036 | CAL | 0.006 | 0.063 | 0.042 | 0.0169 |
| 8 | 0.025 | 0.002 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.005 | 0.000 | 0.011 | CAL | CAL | 0.005 | 0.017 | 0.006 | 0.001 | 0.002 | 0.002 | 0.019 | 0.002 | 0.008 | 0.015 | 0.036 | 0.045 | 0.0094 |
| 9 | 0.038 | 0.051 | 0.039 | 0.042 | 0.056 | 0.005 | 0.022 | 0.037 | 0.051 | 0.033 | 0.009 | 0.009 | 0.005 | 0.002 | 0.001 | 0.001 | 0.001 | 0.005 | 0.014 | 0.017 | 0.003 | 0.007 | 0.016 | 0.025 | 0.0204 |
| 10 | 0.022 | 0.025 | 0.019 | 0.042 | 0.067 | 0.044 | 0.035 | 0.009 | 0.012 | CAL | 0.014 | 0.011 | 0.007 | 0.010 | 0.022 | 0.023 | 0.029 | 0.025 | 0.042 | 0.002 | 0.001 | 0.006 | 0.071 | 0.021 | 0.0243 |
| 11 | 0.033 | 0.015 | 0.006 | 0.036 | 0.020 | 0.004 | 0.020 | 0.029 | 0.021 | 0.019 | 0.010 | 0.009 | 0.012 | 0.012 | 0.014 | 0.022 | 0.012 | 0.007 | 0.001 | 0.001 | 0.004 | 0.023 | 0.022 | 0.024 | 0.0157 |
| 12 | 0.002 | 0.001 | 0.001 | 0.002 | 0.001 | 0.003 | 0.001 | 0.012 | 0.004 | CAL | 0.011 | 0.012 | 0.009 | 0.010 | 0.013 | 0.012 | 0.008 | 0.007 | 0.016 | 0.012 | 0.012 | 0.020 | 0.028 | 0.021 | 0.0095 |
| 13 | 0.018 | 0.027 | 0.007 | 0.001 | 0.001 | 0.001 | 0.021 | 0.009 | 0.002 | 0.005 | 0.004 | 0.006 | 0.010 | 0.012 | 0.014 | 0.035 | 0.038 | 0.030 | 0.026 | 0.025 | 0.019 | 0.013 | 0.008 | 0.037 | 0.0154 |
| 14 | 0.024 | 0.007 | 0.001 | 0.001 | 0.002 | 0.000 | 0.001 | 0.002 | 0.005 | 0.009 | 0.004 | 0.003 | 0.001 | 0.002 | 0.002 | 0.002 | 0.002 | 0.004 | 0.011 | 0.026 | 0.009 | 0.015 | 0.013 | 0.009 | 0.0065 |
| 15 | 0.009 | 0.002 | 0.002 | 0.001 | 0.001 | 0.001 | 0.003 | 0.003 | 0.009 | CAL | 0.019 | 0.009 | 0.005 | 0.011 | 0.002 | 0.001 | 0.000 | 0.004 | 0.004 | 0.017 | 0.026 | 0.024 | 0.070 | 0.043 | 0.0116 |
| 16 | 0.018 | 0.007 | 0.014 | 0.009 | 0.025 | 0.003 | 0.002 | 0.003 | 0.015 | 0.023 | 0.019 | 0.007 | 0.003 | 0.003 | 0.002 | 0.002 | 0.003 | 0.003 | 0.003 | 0.003 | 0.005 | 0.005 | 0.004 | 0.010 | 0.0080 |
| 17 | 0.003 | 0.006 | 0.003 | 0.004 | 0.032 | 0.019 | 0.003 | 0.004 | CAL | 0.003 | 0.003 | 0.004 | 0.003 | 0.003 | 0.001 | 0.003 | 0.002 | 0.001 | 0.002 | 0.003 | 0.004 | 0.004 | 0.002 | 0.007 | 0.0052 |
| 18 | 0.002 | 0.002 | 0.001 | 0.001 | 0.001 | 0.002 | 0.004 | 0.010 | 0.006 | 0.003 | 0.003 | 0.005 | 0.003 | 0.004 | 0.003 | 0.002 | 0.003 | 0.002 | 0.000 | 0.001 | 0.001 | 0.001 | 0.001 | 0.008 | 0.0029 |
| 19 | 0.027 | 0.054 | 0.046 | 0.046 | 0.002 | 0.004 | 0.018 | 0.021 | 0.009 | 0.009 | CAL | 0.007 | 0.009 | 0.005 | 0.004 | 0.003 | 0.005 | 0.006 | 0.013 | 0.029 | 0.037 | 0.008 | 0.072 | 0.099 | 0.0232 |
| 20 | 0.046 | 0.020 | 0.079 | 0.010 | 0.011 | 0.001 | 0.002 | 0.003 | 0.010 | 0.022 | 0.014 | 0.008 | 0.008 | 0.005 | 0.005 | 0.006 | 0.004 | 0.013 | 0.006 | 0.004 | 0.003 | 0.012 | 0.037 | 0.022 | 0.0146 |
| 21 | 0.021 | 0.005 | 0.004 | 0.001 | 0.001 | 0.001 | 0.002 | 0.003 | 0.004 | CAL | 0.020 | 0.003 | 0.003 | 0.002 | 0.000 | 0.002 | 0.002 | 0.003 | 0.001 | 0.008 | 0.019 | 0.007 | 0.012 | 0.011 | 0.0059 |
| 22 | 0.007 | 0.011 | 0.027 | 0.037 | 0.004 | 0.006 | 0.007 | 0.008 | 0.012 | 0.005 | 0.005 | 0.003 | 0.003 | 0.004 | 0.007 | 0.007 | 0.007 | 0.007 | 0.009 | 0.005 | 0.013 | 0.015 | 0.001 | 0.014 | 0.0093 |
| 23 | 0.006 | 0.009 | 0.002 | 0.003 | 0.003 | 0.025 | 0.004 | 0.006 | 0.009 | 0.010 | 0.004 | CAL | 0.005 | 0.003 | 0.004 | 0.005 | 0.007 | 0.009 | 0.009 | 0.011 | 0.048 | 0.012 | 0.130 | 0.180 | 0.0219 |
| 24 | 0.001 | 0.001 | 0.000 | 0.000 | 0.001 | 0.003 | 0.013 | 0.014 | 0.009 | 0.005 | 0.002 | 0.004 | 0.004 | 0.005 | 0.004 | 0.003 | 0.003 | 0.002 | 0.002 | 0.010 | 0.005 | 0.005 | 0.017 | 0.013 | 0.0052 |
| 25 | 0.026 | 0.012 | 0.030 | 0.021 | 0.034 | 0.016 | 0.004 | 0.012 | 0.013 | CAL | 0.075 | 0.005 | 0.006 | 0.004 | 0.003 | 0.006 | 0.003 | 0.003 | 0.006 | 0.048 | 0.035 | 0.087 | 0.029 | 0.080 | 0.0243 |
| 26 | 0.087 | 0.056 | 0.034 | 0.001 | 0.015 | 0.007 | 0.003 | 0.003 | 0.011 | 0.010 | 0.009 | 0.009 | 0.007 | 0.002 | 0.002 | 0.002 | 0.001 | 0.001 | 0.016 | 0.095 | 0.103 | 0.033 | 0.006 | 0.001 | 0.0214 |
| 27 | 0.001 | 0.001 | 0.000 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.003 | CAL | 0.038 | 0.007 | 0.010 | 0.013 | ND | ND | 0.009 | 0.039 | 0.056 | 0.061 | 0.066 | 0.069 | 0.049 | 0.046 | 0.0225 |
| 28 | 0.030 | 0.038 | 0.041 | 0.017 | 0.022 | 0.022 | 0.022 | 0.021 | 0.013 | 0.006 | 0.005 | 0.006 | 0.007 | 0.011 | 0.010 | 0.009 | 0.003 | 0.003 | 0.002 | 0.001 | 0.002 | 0.002 | 0.002 | 0.001 | 0.0123 |
| 29 | 0.001 | 0.001 | 0.001 | 0.001 | 0.002 | 0.004 | 0.007 | 0.008 | 0.002 | CAL | 0.007 | 0.006 | 0.008 | 0.010 | 0.007 | 0.003 | 0.004 | 0.010 | 0.010 | 0.010 | 0.016 | 0.014 | 0.056 | 0.002 | 0.0083 |
| 30 | 0.002 | 0.003 | 0.000 | 0.000 | 0.000 | 0.006 | 0.021 | 0.022 | 0.023 | 0.009 | 0.007 | 0.007 | 0.006 | 0.006 | 0.003 | 0.003 | 0.004 | 0.004 | 0.001 | 0.003 | 0.027 | 0.014 | 0.004 | 0.004 | 0.0075 |
| 31 | 0.001 | 0.002 | 0.005 | 0.001 | 0.033 | 0.016 | 0.014 | 0.005 | 0.003 | 0.008 | 0.003 | 0.003 | 0.001 | 0.001 | 0.001 | 0.002 | 0.006 | 0.022 | 0.006 | 0.006 | 0.014 | 0.052 | 0.011 | 0.004 | 0.0092 |
| | | | | | | | | | | | | | | | | | | | | | | Monthly Average = | | | 0.0130 |

Maximum Hourly Average was 0.180 at Hour 24 on Day 23 with 1 occurences and there were no Hourly Violations

Maximum Daily Average was 0.0243 on Day 10 with 2 occurences and there were no Daily Violations

Operating Efficiency = 97.0 percent

ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data

[CEM 1990]

MEPA - Kuwait

May 1991

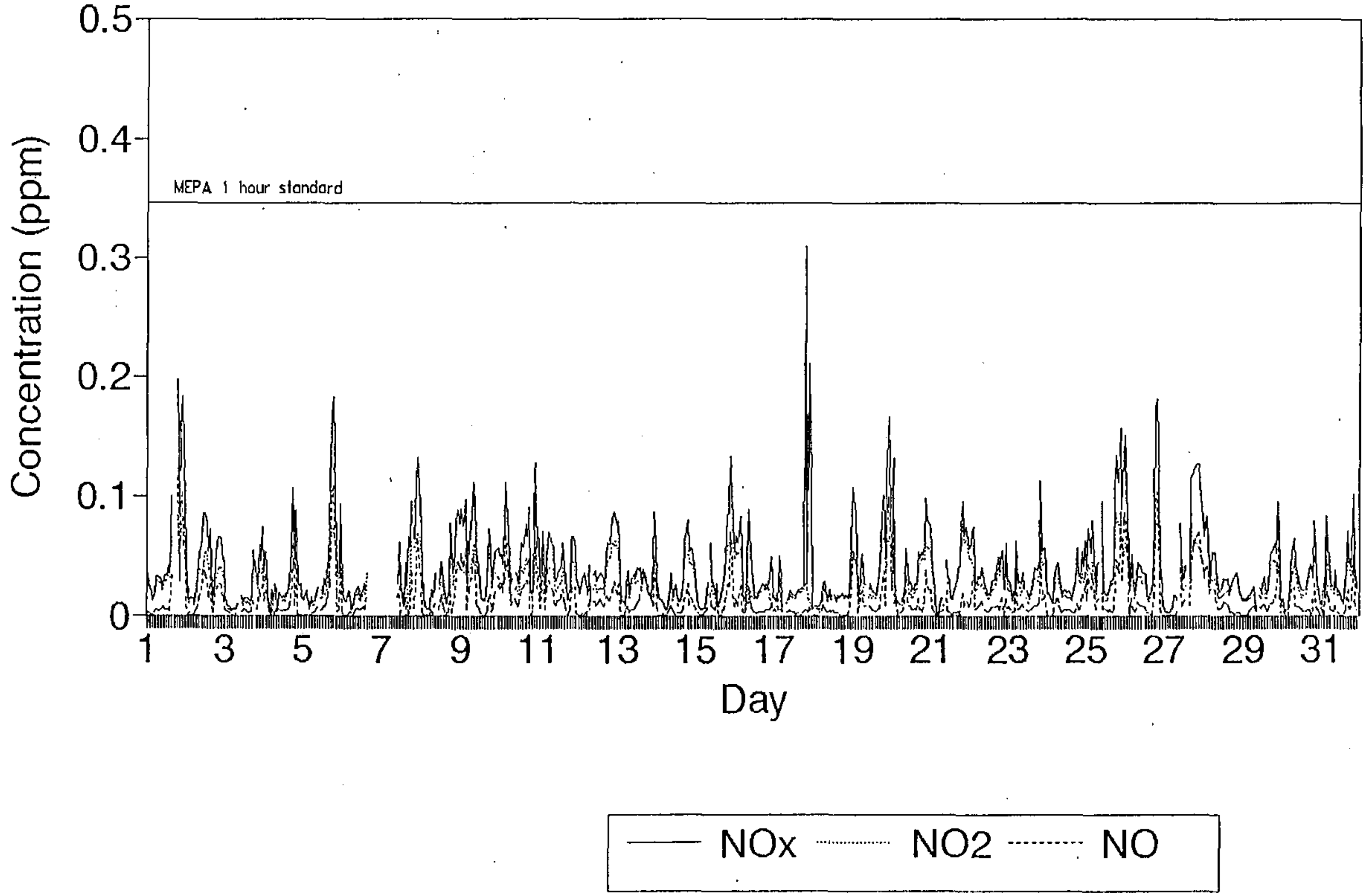
Frequency Distribution

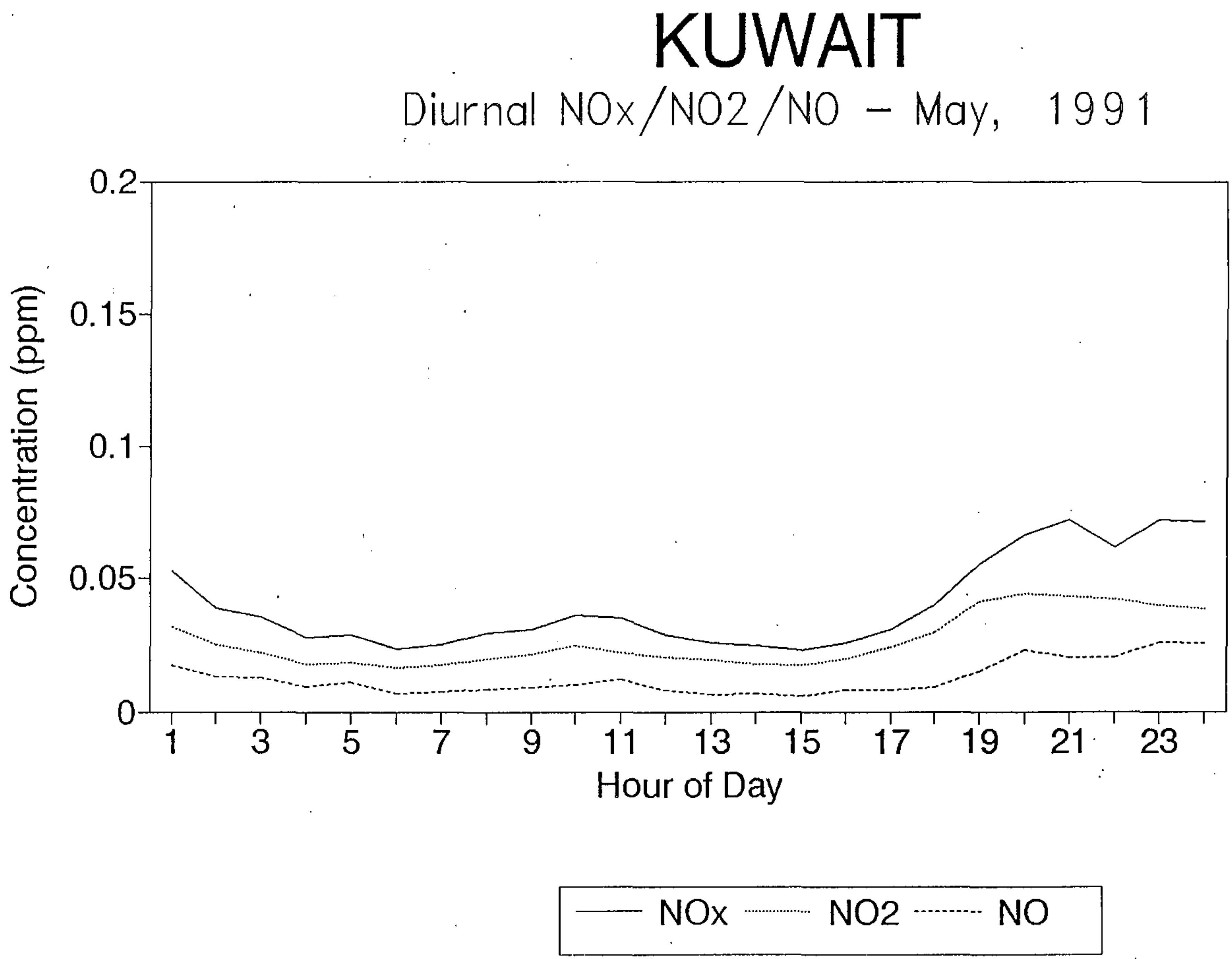
Hourly Averages for NO in ppm

| Concentration | # of Hours | Percentage |
|---|---|---|
| 0.000 - 0.050 | 675 | 95.5 |
| 0.051 - 0.110 | 29 | 4.1 |
| 0.111 - 0.210 | 3 | 0.4 |
| 0.211+ | 0 | 0.0 |

# KUWAIT

Hourly NOx/NO2/NO - May, 1991




KUWAIT
Diurnal NOx/NO2/NO - May, 1991
Concentration (ppm)
0.2
0.15
0.1
0.05
0
1
3
5
7
9
11
13
15
17
19
21
23
Hour of Day
NOx
NO2
NO

MEPA - Kuwait
May 1991
Hourly Averages for H2S in ppm

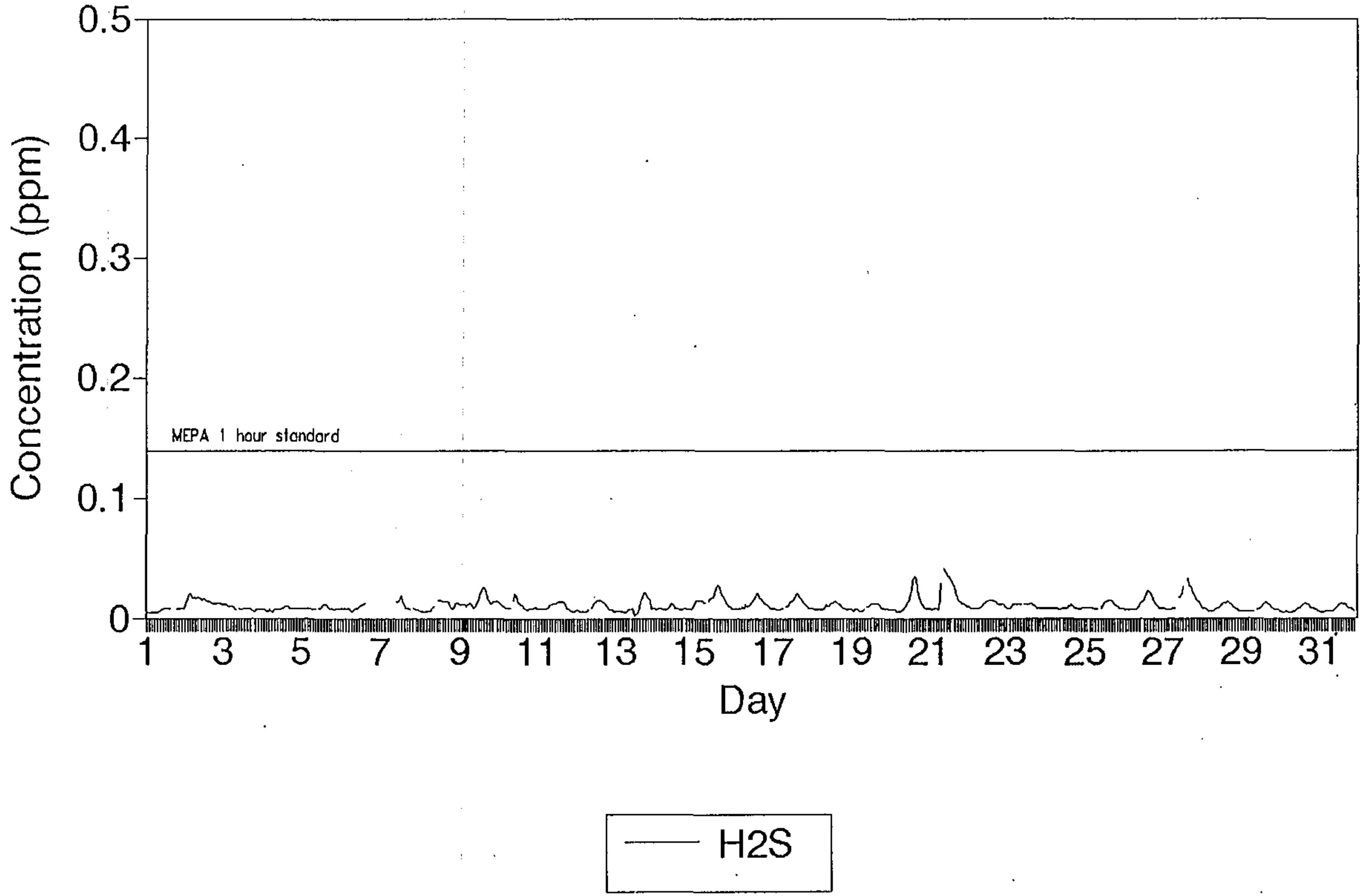
| Day \ Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Averag |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.006 | 0.007 | 0.007 | 0.008 | 0.008 | 0.009 | 0.009 | 0.009 | ND | ND | 0.007 | 0.008 | 0.007 | 0.008 | 0.008 | 0.0066 |
| 2 | 0.008 | 0.012 | 0.015 | 0.019 | 0.020 | 0.018 | 0.016 | 0.017 | 0.016 | 0.017 | 0.016 | 0.015 | 0.016 | 0.015 | 0.014 | 0.014 | 0.013 | 0.012 | 0.012 | 0.012 | 0.012 | 0.012 | 0.012 | 0.012 | 0.0144 |
| 3 | 0.011 | 0.011 | 0.011 | 0.010 | 0.010 | 0.010 | 0.010 | 0.008 | 0.007 | CAL | 0.008 | 0.007 | 0.007 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.007 | 0.006 | 0.007 | 0.007 | 0.007 | 0.007 | 0.0083 |
| 4 | 0.007 | 0.007 | 0.007 | 0.006 | 0.006 | 0.007 | 0.006 | 0.005 | 0.007 | 0.007 | 0.007 | 0.007 | 0.008 | 0.009 | 0.010 | 0.010 | 0.010 | 0.009 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.0076 |
| 5 | 0.008 | 0.008 | 0.008 | 0.008 | 0.009 | 0.009 | 0.008 | 0.007 | 0.007 | 0.007 | CAL | 0.009 | 0.009 | 0.010 | 0.011 | 0.011 | 0.011 | 0.010 | 0.009 | 0.008 | 0.007 | 0.008 | 0.008 | 0.008 | 0.0086 |
| 6 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.006 | 0.006 | 0.007 | 0.008 | 0.009 | 0.010 | 0.011 | 0.011 | 0.012 | ND | ND | ND | ND | ND | ND | ND | ND | 0.0085 |
| 7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.013 | 0.013 | 0.015 | 0.019 | 0.013 | 0.011 | 0.009 | 0.008 | 0.008 | 0.007 | CAL | 0.008 | 0.007 | 0.007 | 0.0106 |
| 8 | 0.006 | 0.006 | 0.006 | 0.005 | 0.006 | 0.006 | 0.006 | 0.006 | 0.008 | 0.010 | CAL | CAL | 0.015 | 0.015 | 0.014 | 0.013 | 0.014 | 0.013 | 0.012 | 0.009 | 0.008 | 0.009 | 0.011 | 0.012 | 0.0095 |
| 9 | 0.012 | 0.011 | 0.011 | 0.011 | 0.011 | 0.010 | 0.011 | 0.012 | 0.010 | 0.009 | 0.010 | 0.012 | 0.015 | 0.019 | 0.023 | 0.025 | 0.025 | 0.021 | 0.016 | 0.013 | 0.012 | 0.012 | 0.013 | 0.014 | 0.0141 |
| 10 | 0.013 | 0.012 | 0.011 | 0.010 | 0.010 | 0.009 | 0.008 | 0.008 | 0.009 | CAL | 0.015 | 0.020 | 0.019 | 0.014 | 0.012 | 0.011 | 0.009 | 0.008 | 0.007 | 0.007 | 0.008 | 0.008 | 0.009 | 0.010 | 0.0107 |
| 11 | 0.009 | 0.009 | 0.009 | 0.009 | 0.008 | 0.008 | 0.009 | 0.009 | 0.011 | 0.011 | 0.012 | 0.012 | 0.012 | 0.013 | 0.014 | 0.014 | 0.014 | 0.013 | 0.011 | 0.009 | 0.008 | 0.007 | 0.006 | 0.006 | 0.0101 |
| 12 | 0.006 | 0.007 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.007 | CAL | 0.009 | 0.011 | 0.012 | 0.013 | 0.015 | 0.015 | 0.015 | 0.014 | 0.012 | 0.010 | 0.008 | 0.007 | 0.007 | 0.006 | 0.0091 |
| 13 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.005 | 0.005 | 0.006 | 0.007 | 0.007 | 0.008 | 0.002 | 0.003 | 0.005 | 0.009 | 0.013 | 0.017 | 0.020 | 0.021 | 0.019 | 0.016 | 0.015 | 0.007 | 0.0092 |
| 14 | 0.008 | 0.008 | 0.007 | 0.008 | 0.008 | 0.007 | 0.007 | 0.007 | 0.007 | 0.008 | 0.010 | 0.012 | 0.011 | 0.009 | 0.008 | 0.008 | 0.007 | 0.007 | 0.007 | 0.008 | 0.007 | 0.007 | 0.007 | 0.007 | 0.0079 |
| 15 | 0.009 | 0.012 | 0.014 | 0.014 | 0.014 | 0.013 | 0.013 | 0.012 | 0.012 | CAL | 0.014 | 0.016 | 0.018 | 0.021 | 0.027 | 0.028 | 0.026 | 0.022 | 0.019 | 0.016 | 0.013 | 0.011 | 0.010 | 0.010 | 0.0158 |
| 16 | 0.009 | 0.008 | 0.008 | 0.009 | 0.009 | 0.009 | 0.010 | 0.008 | 0.011 | 0.010 | 0.010 | 0.011 | 0.013 | 0.015 | 0.017 | 0.020 | 0.020 | 0.018 | 0.016 | 0.014 | 0.012 | 0.011 | 0.010 | 0.009 | 0.0120 |
| 17 | 0.009 | 0.008 | 0.008 | 0.007 | 0.007 | 0.007 | 0.007 | 0.008 | CAL | 0.010 | 0.010 | 0.011 | 0.013 | 0.015 | 0.017 | 0.020 | 0.020 | 0.018 | 0.016 | 0.014 | 0.012 | 0.011 | 0.010 | 0.009 | 0.0116 |
| 18 | 0.009 | 0.008 | 0.008 | 0.007 | 0.007 | 0.007 | 0.007 | 0.007 | 0.007 | 0.011 | 0.010 | 0.010 | 0.011 | 0.012 | 0.012 | 0.013 | 0.013 | 0.012 | 0.011 | 0.010 | 0.008 | 0.008 | 0.007 | 0.007 | 0.0092 |
| 19 | 0.007 | 0.007 | 0.006 | 0.007 | 0.007 | 0.007 | 0.006 | 0.006 | 0.006 | 0.007 | CAL | 0.010 | 0.010 | 0.011 | 0.012 | 0.012 | 0.012 | 0.012 | 0.011 | 0.009 | 0.009 | 0.008 | 0.007 | 0.008 | 0.0086 |
| 20 | 0.007 | 0.007 | 0.007 | 0.007 | 0.007 | 0.006 | 0.006 | 0.006 | 0.007 | 0.008 | 0.010 | 0.012 | 0.014 | 0.018 | 0.024 | 0.030 | 0.035 | 0.033 | 0.023 | 0.017 | 0.013 | 0.011 | 0.010 | 0.009 | 0.0136 |
| 21 | 0.008 | 0.008 | 0.007 | 0.007 | 0.008 | 0.008 | 0.009 | 0.007 | 0.029 | CAL | 0.041 | 0.040 | 0.038 | 0.035 | 0.034 | 0.032 | 0.026 | 0.021 | 0.018 | 0.015 | 0.013 | 0.012 | 0.012 | 0.011 | 0.0191 |
| 22 | 0.010 | 0.010 | 0.010 | 0.009 | 0.009 | 0.009 | 0.008 | 0.009 | 0.009 | 0.010 | 0.011 | 0.012 | 0.013 | 0.014 | 0.015 | 0.015 | 0.015 | 0.014 | 0.013 | 0.012 | 0.011 | 0.011 | 0.011 | 0.011 | 0.0113 |
| 23 | 0.010 | 0.009 | 0.009 | 0.009 | 0.011 | 0.011 | 0.011 | 0.011 | 0.011 | 0.011 | 0.011 | CAL | 0.011 | 0.011 | 0.011 | 0.011 | 0.012 | 0.011 | 0.010 | 0.009 | 0.008 | 0.008 | 0.008 | 0.008 | 0.0101 |
| 24 | 0.008 | 0.009 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.007 | 0.007 | 0.008 | 0.008 | 0.009 | 0.010 | 0.010 | 0.011 | 0.010 | 0.009 | 0.008 | 0.008 | 0.007 | 0.007 | 0.008 | 0.0083 |
| 25 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.007 | 0.007 | 0.007 | CAL | 0.010 | 0.009 | 0.012 | 0.013 | 0.014 | 0.015 | 0.015 | 0.015 | 0.013 | 0.011 | 0.010 | 0.009 | 0.008 | 0.008 | 0.0100 |
| 26 | 0.008 | 0.007 | 0.007 | 0.007 | 0.007 | 0.007 | 0.007 | 0.007 | 0.007 | 0.008 | 0.010 | 0.012 | 0.015 | 0.018 | 0.021 | 0.023 | 0.022 | 0.020 | 0.016 | 0.014 | 0.011 | 0.010 | 0.009 | 0.009 | 0.0118 |
| 27 | 0.009 | 0.009 | 0.008 | 0.007 | 0.007 | 0.007 | 0.008 | 0.008 | 0.009 | CAL | 0.017 | 0.018 | 0.022 | 0.027 | ND | ND | 0.033 | 0.027 | 0.027 | 0.023 | 0.019 | 0.015 | 0.013 | 0.011 | 0.0154 |
| 28 | 0.009 | 0.008 | 0.008 | 0.007 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.007 | 0.009 | 0.009 | 0.010 | 0.011 | 0.012 | 0.012 | 0.013 | 0.012 | 0.011 | 0.010 | 0.008 | 0.008 | 0.007 | 0.006 | 0.0086 |
| 29 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | CAL | 0.007 | 0.008 | 0.009 | 0.010 | 0.011 | 0.012 | 0.013 | 0.012 | 0.011 | 0.010 | 0.009 | 0.008 | 0.007 | 0.007 | 0.0082 |
| 30 | 0.006 | 0.006 | 0.005 | 0.005 | 0.006 | 0.006 | 0.005 | 0.005 | 0.005 | 0.006 | 0.006 | 0.007 | 0.008 | 0.009 | 0.010 | 0.011 | 0.012 | 0.011 | 0.011 | 0.009 | 0.008 | 0.008 | 0.007 | 0.007 | 0.0075 |
| 31 | 0.006 | 0.006 | 0.005 | 0.005 | 0.005 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.007 | 0.009 | 0.010 | 0.011 | 0.011 | 0.012 | 0.011 | 0.011 | 0.010 | 0.009 | 0.008 | 0.008 | 0.007 | 0.006 | 0.0078 |

Monthly Average = 0.0105

Maximum Hourly Average was 0.041 at Hour 11 on Day 21 with 1 occurences and there were no Hourly Violations
Maximum Daily Average was 0.0191 on Day 21 with 1 occurences and there were no Daily Violations
Operating Efficiency = 97.0 percent
ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data
[CEM 1990]

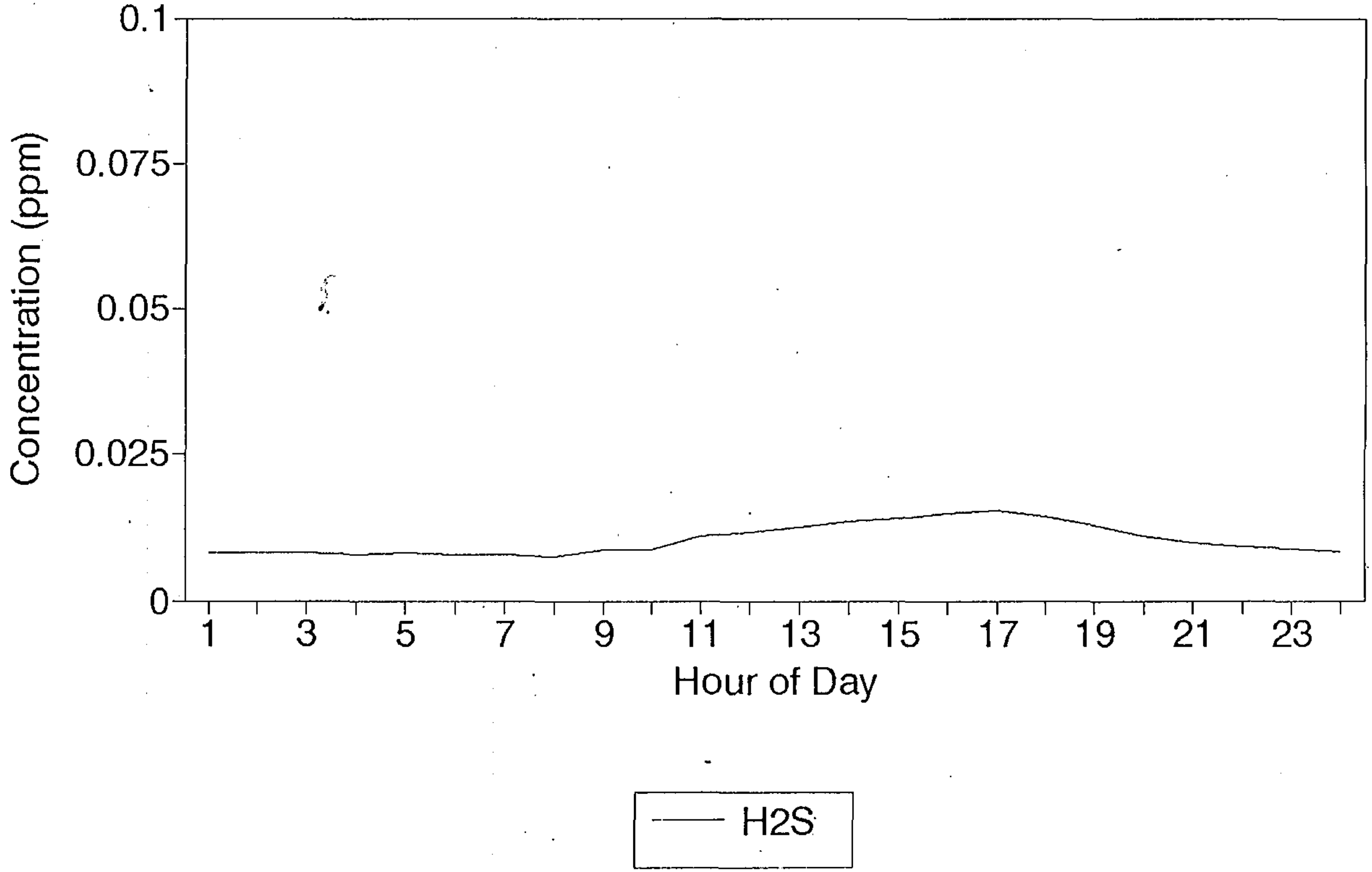
# KUWAIT

## Hourly H2S - May, 1991



# KUWAIT

## Diurnal H2S - May, 1991



MEPA - Kuwait

May 1991

Hourly Averages for SO2 in ppm

| Hour / Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.001 | 0.002 | 0.001 | 0.002 | 0.002 | 0.004 | 0.004 | 0.003 | 0.003 | 0.006 | 0.006 | 0.008 | 0.006 | 0.005 | 0.005 | 0.005 | 0.012 | ND | ND | 0.034 | 0.013 | 0.018 | 0.025 | 0.028 | 0.0088 |
| 2 | 0.025 | 0.037 | 0.043 | 0.056 | 0.078 | 0.049 | 0.052 | 0.054 | 0.074 | 0.111 | 0.107 | 0.052 | 0.030 | 0.025 | 0.018 | 0.023 | 0.019 | 0.007 | 0.010 | 0.016 | 0.021 | 0.022 | 0.019 | 0.017 | 0.0402 |
| 3 | 0.015 | 0.007 | 0.004 | 0.003 | 0.002 | 0.002 | 0.002 | 0.002 | 0.005 | CAL | 0.007 | 0.003 | 0.004 | 0.005 | 0.003 | 0.003 | 0.002 | 0.003 | 0.007 | 0.004 | 0.004 | 0.013 | 0.010 | 0.021 | 0.0057 |
| 4 | 0.010 | 0.016 | 0.012 | 0.002 | 0.001 | 0.008 | 0.004 | 0.008 | 0.007 | 0.007 | 0.006 | 0.006 | 0.010 | 0.005 | 0.007 | 0.007 | 0.012 | 0.016 | 0.024 | 0.007 | 0.018 | 0.003 | 0.003 | 0.003 | 0.0084 |
| 5 | 0.002 | 0.002 | 0.002 | 0.002 | 0.001 | 0.001 | 0.001 | 0.004 | 0.016 | 0.025 | CAL | 0.006 | 0.007 | 0.009 | 0.009 | 0.013 | 0.014 | 0.017 | 0.037 | 0.038 | 0.010 | 0.003 | 0.005 | 0.019 | 0.0106 |
| 6 | 0.003 | 0.003 | 0.002 | 0.001 | 0.002 | 0.002 | 0.002 | 0.003 | 0.008 | 0.018 | 0.012 | 0.007 | 0.006 | 0.008 | 0.006 | 0.017 | ND | ND | ND | ND | ND | ND | ND | ND | 0.0063 |
| 7 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.010 | 0.021 | 0.008 | 0.011 | 0.008 | 0.010 | 0.006 | 0.014 | 0.009 | 0.062 | CAL | 0.008 | 0.017 | 0.015 | 0.0153 |
| 8 | 0.019 | 0.008 | 0.005 | 0.006 | 0.036 | 0.066 | 0.030 | 0.036 | 0.044 | 0.030 | CAL | CAL | 0.023 | 0.019 | 0.012 | 0.009 | 0.010 | 0.008 | 0.015 | 0.009 | 0.031 | 0.215 | 0.128 | 0.001 | 0.0345 |
| 9 | 0.072 | 0.048 | 0.047 | 0.038 | 0.032 | 0.018 | 0.025 | 0.029 | 0.025 | 0.023 | 0.011 | 0.015 | 0.011 | 0.013 | 0.016 | 0.016 | 0.014 | 0.012 | 0.012 | 0.051 | 0.183 | 0.287 | 0.283 | 0.100 | 0.0575 |
| 10 | 0.066 | 0.038 | 0.056 | 0.022 | 0.030 | 0.023 | 0.020 | 0.009 | 0.010 | CAL | 0.015 | 0.018 | 0.013 | 0.013 | 0.018 | 0.016 | 0.020 | 0.015 | 0.019 | 0.005 | 0.004 | 0.007 | 0.031 | 0.014 | 0.0210 |
| 11 | 0.018 | 0.011 | 0.007 | 0.019 | 0.013 | 0.007 | 0.016 | 0.019 | 0.017 | 0.016 | 0.010 | 0.010 | 0.012 | 0.013 | 0.014 | 0.019 | 0.013 | 0.010 | 0.004 | 0.003 | 0.004 | 0.012 | 0.013 | 0.014 | 0.0123 |
| 12 | 0.007 | 0.005 | 0.004 | 0.005 | 0.006 | 0.006 | 0.005 | 0.012 | 0.004 | CAL | 0.016 | 0.016 | 0.019 | 0.017 | 0.015 | 0.014 | 0.012 | 0.009 | 0.011 | 0.005 | 0.005 | 0.006 | 0.005 | 0.007 | 0.0092 |
| 13 | 0.009 | 0.014 | 0.021 | 0.022 | 0.022 | 0.013 | 0.024 | 0.023 | 0.018 | 0.023 | 0.010 | 0.013 | 0.013 | 0.019 | 0.033 | 0.048 | 0.053 | 0.035 | 0.027 | 0.018 | 0.020 | 0.019 | 0.017 | 0.024 | 0.0224 |
| 14 | 0.063 | 0.041 | 0.029 | 0.032 | 0.033 | 0.022 | 0.012 | 0.017 | 0.067 | 0.054 | 0.019 | 0.017 | 0.014 | 0.011 | 0.019 | 0.020 | 0.014 | 0.022 | 0.030 | 0.012 | 0.011 | 0.017 | 0.070 | 0.217 | 0.0360 |
| 15 | 0.203 | 0.159 | 0.084 | 0.030 | 0.027 | 0.021 | 0.051 | 0.023 | 0.018 | CAL | 0.021 | 0.016 | 0.014 | 0.018 | 0.015 | 0.015 | 0.013 | 0.011 | 0.010 | 0.010 | 0.015 | 0.012 | 0.014 | 0.013 | 0.0353 |
| 16 | 0.009 | 0.008 | 0.009 | 0.009 | 0.015 | 0.020 | 0.042 | 0.011 | 0.012 | 0.013 | 0.013 | 0.009 | 0.010 | 0.006 | 0.007 | 0.009 | 0.008 | 0.007 | 0.005 | 0.005 | 0.005 | 0.004 | 0.002 | 0.004 | 0.0101 |
| 17 | 0.002 | 0.001 | 0.004 | 0.025 | 0.020 | 0.012 | 0.009 | 0.003 | CAL | 0.003 | 0.003 | 0.005 | 0.005 | 0.006 | 0.007 | 0.009 | 0.008 | 0.007 | 0.005 | 0.005 | 0.005 | 0.004 | 0.002 | 0.004 | 0.0067 |
| 18 | 0.002 | 0.001 | 0.004 | 0.025 | 0.020 | 0.012 | 0.009 | 0.008 | 0.008 | 0.004 | 0.003 | 0.005 | 0.004 | 0.004 | 0.005 | 0.004 | 0.005 | 0.003 | 0.002 | 0.002 | 0.001 | 0.001 | 0.002 | 0.005 | 0.0058 |
| 19 | 0.013 | 0.026 | 0.021 | 0.023 | 0.009 | 0.012 | 0.012 | 0.014 | 0.007 | 0.007 | CAL | 0.006 | 0.006 | 0.005 | 0.005 | 0.005 | 0.007 | 0.009 | 0.013 | 0.019 | 0.015 | 0.007 | 0.028 | 0.040 | 0.0134 |
| 20 | 0.022 | 0.012 | 0.035 | 0.009 | 0.004 | 0.001 | 0.002 | 0.006 | 0.009 | 0.014 | 0.011 | 0.008 | 0.010 | 0.009 | 0.013 | 0.018 | 0.020 | 0.028 | 0.012 | 0.006 | 0.003 | 0.006 | 0.011 | 0.012 | 0.0117 |
| 21 | 0.022 | 0.010 | 0.004 | 0.003 | 0.004 | 0.012 | 0.022 | 0.015 | 0.037 | CAL | 0.070 | 0.043 | 0.040 | 0.040 | 0.027 | 0.026 | 0.025 | 0.018 | 0.013 | 0.018 | 0.017 | 0.013 | 0.011 | 0.016 | 0.0220 |
| 22 | 0.023 | 0.015 | 0.015 | 0.018 | 0.008 | 0.010 | 0.027 | 0.029 | 0.021 | 0.007 | 0.005 | 0.018 | 0.026 | 0.022 | 0.016 | 0.021 | 0.011 | 0.009 | 0.011 | 0.015 | 0.021 | 0.011 | 0.004 | 0.015 | 0.0157 |
| 23 | 0.013 | 0.020 | 0.006 | 0.009 | 0.014 | 0.023 | 0.010 | 0.013 | 0.011 | 0.010 | 0.007 | CAL | 0.010 | 0.006 | 0.007 | 0.008 | 0.010 | 0.012 | 0.007 | 0.010 | 0.027 | 0.013 | 0.011 | 0.028 | 0.0124 |
| 24 | 0.009 | 0.005 | 0.004 | 0.004 | 0.004 | 0.005 | 0.024 | 0.044 | 0.049 | 0.018 | 0.005 | 0.006 | 0.006 | 0.007 | 0.006 | 0.005 | 0.005 | 0.005 | 0.004 | 0.020 | 0.014 | 0.005 | 0.014 | 0.010 | 0.0116 |
| 25 | 0.019 | 0.013 | 0.023 | 0.017 | 0.026 | 0.016 | 0.006 | 0.012 | 0.013 | CAL | 0.046 | 0.008 | 0.009 | 0.007 | 0.008 | 0.010 | 0.009 | 0.007 | 0.007 | 0.016 | 0.017 | 0.033 | 0.012 | 0.029 | 0.0158 |
| 26 | 0.035 | 0.030 | 0.024 | 0.007 | 0.008 | 0.007 | 0.005 | 0.005 | 0.012 | 0.033 | 0.037 | 0.010 | 0.010 | 0.009 | 0.010 | 0.014 | 0.013 | 0.010 | 0.009 | 0.012 | 0.015 | 0.014 | 0.029 | 0.057 | 0.0173 |
| 27 | 0.044 | 0.027 | 0.010 | 0.008 | 0.022 | 0.056 | 0.150 | 0.144 | 0.028 | CAL | 0.028 | 0.035 | 0.028 | 0.032 | ND | ND | 0.029 | 0.037 | 0.037 | 0.033 | 0.034 | 0.032 | 0.026 | 0.025 | 0.0412 |
| 28 | 0.018 | 0.020 | 0.022 | 0.012 | 0.016 | 0.017 | 0.018 | 0.016 | 0.012 | 0.006 | 0.006 | 0.006 | 0.008 | 0.010 | 0.009 | 0.010 | 0.006 | 0.005 | 0.005 | 0.004 | 0.005 | 0.005 | 0.004 | 0.004 | 0.0102 |
| 29 | 0.004 | 0.004 | 0.005 | 0.005 | 0.005 | 0.006 | 0.008 | 0.008 | 0.004 | CAL | 0.009 | 0.007 | 0.009 | 0.010 | 0.009 | 0.007 | 0.008 | 0.009 | 0.009 | 0.008 | 0.010 | 0.016 | 0.023 | 0.005 | 0.0082 |
| 30 | 0.005 | 0.006 | 0.005 | 0.016 | 0.015 | 0.036 | 0.053 | 0.062 | 0.034 | 0.009 | 0.007 | 0.008 | 0.008 | 0.007 | 0.008 | 0.024 | 0.026 | 0.026 | 0.019 | 0.022 | 0.032 | 0.036 | 0.010 | 0.006 | 0.0200 |
| 31 | 0.005 | 0.007 | 0.057 | 0.133 | 0.131 | 0.155 | 0.109 | 0.088 | 0.015 | 0.028 | 0.030 | 0.027 | 0.017 | 0.012 | 0.021 | 0.021 | 0.014 | 0.012 | 0.012 | 0.009 | 0.020 | 0.008 | 0.006 | 0.019 | 0.0398 |

Monthly Average = 0.0190

Maximum Hourly Average was 0.287 at Hour 22 on Day 9 with 1 occurences and the Number of Hourly Violations were 2

Maximum Daily Average was 0.0575 on Day 9 with 1 occurences and there were no Daily Violations

Operating Efficiency = 97.0 percent

ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data

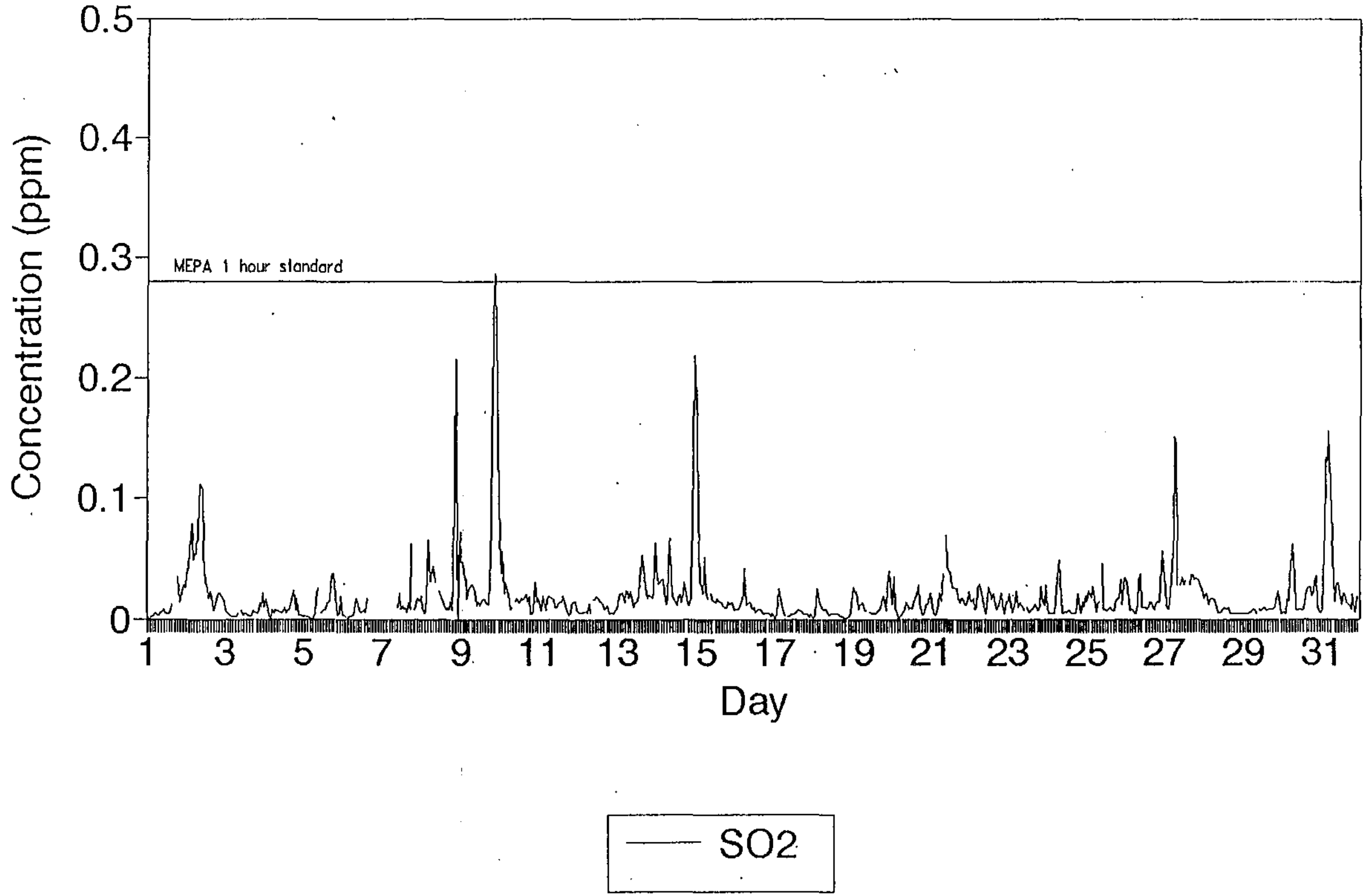
[CEM 1990]

MEPA - Kuwait
May 1991
Frequency Distribution
Hourly Averages for $SO_2$ in ppm

| Concentration | # of Hours | Percentage |
|---|---|---|
| 0.000 - 0.020 | 527 | 74.5 |
| 0.021 - 0.060 | 150 | 21.2 |
| 0.061 - 0.110 | 16 | 2.3 |
| 0.111 - 0.170 | 8 | 1.1 |
| 0.171 - 0.340 | 6 | 0.8 |
| 0.341+ | 0 | 0.0 |

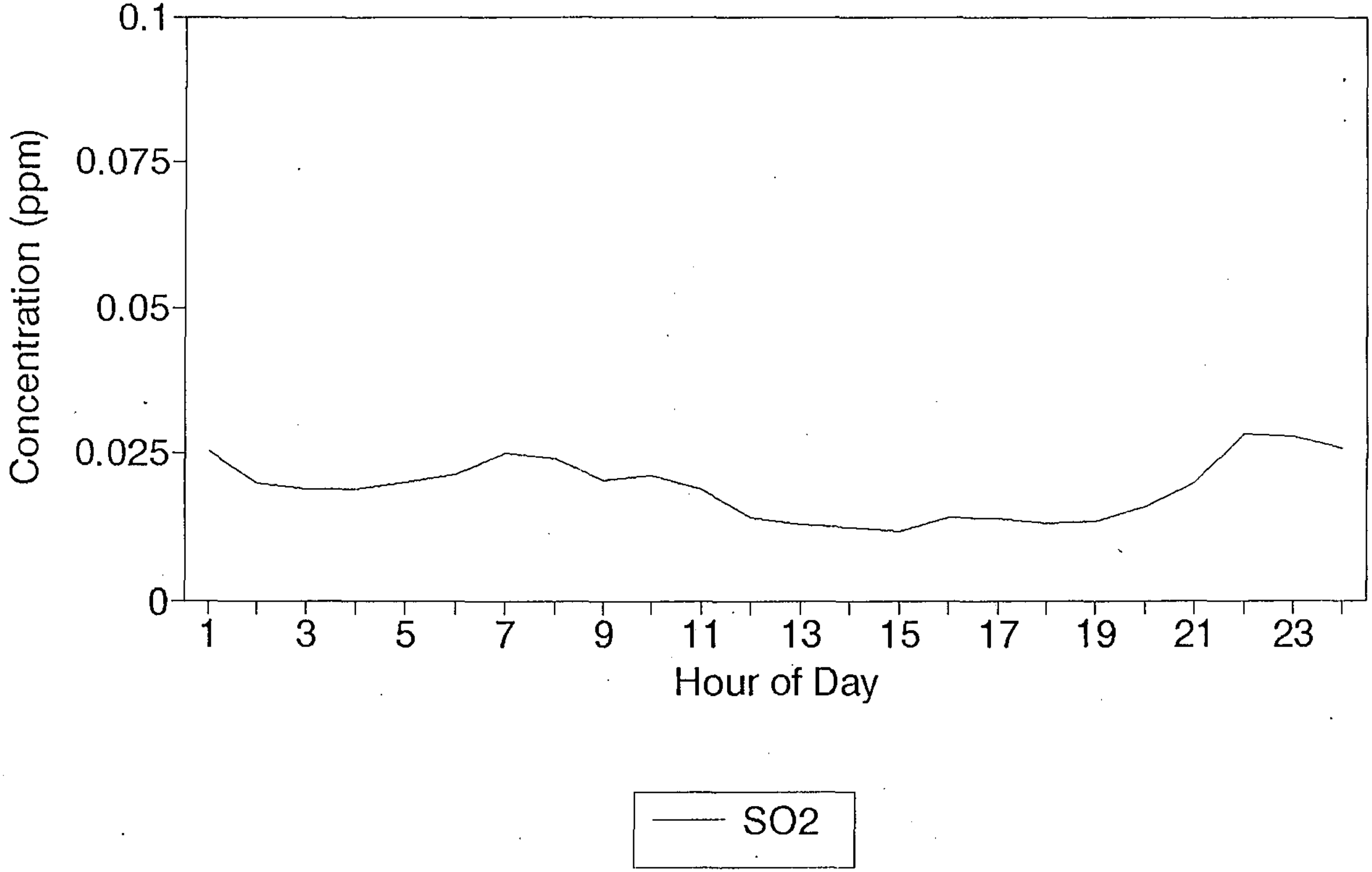
# KUWAIT

Hourly SO2 - May, 1991



# KUWAIT

Diurnal SO2 - May, 1991



MEPA - Kuwait
June 1991
Hourly Averages for Direction(degrees)

| Hour / Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 325 | 328 | 326 | 324 | 326 | 322 | 323 | 328 | 337 | 0 | 16 | 15 | 21 | 21 | 15 | 16 | 19 | 8 | 325 | 309 | 309 | 324 | 320 | 307 | 341.43 |
| 2 | 304 | 319 | 355 | 330 | 327 | 321 | 331 | 336 | 348 | 354 | 1 | 338 | 341 | 312 | 307 | 326 | 322 | 320 | 317 | 307 | 305 | 308 | 315 | 323 | 326.00 |
| 3 | 323 | 324 | 328 | 328 | 328 | 325 | 323 | 320 | 324 | 0 | 323 | 329 | 331 | 333 | 331 | 329 | 335 | 338 | 339 | 338 | 329 | 323 | 322 | 322 | 329.32 |
| 4 | 322 | 322 | 317 | 310 | 299 | 304 | 319 | 323 | 321 | 328 | 327 | 326 | 324 | 326 | 328 | 333 | 332 | 332 | 339 | 339 | 333 | 326 | 319 | 313 | 323.45 |
| 5 | 287 | 291 | 309 | 313 | 311 | 314 | 319 | 323 | 327 | 0 | 330 | 333 | 328 | 330 | 332 | 334 | 334 | 338 | 337 | 327 | 332 | 330 | 325 | 318 | 324.34 |
| 6 | 318 | 322 | 325 | 322 | 321 | 316 | 313 | 327 | 323 | 335 | 342 | 341 | 341 | 337 | 338 | 343 | 341 | 349 | 6 | 10 | 17 | 18 | 17 | 357 | 340.55 |
| 7 | 349 | 323 | 320 | 329 | 331 | 332 | 330 | 312 | 320 | 326 | 330 | 333 | 334 | 334 | 338 | 336 | 334 | 331 | 328 | 329 | 327 | 323 | 317 | 312 | 328.25 |
| 8 | 315 | 319 | 319 | 320 | 317 | 319 | 319 | 327 | 332 | 0 | 333 | 337 | 332 | 337 | 332 | 330 | 328 | 333 | 337 | 336 | 329 | 333 | 321 | 324 | 328.66 |
| 9 | 325 | 332 | 342 | 329 | 323 | 276 | 283 | 300 | 324 | 313 | 314 | 324 | 325 | 338 | 333 | 336 | 340 | 337 | 337 | 332 | 330 | 325 | 319 | 314 | 323.29 |
| 10 | 311 | 288 | 279 | 289 | 279 | 292 | 311 | 313 | 311 | 0 | 315 | 318 | 322 | 328 | 325 | 323 | 322 | 320 | 322 | 326 | 333 | 349 | 352 | 349 | 318.25 |
| 11 | 312 | 289 | 280 | 303 | 317 | 313 | 302 | 323 | 342 | 344 | 341 | 340 | 333 | 340 | 338 | 325 | 323 | 322 | 326 | 328 | 330 | 337 | 347 | 356 | 325.69 |
| 12 | 1 | 0 | 353 | 354 | 341 | 359 | 5 | 5 | 9 | 0 | 18 | 22 | 23 | 20 | 12 | 341 | 340 | 346 | 16 | 15 | 14 | 12 | 14 | 36 | 5.69 |
| 13 | 25 | 33 | 9 | 304 | 287 | 291 | 1 | 327 | 284 | 336 | 0 | 15 | 15 | 15 | 16 | 28 | 47 | 51 | 17 | 300 | 248 | 278 | 7 | 5 | 350.91 |
| 14 | 337 | 326 | 267 | 324 | 337 | 297 | 318 | 334 | 339 | 344 | 341 | 21 | 42 | 43 | 91 | 138 | 130 | 172 | 218 | 302 | 256 | 261 | 260 | 262 | 316.63 |
| 15 | 261 | 268 | 272 | 251 | 265 | 260 | 261 | 266 | 277 | 0 | 358 | 354 | 96 | 80 | 128 | 123 | 123 | 134 | 136 | 128 | 153 | 160 | 188 | 266 | 211.71 |
| 16 | 242 | 242 | 253 | 271 | 275 | 288 | 279 | 280 | 290 | 332 | 338 | 22 | 47 | 63 | 118 | 145 | 140 | 141 | 172 | 264 | 281 | 281 | 280 | 315 | 276.59 |
| 17 | 326 | 329 | 327 | 327 | 328 | 326 | 327 | 325 | 327 | 0 | 332 | 325 | 331 | 328 | 326 | 332 | 331 | 333 | 333 | 325 | 323 | 310 | 308 | 306 | 326.84 |
| 18 | 306 | 301 | 303 | 294 | 294 | 309 | 309 | 314 | 313 | 309 | 317 | 331 | 333 | 333 | 318 | 331 | 334 | 337 | 335 | 324 | 315 | 303 | 285 | 275 | 313.55 |
| 19 | 283 | 286 | 283 | 283 | 280 | 292 | 303 | 306 | 309 | 310 | 309 | 349 | 26 | 61 | 91 | 119 | 102 | 143 | 151 | 197 | 247 | 232 | 247 | 238 | 280.90 |
| 20 | 284 | 326 | 317 | 308 | 307 | 327 | 331 | 340 | 19 | 0 | 45 | 80 | 131 | 145 | 144 | 139 | 141 | 127 | 131 | 162 | 179 | 200 | 253 | 246 | 239.79 |
| 21 | 238 | 186 | 168 | 131 | 171 | 173 | 183 | 207 | 213 | 232 | 239 | 137 | 126 | 149 | 149 | 160 | 158 | 161 | 159 | 165 | 174 | 179 | 186 | 198 | 175.90 |
| 22 | 219 | 243 | 249 | 229 | 148 | 161 | 171 | 234 | 277 | 0 | 104 | 121 | 128 | 113 | 122 | 134 | 140 | 137 | 112 | 92 | 112 | 103 | 100 | 102 | 141.59 |
| 23 | 111 | 126 | 150 | 196 | 134 | 268 | 288 | 11 | 41 | 34- | 53 | 66 | 84 | 92 | 111 | 124 | 99 | 124 | 146 | 167 | 191 | 225 | 225 | 165 | 125.61 |
| 24 | 195 | 184 | 169 | 210 | 244 | 255 | 275 | 272 | 264 | 0 | 283 | 106 | 112 | 12 | 86 | 129 | 132 | 129 | 146 | 177 | 196 | 230 | 232 | 245 | 199.05 |
| 25 | 240 | 229 | 130 | 137 | 192 | 227 | 248 | 241 | 257 | 288 | 330 | 67 | 0 | 126 | 151 | 155 | 176 | 181 | 167 | 167 | 175 | 198 | 215 | 212 | 195.59 |
| 26 | 210 | 164 | 126 | 179 | 138 | 142 | 137 | 125 | 102 | 115 | 121 | 134 | 125 | 132 | 135 | 92 | 74 | 107 | 111 | 126 | 121 | 113 | 117 | 117 | 126.55 |
| 27 | 119 | 104 | 131 | 131 | 94 | 84 | 78 | 78 | 65 | 0 | 65 | 57 | 70 | 75 | 79 | 88 | 96 | 111 | 109 | 338 | 286 | 281 | 3 | 31 | 74.72 |
| 28 | 315 | 335 | 18 | 310 | 307 | 357 | 71 | 32 | 4 | 346 | 340 | 12 | 25 | 45 | 81 | 94 | 100 | 127 | 154 | 184 | 242 | 272 | 267 | 260 | 0.92 |
| 29 | 254 | 251 | 253 | 261 | 269 | 265 | 267 | 269 | 283 | 318 | 347 | 331 | 339 | 334 | 324 | 326 | 338 | 341 | 341 | 337 | 329 | 314 | 310 | 322 | 306.08 |
| 30 | 327 | 324 | 322 | 323 | 311 | 295 | 291 | 310 | 312 | 0 | 318 | 326 | 332 | 333 | 336 | 333 | 336 | 334 | 331 | 327 | 329 | 331 | 329 | 304 | 323.96 |

Monthly Average = 326

Operating Efficiency for Wind Direction = 100.0 percent

** = missing or no data

Last Instrument Calibration Date - unknown

[CEM]

MEPA - Kuwait
June 1991
Hourly Averages for Wind Speed(meters/sec)

| Day \ Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3.5 | 3.6 | 3.1 | 3.6 | 3.4 | 3.3 | 2.5 | 3.2 | 3.6 | 0.0 | 6.4 | 8.1 | 8.2 | 7.8 | 8.1 | 7.8 | 8.0 | 5.8 | 2.4 | 2.5 | 2.7 | 2.9 | 2.3 | 2.6 | 4.39 |
| 2 | 3.6 | 2.2 | 2.6 | 2.5 | 2.7 | 2.1 | 2.6 | 2.1 | 2.5 | 2.6 | 3.5 | 2.9 | 2.5 | 3.9 | 4.1 | 2.7 | 2.3 | 3.2 | 2.5 | 3.6 | 4.3 | 4.6 | 5.0 | 6.3 | 3.20 |
| 3 | 6.7 | 7.1 | 8.4 | 8.4 | 7.3 | 6.9 | 7.4 | 7.6 | 8.2 | 0.0 | 8.6 | 8.7 | 8.6 | 8.6 | 9.0 | 8.4 | 7.5 | 6.3 | 5.2 | 5.0 | 5.4 | 4.6 | 4.7 | 4.1 | 6.78 |
| 4 | 4.0 | 4.0 | 3.8 | 4.3 | 4.0 | 4.5 | 5.8 | 6.7 | 6.9 | 7.6 | 8.6 | 9.2 | 9.2 | 8.6 | 9.3 | 8.7 | 7.9 | 6.7 | 5.9 | 5.5 | 5.1 | 4.6 | 4.2 | 5.0 | 6.25 |
| 5 | 4.5 | 4.8 | 5.7 | 5.6 | 6.3 | 6.3 | 6.2 | 7.4 | 8.6 | 0.0 | 9.3 | 8.2 | 9.1 | 9.5 | 9.3 | 8.9 | 8.2 | 6.6 | 5.8 | 4.9 | 5.3 | 4.9 | 3.7 | 3.7 | 6.37 |
| 6 | 4.3 | 4.7 | 4.2 | 5.3 | 4.9 | 5.4 | 6.1 | 4.4 | 3.2 | 4.3 | 5.0 | 5.2 | 5.8 | 6.2 | 6.8 | 6.4 | 5.7 | 4.6 | 2.9 | 2.7 | 3.3 | 2.5 | 2.2 | 1.2 | 4.47 |
| 7 | 1.3 | 1.4 | 2.4 | 3.7 | 4.2 | 3.9 | 3.8 | 6.5 | 7.0 | 8.6 | 9.0 | 9.1 | 8.7 | 8.4 | 8.2 | 8.3 | 8.1 | 7.8 | 6.9 | 5.9 | 5.4 | 5.3 | 5.2 | 6.1 | 6.05 |
| 8 | 6.0 | 6.2 | 5.6 | 6.0 | 5.0 | 5.0 | 5.0 | 4.3 | 4.6 | 0.0 | 7.1 | 7.0 | 6.8 | 6.3 | 7.5 | 7.8 | 7.2 | 6.4 | 5.0 | 4.8 | 4.1 | 3.6 | 3.6 | 4.0 | 5.37 |
| 9 | 4.0 | 5.1 | 4.6 | 4.2 | 3.8 | 4.1 | 4.7 | 5.8 | 6.5 | 7.7 | 7.9 | 8.3 | 7.7 | 7.7 | 8.0 | 8.2 | 7.3 | 6.4 | 6.1 | 5.4 | 4.7 | 4.1 | 4.0 | 4.5 | 5.87 |
| 10 | 4.1 | 4.1 | 3.4 | 3.3 | 3.4 | 4.9 | 5.5 | 6.3 | 7.2 | 0.0 | 8.0 | 10.0 | 10.6 | 9.5 | 9.5 | 9.2 | 8.2 | 6.3 | 4.9 | 3.8 | 3.6 | 3.2 | 2.4 | 2.2 | 5.57 |
| 11 | 1.8 | 2.8 | 2.6 | 3.3 | 3.5 | 3.9 | 4.1 | 3.5 | 3.5 | 3.4 | 5.8 | 6.3 | 6.5 | 5.8 | 6.2 | 7.1 | 6.6 | 6.2 | 4.7 | 4.6 | 4.2 | 3.4 | 2.2 | 2.3 | 4.35 |
| 12 | 3.2 | 3.2 | 4.0 | 3.3 | 2.7 | 2.8 | 2.7 | 3.3 | 4.0 | 0.0 | 4.5 | 5.0 | 4.7 | 4.3 | 4.4 | 4.6 | 5.0 | 5.1 | 4.1 | 4.9 | 5.4 | 4.7 | 3.4 | 2.3 | 3.82 |
| 13 | 2.4 | 1.7 | 2.0 | 1.1 | 1.4 | 1.2 | 2.1 | 1.7 | 3.0 | 2.4 | 4.4 | 5.2 | 5.4 | 5.9 | 5.3 | 4.1 | 3.8 | 2.5 | 3.9 | 2.6 | 2.4 | 1.9 | 2.7 | 2.7 | 2.99 |
| 14 | 1.9 | 1.6 | 2.4 | 2.3 | 2.4 | 2.2 | 1.6 | 2.2 | 2.7 | 2.7 | 3.7 | 6.9 | 4.9 | 3.9 | 2.3 | 1.2 | 1.4 | 1.0 | 1.0 | 0.9 | 2.4 | 3.7 | 3.8 | 3.8 | 2.62 |
| 15 | 3.5 | 2.7 | 2.7 | 3.8 | 3.6 | 3.8 | 4.0 | 2.4 | 3.5 | 0.0 | 3.4 | 2.2 | 1.0 | 2.2 | 2.8 | 2.8 | 2.5 | 2.2 | 2.4 | 1.6 | 1.7 | 1.7 | 2.8 | 3.7 | 2.62 |
| 16 | 4.3 | 5.4 | 5.1 | 3.7 | 3.8 | 2.8 | 2.7 | 2.8 | 2.7 | 3.0 | 2.4 | 3.0 | 2.1 | 1.6 | 1.6 | 0.9 | 1.4 | 1.5 | 1.5 | 2.4 | 2.7 | 2.6 | 3.4 | 3.9 | 2.80 |
| 17 | 5.1 | 5.4 | 5.3 | 5.6 | 5.1 | 4.5 | 4.5 | 4.1 | 6.3 | 0.0 | 7.5 | 9.0 | 8.9 | 8.7 | 8.8 | 8.6 | 8.4 | 7.4 | 7.6 | 6.8 | 5.9 | 7.0 | 7.6 | 7.8 | 6.50 |
| 18 | 7.5 | 6.9 | 7.7 | 6.0 | 5.5 | 7.5 | 8.8 | 8.6 | 9.4 | 10.5 | 9.1 | 9.1 | 8.0 | 8.0 | 7.3 | 7.4 | 6.8 | 6.4 | 5.6 | 3.8 | 3.7 | 4.9 | 4.8 | 4.3 | 6.98 |
| 19 | 4.9 | 5.4 | 6.2 | 6.1 | 5.4 | 4.8 | 6.1 | 6.8 | 8.5 | 7.6 | 6.1 | 4.4 | 3.9 | 4.9 | 4.0 | 3.7 | 3.2 | 3.6 | 2.5 | 2.0 | 2.7 | 2.5 | 2.9 | 3.7 | 4.66 |
| 20 | 3.5 | 2.3 | 2.5 | 3.7 | 0.0 | 2.2 | 2.2 | 2.6 | 2.3 | 0.0 | 2.8 | 3.4 | 6.1 | 6.2 | 6.5 | 4.9 | 4.5 | 2.6 | 2.2 | 3.0 | 4.2 | 4.2 | 3.3 | 4.1 | 3.30 |
| 21 | 3.5 | 2.1 | 1.4 | 1.8 | 1.0 | 2.0 | 2.3 | 2.1 | 2.2 | 2.6 | 2.8 | 0.7 | 1.2 | 2.5 | 4.5 | 6.5 | 6.5 | 6.2 | 5.9 | 6.7 | 6.0 | 5.7 | 4.5 | 5.9 | 3.61 |
| 22 | 5.3 | 5.4 | 4.2 | 3.9 | 3.1 | 2.3 | 2.0 | 1.8 | 1.4 | 0.0 | 2.5 | 1.5 | 1.6 | 2.0 | 3.2 | 4.9 | 4.8 | 3.9 | 3.5 | 3.5 | 2.5 | 2.0 | 2.2 | 3.0 | 2.94 |
| 23 | 3.0 | 3.4 | 2.0 | 0.9 | 0.0 | 0.0 | 0.1 | 0.1 | 2.2 | 3.3 | 3.0 | 3.5 | 4.6 | 5.0 | 3.1 | 1.2 | 2.8 | 3.0 | 3.1 | 2.6 | 2.2 | 1.9 | 2.0 | 0.7 | 2.24 |
| 24 | 1.5 | 1.0 | 0.2 | 1.1 | 0.4 | 1.5 | 2.3 | 2.6 | 2.3 | 0.0 | 2.4 | 0.8 | 1.8 | 1.1 | 2.2 | 1.5 | 1.3 | 4.0 | 3.7 | 3.5 | 3.2 | 2.9 | 3.1 | 4.2 | 2.03 |
| 25 | 3.7 | 4.0 | 4.2 | 2.4 | 1.3 | 1.8 | 3.1 | 3.3 | 3.3 | 1.6 | 0.1 | 2.0 | 0.0 | 5.1 | 5.7 | 6.0 | 5.9 | 6.0 | 6.7 | 5.8 | 5.6 | 2.9 | 3.2 | 4.4 | 3.67 |
| 26 | 4.7 | 1.6 | 2.9 | 3.5 | 1.3 | 3.0 | 3.3 | 1.8 | 3.9 | 3.1 | 5.3 | 5.1 | 5.2 | 5.7 | 6.7 | 5.0 | 4.6 | 4.9 | 4.3 | 4.3 | 4.1 | 2.5 | 1.7 | 1.7 | 3.76 |
| 27 | 2.3 | 2.0 | 1.2 | 1.2 | 1.7 | 1.2 | 1.8 | 1.8 | 1.3 | 0.0 | 0.6 | 1.1 | 2.2 | 2.8 | 3.2 | 3.3 | 3.5 | 3.3 | 1.2 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | 1.51 |
| 28 | 0.0 | 0.1 | 0.0 | 1.0 | 2.4 | 0.2 | 0.1 | 2.0 | 2.3 | 2.9 | 2.6 | 3.8 | 4.5 | 4.0 | 1.9 | 1.7 | 1.5 | 0.5 | 0.0 | 0.0 | 0.0 | 1.0 | 1.9 | 3.0 | 1.56 |
| 29 | 3.6 | 3.7 | 3.7 | 4.0 | 3.7 | 4.1 | 3.6 | 3.4 | 3.1 | 2.8 | 4.0 | 5.7 | 5.9 | 7.3 | 7.7 | 7.5 | 6.7 | 6.3 | 4.9 | 4.7 | 3.8 | 3.7 | 4.9 | 4.6 | 4.72 |
| 30 | 5.9 | 5.3 | 5.1 | 4.5 | 4.6 | 4.0 | 5.6 | 6.9 | 7.1 | 0.0 | 7.3 | 8.3 | 8.3 | 7.7 | 8.3 | 7.9 | 7.2 | 6.2 | 5.6 | 5.3 | 5.6 | 5.0 | 4.1 | 4.3 | 5.84 |

Monthly Average = 4.23

Maximum Hourly Average Wind Speed was 10.6 meters/sec at Hour 13 on Day 10
Maximum Daily Average Wind Speed was 6.98 meters/sec on Day 18
Operating Efficiency for Wind Speed = 100.0 percent ** = missing or no data
Last Instrument Calibration Date - unknown
[CEM]

MEPA - Kuwait

June 1991

Hourly Averages for Wind Speed(meters/sec) and Direction

| Day \ Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 4NW | 4NNW | 3NW | 4NW | 3NW | 3NW | 2NW | 3NNW | 4NNW | 0N | 6NNE | 8NNE | 8NNE | 8NNE | 8NNE | 8NNE | 8NNE | 6N | 2NW | 2NW | 3NW | 3NW | 2NW | 3NW | 4NNW |
| 2 | 4NW | 2NW | 3N | 2NNW | 3NNW | 2NW | 3NNW | 2NNW | 2NNW | 3N | 4N | 3NNW | 2NNW | 4NW | 4NW | 3NW | 2NW | 3NW | 2NW | 4NW | 4NW | 5NW | 5NW | 6NW | 3NW |
| 3 | 7NW | 7NW | 8NNW | 8NNW | 7NNW | 7NW | 7NW | 8NW | 8NW | 0N | 9NW | 9NNW | 9NNW | 9NNW | 9NNW | 8NNW | 8NNW | 6NNW | 5NNW | 5NNW | 5NNW | 5NW | 5NW | 4NW | 7NNW |
| 4 | 4NW | 4NW | 4NW | 4NW | 4WNW | 4NW | 6NW | 7NW | 7NW | 8NNW | 9NNW | 9NW | 9NW | 9NW | 9NNW | 9NNW | 8NNW | 7NNW | 6NNW | 6NNW | 5NNW | 5NW | 4NW | 5NW | 6NW |
| 5 | 4WNW | 5WNW | 6NW | 6NW | 6NW | 6NW | 6NW | 7NW | 9NNW | 0N | 9NNW | 8NNW | 9NNW | 10NNW | 9NNW | 9NNW | 8NNW | 7NNW | 6NNW | 5NNW | 5NNW | 5NNW | 4NW | 4NW | 6NW |
| 6 | 4NW | 5NW | 4NW | 5NW | 5NW | 5NW | 6NW | 4NNW | 3NW | 4NNW | 5NNW | 5NNW | 6NNW | 6NNW | 7NNW | 6NNW | 6NNW | 5N | 3N | 3N | 3NNE | 2NNE | 2NNE | 1N | 4NNW |
| 7 | 1N | 1NW | 2NW | 4NNW | 4NNW | 4NNW | 4NNW | 6NW | 7NW | 9NW | 9NNW | 9NNW | 9NNW | 8NNW | 8NNW | 8NNW | 8NNW | 8NNW | 7NNW | 6NNW | 5NNW | 5NW | 5NW | 6NW | 6NNW |
| 8 | 6NW | 6NW | 6NW | 6NW | 5NW | 5NW | 5NW | 4NNW | 5NNW | 0N | 7NNW | 7NNW | 7NNW | 6NNW | 8NNW | 8NNW | 7NNW | 6NNW | 5NNW | 5NNW | 4NNW | 4NNW | 4NW | 4NW | 5NNW |
| 9 | 4NW | 5NNW | 5NNW | 4NNW | 4NW | 4W | 5WNW | 6WNW | 6NW | 8NW | 8NW | 8NW | 8NW | 8NNW | 8NNW | 8NNW | 7NNW | 6NNW | 6NNW | 5NNW | 5NNW | 4NW | 4NW | 4NW | 6NW |
| 10 | 4NW | 4WNW | 3W | 3WNW | 3W | 5WNW | 6NW | 6NW | 7NW | 0N | 8NW | 10NW | 11NW | 10NNW | 10NW | 9NW | 8NW | 6NW | 5NW | 4NW | 4NNW | 3N | 2N | 2N | 6NW |
| 11 | 2NW | 3WNW | 3W | 3WNW | 4NW | 4NW | 4WNW | 4NW | 4NNW | 3NNW | 6NNW | 6NNW | 6NNW | 6NNW | 6NNW | 7NW | 7NW | 6NW | 5NW | 5NNW | 4NNW | 3NNW | 2NNW | 2N | 4NW |
| 12 | 3N | 3N | 4N | 3N | 3NNW | 3N | 3N | 3N | 4N | 0N | 4NNE | 5NNE | 5NNE | 4NNE | 4NNE | 5NNW | 5NNW | 5NNW | 4NNE | 5NNE | 5NNE | 5NNE | 3NNE | 2NE | 4N |
| 13 | 2NNE | 2NNE | 2N | 1NW | 1WNW | 1WNW | 2N | 2NNW | 3WNW | 2NNW | 4N | 5NNE | 5NNE | 6NNE | 5NNE | 4NNE | 4NE | 2NE | 4NNE | 3WNW | 2WSW | 2W | 3N | 3N | 3N |
| 14 | 2NNW | 2NW | 2W | 2NW | 2NNW | 2WNW | 2NW | 2NNW | 3NNW | 3NNW | 4NNW | 7NNE | 5NE | 4NE | 2E | 1SE | 1SE | 1S | 1SW | 1WNW | 2WSW | 4W | 4W | 4W | 3NW |
| 15 | 4W | 3W | 3W | 4WSW | 4W | 4W | 4W | 2W | 4W | 0N | 3N | 2N | 1E | 2E | 3SE | 3ESE | 2ESE | 2SE | 2SE | 2SE | 2SSE | 2SSE | 3S | 4W | 3SSW |
| 16 | 4WSW | 5WSW | 5WSW | 4W | 4W | 3WNW | 3W | 3W | 3WNW | 3NNW | 2NNW | 3NNE | 2NE | 2ENE | 2ESE | 1SE | 1SE | 2SE | 2S | 2W | 3W | 3W | 3W | 4NW | 3W |
| 17 | 5NW | 5NNW | 5NNW | 6NNW | 5NNW | 4NW | 4NNW | 4NW | 6NNW | 0N | 8NNW | 9NW | 9NNW | 9NNW | 9NW | 9NNW | 8NNW | 7NNW | 8NNW | 7NW | 6NW | 7NW | 8NW | 8NW | 6NNW |
| 18 | 8NW | 7WNW | 8WNW | 6WNW | 6WNW | 8NW | 9NW | 9NW | 9NW | 10NW | 9NW | 9NNW | 8NNW | 8NNW | 7NW | 7NNW | 7NNW | 6NNW | 6NNW | 4NW | 4NW | 5WNW | 5WNW | 4W | 7NW |
| 19 | 5WNW | 5WNW | 6WNW | 6WNW | 5W | 5WNW | 6WNW | 7NW | 8NW | 8NW | 6NW | 4N | 4NNE | 5ENE | 4E | 4ESE | 3ESE | 4SE | 2SSE | 2SSW | 3WSW | 2SW | 3WSW | 4WSW | 5W |
| 20 | 4WNW | 2NW | 2NW | 4NW | 0NW | 2NNW | 2NNW | 3NNW | 2NNE | 0N | 3NE | 3E | 6SE | 6SE | 6SE | 5SE | 4SE | 3SE | 2SE | 3SSE | 4S | 4SSW | 3WSW | 4WSW | 3WSW |
| 21 | 4WSW | 2S | 1SSE | 2SE | 1S | 2S | 2S | 2SSW | 2SSW | 3SW | 3WSW | 1SE | 1SE | 2SSE | 4SSE | 6SSE | 6SSE | 6SSE | 6SSE | 7SSE | 6S | 6S | 4S | 6SSW | 4S |
| 22 | 5SW | 5WSW | 4WSW | 4SW | 3SSE | 2SSE | 2S | 2SW | 1W | 0N | 2ESE | 2ESE | 2SE | 2ESE | 3ESE | 5SE | 5SE | 4SE | 4ESE | 4E | 2ESE | 2ESE | 2E | 3ESE | 3SE |
| 23 | 3ESE | 3SE | 2SSE | 1SSW | 0SE | 0W | 0WNW | 0N | 2NE | 3NE | 3NE | 4ENE | 5E | 5E | 3ESE | 1SE | 3E | 3SE | 3SE | 3SSE | 2S | 2SW | 2SW | 1SSE | 2SE |
| 24 | 2SSW | 1S | 0S | 1SSW | 0WSW | 2WSW | 2W | 3W | 2W | 0N | 2WNW | 1ESE | 2ESE | 1NNE | 2E | 2SE | 1SE | 4SE | 4SE | 4S | 3SSW | 3SW | 3SW | 4WSW | 2SSW |
| 25 | 4WSW | 4SW | 4SE | 2SE | 1SSW | 2SW | 3WSW | 3WSW | 3WSW | 2WNW | 0NNW | 2ENE | 0N | 5SE | 6SSE | 6SSE | 6S | 6S | 7SSE | 6SSE | 6S | 3SSW | 3SW | 4SSW | 4SSW |
| 26 | 5SSW | 2SSE | 3SE | 4S | 1SE | 3SE | 3SE | 2SE | 4ESE | 3ESE | 5ESE | 5SE | 5SE | 6SE | 7SE | 5E | 5ENE | 5ESE | 4ESE | 4SE | 4ESE | 2ESE | 2ESE | 2ESE | 4SE |
| 27 | 2ESE | 2ESE | 1SE | 1SE | 2E | 1E | 2ENE | 2ENE | 1ENE | 0N | 1ENE | 1ENE | 2ENE | 3ENE | 3E | 3E | 4E | 3ESE | 1ESE | 0NNW | 0WNW | 0W | 0N | 0NNE | 2ENE |
| 28 | 0NW | 0NNW | 0NNE | 1NW | 2NW | 0N | 0ENE | 2NNE | 2N | 3NNW | 3NNW | 4NNE | 4NNE | 4NE | 2E | 2E | 2E | 0SE | 0SSE | 0S | 0WSW | 1W | 2W | 3W | 2N |
| 29 | 4WSW | 4WSW | 4WSW | 4W | 4W | 4W | 4W | 3W | 3WNW | 3NW | 4NNW | 6NNW | 6NNW | 7NNW | 8NW | 8NW | 7NNW | 6NNW | 5NNW | 5NNW | 4NNW | 4NW | 5NW | 5NW | 5NW |
| 30 | 6NNW | 5NW | 5NW | 4NW | 5NW | 4WNW | 6WNW | 7NW | 7NW | 0N | 7NW | 8NW | 8NNW | 8NNW | 8NNW | 8NNW | 7NNW | 6NNW | 6NNW | 5NNW | 6NNW | 5NNW | 4NNW | 4NW | 6NW |

Monthly Average = 4NNW

Maximum Hourly Average Wind Speed was 11 meters/sec at Hour 13 on Day 10 and Wind Direction was from the NW .

Maximum Daily Average Wind Speed was 7 meters/sec on Day 18 and Wind Direction was from the NW

Operating Efficiency for Wind Speed = 100.0 percent

Operating Efficiency for Wind Direction = 100.0 percent

** = missing or no data

Last Instrument Calibration Date - unknown

[CEM]

MEPA - Kuwait
June 1991
Hourly Averages for Pressure in millibars

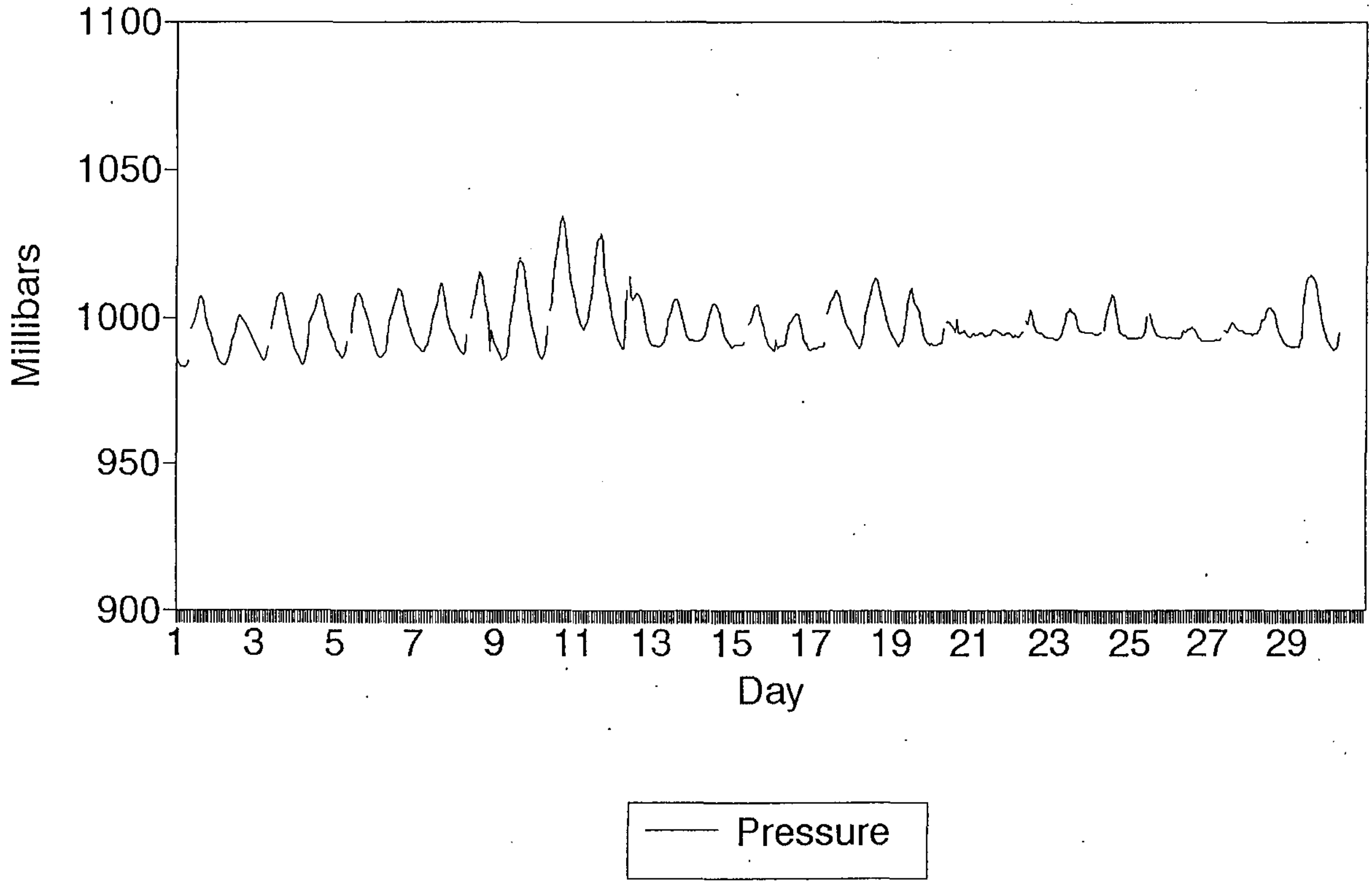
| Day \ Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 986 | 985 | 984 | 983 | 983 | 984 | 984 | 984 | 986 | ND | 997 | 998 | 1001 | 1004 | 1006 | 1007 | 1007 | 1006 | 1003 | 999 | 996 | 994 | 992 | 990 | 993.9 |
| 2 | 989 | 988 | 986 | 985 | 984 | 984 | 984 | 984 | 986 | 989 | 992 | 994 | 996 | 998 | 1000 | 1001 | 1000 | 1000 | 998 | 997 | 996 | 995 | 994 | 993 | 992.2 |
| 3 | 992 | 990 | 989 | 988 | 987 | 986 | 986 | 988 | 990 | ND | 996 | 1000 | 1002 | 1005 | 1007 | 1008 | 1008 | 1007 | 1005 | 1002 | 999 | 997 | 995 | 993 | 996.5 |
| 4 | 991 | 989 | 987 | 986 | 985 | 984 | 985 | 988 | 991 | 998 | 1000 | 1000 | 1002 | 1005 | 1007 | 1008 | 1007 | 1006 | 1003 | 1001 | 999 | 997 | 994 | 993 | 996.1 |
| 5 | 991 | 990 | 988 | 987 | 987 | 987 | 988 | 989 | 994 | 998 | 1000 | 1002 | 1004 | 1006 | 1008 | 1010 | 1009 | 1007 | 1004 | 1002 | 999 | 997 | 996 | 994 | 997.4 |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 7 | 993 | 992 | 991 | 990 | 989 | 988 | 989 | 990 | 991 | 993 | 995 | 998 | 1001 | 1004 | 1006 | 1009 | 1011 | 1011 | 1008 | 1004 | 1001 | 999 | 997 | 995 | 997.7 |
| 8 | 993 | 992 | 990 | 989 | 989 | 988 | 988 | 988 | 994 | ND | 1000 | 1004 | 1006 | 1008 | 1011 | 1014 | 1015 | 1014 | 1010 | 1006 | 1002 | 989 | 996 | 994 | 999.1 |
| 9 | 992 | 990 | 989 | 988 | 986 | 985 | 986 | 987 | 991 | 997 | 1000 | 1004 | 1006 | 1010 | 1015 | 1018 | 1019 | 1018 | 1015 | 1011 | 1007 | 1003 | 1000 | 997 | 1000.6 |
| 10 | 995 | 993 | 990 | 988 | 986 | 986 | 987 | 991 | 997 | ND | 1003 | 1006 | 1012 | 1018 | 1024 | 1029 | 1032 | 1034 | 1033 | 1030 | 1025 | 1020 | 1016 | 1012 | 1009.0 |
| 11 | 1008 | 1005 | 1002 | 1000 | 998 | 997 | 996 | 997 | 998 | 999 | 1004 | 1009 | 1013 | 1020 | 1025 | 1026 | 1027 | 1028 | 1026 | 1018 | 1013 | 1008 | 1005 | 1001 | 1009.3 |
| 12 | 999 | 997 | 995 | 993 | 992 | 990 | 990 | 990 | 1009 | ND | 1014 | 1008 | 1006 | 1007 | 1008 | 1008 | 1008 | 1007 | 1004 | 1000 | 997 | 994 | 993 | 991 | 1000.0 |
| 13 | 991 | 991 | 991 | 991 | 990 | 991 | 991 | 992 | 993 | 995 | 999 | 1001 | 1003 | 1005 | 1006 | 1006 | 1005 | 1003 | 1000 | 998 | 996 | 995 | 993 | 993 | 996.6 |
| 14 | 993 | 993 | 992 | 992 | 992 | 992 | 993 | 993 | 994 | 996 | 998 | 1001 | 1004 | 1005 | 1005 | 1004 | 1003 | 1001 | 998 | 996 | 994 | 993 | 991 | 991 | 996.4 |
| 15 | 990 | 990 | 991 | 991 | 991 | 991 | 991 | 991 | 992 | ND | 998 | 998 | 999 | 1002 | 1004 | 1004 | 1005 | 1003 | 1000 | 997 | 994 | 993 | 991 | 990 | 995.5 |
| 16 | 990 | 989 | 989 | 993 | 990 | 990 | 990 | 991 | 991 | 994 | 997 | 998 | 999 | 999 | 1000 | 1002 | 1001 | 999 | 996 | 993 | 992 | 991 | 990 | 989 | 993.9 |
| 17 | 989 | 990 | 990 | 990 | 990 | 990 | 990 | 990 | 992 | ND | 1001 | 1004 | 1006 | 1008 | 1009 | 1009 | 1008 | 1007 | 1005 | 1002 | 1000 | 998 | 997 | 996 | 998.3 |
| 18 | 995 | 993 | 992 | 991 | 990 | 990 | 991 | 992 | 995 | 1001 | 1005 | 1007 | 1010 | 1011 | 1013 | 1014 | 1013 | 1011 | 1008 | 1005 | 1002 | 1000 | 998 | 997 | 1001.0 |
| 19 | 995 | 994 | 993 | 992 | 991 | 990 | 991 | 992 | 996 | 1000 | 1005 | 1007 | 1010 | 1010 | 1007 | 1005 | 1004 | 1002 | 998 | 996 | 994 | 993 | 992 | 991 | 997.8 |
| 20 | 991 | 991 | 991 | 991 | 991 | 991 | 991 | 991 | 997 | ND | 998 | 999 | 998 | 998 | 997 | 995 | 999 | 996 | 995 | 995 | 995 | 996 | 995 | 994 | 994.6 |
| 21 | 994 | 994 | 995 | 994 | 994 | 994 | 995 | 995 | 995 | 994 | 994 | 994 | 994 | 995 | 996 | 996 | 996 | 995 | 995 | 995 | 995 | 994 | 995 | 995 | 994.7 |
| 22 | 995 | 994 | 994 | 994 | 994 | 994 | 994 | 994 | 996 | ND | 999 | 998 | 1000 | 1003 | 1001 | 998 | 997 | 995 | 995 | 995 | 994 | 994 | 994 | 994 | 995.9 |
| 23 | 993 | 993 | 993 | 993 | 993 | 993 | 993 | 994 | 996 | 997 | 999 | 1002 | 1002 | 1003 | 1002 | 1002 | 1001 | 998 | 996 | 996 | 995 | 995 | 995 | 995 | 996.6 |
| 24 | 995 | 995 | 995 | 994 | 994 | 994 | 995 | 995 | 995 | ND | 996 | 1001 | 1005 | 1006 | 1008 | 1008 | 1005 | 1001 | 997 | 995 | 995 | 994 | 994 | 993 | 997.8 |
| 25 | 993 | 993 | 994 | 993 | 993 | 993 | 994 | 994 | 994 | 994 | 997 | 1001 | ND | 1002 | 999 | 997 | 996 | 995 | 994 | 994 | 994 | 994 | 994 | 993 | 995.0 |
| 26 | 993 | 994 | 994 | 993 | 993 | 993 | 993 | 993 | 994 | 996 | 996 | 995 | 996 | 996 | 996 | 997 | 996 | 995 | 994 | 993 | 993 | 992 | 992 | 992 | 994.1 |
| 27 | 992 | 992 | 992 | 992 | 992 | 993 | 993 | 992 | 993 | ND | 996 | 996 | 995 | 997 | 998 | 999 | 998 | 997 | 996 | 996 | 996 | 996 | 995 | 995 | 994.8 |
| 28 | 995 | 995 | 995 | 995 | 995 | 995 | 995 | 996 | 997 | 999 | 1000 | 1002 | 1003 | 1004 | 1003 | 1003 | 1003 | 1001 | 999 | 996 | 994 | 992 | 992 | 991 | 997.5 |
| 29 | 991 | 991 | 991 | 990 | 990 | 990 | 990 | 990 | 993 | 993 | 1004 | 1009 | 1012 | 1013 | 1014 | 1014 | 1014 | 1013 | 1010 | 1006 | 1003 | 1000 | 998 | 996 | 1000.6 |
| 30 | 994 | 993 | 992 | 990 | 989 | 989 | 990 | 991 | 995 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 991.4 |

Monthly Average = 997.5

Maximum Hourly Average was 1034 at Hour 18 on Day 10 with 1 occurences
Maximum Daily Average was 1009.3 on Day 11 with 1 occurences
Operating Efficiency = 92.9 percent
ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data
[CEM 1990]

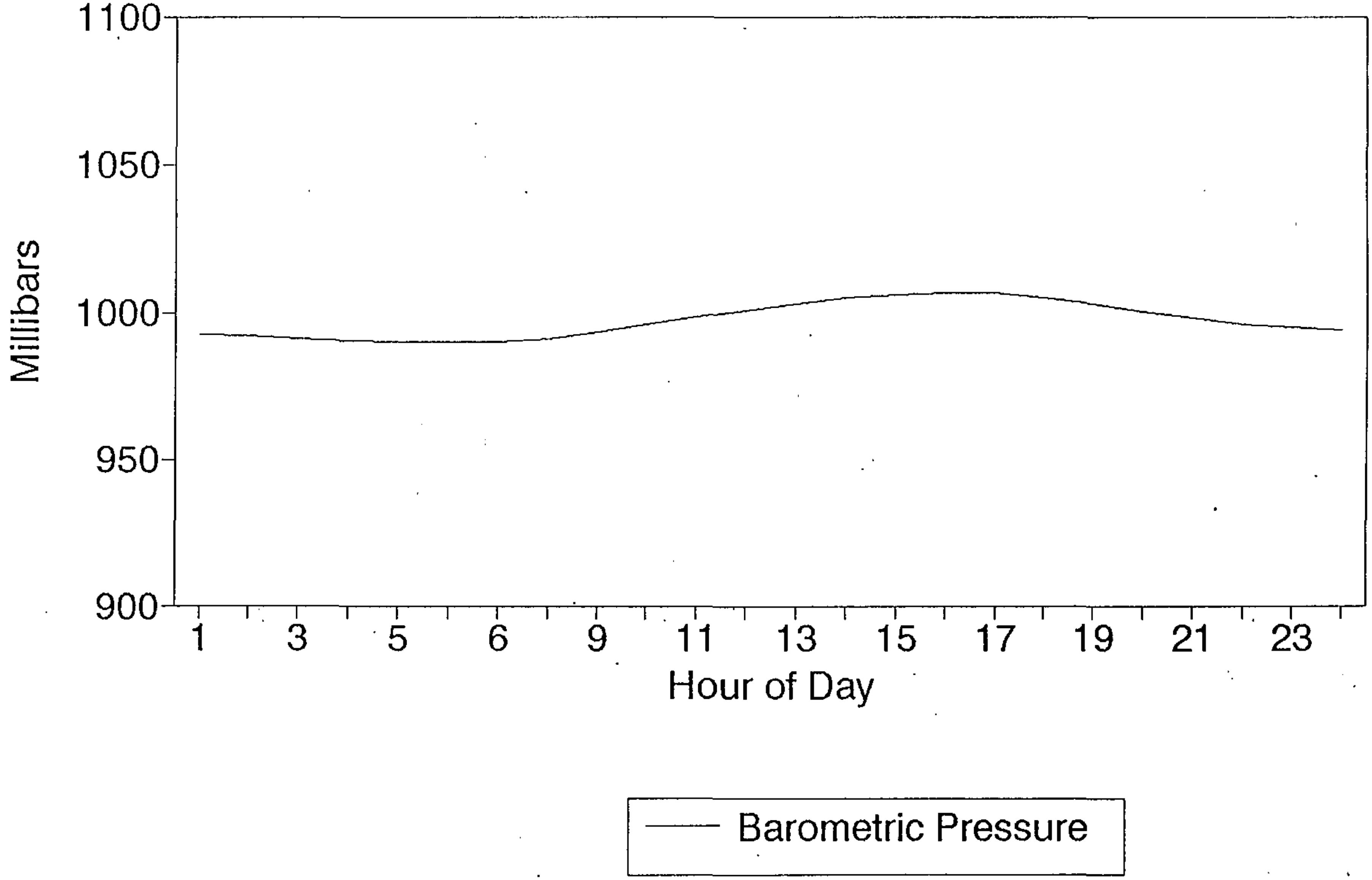
# KUWAIT

Hourly Barometric Pressure – June, 1991



# KUWAIT

Diurnal Pressure – June, 1991



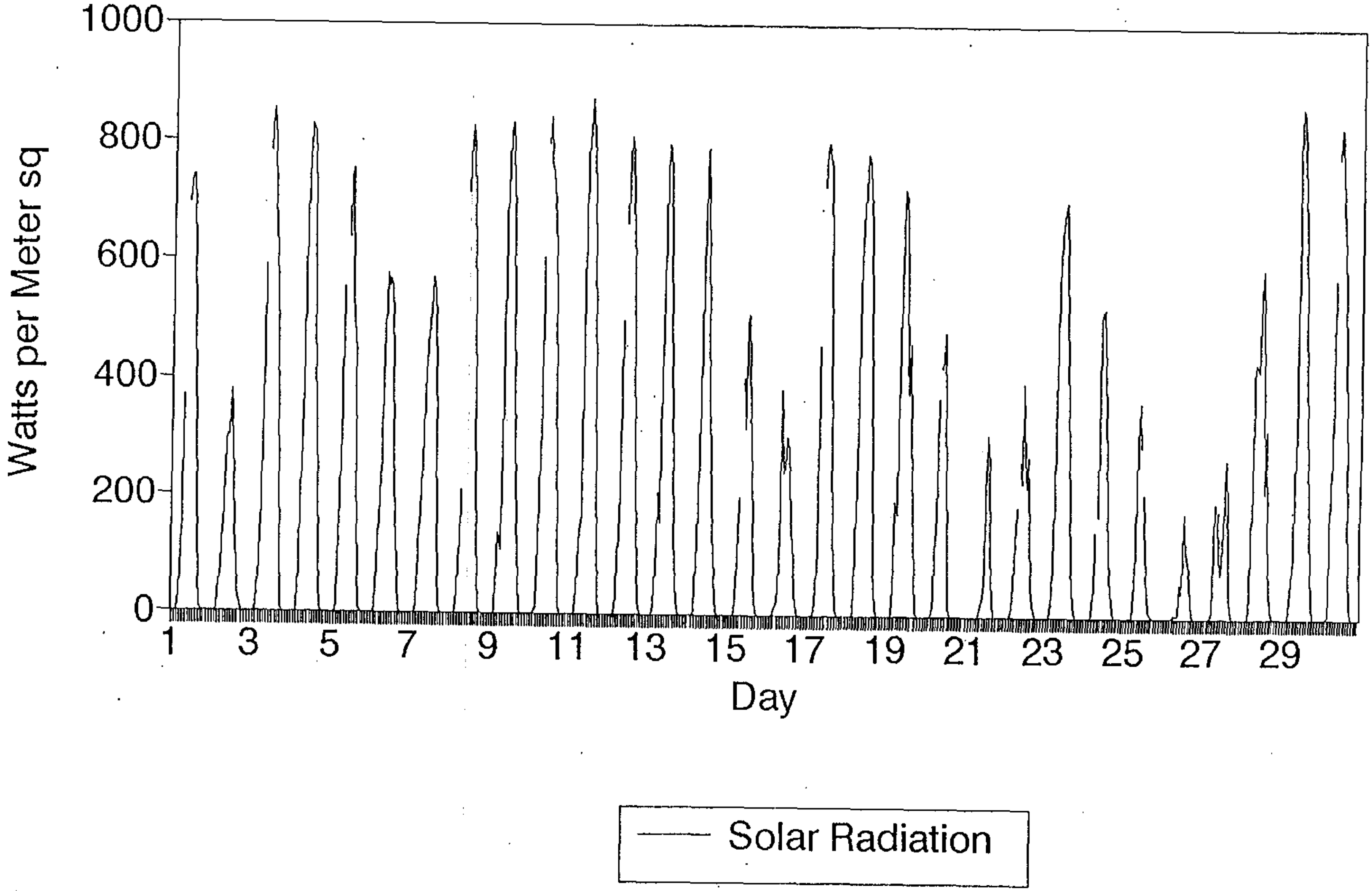
MEPA - Kuwait
June 1991
Hourly Averages for Solar Radiation in Watts/ M2

| Hour / Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 1 | 29 | 70 | 142 | 368 | ND | 692 | 736 | 740 | 622 | 479 | 320 | 185 | 60 | 5 | 0 | 0 | 0 | 0 | 0 | 193.4 |
| 2 | 0 | 0 | 0 | 0 | 4 | 34 | 61 | 76 | 179 | 289 | 299 | 301 | 378 | 340 | 228 | 140 | 78 | 33 | 2 | 0 | 0 | 0 | 0 | 0 | 101.8 |
| 3 | 0 | 0 | 0 | 0 | 13 | 85 | 193 | 313 | 589 | ND | 780 | 843 | 852 | 798 | 703 | 560 | 357 | 109 | 8 | 0 | 0 | 0 | 0 | 0 | 269.7 |
| 4 | 0 | 0 | 0 | 0 | 11 | 78 | 201 | 293 | 565 | 666 | 775 | 827 | 813 | 716 | 486 | 356 | 232 | 86 | 6 | 0 | 0 | 0 | 0 | 0 | 254.6 |
| 5 | 0 | 0 | 0 | 0 | 12 | 85 | 196 | 265 | 434 | 517 | 575 | 554 | 568 | 552 | 443 | 270 | 119 | 50 | 5 | 0 | 0 | 0 | 0 | 0 | 193.5 |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 7 | 0 | 0 | 0 | 0 | 11 | 59 | 153 | 167 | 248 | 307 | 417 | 457 | 488 | 571 | 547 | 494 | 327 | 129 | 11 | 0 | 0 | 0 | 0 | 0 | 182.8 |
| 8 | 0 | 0 | 0 | 0 | 5 | 36 | 90 | 117 | 208 | ND | 714 | 803 | 825 | 788 | 688 | 550 | 323 | 121 | 10 | 0 | 0 | 0 | 0 | 0 | 229.5 |
| 9 | 0 | 0 | 0 | 0 | 6 | 59 | 137 | 105 | 405 | 661 | 757 | 815 | 830 | 783 | 677 | 501 | 284 | 99 | 7 | 0 | 0 | 0 | 0 | 0 | 255.3 |
| 10 | 0 | 0 | 0 | 0 | 13 | 63 | 204 | 327 | 603 | ND | 797 | 840 | 763 | 748 | 670 | 548 | 369 | 158 | 11 | 0 | 0 | 0 | 0 | 0 | 265.8 |
| 11 | 0 | 0 | 0 | 0 | 6 | 39 | 121 | 135 | 170 | 521 | 776 | 841 | 872 | 812 | 724 | 599 | 415 | 206 | 29 | 0 | 0 | 0 | 0 | 0 | 261.1 |
| 12 | 0 | 0 | 0 | 0 | 1 | 30 | 107 | 124 | 497 | ND | 662 | 729 | 805 | 780 | 704 | 592 | 425 | 203 | 19 | 0 | 0 | 0 | 0 | 0 | 246.9 |
| 13 | 0 | 0 | 0 | 0 | 18 | 112 | 207 | 155 | 308 | 509 | 660 | 795 | 781 | 752 | 499 | 273 | 130 | 49 | 7 | 0 | 0 | 0 | 0 | 0 | 219.0 |
| 14 | 0 | 0 | 0 | 0 | 5 | 53 | 125 | 183 | 351 | 572 | 677 | 788 | 515 | 353 | 292 | 186 | 97 | 28 | 3 | 0 | 0 | 0 | 0 | 0 | 176.2 |
| 15 | 0 | 0 | 0 | 0 | 0 | 4 | 26 | 95 | 199 | ND | 402 | 315 | 494 | 511 | 423 | 295 | 163 | 50 | 5 | 0 | 0 | 0 | 0 | 0 | 129.7 |
| 16 | 0 | 0 | 0 | 0 | 0 | 7 | 24 | 47 | 142 | 384 | 258 | 244 | 272 | 302 | 281 | 168 | 92 | 36 | 7 | 0 | 0 | 0 | 0 | 0 | 94.3 |
| 17 | 0 | 0 | 0 | 0 | 1 | 23 | 47 | 112 | 459 | ND | 726 | 792 | 799 | 756 | 602 | 289 | 131 | 56 | 9 | 0 | 0 | 0 | 0 | 0 | 208.8 |
| 18 | 0 | 0 | 0 | 0 | 4 | 51 | 184 | 211 | 516 | 630 | 719 | 781 | 768 | 718 | 665 | 495 | 266 | 82 | 11 | 0 | 0 | 0 | 0 | 0 | 254.2 |
| 19 | 0 | 0 | 0 | 0 | 5 | 47 | 194 | 169 | 448 | 628 | 720 | 705 | 673 | 437 | 379 | 463 | 301 | 68 | 7 | 0 | 0 | 0 | 0 | 0 | 218.5 |
| 20 | 0 | 0 | 0 | 0 | 3 | 33 | 110 | 148 | 370 | ND | 421 | 441 | 481 | 346 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 102.9 |
| 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 15 | 35 | 58 | 203 | 307 | 261 | 102 | 28 | 0 | 0 | 0 | 0 | 0 | 0 | 42.3 |
| 22 | 0 | 0 | 0 | 0 | 0 | 16 | 55 | 94 | 187 | ND | 265 | 227 | 397 | 270 | 219 | 271 | 146 | 48 | 8 | 0 | 0 | 0 | 0 | 0 | 95.8 |
| 23 | 0 | 0 | 0 | 0 | 2 | 38 | 142 | 202 | 450 | 558 | 649 | 657 | 687 | 701 | 585 | 363 | 200 | 84 | 20 | 0 | 0 | 0 | 0 | 0 | 222.4 |
| 24 | 0 | 0 | 0 | 0 | 0 | 6 | 25 | 48 | 145 | ND | 169 | 508 | 525 | 421 | 342 | 200 | 100 | 43 | 9 | 0 | 0 | 0 | 0 | 0 | 110.5 |
| 25 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 23 | 60 | 299 | 365 | 289 | ND | 210 | 113 | 71 | 9 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 62.8 |
| 26 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 7 | 3 | 3 | 8 | 59 | 41 | 95 | 178 | 109 | 83 | 29 | 5 | 0 | 0 | 0 | 0 | 0 | 25.9 |
| 27 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 61 | 195 | ND | 182 | 101 | 73 | 149 | 269 | 249 | 127 | 30 | 4 | 0 | 0 | 0 | 0 | 0 | 63.1 |
| 28 | 0 | 0 | 0 | 0 | 2 | 37 | 141 | 216 | 408 | 433 | 419 | 552 | 592 | 408 | 213 | 322 | 133 | 49 | 14 | 0 | 0 | 0 | 0 | 0 | 164.1 |
| 29 | 0 | 0 | 0 | 0 | 0 | 16 | 46 | 103 | 230 | 321 | 788 | 863 | 852 | 779 | 668 | 503 | 325 | 144 | 24 | 0 | 0 | 0 | 0 | 0 | 235.9 |
| 30 | 0 | 0 | 0 | 0 | 3 | 42 | 236 | 236 | 575 | ND | 782 | 830 | 813 | 709 | 566 | 435 | 265 | 90 | 12 | 0 | 0 | 0 | 0 | 0 | 243.2 |
| Monthly Average = | | | | | | | | | | | | | | | | | | | | | | | | | 176.8 |

Maximum Hourly Average was 872 at Hour 13 on Day 11 with 1 occurences
Maximum Daily Average was 269.7 on Day 3 with 1 occurences
Operating Efficiency = 94.9 percent
ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data
[CEM 1990]

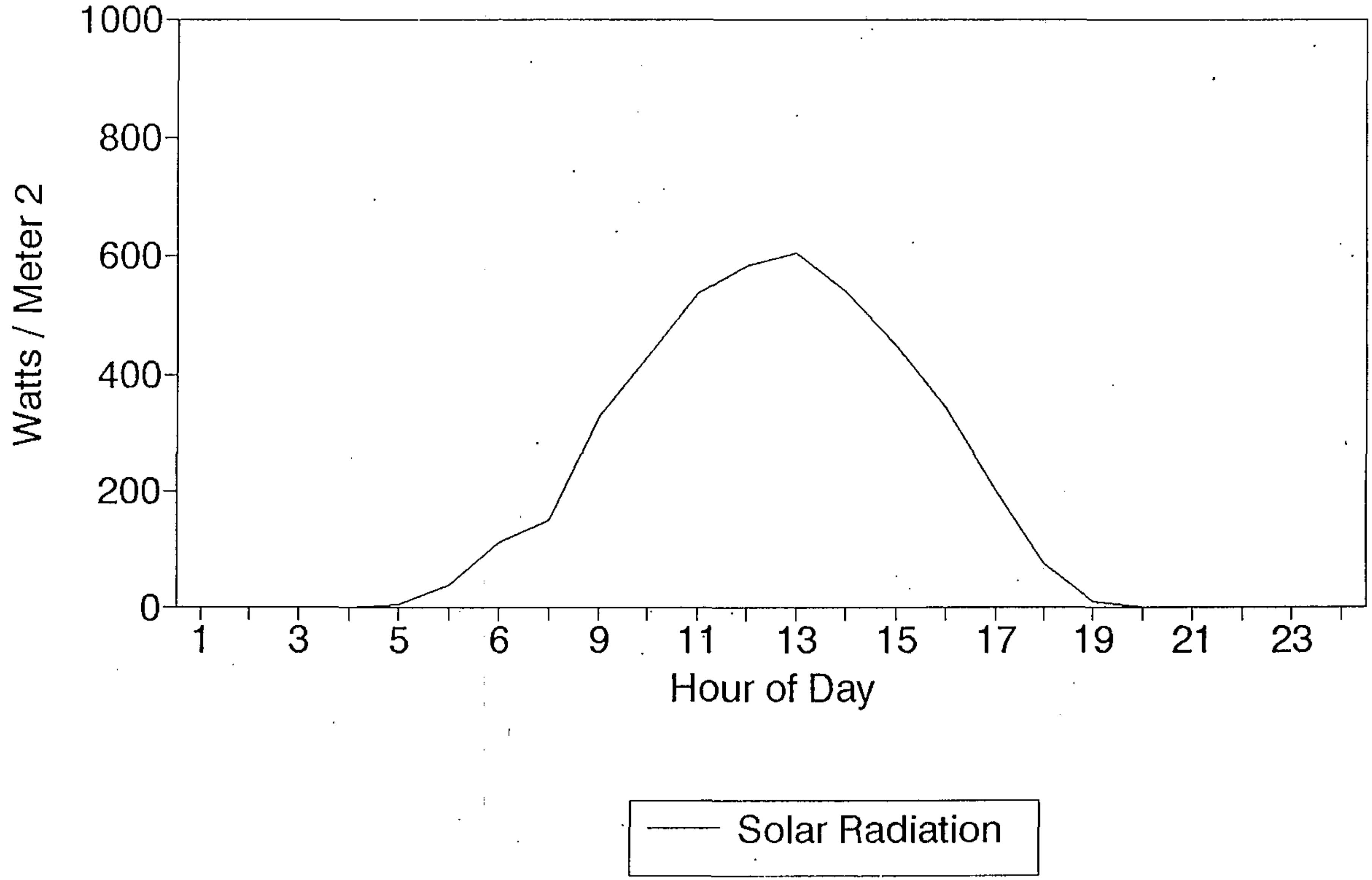
# KUWAIT

## Hourly Solar Radiation – June, 1991



# KUWAIT

Diurnal Radiation - June, 1991



MEPA - Kuwait

June 1991

Hourly Averages for Relative Humidity in Per Cent

| Day \ Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 18.5 | 18.8 | 19.2 | 19.6 | 19.5 | 19.3 | 19.6 | 19.4 | 18.1 | ND | 15.6 | 14.5 | 13.5 | 12.9 | 12.0 | 12.0 | 12.6 | 13.1 | 14.1 | 14.8 | 15.2 | 15.6 | 16.4 | 17.3 | 16.16 |
| 2 | 18.1 | 19.2 | 20.3 | 20.0 | 19.9 | 21.2 | 20.8 | 19.8 | 18.4 | 17.5 | 16.9 | 16.7 | 16.3 | 14.6 | 13.6 | 13.1 | 13.3 | 13.7 | 14.6 | 15.0 | 15.2 | 15.8 | 16.5 | 17.9 | 17.02 |
| 3 | 18.9 | 19.9 | 20.7 | 21.0 | 21.7 | 21.6 | 20.1 | 18.7 | 17.6 | ND | 15.3 | 14.3 | 13.1 | 12.2 | 11.2 | 10.5 | 11.0 | 12.4 | 13.3 | 13.9 | 14.4 | 14.8 | 15.2 | 16.1 | 16.00 |
| 4 | 16.7 | 17.3 | 17.8 | 18.2 | 18.1 | 17.5 | 17.1 | 16.2 | 15.5 | 14.9 | 14.0 | 13.0 | 12.4 | 12.3 | 12.1 | 12.2 | 12.4 | 14.1 | 14.6 | 14.6 | 14.7 | 15.3 | 15.6 | 15.9 | 15.10 |
| 5 | 16.8 | 17.3 | 17.6 | 18.0 | 18.2 | 18.3 | 18.1 | 17.7 | 17.0 | 16.1 | 15.1 | 14.3 | 13.4 | 13.0 | 13.0 | 13.8 | 14.7 | 15.7 | 16.4 | 16.8 | 17.3 | 18.2 | 18.7 | 19.3 | 16.45 |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 7 | 20.4 | 21.6 | 22.4 | 22.6 | 23.1 | 23.1 | 22.3 | 21.7 | 20.8 | 19.2 | 17.7 | 16.7 | 15.9 | 15.2 | 14.5 | 14.3 | 14.2 | 14.4 | 15.7 | 17.1 | 18.7 | 19.4 | 20.4 | 21.3 | 18.86 |
| 8 | 21.6 | 22.4 | 23.0 | 24.0 | 25.0 | 24.5 | 22.9 | 22.2 | 20.7 | ND | 15.4 | 13.5 | 11.8 | 10.6 | 10.3 | 10.1 | 10.5 | 11.6 | 12.8 | 13.4 | 13.9 | 15.2 | 15.6 | 16.5 | 16.85 |
| 9 | 17.2 | 18.1 | 18.5 | 19.2 | 20.0 | 19.4 | 17.7 | 16.8 | 16.1 | 15.0 | 13.7 | 11.8 | 10.6 | 10.1 | 10.1 | 10.1 | 10.1 | 10.5 | 11.6 | 12.4 | 13.6 | 14.5 | 15.4 | 15.6 | 14.50 |
| 10 | 15.8 | 16.2 | 16.3 | 16.5 | 16.6 | 16.3 | 15.6 | 14.9 | 14.3 | ND | 12.7 | 11.3 | 10.2 | 10.1 | 10.1 | 10.1 | 10.1 | 10.1 | 10.8 | 11.5 | 12.2 | 12.6 | 13.4 | 14.1 | 13.12 |
| 11 | 14.8 | 15.5 | 16.1 | 16.8 | 18.6 | 19.8 | 20.2 | 19.3 | 18.9 | 17.9 | 14.5 | 12.5 | 11.3 | 10.5 | 10.2 | 10.1 | 10.1 | 10.6 | 11.9 | 12.9 | 13.4 | 14.0 | 14.5 | 15.3 | 14.57 |
| 12 | 16.1 | 17.0 | 17.7 | 18.2 | 18.9 | 18.8 | 19.1 | 18.6 | 17.0 | ND | 15.3 | 14.6 | 14.2 | 13.9 | 13.6 | 12.8 | 12.6 | 12.7 | 14.9 | 16.3 | 17.4 | 18.1 | 18.8 | 19.8 | 16.37 |
| 13 | 21.2 | 21.2 | 21.2 | 21.8 | 22.6 | 23.3 | 22.0 | 20.4 | 19.7 | 18.4 | 17.0 | 16.1 | 15.1 | 14.7 | 14.4 | 14.9 | 16.4 | 18.9 | 18.3 | 18.2 | 18.0 | 18.2 | 19.0 | 19.3 | 18.76 |
| 14 | 19.8 | 19.5 | 20.4 | 20.9 | 21.5 | 21.3 | 21.2 | 19.9 | 18.9 | 17.3 | 15.6 | 12.7 | 12.0 | 13.5 | 14.1 | 13.7 | 13.9 | 13.1 | 13.7 | 13.7 | 13.8 | 14.9 | 15.5 | 15.6 | 16.52 |
| 15 | 15.6 | 15.7 | 15.7 | 16.6 | 16.9 | 17.0 | 17.0 | 17.0 | 16.3 | ND | 14.6 | 14.5 | 13.2 | 12.1 | 12.2 | 11.0 | 10.7 | 10.9 | 11.6 | 12.2 | 12.9 | 13.7 | 14.4 | 14.6 | 14.19 |
| 16 | 18.8 | 14.9 | 14.6 | 14.9 | 14.8 | 14.7 | 14.7 | 14.7 | 14.3 | 13.9 | 13.7 | 13.4 | 13.4 | 13.2 | 12.6 | 12.4 | 12.7 | 13.3 | 14.2 | 14.7 | 14.9 | 15.2 | 15.7 | 16.3 | 14.42 |
| 17 | 17.8 | 18.5 | 19.1 | 19.2 | 19.0 | 19.1 | 18.9 | 18.7 | 17.1 | ND | 13.9 | 12.4 | 11.7 | 10.8 | 10.3 | 11.0 | 11.9 | 12.7 | 13.3 | 13.3 | 13.6 | 14.0 | 13.6 | 13.6 | 14.93 |
| 18 | 13.6 | 13.9 | 14.1 | 14.5 | 14.8 | 14.9 | 14.6 | 14.3 | 14.0 | 13.1 | 12.4 | 12.6 | 12.2 | 11.6 | 10.5 | 10.3 | 10.7 | 11.3 | 11.8 | 13.2 | 12.9 | 12.5 | 12.8 | 13.5 | 12.92 |
| 19 | 14.2 | 14.7 | 14.9 | 15.0 | 15.3 | 15.3 | 15.1 | 14.9 | 14.9 | 14.8 | 14.4 | 13.7 | 13.7 | 14.7 | 17.4 | 18.3 | 18.0 | 18.6 | 18.6 | 18.5 | 18.5 | 18.9 | 19.2 | 19.0 | 16.27 |
| 20 | 18.9 | 19.0 | 20.0 | 20.1 | 19.4 | 19.3 | 19.2 | 18.9 | 18.1 | ND | 17.4 | 18.8 | 22.3 | 21.3 | 25.2 | 37.1 | 43.0 | 42.1 | 43.1 | 36.5 | 26.9 | 22.1 | 21.5 | 22.0 | 24.88 |
| 21 | 21.9 | 21.9 | 22.7 | 33.6 | 36.0 | 30.0 | 25.5 | 22.3 | 23.2 | 23.5 | 22.9 | 23.6 | 29.0 | 31.2 | 27.1 | 22.8 | 22.9 | 23.4 | 23.4 | 23.1 | 21.7 | 21.2 | 24.8 | 25.2 | 25.12 |
| 22 | 25.2 | 26.9 | 27.9 | 28.5 | 39.0 | 52.7 | 50.1 | 31.8 | 23.9 | ND | 32.3 | 40.7 | 34.0 | 30.3 | 53.1 | 58.7 | 65.5 | 62.9 | 67.3 | 85.8 | 86.2 | 89.2 | 91.6 | 93.3 | 52.04 |
| 23 | 94.2 | 94.3 | 94.4 | 94.6 | 94.6 | 93.7 | 93.6 | 87.0 | 58.1 | 55.4 | 46.7 | 43.3 | 44.1 | 43.1 | 38.8 | 32.7 | 41.1 | 43.9 | 48.1 | 52.7 | 53.6 | 49.8 | 45.4 | 58.9 | 62.59 |
| 24 | 59.7 | 56.8 | 60.1 | 64.2 | 53.2 | 42.9 | 36.5 | 34.1 | 27.1 | ND | 21.1 | 19.5 | 23.3 | 13.8 | 22.9 | 33.7 | 29.9 | 47.7 | 50.0 | 37.3 | 27.9 | 25.7 | 26.6 | 23.3 | 36.40 |
| 25 | 19.7 | 17.8 | 34.6 | 49.9 | 39.9 | 26.2 | 23.7 | 22.4 | 19.3 | 16.1 | 12.5 | 13.5 | ND | 30.1 | 30.5 | 28.4 | 27.8 | 27.2 | 25.5 | 23.7 | 20.4 | 19.2 | 19.9 | 21.2 | 24.76 |
| 26 | 20.3 | 23.4 | 53.6 | 50.6 | 46.7 | 51.5 | 57.4 | 48.3 | 66.2 | 86.1 | 84.3 | 76.4 | 67.8 | 66.6 | 56.8 | 57.2 | 60.8 | 56.9 | 59.0 | 52.3 | 48.1 | 58.2 | 61.2 | 69.9 | 57.48 |
| 27 | 76.6 | 82.7 | 81.6 | 78.1 | 86.3 | 84.6 | 84.5 | 85.0 | 82.6 | ND | 63.9 | 65.5 | 70.0 | 72.4 | 59.8 | 58.6 | 59.4 | 73.5 | 76.4 | 75.5 | 72.6 | 67.7 | 69.1 | 74.9 | 73.97 |
| 28 | 76.9 | 68.5 | 78.4 | 85.9 | 81.1 | 85.6 | 84.4 | 69.9 | 45.0 | 39.1 | 29.0 | 24.7 | 21.3 | 19.6 | 24.0 | 21.8 | 21.2 | 19.7 | 19.4 | 20.9 | 21.2 | 20.9 | 21.1 | 22.8 | 42.60 |
| 29 | 23.5 | 22.6 | 21.8 | 22.0 | 20.8 | 20.2 | 20.0 | 19.4 | 17.9 | 16.4 | 12.8 | 10.1 | 10.1 | 10.1 | 10.1 | 10.1 | 10.1 | 10.1 | 10.1 | 10.1 | 10.2 | 11.3 | 11.6 | 12.9 | 14.76 |
| 30 | 13.3 | 14.1 | 14.8 | 15.9 | 17.1 | 17.5 | 16.4 | 15.9 | 15.1 | ND | 12.5 | 10.4 | 10.1 | 10.1 | 10.1 | 10.1 | 10.2 | 10.1 | 10.3 | 10.1 | 10.1 | 11.1 | 12.4 | 12.9 | 12.63 |

Monthly Average = 24.47

Maximum Hourly Average was 94.6 at Hour 4 on Day 23 with 2 occurences

Maximum Daily Average was 73.97 on Day 27 with 1 occurences

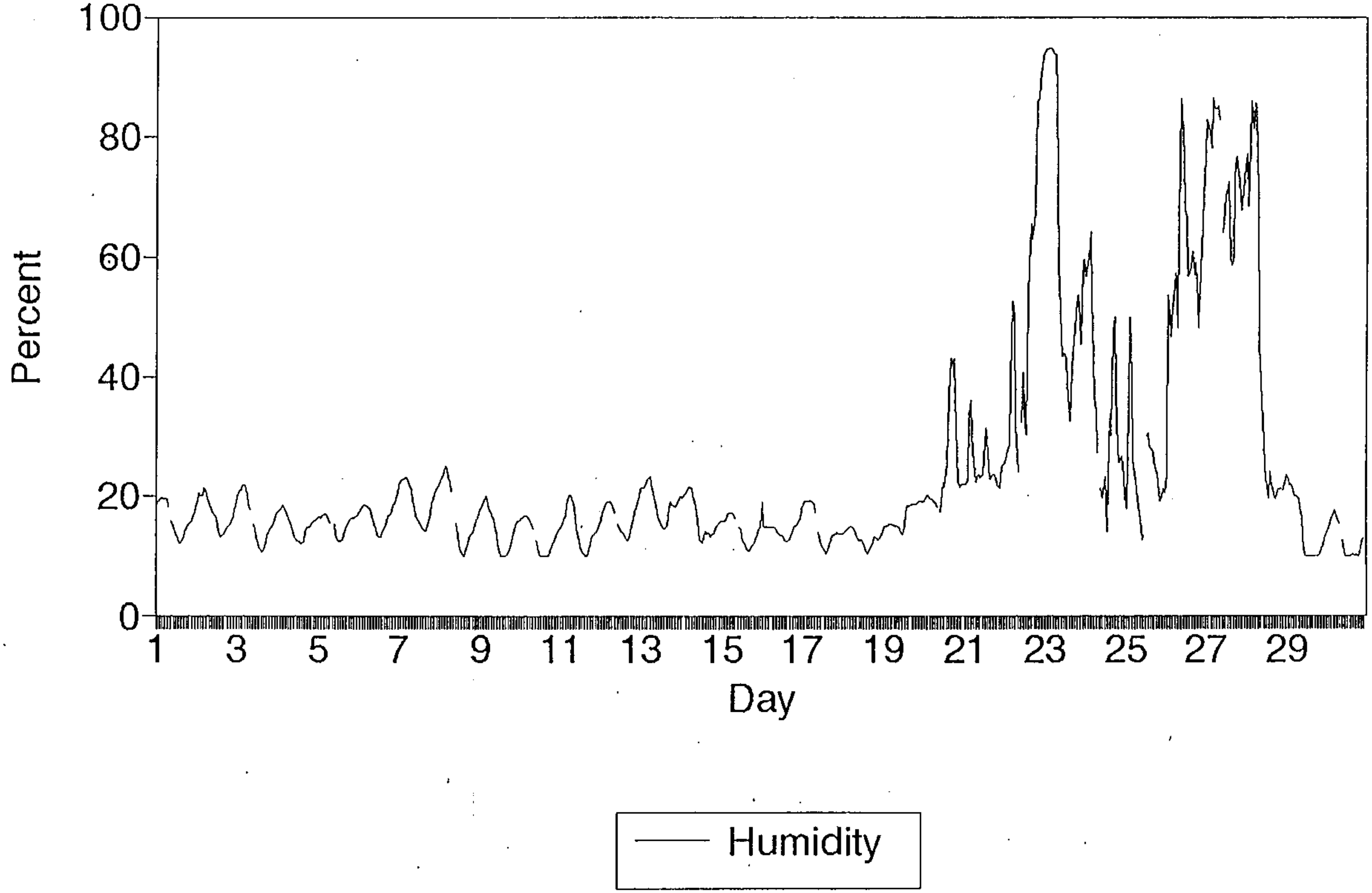
Operating Efficiency = 94.9 percent

ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data

[CEM 1990]

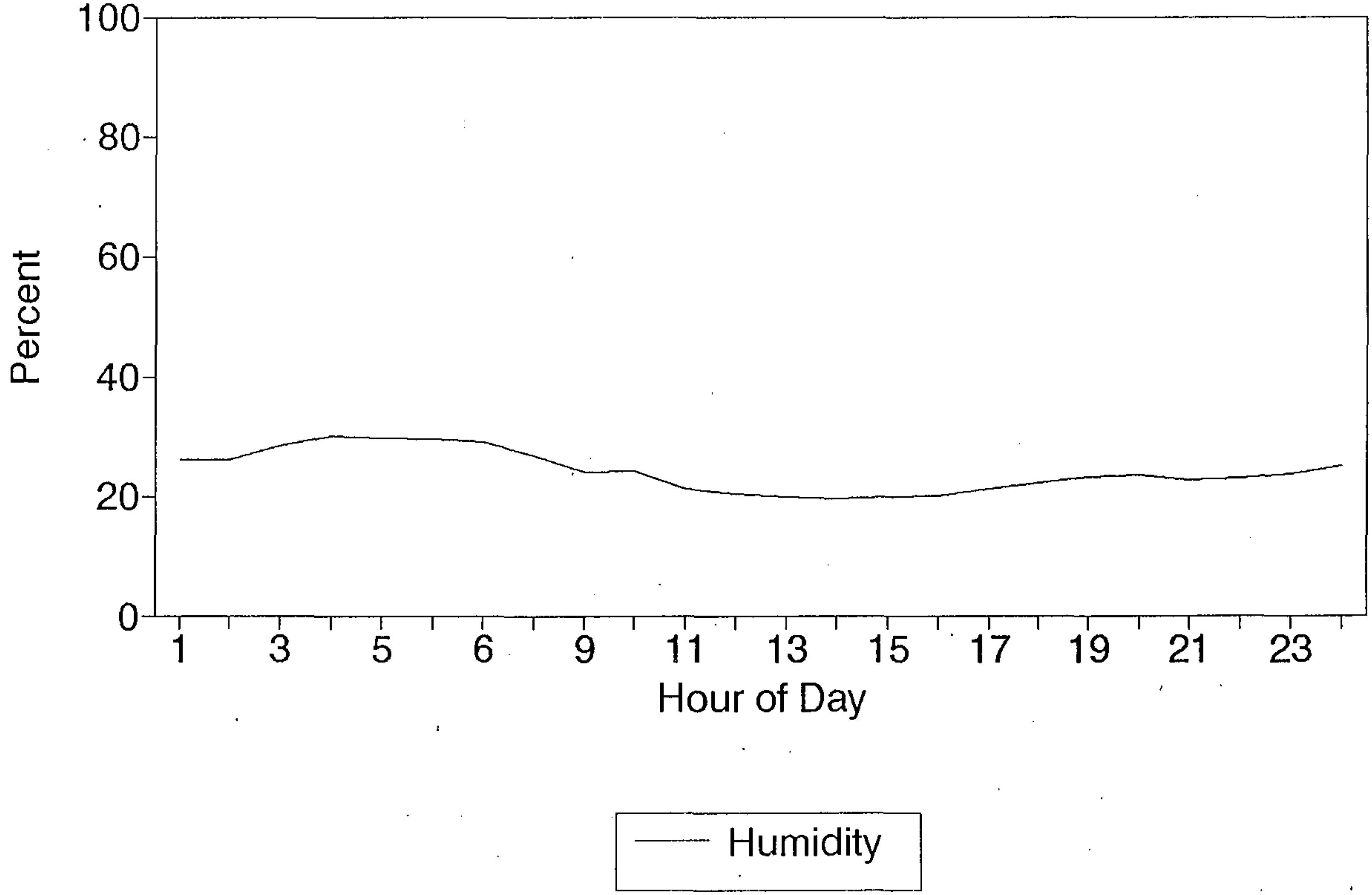
# KUWAIT

Hourly Humidity - June, 1991



# KUWAIT

Diurnal Humidity - June, 1991



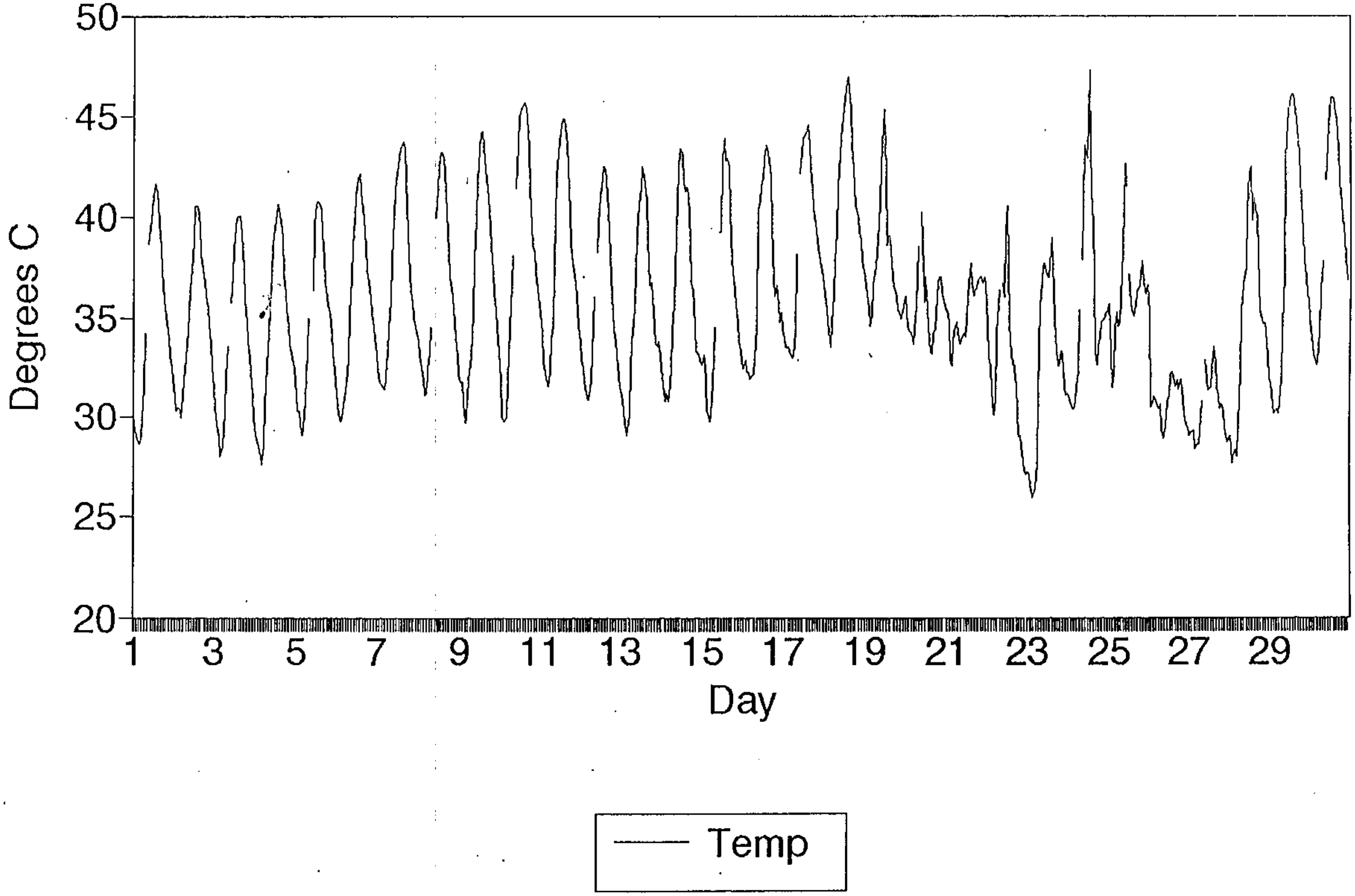
MEPA - Kuwait
June 1991
Hourly Averages for Temperature in Degrees C

| Day \ Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 30.1 | 29.6 | 29.1 | 28.9 | 28.6 | 28.9 | 29.9 | 31.5 | 34.2 | ND | 38.7 | 39.8 | 41.0 | 41.6 | 41.5 | 40.7 | 39.7 | 38.5 | 37.3 | 35.9 | 35.1 | 34.0 | 33.1 | 32.5 | 34.79 |
| 2 | 32.0 | 31.0 | 30.3 | 30.5 | 30.4 | 29.9 | 31.0 | 31.9 | 33.6 | 35.2 | 36.5 | 37.4 | 38.8 | 40.5 | 40.5 | 40.5 | 39.6 | 38.2 | 36.8 | 36.2 | 35.5 | 34.7 | 33.7 | 32.6 | 34.89 |
| 3 | 31.5 | 30.4 | 29.6 | 29.0 | 28.0 | 28.5 | 30.3 | 32.1 | 33.6 | ND | 35.8 | 37.2 | 38.4 | 39.5 | 40.0 | 40.1 | 39.2 | 37.4 | 35.9 | 34.8 | 33.9 | 33.0 | 32.3 | 31.1 | 33.98 |
| 4 | 29.9 | 29.1 | 28.5 | 28.0 | 27.6 | 28.6 | 30.6 | 32.7 | 34.3 | 35.5 | 37.2 | 38.7 | 39.8 | 40.6 | 40.4 | 39.8 | 39.0 | 37.2 | 36.2 | 35.4 | 34.6 | 33.7 | 33.0 | 32.5 | 34.29 |
| 5 | 31.7 | 30.6 | 30.1 | 29.8 | 29.9 | 30.6 | 31.7 | 33.0 | 35.2 | 37.0 | 38.6 | 40.0 | 41.0 | 41.9 | 42.1 | 41.2 | 39.9 | 38.5 | 37.4 | 36.8 | 36.0 | 35.2 | 34.5 | 34.0 | 35.70 |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 7 | 33.2 | 32.4 | 31.7 | 31.6 | 31.4 | 32.1 | 33.4 | 34.5 | 35.9 | 37.9 | 40.0 | 41.3 | 42.2 | 43.3 | 43.6 | 43.7 | 43.3 | 41.8 | 39.2 | 37.2 | 36.3 | 35.8 | 35.0 | 34.3 | 37.13 |
| 8 | 33.8 | 33.1 | 32.5 | 31.9 | 31.1 | 31.2 | 32.4 | 33.3 | 34.5 | ND | 39.9 | 41.4 | 42.4 | 43.2 | 43.2 | 42.9 | 42.2 | 40.2 | 38.3 | 37.1 | 36.1 | 34.8 | 34.1 | 33.1 | 36.64 |
| 9 | 32.2 | 31.7 | 31.8 | 30.7 | 29.7 | 30.0 | 32.0 | 33.1 | 35.2 | 37.9 | 39.9 | 41.8 | 43.3 | 44.1 | 44.2 | 43.4 | 42.3 | 40.9 | 39.5 | 38.5 | 37.3 | 36.2 | 35.4 | 34.5 | 36.90 |
| 10 | 33.3 | 32.0 | 29.9 | 29.8 | 30.0 | 31.9 | 34.5 | 36.7 | 38.1 | ND | 41.4 | 43.6 | 44.9 | 45.4 | 45.7 | 45.4 | 44.9 | 43.4 | 41.3 | 39.6 | 38.6 | 38.3 | 37.3 | 36.5 | 38.37 |
| 11 | 35.2 | 34.2 | 32.8 | 32.3 | 32.0 | 31.6 | 32.3 | 34.1 | 34.6 | 37.6 | 42.0 | 43.7 | 44.2 | 44.8 | 44.8 | 44.4 | 43.6 | 42.4 | 40.2 | 38.7 | 37.7 | 36.7 | 35.4 | 34.6 | 37.91 |
| 12 | 33.8 | 32.9 | 32.5 | 31.8 | 31.2 | 30.9 | 31.1 | 31.9 | 36.0 | ND | 38.3 | 39.7 | 41.0 | 41.9 | 42.5 | 42.3 | 41.7 | 40.4 | 37.0 | 35.3 | 34.4 | 33.8 | 33.1 | 32.1 | 35.90 |
| 13 | 31.6 | 31.1 | 30.9 | 29.8 | 29.1 | 30.1 | 32.7 | 34.6 | 34.5 | 37.2 | 39.2 | 40.6 | 41.4 | 42.5 | 42.0 | 40.8 | 38.9 | 36.6 | 36.8 | 36.0 | 34.6 | 33.7 | 33.6 | 33.8 | 35.50 |
| 14 | 33.1 | 32.5 | 30.8 | 31.2 | 30.8 | 31.1 | 32.4 | 34.4 | 35.7 | 39.1 | 41.0 | 43.3 | 43.1 | 41.6 | 41.2 | 41.5 | 41.1 | 38.9 | 36.7 | 36.3 | 35.6 | 33.4 | 33.1 | 32.9 | 36.28 |
| 15 | 32.7 | 33.1 | 32.9 | 30.3 | 30.2 | 29.8 | 30.1 | 31.7 | 34.5 | ND | 39.2 | 39.3 | 42.9 | 43.9 | 42.7 | 42.9 | 42.4 | 40.2 | 37.9 | 36.3 | 35.7 | 34.8 | 33.8 | 33.4 | 36.12 |
| 16 | 32.4 | 32.6 | 32.9 | 32.3 | 32.3 | 32.0 | 32.2 | 33.0 | 34.5 | 40.4 | 40.8 | 41.5 | 41.9 | 42.9 | 43.5 | 43.1 | 41.9 | 39.6 | 36.9 | 36.1 | 36.6 | 35.7 | 34.8 | 35.3 | 36.88 |
| 17 | 34.4 | 34.0 | 33.5 | 33.5 | 33.2 | 33.0 | 33.1 | 34.3 | 38.2 | ND | 42.1 | 43.2 | 43.8 | 44.3 | 44.5 | 43.6 | 42.4 | 41.3 | 40.4 | 39.7 | 38.9 | 38.4 | 37.8 | 37.1 | 38.47 |
| 18 | 36.6 | 35.8 | 35.4 | 34.3 | 33.5 | 34.8 | 36.2 | 37.8 | 39.3 | 41.5 | 43.9 | 44.9 | 45.8 | 46.4 | 46.9 | 46.4 | 45.3 | 43.6 | 42.3 | 40.5 | 39.9 | 39.2 | 38.8 | 37.8 | 40.29 |
| 19 | 37.3 | 37.0 | 36.2 | 35.5 | 34.6 | 35.1 | 36.6 | 37.6 | 38.9 | 40.7 | 42.4 | 44.5 | 45.3 | 42.1 | 38.6 | 39.1 | 39.0 | 36.5 | 36.5 | 36.0 | 35.4 | 35.2 | 34.9 | 35.3 | 37.93 |
| 20 | 35.7 | 36.1 | 34.6 | 34.4 | 34.2 | 33.7 | 34.4 | 35.6 | 38.5 | ND | 40.2 | 38.9 | 35.8 | 37.1 | 34.6 | 33.3 | 33.2 | 34.3 | 34.4 | 35.3 | 36.8 | 37.0 | 37.0 | 36.2 | 35.71 |
| 21 | 35.4 | 35.4 | 34.8 | 32.9 | 32.6 | 33.9 | 34.6 | 34.8 | 34.2 | 33.7 | 33.9 | 34.2 | 34.1 | 35.2 | 36.8 | 37.7 | 36.8 | 36.1 | 36.4 | 36.5 | 36.9 | 37.1 | 36.7 | 37.0 | 35.32 |
| 22 | 36.6 | 34.7 | 33.0 | 32.6 | 31.3 | 30.1 | 30.9 | 34.3 | 36.4 | ND | 36.7 | 36.0 | 39.4 | 40.5 | 34.8 | 33.8 | 32.7 | 32.9 | 31.6 | 29.0 | 29.1 | 28.5 | 27.8 | 27.3 | 33.04 |
| 23 | 27.1 | 27.3 | 27.1 | 26.6 | 26.0 | 26.4 | 27.7 | 31.2 | 35.7 | 36.1 | 37.6 | 37.7 | 37.3 | 37.0 | 37.0 | 39.0 | 36.3 | 34.9 | 33.3 | 32.6 | 32.8 | 33.4 | 33.2 | 31.6 | 32.70 |
| 24 | 31.1 | 31.2 | 30.7 | 30.4 | 30.4 | 30.8 | 31.6 | 32.3 | 35.4 | ND | 37.9 | 43.5 | 42.9 | 47.2 | 43.2 | 40.1 | 40.1 | 33.3 | 32.7 | 33.6 | 34.1 | 34.8 | 34.9 | 35.3 | 35.54 |
| 25 | 35.3 | 35.7 | 33.3 | 31.5 | 32.2 | 34.5 | 35.3 | 34.6 | 34.8 | 38.4 | 42.6 | 41.5 | ND | 37.2 | 35.7 | 35.4 | 35.1 | 35.6 | 36.3 | 36.6 | 37.8 | 37.4 | 36.3 | 36.2 | 36.06 |
| 26 | 36.6 | 35.3 | 30.5 | 30.6 | 31.0 | 30.9 | 30.4 | 30.6 | 29.3 | 28.9 | 29.1 | 30.1 | 30.8 | 31.1 | 32.2 | 32.3 | 31.6 | 31.9 | 31.4 | 31.9 | 31.9 | 30.9 | 30.2 | 29.6 | 31.21 |
| 27 | 29.5 | 29.1 | 29.2 | 29.3 | 28.4 | 28.6 | 28.6 | 29.2 | 30.8 | ND | 32.9 | 32.4 | 31.3 | 31.5 | 33.1 | 33.5 | 32.8 | 31.5 | 31.0 | 30.4 | 30.6 | 30.3 | 29.5 | 28.7 | 30.53 |
| 28 | 29.0 | 29.1 | 27.7 | 28.0 | 28.4 | 28.0 | 29.6 | 32.3 | 35.3 | 36.7 | 37.5 | 40.4 | 42.2 | 42.5 | 39.8 | 40.9 | 40.3 | 40.1 | 38.1 | 35.3 | 34.7 | 34.8 | 34.3 | 33.1 | 34.92 |
| 29 | 31.9 | 31.7 | 31.1 | 30.2 | 30.3 | 30.4 | 30.2 | 32.0 | 34.5 | 37.2 | 42.9 | 44.7 | 45.6 | 45.9 | 46.1 | 46.0 | 45.2 | 43.8 | 42.0 | 40.7 | 39.3 | 37.8 | 37.1 | 36.1 | 38.03 |
| 30 | 35.9 | 34.8 | 34.1 | 33.1 | 32.7 | 32.8 | 34.4 | 36.4 | 37.8 | ND | 41.8 | 43.6 | 44.5 | 45.8 | 45.8 | 45.4 | 44.8 | 43.3 | 41.6 | 40.6 | 39.9 | 39.0 | 37.9 | 36.9 | 39.26 |
| | | | | | | | | | | | | | | | | | | | | | | Monthly Average = | | | 35.87 |

Maximum Hourly Average was 47.2 at Hour 14 on Day 24 with 1 occurences
Maximum Daily Average was 40.29 on Day 18 with 1 occurences
Operating Efficiency = 94.9 percent
ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data
[CEM 1990]

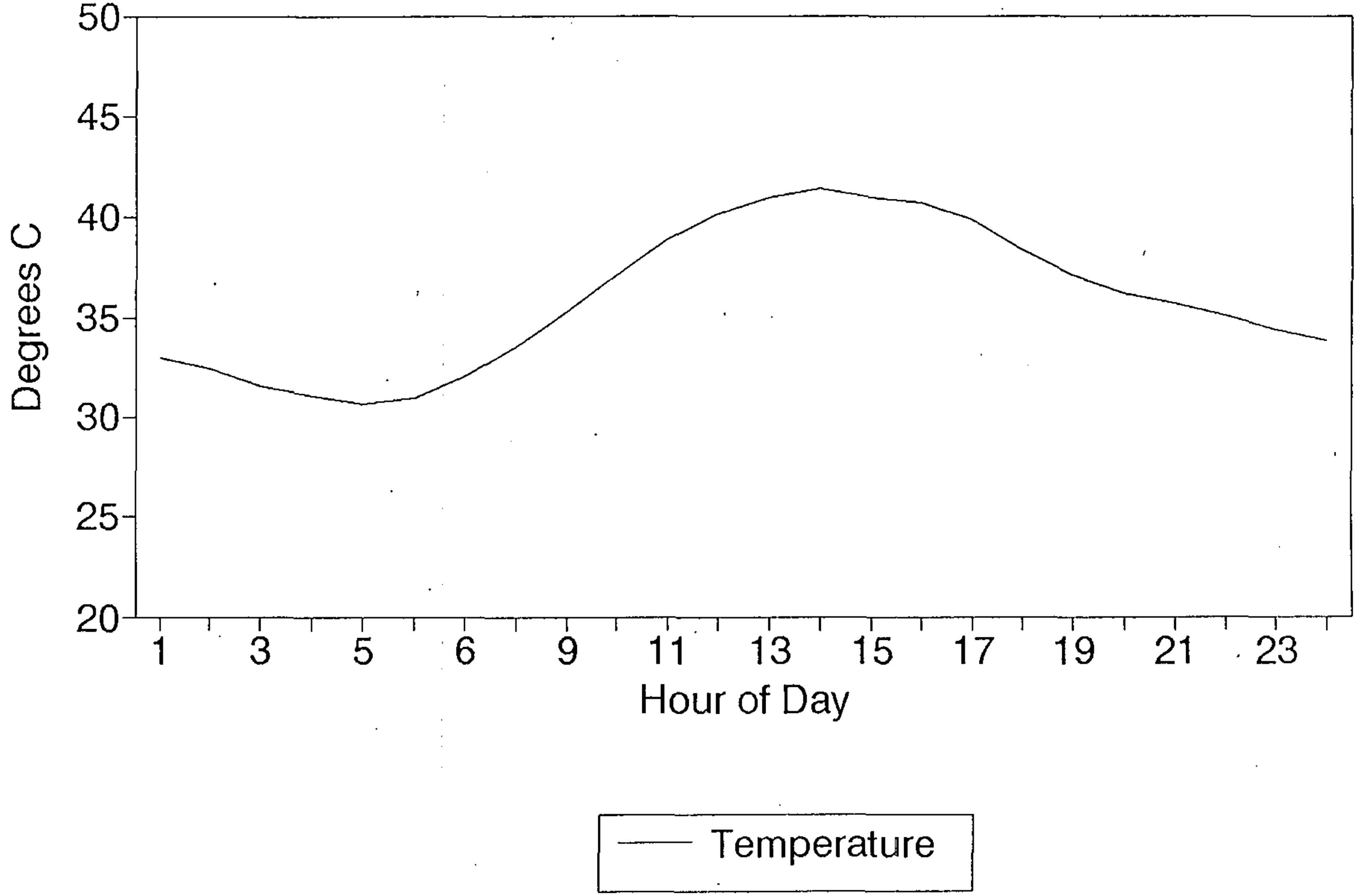
# KUWAIT

Hourly Temperature – June, 1991



# KUWAIT

## Diurnal Temperature – June, 1991



MEPA - Kuwait

June 1991

Hourly Averages for Total Particulate in MG/M3

| Hour / Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.014 | 0.023 | 0.043 | 0.049 | 0.024 | 0.024 | 0.051 | 0.033 | 0.032 | ND | 0.016 | 0.014 | 0.015 | 0.015 | 0.016 | 0.016 | 0.016 | 0.015 | 0.016 | 0.017 | 0.020 | 0.018 | 0.017 | 0.016 | 0.0226 |
| 2 | 0.019 | 0.029 | 0.052 | 0.105 | 0.106 | 0.092 | 0.089 | 0.074 | 0.045 | 0.027 | 0.020 | 0.023 | 0.024 | 0.023 | 0.024 | 0.023 | 0.020 | 0.018 | 0.021 | 0.019 | 0.017 | 0.017 | 0.018 | 0.021 | 0.0386 |
| 3 | 0.023 | 0.026 | 0.028 | 0.026 | 0.023 | 0.023 | 0.024 | 0.021 | 0.022 | ND | 0.024 | 0.022 | 0.020 | 0.020 | 0.020 | 0.019 | 0.018 | 0.028 | 0.034 | 0.045 | 0.033 | 0.031 | 0.029 | 0.024 | 0.0253 |
| 4 | 0.019 | 0.016 | 0.016 | 0.015 | 0.014 | 0.014 | 0.019 | 0.022 | 0.024 | 0.022 | 0.019 | 0.019 | 0.026 | 0.030 | 0.041 | 0.039 | 0.029 | 0.033 | 0.058 | 0.055 | 0.045 | 0.041 | 0.043 | 0.033 | 0.0288 |
| 5 | 0.027 | 0.016 | 0.011 | 0.011 | 0.011 | 0.013 | 0.014 | 0.014 | 0.019 | 0.031 | 0.040 | 0.055 | 0.041 | 0.031 | 0.037 | 0.041 | 0.048 | 0.032 | 0.023 | 0.024 | 0.027 | 0.027 | 0.025 | 0.024 | 0.0267 |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 7 | 0.022 | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 | 0.026 | 0.030 | 0.034 | 0.036 | 0.028 | 0.022 | 0.022 | 0.021 | 0.021 | 0.021 | 0.021 | 0.022 | 0.024 | 0.027 | 0.024 | 0.024 | 0.024 | 0.024 | 0.0237 |
| 8 | 0.024 | 0.025 | 0.035 | 0.037 | 0.047 | 0.072 | 0.064 | 0.060 | 0.033 | ND | 0.018 | 0.017 | 0.016 | 0.015 | 0.016 | 0.016 | 0.022 | 0.021 | 0.022 | 0.021 | 0.021 | 0.021 | 0.020 | 0.016 | 0.0287 |
| 9 | 0.015 | 0.015 | 0.047 | 0.100 | 0.049 | 0.016 | 0.013 | 0.013 | 0.013 | 0.014 | 0.014 | 0.014 | 0.015 | 0.017 | 0.019 | 0.024 | 0.029 | 0.027 | 0.027 | 0.030 | 0.033 | 0.036 | 0.032 | 0.022 | 0.0264 |
| 10 | 0.016 | 0.015 | 0.014 | 0.013 | 0.013 | 0.013 | 0.014 | 0.014 | 0.014 | ND | ND | 0.018 | 0.020 | 0.023 | 0.021 | 0.023 | 0.019 | 0.018 | 0.018 | 0.017 | 0.017 | 0.036 | 0.085 | 0.048 | 0.0222 |
| 11 | 0.053 | 0.059 | 0.050 | 0.022 | 0.025 | 0.057 | 0.057 | 0.051 | 0.020 | 0.020 | 0.017 | 0.015 | 0.014 | 0.015 | 0.016 | 0.017 | 0.018 | 0.017 | 0.018 | 0.019 | 0.021 | 0.026 | 0.040 | 0.053 | 0.0300 |
| 12 | 0.038 | 0.035 | 0.031 | 0.032 | 0.039 | 0.030 | 0.028 | 0.022 | 0.023 | ND | 0.017 | 0.018 | 0.016 | 0.016 | 0.015 | 0.014 | 0.014 | 0.014 | 0.020 | 0.016 | 0.015 | 0.015 | 0.017 | 0.017 | 0.0218 |
| 13 | 0.018 | 0.020 | 0.019 | 0.020 | 0.032 | 0.028 | 0.023 | 0.020 | 0.036 | 0.027 | 0.017 | 0.019 | 0.021 | 0.023 | 0.025 | 0.015 | 0.016 | 0.015 | 0.015 | 0.029 | 0.038 | 0.034 | 0.024 | 0.013 | 0.0228 |
| 14 | 0.014 | 0.014 | 0.031 | 0.045 | 0.023 | 0.025 | 0.030 | 0.030 | 0.030 | 0.031 | 0.024 | 0.016 | 0.013 | 0.014 | 0.014 | 0.014 | 0.013 | 0.013 | 0.017 | 0.014 | 0.014 | 0.024 | 0.027 | 0.023 | 0.0214 |
| 15 | 0.025 | 0.020 | 0.021 | 0.027 | 0.028 | 0.031 | 0.030 | 0.033 | 0.022 | ND | 0.014 | 0.016 | 0.026 | 0.019 | 0.019 | 0.015 | 0.016 | 0.015 | 0.015 | 0.014 | 0.015 | 0.015 | 0.017 | 0.198 | 0.0283 |
| 16 | 0.141 | 0.040 | 0.047 | 0.030 | 0.042 | 0.060 | 0.077 | 0.091 | 0.086 | 0.042 | 0.037 | 0.034 | 0.028 | 0.017 | 0.015 | 0.016 | 0.017 | 0.017 | 0.019 | 0.020 | 0.022 | 0.021 | 0.024 | 0.024 | 0.0403 |
| 17 | 0.028 | 0.025 | 0.030 | 0.023 | 0.015 | 0.023 | 0.023 | 0.020 | 0.025 | ND | 0.024 | 0.023 | 0.021 | 0.022 | 0.027 | 0.043 | 0.059 | 0.072 | 0.061 | 0.052 | 0.046 | 0.042 | 0.044 | 0.025 | 0.0336 |
| 18 | 0.017 | 0.016 | 0.017 | 0.017 | 0.017 | 0.017 | 0.018 | 0.017 | 0.021 | 0.027 | 0.027 | 0.022 | 0.019 | 0.020 | 0.019 | 0.021 | 0.026 | 0.035 | 0.040 | 0.036 | 0.025 | 0.020 | 0.021 | 0.024 | 0.0225 |
| 19 | 0.021 | 0.019 | 0.018 | 0.016 | 0.015 | 0.014 | 0.015 | 0.015 | 0.016 | 0.017 | 0.017 | 0.017 | 0.018 | 0.025 | 0.017 | 0.017 | 0.016 | 0.016 | 0.017 | 0.019 | 0.175 | 0.262 | 0.210 | 0.206 | 0.0499 |
| 20 | 0.135 | 0.049 | 0.032 | 0.027 | 0.025 | 0.020 | 0.016 | 0.016 | 0.025 | ND | 0.023 | 0.022 | 0.023 | 0.025 | 0.025 | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 | 0.023 | 0.026 | 0.149 | 0.040 | 0.0357 |
| 21 | 0.043 | 0.061 | 0.111 | 0.040 | 0.031 | 0.093 | 0.096 | 0.050 | 0.103 | 0.084 | 0.043 | 0.047 | 0.049 | 0.031 | 0.024 | 0.026 | 0.024 | 0.023 | 0.023 | 0.021 | 0.020 | 0.021 | 0.020 | 0.076 | 0.0483 |
| 22 | 0.211 | 0.057 | 0.028 | 0.039 | 0.078 | 0.050 | 0.058 | 0.064 | 0.031 | ND | 0.026 | 0.024 | 0.023 | 0.022 | 0.021 | 0.021 | 0.021 | 0.022 | 0.022 | 0.022 | 0.022 | 0.022 | 0.020 | 0.019 | 0.0401 |
| 23 | 0.018 | 0.018 | 0.019 | 0.020 | 0.021 | 0.021 | 0.023 | 0.025 | 0.024 | 0.024 | 0.023 | 0.025 | 0.026 | 0.026 | 0.027 | 0.028 | 0.030 | 0.029 | 0.030 | 0.031 | 0.032 | 0.132 | 0.130 | 0.074 | 0.0357 |
| 24 | 0.120 | 0.146 | 0.127 | 0.070 | 0.170 | 0.182 | 0.180 | 0.204 | 0.186 | ND | 0.101 | 0.105 | 0.076 | 0.042 | 0.042 | 0.043 | 0.045 | 0.026 | 0.027 | 0.025 | 0.028 | 0.131 | 0.377 | 0.214 | 0.1160 |
| 25 | 0.080 | 0.060 | 0.082 | 0.030 | 0.051 | 0.228 | 0.196 | 0.015 | 0.088 | 0.033 | 0.019 | 0.042 | ND | 0.035 | 0.030 | 0.026 | 0.026 | 0.026 | 0.025 | 0.025 | 0.024 | 0.033 | 0.072 | 0.175 | 0.0618 |
| 26 | 0.166 | 0.231 | 0.026 | 0.028 | 0.042 | 0.039 | 0.027 | 0.027 | 0.027 | 0.014 | 0.019 | 0.018 | 0.021 | 0.024 | 0.023 | 0.025 | 0.025 | 0.024 | 0.025 | 0.025 | 0.025 | 0.025 | 0.027 | 0.028 | 0.0400 |
| 27 | 0.029 | 0.031 | 0.034 | 0.034 | 0.034 | 0.032 | 0.030 | 0.026 | 0.024 | ND | 0.023 | 0.022 | 0.023 | 0.024 | 0.026 | 0.027 | 0.029 | 0.028 | 0.030 | 0.032 | 0.033 | 0.036 | 0.040 | 0.039 | 0.0298 |
| 28 | 0.037 | 0.034 | 0.037 | 0.034 | 0.035 | 0.035 | 0.035 | 0.035 | 0.035 | 0.038 | 0.035 | 0.028 | 0.025 | 0.026 | 0.030 | 0.026 | 0.026 | 0.023 | 0.023 | 0.025 | 0.026 | 0.024 | 0.046 | 0.085 | 0.0335 |
| 29 | 0.025 | 0.024 | 0.044 | 0.040 | 0.025 | 0.023 | 0.049 | 0.028 | 0.021 | 0.020 | 0.016 | 0.014 | 0.014 | 0.014 | 0.015 | 0.016 | 0.016 | 0.016 | 0.018 | 0.017 | 0.019 | 0.017 | 0.016 | 0.015 | 0.0217 |
| 30 | 0.013 | 0.013 | 0.013 | 0.013 | 0.013 | 0.013 | 0.014 | 0.014 | 0.015 | ND | 0.016 | 0.015 | 0.017 | 0.028 | 0.033 | 0.027 | 0.020 | 0.025 | 0.033 | 0.034 | 0.032 | 0.031 | 0.031 | 0.026 | 0.0213 |

Monthly Average = 0.0344

Maximum Hourly Average was 0.377 at Hour 23 on Day 24 with 1 occurences

Maximum Daily Average was 0.1160 on Day 24 with 1 occurences

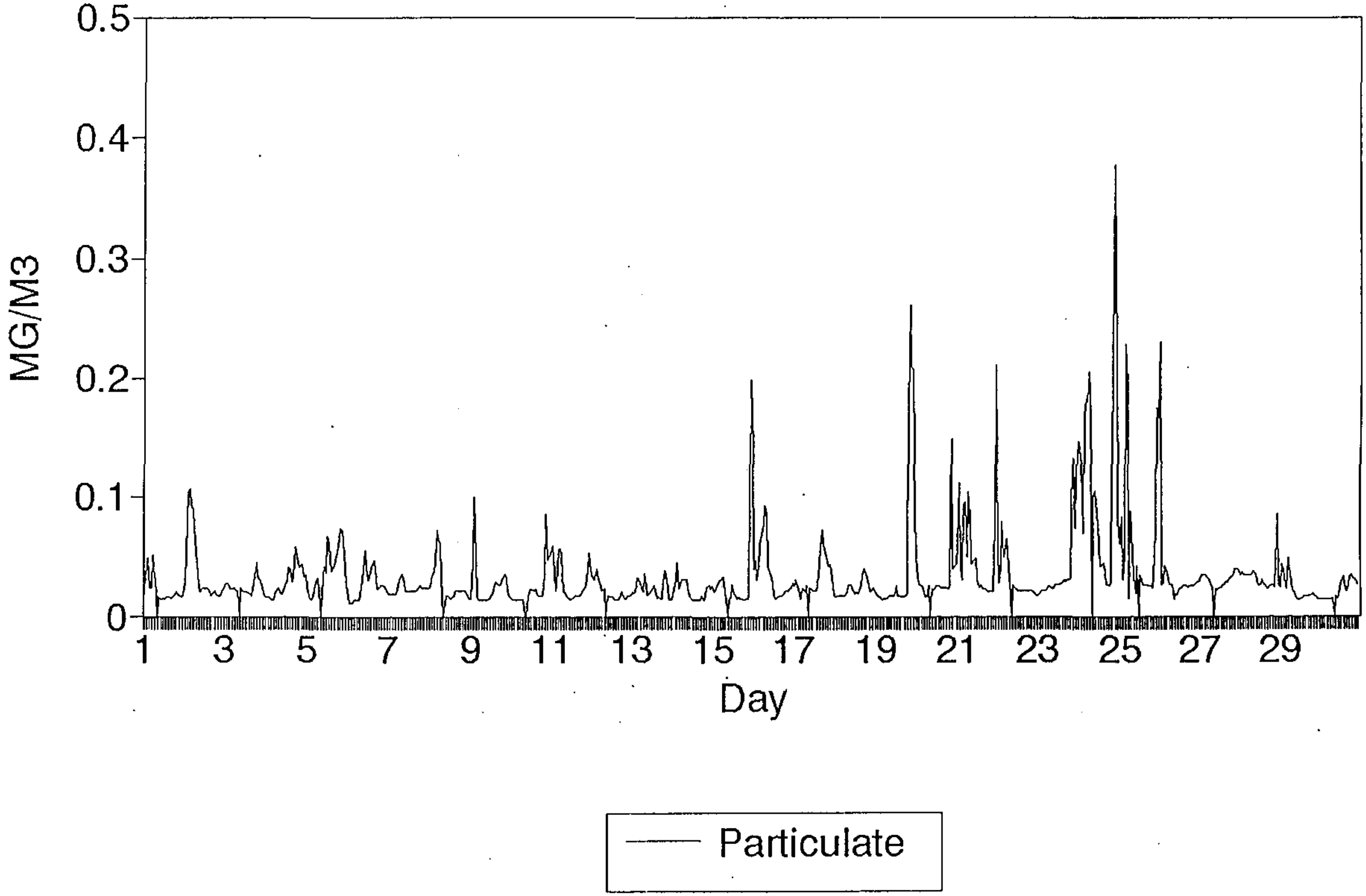
Operating Efficiency = 94.7 percent

ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data

[CEM 1990]

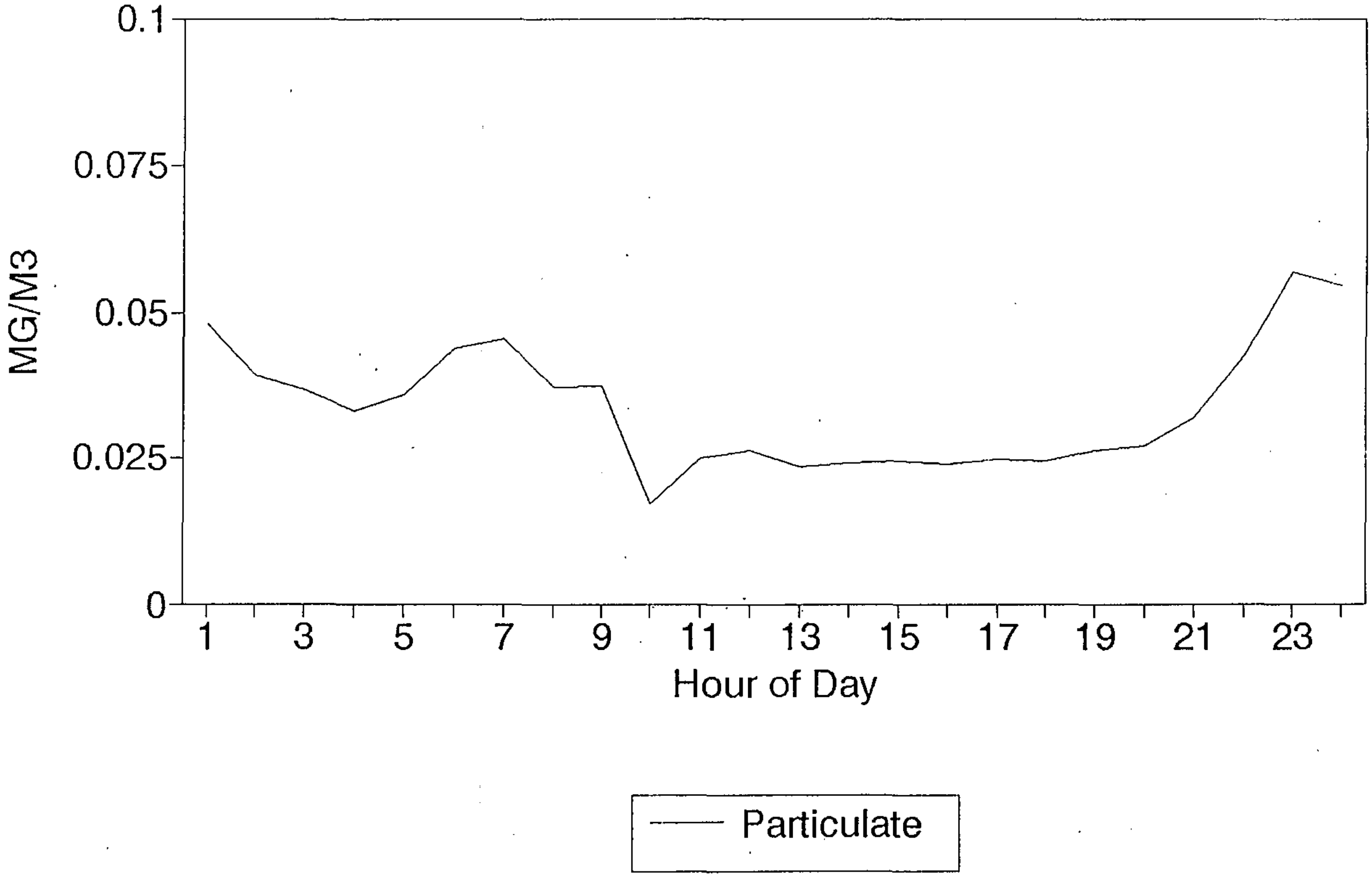
# KUWAIT

Hourly Particulate – June, 1991



# KUWAIT

## Diurnal Particulate - June, 1991



MEPA - Kuwait

June 1991

Hourly Averages for NH3 in ppm

| Day \ Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.004 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | CAL | 0.002 | 0.002 | 0.004 | 0.006 | 0.004 | 0.005 | 0.005 | 0.006 | 0.007 | 0.009 | 0.016 | 0.016 | 0.028 | 0.016 | 0.0057 |
| 2 | 0.004 | 0.014 | 0.004 | 0.002 | 0.000 | 0.006 | 0.000 | 0.003 | 0.006 | 0.003 | 0.004 | 0.004 | 0.005 | 0.005 | 0.003 | 0.009 | 0.015 | 0.018 | 0.030 | 0.025 | 0.011 | 0.020 | 0.021 | 0.008 | 0.0092 |
| 3 | 0.001 | 0.000 | 0.004 | 0.004 | 0.002 | 0.001 | 0.002 | 0.004 | 0.003 | CAL | 0.011 | 0.005 | 0.006 | 0.005 | 0.004 | 0.004 | 0.006 | 0.009 | 0.007 | 0.005 | 0.005 | 0.006 | 0.007 | 0.007 | 0.0047 |
| 4 | 0.010 | 0.012 | 0.018 | 0.014 | 0.005 | 0.003 | 0.008 | 0.007 | 0.009 | 0.005 | 0.004 | 0.005 | 0.005 | 0.004 | 0.003 | 0.005 | 0.006 | 0.006 | 0.006 | 0.005 | 0.005 | 0.004 | 0.014 | 0.015 | 0.0074 |
| 5 | 0.016 | 0.000 | 0.005 | 0.004 | 0.005 | 0.007 | 0.005 | 0.006 | 0.008 | 0.003 | 0.003 | 0.006 | 0.008 | 0.016 | 0.007 | 0.008 | 0.003 | 0.004 | 0.002 | 0.002 | 0.001 | 0.000 | 0.002 | 0.006 | 0.0053 |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 7 | 0.005 | 0.003 | 0.003 | 0.002 | 0.003 | 0.004 | 0.004 | 0.003 | 0.004 | 0.003 | 0.003 | 0.007 | 0.008 | 0.010 | 0.005 | 0.005 | 0.005 | 0.002 | 0.001 | 0.004 | 0.007 | 0.008 | 0.013 | 0.008 | 0.0050 |
| 8 | 0.006 | 0.002 | 0.002 | 0.001 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | CAL | 0.003 | 0.004 | 0.005 | 0.007 | 0.007 | 0.006 | 0.007 | 0.009 | 0.004 | 0.002 | 0.001 | 0.000 | 0.022 | 0.000 | 0.0039 |
| 9 | 0.002 | 0.005 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.002 | 0.002 | 0.002 | 0.002 | 0.003 | 0.004 | 0.009 | 0.009 | 0.011 | 0.007 | 0.002 | 0.003 | 0.004 | 0.007 | 0.005 | 0.0034 |
| 10 | 0.005 | 0.003 | 0.003 | 0.004 | 0.002 | 0.002 | 0.002 | 0.004 | 0.004 | CAL | CAL | 0.004 | 0.006 | 0.007 | 0.010 | 0.015 | 0.015 | 0.000 | 0.015 | 0.025 | 0.023 | 0.015 | 0.007 | 0.004 | 0.0080 |
| 11 | 0.005 | 0.007 | 0.009 | 0.004 | 0.004 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.003 | 0.003 | 0.006 | 0.008 | 0.009 | 0.013 | 0.013 | 0.015 | 0.016 | 0.016 | 0.013 | 0.008 | 0.006 | 0.002 | 0.0067 |
| 12 | 0.002 | 0.005 | 0.005 | 0.004 | 0.001 | 0.001 | 0.000 | 0.000 | 0.002 | CAL | 0.002 | 0.004 | 0.003 | 0.001 | 0.005 | 0.005 | 0.006 | 0.002 | 0.000 | 0.003 | 0.004 | 0.003 | 0.005 | 0.006 | 0.0030 |
| 13 | 0.003 | 0.005 | 0.001 | 0.003 | 0.004 | 0.000 | 0.000 | 0.002 | 0.001 | 0.000 | 0.001 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.005 | 0.008 | 0.005 | 0.000 | 0.000 | 0.003 | 0.0018 |
| 14 | 0.001 | 0.002 | 0.003 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.002 | 0.001 | 0.002 | 0.001 | 0.003 | 0.005 | 0.009 | 0.009 | 0.005 | 0.003 | 0.002 | 0.001 | 0.0021 |
| 15 | 0.001 | 0.001 | 0.000 | 0.003 | 0.001 | 0.002 | 0.002 | 0.000 | 0.001 | CAL | 0.005 | 0.007 | 0.005 | 0.005 | 0.004 | 0.001 | 0.004 | 0.017 | 0.037 | 0.058 | 0.039 | 0.023 | 0.021 | 0.000 | 0.0103 |
| 16 | 0.006 | 0.002 | 0.012 | 0.019 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.002 | 0.008 | 0.012 | 0.009 | 0.023 | 0.037 | 0.051 | 0.046 | 0.030 | 0.032 | 0.030 | 0.022 | 0.0144 |
| 17 | 0.009 | 0.009 | 0.010 | 0.016 | 0.014 | 0.014 | 0.019 | 0.012 | 0.016 | CAL | 0.019 | 0.023 | 0.005 | 0.006 | 0.007 | 0.005 | 0.008 | 0.012 | 0.011 | 0.012 | 0.013 | 0.005 | 0.004 | 0.006 | 0.0111 |
| 18 | 0.014 | 0.005 | 0.005 | 0.009 | 0.005 | 0.011 | 0.012 | 0.012 | 0.018 | 0.012 | 0.016 | 0.017 | 0.012 | 0.004 | 0.004 | 0.006 | 0.019 | 0.022 | 0.031 | 0.026 | 0.006 | 0.007 | 0.003 | 0.013 | 0.0120 |
| 19 | 0.005 | 0.001 | 0.001 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.006 | 0.008 | 0.008 | 0.026 | 0.018 | 0.018 | 0.016 | 0.014 | 0.020 | 0.004 | 0.000 | 0.000 | 0.000 | 0.0061 |
| 20 | 0.000 | 0.000 | 0.006 | 0.007 | 0.000 | 0.001 | 0.009 | 0.008 | 0.019 | CAL | 0.016 | 0.008 | 0.008 | 0.007 | 0.010 | 0.015 | 0.006 | 0.004 | 0.010 | 0.011 | 0.019 | 0.023 | 0.012 | 0.016 | 0.0093 |
| 21 | 0.014 | 0.050 | 0.015 | 0.010 | 0.013 | 0.004 | 0.001 | 0.006 | 0.008 | 0.010 | 0.012 | 0.017 | 0.026 | 0.021 | 0.016 | 0.021 | 0.015 | 0.017 | 0.027 | 0.017 | 0.019 | 0.038 | 0.022 | 0.012 | 0.0171 |
| 22 | 0.002 | 0.020 | 0.025 | 0.015 | 0.010 | 0.011 | 0.010 | 0.014 | 0.034 | CAL | 0.021 | 0.012 | 0.013 | 0.019 | 0.025 | 0.018 | 0.026 | 0.019 | 0.029 | 0.041 | 0.049 | 0.061 | 0.068 | 0.075 | 0.0268 |
| 23 | 0.077 | 0.078 | 0.085 | 0.086 | 0.086 | 0.076 | 0.079 | 0.078 | 0.079 | 0.080 | 0.082 | 0.092 | 0.082 | 0.086 | 0.088 | 0.090 | 0.080 | 0.073 | 0.055 | 0.052 | 0.056 | 0.048 | 0.044 | 0.058 | 0.0746 |
| 24 | 0.058 | 0.048 | 0.050 | 0.053 | 0.043 | 0.033 | 0.012 | 0.013 | 0.005 | CAL | 0.009 | 0.027 | 0.028 | 0.023 | 0.029 | 0.049 | 0.004 | 0.037 | 0.036 | 0.030 | 0.028 | 0.030 | 0.018 | 0.026 | 0.0300 |
| 25 | 0.020 | 0.019 | 0.021 | 0.022 | 0.021 | 0.009 | 0.009 | 0.009 | 0.013 | 0.020 | 0.021 | 0.026 | CAL | 0.010 | 0.014 | 0.012 | 0.026 | 0.021 | 0.007 | 0.006 | 0.006 | 0.005 | 0.002 | 0.000 | 0.0139 |
| 26 | 0.000 | 0.000 | 0.007 | 0.010 | 0.012 | 0.016 | 0.016 | 0.018 | 0.020 | 0.017 | 0.013 | 0.012 | 0.014 | 0.017 | 0.028 | 0.032 | 0.027 | 0.030 | 0.027 | 0.028 | 0.028 | 0.027 | 0.033 | 0.033 | 0.0194 |
| 27 | 0.037 | 0.040 | 0.034 | 0.034 | 0.039 | 0.035 | 0.033 | 0.031 | CAL | CAL | 0.025 | 0.087 | 0.108 | 0.110 | 0.106 | 0.133 | 0.103 | 0.092 | 0.090 | 0.090 | 0.081 | 0.074 | 0.069 | 0.077 | 0.0695 |
| 28 | 0.088 | 0.068 | 0.085 | 0.078 | 0.082 | 0.070 | 0.072 | 0.059 | 0.058 | 0.057 | 0.034 | 0.030 | 0.028 | 0.025 | 0.023 | 0.022 | 0.015 | 0.011 | 0.016 | 0.017 | 0.017 | 0.008 | 0.007 | 0.018 | 0.0412 |
| 29 | 0.007 | 0.007 | 0.006 | 0.003 | 0.004 | 0.005 | 0.011 | 0.009 | 0.007 | 0.010 | 0.010 | 0.007 | 0.010 | 0.010 | 0.010 | 0.012 | 0.010 | 0.009 | 0.007 | 0.006 | 0.080 | 0.006 | 0.005 | 0.005 | 0.0107 |
| 30 | 0.006 | 0.003 | 0.004 | 0.005 | 0.004 | 0.003 | 0.003 | 0.004 | 0.007 | CAL | 0.000 | 0.000 | 0.000 | 0.008 | 0.009 | 0.005 | 0.008 | 0.007 | 0.007 | 0.008 | 0.007 | 0.005 | 0.005 | 0.005 | 0.0049 |

Monthly Average = 0.0150

Maximum Hourly Average was 0.133 at Hour 16 on Day 27 with 1 occurences

Maximum Daily Average was 0.0746 on Day 23 with 1 occurences

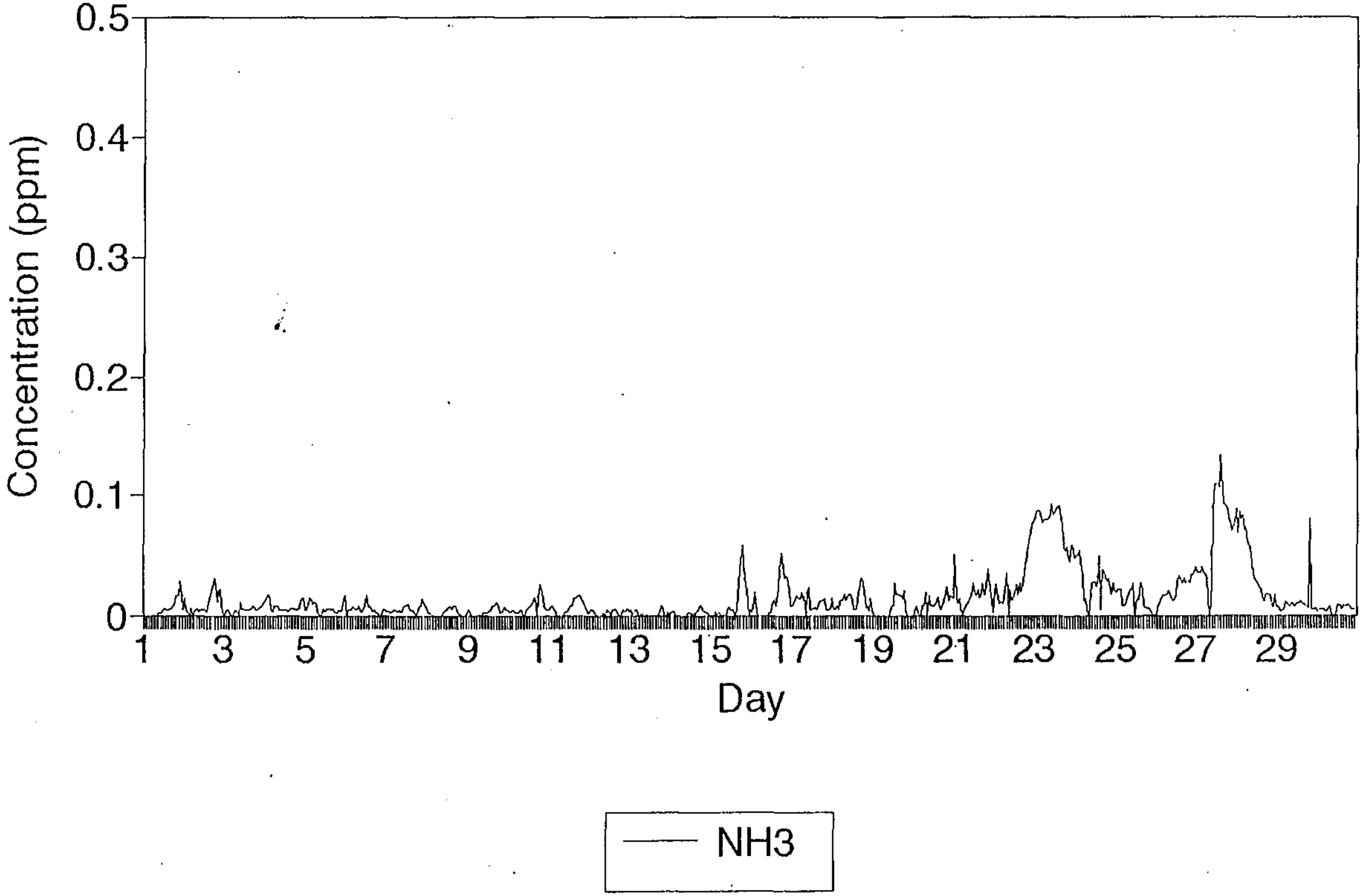
Operating Efficiency = 96.7 percent

ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data

[CEM 1990]

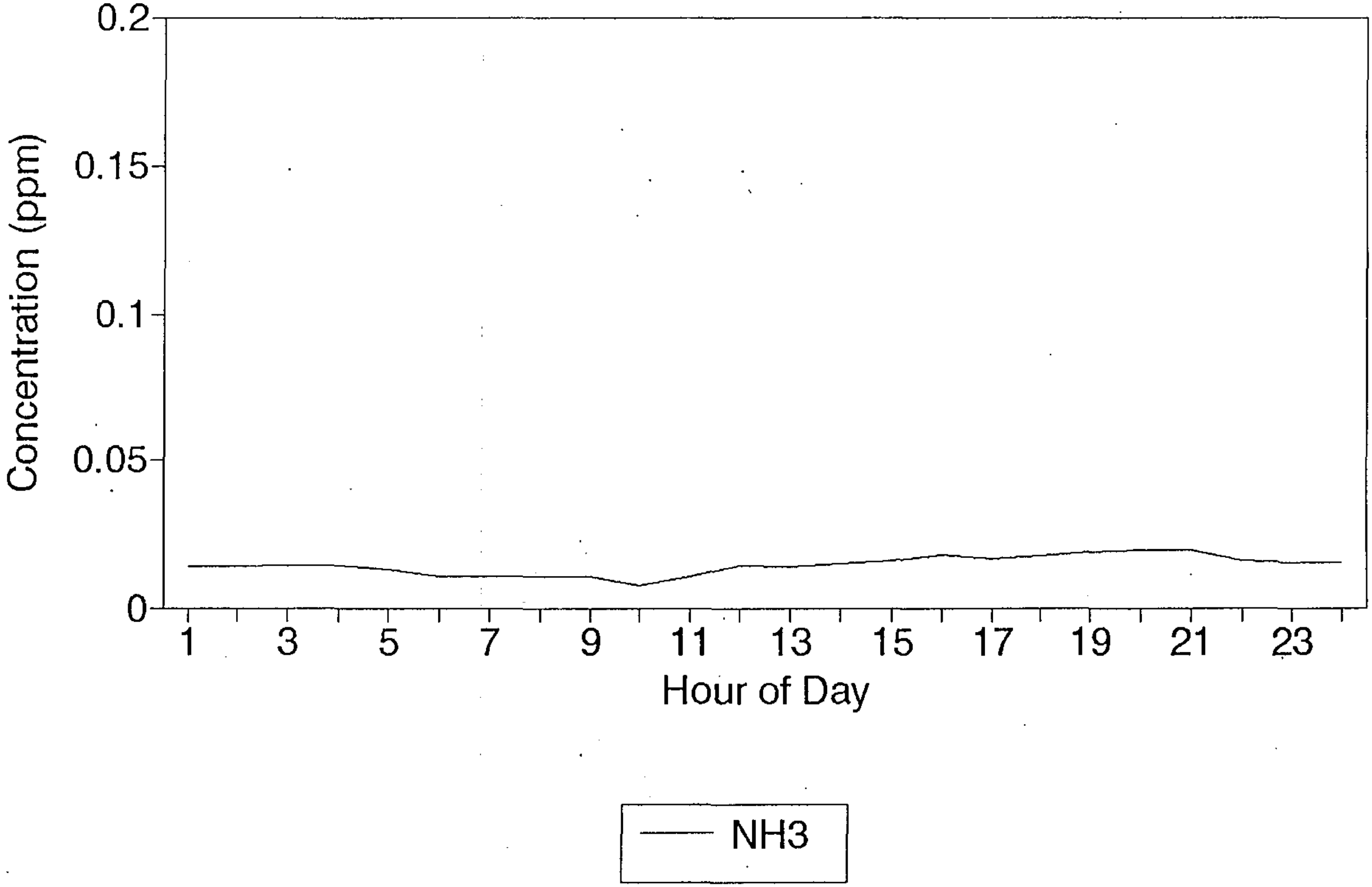
# KUWAIT

Hourly NH3 – June, 1991



# KUWAIT

Diurnal NH3 - June, 1991



MEPA - Kuwait
June 1991
Hourly Averages for O3 in ppm

| Hour / Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.014 | 0.019 | 0.016 | 0.012 | 0.021 | 0.021 | 0.005 | 0.009 | 0.018 | CAL | 0.025 | 0.030 | 0.023 | 0.022 | 0.023 | 0.020 | 0.012 | 0.008 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.0130 |
| 2 | 0.009 | 0.000 | 0.004 | 0.009 | 0.011 | 0.002 | 0.005 | 0.001 | 0.004 | 0.010 | 0.013 | 0.007 | 0.008 | 0.017 | 0.018 | 0.005 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.012 | 0.0057 |
| 3 | 0.023 | 0.022 | 0.029 | 0.031 | 0.031 | 0.025 | 0.021 | 0.021 | 0.029 | CAL | 0.057 | 0.037 | 0.040 | 0.039 | 0.040 | 0.036 | 0.039 | 0.037 | 0.035 | 0.031 | 0.032 | 0.011 | 0.014 | 0.016 | 0.0303 |
| 4 | 0.006 | 0.006 | 0.002 | 0.008 | 0.025 | 0.024 | 0.013 | 0.015 | 0.019 | 0.022 | 0.028 | 0.029 | 0.023 | 0.024 | 0.030 | 0.032 | 0.031 | 0.032 | 0.028 | 0.029 | 0.027 | 0.017 | 0.001 | 0.000 | 0.0196 |
| 5 | 0.000 | 0.011 | 0.015 | 0.016 | 0.009 | 0.010 | 0.011 | 0.006 | 0.002 | 0.015 | 0.020 | 0.019 | 0.020 | 0.019 | 0.021 | 0.021 | 0.020 | 0.014 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.0104 |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 7 | 0.002 | 0.002 | 0.003 | 0.009 | 0.012 | 0.012 | 0.014 | 0.012 | 0.012 | 0.021 | 0.029 | 0.031 | 0.033 | 0.033 | 0.034 | 0.032 | 0.027 | 0.023 | 0.022 | 0.021 | 0.017 | 0.007 | 0.000 | 0.000 | 0.0170 |
| 8 | 0.002 | 0.003 | 0.003 | 0.004 | 0.001 | 0.003 | 0.003 | 0.012 | 0.015 | CAL | 0.029 | 0.034 | 0.034 | 0.034 | 0.034 | 0.031 | 0.024 | 0.028 | 0.024 | 0.024 | 0.022 | 0.015 | 0.003 | 0.018 | 0.0174 |
| 9 | 0.021 | 0.036 | 0.037 | 0.023 | 0.015 | 0.027 | 0.033 | 0.033 | 0.031 | 0.027 | 0.031 | 0.031 | 0.034 | 0.040 | 0.038 | 0.039 | 0.035 | 0.030 | 0.026 | 0.024 | 0.027 | 0.019 | 0.001 | 0.004 | 0.0276 |
| 10 | 0.012 | 0.026 | 0.023 | 0.022 | 0.027 | 0.029 | 0.017 | 0.016 | 0.019 | CAL | CAL | 0.027 | 0.032 | 0.035 | 0.032 | 0.029 | 0.026 | 0.019 | 0.006 | 0.003 | 0.003 | 0.003 | 0.002 | 0.008 | 0.0189 |
| 11 | 0.003 | 0.006 | 0.006 | 0.007 | 0.003 | 0.007 | 0.015 | 0.006 | 0.012 | 0.018 | 0.033 | 0.036 | 0.035 | 0.034 | 0.034 | 0.025 | 0.020 | 0.015 | 0.007 | 0.006 | 0.007 | 0.007 | 0.002 | 0.005 | 0.0145 |
| 12 | 0.015 | 0.020 | 0.026 | 0.027 | 0.023 | 0.026 | 0.021 | 0.018 | 0.017 | CAL | 0.024 | 0.026 | 0.029 | 0.032 | 0.036 | 0.036 | 0.037 | 0.034 | 0.007 | 0.004 | 0.006 | 0.002 | 0.000 | 0.002 | 0.0203 |
| 13 | 0.004 | 0.012 | 0.012 | 0.009 | 0.011 | 0.010 | 0.012 | 0.018 | 0.024 | 0.034 | 0.039 | 0.038 | 0.037 | 0.036 | 0.036 | 0.030 | 0.023 | 0.014 | 0.000 | 0.008 | 0.017 | 0.018 | 0.001 | 0.010 | 0.0189 |
| 14 | 0.018 | 0.023 | 0.015 | 0.018 | 0.025 | 0.022 | 0.022 | 0.027 | 0.030 | 0.040 | 0.044 | 0.036 | 0.037 | 0.033 | 0.032 | 0.020 | 0.016 | 0.001 | 0.003 | 0.011 | 0.015 | 0.018 | 0.016 | 0.021 | 0.0226 |
| 15 | 0.021 | 0.024 | 0.019 | 0.020 | 0.019 | 0.016 | 0.018 | 0.015 | 0.019 | CAL | 0.015 | 0.004 | 0.019 | 0.036 | 0.039 | 0.031 | 0.010 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.016 | 0.0149 |
| 16 | 0.015 | 0.020 | 0.021 | 0.022 | 0.022 | 0.014 | 0.005 | 0.000 | 0.000 | 0.015 | 0.011 | 0.008 | 0.015 | 0.028 | 0.030 | 0.023 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.004 | 0.0106 |
| 17 | 0.022 | 0.029 | 0.031 | 0.035 | 0.037 | 0.035 | 0.033 | 0.027 | 0.035 | CAL | 0.042 | 0.044 | 0.044 | 0.044 | 0.044 | 0.042 | 0.040 | 0.037 | 0.037 | 0.037 | 0.037 | 0.038 | 0.038 | 0.039 | 0.0368 |
| 18 | 0.039 | 0.036 | 0.036 | 0.028 | 0.029 | 0.039 | 0.041 | 0.040 | 0.041 | 0.043 | 0.045 | 0.045 | 0.046 | 0.047 | 0.049 | 0.050 | 0.049 | 0.043 | 0.038 | 0.029 | 0.030 | 0.035 | 0.035 | 0.032 | 0.0394 |
| 19 | 0.032 | 0.030 | 0.033 | 0.033 | 0.034 | 0.031 | 0.029 | 0.027 | 0.033 | 0.028 | 0.029 | 0.041 | 0.035 | 0.034 | 0.034 | 0.029 | 0.031 | 0.022 | 0.004 | 0.000 | 0.015 | 0.010 | 0.010 | 0.011 | 0.0256 |
| 20 | 0.008 | 0.013 | 0.015 | 0.021 | 0.026 | 0.024 | 0.023 | 0.023 | 0.015 | CAL | 0.033 | 0.031 | 0.028 | 0.030 | 0.021 | 0.006 | 0.003 | 0.000 | 0.000 | 0.000 | 0.012 | 0.023 | 0.019 | 0.022 | 0.0172 |
| 21 | 0.023 | 0.017 | 0.008 | 0.001 | 0.000 | 0.001 | 0.000 | 0.007 | 0.017 | 0.018 | 0.016 | 0.000 | 0.000 | 0.000 | 0.010 | 0.018 | 0.016 | 0.010 | 0.007 | 0.012 | 0.022 | 0.021 | 0.009 | 0.009 | 0.0101 |
| 22 | 0.009 | 0.008 | 0.011 | 0.009 | 0.001 | 0.000 | 0.000 | 0.005 | 0.014 | CAL | 0.023 | 0.000 | 0.003 | 0.006 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.0039 |
| 23 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.002 | 0.005 | 0.008 | 0.003 | 0.001 | 0.001 | 0.000 | 0.001 | 0.005 | 0.002 | 0.000 | 0.0013 |
| 24 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.002 | CAL | 0.005 | 0.001 | 0.016 | 0.046 | 0.026 | 0.007 | 0.003 | 0.007 | 0.001 | 0.007 | 0.010 | 0.013 | 0.007 | 0.008 | 0.0070 |
| 25 | 0.010 | 0.010 | 0.002 | 0.004 | 0.008 | 0.003 | 0.004 | 0.007 | 0.007 | 0.013 | 0.022 | 0.014 | CAL | 0.012 | 0.012 | 0.017 | 0.015 | 0.023 | 0.026 | 0.027 | 0.029 | 0.025 | 0.025 | 0.023 | 0.0147 |
| 26 | 0.024 | 0.009 | 0.002 | 0.005 | 0.003 | 0.000 | 0.002 | 0.000 | 0.002 | 0.007 | 0.016 | 0.012 | 0.012 | 0.011 | 0.014 | 0.017 | 0.018 | 0.017 | 0.018 | 0.011 | 0.004 | 0.009 | 0.005 | 0.000 | 0.0091 |
| 27 | 0.004 | 0.007 | 0.002 | 0.002 | 0.007 | 0.007 | 0.006 | 0.003 | CAL | CAL | 0.008 | 0.007 | 0.006 | 0.007 | 0.013 | 0.015 | 0.014 | 0.011 | 0.008 | 0.000 | 0.002 | 0.001 | 0.000 | 0.000 | 0.0059 |
| 28 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.009 | 0.018 | 0.028 | 0.024 | 0.028 | 0.028 | 0.029 | 0.027 | 0.031 | 0.019 | 0.010 | 0.000 | 0.000 | 0.000 | 0.006 | 0.000 | 0.000 | 0.0107 |
| 29 | 0.004 | 0.011 | 0.009 | 0.007 | 0.010 | 0.012 | 0.013 | 0.016 | 0.019 | 0.013 | 0.033 | 0.042 | 0.042 | 0.042 | 0.041 | 0.042 | 0.041 | 0.037 | 0.030 | 0.027 | 0.022 | 0.017 | 0.021 | 0.026 | 0.0240 |
| 30 | 0.033 | 0.033 | 0.033 | 0.034 | 0.032 | 0.030 | 0.030 | 0.036 | 0.037 | CAL | 0.077 | 0.047 | 0.049 | 0.051 | 0.051 | 0.050 | 0.047 | 0.039 | 0.032 | 0.032 | 0.038 | 0.038 | 0.037 | 0.031 | 0.0399 |
| | | | | | | | | | | | | | | | | | | | | | Monthly Average = | | | | 0.0175 |

Maximum Hourly Average was 0.077 at Hour 11 on Day 30 with 1 occurences and there were no Hourly Violations

Maximum Daily Average was 0.0399 on Day 30 with 1 occurences and there were no Daily Violations

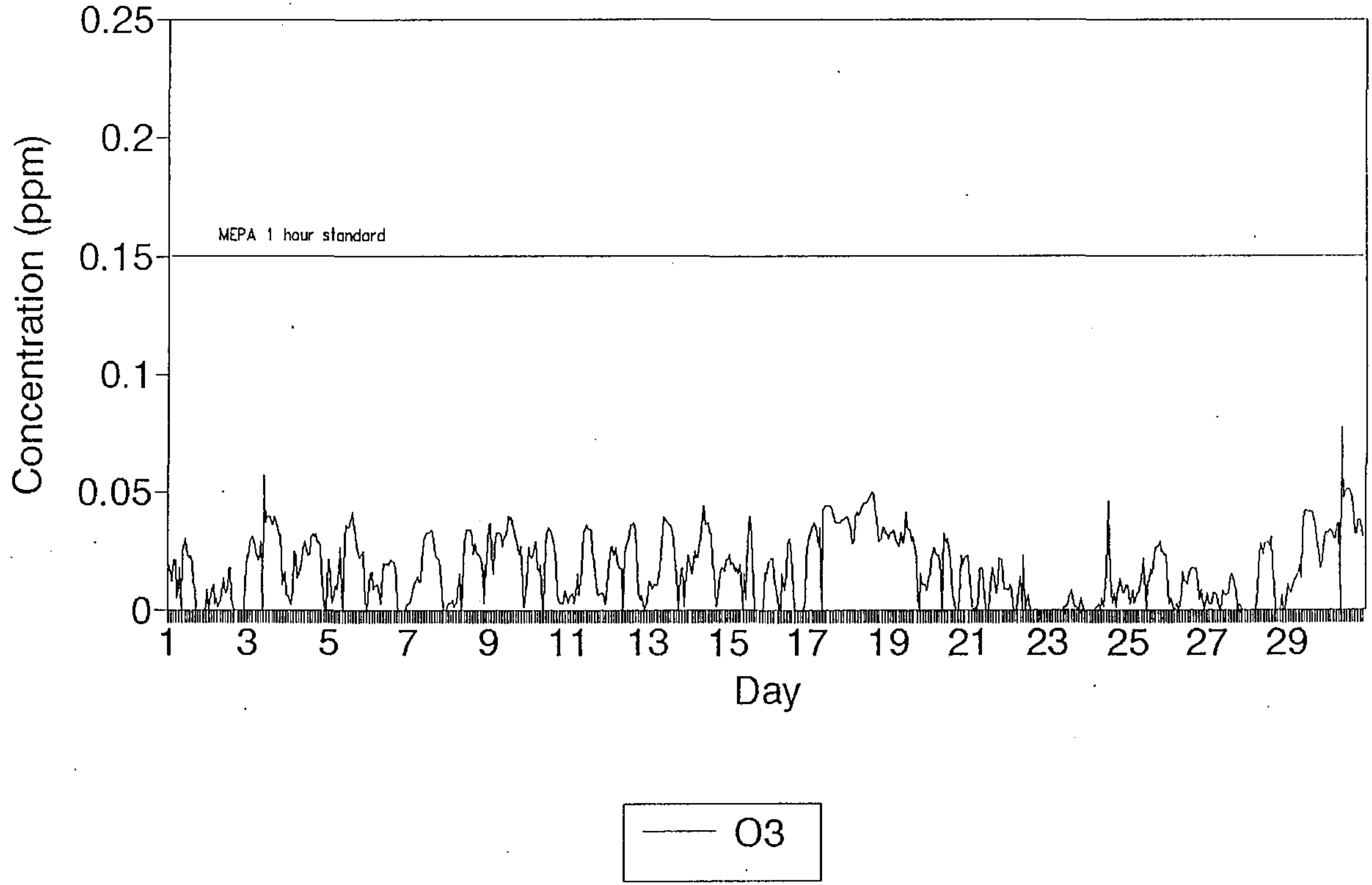
Operating Efficiency = 96.7 percent

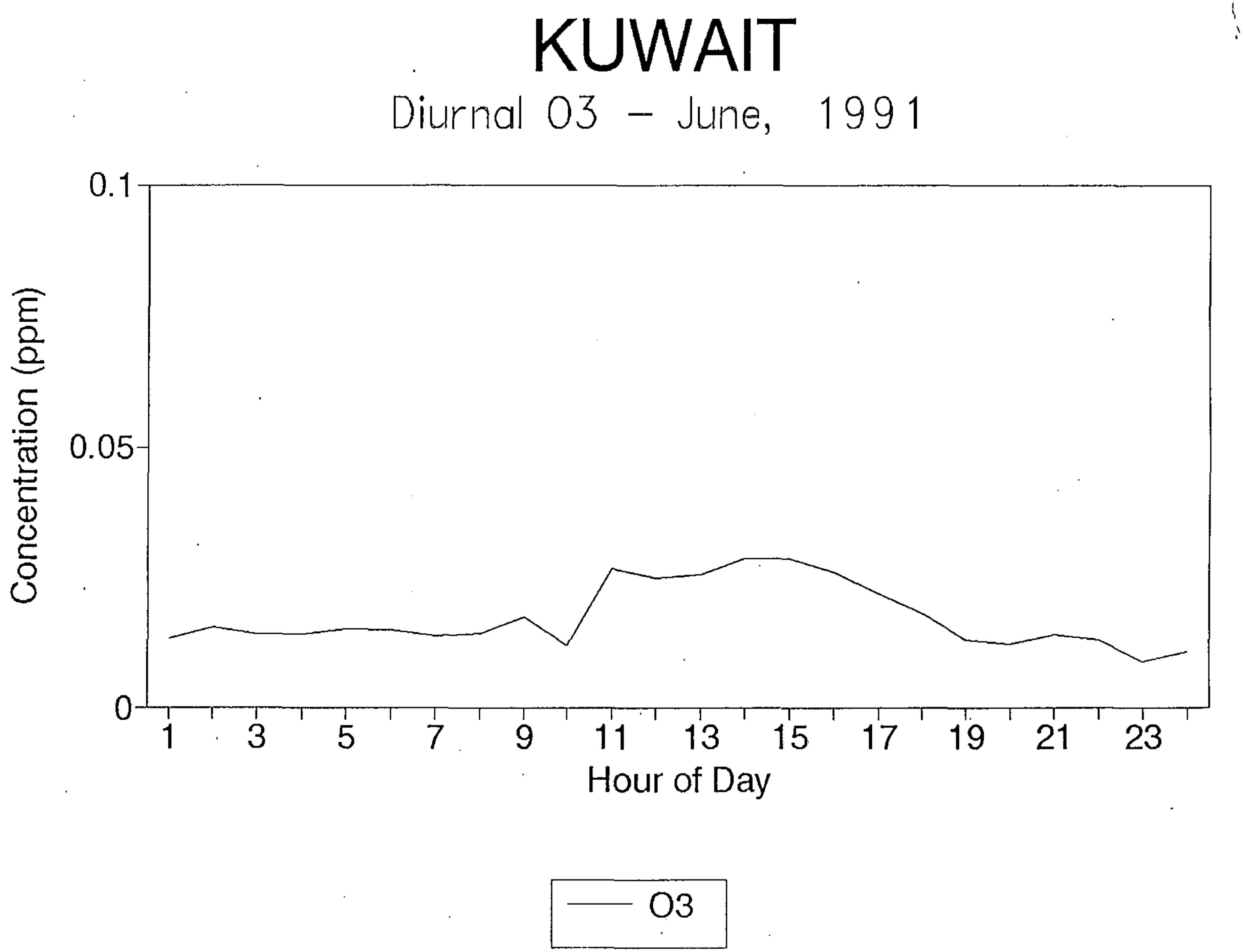
ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data

[CEM 1990]

# KUWAIT

Hourly O3 - June, 1991




KUWAIT
Diurnal O3 – June, 1991
Concentration (ppm)
0.1
0.05
0
1
3
5
7
9
11
13
15
17
19
21
23
Hour of Day
O3

MEPA - Kuwait
June 1991
Hourly Averages for NOx in ppm

| Hour / Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.071 | 0.031 | 0.039 | 0.055 | 0.025 | 0.029 | 0.099 | 0.072 | 0.043 | CAL | 0.049 | 0.038 | 0.044 | 0.041 | 0.035 | 0.036 | 0.060 | 0.054 | 0.086 | 0.087 | 0.150 | 0.109 | 0.181 | 0.101 | 0.0667 |
| 2 | 0.037 | 0.142 | 0.079 | 0.051 | 0.060 | 0.117 | 0.059 | 0.090 | 0.079 | 0.056 | 0.053 | 0.081 | 0.076 | 0.063 | 0.044 | 0.091 | 0.134 | 0.136 | 0.217 | 0.170 | 0.080 | 0.147 | 0.161 | 0.074 | 0.0957 |
| 3 | 0.029 | 0.026 | 0.005 | 0.003 | 0.005 | 0.024 | 0.047 | 0.056 | 0.044 | CAL | 0.080 | 0.027 | 0.018 | 0.017 | 0.015 | 0.022 | 0.014 | 0.012 | 0.014 | 0.018 | 0.018 | 0.090 | 0.073 | 0.061 | 0.0312 |
| 4 | 0.113 | 0.123 | 0.154 | 0.115 | 0.033 | 0.033 | 0.079 | 0.077 | 0.058 | 0.039 | 0.032 | 0.031 | 0.045 | 0.041 | 0.021 | 0.015 | 0.018 | 0.013 | 0.014 | 0.013 | 0.018 | 0.051 | 0.165 | 0.193 | 0.0623 |
| 5 | 0.182 | 0.085 | 0.058 | 0.052 | 0.081 | 0.082 | 0.076 | 0.071 | 0.077 | 0.046 | 0.025 | 0.020 | 0.012 | 0.007 | 0.007 | 0.008 | 0.013 | 0.017 | 0.018 | 0.018 | 0.026 | 0.059 | 0.127 | 0.137 | 0.0543 |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 7 | 0.107 | 0.079 | 0.078 | 0.075 | 0.103 | 0.084 | 0.085 | 0.060 | 0.084 | 0.019 | 0.010 | 0.008 | 0.006 | 0.011 | 0.007 | 0.008 | 0.008 | 0.018 | 0.069 | 0.094 | 0.128 | 0.014 | 0.132 | 0.071 | 0.0566 |
| 8 | 0.030 | 0.038 | 0.045 | 0.008 | 0.006 | 0.012 | 0.022 | 0.032 | 0.030 | CAL | 0.025 | 0.013 | 0.016 | 0.017 | 0.015 | 0.018 | 0.030 | 0.017 | 0.019 | 0.021 | 0.024 | 0.045 | 0.127 | 0.047 | 0.0286 |
| 9 | 0.038 | 0.006 | 0.007 | 0.028 | 0.063 | 0.020 | 0.011 | 0.019 | 0.027 | 0.050 | 0.038 | 0.036 | 0.029 | 0.011 | 0.013 | 0.005 | 0.008 | 0.009 | 0.013 | 0.018 | 0.019 | 0.039 | 0.114 | 0.098 | 0.0300 |
| 10 | 0.067 | 0.011 | 0.008 | 0.014 | 0.009 | 0.013 | 0.066 | 0.076 | 0.062 | CAL | CAL | 0.039 | 0.022 | 0.014 | 0.016 | 0.015 | 0.019 | 0.030 | 0.075 | 0.072 | 0.060 | 0.039 | 0.043 | 0.031 | 0.0364 |
| 11 | 0.058 | 0.033 | 0.027 | 0.033 | 0.087 | 0.063 | 0.027 | 0.078 | 0.039 | 0.037 | 0.015 | 0.008 | 0.010 | 0.011 | 0.007 | 0.022 | 0.029 | 0.035 | 0.059 | 0.039 | 0.036 | 0.033 | 0.039 | 0.030 | 0.0356 |
| 12 | 0.017 | 0.010 | 0.005 | 0.005 | 0.007 | 0.008 | 0.017 | 0.033 | 0.075 | CAL | 0.053 | 0.041 | 0.037 | 0.032 | 0.020 | 0.009 | 0.006 | 0.010 | 0.060 | 0.065 | 0.062 | 0.072 | 0.087 | 0.078 | 0.0352 |
| 13 | 0.073 | 0.041 | 0.040 | 0.039 | 0.024 | 0.036 | 0.052 | 0.049 | 0.032 | 0.029 | 0.026 | 0.023 | 0.024 | 0.021 | 0.019 | 0.023 | 0.033 | 0.042 | 0.088 | 0.050 | 0.021 | 0.019 | 0.084 | 0.045 | 0.0389 |
| 14 | 0.027 | 0.017 | 0.017 | 0.017 | 0.010 | 0.016 | 0.017 | 0.019 | 0.022 | 0.023 | 0.016 | 0.022 | 0.014 | 0.015 | 0.015 | 0.036 | 0.043 | 0.075 | 0.083 | 0.070 | 0.038 | 0.012 | 0.012 | 0.009 | 0.0269 |
| 15 | 0.008 | 0.008 | 0.016 | 0.004 | 0.004 | 0.009 | 0.009 | 0.031 | 0.032 | CAL | 0.050 | 0.076 | 0.046 | 0.025 | 0.021 | 0.024 | 0.045 | 0.144 | 0.234 | 0.135 | 0.000 | 0.069 | 0.108 | 0.029 | 0.0490 |
| 16 | 0.014 | 0.004 | 0.006 | 0.000 | 0.003 | 0.016 | 0.032 | 0.059 | 0.096 | 0.053 | 0.057 | 0.076 | 0.054 | 0.020 | 0.013 | 0.026 | 0.123 | 0.255 | 0.250 | 0.200 | 0.121 | 0.146 | 0.099 | 0.051 | 0.0739 |
| 17 | 0.010 | 0.005 | 0.005 | 0.003 | 0.002 | 0.004 | 0.007 | 0.017 | 0.015 | CAL | 0.007 | 0.005 | 0.004 | 0.004 | 0.004 | 0.006 | 0.009 | 0.013 | 0.013 | 0.012 | 0.012 | 0.012 | 0.009 | 0.008 | 0.0081 |
| 18 | 0.005 | 0.007 | 0.005 | 0.013 | 0.012 | 0.005 | 0.006 | 0.008 | 0.008 | 0.007 | 0.008 | 0.007 | 0.007 | 0.006 | 0.003 | 0.003 | 0.008 | 0.014 | 0.016 | 0.024 | 0.023 | 0.021 | 0.019 | 0.018 | 0.0105 |
| 19 | 0.014 | 0.014 | 0.010 | 0.008 | 0.006 | 0.013 | 0.022 | 0.028 | 0.018 | 0.029 | 0.026 | 0.011 | 0.022 | 0.016 | 0.011 | 0.017 | 0.018 | 0.038 | 0.077 | 0.099 | 0.024 | 0.027 | 0.016 | 0.015 | 0.0241 |
| 20 | 0.024 | 0.024 | 0.018 | 0.028 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.0235 |
| 21 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 22 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 23 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 24 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 25 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 26 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.033 | 0.038 | 0.039 | 0.029 | 0.026 | 0.026 | 0.038 | 0.043 | 0.057 | 0.063 | 0.045 | 0.060 | 0.081 | 0.0445 |
| 27 | 0.049 | 0.030 | 0.036 | 0.036 | 0.016 | 0.013 | 0.013 | 0.024 | CAL | CAL | 0.019 | 0.019 | 0.023 | 0.020 | 0.015 | 0.015 | 0.023 | 0.028 | 0.040 | 0.066 | 0.049 | 0.059 | 0.089 | 0.201 | 0.0401 |
| 28 | 0.235 | 0.126 | 0.252 | 0.244 | 0.245 | 0.133 | 0.170 | 0.039 | 0.032 | 0.027 | 0.016 | 0.030 | 0.026 | 0.014 | 0.009 | 0.003 | 0.000 | 0.007 | 0.140 | 0.131 | 0.121 | 0.044 | 0.061 | 0.046 | 0.0896 |
| 29 | 0.025 | 0.010 | 0.007 | 0.006 | 0.006 | 0.012 | 0.013 | 0.021 | 0.042 | 0.060 | 0.036 | 0.012 | 0.006 | 0.007 | 0.006 | 0.005 | 0.007 | 0.012 | 0.019 | 0.023 | 0.028 | 0.030 | 0.020 | 0.011 | 0.0177 |
| 30 | 0.005 | 0.004 | 0.004 | 0.004 | 0.006 | 0.009 | 0.013 | 0.011 | 0.012 | CAL | 0.058 | 0.008 | 0.006 | 0.006 | 0.005 | 0.006 | 0.007 | 0.014 | 0.020 | 0.019 | 0.017 | 0.018 | 0.015 | 0.017 | 0.0123 |

Monthly Average = 0.0421

Maximum Hourly Average was 0.255 at Hour 18 on Day 16 with 1 occurences and there were no Hourly Violations
Maximum Daily Average was 0.0957 on Day 2 with 1 occurences and there were no Daily Violations
Operating Efficiency = 75.7 percent
ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data
[CEM 1990]

MEPA - Kuwait

June 1991

Frequency Distribution

Hourly Averages for NOx in ppm

| Concentration | # of Hours | Percentage |
| --- | --- | --- |
| 0.000 - 0.050 | 385 | 72.1 |
| 0.051 - 0.110 | 106 | 19.9 |
| 0.111 - 0.210 | 35 | 6.6 |
| 0.211+ | 8 | 1.5 |

MEPA - Kuwait
June 1991
Hourly Averages for NO2 in ppm

| Hour / Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.030 | 0.018 | 0.023 | 0.029 | 0.017 | 0.020 | 0.048 | 0.042 | 0.032 | CAL | 0.031 | 0.026 | 0.027 | 0.026 | 0.023 | 0.024 | 0.038 | 0.042 | 0.054 | 0.059 | 0.064 | 0.057 | 0.052 | 0.043 | 0.0359 |
| 2 | 0.026 | 0.041 | 0.033 | 0.028 | 0.023 | 0.039 | 0.036 | 0.049 | 0.050 | 0.042 | 0.041 | 0.055 | 0.055 | 0.049 | 0.034 | 0.058 | 0.064 | 0.062 | 0.062 | 0.059 | 0.047 | 0.047 | 0.051 | 0.038 | 0.0454 |
| 3 | 0.019 | 0.016 | 0.004 | 0.001 | 0.003 | 0.015 | 0.028 | 0.034 | 0.028 | CAL | 0.028 | 0.020 | 0.013 | 0.013 | 0.013 | 0.016 | 0.011 | 0.011 | 0.015 | 0.018 | 0.017 | 0.052 | 0.045 | 0.037 | 0.0199 |
| 4 | 0.055 | 0.057 | 0.064 | 0.051 | 0.021 | 0.020 | 0.042 | 0.041 | 0.035 | 0.023 | 0.019 | 0.020 | 0.028 | 0.025 | 0.015 | 0.013 | 0.016 | 0.013 | 0.015 | 0.013 | 0.018 | 0.033 | 0.064 | 0.068 | 0.0320 |
| 5 | 0.065 | 0.042 | 0.031 | 0.028 | 0.038 | 0.038 | 0.036 | 0.027 | 0.035 | 0.014 | 0.009 | 0.007 | 0.005 | 0.008 | 0.005 | 0.006 | 0.008 | 0.016 | 0.040 | 0.047 | 0.050 | 0.052 | 0.051 | 0.047 | 0.0294 |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 7 | 0.028 | 0.027 | 0.020 | 0.007 | 0.005 | 0.021 | 0.018 | 0.035 | 0.038 | 0.026 | 0.016 | 0.014 | 0.009 | 0.006 | 0.007 | 0.008 | 0.011 | 0.015 | 0.018 | 0.017 | 0.022 | 0.032 | 0.046 | 0.047 | 0.0205 |
| 8 | 0.041 | 0.033 | 0.032 | 0.031 | 0.036 | 0.033 | 0.033 | 0.026 | 0.023 | CAL | 0.018 | 0.011 | 0.011 | 0.013 | 0.013 | 0.014 | 0.023 | 0.018 | 0.020 | 0.022 | 0.025 | 0.034 | 0.056 | 0.030 | 0.0259 |
| 9 | 0.026 | 0.005 | 0.007 | 0.018 | 0.031 | 0.014 | 0.011 | 0.017 | 0.021 | 0.032 | 0.026 | 0.026 | 0.021 | 0.010 | 0.010 | 0.008 | 0.011 | 0.013 | 0.014 | 0.020 | 0.019 | 0.030 | 0.057 | 0.050 | 0.0207 |
| 10 | 0.039 | 0.011 | 0.008 | 0.014 | 0.009 | 0.011 | 0.036 | 0.042 | 0.036 | CAL | CAL | 0.026 | 0.017 | 0.013 | 0.014 | 0.015 | 0.020 | 0.028 | 0.051 | 0.049 | 0.041 | 0.040 | 0.041 | 0.032 | 0.0270 |
| 11 | 0.039 | 0.030 | 0.025 | 0.024 | 0.042 | 0.036 | 0.022 | 0.044 | 0.034 | 0.031 | 0.014 | 0.007 | 0.009 | 0.010 | 0.009 | 0.018 | 0.022 | 0.028 | 0.041 | 0.032 | 0.031 | 0.031 | 0.039 | 0.029 | 0.0270 |
| 12 | 0.016 | 0.009 | 0.005 | 0.005 | 0.007 | 0.007 | 0.016 | 0.028 | 0.046 | CAL | 0.034 | 0.029 | 0.027 | 0.026 | 0.016 | 0.008 | 0.006 | 0.009 | 0.048 | 0.054 | 0.052 | 0.060 | 0.066 | 0.054 | 0.0273 |
| 13 | 0.047 | 0.031 | 0.033 | 0.035 | 0.032 | 0.027 | 0.037 | 0.038 | 0.028 | 0.025 | 0.023 | 0.019 | 0.020 | 0.018 | 0.016 | 0.020 | 0.030 | 0.039 | 0.063 | 0.044 | 0.019 | 0.017 | 0.054 | 0.043 | 0.0312 |
| 14 | 0.026 | 0.017 | 0.016 | 0.016 | 0.009 | 0.015 | 0.015 | 0.018 | 0.020 | 0.020 | 0.015 | 0.017 | 0.013 | 0.014 | 0.013 | 0.033 | 0.039 | 0.064 | 0.062 | 0.045 | 0.029 | 0.011 | 0.010 | 0.009 | 0.0227 |
| 15 | 0.007 | 0.008 | 0.015 | 0.003 | 0.005 | 0.008 | 0.009 | 0.028 | 0.030 | CAL | 0.040 | 0.050 | 0.037 | 0.024 | 0.021 | 0.024 | 0.041 | 0.067 | 0.073 | 0.038 | 0.002 | 0.034 | 0.060 | 0.027 | 0.0283 |
| 16 | 0.013 | 0.003 | 0.005 | 0.000 | 0.003 | 0.014 | 0.029 | 0.041 | 0.049 | 0.045 | 0.050 | 0.057 | 0.048 | 0.018 | 0.012 | 0.023 | 0.059 | 0.064 | 0.068 | 0.069 | 0.068 | 0.068 | 0.061 | 0.043 | 0.0379 |
| 17 | 0.009 | 0.005 | 0.004 | 0.002 | 0.002 | 0.003 | 0.007 | 0.016 | 0.012 | CAL | 0.006 | 0.005 | 0.004 | 0.006 | 0.003 | 0.006 | 0.010 | 0.013 | 0.013 | 0.013 | 0.012 | 0.012 | 0.008 | 0.007 | 0.0077 |
| 18 | 0.004 | 0.007 | 0.005 | 0.012 | 0.012 | 0.006 | 0.005 | 0.007 | 0.007 | 0.007 | 0.007 | 0.006 | 0.007 | 0.005 | 0.004 | 0.005 | 0.009 | 0.015 | 0.017 | 0.024 | 0.022 | 0.021 | 0.019 | 0.018 | 0.0105 |
| 19 | 0.014 | 0.013 | 0.010 | 0.006 | 0.007 | 0.013 | 0.020 | 0.023 | 0.015 | 0.023 | 0.022 | 0.010 | 0.019 | 0.016 | 0.011 | 0.016 | 0.017 | 0.036 | 0.067 | 0.074 | 0.023 | 0.021 | 0.015 | 0.013 | 0.0210 |
| 20 | 0.022 | 0.024 | 0.017 | 0.005 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.0170 |
| 21 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 22 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 23 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 24 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 25 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 26 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.027 | 0.032 | 0.033 | 0.024 | 0.021 | 0.021 | 0.033 | 0.038 | 0.051 | 0.055 | 0.040 | 0.049 | 0.062 | 0.0374 |
| 27 | 0.042 | 0.025 | 0.031 | 0.029 | 0.011 | 0.009 | 0.009 | 0.017 | CAL | CAL | 0.013 | 0.013 | 0.017 | 0.015 | 0.009 | 0.010 | 0.017 | 0.021 | 0.034 | 0.055 | 0.040 | 0.048 | 0.060 | 0.063 | 0.0267 |
| 28 | 0.069 | 0.059 | 0.061 | 0.064 | 0.065 | 0.059 | 0.067 | 0.029 | 0.024 | 0.019 | 0.011 | 0.023 | 0.019 | 0.011 | 0.007 | 0.004 | 0.000 | 0.007 | 0.065 | 0.066 | 0.070 | 0.037 | 0.049 | 0.039 | 0.0385 |
| 29 | 0.020 | 0.006 | 0.003 | 0.002 | 0.003 | 0.009 | 0.010 | 0.016 | 0.036 | 0.052 | 0.029 | 0.009 | 0.002 | 0.004 | 0.003 | 0.003 | 0.005 | 0.009 | 0.017 | 0.020 | 0.025 | 0.027 | 0.017 | 0.008 | 0.0140 |
| 30 | 0.003 | 0.001 | 0.001 | 0.001 | 0.003 | 0.006 | 0.009 | 0.008 | 0.009 | CAL | 0.007 | 0.007 | 0.004 | 0.004 | 0.003 | 0.003 | 0.005 | 0.013 | 0.017 | 0.018 | 0.015 | 0.016 | 0.013 | 0.014 | 0.0078 |

Monthly Average = 0.0256

Maximum Hourly Average was 0.074 at Hour 20 on Day 19 with 1 occurences and there were no Hourly Violations
Maximum Daily Average was 0.0454 on Day 2 with 1 occurences and there were no Daily Violations
Operating Efficiency = 75.7 percent
ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data
[CEM 1990]

MEPA - Kuwait
June 1991
Frequency Distribution
Hourly Averages for $NO_2$ in ppm

| Concentration | # of Hours | Percentage |
|---|---|---|
| 0.000 - 0.050 | 469 | 87.8 |
| 0.051 - 0.110 | 65 | 12.2 |
| 0.111 - 0.210 | 0 | 0.0 |
| 0.211+ | 0 | 0.0 |

MEPA - Kuwait
June 1991
Hourly Averages for NO in ppm

| Day \ Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.041 | 0.013 | 0.016 | 0.026 | 0.008 | 0.008 | 0.051 | 0.030 | 0.012 | CAL | 0.017 | 0.012 | 0.017 | 0.014 | 0.012 | 0.012 | 0.022 | 0.013 | 0.032 | 0.028 | 0.085 | 0.051 | 0.127 | 0.057 | 0.0306 |
| 2 | 0.011 | 0.101 | 0.047 | 0.022 | 0.036 | 0.077 | 0.023 | 0.041 | 0.029 | 0.014 | 0.012 | 0.025 | 0.022 | 0.014 | 0.001 | 0.032 | 0.068 | 0.073 | 0.154 | 0.110 | 0.033 | 0.099 | 0.109 | 0.036 | 0.0495 |
| 3 | 0.010 | 0.010 | 0.001 | 0.001 | 0.005 | 0.009 | 0.019 | 0.022 | 0.016 | CAL | 0.052 | 0.007 | 0.004 | 0.004 | 0.002 | 0.006 | 0.003 | 0.001 | 0.000 | 0.000 | 0.001 | 0.038 | 0.028 | 0.024 | 0.0114 |
| 4 | 0.057 | 0.066 | 0.089 | 0.064 | 0.011 | 0.012 | 0.036 | 0.036 | 0.023 | 0.015 | 0.012 | 0.011 | 0.018 | 0.015 | 0.006 | 0.002 | 0.003 | 0.000 | 0.000 | 0.000 | 0.001 | 0.018 | 0.099 | 0.122 | 0.0298 |
| 5 | 0.117 | 0.043 | 0.027 | 0.024 | 0.043 | 0.044 | 0.040 | 0.036 | 0.039 | 0.020 | 0.009 | 0.005 | 0.002 | 0.000 | 0.000 | 0.000 | 0.002 | 0.002 | 0.001 | 0.001 | 0.005 | 0.027 | 0.081 | 0.090 | 0.0274 |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 7 | 0.066 | 0.047 | 0.046 | 0.044 | 0.067 | 0.051 | 0.051 | 0.033 | 0.049 | 0.005 | 0.001 | 0.001 | 0.001 | 0.004 | 0.002 | 0.002 | 0.000 | 0.002 | 0.029 | 0.047 | 0.078 | 0.090 | 0.080 | 0.023 | 0.0341 |
| 8 | 0.002 | 0.011 | 0.024 | 0.001 | 0.001 | 0.002 | 0.005 | 0.006 | 0.007 | CAL | 0.007 | 0.002 | 0.004 | 0.003 | 0.002 | 0.004 | 0.007 | 0.000 | 0.000 | 0.000 | 0.000 | 0.011 | 0.070 | 0.017 | 0.0081 |
| 9 | 0.011 | 0.001 | 0.001 | 0.010 | 0.031 | 0.006 | 0.001 | 0.003 | 0.006 | 0.016 | 0.012 | 0.010 | 0.007 | 0.001 | 0.003 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.009 | 0.057 | 0.048 | 0.0097 |
| 10 | 0.028 | 0.000 | 0.000 | 0.001 | 0.000 | 0.002 | 0.029 | 0.034 | 0.026 | CAL | CAL | 0.013 | 0.005 | 0.001 | 0.002 | 0.000 | 0.000 | 0.001 | 0.025 | 0.024 | 0.018 | 0.000 | 0.001 | 0.000 | 0.0095 |
| 11 | 0.019 | 0.003 | 0.002 | 0.009 | 0.045 | 0.027 | 0.006 | 0.033 | 0.005 | 0.006 | 0.001 | 0.001 | 0.001 | 0.000 | 0.000 | 0.004 | 0.007 | 0.007 | 0.017 | 0.007 | 0.005 | 0.002 | 0.000 | 0.001 | 0.0087 |
| 12 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.005 | 0.028 | CAL | 0.018 | 0.012 | 0.010 | 0.007 | 0.003 | 0.000 | 0.000 | 0.000 | 0.012 | 0.009 | 0.009 | 0.012 | 0.020 | 0.024 | 0.0075 |
| 13 | 0.025 | 0.010 | 0.007 | 0.003 | 0.001 | 0.009 | 0.015 | 0.010 | 0.005 | 0.005 | 0.003 | 0.003 | 0.002 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.025 | 0.006 | 0.001 | 0.002 | 0.030 | 0.002 | 0.0075 |
| 14 | 0.001 | 0.000 | 0.001 | 0.001 | 0.001 | 0.002 | 0.002 | 0.002 | 0.000 | 0.003 | 0.001 | 0.005 | 0.000 | 0.001 | 0.002 | 0.003 | 0.004 | 0.011 | 0.022 | 0.025 | 0.009 | 0.001 | 0.002 | 0.000 | 0.0041 |
| 15 | 0.001 | 0.000 | 0.011 | 0.000 | 0.000 | 0.000 | 0.000 | 0.003 | 0.003 | CAL | 0.010 | 0.025 | 0.009 | 0.001 | 0.001 | 0.000 | 0.004 | 0.077 | 0.160 | 0.097 | 0.000 | 0.035 | 0.047 | 0.002 | 0.0211 |
| 16 | 0.002 | 0.001 | 0.000 | 0.000 | 0.000 | 0.001 | 0.004 | 0.018 | 0.047 | 0.009 | 0.006 | 0.019 | 0.007 | 0.002 | 0.001 | 0.002 | 0.064 | 0.160 | 0.181 | 0.131 | 0.053 | 0.078 | 0.038 | 0.008 | 0.0347 |
| 17 | 0.001 | 0.000 | 0.001 | 0.001 | 0.000 | 0.000 | 0.000 | 0.001 | 0.002 | CAL | 0.002 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.0004 |
| 18 | 0.001 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.0002 |
| 19 | 0.000 | 0.000 | 0.000 | 0.002 | 0.000 | 0.000 | 0.003 | 0.004 | 0.003 | 0.006 | 0.004 | 0.001 | 0.003 | 0.000 | 0.000 | 0.002 | 0.001 | 0.002 | 0.010 | 0.025 | 0.001 | 0.006 | 0.002 | 0.001 | 0.0032 |
| 20 | 0.002 | 0.000 | 0.001 | 0.023 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.0065 |
| 21 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 22 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 23 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 24 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 25 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 26 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.006 | 0.006 | 0.006 | 0.006 | 0.005 | 0.005 | 0.005 | 0.005 | 0.007 | 0.009 | 0.005 | 0.011 | 0.018 | 0.0072 |
| 27 | 0.007 | 0.004 | 0.005 | 0.007 | 0.005 | 0.004 | 0.004 | 0.006 | CAL | CAL | 0.006 | 0.006 | 0.006 | 0.005 | 0.006 | 0.005 | 0.006 | 0.007 | 0.006 | 0.011 | 0.009 | 0.011 | 0.030 | 0.138 | 0.0134 |
| 28 | 0.166 | 0.067 | 0.190 | 0.180 | 0.180 | 0.075 | 0.102 | 0.009 | 0.008 | 0.008 | 0.005 | 0.007 | 0.007 | 0.003 | 0.002 | 0.000 | 0.000 | 0.000 | 0.075 | 0.065 | 0.051 | 0.007 | 0.012 | 0.007 | 0.0511 |
| 29 | 0.005 | 0.004 | 0.004 | 0.004 | 0.004 | 0.003 | 0.003 | 0.004 | 0.006 | 0.013 | 0.007 | 0.003 | 0.004 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.003 | 0.003 | 0.003 | 0.003 | 0.002 | 0.0037 |
| 30 | 0.002 | 0.003 | 0.003 | 0.003 | 0.003 | 0.002 | 0.004 | 0.003 | 0.003 | CAL | 0.051 | 0.001 | 0.002 | 0.002 | 0.001 | 0.002 | 0.002 | 0.001 | 0.003 | 0.001 | 0.002 | 0.002 | 0.001 | 0.002 | 0.0043 |
| | | | | | | | | | | | | | | | | | | | | | | | | Monthly Average = | 0.0166 |

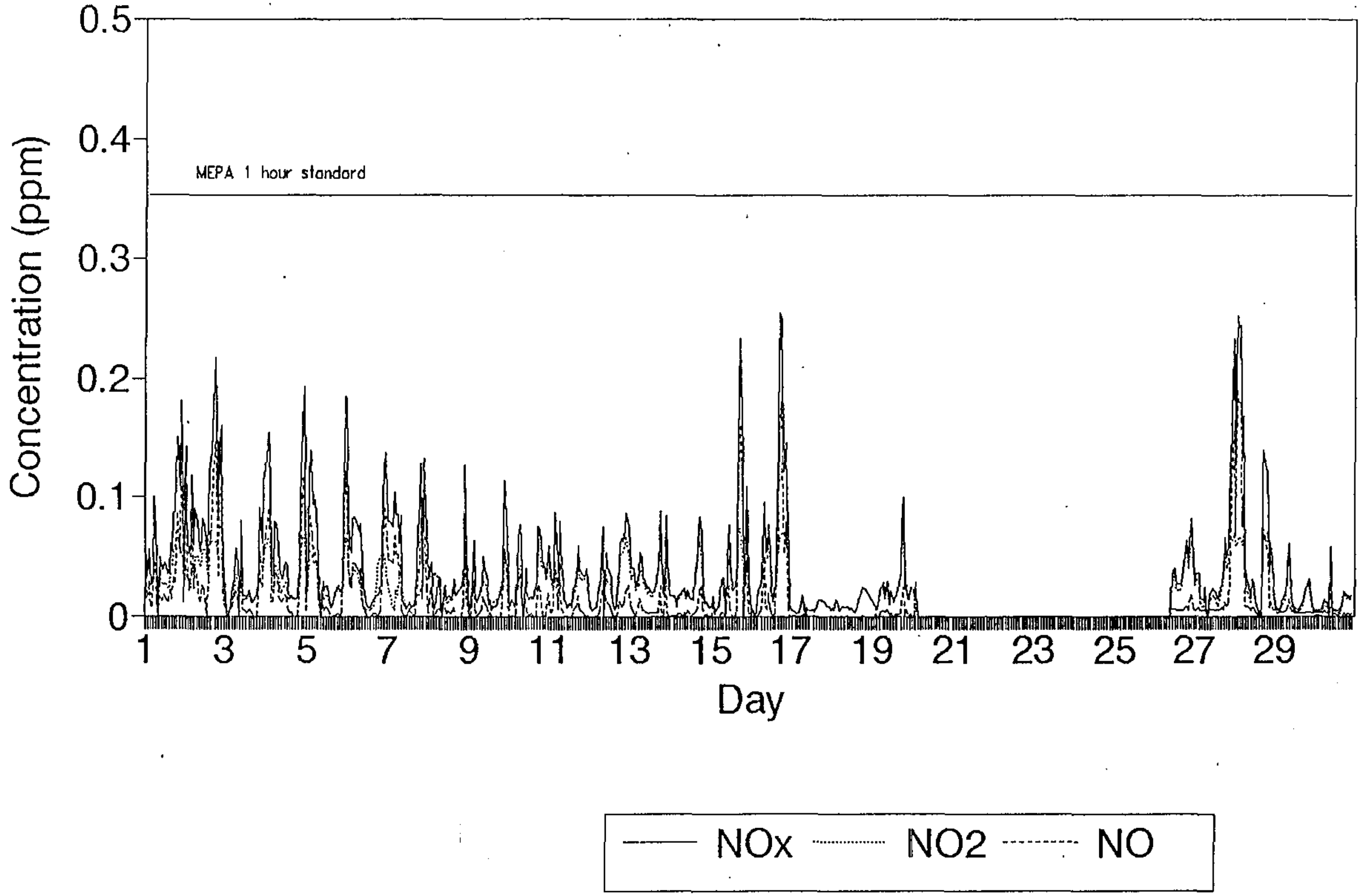
Maximum Hourly Average was 0.190 at Hour 3 on Day 28 with 1 occurences and there were no Hourly Violations
Maximum Daily Average was 0.0511 on Day 28 with 1 occurences and there were no Daily Violations
Operating Efficiency = 75.7 percent
ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data
[CEM 1990]

MEPA - Kuwait
June 1991
Frequency Distribution
Hourly Averages for NO in ppm

| Concentration | # of Hours | Percentage |
|---|---|---|
| 0.000 - 0.050 | 481 | 90.1 |
| 0.051 - 0.110 | 40 | 7.5 |
| 0.111 - 0.210 | 13 | 2.4 |
| 0.211+ | 0 | 0.0 |

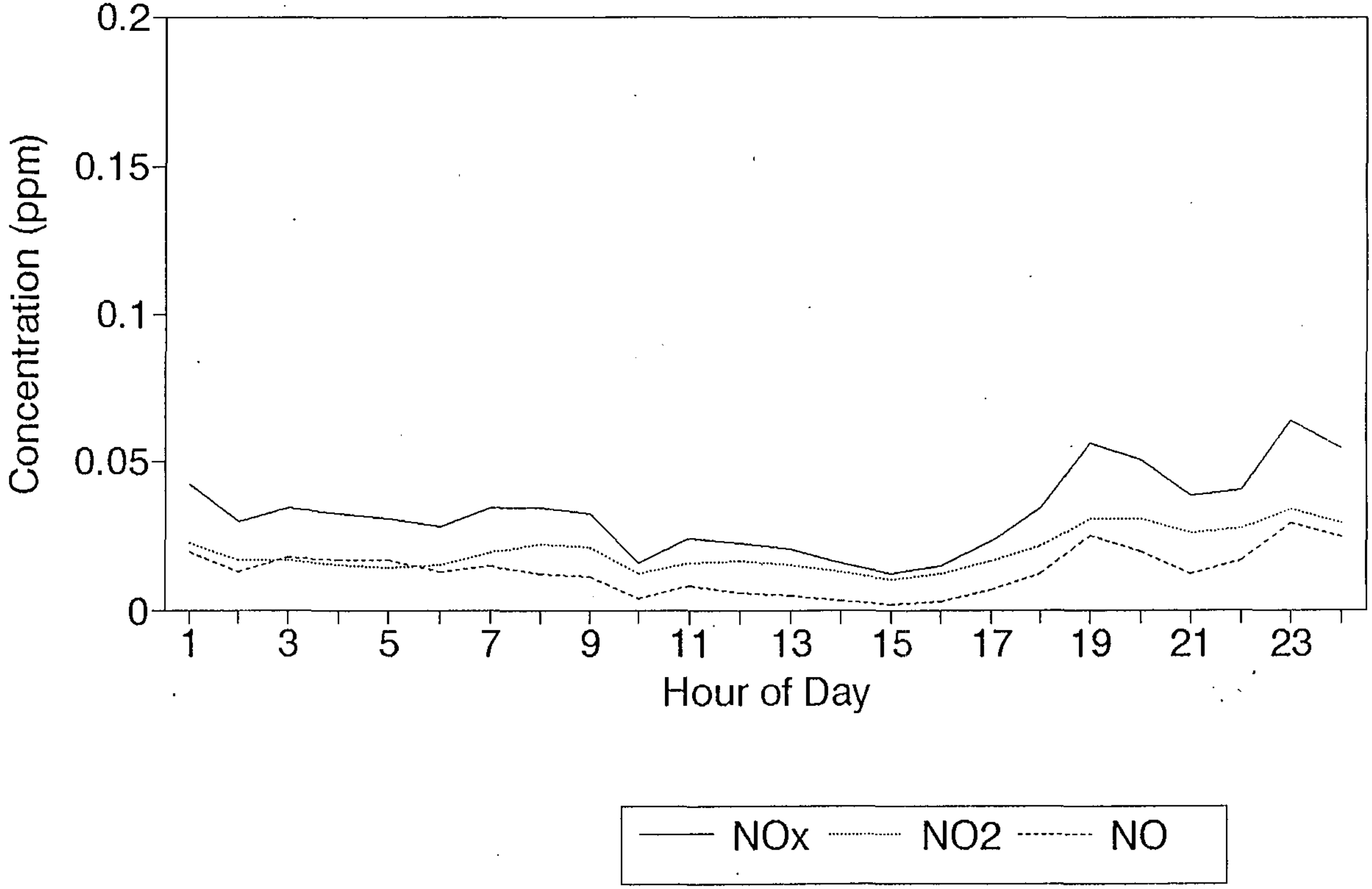
# KUWAIT

## Hourly NOX/NO2/NO - June, 1991



# KUWAIT

Diurnal NOx/NO2/NO - June, 1991

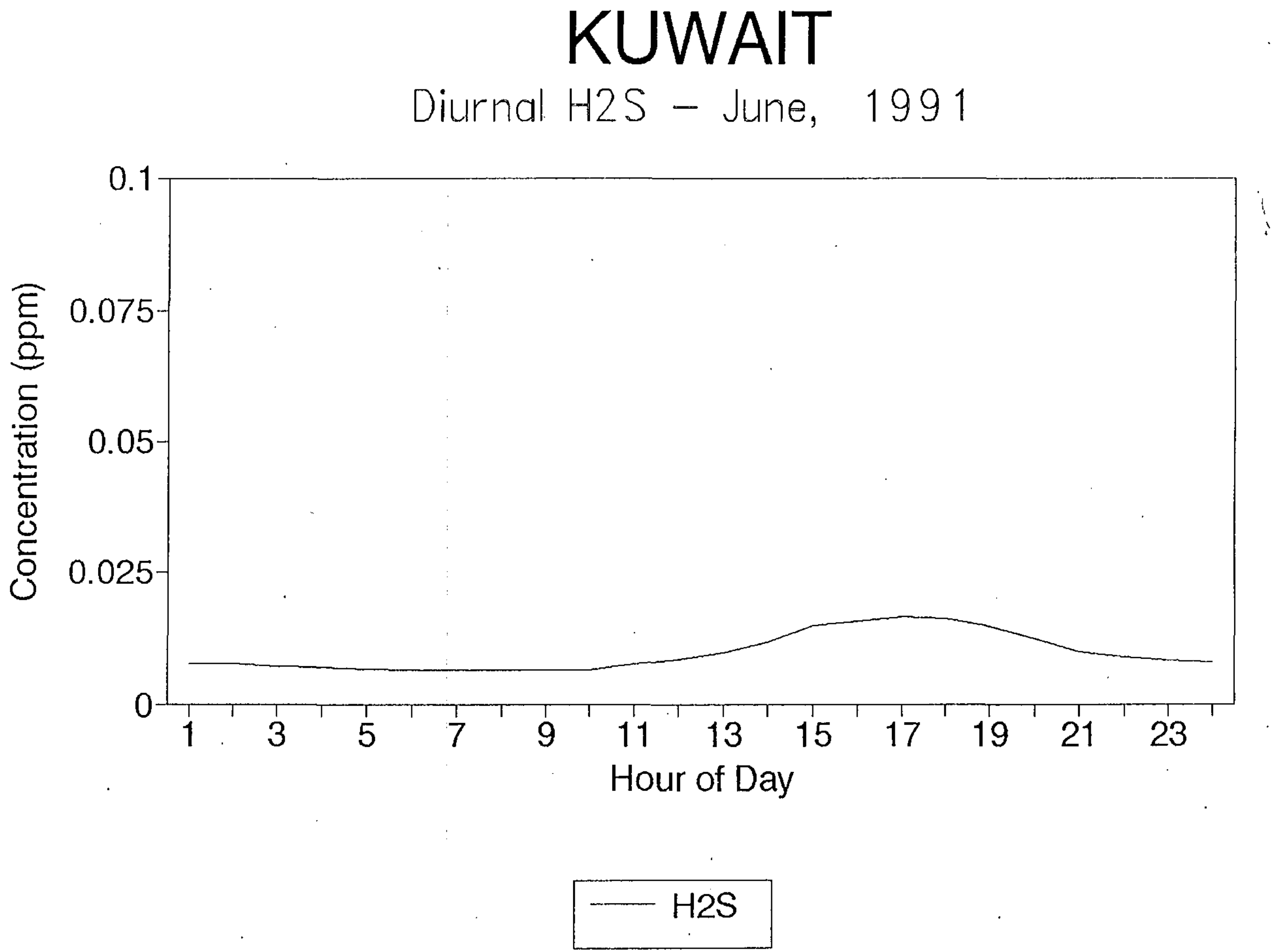


MEPA - Kuwait
June 1991
Hourly Averages for H2S in ppm

| Hour / Day | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.006 | 0.006 | 0.006 | 0.005 | 0.005 | 0.005 | 0.006 | 0.005 | 0.006 | CAL | 0.009 | 0.010 | 0.012 | 0.015 | 0.018 | 0.020 | 0.021 | 0.019 | 0.016 | 0.013 | 0.011 | 0.010 | 0.009 | 0.008 | 0.0105 |
| 2 | 0.007 | 0.007 | 0.006 | 0.006 | 0.006 | 0.006 | 0.005 | 0.006 | 0.006 | 0.006 | 0.007 | 0.008 | 0.009 | 0.010 | 0.011 | 0.012 | 0.012 | 0.012 | 0.011 | 0.010 | 0.009 | 0.009 | 0.009 | 0.008 | 0.0083 |
| 3 | 0.007 | 0.007 | 0.006 | 0.006 | 0.006 | 0.005 | 0.005 | 0.005 | 0.006 | CAL | 0.008 | 0.010 | 0.011 | 0.013 | 0.015 | 0.017 | 0.017 | 0.017 | 0.015 | 0.013 | 0.011 | 0.010 | 0.009 | 0.009 | 0.0099 |
| 4 | 0.008 | 0.006 | 0.006 | 0.006 | 0.005 | 0.005 | 0.005 | 0.005 | 0.006 | 0.008 | 0.009 | 0.010 | 0.011 | 0.013 | 0.015 | 0.016 | 0.016 | 0.015 | 0.013 | 0.012 | 0.010 | 0.009 | 0.008 | 0.008 | 0.0094 |
| 5 | 0.007 | 0.006 | 0.006 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.006 | 0.006 | 0.007 | 0.008 | 0.009 | 0.011 | 0.013 | 0.016 | 0.019 | 0.021 | 0.018 | 0.015 | 0.013 | 0.011 | 0.010 | 0.007 | 0.0098 |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 7 | 0.008 | 0.007 | 0.006 | 0.006 | 0.006 | 0.005 | 0.005 | 0.005 | 0.006 | 0.007 | 0.009 | 0.010 | 0.012 | 0.014 | 0.016 | 0.018 | 0.019 | 0.017 | 0.014 | 0.012 | 0.010 | 0.009 | 0.009 | 0.008 | 0.0099 |
| 8 | 0.007 | 0.007 | 0.006 | 0.006 | 0.006 | 0.005 | 0.005 | 0.005 | 0.006 | CAL | 0.008 | 0.010 | 0.012 | 0.014 | 0.018 | 0.023 | 0.026 | 0.026 | 0.021 | 0.016 | 0.012 | 0.010 | 0.009 | 0.007 | 0.0115 |
| 9 | 0.006 | 0.006 | 0.005 | 0.005 | 0.005 | 0.005 | 0.004 | 0.005 | 0.005 | 0.006 | 0.008 | 0.009 | 0.012 | 0.015 | 0.022 | 0.029 | 0.032 | 0.032 | 0.028 | 0.021 | 0.015 | 0.012 | 0.010 | 0.008 | 0.0127 |
| 10 | 0.007 | 0.006 | 0.005 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.005 | CAL | CAL | 0.010 | 0.012 | 0.010 | 0.031 | 0.056 | 0.071 | 0.080 | 0.077 | 0.063 | 0.045 | 0.033 | 0.024 | 0.018 | 0.0260 |
| 11 | 0.014 | 0.011 | 0.010 | 0.008 | 0.008 | 0.007 | 0.006 | 0.006 | 0.007 | 0.007 | 0.008 | 0.011 | 0.014 | 0.024 | 0.034 | 0.038 | 0.039 | 0.046 | 0.043 | 0.027 | 0.018 | 0.013 | 0.010 | 0.008 | 0.0174 |
| 12 | 0.007 | 0.006 | 0.006 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.010 | CAL | 0.016 | 0.012 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 | 0.009 | 0.008 | 0.006 | 0.006 | 0.006 | 0.005 | 0.0079 |
| 13 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.006 | 0.007 | 0.007 | 0.008 | 0.009 | 0.009 | 0.009 | 0.008 | 0.007 | 0.007 | 0.006 | 0.005 | 0.005 | 0.005 | 0.0062 |
| 14 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.006 | 0.006 | 0.006 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.007 | 0.007 | 0.006 | 0.005 | 0.005 | 0.005 | 0.005 | 0.0060 |
| 15 | 0.005 | 0.005 | 0.005 | 0.006 | 0.007 | 0.006 | 0.005 | 0.005 | 0.005 | CAL | 0.006 | 0.007 | 0.007 | 0.007 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.006 | 0.006 | 0.005 | 0.005 | 0.0063 |
| 16 | 0.008 | 0.009 | 0.009 | 0.007 | 0.007 | 0.007 | 0.007 | 0.007 | 0.006 | 0.006 | 0.006 | 0.006 | 0.007 | 0.007 | 0.030 | 0.007 | 0.007 | 0.007 | 0.006 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.0075 |
| 17 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | CAL | 0.005 | 0.006 | 0.007 | 0.009 | 0.010 | 0.010 | 0.010 | 0.010 | 0.009 | 0.008 | 0.006 | 0.006 | 0.005 | 0.004 | 0.0061 |
| 18 | 0.004 | 0.004 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.004 | 0.005 | 0.007 | 0.009 | 0.011 | 0.012 | 0.013 | 0.014 | 0.013 | 0.012 | 0.010 | 0.008 | 0.006 | 0.005 | 0.005 | 0.0068 |
| 19 | 0.004 | 0.004 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.004 | 0.005 | 0.007 | 0.008 | 0.009 | 0.008 | 0.007 | 0.007 | 0.006 | 0.005 | 0.004 | 0.005 | 0.005 | 0.006 | 0.008 | 0.0051 |
| 20 | 0.008 | 0.006 | 0.006 | 0.006 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | CAL | 0.005 | 0.006 | 0.006 | 0.006 | 0.006 | 0.005 | 0.006 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.006 | 0.0055 |
| 21 | 0.005 | 0.005 | 0.007 | 0.007 | 0.007 | 0.007 | 0.007 | 0.007 | 0.008 | 0.012 | 0.014 | 0.016 | 0.016 | 0.013 | 0.012 | 0.011 | 0.010 | 0.009 | 0.009 | 0.008 | 0.007 | 0.007 | 0.007 | 0.007 | 0.0091 |
| 22 | 0.007 | 0.009 | 0.008 | 0.009 | 0.009 | 0.009 | 0.009 | 0.009 | 0.009 | CAL | 0.009 | 0.009 | 0.009 | 0.010 | 0.011 | 0.010 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.008 | 0.007 | 0.007 | 0.0086 |
| 23 | 0.007 | 0.007 | 0.007 | 0.007 | 0.007 | 0.007 | 0.007 | 0.007 | 0.008 | 0.008 | 0.002 | 0.000 | 0.000 | 0.008 | 0.009 | 0.009 | 0.009 | 0.008 | 0.007 | 0.007 | 0.007 | 0.009 | 0.013 | 0.016 | 0.0073 |
| 24 | 0.015 | 0.014 | 0.014 | 0.013 | 0.013 | 0.015 | 0.015 | 0.014 | 0.013 | CAL | 0.012 | 0.012 | 0.013 | 0.015 | 0.017 | 0.013 | 0.011 | 0.009 | 0.007 | 0.006 | 0.006 | 0.006 | 0.009 | 0.012 | 0.0119 |
| 25 | 0.017 | 0.025 | 0.013 | 0.012 | 0.011 | 0.010 | 0.011 | 0.012 | 0.011 | 0.011 | 0.010 | 0.012 | CAL | 0.013 | 0.012 | 0.010 | 0.009 | 0.008 | 0.008 | 0.007 | 0.007 | 0.007 | 0.008 | 0.011 | 0.0111 |
| 26 | 0.013 | 0.014 | 0.015 | 0.013 | 0.012 | 0.012 | 0.011 | 0.011 | 0.011 | 0.010 | 0.010 | 0.009 | 0.009 | 0.009 | 0.009 | 0.009 | 0.008 | 0.008 | 0.008 | 0.007 | 0.007 | 0.007 | 0.007 | 0.007 | 0.0098 |
| 27 | 0.007 | 0.007 | 0.007 | 0.007 | 0.007 | 0.007 | 0.007 | 0.007 | CAL | CAL | 0.007 | 0.007 | 0.007 | 0.007 | 0.008 | 0.009 | 0.008 | 0.008 | 0.008 | 0.009 | 0.009 | 0.009 | 0.009 | 0.010 | 0.0078 |
| 28 | 0.011 | 0.011 | 0.011 | 0.012 | 0.012 | 0.011 | 0.012 | 0.011 | 0.011 | 0.076 | 0.011 | 0.011 | 0.012 | 0.013 | 0.013 | 0.013 | 0.012 | 0.011 | 0.010 | 0.009 | 0.008 | 0.007 | 0.007 | 0.007 | 0.0134 |
| 29 | 0.007 | 0.008 | 0.013 | 0.017 | 0.009 | 0.007 | 0.007 | 0.007 | 0.007 | 0.007 | 0.011 | 0.015 | 0.021 | 0.023 | 0.025 | 0.026 | 0.027 | 0.025 | 0.022 | 0.018 | 0.014 | 0.011 | 0.010 | 0.008 | 0.0144 |
| 30 | 0.007 | 0.006 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | CAL | 0.004 | 0.000 | 0.012 | 0.016 | 0.019 | 0.021 | 0.022 | 0.021 | 0.018 | 0.015 | 0.013 | 0.011 | 0.009 | 0.008 | 0.0103 |

Monthly Average = 0.0099

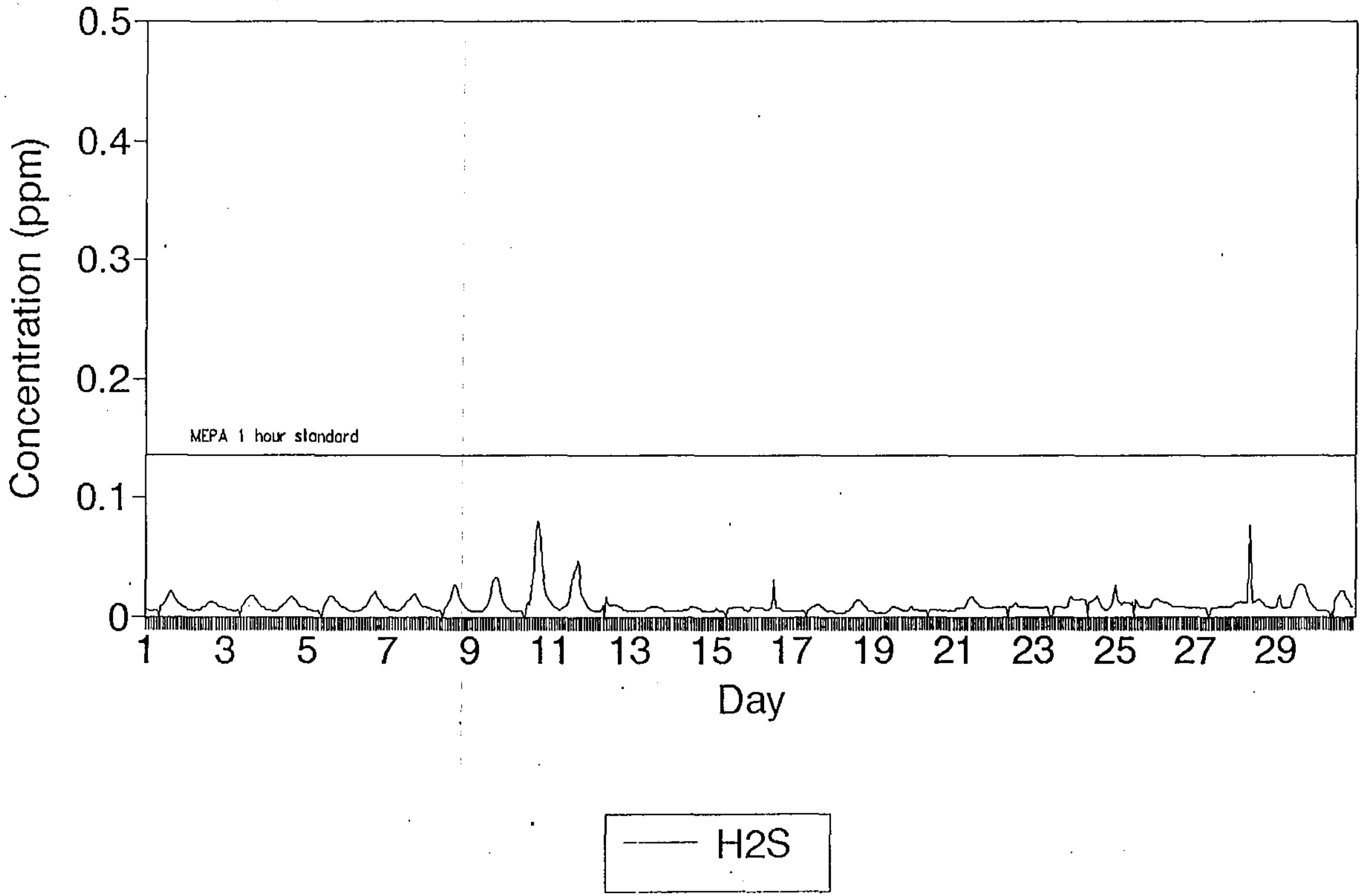
Maximum Hourly Average was 0.080 at Hour 18 on Day 10 with 1 occurences and there were no Hourly Violations
Maximum Daily Average was 0.0260 on Day 10 with 1 occurences and there were no Daily Violations
Operating Efficiency = 96.7 percent
ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data
[CEM 1990]



KUWAIT
Diurnal H2S - June, 1991
Concentration (ppm)
0.1
0.075
0.05
0.025
0
1
3
5
7
9
11
13
15
17
19
21
23
Hour of Day
H2S

# KUWAIT

Hourly H2S - June, 1991



MEPA - Kuwait
June 1991
Hourly Averages for SO2 in ppm

| Day \ Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Daily Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.019 | 0.020 | 0.045 | 0.049 | 0.020 | 0.024 | 0.071 | 0.043 | 0.031 | CAL | 0.016 | 0.014 | 0.018 | 0.019 | 0.018 | 0.018 | 0.024 | 0.015 | 0.015 | 0.011 | 0.022 | 0.015 | 0.038 | 0.021 | 0.0255 |
| 2 | 0.012 | 0.049 | 0.049 | 0.077 | 0.085 | 0.099 | 0.071 | 0.067 | 0.041 | 0.020 | 0.013 | 0.016 | 0.018 | 0.017 | 0.018 | 0.027 | 0.028 | 0.023 | 0.034 | 0.029 | 0.014 | 0.028 | 0.035 | 0.019 | 0.0370 |
| 3 | 0.011 | 0.010 | 0.005 | 0.005 | 0.005 | 0.010 | 0.016 | 0.018 | 0.014 | CAL | 0.034 | 0.009 | 0.008 | 0.009 | 0.010 | 0.012 | 0.010 | 0.008 | 0.007 | 0.014 | 0.005 | 0.020 | 0.018 | 0.016 | 0.0119 |
| 4 | 0.027 | 0.029 | 0.039 | 0.032 | 0.013 | 0.012 | 0.024 | 0.022 | 0.016 | 0.012 | 0.010 | 0.011 | 0.015 | 0.014 | 0.011 | 0.010 | 0.010 | 0.007 | 0.007 | 0.006 | 0.005 | 0.010 | 0.034 | 0.041 | 0.0174 |
| 5 | 0.038 | 0.019 | 0.014 | 0.014 | 0.022 | 0.023 | 0.021 | 0.018 | 0.023 | 0.016 | 0.014 | 0.004 | 0.004 | 0.006 | 0.006 | 0.008 | 0.009 | 0.011 | 0.015 | 0.017 | 0.023 | 0.029 | 0.023 | 0.006 | 0.0160 |
| 6 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ***** |
| 7 | 0.005 | 0.007 | 0.020 | 0.020 | 0.030 | 0.063 | 0.064 | 0.019 | 0.020 | 0.013 | 0.008 | 0.007 | 0.007 | 0.007 | 0.008 | 0.009 | 0.009 | 0.008 | 0.007 | 0.005 | 0.005 | 0.013 | 0.029 | 0.033 | 0.0173 |
| 8 | 0.026 | 0.021 | 0.021 | 0.021 | 0.029 | 0.027 | 0.026 | 0.061 | 0.031 | CAL | 0.009 | 0.006 | 0.008 | 0.009 | 0.012 | 0.016 | 0.021 | 0.015 | 0.009 | 0.006 | 0.005 | 0.008 | 0.032 | 0.012 | 0.0187 |
| 9 | 0.010 | 0.004 | 0.042 | 0.130 | 0.062 | 0.012 | 0.006 | 0.012 | 0.020 | 0.015 | 0.011 | 0.012 | 0.011 | 0.009 | 0.013 | 0.017 | 0.019 | 0.019 | 0.015 | 0.009 | 0.006 | 0.008 | 0.028 | 0.024 | 0.0214 |
| 10 | 0.016 | 0.003 | 0.003 | 0.003 | 0.002 | 0.003 | 0.016 | 0.018 | 0.018 | CAL | CAL | 0.010 | 0.010 | 0.014 | 0.026 | 0.041 | 0.054 | 0.066 | 0.080 | 0.061 | 0.040 | 0.035 | 0.066 | 0.031 | 0.0280 |
| 11 | 0.036 | 0.029 | 0.015 | 0.010 | 0.038 | 0.078 | 0.061 | 0.064 | 0.006 | 0.004 | 0.004 | 0.004 | 0.007 | 0.013 | 0.021 | 0.028 | 0.031 | 0.040 | 0.040 | 0.018 | 0.009 | 0.004 | 0.010 | 0.016 | 0.0244 |
| 12 | 0.002 | 0.000 | 0.001 | 0.001 | 0.011 | 0.008 | 0.007 | 0.006 | 0.022 | CAL | 0.020 | 0.015 | 0.014 | 0.012 | 0.006 | 0.003 | 0.002 | 0.002 | 0.009 | 0.006 | 0.004 | 0.004 | 0.006 | 0.007 | 0.0073 |
| 13 | 0.014 | 0.009 | 0.008 | 0.009 | 0.008 | 0.008 | 0.010 | 0.008 | 0.014 | 0.012 | 0.004 | 0.006 | 0.009 | 0.012 | 0.018 | 0.005 | 0.003 | 0.002 | 0.006 | 0.004 | 0.022 | 0.034 | 0.016 | 0.002 | 0.0101 |
| 14 | 0.001 | 0.002 | 0.007 | 0.018 | 0.006 | 0.008 | 0.013 | 0.015 | 0.016 | 0.018 | 0.011 | 0.006 | 0.002 | 0.001 | 0.001 | 0.003 | 0.002 | 0.002 | 0.006 | 0.005 | 0.002 | 0.011 | 0.011 | 0.012 | 0.0075 |
| 15 | 0.009 | 0.008 | 0.010 | 0.008 | 0.009 | 0.009 | 0.008 | 0.009 | 0.005 | CAL | 0.002 | 0.005 | 0.016 | 0.008 | 0.008 | 0.004 | 0.004 | 0.008 | 0.014 | 0.014 | 0.011 | 0.011 | 0.014 | 0.174 | 0.0160 |
| 16 | 0.134 | 0.058 | 0.061 | 0.037 | 0.034 | 0.042 | 0.060 | 0.077 | 0.073 | 0.035 | 0.029 | 0.030 | 0.021 | 0.008 | 0.006 | 0.007 | 0.010 | 0.011 | 0.014 | 0.014 | 0.013 | 0.013 | 0.012 | 0.014 | 0.0339 |
| 17 | 0.020 | 0.017 | 0.022 | 0.014 | 0.005 | 0.013 | 0.013 | 0.006 | 0.005 | CAL | 0.004 | 0.005 | 0.004 | 0.005 | 0.006 | 0.006 | 0.005 | 0.005 | 0.005 | 0.004 | 0.004 | 0.005 | 0.005 | 0.006 | 0.0080 |
| 18 | 0.006 | 0.009 | 0.014 | 0.031 | 0.027 | 0.010 | 0.007 | 0.006 | 0.005 | 0.004 | 0.007 | 0.006 | 0.007 | 0.008 | 0.008 | 0.009 | 0.010 | 0.006 | 0.007 | 0.006 | 0.005 | 0.008 | 0.009 | 0.008 | 0.0093 |
| 19 | 0.000 | 0.000 | 0.021 | 0.021 | 0.012 | 0.022 | 0.052 | 0.084 | 0.034 | 0.093 | 0.095 | 0.009 | 0.008 | 0.016 | 0.007 | 0.007 | 0.008 | 0.012 | 0.010 | 0.011 | 0.114 | 0.185 | 0.166 | 0.198 | 0.0494 |
| 20 | 0.102 | 0.026 | 0.014 | 0.015 | 0.013 | 0.010 | 0.006 | 0.006 | 0.019 | CAL | 0.013 | 0.009 | 0.011 | 0.011 | 0.011 | 0.013 | 0.010 | 0.008 | 0.009 | 0.012 | 0.011 | 0.010 | 0.114 | 0.038 | 0.0213 |
| 21 | 0.047 | 0.052 | 0.095 | 0.028 | 0.021 | 0.068 | 0.071 | 0.058 | 0.066 | 0.065 | 0.037 | 0.037 | 0.042 | 0.033 | 0.022 | 0.016 | 0.015 | 0.016 | 0.016 | 0.019 | 0.016 | 0.010 | 0.011 | 0.047 | 0.0378 |
| 22 | 0.189 | 0.078 | 0.035 | 0.036 | 0.066 | 0.035 | 0.042 | 0.050 | 0.024 | CAL | 0.038 | 0.016 | 0.018 | 0.021 | 0.012 | 0.010 | 0.008 | 0.007 | 0.007 | 0.007 | 0.007 | 0.007 | 0.007 | 0.007 | 0.0316 |
| 23 | 0.007 | 0.006 | 0.006 | 0.007 | 0.007 | 0.007 | 0.007 | 0.007 | 0.008 | 0.008 | 0.007 | 0.007 | 0.008 | 0.008 | 0.008 | 0.009 | 0.009 | 0.008 | 0.008 | 0.008 | 0.008 | 0.010 | 0.031 | 0.026 | 0.0094 |
| 24 | 0.012 | 0.035 | 0.026 | 0.020 | 0.056 | 0.128 | 0.176 | 0.164 | 0.191 | CAL | 0.089 | 0.071 | 0.060 | 0.038 | 0.032 | 0.039 | 0.039 | 0.023 | 0.017 | 0.020 | 0.022 | 0.075 | 0.288 | 0.168 | 0.0778 |
| 25 | 0.075 | 0.064 | 0.065 | 0.028 | 0.033 | 0.222 | 0.177 | 0.110 | 0.067 | 0.027 | 0.023 | 0.040 | CAL | 0.034 | 0.028 | 0.023 | 0.025 | 0.024 | 0.026 | 0.019 | 0.020 | 0.027 | 0.048 | 0.150 | 0.0589 |
| 26 | 0.153 | 0.191 | 0.028 | 0.025 | 0.036 | 0.033 | 0.024 | 0.027 | 0.021 | 0.017 | 0.016 | 0.014 | 0.014 | 0.013 | 0.013 | 0.013 | 0.013 | 0.012 | 0.011 | 0.012 | 0.016 | 0.017 | 0.021 | 0.019 | 0.0316 |
| 27 | 0.019 | 0.018 | 0.017 | 0.016 | 0.016 | 0.018 | 0.017 | 0.019 | CAL | CAL | 0.021 | 0.021 | 0.021 | 0.024 | 0.021 | 0.019 | 0.018 | 0.017 | 0.017 | 0.017 | 0.019 | 0.021 | 0.024 | 0.025 | 0.0193 |
| 28 | 0.025 | 0.028 | 0.028 | 0.026 | 0.028 | 0.028 | 0.027 | 0.025 | 0.028 | 0.115 | 0.029 | 0.028 | 0.029 | 0.028 | 0.030 | 0.043 | 0.057 | 0.040 | 0.047 | 0.042 | 0.047 | 0.041 | 0.040 | 0.030 | 0.0370 |
| 29 | 0.020 | 0.018 | 0.030 | 0.028 | 0.018 | 0.014 | 0.014 | 0.013 | 0.013 | 0.017 | 0.016 | 0.017 | 0.020 | 0.023 | 0.024 | 0.025 | 0.025 | 0.024 | 0.022 | 0.018 | 0.016 | 0.014 | 0.012 | 0.011 | 0.0188 |
| 30 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 | 0.011 | 0.013 | 0.011 | 0.012 | CAL | 0.037 | 0.017 | 0.021 | 0.018 | 0.019 | 0.021 | 0.021 | 0.021 | 0.018 | 0.016 | 0.014 | 0.013 | 0.012 | 0.013 | 0.0156 |
| | | | | | | | | | | | | | | | | | | | | | | Monthly Average = | | | 0.0247 |

Maximum Hourly Average was 0.288 at Hour 23 on Day 24 with 1 occurences and the Number of Hourly Violations were 1

Maximum Daily Average was 0.0778 on Day 24 with 1 occurences and there were no Daily Violations

Operating Efficiency = 96.7 percent

ND = no data, ZS = zero/span, CAL = calibration, IR = repair, RL = relocation, OFF = off, AZS = daily zero/span, INS = insufficient data

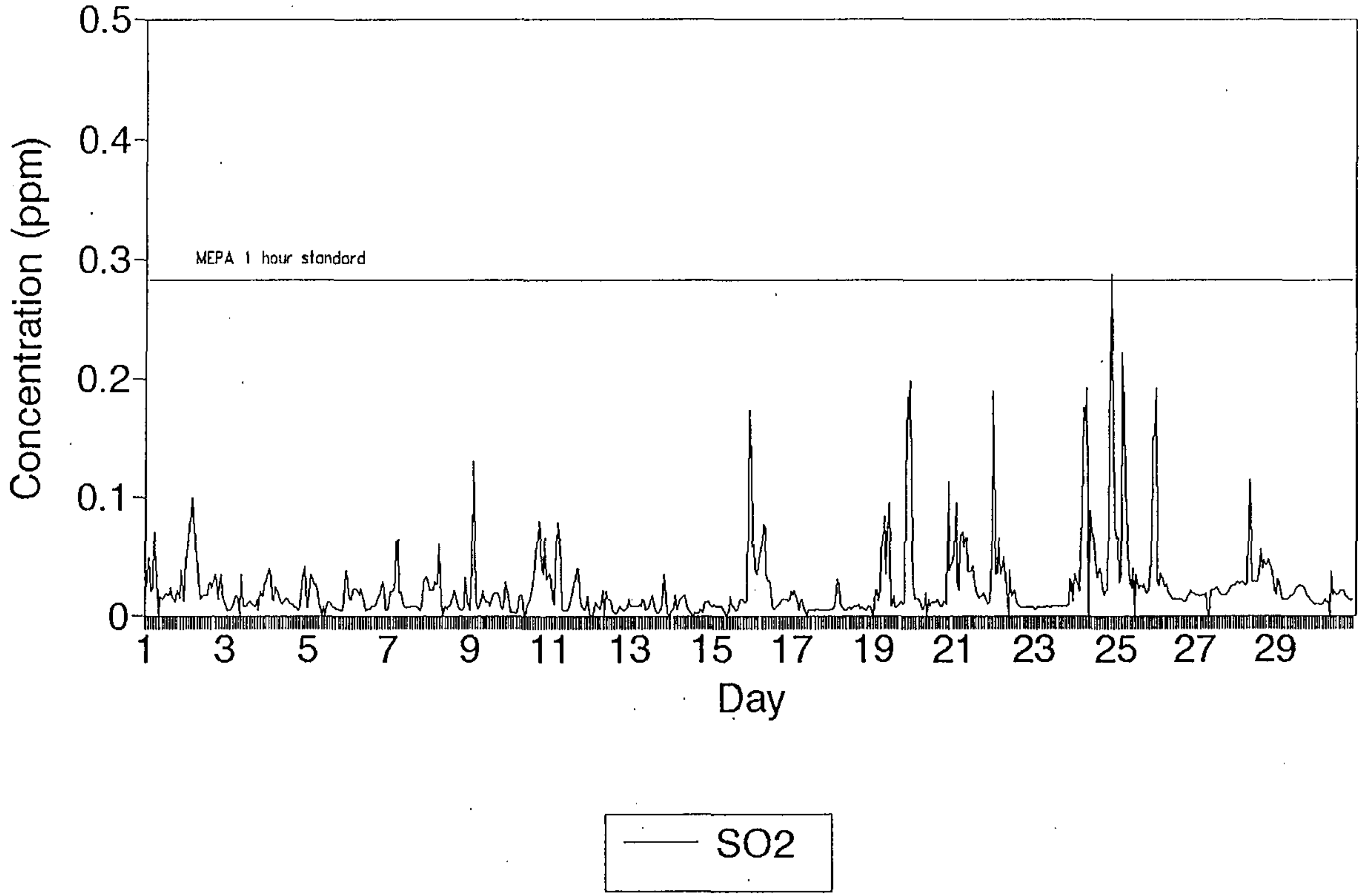
[CEM 1990]

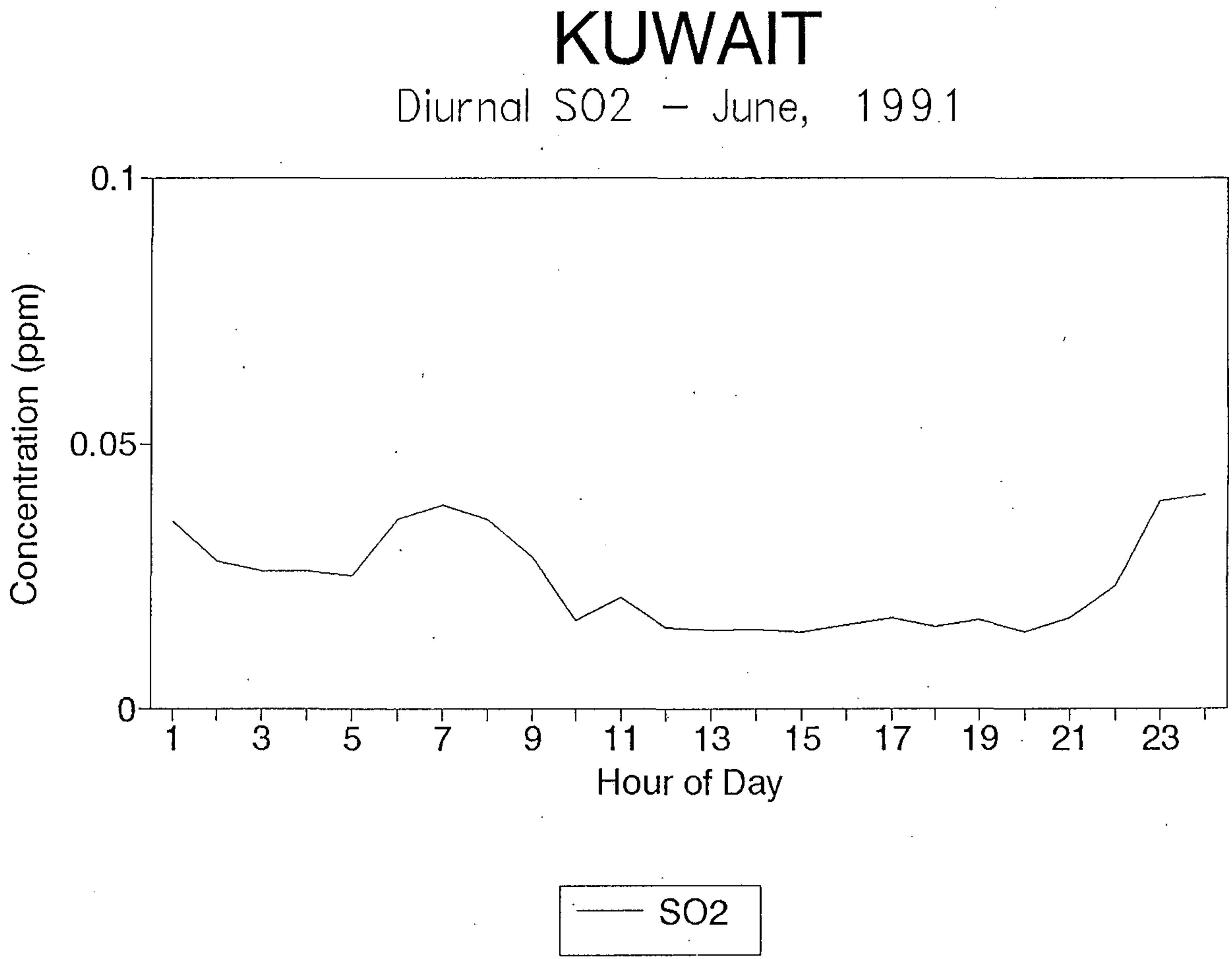
MEPA - Kuwait
June 1991
Frequency Distribution
Hourly Averages for SO2 in ppm

| Concentration | # of Hours | Percentage |
|---|---|---|
| 0.000 - 0.020 | 437 | 64.2 |
| 0.021 - 0.060 | 184 | 27.0 |
| 0.061 - 0.110 | 39 | 5.7 |
| 0.111 - 0.170 | 11 | 1.6 |
| 0.171 - 0.340 | 10 | 1.5 |
| 0.341+ | 0 | 0.0 |

# KUWAIT

Hourly SO2 - June, 1991




KUWAIT
Diurnal SO2 – June, 1991
Concentration (ppm)
0.1
0.05
0
1
3
5
7
9
11
13
15
17
19
21
23
Hour of Day
SO2

[SEPTEMBER]

DRAFT

# AMBIENT AIR MONITORING DATA
Dammam

[KAFJI]

Meteorology and Environmental Protection Administration
Kingdom of Saudi Arabia

MEPA - Kafji

| | SO2 ppm | NO ppm | NO2 ppm | NOx ppm | O3 ppm | NH3 ppm | H2S ppm |
|---|---|---|---|---|---|---|---|
| 11:00:00 | 0.000 | 0.003 | 0.006 | 0.009 | 0.044 | 0.00 | 0.001 |
| 12:00:00 | 0.000 | 0.001 | 0.013 | 0.014 | 0.053 | 0.00 | 0.001 |
| 13:00:00 | 0.000 | 0.001 | 0.010 | 0.011 | 0.053 | 0.00 | 0.002 |
| 14:00:00 | 0.000 | 0.001 | 0.010 | 0.011 | 0.050 | 0.00 | 0.002 |
| 15:00:00 | 0.000 | 0.001 | 0.014 | 0.016 | 0.047 | 0.00 | 0.001 |
| 16:00:00 | 0.000 | 0.001 | 0.010 | 0.010 | 0.047 | 0.00 | 0.001 |
| 17:00:00 | 0.000 | 0.002 | 0.019 | 0.021 | 0.039 | 0.00 | 0.000 |
| 18:00:00 | 0.000 | 0.002 | 0.022 | 0.024 | 0.034 | 0.00 | 0.000 |
| 19:00:00 | 0.000 | 0.008 | 0.028 | 0.035 | 0.018 | 0.00 | 0.001 |
| 20:00:00 | 0.000 | 0.005 | 0.016 | 0.020 | 0.020 | 0.00 | 0.000 |
| 21:00:00 | 0.000 | 0.003 | 0.016 | 0.018 | 0.022 | 0.00 | 0.000 |
| 22:00:00 | 0.000 | 0.003 | 0.013 | 0.015 | 0.026 | 0.00 | 0.000 |
| 23:00:00 | 0.000 | 0.002 | 0.011 | 0.013 | 0.029 | 0.00 | 0.000 |
| 24:00:00 | 0.000 | 0.002 | 0.006 | 0.008 | 0.026 | 0.00 | 0.000 |
| 09 / 10 / 91 | | | | | | | |
| 01:00:00 | 0.000 | 0.001 | 0.005 | 0.006 | 0.031 | 0.00 | 0.000 |
| 02:00:00 | 0.000 | 0.001 | 0.006 | 0.007 | 0.032 | 0.00 | 0.000 |
| 03:00:00 | 0.000 | 0.001 | 0.006 | 0.007 | 0.031 | 0.00 | 0.000 |
| 04:00:00 | 0.000 | 0.001 | 0.006 | 0.007 | 0.031 | 0.00 | 0.000 |
| 05:00:00 | 0.000 | 0.001 | 0.005 | 0.006 | 0.030 | 0.00 | 0.000 |
| 06:00:00 | 0.000 | 0.001 | 0.005 | 0.006 | 0.029 | 0.00 | 0.000 |
| 07:00:00 | 0.000 | 0.003 | 0.008 | 0.010 | 0.029 | 0.00 | 0.000 |
| 08:00:00 | 0.000 | 0.003 | 0.010 | 0.014 | 0.031 | 0.00 | 0.000 |
| 09:00:00 | 0.000 | 0.002 | 0.011 | 0.013 | 0.038 | 0.00 | 0.000 |
| 10:00:00 | 0.000 | 0.004 | 0.014 | 0.019 | 0.034 | 0.00 | 0.000 |
| 11:00:00 | 0.000 | 0.002 | 0.009 | 0.011 | 0.041 | 0.00 | 0.000 |
| 12:00:00 | 0.000 | 0.003 | 0.014 | 0.017 | 0.052 | 0.00 | 0.001 |
| 13:00:00 | 0.000 | 0.002 | 0.013 | 0.015 | 0.051 | 0.00 | 0.002 |
| 14:00:00 | 0.000 | 0.002 | 0.010 | 0.011 | 0.054 | 0.00 | 0.001 |
| 15:00:00 | 0.000 | 0.002 | 0.007 | 0.009 | 0.048 | 0.00 | 0.001 |
| 16:00:00 | 0.000 | 0.002 | 0.012 | 0.014 | 0.038 | 0.00 | 0.001 |
| 17:00:00 | 0.000 | 0.011 | 0.036 | 0.047 | 0.022 | 0.00 | 0.001 |
| 18:00:00 | 0.000 | 0.012 | 0.034 | 0.046 | 0.020 | 0.00 | 0.001 |
| 19:00:00 | 0.000 | 0.008 | 0.042 | 0.050 | 0.012 | 0.00 | 0.001 |
| 20:00:00 | 0.000 | 0.014 | 0.050 | 0.063 | 0.006 | 0.00 | 0.001 |
| 21:00:00 | 0.000 | 0.003 | 0.029 | 0.032 | 0.020 | 0.00 | 0.001 |
| 22:00:00 | 0.000 | 0.004 | 0.027 | 0.030 | 0.020 | 0.00 | 0.001 |
| 23:00:00 | 0.000 | 0.008 | 0.035 | 0.042 | 0.010 | 0.00 | 0.002 |
| 24:00:00 | 0.000 | 0.002 | 0.009 | 0.011 | 0.022 | 0.00 | 0.001 |
| 09 / 11 / 91 | | | | | | | |
| 01:00:00 | 0.000 | 0.002 | 0.008 | 0.011 | 0.019 | 0.00 | 0.002 |
| 02:00:00 | 0.000 | 0.000 | 0.007 | 0.006 | 0.021 | 0.00 | 0.002 |
| 03:00:00 | 0.000 | 0.001 | 0.004 | 0.005 | 0.024 | 0.00 | 0.003 |
| 04:00:00 | 0.000 | 0.001 | 0.003 | 0.004 | 0.024 | 0.00 | 0.004 |
| 05:00:00 | 0.000 | 0.001 | 0.004 | 0.005 | 0.024 | 0.00 | 0.003 |
| 06:00:00 | 0.000 | 0.001 | 0.005 | 0.006 | 0.024 | 0.00 | 0.002 |
| 07:00:00 | 0.000 | 0.003 | 0.005 | 0.008 | 0.025 | 0.00 | 0.001 |
| 08:00:00 | 0.000 | 0.003 | 0.009 | 0.012 | 0.023 | 0.00 | 0.002 |

MEPA - Kafji

| | SO2 ppm | NO ppm | NO2 ppm | NOx ppm | O3 ppm | NH3 ppm | H2S ppm |
|---|---|---|---|---|---|---|---|
| 09:00:00 | 0.000 | 0.002 | 0.012 | 0.014 | 0.030 | 0.00 | 0.001 |
| 10:00:00 | 0.000 | 0.003 | 0.012 | 0.015 | 0.037 | 0.00 | 0.001 |
| 11:00:00 | 0.000 | 0.001 | 0.009 | 0.010 | 0.039 | 0.00 | 0.001 |
| 12:00:00 | 0.000 | 0.002 | 0.006 | 0.008 | 0.038 | 0.00 | 0.002 |
| 13:00:00 | 0.000 | 0.002 | 0.003 | 0.004 | 0.041 | 0.00 | 0.002 |
| 14:00:00 | 0.000 | 0.002 | 0.002 | 0.004 | 0.037 | 0.00 | 0.003 |
| 15:00:00 | 0.000 | 0.002 | 0.003 | 0.004 | 0.037 | 0.00 | 0.003 |
| 16:00:00 | 0.000 | 0.002 | 0.004 | 0.006 | 0.034 | 0.00 | 0.002 |
| 17:00:00 | 0.000 | 0.002 | 0.005 | 0.007 | 0.033 | 0.00 | 0.001 |
| 18:00:00 | 0.000 | 0.003 | 0.009 | 0.013 | 0.019 | 0.00 | 0.001 |
| 19:00:00 | 0.000 | 0.005 | 0.008 | 0.013 | 0.010 | 0.00 | 0.001 |
| 20:00:00 | 0.000 | 0.005 | 0.010 | 0.015 | 0.012 | 0.00 | 0.001 |
| 21:00:00 | 0.000 | 0.004 | 0.017 | 0.020 | 0.010 | 0.00 | 0.001 |
| 22:00:00 | 0.000 | 0.006 | 0.022 | 0.028 | 0.010 | 0.00 | 0.000 |
| 23:00:00 | 0.000 | 0.003 | 0.020 | 0.023 | 0.011 | 0.00 | 0.001 |
| 24:00:00 | 0.000 | 0.002 | 0.008 | 0.010 | 0.018 | 0.00 | 0.000 |
| 09 / 12 / 91 | | | | | | | |
| 01:00:00 | 0.000 | 0.001 | 0.005 | 0.006 | 0.024 | 0.00 | 0.000 |

MEPA - Kafji

| | DUST mg/m3 | WS m/sec | WD degrees | TEMP C | HUMIDITY % | RAD watts | PRESS mb |
|---|---|---|---|---|---|---|---|
| 09 / 07 / 91 | | | | | | | |
| 14:00:00 | 0.018 | 4.0 | 50 | 32.4 | 58.0 | 341.5 | 997.2 |
| 15:00:00 | 0.014 | 3.9 | 53 | 32.3 | 55.0 | 267.3 | 995.5 |
| 16:00:00 | 0.013 | 3.3 | 58 | 31.5 | 68.6 | 212.9 | 993.9 |
| 17:00:00 | 0.013 | 2.8 | 62 | 31.5 | 67.7 | 140.2 | 992.8 |
| 18:00:00 | 0.013 | 2.0 | 102 | 30.4 | 75.2 | 34.4 | 992.8 |
| 19:00:00 | 0.013 | 1.2 | 208 | 29.4 | 73.6 | 0.0 | 992.5 |
| 20:00:00 | 0.013 | 0.2 | 243 | 29.0 | 70.6 | 0.0 | 992.1 |
| 21:00:00 | 0.013 | 1.5 | 266 | 28.7 | 63.0 | 0.0 | 991.9 |
| 22:00:00 | 0.013 | 1.8 | 273 | 27.7 | 49.6 | 0.0 | 991.8 |
| 23:00:00 | 0.013 | 2.2 | 275 | 27.4 | 43.3 | 0.0 | 991.9 |
| 24:00:00 | 0.013 | 2.3 | 266 | 27.6 | 41.1 | 0.0 | 991.7 |
| 09 / 08 / 91 | | | | | | | |
| 01:00:00 | 0.013 | 2.5 | 265 | 27.2 | 37.1 | 0.0 | 991.6 |
| 02:00:00 | 0.013 | 2.5 | 272 | 26.8 | 33.5 | 0.0 | 991.5 |
| 03:00:00 | 0.014 | 3.4 | 276 | 26.1 | 31.8 | 0.0 | 991.2 |
| 04:00:00 | 0.015 | 4.1 | 286 | 25.7 | 30.8 | 0.0 | 991.1 |
| 05:00:00 | 0.014 | 3.8 | 292 | 24.9 | 31.2 | 0.0 | 990.8 |
| 06:00:00 | 0.015 | 3.9 | 293 | 25.0 | 30.4 | 3.7 | 990.4 |
| 07:00:00 | 0.016 | 3.8 | 291 | 26.0 | 28.6 | 16.1 | 990.4 |
| 08:00:00 | 0.017 | 3.9 | 290 | 26.4 | 27.5 | 8.2 | 990.7 |
| 09:00:00 | 0.017 | 3.8 | 292 | 27.2 | 26.9 | 23.6 | 990.9 |
| 10:00:00 | 0.015 | 4.2 | 313 | 29.1 | 25.7 | 81.2 | 991.0 |
| 11:00:00 | 0.023 | 4.9 | 332 | 31.2 | 23.3 | 41.6 | 992.2 |
| 12:00:00 | 0.017 | 5.7 | 359 | 34.0 | 21.6 | 57.9 | 992.8 |
| 13:00:00 | 0.014 | 5.8 | 10 | 34.5 | 26.5 | 192.0 | 993.2 |
| 14:00:00 | 0.012 | 5.7 | 12 | 35.4 | 28.6 | 385.4 | 994.0 |
| 15:00:00 | 0.014 | 6.3 | 19 | 35.4 | 32.3 | 355.9 | 994.7 |
| 16:00:00 | 0.014 | 6.5 | 18 | 34.5 | 36.6 | 222.5 | 995.2 |
| 17:00:00 | 0.014 | 6.1 | 13 | 34.1 | 37.6 | 90.4 | 994.6 |
| 18:00:00 | 0.014 | 6.1 | 12 | 33.5 | 38.0 | 14.5 | 994.1 |
| 19:00:00 | 0.016 | 7.3 | 4 | 34.2 | 33.4 | 0.0 | 993.7 |
| 20:00:00 | 0.018 | 6.5 | 347 | 32.9 | 37.4 | 0.0 | 994.2 |
| 21:00:00 | 0.023 | 6.8 | 348 | 32.8 | 36.0 | 0.0 | 994.1 |
| 22:00:00 | 0.023 | 6.2 | 1 | 32.6 | 35.6 | 0.0 | 993.9 |
| 23:00:00 | 0.018 | 3.3 | 323 | 29.1 | 39.9 | 0.0 | 993.6 |
| 24:00:00 | 0.015 | 4.6 | 327 | 28.7 | 30.3 | 0.0 | 992.8 |
| 09 / 09 / 91 | | | | | | | |
| 01:00:00 | 0.015 | 5.8 | 331 | 29.1 | 26.2 | 0.0 | 992.8 |
| 02:00:00 | 0.016 | 5.0 | 328 | 28.2 | 26.4 | 0.0 | 992.6 |
| 03:00:00 | 0.015 | 4.9 | 322 | 27.0 | 27.3 | 0.0 | 992.1 |
| 04:00:00 | 0.016 | 5.3 | 329 | 26.9 | 27.6 | 0.0 | 991.2 |
| 05:00:00 | 0.015 | 4.6 | 322 | 26.1 | 27.8 | 0.0 | 990.8 |
| 06:00:00 | 0.015 | 4.0 | 317 | 24.7 | 29.2 | 6.1 | 990.2 |
| 07:00:00 | 0.016 | 5.0 | 328 | 26.7 | 27.7 | 63.4 | 990.4 |
| 08:00:00 | 0.015 | 6.7 | 330 | 31.1 | 24.1 | 239.3 | 992.7 |
| 09:00:00 | 0.016 | 8.7 | 344 | 34.7 | 21.4 | 526.6 | 995.3 |
| 10:00:00 | 0.016 | 9.3 | 340 | 37.4 | 17.5 | 627.8 | 997.6 |

MEPA - Kafji

| | DUST mg/m3 | WS m/sec | WD degrees | TEMP C | HUMIDITY % | RAD watts | PRESS mb |
|---|---|---|---|---|---|---|---|
| 11:00:00 | 0.022 | 8.1 | 320 | 38.1 | 15.8 | 531.4 | 998.9 |
| 12:00:00 | 0.016 | 6.1 | 356 | 38.8 | 16.3 | 591.6 | 999.8 |
| 13:00:00 | 0.014 | 4.2 | 5 | 37.7 | 19.4 | 336.8 | 1000.8 |
| 14:00:00 | 0.014 | 3.9 | 12 | 37.0 | 22.0 | 194.9 | 999.6 |
| 15:00:00 | 0.014 | 4.6 | 4 | 36.9 | 20.7 | 10.0 | 997.2 |
| 16:00:00 | 0.014 | 4.2 | 12 | 36.5 | 20.6 | 64.1 | 995.7 |
| 17:00:00 | 0.014 | 4.9 | 2 | 36.6 | 20.4 | 40.9 | 994.7 |
| 18:00:00 | 0.015 | 4.3 | 342 | 35.1 | 23.7 | 7.1 | 994.8 |
| 19:00:00 | 0.014 | 2.5 | 304 | 33.4 | 24.9 | 0.0 | 994.6 |
| 20:00:00 | 0.018 | 3.6 | 317 | 33.3 | 17.9 | 0.0 | 994.3 |
| 21:00:00 | 0.019 | 3.7 | 313 | 32.7 | 17.4 | 0.0 | 993.8 |
| 22:00:00 | 0.019 | 4.0 | 314 | 32.1 | 17.6 | 0.0 | 993.6 |
| 23:00:00 | 0.018 | 4.0 | 307 | 30.8 | 18.3 | 0.0 | 993.2 |
| 24:00:00 | 0.019 | 4.0 | 306 | 29.2 | 19.1 | 0.0 | 992.7 |
| 09 / 10 / 91 | | | | | | | |
| 01:00:00 | 0.020 | 4.4 | 309 | 28.9 | 20.1 | 0.0 | 992.4 |
| 02:00:00 | 0.024 | 5.2 | 315 | 28.8 | 20.2 | 0.0 | 992.2 |
| 03:00:00 | 0.028 | 6.3 | 318 | 28.6 | 19.5 | 0.0 | 992.2 |
| 04:00:00 | 0.031 | 6.6 | 322 | 28.0 | 19.0 | 0.0 | 992.1 |
| 05:00:00 | 0.031 | 6.0 | 318 | 26.9 | 19.4 | 0.0 | 991.8 |
| 06:00:00 | 0.024 | 5.1 | 315 | 26.0 | 20.1 | 5.0 | 991.3 |
| 07:00:00 | 0.029 | 6.4 | 318 | 27.0 | 20.3 | 55.8 | 991.2 |
| 08:00:00 | 0.030 | 6.5 | 320 | 29.9 | 18.7 | 188.9 | 992.6 |
| 09:00:00 | 0.028 | 6.9 | 329 | 34.4 | 16.6 | 410.3 | 995.0 |
| 10:00:00 | 0.017 | 5.2 | 21 | 35.9 | 21.8 | 609.9 | 996.2 |
| 11:00:00 | 0.014 | 4.3 | 24 | 36.4 | 29.3 | 712.1 | 996.7 |
| 12:00:00 | 0.015 | 5.0 | 34 | 34.1 | 38.8 | 669.8 | 997.4 |
| 13:00:00 | 0.014 | 3.9 | 50 | 33.7 | 44.4 | 530.2 | 997.1 |
| 14:00:00 | 0.014 | 3.3 | 47 | 34.1 | 41.3 | 369.4 | 997.0 |
| 15:00:00 | 0.013 | 3.5 | 66 | 33.2 | 47.1 | 220.8 | 995.9 |
| 16:00:00 | 0.013 | 2.0 | 122 | 33.4 | 41.3 | 110.7 | 994.4 |
| 17:00:00 | 0.013 | 1.1 | 190 | 33.3 | 35.5 | 49.0 | 994.3 |
| 18:00:00 | 0.013 | 1.7 | 207 | 31.7 | 40.4 | 7.9 | 994.1 |
| 19:00:00 | 0.013 | 1.8 | 237 | 30.9 | 37.4 | 0.0 | 993.8 |
| 20:00:00 | 0.014 | 2.2 | 247 | 30.6 | 34.5 | 0.0 | 993.5 |
| 21:00:00 | 0.014 | 3.0 | 249 | 30.0 | 33.8 | 0.0 | 993.3 |
| 22:00:00 | 0.014 | 3.0 | 259 | 29.9 | 31.2 | 0.0 | 993.3 |
| 23:00:00 | 0.015 | 3.3 | 276 | 29.7 | 26.7 | 0.0 | 993.3 |
| 24:00:00 | 0.016 | 3.6 | 298 | 28.8 | 24.3 | 0.0 | 993.0 |
| 09 / 11 / 91 | | | | | | | |
| 01:00:00 | 0.016 | 3.7 | 303 | 27.7 | 24.1 | 0.0 | 992.6 |
| 02:00:00 | 0.018 | 4.0 | 309 | 27.8 | 24.3 | 0.0 | 992.3 |
| 03:00:00 | 0.021 | 5.3 | 321 | 27.8 | 24.9 | 0.0 | 992.3 |
| 04:00:00 | 0.022 | 5.4 | 322 | 27.1 | 26.1 | 0.0 | 992.3 |
| 05:00:00 | 0.023 | 5.1 | 319 | 26.6 | 27.3 | 0.0 | 992.1 |
| 06:00:00 | 0.021 | 4.9 | 318 | 26.2 | 28.7 | 3.9 | 991.9 |
| 07:00:00 | 0.022 | 5.3 | 318 | 27.1 | 28.8 | 48.5 | 991.9 |
| 08:00:00 | 0.022 | 5.0 | 324 | 29.1 | 27.1 | 150.6 | 992.9 |

LOUISIANA STATE UNIVERSITY
AND AGRICULTURAL AND MECHANICAL COLLEGE
*Institute for Environmental Studies*

24 September, 1991

John Robinson, Director
NOAA/Arabian Gulf Program

**Re: Draft report on Kuwait PAH analyses.**

Ground-level exposure to PAH was monitored on the road to Al-Wafra south of Al-Bergan oil field, at the International Hotel in Kuwait City, Doha, and the Ahmed Al-Jaber Air Base (abandoned) between august 4 and 9, 1991. A total of 16 samples were collected using standard methods (NIOSH METHOD 5515, Teflon™ filters and XAD-2). The samples along with 6 field blanks were returned to LSU for analysis. In addition to the filter samples, 6 sediment samples were collected along a transact on the road to Al-Wafra. Table 1 provides the sample collection dates, times, identification and sample location information The samples were extracted and analyzed by a detailed gas chromatograph/mass spectrometer (GC/MS) technique which targets the pyrogenic (combustion)-sourced and petrogenic (oil)-sourced PAH. The sediment samples, in addition to the GC/MS analyses, were analyzed to determine total petroleum hydrocarbons (TPH) by a solvent extraction/gravimetric technique.

Attached are the quantitative results for these analyses. They have been proofed by myself for QA/QC. Earlier results for three of the samples released in a preliminary report (memo date 18, August, 1991) were found to be in error due to a data entry mistake in the formula used to calculate concentration. Sorry, but that's what happens when you rush to produce data of this complex nature. The correct values for those samples are incorporated into this report. The qualitative interpretation was not affected, only the absolute concentration value.

The samples collected south of the road to Al-Wafra were intended to be a "worse-case" ground level exposure in that I sought to located an area of high smoke concentration from an integrated plume

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primarily sourced from the Al-Bergan field. What do the results mean? Most of the PAH detected is petrogenic in composition; resembling oil, not incomplete combustion products. Fingerprint comparisons of the PAH homolog profiles suggest that the oil collected at sites south of Al-Bergan is a positive match to oil collected at two lake sites within the Al-Bergan field. Samples collected within Kuwait City showed a different fingerprint suggesting that it was not sourced from the burning fields south of the city. No oil from the northern fields were available for source-fingerprinting (I was advised not to drive up in the northern fields due to mines, etc.). The composition of PAH in the samples collected in the city are probably from a combination of sources including automobile and truck exhaust, the desalination and power generation plants, burning trash, and the northern oil fields.

Expect a final report soon. I had hoped to have it completed sooner, but I've been really inundated since my return. If you have any questions please call.

Sincerely,

Charles B. Henry, Jr.

enclosures

TABLE 1. AIR/PARTICULATE SAMPLING LOG: KUWAIT SAMP.23 SEPT 91

| SAMPLE ID | TYPE | XAD-2 | DATE | S. TIME | E. TIME | PUMP # | FLOW | S.TIME | S. VOL. | LOCATION |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | m/d/y | hh:mm | hh:mm | | L/min. | min. | L | |
| K01 | G.FIL. | 1 | 8/3/91 | 00:45 | 07:30 | 2 | 2 | 405 | 810 | 4th FLOOR BALCONY, RM 424, INTERNATIONAL HOTEL |
| K02 | G.FIL. | 1 | - | - | - | - | - | - | - | FIELD BLANK |
| K03 | G.FIL. | 1 | - | - | - | - | - | - | - | FIELD BLANK |
| K04 | G.FIL. | 1 | 8/4/91 | 11:05 | 13:15 | 2 | 2 | 130 | 260 | AL-WAFRA ROAD, 6.45 km FROM MET.STATION TURN-OFF |
| K05 | G.FIL. | 1 | 8/4/91 | 11:05 | 13:15 | 1 | 2 | 130 | 260 | AL-WAFRA ROAD, 6.45 km FROM MET.STATION TURN-OFF |
| K06 | G.FIL. | 1 | - | - | - | - | - | - | - | FIELD BLANK |
| K07 | G.FIL. | 1 | 8/4/91 | 11:05 | 13:15 | 3 | 2 | 130 | 260 | AL-WAFRA ROAD, 6.45 km FROM MET.STATION TURN-OFF |
| K08 | TFE.FIL | 1 | - | - | - | - | - | - | - | FIELD BLANK |
| K09 | TFE.FIL | 1 | 8/4/91 | 21:35 | 03:35 | 2 | 2 | 360 | 720 | 4th FLOOR BALCONY, RM 424, INTERNATIONAL HOTEL |
| K10 | TFE.FIL | 1 | 8/6/91 | 09:15 | 11:15 | 3 | 2 | 120 | 240 | DOHA |
| K11 | TFE.FIL | 2 | 8/5/91 | 14:00 | - | 2 | 2 | 120 | 1000 | COMPOUND, JUST NORTH OF WAFRA ROAD MET STATION |
| K12 | TFE.FIL | 1 | 8/5/91 | 11:30 | - | 2 | 2 | 500 | 1000 | AIR BASE (CONTROL ?) |
| K13 | TFE.FIL | 1 | 8/5/91 | 13:35 | 15:10 | 3 | 2 | 105 | 210 | AL-WAFRA MET STATION #7 |
| K14 | TFE.FIL | 2 | 8/5/91 | - | - | - | - | - | - | FIELD BLANK |
| K15 | TFE.FIL | 1 | 8/8/91 | 12:00 | 13:10 | 2 | 2 | 70 | 140 | 4th FLOOR BALCONY, RM 424, INTERNATIONAL HOTEL |
| K16 | TFE.FIL | 1 | 8/8/91 | 08:30 | - | 2 | 2 | 164 | 328 | 4th FLOOR BALCONY, RM 424, INTERNATIONAL HOTEL |
| K17 | TFE.FIL | 1 | 8/7/91 | 16:00 | - | 2 | 2 | 332 | 664 | 4th FLOOR BALCONY, RM 424, INTERNATIONAL HOTEL |
| K18 | TFE.FIL | 1 | 8/9/91 | 12:25 | 13:40 | 3 | 2 | 75 | 150 | AL-WAFRA ROAD, 16.1 km FROM MOTOTWAY |
| K19 | TFE.FIL | 1 | 8/9/91 | 12:25 | 13:40 | 2 | 2 | 75 | 150 | AL-WAFRA ROAD, 16.1 km FROM MOTOTWAY |
| K20 | TFE.FIL | 1 | 8/8/91 | 23:00 | - | 3 | 2 | 480 | 960 | 4th FLOOR BALCONY, RM 424, INTERNATIONAL HOTEL |
| K21 | TFE.FIL | 1 | 8/8/91 | 19:00 | 20:06 | 2 | 2 | 66 | 132 | AL-WAFRA MET STATION #7 |
| K22 | TFE.FIL | - | - | - | - | - | - | - | - | FIELD BLANK |
| K31 | PUF | NA | 8/9/91 | 12:25 | 13:40 | 1 | 2 | 75 | 150 | AL-WAFRA ROAD, 16.1 km FROM MOTOTWAY |
| K32 | PUF | NA | - | - | - | - | - | - | - | FIELD BALNK |
| K51 | SURF. | NA | 8/4/91 | 12:00 | NA | NA | NA | NA | NA | AL-WAFRA ROAD, 6.45 km FROM MET.STATION TURN-OFF |
| K52 | SURF. | NA | 8/8/91 | 18:55 | NA | NA | NA | NA | NA | AL-WAFRA ROAD, 10.0 km FROM MET.STATION TURN-OFF |
| K53 | SURF. | NA | 8/8/91 | 19:10 | NA | NA | NA | NA | NA | AL-WAFRA ROAD, 10.7 km FROM MET.STATION TURN-OFF |
| K54 | SURF. | NA | 8/9/91 | 12:30 | NA | NA | NA | NA | NA | AL-WAFRA ROAD |
| K55 | SURF. | NA | 8/9/91 | 12:45 | NA | NA | NA | NA | NA | AL-WAFRA ROAD |
| K56 | SURF. | NA | 8/9/91 | 13:00 | NA | NA | NA | NA | NA | AL-WAFRA ROAD |
| K71 | OIL | NA | 8/5/91 | 11:00 | NA | NA | NA | NA | NA | LAKE IN SOUTHWESTERN PORTION OF BERGAN FIELD |

| | AIR | AIR | AIR | AIR | AIR |
|---|---|---|---|---|---|
| SAMPLE ID: | K01 | K04 | K05 | K07 | K09 |
| | | | | | |
| GC/MS TARGET | ng/M3** | ng/M3** | ng/M3** | ng/M3** | ng/M3** |
| COMPOUND | | | | | |
| NAPHTHALENE | 150.00 | 70.00 | 180.00 | 90.00 | 110.00 |
| C-1 NAPHTHALENE | 45.00 | 180.00 | 290.00 | 220.00 | 24.00 |
| C-2 NAPHTHALENE | 22.00 | 240.00 | 400.00 | 340.00 | 20.00 |
| C-3 NAPHTHALENE | 15.00 | 160.00 | 290.00 | 230.00 | 26.00 |
| C-4 NAPHTHALENE | ND | 59.00 | 71.00 | 110.00 | ND |
| FLUORENE | ND | 7.90 | 12.00 | ND | ND |
| C-1 FLUORENE | ND | 31.00 | 30.00 | 8.70 | ND |
| C-2 FLUORENE | ND | 13.00 | 16.00 | 11.00 | ND |
| C-3 FLUORENE | ND | 18.00 | 8.50 | ND | ND |
| DIBENZOTHIOPHENE | ND | 14.00 | 25.00 | 23.00 | ND |
| C-1 DIBENZOTHIO. | ND | 31.00 | 52.00 | 38.00 | ND |
| C-2 DIBENZOTHIO. | ND | 52.00 | 17.00 | 33.00 | ND |
| C-3 DIBENZOTHIO. | ND | 43.00 | 15.00 | 15.00 | ND |
| PHENANTHRENE | 2.40 | 19.00 | 30.00 | 19.00 | 3.80 |
| C-1 PHENANTHRENE | ND | 15.00 | 27.00 | 21.00 | ND |
| C-2 PHENANTHRENE | ND | 34.00 | 32.00 | 19.00 | ND |
| C-3 PHENANTHRENE | ND | ND | ND | ND | ND |
| ANTHRACENE | 1.00 | 2.10 | 3.60 | 3.20 | ND |
| FLUORANTHENE | ND | 11.00 | 8.60 | 7.40 | ND |
| PYRENE | ND | 7.20 | 6.80 | 4.80 | ND |
| C-1 PYRENE | ND | ND | ND | ND | ND |
| C-2 PYRENE | ND | ND | ND | ND | ND |
| BENZO(a)ANTHRACENE | ND | ND | ND | ND | ND |
| CHRYSENE | ND | 9.10 | 8.90 | 3.20 | ND |
| C-1 CHRYSENE | ND | ND | ND | ND | ND |
| BENZO(b)FLUORANT.* | ND | 19.00 | 6.10 | 6.80 | ND |
| BENZO(e)PYRENE | ND | 12.00 | 4.80 | 3.70 | ND |
| BENZO(a)PYRENE | ND | 11.00 | 3.10 | 2.60 | ND |
| PERYLENE | ND | 18.00 | 2.80 | 2.30 | ND |
| INDENO(1,2,3-cd)PYR. | ND | 20.00 | ND | ND | ND |
| DIBENZO(a,h)ANTHR. | ND | 17.00 | ND | ND | ND |
| * (b) and (k) isomers comb. | | | | | |
| | | | | | |
| TOTAL TARGET PAH: | 240.00 | 1100.00 | 1500.00 | 1200.00 | 180.00 |
| | | | | | |

| | AIR | AIR | AIR | AIR | AIR |
|---|---|---|---|---|---|
| SAMPLE ID: | K10 | K12 | K13 | K15 | K16 |
| | | | | | |
| GC/MS TARGET COMPOUND | ng/M3** | ng/M3** | ng/M3** | ng/M3** | ng/M3** |
| NAPHTHALENE | 760.00 | 5.10 | 420.00 | 560.00 | 390.00 |
| C-1 NAPHTHALENE | 150.00 | 12.00 | 170.00 | 130.00 | 99.00 |
| C-2 NAPHTHALENE | 140.00 | 12.00 | 200.00 | 110.00 | 120.00 |
| C-3 NAPHTHALENE | 170.00 | 26.00 | 160.00 | 140.00 | 110.00 |
| C-4 NAPHTHALENE | ND | ND | 31.00 | ND | ND |
| FLUORENE | 15.00 | 1.60 | 8.80 | 8.80 | 11.00 |
| C-1 FLUORENE | 46.00 | 5.70 | 26.00 | 38.00 | 41.00 |
| C-2 FLUORENE | ND | ND | ND | ND | ND |
| C-3 FLUORENE | ND | ND | ND | ND | ND |
| DIBENZOTHIOPHENE | 9.20 | ND | 8.80 | 11.00 | 3.30 |
| C-1 DIBENZOTHIO. | ND | ND | ND | 13.00 | 2.20 |
| C-2 DIBENZOTHIO. | ND | ND | ND | 45.00 | 20.00 |
| C-3 DIBENZOTHIO. | ND | ND | ND | ND | ND |
| PHENANTHRENE | 29.00 | 2.10 | 16.00 | 27.00 | 12.00 |
| C-1 PHENANTHRENE | 15.00 | ND | ND | ND | 12.00 |
| C-2 PHENANTHRENE | ND | ND | ND | ND | ND |
| C-3 PHENANTHRENE | ND | ND | ND | ND | ND |
| ANTHRACENE | ND | ND | ND | 5.70 | 1.90 |
| FLUORANTHENE | ND | ND | ND | 9.00 | 3.20 |
| PYRENE | ND | ND | ND | 5.50 | 2.10 |
| C-1 PYRENE | ND | ND | ND | ND | ND |
| C-2 PYRENE | ND | ND | ND | ND | ND |
| BENZO(a)ANTHRACENE | ND | ND | ND | ND | ND |
| CHRYSENE | ND | ND | ND | 6.60 | 7.00 |
| C-1 CHRYSENE | ND | ND | ND | ND | ND |
| BENZO(b)FLUORANT.* | ND | ND | ND | ND | 5.00 |
| BENZO(e)PYRENE | ND | ND | ND | ND | 2.40 |
| BENZO(a)PYRENE | ND | ND | ND | ND | 5.70 |
| PERYLENE | ND | ND | ND | ND | 3.40 |
| INDENO(1,2,3-cd)PYR. | ND | ND | ND | ND | ND |
| DIBENZO(a,h)ANTHR. | ND | ND | ND | ND | ND |
| * (b) and (k) isomers comb. | | | | | |
| | | | | | |
| TOTAL TARGET PAH: | 1300.00 | 65.00 | 1000.00 | 1100.00 | 850.00 |
| | | | | | |

C.B. Henry, Inst. for Environmental Studies, LSU phone (504) 388-8521

| | AIR | AIR | AIR | AIR | AIR |
|---|---|---|---|---|---|
| SAMPLE ID: | K17 | K18 | K19 | K20 | K21 |
| | | | | | |
| GC/MS TARGET COMPOUND | ng/M3** | ng/M3** | ng/M3** | ng/M3** | ng/M3** |
| NAPHTHALENE | 180.00 | 350.00 | 39.00 | 21.00 | 50.00 |
| C-1 NAPHTHALENE | 96.00 | 420.00 | 360.00 | 27.00 | 60.00 |
| C-2 NAPHTHALENE | 54.00 | 520.00 | 390.00 | 21.00 | 47.00 |
| C-3 NAPHTHALENE | 33.00 | 380.00 | 240.00 | 21.00 | 73.00 |
| C-4 NAPHTHALENE | 13.00 | 130.00 | 140.00 | ND | ND |
| FLUORENE | 4.90 | 16.00 | 14.00 | 2.70 | 9.00 |
| C-1 FLUORENE | 10.00 | 16.00 | 31.00 | 6.70 | ND |
| C-2 FLUORENE | ND | 20.00 | 22.00 | ND | ND |
| C-3 FLUORENE | ND | 35.00 | 17.00 | ND | ND |
| DIBENZOTHIOPHENE | 3.70 | 29.00 | 21.00 | 0.98 | 3.60 |
| C-1 DIBENZOTHIO. | 4.90 | 88.00 | 49.00 | 1.40 | ND |
| C-2 DIBENZOTHIO. | 8.00 | 40.00 | 57.00 | 2.40 | ND |
| C-3 DIBENZOTHIO. | ND | 22.00 | 38.00 | ND | ND |
| PHENANTHRENE | 10.00 | 38.00 | 24.00 | 3.40 | 18.00 |
| C-1 PHENANTHRENE | 3.60 | 35.00 | 30.00 | 1.70 | 9.00 |
| C-2 PHENANTHRENE | ND | 51.00 | 28.00 | ND | ND |
| C-3 PHENANTHRENE | ND | 20.00 | ND | ND | ND |
| ANTHRACENE | ND | 3.60 | 1.80 | 0.37 | 3.40 |
| FLUORANTHENE | 3.30 | 7.10 | 7.20 | 1.20 | 9.50 |
| PYRENE | 3.00 | 5.70 | 6.90 | 1.00 | 14.00 |
| C-1 PYRENE | ND | ND | ND | ND | ND |
| C-2 PYRENE | ND | ND | ND | ND | ND |
| BENZO(a)ANTHRACENE | ND | ND | ND | ND | ND |
| CHRYSENE | 2.30 | 4.40 | 4.70 | 0.72 | 7.00 |
| C-1 CHRYSENE | ND | ND | ND | ND | ND |
| BENZO(b)FLUORANT.* | 2.50 | 7.60 | 9.00 | 1.30 | 15.00 |
| BENZO(e)PYRENE | 1.80 | 5.10 | 5.80 | 1.20 | 12.00 |
| BENZO(a)PYRENE | 1.40 | 3.60 | 2.00 | 0.50 | 11.00 |
| PERYLENE | 0.70 | ND | ND | 0.38 | 3.70 |
| INDENO(1,2,3-cd)PYR. | ND | 5.50 | ND | ND | ND |
| DIBENZO(a,h)ANTHR. | ND | ND | ND | ND | ND |
| * (b) and (k) isomers comb. | | | | | |
| | | | | | |
| TOTAL TARGET PAH: | 440.00 | 2300.00 | 1500.00 | 120.00 | 350.00 |
| | | | | | |

| | SEDIMENT | SEDIMENT | SEDIMENT | SEDIMENT | SEDIMENT |
|---|---|---|---|---|---|
| SAMPLE ID: | K51 | K52 | K53 | K54 | K55 |
| | | | | | |
| GC/MS TARGET COMPOUND | ug/g | ug/g | ug/g | ug/g | ug/g |
| NAPHTHALENE | ND | ND | ND | ND | ND |
| C-1 NAPHTHALENE | ND | ND | ND | ND | ND |
| C-2 NAPHTHALENE | ND | ND | ND | ND | ND |
| C-3 NAPHTHALENE | ND | ND | ND | ND | ND |
| C-4 NAPHTHALENE | ND | ND | ND | ND | ND |
| FLUORENE | ND | ND | ND | ND | ND |
| C-1 FLUORENE | ND | ND | ND | ND | ND |
| C-2 FLUORENE | ND | ND | ND | 0.100 | ND |
| C-3 FLUORENE | ND | ND | 0.680 | 0.590 | ND |
| DIBENZOTHIOPHENE | ND | 0.016 | 0.036 | 0.023 | ND |
| C-1 DIBENZOTHIO. | 0.089 | 0.190 | 0.410 | 0.310 | 0.014 |
| C-2 DIBENZOTHIO. | 0.650 | 1.200 | 2.700 | 2.200 | 0.170 |
| C-3 DIBENZOTHIO. | 1.400 | 3.100 | 6.900 | 5.700 | 0.420 |
| PHENANTHRENE | 0.021 | 0.028 | 0.052 | 0.034 | 0.000 |
| C-1 PHENANTHRENE | 0.083 | 0.160 | 0.360 | 0.290 | 0.020 |
| C-2 PHENANTHRENE | 0.270 | 0.560 | 1.300 | 0.990 | 0.065 |
| C-3 PHENANTHRENE | 0.360 | 0.990 | 2.200 | 1.600 | 0.160 |
| ANTHRACENE | ND | ND | 0.004 | ND | ND |
| FLUORANTHENE | 0.036 | 0.068 | 0.160 | 0.099 | 0.011 |
| PYRENE | 0.044 | 0.085 | 0.200 | 0.140 | 0.013 |
| C-1 PYRENE | 0.023 | 0.150 | 0.320 | 0.220 | 0.017 |
| C-2 PYRENE | 0.160 | 0.350 | 0.790 | 0.450 | 0.052 |
| BENZO(a)ANTHRACENE | 0.013 | 0.024 | 0.063 | 0.031 | 0.012 |
| CHRYSENE | 0.054 | 0.082 | 0.170 | 0.098 | 0.028 |
| C-1 CHRYSENE | 0.076 | 0.210 | 0.340 | 0.170 | 0.028 |
| BENZO(b)FLUORANT.* | 0.012 | 0.027 | 0.046 | 0.025 | 0.027 |
| BENZO(e)PYRENE | 0.022 | 0.016 | 0.033 | 0.017 | 0.023 |
| BENZO(a)PYRENE | 0.011 | 0.012 | 0.028 | 0.012 | 0.014 |
| PERYLENE | ND | 0.001 | 0.030 | 0.006 | 0.032 |
| INDENO(1,2,3-cd)PYR. | ND | ND | 0.009 | 0.019 | ND |
| DIBENZO(a,h)ANTHR. | ND | ND | 0.001 | ND | 0.009 |
| * (b) and (k) isomers comb. | | | | | |
| | | | | | |
| TOTAL TARGET PAH: | 3.300 | 7.300 | 17.000 | 13.000 | 1.100 |
| | | | | | |

| | SEDIMENT | SEDIMENT | OIL | OIL |
|---|---|---|---|---|
| SAMPLE ID: | K56 | K56 (dup.) | K71 | N1183-1 |
| | | | | |
| GC/MS TARGET | ug/g | ug/g | ug/g | ug/g |
| COMPOUND | | | | |
| NAPHTHALENE | ND | ND | 3.500 | 210.000 |
| C-1 NAPHTHALENE | ND | ND | 91.000 | 1400.000 |
| C-2 NAPHTHALENE | ND | ND | 780.000 | 3500.000 |
| C-3 NAPHTHALENE | ND | ND | 1500.000 | 4300.000 |
| C-4 NAPHTHALENE | ND | ND | 1300.000 | 2900.000 |
| FLUORENE | ND | ND | 47.000 | 110.000 |
| C-1 FLUORENE | ND | ND | 170.000 | 330.000 |
| C-2 FLUORENE | ND | ND | 390.000 | 780.000 |
| C-3 FLUORENE | 0.068 | ND | 640.000 | 1200.000 |
| DIBENZOTHIOPHENE | ND | ND | 160.000 | 350.000 |
| C-1 DIBENZOTHIO. | 0.023 | ND | 620.000 | 1600.000 |
| C-2 DIBENZOTHIO. | 0.260 | 0.160 | 1700.000 | 3500.000 |
| C-3 DIBENZOTHIO. | 0.843 | 0.660 | 2300.000 | 4200.000 |
| PHENANTHRENE | ND | ND | 110.000 | 210.000 |
| C-1 PHENANTHRENE | 0.025 | 0.012 | 400.000 | 730.000 |
| C-2 PHENANTHRENE | 0.130 | 0.076 | 630.000 | 1200.000 |
| C-3 PHENANTHRENE | 0.210 | 0.061 | 670.000 | 1200.000 |
| ANTHRACENE | ND | ND | 1.200 | 3.600 |
| FLUORANTHENE | 0.015 | ND | 2.300 | 7.800 |
| PYRENE | 0.010 | ND | 10.000 | 16.000 |
| C-1 PYRENE | ND | 0.026 | 67.000 | 100.000 |
| C-2 PYRENE | 0.071 | 0.057 | 150.000 | 200.000 |
| BENZO(a)ANTHRACENE | 0.007 | ND | 15.000 | 0.440 |
| CHRYSENE | 0.054 | 0.036 | 22.000 | 28.000 |
| C-1 CHRYSENE | 0.180 | 0.099 | 79.000 | 0.260 |
| BENZO(b)FLUORANT.* | 0.018 | 0.016 | 6.600 | 5.400 |
| BENZO(e)PYRENE | 0.021 | 0.013 | 7.400 | 5.600 |
| BENZO(a)PYRENE | 0.010 | 0.009 | 4.100 | 2.500 |
| PERYLENE | ND | ND | 2.200 | 1.200 |
| INDENO(1,2,3-cd)PYR. | ND | ND | ND | ND |
| DIBENZO(a,h)ANTHR. | ND | ND | ND | ND |
| * (b) and (k) isomers comb. | | | | |
| | | | | |
| TOTAL TARGET PAH: | 2.000 | 1.200 | 12000.000 | 28000.000 |
| | | | | |

DATE: September 19,1991

TO: Charlie Henry, RA IV, Institute for Environmental Studies

FROM: M. Michelle Mayfield, LA I, Institute for Environmental Studies

RE: **Kuwait sediment residual oil weights**

Below are the residual oil weights for the Kuwait sediments as requested. Six samples and one duplicate sample were analyzed. High percentages of residual oil (.7 to almost 6%) were seen as expected from these highly contaminated soils.

| FIELD ID | mg OIL/ g SAMPLE (ppt) |
|---|---|
| K51 | 7.4 |
| K52 | 32 |
| K53 | 56 |
| K54 | 22.0* |
| K55 | 8.2 |
| K56 | 11 |
| K56DUP | 9 |

OK CB Henry 23 Sept '91

*Semiquantitative value due to lab accident. Actual value higher.

بسم الله الرحمن الرحيم

**SULTANATE OF OMAN**

**Ministry of Water Resources**

سلطنة عمان

وزارة موارد المياه

No. : MWR/WAS/26-5/627/471/91 الرقم :

Date : 9 November 1991 التاريخ :

الموافق :

Arabian Gulf Program Office
NOAA
14th Constitution Ave. NW
Rm. 5128
Washington D.C. 20230
U.S.A.

Attn: Mr. John H. Robinson, Chief
Hazardous Materials Response Branch

After Compliments,

Sub: Rainfall Samples - Hydrocarbon Analyses

In response to your discussion with Don Davison, concerning pollution caused by Kuwait oil fires, the Ministry of Water Resources has taken 3 samples of rainfall for hydrocarbon analyses.

Attached are copies of Analytical Data Reporting Forms with lab analysis results from rainfall samples taken in Oman since March 1991. The Total Hydrocarbon is expressed in micrograms /liter.

I trust these samples will provide some information as to the extent of the effects of the oil fires. The people in this part of the world are thankful that the fires have now been extinguished.

If you have any questions concerning these data, feel free to contact me.

Best regards,

Wayne C. Curry

Wayne C. Curry
Director, Surface Water Department


P.O. Box 5575 Ruwi
Tel. : 703552/703553
Telex : 3629 MWR ON
Fax : 706782 (Technical) - 701515 (Admin)

ص.ب ٥٥٧٥ روي
هاتف : ٧٠٣٥٥٢/٧٠٣٥٥٣
تلكس : MWR ON ٣٦٢٩
فاكس : ٧٠٦٧٨٢ (الشؤون الفنية) - ٧٠١٥١٥ (الشؤون الادارية)

SULTANATE OF OMAN
Ministry of Water Resource
Water Quality Laboratory
Tel. 561905 / 561914

بسم الله الرحمن الرحيم

سلطنة عمان
وزارة موارد المياه
مختبر نوعية المياه
تليفون ٥٦١٩١٤ / ٥٦١٩٠٥

ALTITUDE:
100 M. (mASL)

## ANALYTICAL DATA REPORTING FORM

Urgent

KHASAB TOWN

Rain water,

LABORATORY JOB No. 20925

SITE NUMBER DP293187AF

Musandam Khasab Town

Source ☐ * Sampling date 22 (dd) 03 (mm) 91 (yy) (26°08'30"N 56°14'21"E) Time

Requested by DGWRA Sampled by Ali Khamis Return Results to S. W. Dept.

Field Analysis : Conductance ______ microS. / cm. Temp. __ . _ °C pH __ . __ Units

Sample Volume 1500 m.l. Surface water : flow rate ____ l/s Gauge Height ____ . ____ m

Ground Water : Water Level ____ . ____ m Pumping rate ____ l/s

Hours pumped __ hours __ mins. Region ☐ Analysis Required ☐ Complete ☐ Partial ☐ Special

Comments * Sample of Rainfall accumulation from 2-22 March 1991 (TOTAL: 7.2 mm)

| Req. | Constituent | Value mg/L | me/L= mg/Lx | Req. | Constituent | Value mg/L | me/L= mg/Lx |
|---|---|---|---|---|---|---|---|
| | pH (Units). | 6.59 | | ✓ | Tot. Hardness, Ca CO3 | 50. | 0.0200 |
| | Tot. Alkalin. Ca CO3 | 48.- | 0.0200 | ✓ | Calcium Hardness, Ca CO3 | 28 | 0.0200 |
| | Carb. Alkalin., CaCO3 | | 0.0200 | ✓ | Magn. Hardness, Ca CO3 | 22 | 0.0200 |
| | Bicarb. Alkalin., CaCO3 | | 0.0200 | ✓ | Calcium, Ca ++ | 11 | 0.04990 |
| | Hyd. Alkalin., CaCO3 | | 0.0200 | ✓ | Magnesium, Mg++ | 5 | 0.08229 |
| | Phenolph. Alkalin., CaCO3 | | 0.0200 | ✓ | Sodium, Na+ | 18.- | 0.04350 |
| ✓ | Conductance, (microS/cm.) | 248 | | ✓ | Potassium, K+ | 2.0 | 0.02556 |
| ✓ | Chloride, $Cl^-$ | 22.- | 0.02821 | | Boron, B | | 0.02775 |
| ✓ | Sulphate, $SO_4^{=}$ | 15 | 0.02092 | | Soluble Iron, Fe | | 0.03581 |
| ✓ | Fluoride, $F^-$ | <0.01 | 0.05264 | | Soluble Manganese, Mn | | 0.03640 |
| | Bromide, $Br^-$ | | 0.01252 | | Ion Balance (%error) | -3.27 | |
| ✓ | Nitrate Nitrogen, $NO_3^-$-N | 0.84 | 0.0714 | | Sodium Absorbtion Ratio | 1.11 | |
| | Nitrite Nitrogen, $NO_2^-$-N | | 0.0714 | | Sodium Equivalent Ratio | 42.71 | |
| | Ammonia Nitrogen, $NH_3$-N | | 0.0714 | | Total Hydrocarbon | 1.46 ug/l | |
| ✓ | Total Phosphate; $PO_4^{\equiv}$-P | 0.112 | 0.0316 | | | | |
| | Orthophosphate, $PO_4^{\equiv}$-P | | 0.0316 | | | | |
| | Tot. Solids at 180 °C | | | | | | |
| ✓ | Tot. Dis. Solids at180 °C | 148.- | | | | | |
| | Sus. Solids at 103 °C | | | | | | |

Approved [signature] Date 4.5.91

LAB. NOTES The sample contained suspended black coloured particulate matter.
The higher than acceptable level of Total Hydrocarbon indicates pollution. However
Inappropriate sampling could have caused loss of some constituents.

بسم الله الرحمن الرحيم

**SULTANATE OF OMAN**
**Ministry of Water Resource**
Water Quality Laboratory
Tel. 561905 / 561914

سلطنة عمان
وزارة موارد المياه
مختبر نوعية المياه
تليفون ٥٦١٩١٤ / ٥٦١٩٠٥

(23°14'20"N, 57° 15'41"E)
JEBAL SHAMS

## ANALYTICAL DATA REPORTING FORM

LABORATORY JOB No. 21581 (21531)    SITE NUMBER EL2679090AF

ALTITUDE: 2820 M. (m ASL)

Source F    Sampling date 19 05 91 (d d m m y y)    Time

Requested by Wayne Curry    Sampled by ....    Return Results to Surface Water

Field Analysis : Conductance ____ microS./cm.    Temp. __ · __ °C    pH __ · __ Units

Sample Volume ____ m.L    Surface water : flow rate ____ L/s    Gauge Height ____ · ____ m

Ground Water : Water Level ____ · ____ m    Pumping rate ____ L/s

Hours pumped __ hours __ mins.    Region __    Analysis Required __ Complete __ Partial __ Special

Comments Jabel Shams, rain water: CUMULATIVE: 27 MAR. 1991 – 9.0 mm, 25 APR. 0.2 mm + 28 APR. 44.6 mm (TOTAL: 53.8 mm)

| Req. | Constituent | Value mg/L | me/L= mg/Lx | Req. | Constituent | Value mg/L | me/L= mg/Lx |
|---|---|---|---|---|---|---|---|
| ✓ | pH (Units) | 7.70 | | ✓ | Tot. Hardness, Ca CO3 | 100 | 0.0200 |
| ✓ | Tot. Alkalin. Ca CO3 | 98 | 0.0200 | ✓ | Calcium Hardness, Ca CO3 | 90 | 0.0200 |
| ✓ | Carb. Alkalin., CaCO3 | 0 | 0.0200 | ✓ | Magn. Hardness, Ca CO3 | 10 | 0.0200 |
| ✓ | Bicarb. Alkalin., CaCO3 | 98 | 0.0200 | ✓ | Calcium, Ca ++ | 36 | 0.04990 |
| ✓ | Hyd. Alkalin., CaCO3 | 0 | 0.0200 | ✓ | Magnesium, Mg++ | 2 | 0.08229 |
| ✓ | Phenolph. Alkalin., CaCO3 | 0 | 0.0200 | ✓ | Sodium, Na+ | 8 | 0.04350 |
| ✓ | Conductance, (microS/cm.) | 193 | | ✓ | Potassium, K+ | 1 | 0.02556 |
| ✓ | Chloride, $Cl^-$ | 5.00 | 0.02821 | | Boron, B | | 0.02775 |
| ✓ | Sulphate, $SO_4^{=}$ | 12 | 0.02082 | | Soluble Iron, Fe | | 0.03581 |
| ✓ | Fluoride, $F^-$ | 0.04 | 0.05264 | | Soluble Manganese, Mn | | 0.03640 |
| | Bromide, $Br^-$ | | 0.01252 | | Ion Balance (%error) | -1.75 | |
| ✓ | Nitrate Nitrogen, $NO_3^-$-N | 1.45 | 0.0714 | | Sodium Absorbtion Ratio | 0.35 | |
| | Nitrite Nitrogen, $NO_2^-$-N | | 0.0714 | | Sodium Equivalent Ratio | 14.67 | |
| | Ammonia Nitrogen, $NH_3$-N | | 0.0714 | | Total Hydrocarbon | 0.7 mg/l | |
| ✓ | Total Phosphate, $PO_4^{\equiv}$-P | <0.01 | 0.0316 | | | | |
| | Orthophosphate, $PO_4^{\equiv}$-P | | 0.0316 | | | | |
| | Tot. Solids at 180 °C | | | | | | |
| ✓ | Tot. Dis. Solids at180 °C | 100 | | | | | |
| | Sus. Solids at 103 °C | | | | | | |

Approved [signature] Date 29/7/91

LAB. NOTES ....................................

بسم الله الرحمن الرحيم

ADRF/F-1
JAN 87

**SULTANATE OF OMAN**

سلطنة عمان

Council for Conservation of Environment and Water Resources

مجلس حماية البيئة وموارد المياه

Laboratory Section — ALTITUDE: 335 M. (mASL) (23°25'33"N 57°25'34"E)

قسم المختبرات

TEL. 561905/561914

ت : ٥٦١٩٠٥/٥٦١٩١٤

LABORATORY JOB NO. 21783 SITE NUMBER EL49805 7AF

Source F  Sampling date 01 / 10 / 91 (d d / m m / y y)  Time

Requested by WASH  Sampled by WASH  Return Results to WASH — SURFACE WATER DEPT.

Field Analysis: Conductance ____ umhos/cm.  Temp. __.__ °C  pH __.__ Units

Sample Volume ____ m.l.  Surface water: flow rate ____ l/s  Gauge Height __.__ m

Ground Water: Water Level __.__ m.  Pumping rate ____ l/s

Hours pumped ____  District B  Analysis Required S (C = Complete, P = Partial, S = Special)

Comments Make hydrocarbon analysis as well as chemical analysis

RUSTAQ MET. STATION  Analytical Data Reporting Form.  CUMULATIVE RAINFALL: 28 SEPT. 1991 — 0.2 mm, 29 SEPT. — 46.0, 30 SEPT. — 34.0 mm (TOTAL: 80.2 mm)

| Req. | Constituent | Value mg/1 | me/1= mg/1x | Req. | Constituent | Value mg/1 | me/1= mg/1x |
|---|---|---|---|---|---|---|---|
| | PH (Units) | 7.16 | | | Tot. Hardness, Ca $CO_3$ | 45 | 0.0200 |
| / | Tot. Alkalin. Ca $CO_3$ | 20 | 0.0200 | / | Calcium Hardness, Ca $CO_3$ | 35 | 0.0200 |
| / | Carb. Alkalin., $CaCO_3$ | 0 | 0.0200 | | Magn. Hardness, $CaCO_3$ | 10 | [illegible] |
| / | Bicarb. Alkalin., $CaCO_3$ | 20 | 0.0200 | | Calcium, $Ca^{++}$ | 14 | 0.04990 |
| | Hyd. Alkalin., $CaCO_3$ | 0 | 0.0200 | / | Magnesium. $Mg^{++}$ | 2 | 0.08229 |
| | Phenolph. Alkalin., $CaCO_3$ | 0 | 0.0200 | / | Sodium, $Na^+$ | 2 | 0.04350 |
| / | Conductance, (umhos/cm.) | 84 | | / | Potassium, $K^+$ | .3 | 0.02556 |
| | Chloride, $Cl^-$ | 3.0 | 0.02821 | | Boron, B | | 0.02775 |
| / | Sulfate, $SO_4^=$ | 16 | 0.02082 | | Soluble Iron, Fe (µg/1) | | 0.03581 |
| | Fluoride, $F^-$ | | 0.05264 | | Soluble Manganese, Mn (µg/1) | | 0.03640 |
| | Bromide, $Br^-$ | | 0.01252 | | Ion Balance (%error) | 3.41 | |
| / | Nitrate Nitrogen, $NO_3^-$—N | 1.55 | 0.0714 | | Sodium Adsorbtion Ratio | 0.13 | |
| | Nitrite Nitrogen, $NO_2^-$—N | | 0.0714 | | Sodium Equivalent Ratio | 8.75 | |
| | Ammonia Nitrogen, $NH_3$—N | | 0.0714 | | Total Hydrocarbon, mg/l | 0.36 | |
| | Total Phosphate, $PO_4^{\equiv}$—P | | 0.0316 | | | | |
| | Orthophosphate, $PO_4^{\equiv}$—P | | 0.0316 | | | | |
| | Tot. Solids at 180°C | | | | | | |
| / | Tot. Dis. Solids 180°C | 18 | | | | | |
| | Sus. Solids at 103°C | | | | | | |

Approved [signature] Date 4/11/9

LAB. NOTES

# ASSESSMENT OF EFFECTS ON HUMAN HEALTH FROM KUWAITI OIL FIRES

SANDIA [illegible]

ALBUQUERQUE [illegible]

MARCH [illegible]

Sandia National Laboratories
Albuquerque, New Mexico 87185

date: March 29, 1991

to: John B. Stewart
Director, Office of Foreign Intelligence
U.S. Department of Energy

from: Dennis Engi
Strategic Technologies Division, 6601

subject: Assessment of Effects on Human Health from Kuwaiti Oil Field Fires

## Introduction

The certainty of long-term smoke emissions (possibly one to two years based on estimates by well-control experts) from burning Kuwaiti oil wells has increased concerns regarding personnel exposure and acute and chronic health effects. Before the war, environmental scientists could only roughly estimate possible adverse environmental effects using pollutant dispersion models and limited source-term data. These estimates, though credible, had to be regarded with circumspection. Now, two complementary approaches to improved assessments of health effects can be taken. First, pollutants can be measured at various sites in the regions where exposure levels and health effects need to be assessed. This approach is currently being pursued by a contingent of the EPA. Second, with known numbers and locations of burning wells, better assessments of exposure levels can be made using pollutant dispersion models. Exposure levels from both approaches can be compared and used with known dose-response relationships to estimate short-term and long-term health effects. This memo describes follow-on efforts to the pre-war modeling studies of the threat to exposed populations. Estimates of the ground-level concentrations for pollutants with potentially adverse effects on health have been made using an improved (two-dimensional, multi-source) dispersion model and the best data available to assess both short-term and long-term effects on exposed populations.

## Background

Before the ignition of the Kuwaiti fields, SNL provided preliminary estimates of regional toxicological threats for a number of well-burning scenarios in Sandia Report, SAND91-0184, *Potential Impacts of Iraqi Use of Oil as a Defensive Weapon*. Burning wells in each of three principal production areas (Southeast, West, and North fields) were modeled as line sources oriented normal to the expected wind direction. Expected ground-level concentrations of $NO_x$, $SO_2$, CO, and soot were calculated at distances ranging from 1 to 100 kilometers downwind from each line source. Major population centers were not expected to be affected by the pollutants even for the worst-case scenario (a total of 720 wells ignited). Where some impact appeared possible (in the vicinity of the Southeastern fields), no acute health effects were expected, except within a small sensitive population (infants, elderly, asthmatics) susceptible to $SO_2$ and soot. No computer calculations of exposure levels for representative volatile organic compounds (VOCs) and polynuclear aromatic compounds (PNAs) were made because their concentrations were expected to be too low to cause adverse health effects.

### Multi-Source Dispersion Calculations

#### *Dispersion Model*

The Industrial Source Complex Short Term Dispersion Model was used to compute downwind ground-level concentration isopleths for pollutants ($NO_x$, $SO_2$, CO, soot, benzene vapor, and benzo(a)pyrene vapor) generated by 516 burning wells in eight fields in the principal oil production areas. This model is widely used in the U.S. to assess the effects of pollutants on local air quality. The model assumes that the downwind spread of a plume in both the horizontal and vertical directions behaves in a Gaussian manner that can be parameterized by dispersion coefficients that increase with downwind distance from the source. Values for the dispersion coefficients (standard deviations of plume width) are determined by direct meteorological measurements such as wind speed, the mixing depth of the atmosphere, and the temperature-altitude structure of the atmosphere. Input data can be obtained from routine measurements at a weather station in the locale of interest. Most useful in this analysis is the model's ability to account for multiple sources simultaneously so that the exposure level calculated for a specified pollutant at any given location is that from all sources.

#### *Inputs*

Two types of input to the model are needed to obtain reasonable estimates of pollutant concentrations :

- Source information, including realistic estimates of source location, size, oil blowout rate, plume injection height, and pollutant production rate,

- Meteorological information for the region of interest, including surface temperature, Pasquill stability category, wind speed and direction, and mixing height.

Source Information

Source location and size - Fields with burning wells and the number of these wells have been identified. The size (areal extent) of each oil field was approximated using satellite photos of the region. All fields are assumed to be 10 km on a side. A map of Kuwait showing the locations of the eight oil fields with burning wells and the location of the densely populated Kuwait City area is shown in Figure 1.

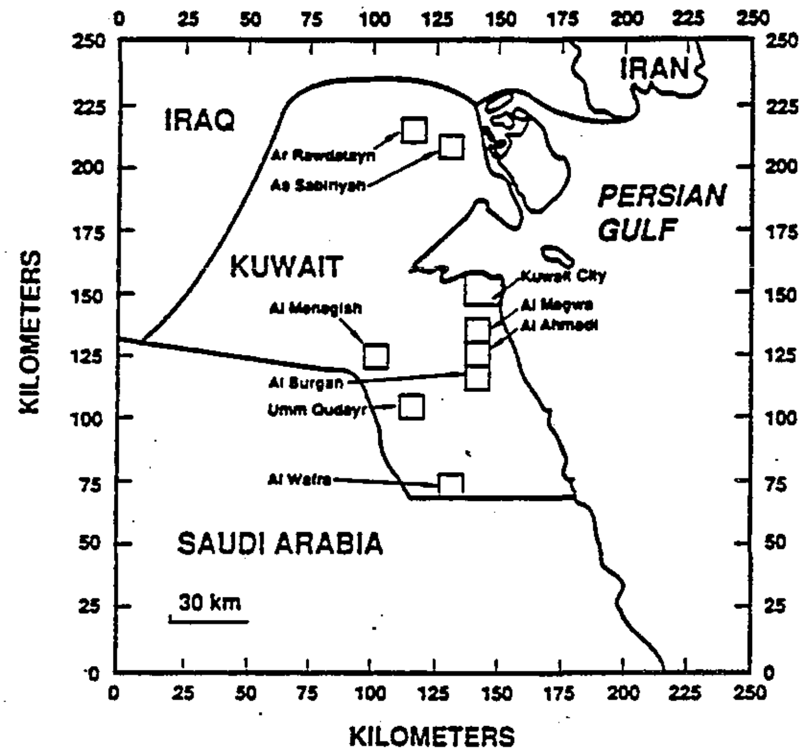



Figure 1. Locations of Burning Fields and Principal Population Center.

Oil blowout rate - The rate is dependent on many factors, including wellhead pressure, size of the well, extent of damage to plumbing, and inter-well pressure effects. Pre-war information provided by Kuwaiti engineers regarding well pressure, well size, subterranean geological formation, etc., was used in previous analyses to calculate expected oil blowout rates for completely breached wellheads. Because no new information is available, the blowout rates used here are unchanged from those in the pre-war calculations.

Plume injection height - Earlier calculations of buoyant rise of the smoke plume gave injection heights of about 200 to 450 meters for most wells in the affected oil fields. An average plume injection height of 300 meters is used for these calculations.

Pollutant emission factors - The emission factor for a pollutant is the mass of the pollutant that is released per unit mass of crude oil burned. An emission factor of 0.01 for nitrogen oxides would release 1 kilogram of $NO_x$ for every 100 kilograms of oil consumed. The values used for the pollutants examined in this analysis are based on work for the Nuclear Winter Source-Term Measurement Program on aviation fuel pool fires. Because there are few data for actual crude oil fires, these values are the best estimates at this time. The emission factor for each pollutant likely to cause adverse short-term or long-term health effects was used to calculate a total release rate for that pollutant for each affected oil field. Table 1 shows that the three southeastern fields (Al Burgan, Al Ahmadi, Al Magwa) have the highest release rates.

**Table 1. Pollutant Release Rates**

| Oil Field | $NO_x$ (g/s/m²) | $SO_2$ (g/s/m²) | CO (g/s/m²) | Soot (g/s/m²) | Benzene (μg/s/m²) | Benzopyrene (μg/s/m²) |
|---|---|---|---|---|---|---|
| Ar Rawdatayn | 9.98E-05 | 4.99E-04 | 5.59E-05 | 5.99E-04 | 6.49E+00 | 9.98E-03 |
| Al Sabiriyah | 7.59E-05 | 379E-04 | 4.25E-05 | 4.55E-04 | 4.93E+00 | 7.59E-03 |
| Al Magwa | 1.53E-04 | 7.67E-04 | 8.59E-05 | 9.20E-04 | 9.97E+00 | 1.53E-02 |
| Al Ahmadi | 1.56E-04 | 7.79E-04 | 8.73E-05 | 9.35E-04 | 1.01E+01 | 1.56E-02 |
| Al Burgan | 4.52E-04 | 2.26E-03 | 2.53E-04 | 2.71E-03 | 2.94E+01 | 4.52E-02 |
| Al Managish | 3.13E-05 | 1.57E-04 | 1.75E-05 | 1.88E-04 | 2.03E+00 | 3.13E-03 |
| Umm Qudayr | 1.60E-05 | 7.98E-05 | 8.94E-06 | 9.57E-05 | 1.04E+00 | 1.60E-03 |
| Al Wafra | 1.02E-05 | 5.11E-05 | 5.72E-06 | 6.13E-05 | 6.64E-01 | 1.02E-03 |

Emission Factors: $NO_x$ = 0.01; $SO_2$ = 0.05; CO = 5.6E-03; Soot = 0.06; Benzene = 6.5E-04; Benzo(a)pyrene = 1E-06

Meteorological Information

Although the model can accept hourly meteorological data for an entire year, such data are not available for the region. Consequently, 10-year climatological summaries of meteorological data from Kuwait City airport have been used to provide a single average daytime (3PM Kuwait time) and a single average nighttime (3AM Kuwait time) summary for each month. The resulting set of data applies to 24 discrete meteorological periods (Table 2) for which the model calculates downwind pollutant concentrations. Specific meteorological parameters required for each period are discussed below.

Surface temperatures - These data are taken directly from the climatological summaries.

Pasquill stability category - This parameter characterizes the temperature-altitude structure, which affects the degree of vertical mixing in the plume. For these calculations, the daytime category selected is unstable (A) and the nighttime category selected is stable (D).

Wind speed and direction - These data are taken directly from the climatological summary and, as indicated above, provide an average daytime and nighttime speed and direction for each month. Note that the average wind direction is relatively constant throughout the year. Winds are typically from the northwest with little variation.

Mixing height - This parameter characterizes the height of the mixed layer into which the plume in injected. Atmospheric mixing-height data for each of the 24 periods were taken from a 10-year summary of atmospheric inversion data that excluded surface inversions. Surface inversions were excluded because the heat content of these plumes is considered to be great enough to penetrate any shallow surface inversion. Mixing heights (median inversion heights) in the Kuwaiti region range from a minimum of 800 meters during the winter season to a maximum of 4800 meters during the summer months.

Table 2. Kuwait City Airport Ten-year Climatological Summary

| Period Month | Period Time | Avg Temp (C) | Avg Press (mbar) | Avg Wspeed (m/s) | Avg Wdir (Deg) | Flow Vector[a] (Deg) | Median Invht[b] (m) |
|---|---|---|---|---|---|---|---|
| Jan | 0300 | 9.4 | 1013.9 | 2.5 | 11.0 | 191.0 | 800 |
| Jan | 1500 | 17.5 | 1013.0 | 5.3 | 326.0 | 146.0 | 1000 |
| Feb | 0300 | 11.3 | 1011.8 | 2.5 | 11.0 | 191.0 | 1200 |
| Feb | 1500 | 20.0 | 1010.7 | 5.7 | 326.0 | 146.0 | 1200 |
| Mar | 0300 | 15.4 | 1008.1 | 2.9 | 11.0 | 191.0 | 1000 |
| Mar | 1500 | 24.3 | 1007.4 | 5.9 | 326.0 | 146.0 | 1600 |
| Apr | 0300 | 21.5 | 1004.9 | 3.0 | 11.0 | 191.0 | 1000 |
| Apr | 1500 | 31.3 | 1004.8 | 6.0 | 349.0 | 169.0 | 2000 |
| May | 0300 | 27.1 | 1001.6 | 3.3 | 11.0 | 191.0 | 1200 |
| May | 1500 | 37.9 | 1001.6 | 6.6 | 349.0 | 169.0 | 2200 |
| Jun | 0300 | 30.8 | 996.2 | 4.5 | 326.0 | 146.0 | 2000 |
| Jun | 1500 | 42.6 | 995.9 | 8.2 | 349.0 | 169.0 | 3800 |
| Jul | 0300 | 32.8 | 992.8 | 3.7 | 326.0 | 146.0 | 3400 |
| Jul | 1500 | 44.9 | 992.2 | 7.5 | 349.0 | 169.0 | 4800 |
| Aug | 0300 | 31.9 | 993.9 | 3.3 | 11.0 | 191.0 | 2000 |
| Aug | 1500 | 43.6 | 993.7 | 7.2 | 326.0 | 146.0 | 4400 |
| Sep | 0300 | 27.6 | 999.9 | 2.2 | 11.0 | 191.0 | 3800 |
| Sep | 1500 | 41.0 | 999.6 | 5.7 | 349.0 | 169.0 | 4800 |
| Oct | 0300 | 22.4 | 1006.6 | 2.4 | 11.0 | 191.0 | 1200 |
| Oct | 1500 | 34.3 | 1006.1 | 5.5 | 349.0 | 169.0 | 1800 |
| Nov | 0300 | 16.5 | 1011.5 | 2.7 | 11.0 | 191.0 | 1000 |
| Nov | 1500 | 25.7 | 1010.7 | 5.5 | 349.0 | 169.0 | 1200 |
| Dec | 0300 | 10.7 | 1013.9 | 2.3 | 11.0 | 191.0 | 800 |
| Dec | 1500 | 19.1 | 1012.8 | 5.2 | 326.0 | 146.0 | 1000 |

[a]180 deg from the wind direction

[b]Median inversion heights exclude surface-based inversions.

*Results*

Results of computations are given as downwind, ground-level concentration isopleths in Figures 2 to 8. The pollutants analyzed include nitrogen oxides ($NO_x$ = $NO_2$, NO), sulfur dioxide ($SO_2$), carbon monoxide (CO), particulates (soot), VOCs (benzene), and PNAs (benzo(a)pyrene). Figures 2 through 4 show the second highest hourly concentration levels obtained for $NO_x$, $SO_2$, CO, and soot during the 24 meteorological periods treated by the model. The highest hourly concentration levels are treated as unrepresentative and are discarded. Second highest hourly concentration levels represent short-term levels and are used as acute exposure levels. Figures 6 through 8 show average concentrations for soot, benzene, and benzo(a)pyrene averaged over all 24 periods examined by the model. These isopleths represent long-term, or chronic, exposure levels. In all cases, the highest exposure levels are immediately downwind of the Al Magwa, Al Ahmadi, and Al Burgan fields. This is not surprising because these oil fields have the highest wellhead pressures and the largest number of burning wells (70% of the total).

Nitrogen oxide levels (Figure 2) include nitric oxide (NO) and nitrogen dioxide ($NO_2$). Although most of the $NO_x$ produced at the wellhead is NO, some fraction (about 25%) reacts with ambient oxygen to form $NO_2$. The rate of this reaction is proportional to the square of the NO concentration, so a high rate of conversion of NO to $NO_2$ occurs when the NO concentration is high. However, when the NO concentration falls as a result of plume dilution, this reaction pathway ceases to contribute to $NO_2$ formation. The highest $NO_x$ level in the model calculations is 520 $\mu g\ m^{-3}$ (computed as $NO_2$). Assuming conservatively that 25% is $NO_2$, then hourly average levels of about 250 $\mu g\ m^{-3}$ of NO and 130 $\mu g\ m^{-3}$ of $NO_2$ would be expected in the region of high-level exposure southeast of the Al Burgan field. Levels along the more heavily populated coastal area would be lower by about a factor of two, and levels in the region of Kuwait City would be lower by about a factor of five. Ozone formation and ozone reactions with the nitrogen oxides are not examined in this analysis.

Hourly average sulfur dioxide levels (Figure 3) are among the highest encountered for any of the pollutants examined (Kuwaiti oil has a sulfur content near 2.5%). The $SO_2$ emission factor (0.05) and resultant downwind concentrations are correspondingly higher than those observed for $NO_x$ (emission factor = 0.01). The highest level is about 2,200 $\mu g\ m^{-3}$ and occurs immediately southeast of the Al Burgan field. Levels drop off to about 1,000 $\mu g\ m^{-3}$ along the gulf coastal areas and to about 300 $\mu g\ m^{-3}$ in the region of Kuwait City.

Carbon monoxide levels are low in all areas (the emission factor for CO in these crude oil fires is about one-tenth that for $SO_2$). Background CO levels for clean air are typically about 100 $\mu g\ m^{-3}$. Most of the downwind CO levels (Figure 4) are no more than a factor of two or three greater than the background level.

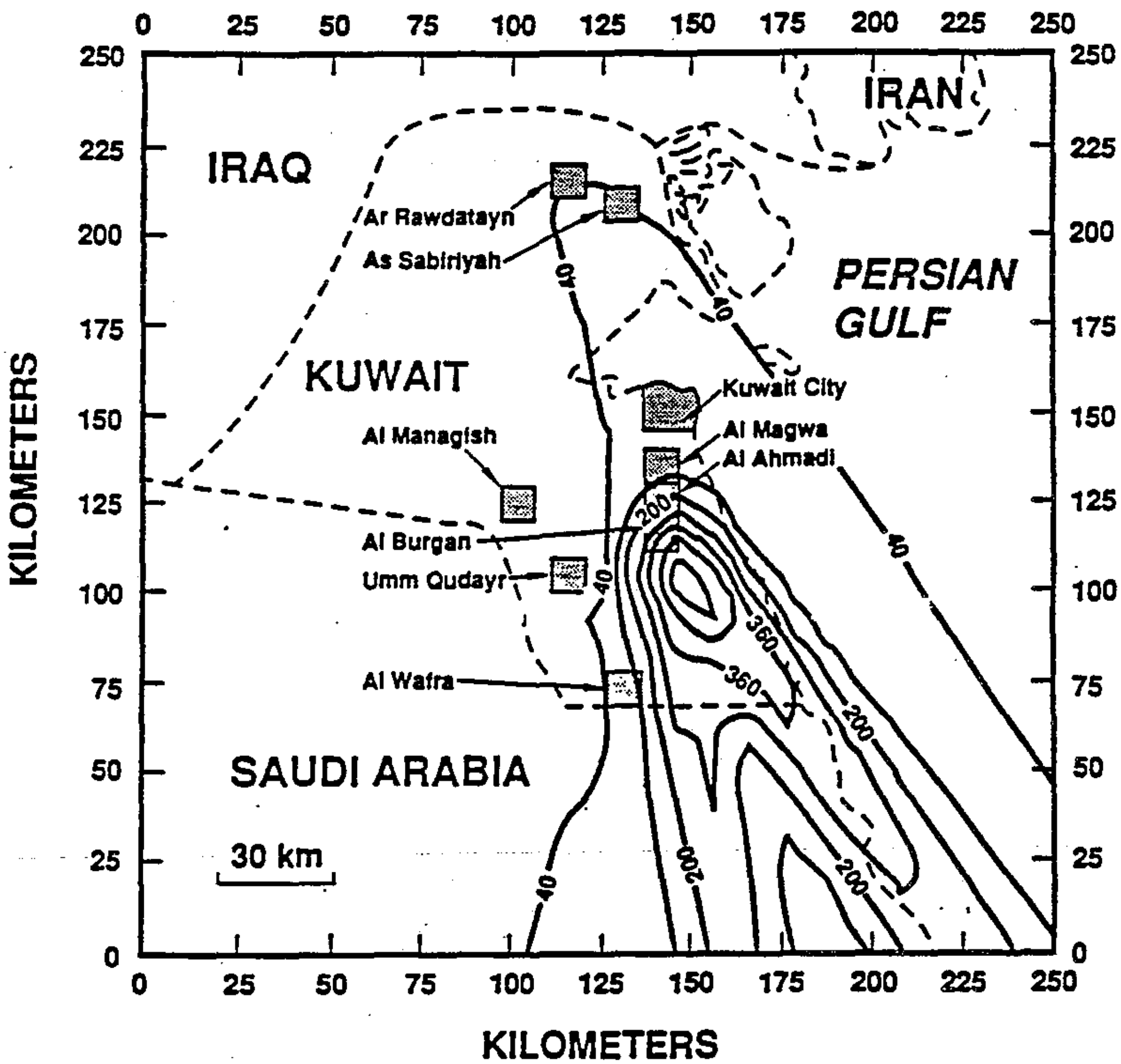



Figure 2. Downwind Ground-level Concentration Isopleths for $NO_x$ Released from Burning Kuwaiti Oil Fields. The plot depicts the second highest hourly values in $\mu g\ m^{-3}$ (as $NO_2$) calculated using a multi-source dispersion model run for 24 1-hour periods that represent average day and night meteorological conditions for each month. Contour interval is 80 $\mu g\ m^{-3}$.

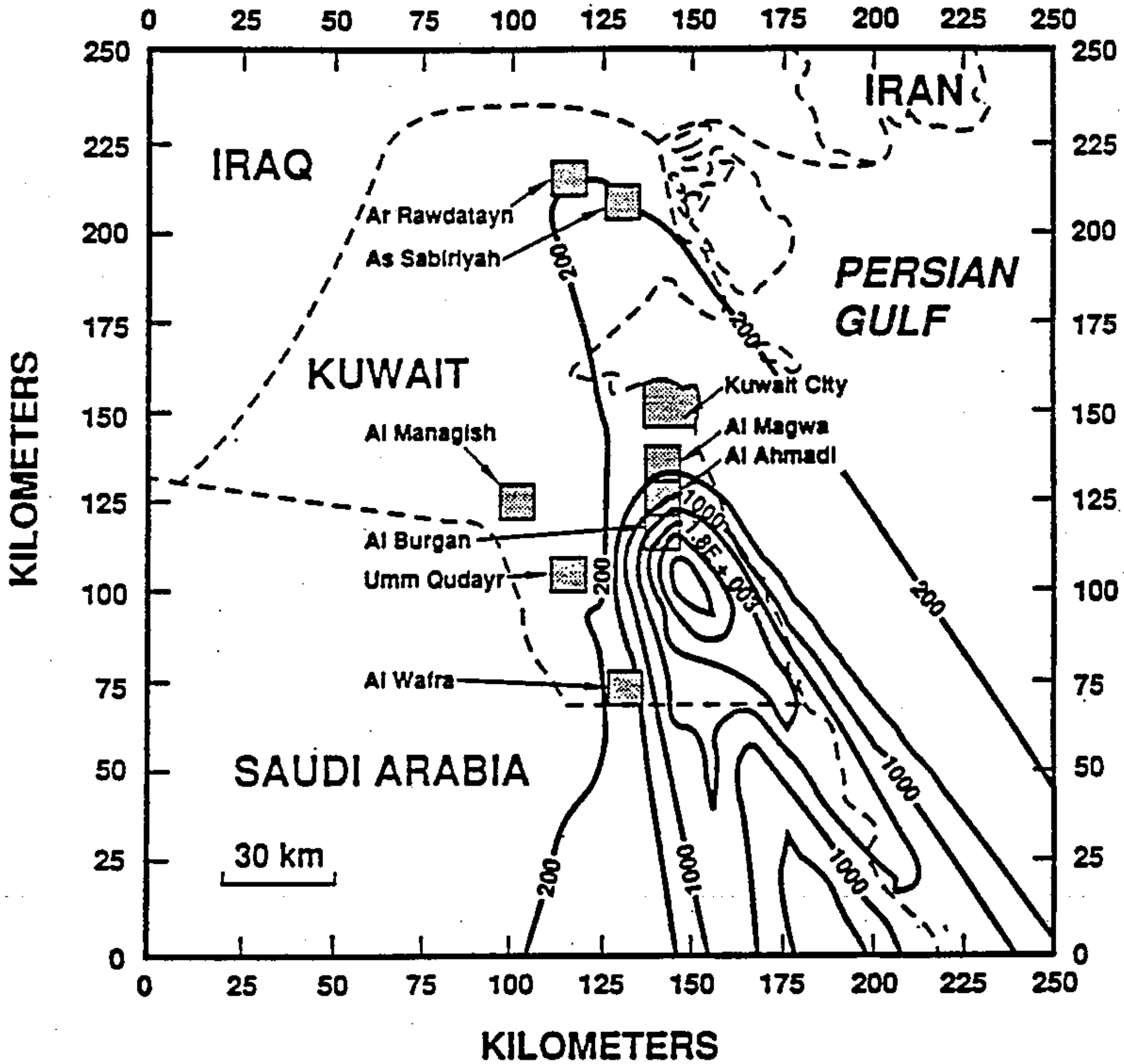



Figure 3. Downwind Ground-level Concentration Isopleths for $SO_2$ Released from Burning Kuwaiti Oil Fields. The plot depicts the second highest hourly values in $\mu g\ m^{-3}$ calculated using a multi-source dispersion model run for 24 1-hour periods that represent average day and night meteorological conditions for each month. Contour interval is 400 $\mu g\ m^{-3}$.

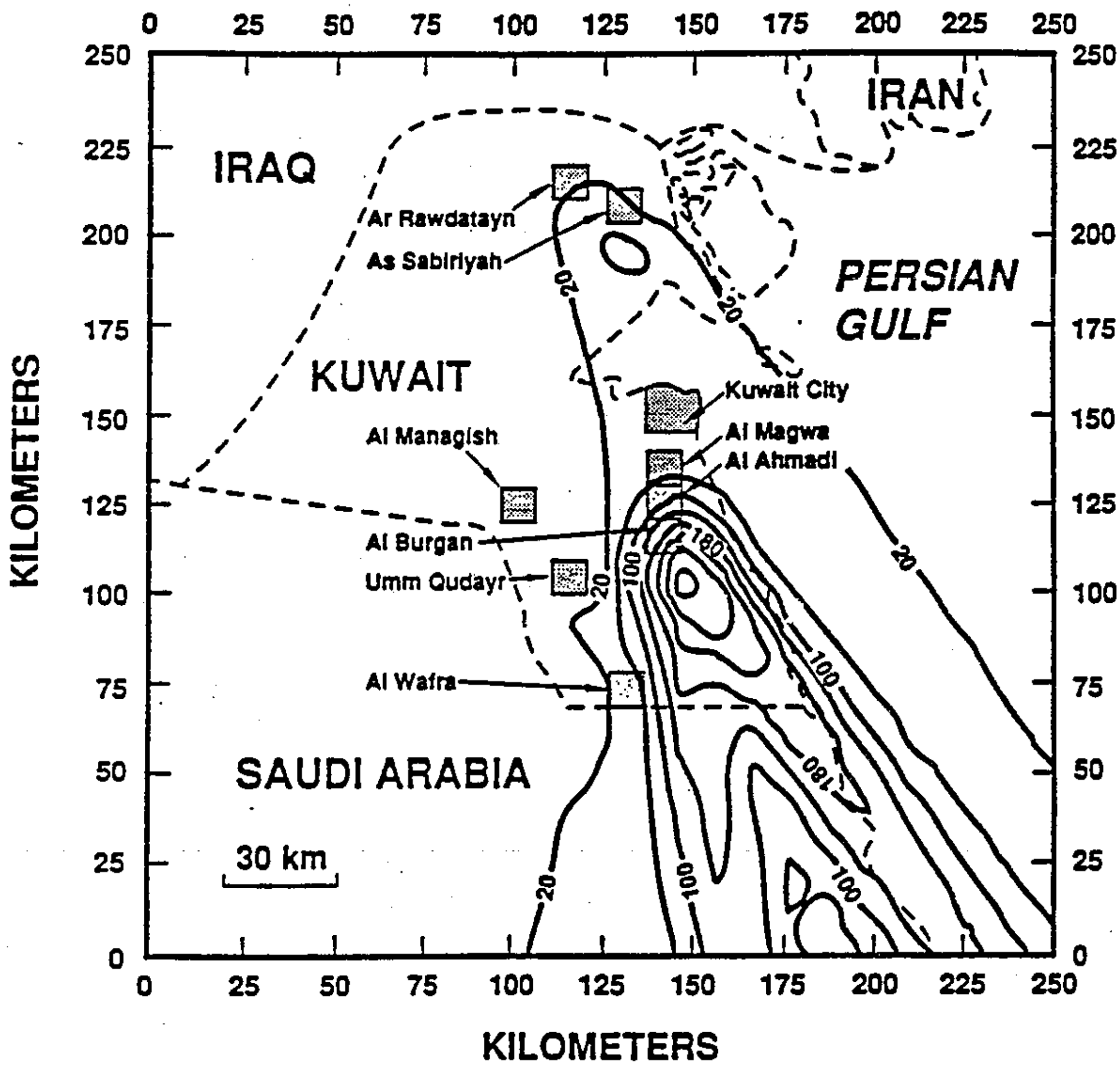



Figure 4. Downwind Ground-level Concentration Isopleths for CO Released from Burning Kuwaiti Oil Fields. The plot depicts the second highest hourly values in $\mu g\ m^{-3}$ calculated using a multi-source dispersion model run for 24 1-hour periods that represent average day and night meteorological conditions for each month. Contour interval is 40 $\mu g\ m^{-3}$.

Acute exposure levels for soot are shown as second highest hourly concentrations in the 3-D surface plot of Figure 5, and chronic exposure levels for soot are shown as annual average concentration isopleths in Figure 6. Hourly average values are in excess of 1,600 $\mu g\ m^{-3}$ immediately southeast of the Al Burgan field and drop to 800 to 1,000 $\mu g\ m^{-3}$ range near the Kuwait-Saudi border and along the gulf coastal region. Annual average soot levels, as shown in Figure 6, are lower than the second highest hourly values by about a factor of five.

Benzene is a typical VOC and is used here to represent this class of compounds. The benzene emission factor ( $\sim 7 \times 10^{-4}$) was estimated in earlier SNL work involving smoke samples collected from large aviation fuel pool fires. Downwind annual average concentrations of benzene (Figure 7) range from a low of $< 1\ \mu g\ m^{-3}$ near the northern oil fields of Ar Rawdatayn and Al Sabiriyah to a high of about 9 $\mu g\ m^{-3}$ southeast of the Al Burgan field.

Benzo(a)pyrene is a typical PNA and is representative of the whole class of similar compounds many of which are either suspected or confirmed carcinogens. Emission factors for benzo(a)pyrene in crude oil or aviation pool fires are not well defined, so a value of $1 \times 10^{-6}$ (obtained from published data on smoke samples collected from burning refuse piles) was used to provide an upper bound. Downwind exposure levels (Figure 8) range from a low of $< 1\ ng\ m^{-3}$ in the north to a high of about $> 12\ ng\ m^{-3}$ near the Al Burgan field.

Table 3 summarizes the hourly or annual average concentrations of pollutants that would be expected in the populated coastal region east of the Al Burgan field and in the vicinity of Kuwait City and, for comparison, lists typical values for these pollutants in urban areas of the U.S. In comparison to urban regions of the U.S., populated regions of Kuwait are likely to experience higher levels of $SO_2$ and soot.

**Table 3. Comparison of Expected Hourly or Annual Average Concentrations of Selected Pollutants in Populated Areas of Kuwait with Levels Measured in Typical Urban Areas of the U.S.**

| | | Concentration Levels ($\mu g\ m^{-3}$) | | |
|---|---|---|---|---|
| **Species** | **Average Type** | **Coastal Areas** | **Kuwait City** | **Urban U.S.** |
| NO | Hourly | 175 | 40 | 50-750 |
| $NO_2$ | Hourly | 90 | 20 | 50-250 |
| $SO_2$ | Hourly | 1,100 | 300 | 20-200 |
| CO | Hourly | 180 | 40 | 1,000-10,000 |
| Soot | Annual | 180 | 80 | 10-30 |
| Benzene | Annual | 3 | 1 | 40-1,000 |
| Benzo(a)Pyrene | Annual | 5E-03 | 1E-03 | 2E-03 to 1E-02 |

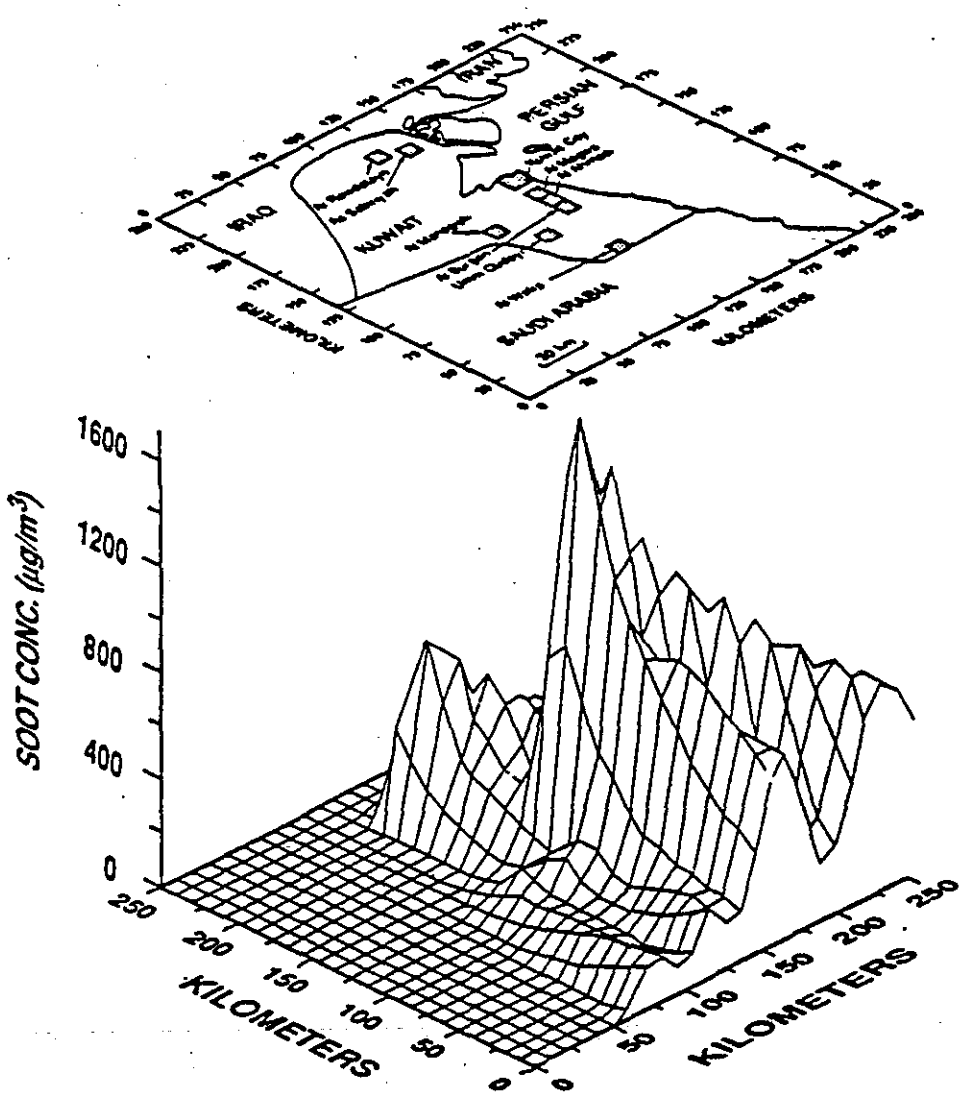



Figure 5. Three dimensional Surface Plot of Soot Concentrations Released from Burning Kuwaiti Oil Fields. The plot depicts the second highest hourly values in $\mu g\ m^{-3}$ calculated using a multi-source dispersion model run for 24 1-hour periods that represent average day and night meteorological conditions for each month. The viewer perspective is from the southwest. The grid shown is the same as that depicted in the map shown in Figure 1. Kuwait City is located at the grid point X=150 km, Y=150 km.

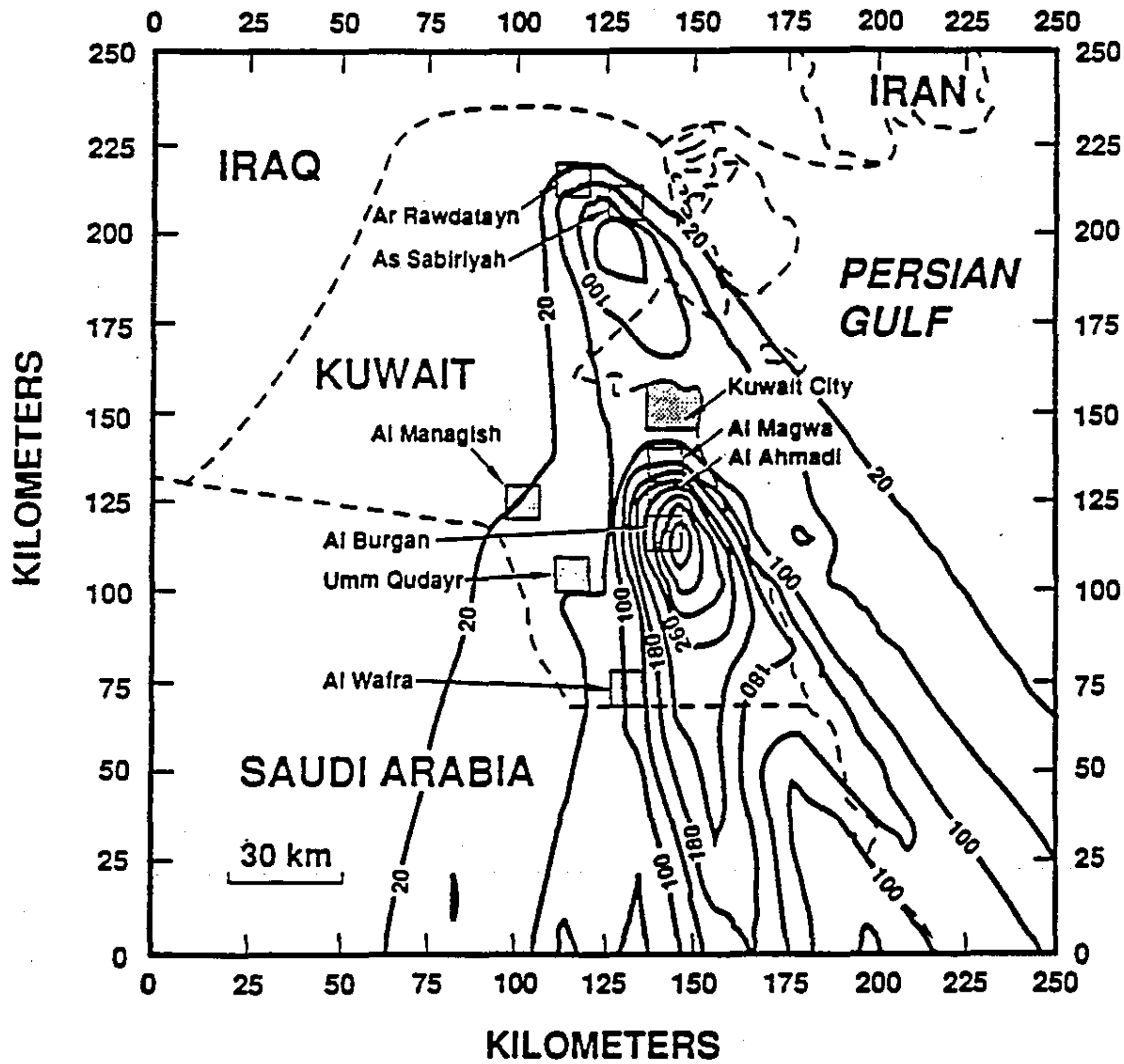



Figure 6. Downwind Ground-level Concentration Isopleths for Soot Released from Burning Kuwaiti Oil Fields. The plot depicts an annual average concentration in $\mu g\ m^{-3}$ calculated using a multi-source dispersion model run for 24 1-hour periods that represent average day and night meteorological conditions for each month. Contour interval is 40 $\mu g\ m^{-3}$.

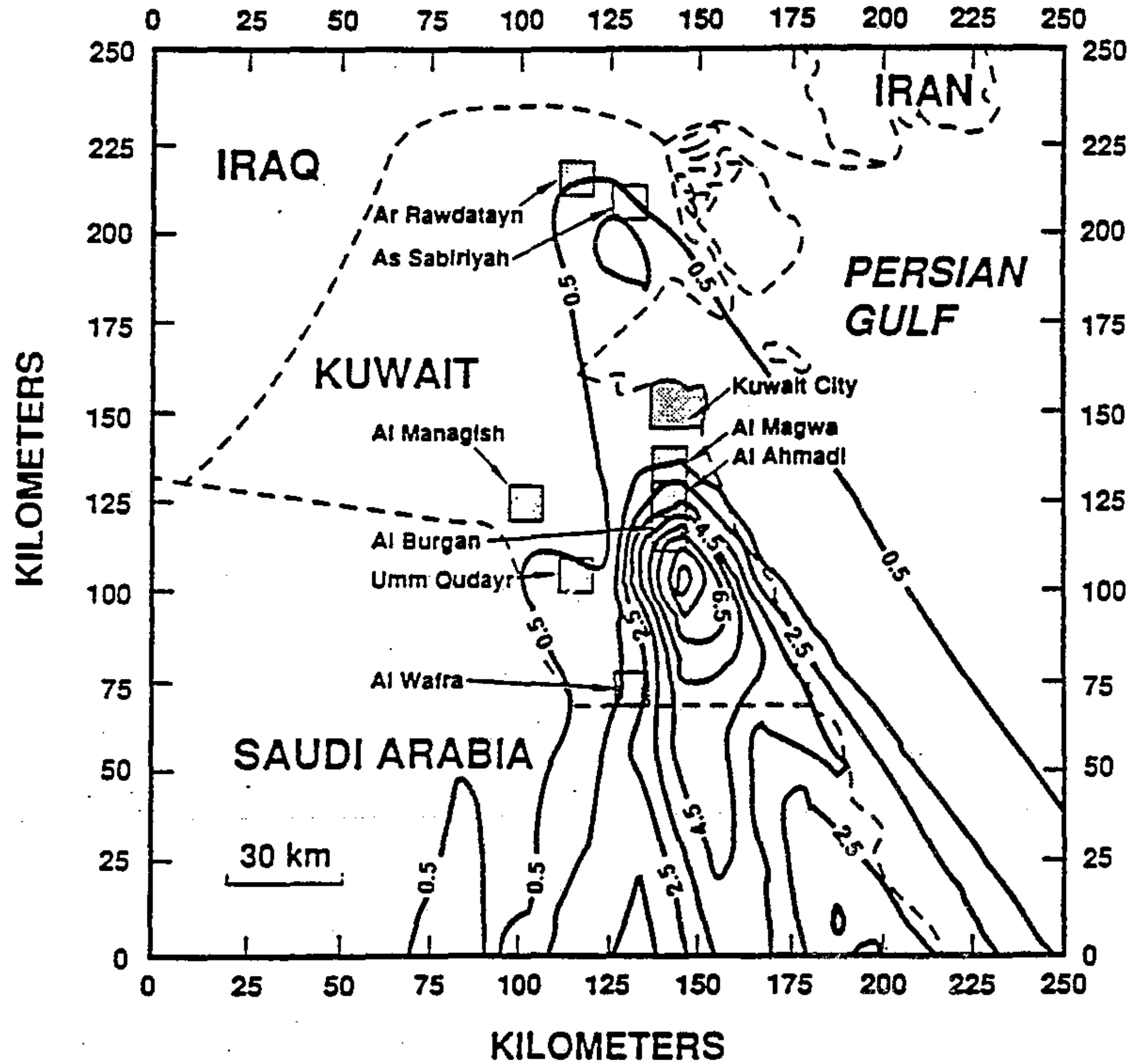



Figure 7. Downwind Ground-level Concentration Isopleths for Benzene Vapors Released from Burning Kuwaiti Oil Fields. The plot depicts an annual average concentration in $\mu g\ m^{-3}$ calculated using a multi-source dispersion model run for 24 1-hour periods that represent average day and night meteorological conditions for each month. Contour interval is $1\ \mu g\ m^{-3}$.

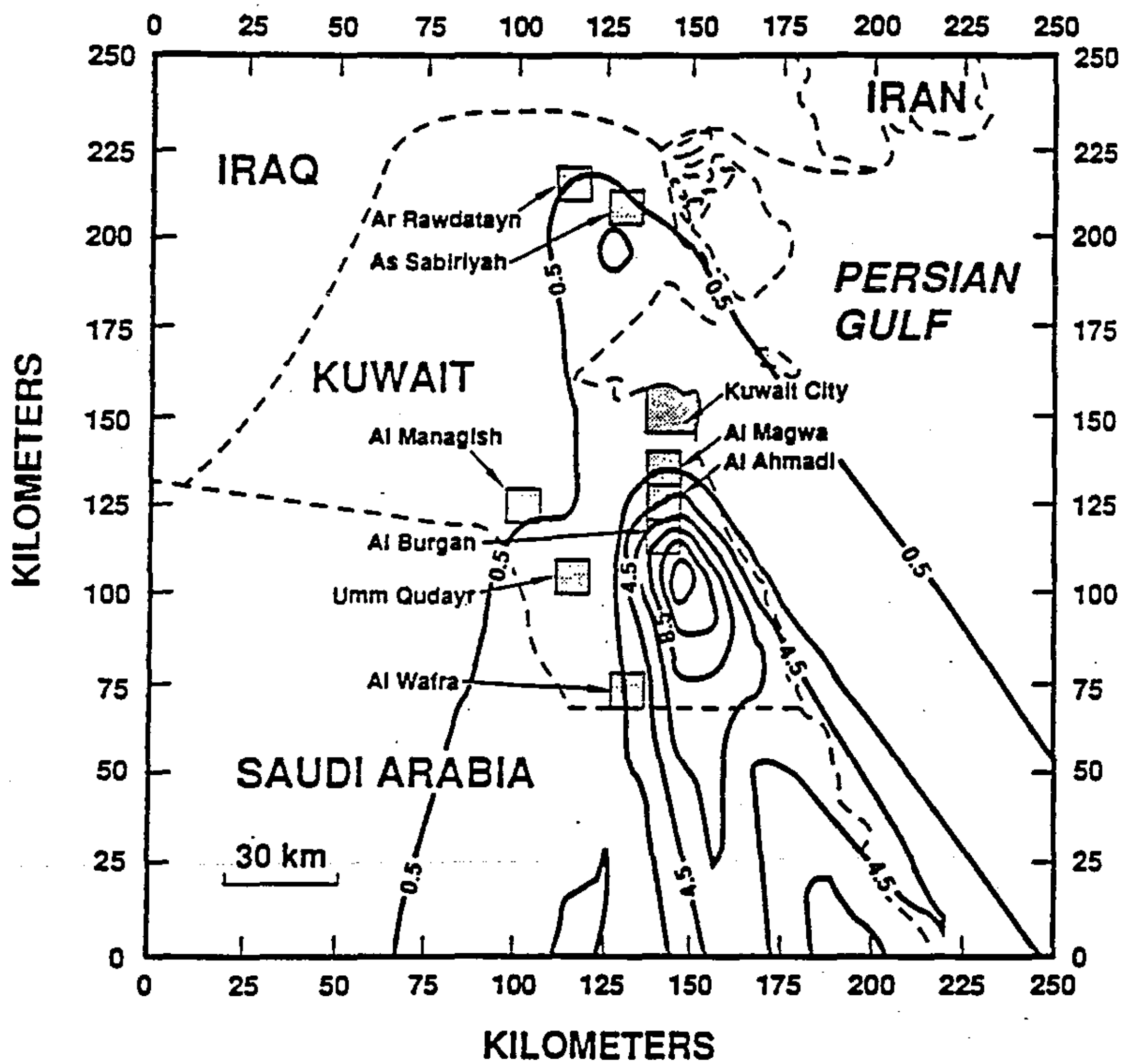



Figure 8. Downwind Ground-level Concentration Isopleths for Benzo(a)pyrene Vapors Released from Burning Kuwaiti Oil Fields. The plot depicts an annual average concentration in ng $m^{-3}$ calculated using a multi-source dispersion model run for 24 1-hour periods that represent average day and night meteorological conditions for each month. Contour interval is 2 ng $m^{-3}$.

## Recommendations for Further Work

Now that access to the Kuwaiti oil fields is possible, there is opportunity to do experiments that will

- Generate actual concentration isopleths (and, collaterally, help to validate source-term/dispersion models),
- Establish legally unimpeachable exposure levels, and
- Explore means to alter the smoke plume so as to mitigate adverse health effects,
- Improve understanding of smoke source terms in oil well fires,
- Provide a well-characterized smoke environment in which to test the performance of military systems.

A data acquisition program should be carried out to measure pollutant concentrations at various locations and times in order to generate actual concentration isopleths that will provide a realistic picture of exposure hazards in the region. The program should be carefully designed and should take advantage of state-of-the-art instrumentation and sampling techniques.

Exposure levels should be carefully documented because the documentation may be especially useful should litigation arise from claims from military or U.S. civilian personnel exposed to oil fire smoke. The scientific uncertainties surrounding the nature and extent of exposure of personnel, as was the case with Agent Orange in Vietnam, should not be repeated.

Experiments should be done in conjunction with computer calculations of oil combustion to determine the feasibility and practicality of adding materials to the well fire that would alter the chemical composition or the dynamics of the plume so as to reduce the health hazard.

It should no longer be necessary to rely on estimates of oil blowout rates and pollutant emission factors. Insofar as possible, these quantities should be measured. Physical methods should be investigated to measure remotely the oil blowout rates at breached wellheads. Techniques using overhead doppler radar and ground-based passive thermal measurements of burning wellheads may be successfully developed to measure these rates. Measurements can be made using an instrumented aircraft platform and a technique known as the carbon balance method for determining emission factors. The availability of carefully measured emission factors for pollutants in crude oil smoke would promote greater confidence in the results of dispersion model calculations.

Optically thick, well-characterized plumes could be used for realistic tests of various military targeting and tracking systems.

STATUS REPORT OF PUBLIC HEALTH IN KUWAIT
AS OF MARCH 21, 1991

Prepared by John S. Andrews, Jr., M.D., M.P.H.
Associate Administrator for Science
Agency for Toxic Substances and Disease Registry

## I. Background

I was attached to the Kuwait Task Force (KTF) of the U.S. Army's 352nd Civil Affairs Command beginning on January 30, 1991, to serve as liaison for additional U.S. Public Health Service personnel who were to be deployed from the United States. From January 30 until February 15, I trained with the U.S. Army at Fort Meade, Maryland. From February 16 until February 28, I was in Dammam, Saudi Arabia, working with the Kuwait Task Force and Dr. Saleh AL-Kandari from the Kuwaiti Ministry of Public Health. From March 1 through March 21, I was in Kuwait City working with Kuwaitis in the Ministry of Public Health (Dr. Jaffar Dawood, Dr. Rached AL-Owaish, Mr. Ibrahim Hadi).

Due to the short war, the small number of United States casualties, and the small number of civilian casualties, U.S. military personnel already in Saudi Arabia or Kuwait became available to carry out public health activities and they decreased the need to deploy public health personnel from the United States. Mr. Jorge Lambrinos, Chief of Staff for Congressman Edward Roybal of California and a member of the KTF, and I coordinated public health activities of these additional military personnel for the KTF.

The available public health personnel were divided into teams to work with personnel from the Kuwaiti Ministry of Public Health. Much of the work described in this report was carried out by military personnel or by personnel in the Kuwaiti Ministry of Public Health.

## II. Persons Met

A. Ministry of Public Health - Kuwait

1. Dr. Ali Saif, Undersecretary for Public Health
2. Dr. Rached AL-Owaish, Director of Department of Public Health
3. Dr. Jaffar Dawood, Chief of Preventive Medicine
4. Dr. Saleh AL-Kandari, Infectious Disease
5. Dr. Mussab AL-Saleh, Preventive Medicine Physician
6. Mr. Ibrahim M. Hadi, Department of Environmental Health
7. Dr. Ramsey Ishmael, Preventive Medicine Physician

B. Vector Control Team

CDR George Schultz, Navy Forward Medical Laboratory - Team Leader
LT Manuel Lluberas, Navy Forward Medical Laboratory
HM1 Burger, Navy Forward Medical Laboratory
HM1 Richard Congo, Navy Forward Medical Laboratory
CPT Craft, Navy Forward Medical Laboratory
CAPT Steve Leonard, Navy Forward Medical Laboratory
Sgt Stone, British Army
Sgt Jones, British Army

C. Public Health Laboratory Team

CDR Jim Burans, Navy Forward Medical Laboratory - Team Leader
LT Scott Thornton, Navy Forward Medical Laboratory
HM1 Edna Bory, Navy Forward Medical Laboratory
HM1 Avelino Cardwell, Navy Forward Medical Laboratory

D. Public Health Headquarters, Environmental Laboratory, Ministry of Municipalities Team

CDR Mary Anderson, Navy Forward Medical Laboratory - Team Leader
Major John Graham, British Army
CAPT Steve Wignall, Navy Forward Medical Laboratory
HM1 McMahon, Navy Forward Medical Laboratory
LCOL Jorge Lambrinos, KTF, 352nd Civil Affairs Command, U.S. Army
CAPT John Andrews, KTF, 352nd Civil Affairs Command, U.S. Public Health Service liaison

III. Public Health Situation Prior to August 2, 1990

A. Organization. The Department of Health, under the Minister of Public Health, consisted of five divisions: (1) Preventive Medicine, (2) Ports and Borders Health, (3) Radiation Protection, (4) Rodent and Medical Insect Control, and (5) Public Health Laboratories.

B. The country was divided into five health regions. Each region had its "Head of Public Health Office" who reported to both the national Preventive Medicine Division and the Director in the region.

C. The Preventive Medicine Division consisted of three units: (1) Unit for Control of Epidemic Diseases, (2) Environmental Health Unit, and (3) Nutrition Unit. The main function of the Preventive Medicine Division was to plan, direct, and control the activities of the 23 Preventive Medicine Centers located in Kuwait City and

Preventive Medicine Centers located in Kuwait City and residential districts (Figure 1). These activities included the investigation and implementation of health regulations to control the spread of epidemic diseases. Through a mandatory reporting system, notifications of infectious diseases were investigated by the preventive medicine centers that were staffed with a preventive medicine doctor, two to three health inspectors, and a public health nurse for immunization activity. In addition, a preventive medicine center was located in each of the general regional hospitals, as well as the Hospital for Infectious Diseases and the Maternity Hospital. Attached to the Preventive Medicine Division was a center for the examination of food handlers.

D. Ports and Borders Division

The Ports and Borders Division was responsible for implementation of the international health regulations related to land, air, and sea movement; for preventive medical activities at the border areas; and for health control of arrivals to Kuwait from endemic areas through the International Airport. In addition, the Ports and Borders Division was responsible for the medical examination of expatriates for residency permits which included the examination for evidence of HIV infection, pulmonary tuberculosis, malaria, and leprosy.

E. Water

Prior to the occupation, 93-97 percent of Kuwait's water supply came from desalination plants. The rest of the water came from wells. All of Kuwait City was on municipal water. Results of drinking water testing for September 1989, January 1990, and June 1990 by the Environmental Protection Council are shown in Table 1.

F. Food

1. Food and Food Handler Testing

Legislation for food control was the responsibility of the Ministry of Commerce and the Ministry of Public Health. The municipalities were responsible for the control of distribution, as well as sampling imported food and the inspection of food stores and shops. The Division of Public Health Laboratories assisted in the examination of food and water and in the adoption of The Kuwaiti Specifications for Food.

2. Veterinary

This was done under the Department of Animal Health at the Public Authority for Agriculture and Fisheries.

G. Sewage

This was the responsibility of the Ministry of Public Works. Data on the quality of treated effluent for September 1989, and January and June 1990 are shown in Table 2.

H. Environmental

1. Garbage collection and disposal was the responsibility of the Ministry of Municipalities and their contractors.

2. Air quality monitoring was the responsibility of the Department of Environmental Protection of the Ministry of Public Health. The tables below are copied from three monthly reports of the Department of Environmental Protection (Environmental Protection Council).

   The concentration of gases expressed as ppm and ppb for September 1989, January 1990, and June 1990 for Mansoria, Rabia, and Rega is shown in Table 3.

   The distribution of settled dust in grams/square meter/day for January and June 1990 for the Shuwaikh Industrial area, Kuwait City, and Jahra is shown in Table 4.

   The concentration of suspended particulate matter in daily samples for January and June 1990 in micrograms per cubic meter for the Schuwaikh Industrial area, Kuwait City, Shamieh, and Jahra is shown in Table 5.

   The size distribution of suspended particulate matter for January and June 1990 for the Shuwaikh Industrial area, Kuwait City, and Shamiah is shown in Table 6.

I. Vector and Rodent Control was the responsibility of the Rodent and Insect Control Department of the Ministry of Municipalities.

J. Disease Surveillance

Disease surveillance in Kuwait covered the occurrence of disease and a watch on the risk factors that contribute to this occurrence. A list of reportable diseases is shown in Table 7. Reported communicable disease for 1988-1990 are shown on Tables 8-10, respectively.

Disease surveillance included active surveillance amongst population groups at risk, e.g., the expatriates for AIDS, tuberculosis, malaria, and leprosy and food handlers and others in high-risk vocations in the community. The reporting of disease included active case finding and looking at laboratory reports at all laboratories, as well as hospital admissions.

K. Immunizations

1. Childhood Immunizations

The last assessment of immunization in Kuwait (1989) showed a very good coverage of basic vaccines in infants and children. This reached about 95 percent for OPV, DPT, and measles. There were no cases of polio, neonatal tetanus, or diphtheria in Kuwait for a number of years. Measles control was well on its way to succeed in breaking the every other year increase in cases indicating success in the expanded program in immunization in Kuwait. The immunization schedule is shown in Table 11 and the number of immunizations given from 1977 through 1990 is shown in Tables 12-14.

2. Hepatitis B Vaccine

Hepatitis B vaccine was introduced in the Expanded Program of Immunization (EPI) in January 1990. The first dose of HBV is given the second day of birth; the second dose at 3 months of age; and a third dose at 6 months of age.

3. BCG Immunization

BCG vaccinations were one of the main functions of the Tuberculosis Control Unit. The section had four tuberculosis control units with static and mobile X-ray, tuberculin testing, and BCG vaccination facilities. The units were distributed all over Kuwait. The BCG vaccination is conducted by a joint effort between the Tuberculosis Control Unit and the School Health Division. BCG vaccination is given at the age of 4 years as part of the medical examination for school entry.

## L. Laboratories

### 1. Public Health Laboratory

The Public Health Laboratories under the Division of Public Health Laboratories of the Department of Public Health, carried out bacteriological, chemical, and virological examinations. It examined food, water, and sewage, as well as stool samples. It was the only laboratory that handled examinations of stools for Vibrio cholerae. The Virology Laboratory was responsible for all viral disease identification, including AIDS and hepatitis.

### 2. Environmental Laboratory

The Environmental Laboratory had sections on air pollution, water pollution, occupational exposure, and oil. The air pollution program had three fixed stations to monitor the air every 5 minutes by computer and analyze the data. One mobile laboratory went to Iraq. The laboratories also could measure dust. The laboratory can also measure temperature inversions, noise at the airport, and sulfur dioxide pollution from cars.

When the environmental laboratory was working, seawater, drinking water, brackish water, and sewage were tested. Trihalomethanes were tested in the drinking water. Water was tested for total alkalinity, total dissolved solids, electrical conductivity, sulphates, residual chlorine, Ph, hardness, total chloride, and nitrate.

### 3. Nerve Gases

There was a laboratory to test for nerve gases during the Iran/Iraq war, but it was not felt to be sensitive enough to be of much use.

## M. Other

The overall health status of the Kuwait population (about 2.1 million) was good, with a life expectancy of about 70 years and an infant mortality rate as low as 12/1,000. Health care was free in a welfare state system.

IV. Public Health Situation August 2 - January 15, 1991.

A. Organization. After the occupation the Iraqis tried to interfere with day-to-day operations of the Department of Public Health, but were constantly kept in the dark. Under the Iraqis, the Ministry of Public Health was headed by an Iraqi Public Health General. The organization is shown in Figure 2. The Preventive Health and Environmental Control Section was one of the five sections under the Public Health General. During the occupation, the main concern of this section was health preservation, not health promotion. Special emphasis was given to water quality, immunization, disease reporting, and the implementation of control measures, examination of all expatriates for AIDS and pulmonary tuberculosis, inspection of food and food handlers, garbage collection, laboratory testing for food and water. Food handlers and contacts of cases of disease were given stool and serum examinations.

B. Manpower

The main problem was the continual decrease in manpower as workers left the country or stayed inside. Even though enough preventive health physicians, community nurses, and health inspectors continued to work during the occupation. However, they worked fewer days to give them the chance to wait in various long lines for bread, gas, and food.

Many of the decisions of the Iraqis were revoked and simply ignored, including decisions to require preventive medicine doctors to work as general practitioners or to make changes in the immunization schedule. This was the main reason that the high dropout percentage was highest among senior staff, since jail or death might be the punishment for such action. Some had stayed away from the decision-making process. Those who stayed to the last days were those showing strong will and courage.

Because of the war situation and the blockage, during the first days of occupation, all ports were closed. Fifty to sixty health inspectors with five physicians from the Ports and Border Health Department were transferred to preventive health centers. Most of them were Palestinians. This gave the preventive health centers a good boost, since most of those who used to work in PHS were Egyptian and many of them left Kuwait gradually during the occupation.

C. The water sources for the Iraqi solders located in Kuwait came from the distillation plants in Kuwait. Therefore, the Iraqis were keen to keep a safe water supply. To insure that the water supply was safe, the Iraqis dispatched some of their military health inspectors to join the Kuwait Ministry of Public Health team in military vehicles to make daily visits and water sampling for the desalination plants and main distribution centers. As an insurance for the Kuwaitis, personnel in the preventive health clinics were instructed to take water samples from nearby distribution centers to insure that the Kuwaiti citizens had a safe water supply. This was explained to the Iraqis as a routine procedure for disease control.

The water supply was checked for bacteriology and chemicals at the Public Health Laboratory. Most results were clear. An investigation was carried out on a water sample from the Chest Hospital that was tested as being unsatisfactory. An investigation showed that water had come from an infrequently used tank. The tank was cleaned and future specimens were satisfactory. All specimens from desalination plants and main distribution centers were satisfactory.

Water quality continued to be checked even after the air war started. One hundred sixty-five samples were taken from December 1990 until the beginning of February 1991.

D. Food

1. Food and Food Handler Testing

Most of the Iraqi soldiers obtained their food from Kuwait. Therefore, a lot of interest was given to keeping the food supply good. The health inspection unit was assigned the responsibility of inspecting food and food handlers. With the shortage of available transportation for the Public Health Department (one car for all of Kuwait), districts were inspected every 2 weeks according to a pre-arranged time table. The main emphasis of inspection was on factories and main food suppliers to check food before it reached general stores and small shops. Food handlers were mainly inspected clinically since laboratory facilities were scarce. Priority was given for foods that were more likely to be contaminated, such as milk and dairy products, meat, poultry, and soft drinks like canned juice and Pepsi. About 400 food samples were collected. Only five of them that were not acceptable for human consumption were destroyed.

Small shops and food stores were mostly closed because of Iraqi hassling, including a tax and fee payment that was required by the Iraqi government. Therefore, persons started selling food and other items in stalls and on sidewalks, changing from one place to another each day or week. Despite that, food was inspected and samples were collected from such stalls to make sure that expired or contaminated food was not sold to the public. However, it was difficult to obtain good results since most persons changed location, increasing the difficulty in enforcing public health laws under the occupation.

Fruits and vegetables came from Iraq and Jordan in large amounts for profit reasons since these goods were sold at prices more than five times higher than in Iraq and Jordan. Regular samples were taken of such food.

2. Veterinary

During the occupation, there were health inspectors and a veterinarian at the abattoir. Ill animals were isolated and treated, if possible. Remnants of animals were burned. Dead animals were regularly buried as a joint effort between the Ministry of Public Health and firemen. Although the Iraqis formed small teams of garbage collectors under their supervision, they were not able to carry out all of the activities that were needed.

E. Sewage

Just at the beginning of the invasion, sewage was directed to the sea via the rain drainage sewer system. This system continued for some time without any problems. However, due to the lack of maintenance, breakdowns did occur. A major breakdown occurred at the Istiqial Street (The Embassies Street) which continued for days. Other breakdowns occurred in the heavily populated provinces. The main reason for that was direct blockage which was mostly managed through local efforts by the people themselves.

F. Environmental

1. Garbage

During the occupation, there was a failure to collect garbage. There were piles of garbage all over the streets, mainly near expatriate populations. These were ineffectively set ablaze. Fire and smoke were a public annoyance. However, in the mainly Kuwaiti districts, Kuwaitis managed to somehow succeed in setting up neighborhood collection of garbage from in front of houses and to burn it in large heaps which kept the residential streets fairly clean.

An effort was launched by the Iraqi government to clean all Kuwait through volunteer teams from inside Iraq. They called it the Kuwait Garbage Campaign. This campaign was merely for propaganda reasons. The real objective was not accomplished. The campaign ended and was not retried.

2. Air

During the occupation, there were minimal air monitoring activities because the mobile and several of the static stations were taken to Iraq.

G. Vectors

Anopheles mosquitoes are in Kuwait (in few numbers). But, there have been no cases of indigenous malaria in many years. There were no malaria investigations or malaria control activities since the occupation. Almost all insecticides were taken to Baghdad. In addition 80-90 cars of the Vector Control Program were taken to Baghdad. During the occupation there was limited spraying of garbage and spraying for rodents and vectors in and around hospitals. There was no other vector control.

H. Disease Surveillance.

1. Summary of Reported Diseases

The list of reportable diseases remained unchanged. However, notifications were mainly from the Infectious Disease Hospital. The cases reported from the hospital were relatively severe. It is believed that milder cases were treated at primary health clinics where reporting was omitted. This is supported by the greatly decreased reporting of diseases from August through December 1990 (Table 10).

So far, there is no knowledge of the occurrence of cases of polio, diphtheria, neonatal tetanus, or outbreaks of vaccine preventable diseases amongst infants or children. The high immunization level in the last 5 years has shown its fruit during the occupation. In addition, the efforts that were made to make vaccine available and in good supply from the Preventive Health Centers during the occupation were helpful. There were no outbreaks of food poisoning during the occupation. During the occupation, 130 cases of viral hepatitis were reported, mainly in children less than 10 years of age in the previously known endemic districts. These cases appeared in the January 1991 report of disease during the period when water supply was scarce and houses became crowded.

The number of notified cases could not be compared with previous periods due to the lack of a denominator. The notifications during the occupation served as a means of access to cases so that preventive health efforts could be carried out among contacts.

2. Diseases in Iraqi Troops

No outbreaks of disease occurred among Iraqi troops during the occupation. However, 37 cases of cholera were documented in Iraq in the 45-day period before the war. There was no spread to the rest of the population. Iraq continued to be concerned about the possibility of cholera. In addition, some cases of hepatitis A were detected in Iraqi soldiers. There were rumors of malaria in Iraqi troops, but no documented reports.

3. Cholera

Only one case of cholera was reported from a native Kuwaiti woman. She was one of a group of 3,000 Kuwaitis who tried to escape through the Iranian border who drank water from a contaminated stream because no other water was available. The management and control measures for the case and her contacts were implemented.

4. Dog Bites

Seven persons were reported to have been bitten by dogs. All persons bitten by dogs were treated with tetanus toxoid and with human diploid rabies vaccine.

5. Quarantine and Screening of Expatriates

Dr. AL-Owaish carried out inspections of non-Arabs wanting to work in Kuwait. Through December, persons were checked for HIV antibody and tuberculosis. Most of these persons were Filipinos, Indians, Bengali, other Asians, and Africans.

6. AIDS

During this time, one case of AIDS in an Ethiopian worker was found. She was sent to Baghdad.

I. Immunizations

1. Immunization Sites

During the occupation, the 29 centers attached to the Preventive Medicine Division were decreased to 17 immunization centers due to (i) looting and stealing of equipment from health centers, (ii) destruction of health centers from shooting, and (iii) loss of manpower, especially public health nurses.

2. Immunization Statistics

It was obligatory to report to the Iraqi officials. The provided statistics were the bare minimal information on total numbers from the functioning immunization centers. Information on age, sex, nationality, etc. (place, person, and time), were not reported. The statistics of the first and last month of occupation are not reliable since some of the 17 centers did not report, whereas others remained nonfunctional because of the war situation. However, from September to December, more people were willing to leave their homes and be immunized. The statistics provided to the Iraqis did not include the effort of some physicians to immunize children in their local area.

People who came from Iraq and Jordan (either bringing food or for work) frequently asked for immunizations against certain diseases (HBV and meningococcal vaccine), increasing the numbers of immunizations for such disease during certain months (October and November 1990).

3. Immunization Schedules

The Iraqi officials were keen to change the immunization schedule in Kuwait so that it would be in accordance with the Iraqi immunization schedule. Official memos circulated instructing the discontinuance of certain vaccine and booster doses of polio and DPT. These memos were ignored and the Kuwait immunization schedule continued without any changes. The change happened in statistical reporting only (Table 14).

4. BCG Vaccination

During the invasion, the Central Tuberculosis Unit and the School Health Division, organized under the supervision of physicians from the Preventive Medicine Department, were responsible for coming up with a plan to immunize Kuwaiti children who did not go to school. Palestinian and other children continued to go to school. However, most schools were occupied by Iraqi soldiers. Therefore, the plan included the assignment of the remaining staff for BCG vaccination to two mobile teams to cover highly populated residential districts at five different locations. Three static teams were present at previously identified BCG vaccination centers. Health officers and nurses went to the few opened schools to give BCG vaccination to the children to insure a good BCG vaccination coverage.

J. Laboratories

1. Public Health Laboratory

The laboratory continued to carry out bacteriological examinations on food, water, sewage, stool samples, and serum specimens. It was the only laboratory that handled the examination for Vibrio cholera because it had peptone water.

The virological disease laboratory facilities were taken to Baghdad so there was no way to carry out tests for virological disease. Hepatitis cases were diagnosed clinically. Serotyping was not possible since the virology laboratory became non-functioning.

2. Environmental Laboratory

During the occupation, the environmental laboratory continued to carry out water quality testing as previously described, although the mobile monitoring unit was taken to Baghdad and the fixed monitoring stations gradually became nonfunctional.

## K. Other

### 1. Public Health Education

There was great difficulty in informing the public. Health instructions were given at mosques and information was passed from family to family. Information and circulars about vaccination availability were passed out at mosques, informal community groups, and posted inside the mosques, supermarkets, primary health clinics, and hospitals. When a case of cholera was identified, information was given out through such routes for people not to panic or worry. Information was also given that cholera vaccinations were not needed even though people requested it because the Department of Public Health did not feel that vaccinations were needed or useful. Such methods of health education were adopted since the Department of Public Health had no access to radio, TV, or other media.

### 2. Institute for Handicapped and Mentally Retarded

At the beginning of the occupation, there were some 1,300 children at the Institute. Some died because of lack of employees to take care of them (who left the country after the invasion.) During the first 1-2 months, entire families went to the Institute to volunteer and improvements were made. Later on, the Iraqis did not accept volunteers, unless new job contracts with the Iraqi government were signed. This was resented because non-compliance with the contract might lead to severe penalties by the Iraqi government. Therefore, many volunteers left the Institution. Accordingly, one outbreak of diarrhea occurred at the Institute. The impression was that the diarrhea was due to starvation. One hundred bacteriological samples were collected, but all reports were negative. The remaining working staff in the Institute brought their own families for help and the health situation improved to some extent.

### 3. Dead People

During the occupation, people were taken to the hospital morgues. At one time near the beginning of the occupation, there were so many bodies that they were taken to the ice rink where they were kept cool. The Kuwaiti Red Crescent was burying people together. Most of the time, the Department of Public Health would try to wait a week before burying bodies so that families could come to identify relatives.

4. Kuwaiti Red Crescent

For a time, the Kuwaiti Red Crescent was receiving instructions from the Kuwaiti Government in Exile. This resulted in Kuwaiti Red Crescent people being put in jail.

V. March 4-21, 1991

A. Organization

The organization of the Ministry of Public Health, Departments, and Department Directors are shown in Figure 3. The organization of the Department of Public Health, the Division Chiefs, and the Units in the Preventive Medicine Division are shown in Figure 4. The Health Districts and District Directors are shown in Figure 5.

B. Manpower

Some public health personnel started returning to their offices on March 4. By March 9, public health inspectors and other workers returned to work. As of March 16, 1991, there were 16 Kuwaiti public health physicians and 8 non-Kuwaiti public health physicians in Kuwait. These physicians were assigned to five hospitals and five health centers. By March 16, 75 public health inspectors and other workers were available to work.

C. Hospitals and Clinics

The hospitals and clinics were beginning to function. From March 4 to 21, there were increasing numbers of persons coming to the outpatient and emergency rooms of the hospitals. The hospitals and hospital directors are shown in Figure 6.

D. Water

A report from the team that assessed the water situation is provided as Attachment 1. Municipal water was shut off from the time of the ground war (February 23) through March 21. Initially, the only water available to Kuwaitis was water that had been stored on roofs or in cisterns or water (bottled and in tankers) that was brought by the Kuwait Task Force from Saudi Arabia. In early March, however, water became available by truck. The trucks were filling up with water from one of the three 500,000 million gallon reservoirs. These reservoirs had been tested. The reservoir supplying the Americans was being chlorinated at a level of 4 ppm by the U.S. Army. I was unable to find out the details of how much chlorine was being added to the water being trucked into Kuwait City, although one person complained to me that a residual of only 0.5 ppm was present in some of the water he had tested. Although I would have liked the level to be higher, the result indicated that chlorine was being added to the water. I recommended that U.S. Army personnel working with the Ministry of Electricity and Power increase the level of chlorine at the delivery point to 4 ppm.

Since liberation, radio messages telling people to boil water had been heard by my interpreter.

E. Food

1. Food and Food Handlers

The U.S. Army brought in many truckloads of rice, and staples had been obtained from approved food sources. However, as of March 21, inspection of food and food handlers by the Government of Kuwait had not yet been reinstated.

2. Veterinary

As of mid-March sheep were again being slaughtered at the slaughter house. KTF personnel worked with the Minister of Municipalities to have garbage picked up from the slaughter house. Although there were a few stray cats in Kuwait City, there were few if any stray dogs.

F. Sewage

During the Iraqi occupation, the Polish engineers who had been operating the sewage system protected the sewage system by having raw sewage bypass the system and flow directly into the Gulf. KTF personnel who assessed the sewage system in early March reported that the system would be operational as soon as electricity was available.

G. Environmental

1. Garbage

Garbage trucks were brought from Saudi Arabia to Kuwait in early March. In addition, a number of garbage trucks still in Kuwait were made operational by adding tires or batteries. There are contracts with four Saudi Arabian companies to provide garbage pickup. As of March 16, these four companies were reported to have had 4,000 workers in Saudi Arabia who were available to enter Kuwait and assist with cleaning up the city and collecting garbage. The United States company, Waste Management, Inc., was also cleaning up one area in Kuwait on speculation that they would be able to obtain future contracts.

2. Air

With the oil well fires, residents have had eye tearing, sore throats, sneezing, and coughing. Persons with a previous history of respiratory disease or asthma have reported increasing severity of symptoms. The British Royal Commission in Jubail, Saudi Arabia, examined the oil fire smoke and found that it contained carbon particles, but it did not have significant amounts of hydrocarbons, $SO_2$, or $NO_2$. The United States Interagency Air Assessment Team (USIAAT) from the EPA sampled for several days in Kuwait City. Paul Seligman, M.D., from the National Institute for Occupational Safety and Health was in Kuwait as a part of the team.

H. Vector

The reports of the Vector Control Team and the Entomology Team are shown as Attachments 2 and 3, respectively. There were fewer mosquitoes and flies than expected, primarily because garbage had been burned or picked up throughout most of Kuwait City during the occupation. No spraying for vectors was done from January 15 until March 9. Beginning on March 9, vector control efforts were restarted. Anecdotally, there are reports of some increase in the numbers of domestic and Norwegian rats. Three hundred laborers have been contracted to carry out vector control. There are six ultralow-volume (ULV) sprayers as well as an inventory of pesticides and vehicles. A 3-month program of spraying was set up. Public health inspectors were to continue on the program that was in existence prior to the occupation.

I. Disease Surveillance

The report of the Epidemiology Team is shown as Attachment 4. The Report of the Team assisting the Mubarak Hospital laboratory is provided as Attachment 5.

The Department of Public Health continues to be notified of cases of infectious disease admitted to the Infectious Disease Hospital. Notifications come in every Sunday. Every health inspector comes to the headquarters each Sunday. The health inspectors are assigned to investigate cases of disease. The inspectors also check on the immunization level of children. The diseases reported in 1991 through March 9 are shown in Table 15.

Kuwaiti physicians were concerned about the possibility of a hepatitis A outbreak. Although there was no evidence of such an outbreak based on disease reporting (Table 9 above) or by reviewing hepatitis A reports from 1988 through March 9, 1991 (Table 16), Ministry of Public Health physicians were alerted to this concern.

The routine disease surveillance program is scheduled to be restarted as soon as the telephones are working and transportation is available.

J. Immunization

The routine immunization program had not been started by March 21. However, vaccine was available in the central warehouse and immunizations were being given by some physicians.

K. Laboratories

1. Public Health

Although the public health laboratory had some water, it did not yet have electricity. It cannot process specimens until it has electricity. Neither can the laboratory process food or cholera samples at the present time. A protocol for the identification of *Vibrio cholerae* 01 carriers is provided as Attachment 6.

The virological laboratory was destroyed and the equipment removed. In addition, the laboratories needed to be cleaned.

2. Environmental

Although only one piece of equipment was stolen from the Environmental Laboratory, specimens could not be processed until water and electricity were available.

L. Other

1. Injury

Two people have died from explosives taken to their house. The problem is that people have been in their houses for 7 months, without sports, games, or movies. They are delighted to be outside. Citizens have been instructed to inform their local police station if weapons or munitions are found. In addition, announcements telling people not to pick up explosives have been heard.

2. Biological and Chemical Weapons

I was told that no biological weapons had been found in Kuwait. There were reports of cases of anthrax occurring in Iraq, near to where a biological weapons facility was thought to exist.

I only heard one report of several chemical projectiles being found inside Kuwait.

3. Noise and Odors

There were reports of people breeding chickens in their yards which has caused an increase in noise and odors in communities.

4. Cattle

There were approximately 2,000 head of cattle in the Kuwait. Animals that died were buried in place by the municipalities with at least one meter of sand covering them. Some of them were disposed of in a landfill.

5. Zoo

The Iraqis opened the cages of many of the zoo animals. For a while there was a tiger and a leopard running lose.

## VI. Summary

Prior to the Iraqi occupation, Kuwait had a very advanced public health system. The water, sewage, electricity, and garbage collection systems appear to be on the verge of functioning. However, the public health infrastructure that depends on people needs more attention. This other part of the public health system needs to be reinstated. When it is reinstated, the disease surveillance system needs to be computerized. It should be possible to have all of the hospitals and clinics with an on-line disease surveillance system that would provide data within hours to decision makers. It could even serve as a model for the system that needs to be set up in the United States.

The major upheavals that have occurred in Kuwait will necessitate intensive retraining and rebuilding of the public health infrastructure.

John S. Andrews, Jr., M.D., M.P.H.

Table 1

Table(2)
Drinking Water Quality

جدول رقم (٢)
نتائج مراقبة مواصفات مياه الشرب

September - 1989 - سبتمبر

| LOCATION | TEMP (C) | Cl2 mg/l | PH | E.C u mhos | T.ALK mg/l | T.HARD mg/l | Cl mg/l | F mg/l | N-NO3 mg/l | SO4 mg/l | T.D.S mg/l | Na mg/l | K mg/l | Ca mg/l |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JAHRA | 30 | 0.0 | 8.7 | 780 | 20.0 | 156.01 | 88.00 | -- | 1.10 | 127 | 499 | 56.0 | 1.57 | 38.5 |
| SULAIBIKHAT | 34 | 0.0 | 7.9 | 730 | 16.0 | 144.01 | 80.00 | -- | 0.80 | 115 | 467 | 53.4 | 1.40 | 35.3 |
| FARWANIYA | 38 | 0.2 | 8.5 | 690 | 20.0 | 132.01 | 78.00 | -- | 0.90 | 99 | 442 | 42.9 | 1.50 | 33.7 |
| SHUWAIKH | 29 | 0.0 | 8.1 | 653 | 20.0 | 140.01 | 76.00 | -- | 1.00 | 114 | 418 | 42.9 | 1.30 | 33.7 |
| SHUWAIKH * | 33 | 0.0 | 7.7 | 660 | 18.0 | 140.01 | 76.00 | -- | 1.20 | 116 | 422 | 42.5 | 1.30 | 33.7 |
| SHARG | 35 | 0.0 | 8.0 | 533 | 50.0 | 136.01 | 53.00 | -- | 0.60 | 71 | 341 | 33.1 | 0.80 | 38.5 |
| HAWALLI | 33 | 0.0 | 7.8 | 650 | 20.0 | 132.01 | 78.00 | -- | 0.90 | 110 | 416 | 43.1 | 1.30 | 35.3 |
| SALMIYA | 35 | 0.1 | 8.5 | 607 | 20.0 | 132.01 | 78.00 | -- | 0.90 | 95 | 388 | 41.9 | 1.40 | 33.7 |
| BAYAN | 26 | 0.0 | 8.6 | 697 | 18.0 | 120.01 | 99.00 | -- | 0.70 | 94 | 446 | 42.3 | 1.50 | 32.1 |
| REGA | 32 | 0.0 | 8.9 | 670 | 12.0 | 112.01 | 87.00 | -- | 2.10 | 68 | 429 | 41.3 | 1.30 | 30.5 |
| FAHAHEEL | 34 | 0.0 | 8.9 | 650 | 12.0 | 108.01 | 92.00 | -- | 2.50 | 64 | 416 | 41.9 | 1.10 | 32.1 |
| FAILAKA | 31 | 0.0 | 8.4 | 700 | 18.0 | 124.01 | 81.00 | -- | 0.90 | 95 | 448 | 42.3 | 1.50 | 33.7 |

| LOCATION | Hg ug/l | Cd ug/l | Pb ug/l | Mn ug/l | Cr ug/l | Cu ug/l | Zn ug/l | Fe ug/l | Ni ug/l | TOC mgC/l | THMS ug/l | TOTAL COLIFORM cfu/100ml | FAECAL COLIFORM cfu/100ml |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JAHRA | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 0 | 0 |
| SULAIBIKHAT | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 13 | 0 |
| FARWANIYA | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 0 | 0 |
| SHUWAIKH | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 0 | 0 |
| SHUWAIKH * | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 4 | 0 |
| SHARG | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 14 | 0 |
| HAWALLI | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 7 | 0 |
| SALMIYA | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 9 | 0 |
| BAYAN | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1 | 0 |
| REGA | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 0 | 0 |
| FAHAHEEL | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 0 | 0 |
| FAILAKA | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1 | 0 |

( * : BEFOR FILTER )

Source: Environment Protection Council/Environmental Protection Department, Kuwait

Table 1

Table(2)
Drinking Water Quality

جدول رقم (٢)
نتائج مراقبة مواصفات مياه الشرب

January - 1990 يناير

| LOCATION | TEMP (C) | Cl2 mg/l | PH | E.C u mhos | T.ALK mg/l | T.HARD mg/l | Cl mg/l | F mg/l | N-NO3 mg/l | SO4 mg/l | T.D.S mg/l | Na mg/l | K mg/l | Ca mg/l |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JAHRA | 20 | 0.3 | 8.1 | 630 | 20.0 | 180.0 | 100.00 | -- | 1.26 | 125 | 403 | 57.0 | 1.80 | 39.0 |
| BULAIBIKHAT | 19 | 0.0 | 7.5 | 660 | 18.0 | 160.0 | 96.00 | -- | 1.52 | 122 | 422 | 54.8 | 1.50 | 36.9 |
| FARWANIYA | 23 | 0.5 | 7.6 | 650 | 18.0 | 184.0 | 82.00 | -- | 1.40 | 115 | 416 | 54.0 | 1.50 | 37.4 |
| SHUWAIKH | 22 | 0.0 | 7.3 | 670 | 20.0 | 172.0 | 84.00 | -- | 1.40 | 118 | 428 | 54.8 | 1.50 | 40.1 |
| SHUWAIKH * | 20 | 0.0 | 7.4 | 675 | 26.0 | 180.0 | 96.00 | -- | 1.29 | 118 | 430 | 45.8 | 1.50 | 40.1 |
| SHARG | 20 | 0.0 | 7.7 | 420 | 24.0 | 160.0 | 72.00 | -- | 0.54 | 43 | 274 | 24.5 | 0.80 | 36.9 |
| HAWALLI | 16 | 0.0 | 7.1 | 600 | 20.0 | 164.0 | 90.00 | -- | 1.11 | 102 | 384 | 52.5 | 1.60 | 36.9 |
| SALMIYA | 16 | 0.3 | 7.5 | 680 | 18.0 | 156.0 | 80.00 | -- | 1.34 | 115 | 435 | 54.0 | 1.50 | 38.0 |
| BAYAN | 24 | 0.0 | 7.7 | 610 | 18.0 | 156.0 | 90.00 | -- | 1.16 | 110 | 390 | 54.0 | 1.50 | 37.4 |
| REGA | 22 | 0.0 | 8.1 | 420 | 14.0 | 184.0 | 88.00 | -- | 0.93 | 78 | 332 | 41.3 | 2.00 | 28.9 |
| FAHAHEEL | 23 | 0.0 | 8.7 | 520 | 14.0 | 148.0 | 66.00 | -- | 1.03 | 35 | 274 | 36.3 | 1.60 | 21.3 |
| FAILAKA | 20 | 0.0 | 7.7 | 610 | 24.0 | 180.0 | 84.00 | -- | 0.95 | 98 | 390 | 43.1 | 1.80 | 37.3 |

| LOCATION | Hg ug/l | Cd ug/l | Pb ug/l | Mn ug/l | Cr ug/l | Cu ug/l | Zn ug/l | Fe ug/l | Ni ug/l | TOC mgC/l | THMS ug/l | TOTAL COLIFORM cfu/100ml | FAECAL COLIFORM cfu/100ml |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JAHRA | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 0 | 0 |
| BULAIBIKHAT | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 0 | 0 |
| FARWANIYA | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 2 | 0 |
| SHUWAIKH | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 0 | 0 |
| SHUWAIKH * | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 0 | 0 |
| SHARQ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 15 | 0 |
| HAWALLI | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 8 | 0 |
| SALMIYA | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 0 | 0 |
| BAYAN | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 0 | 0 |
| REGA | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 0 | 0 |
| FAHAHEEL | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 3 | 0 |
| FAILAKA | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 0 | 0 |

* : BEFOR FILTER )

Table(2)
Drinking Water Quality

جدول رقم (٢)
نتائج مراقبة مواصفات مياه الشرب.

JUNE - 1990 - يونيو

| LOCATION | TEMP (C) | C12 mg/l | PH | E.C u mhos | T.ALK mg/l | T.HARD mg/l | Cl mg/l | F mg/l | N-NO3 mg/l | SO4 mg/l | T.D.S mg/l | Na mg/l | K mg/l | Ca mg/l |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JAHRA | 37 | 0.2 | 8.1 | 670 | 22.0 | 172.0 | 96.00 | -- | 1.40 | 147 | 428 | 59.3 | 1.60 | 40.1 |
| SULAIBIKHAT | 37 | 0.0 | 7.6 | 600 | 22.0 | 180.0 | 86.00 | -- | 1.33 | 138 | 384 | 54.0 | 1.30 | 34.5 |
| FARWANIYA | 35 | 0.5 | 8.2 | 610 | 18.0 | 144.0 | 86.00 | -- | 1.23 | 131 | 390 | 55.5 | 1.50 | 36.9 |
| SHUWAIKH | 31 | 0.0 | 7.7 | 580 | 20.0 | 152.0 | 70.00 | -- | 0.87 | 123 | 371 | 43.1 | 1.30 | 35.3 |
| SHUWAIKH * | 31 | 0.0 | 7.6 | 430 | 22.0 | 164.0 | 74.00 | -- | 1.00 | 122 | 275 | 43.1 | 1.30 | 35.3 |
| SHARQ | 28 | 0.0 | 7.7 | 600 | 20.0 | 136.0 | 82.00 | -- | 0.50 | 50 | 384 | 23.0 | 0.60 | 40.1 |
| HAWALLI | 28 | 0.0 | 7.9 | 530 | 18.0 | 120.0 | 80.00 | -- | 0.63 | 90 | 339 | 42.5 | 1.60 | 32.1 |
| SALMIYA | 32 | 0.2 | 8.0 | 590 | 20.0 | 186.0 | 80.00 | -- | 1.37 | 113 | 377 | 54.0 | 1.40 | 35.3 |
| BAYAN | 30 | 0.0 | 8.3 | 530 | 16.0 | 140.0 | 80.00 | -- | 1.10 | 108 | 339 | 53.3 | 1.40 | 35.3 |
| REQA | 37 | 0.0 | 7.9 | 410 | 22.0 | 156.0 | 78.00 | -- | 0.17 | 37 | 262 | 38.1 | 1.80 | 36.9 |
| FAHAHEEL | 37 | 0.0 | 8.0 | 470 | 16.0 | 136.0 | 82.00 | -- | 1.83 | 51 | 300 | 40.0 | 1.30 | 25.7 |
| FAILAKA | 25 | 0.0 | 7.8 | 540 | 26.0 | 160.0 | 76.00 | -- | 1.27 | 104 | 345 | 53.3 | 1.50 | 36.4 |

| LOCATION | Hg ug/l | Cd ug/l | Pb ug/l | Mn ug/l | Cr ug/l | Cu ug/l | Zn ug/l | Fe ug/l | Ni ug/l | TOC mgC/l | THMS ug/l | TOTAL COLIFORM cfu/100ml | FAECAL COLIFORM cfu/100ml |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JAHRA | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 0 | 0 |
| SULAIBIKHAT | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 0 | 0 |
| FARWANIYA | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 0 | 0 |
| SHUWAIKH | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 2 | 0 |
| SHUWAIKH * | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 29 | 0 |
| SHARQ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 0 | 0 |
| HAWALLI | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 4 | 0 |
| SALMIYA | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 0 | 0 |
| BAYAN | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 0 | 0 |
| REQA | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 2 | 0 |
| FAHAHEEL | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 9 | 0 |
| FAILAKA | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 0 | 0 |

( * : BEFOR FILTER )

Table(4)
Treated Effluent Quality

Table 2
جدول رقم ( ٤ )
نتائج مراقبة مياه الصرف الصحي

September - 1989 - سبتمبر

| STAGE | LOC. | TEMP (C) | Cl2 mg/l | PH | E.C u mhos | T.ALK mg/l | T.HARD mg/l | Br mg/l | Cl mg/l | N-NH3 mg/l | N-NO3 mg/l | ORG.N. mg/l | P-PO4 mg/l | -S mg/l | SO4 mg/l | T.D.S mg/l | Na mg/l | K mg/l | Ca mg/l | B mg/l |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SEC | | | | | | | | | | | | | | | | | | | | |
| | JAHRA | 31 | 0.0 | 7.4 | 2300 | 184 | 440 | -- | 357 | 13.47 | 3.90 | 13.72 | 5.76 | 1.60 | 362 | 1472 | -- | -- | -- | -- |
| | ARDEAH | 36 | 0.0 | 7.6 | 2900 | 232 | 460 | -- | 280 | 24.93 | 8.90 | 22.40 | 8.88 | 2.08 | 255 | 1856 | -- | -- | -- | -- |
| | REGA | 28 | 0.0 | 7.2 | 2300 | 114 | 420 | -- | 410 | 2.68 | 1.90 | 3.30 | 13.92 | 1.68 | 277 | 1472 | -- | -- | -- | -- |
| | FAILAKA | 30 | 0.0 | 8.2 | 6400 | 300 | 740 | -- | 1710 | 12.38 | 7.50 | 11.59 | 4.80 | 1.53 | 272 | 4096 | -- | -- | -- | -- |
| TER | | | | | | | | | | | | | | | | | | | | |
| | JAHRA | 32 | 2.0 | 7.5 | 2000 | 168 | 360 | -- | 399 | 13.64 | 4.70 | 12.94 | 7.62 | 1.56 | 369 | 1280 | -- | -- | -- | -- |
| | ARDEAH | 37 | 1.8 | 7.7 | 2400 | 206 | 380 | -- | 320 | 26.05 | 7.90 | 27.78 | 7.95 | 1.65 | 258 | 1536 | -- | -- | -- | -- |
| | REGA | 29 | 1.8 | 7.3 | 2800 | 76 | 420 | -- | 455 | 1.26 | 3.90 | 3.08 | 13.96 | 1.95 | 358 | 1792 | -- | -- | -- | -- |

| STAGE | LOC. | Cd mg/l | Pb mg/l | Cr mg/l | Cu mg/l | Zn mg/l | Fe mg/l | Ni mg/l | V mg/l | TOTAL COLIFORM cfu/100ml | FAECAL COLIFORM cfu/100ml | FAECAL STREPTOCOCCI cfu/100ml | COLLOPHAGE pfu/100ml |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SEC | | | | | | | | | | | | | |
| | JAHRA | 0.73 | 3.93 | 2.00 | 1.50 | 115.9 | 400.0 | 4.70 | 2.40 | 276000 | 258000 | 15000 | 184000 |
| | ARDEAH | 0.53 | 4.80 | 2.40 | 1.80 | 167.8 | 500.0 | 4.00 | 2.80 | 46000000 | 26000000 | 410000 | 12650 |
| | REGA | 0.30 | 3.30 | 1.60 | 4.80 | 110.1 | 400.0 | 1.90 | 2.40 | 132000000 | 430000 | 90000 | 0 |
| | FAILAKA | 0.30 | 2.93 | 16.00 | 5.40 | 81.2 | 550.0 | 10.30 | 2.40 | 5700000 | 18000 | 3000 | 0 |
| TER | | | | | | | | | | | | | |
| | JAHRA | 0.30 | 2.15 | 1.40 | 1.30 | 144.7 | 200.0 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| | ARDEAH | 1.00 | 4.10 | 3.00 | 2.40 | 393.0 | 550.0 | 7.50 | 5.40 | 5 | 0 | 0 | 3450 |
| | REGA | 0.30 | 2.80 | 1.60 | 8.30 | 300.5 | 575.0 | 1.90 | 4.10 | 0 | 0 | 0 | 0 |

Source: Environment Protection Council/Environment Protection Department, Kuwait

Table(4)
Treated Effluent Quality

جدول رقم ( ٤ )
نتائج مراقبة مياه الصرف الصحي

January - 1990 يناير

| STAGE | LOC. | TEMP (C) | Cl2 mg/l | PH | E.C u mhos | T.ALK mg/l | T.HARD mg/l | Br mg/l | Cl mg/l | N-NH3 mg/l | N-NO3 mg/l | ORG.N. mg/l | P-PO4 mg/l | -S mg/l | SO4 mg/l | T.D.S mg/l | Na mg/l | K mg/l | Ca mg/l | B mg/l |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SEC | | | | | | | | | | | | | | | | | | | | |
| | JAHRA | 24 | 0.01 | 7.7 | 4250 | 206 | 424 | -- | 385 | 24.82 | 6.52 | 28.62 | 9.20 | 0.47 | 270 | 2720 | -- | -- | -- | -- |
| | ARDEAH | 24 | 0.01 | 7.7 | 3400 | 318 | 376 | -- | 320 | 33.19 | 5.53 | 43.90 | 13.70 | 0.35 | 125 | 2176 | -- | -- | -- | -- |
| | REGA | 24 | 0.01 | 7.4 | 3480 | 80 | 404 | -- | 460 | 4.40 | 3.71 | 4.65 | 8.90 | 0.00 | 162 | 2227 | -- | -- | -- | -- |
| | FAILAKA | 20 | 0.01 | 7.4 | 9980 | 268 | 980 | -- | 3274 | 26.50 | 6.31 | 30.86 | 6.30 | 0.00 | 400 | 6387 | -- | -- | -- | -- |
| TER | | | | | | | | | | | | | | | | | | | | |
| | JAHRA | 25 | 2.1 | 7.5 | 4100 | 168 | 460 | -- | 415 | 17.77 | 6.37 | 24.47 | 8.50 | 0.00 | 285 | 2624 | -- | -- | -- | -- |
| | ARDEAH | 25 | 0.8 | 7.3 | 3350 | 270 | 400 | -- | 530 | 3.83 | 7.11 | 3.30 | 7.50 | 0.00 | 189 | 2144 | -- | -- | -- | -- |
| | REGA | 25 | 1.4 | 7.4 | 3300 | 94 | 408 | -- | 450 | 2.29 | 10.89 | 1.90 | 7.60 | 0.00 | 193 | 2112 | -- | -- | -- | -- |

| STAGE | LOC. | Cd mg/l | Pb mg/l | Cr mg/l | Cu mg/l | Zn mg/l | Fe mg/l | Ni mg/l | V mg/l | TOTAL COLIFORM cfu/100ml | FAECAL COLIFORM cfu/100ml | FAECAL STREPTOCCOCI cfu/100ml | COLLEPHAGE pfu/100ml |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SEC | | | | | | | | | | | | | |
| | JAHRA | -- | -- | -- | -- | -- | -- | -- | -- | 11000000 | 1000000 | 100 | 360000 |
| | ARDEAH | -- | -- | -- | -- | -- | -- | -- | -- | 188000000 | 2790000 | 310000 | 122000 |
| | REGA | -- | -- | -- | -- | -- | -- | -- | -- | 4000000 | 1000000 | 120000 | 690000 |
| | FAILAKA | -- | -- | -- | -- | -- | -- | -- | -- | 50000 | 600 | 0 | 2300 |
| TER | | | | | | | | | | | | | |
| | JAHRA | -- | -- | -- | -- | -- | -- | -- | -- | 0 | 0 | 0 | 0 |
| | ARDEAH | -- | -- | -- | -- | -- | -- | -- | -- | 0 | 0 | 0 | 0 |
| | REGA | -- | -- | -- | -- | -- | -- | -- | -- | 0 | 0 | 0 | 0 |

Table(4)
Treated Effluent Quality

Table 2
جدول رقم ( ٤ )
نتائج مراقبة مياه الصرف الصحى

JUNE - 1990 - يونيو

| STAGE | LOC. | TEMP (C) | C12 mg/l | PH | E.C u mhos | T.ALK mg/l | T.HARD mg/l | Br mg/l | Cl mg/l | N-NH3 mg/l | N-NO3 mg/l | ORG.N. mg/l | P-PO4 mg/l | -S mg/l | SO4 mg/l | T.D.S mg/l | Na mg/l | K mg/l | Ca mg/l | B mg/l |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SEC | | | | | | | | | | | | | | | | | | | | |
| | JAHRA | 27 | 0.0 | 7.5 | 3700 | 320 | 460 | -- | 430 | 36.37 | 16.14 | 42.36 | 6.50 | 0.31 | 210 | 2368 | -- | -- | -- | -- |
| | ARDEAH | 30 | 0.0 | 7.3 | 3150 | 285 | 310 | -- | 475 | 18.83 | 10.43 | 24.50 | 5.40 | 0.69 | 78 | 2016 | -- | -- | -- | -- |
| | REQA | 31 | 0.0 | 7.5 | 4650 | 135 | 566 | -- | 880 | 28.15 | 4.96 | 32.98 | 5.00 | 0.23 | 263 | 2976 | -- | -- | -- | -- |
| | FAILAKA | 30 | 0.0 | 7.6 | 1600 | 355 | 835 | -- | 3762 | 0.00 | 3.91 | 0.81 | 4.10 | 0.00 | 129 | 1024 | -- | -- | -- | -- |
| TER | | | | | | | | | | | | | | | | | | | | |
| | JAHRA | 30 | 1.1 | 7.7 | 4160 | 275 | 463 | -- | 460 | 35.96 | 5.86 | 33.82 | 6.10 | 0.78 | 270 | 2669 | -- | -- | -- | -- |
| | ARDEAH | 32 | 1.1 | 7.4 | 3125 | 280 | 312 | -- | 436 | 26.26 | 6.19 | 32.45 | 6.80 | 0.13 | 70 | 2000 | -- | -- | -- | -- |
| | REQA | 30 | 1.3 | 7.8 | 4360 | 140 | 750 | -- | 376 | 29.40 | 5.10 | 30.18 | 5.40 | 0.00 | 253 | 2790 | -- | -- | -- | -- |

| STAGE | LOC. | Hg mg/l | Cd mg/l | Pb mg/l | Cr mg/l | Cu mg/l | Zn mg/l | Fe mg/l | Ni mg/l | V mg/l | TOTAL COLIFORM cfu/100ml | FAECAL COLIFORM cfu/100ml | FAECAL STREPTOCOCCI cfu/100ml | SALMO-NELLA cfu/l | COLIPHAGE pfu/l |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SEC | | | | | | | | | | | | | | | |
| | JAHRA | 2.000 | 0.30 | 2.20 | 1.60 | 2.9 | 129.0 | 46.5 | 1.00 | 2.40 | 103000000 | 14000000 | 850 | 17 | 35650 |
| | ARDEAH | 2.000 | 0.30 | 2.70 | 1.10 | 3.3 | 82.0 | 423.3 | 1.00 | 2.40 | 1000000 | 300000 | 180000 | 140 | 102350 |
| | REQA | --- | --- | --- | --- | --- | --- | --- | --- | --- | 256000000 | 4760000 | 4300 | 10 | 19600 |
| | FAILAKA | 2.000 | 0.30 | 2.33 | 1;10 | 2.3 | 73.6 | 243.1 | 1.00 | 2.40 | 27000000 | 33 | 70 | 230 | 10350 |
| TER | | | | | | | | | | | | | | | |
| | JAHRA | 2.000 | 0.40 | 1.40 | 2.00 | 1.3 | 68.1 | 30.1 | 1.00 | 3.00 | 0 | 0 | 0 | 0 | 0 |
| | ARDEAH | 2.000 | 0.50 | -2.00 | 2.80 | 6.2 | 151.0 | 259.5 | 1.00 | 2.40 | 0 | 0 | 0 | 0 | 1150 |
| | REQA | 2.000 | 0.30 | 1.72 | 0.80 | 1.3 | 101.3 | 95.6 | 1.00 | 2.40 | 0 | 0 | 0 | 0 | 0 |

جـــــــدول رقم (١)

MONTHLY MEAN CONCENTRATION OF THE GASES EXPRESSED AS PPM AND PPB RECORDED BY THE AIR POLUTION MONITORING STATIONS TOGETHER WITH THE MAXIMUM LEVEL AND THE PERCENTAGE DISTRIBUTION OF THE VALUES EXCEEDING THE THRESHOLD LEVEL DURING SEPTEMBER 1989

| CASES | LOCATIONS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | MANSORIA | | | RABIA | | | REGA | | |
| | MEAN | MAX | %EX. LIMIT | MEAN | MAX | %EX. LIMIT | MEAN | MAX | %EX. LIMIT |
| TS IN PPB | 2.668 | 58.000 | -- | 14.388 | 929.000 | -- | 1.517 | 18.000 | -- |
| H2S IN PPB | 0.615 | 56.000 | 3.1 | 11.625 | 887.000 | 18.4 | 0.233 | 15.000 | 0.2 |
| SO2 IN PPB | 2.039 | 9.000 | 0.0 | 3.421 | 951.000 | 0.8 | 1.196 | 9.000 | 0.0 |
| THC IN PPM | 2.702 | 13.310 | -- | 2.218 | 8.410 | -- | 1.930 | 7.260 | -- |
| NCH4 IN PPM | 0.839 | 11.260 | 73.6 | 0.336 | 6.290 | 79.8 | 0.162 | 5.870 | 16.7 |
| CH4 IN PPM | 1.862 | 4.290 | -- | 1.681 | 4.730 | -- | 1.708 | 4.480 | -- |
| NOX IN PPB | 52.518 | 888.000 | -- | 49.379 | 882.000 | -- | 32.126 | 695.000 | -- |
| NO IN PPB | 23.061 | 789.000 | 11.6 | 20.321 | 800.000 | 9.5 | 14.585 | 573.000 | 6.7 |
| NO2 IN PPB | 29.394 | 504.000 | 12.4 | 28.039 | 281.000 | 9.9 | 17.351 | 312.000 | 5.6 |
| CO IN PPM | 1.054 | 13.240 | 0.6 | 1.153 | 20.750 | 0.5 | 1.111 | 34.370 | 0.6 |
| O3 IN PPM | 0.004 | 0.036 | 0.0 | 0.003 | 0.039 | 0.0 | 0.002 | 0.138 | 0.0 |
| NH3 IN PPM | --- | --- | -- | --- | --- | -- | 0.176 | 2.300 | 32.3 |

Source: Environment Protection Council/Environment Protection Department, Kuwait

جدول رقم (١)

MONTHLY MEAN CONCENTRATION OF THE GASES EXPRESSED AS PPM AND PPB RECORDED BY THE AIR POLUTION MONITORING STATIONS TOGETHER WITH THE MAXIMUM LEVEL AND THE PERCENTAGE DISTRIBUTION OF THE VALUES EXCEEDING THE THRESHOLD LEVEL DURING JANUARY 1990

| GASES | LOCATIONS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | MANSORIA | | | RABIA | | | REGA | | |
| | MEAN | MAX | %EX. LIMIT | MEAN | MAX | %EX. LIMIT | MEAN | MAX | %EX. LIMIT |
| TS IN PPB | 2.346 | 35.000 | — | 5.316 | 407.000 | — | 1.589 | 18.000 | — |
| H2S IN PPB | 0.355 | 33.000 | 2.4 | 3.178 | 396.000 | 7.4 | 0.260 | 17.000 | 1.0 |
| SO2 IN PPB | 1.951 | 3.000 | 0.0 | 2.105 | 17.000 | 0.0 | 1.009 | 3.000 | 0.0 |
| THC IN PPM | 2.287 | 9.420 | — | 1.864 | 7.580 | — | 2.231 | 8.720 | — |
| NCH4 IN PPM | 0.418 | 7.720 | 54.1 | 0.411 | 5.450 | 60.7 | 0.507 | 6.870 | 81.9 |
| CH4 IN PPM | 1.868 | 4.580 | — | 1.452 | 4.610 | — | 1.724 | 3.480 | — |
| NOX IN PPB | 57.355 | 756.000 | — | 53.742 | 712.000 | — | 52.219 | 698.000 | — |
| NO IN PPB | 29.683 | 647.000 | 15.1 | 27.806 | 498.000 | 16.1 | 25.828 | 636.000 | 13.6 |
| NO2 IN PPB | 27.671 | 327.000 | 10.4 | 25.912 | 229.000 | 6.0 | 26.349 | 287.000 | 7.8 |
| CO IN PPM | 1.008 | 9.800 | 0.3 | 1.155 | 13.770 | 0.4 | 1.040 | 31.490 | 0.5 |
| O3 IN PPM | 0.002 | 0.016 | 0.0 | 0.005 | 0.062 | 0.0 | 0.004 | 0.021 | 0.0 |
| NH3 IN PPM | — | — | — | — | — | — | 0.054 | 2.690 | 10.2 |

Table 3

( 1 ) جـدول رقم

MONTHLY MEAN CONCENTRATION OF THE GASES EXPRESSED AS PPM AND PPB RECORDED BY THE AIR POLUTION MONITORING STATIONS TOGETHER WITH THE MAXIMUM LEVEL AND THE PERCENTAGE DISTRIBUTION OF THE VALUES EXCEEDING THE THRESHOLD LEVEL DURING
JUNE 1990

| GASES | LOCATIONS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | MANSORIA | | | RABIA | | | REGA | | |
| | MEAN | MAX | %EX. LIMIT | MEAN | MAX | %EX. LIMIT | MEAN | MAX | %EX. LIMIT |
| TS IN PPB | 2.765 | 85.000 | -- | 15.378 | 932.000 | -- | 1.873 | 21.000 | -- |
| H2S IN PPB | 1.251 | 84.000 | 5.5 | 12.463 | 863.000 | 16.5 | 0.253 | 20.000 | 1.3 |
| SO2 IN PPB | 1.431 | 12.000 | 0.0 | 2.953 | 142.000 | 1.2 | 1.284 | 3.000 | 0.0 |
| THC IN PPM | 2.116 | 8.060 | -- | 2.081 | 9.070 | -- | 2.138 | 9.410 | -- |
| NCH4 IN PPM | 0.342 | 6.130 | 49.9 | 0.650 | 4.250 | 87.1 | 0.357 | 7.690 | 39.2 |
| CH4 IN PPM | 1.772 | 4.520 | -- | 1.431 | 6.130 | -- | 1.780 | 4.600 | -- |
| NOX IN PPB | 26.224 | 460.000 | -- | 28.011 | 251.000 | -- | 33.533 | 540.000 | -- |
| NO IN PPB | 5.332 | 340.000 | 3.3 | 7.665 | 208.000 | 2.8 | 10.278 | 445.000 | 5.0 |
| NO2 IN PPB | 20.895 | 178.000 | 11.1 | 20.357 | 120.000 | 3.3 | 23.263 | 242.000 | 8.3 |
| CO IN PPM | 0.846 | 11.910 | 0.1 | 0.803 | 7.320 | 0.0 | 0.774 | 37.060 | 0.2 |
| O3 IN PPM | 0.013 | 0.137 | 0.4 | 0.010 | 0.066 | 0.0 | 0.012 | 0.053 | 0.0 |
| NH3 IN PPM | --- | --- | -- | --- | --- | -- | 0.063 | 1.580 | 10.8 |

Distribution of Settled Daily Dust
....January..1990....
(grams/square meter/day)

Table 4

| Date | Locations | | | Daily Mean | Total No. of Sample |
|---|---|---|---|---|---|
| | Shuwaikh Industrial Area | Kuwait City | Jahra | | |
| 1/1/90 | 0.082 | 0.814 | 0.328 | 0.408 | 3 |
| 2/1/90 | 0.320 | 0.086 | 4.041 | 1.482 | 3 |
| 3/1/90 | 0.330 | 0.824 | 0.265 | 0.473 | 3 |
| 4/1/90 | 1.099 | 2.209 | - | 1.654 | 2 |
| 5/1/90 | 0.685 | 0.211 | - | 0.448 | 2 |
| 6/1/90 | 0.022 | 0.127 | 0.024 | 0.058 | 3 |
| 7/1/90 | 1.097 | 1.927 | 1.855 | 1.626 | 3 |
| 8/1/90 | 1.877 | 1.620 | 2.890 | 2.129 | 3 |
| 9/1/90 | 0.378 | 0.042 | 0.595 | 0.338 | 3 |
| 10/1/90 | 0.434 | 0.265 | 0.022 | 0.240 | 3 |
| 11/1/90 | 0.275 | 0.472 | - | 0.374 | 2 |
| 12/1/90 | 0.780 | 0.623 | - | 0.702 | 2 |
| 13/1/90 | 1.560 | 0.563 | 0.784 | 0.969 | 3 |
| 14/1/90 | 0.484 | 0.390 | 0.301 | 0.392 | 3 |
| 15/1/90 | 0.358 | 0.458 | 0.358 | 0.391 | 3 |
| 16/1/90 | 0.448 | 0.597 | 0.474 | 0.506 | 3 |
| 17/1/90 | 0.444 | 0.537 | 0.537 | 0.506 | 3 |
| 18/1/90 | 0.872 | 1.218 | - | 1.045 | 2 |
| 19/1/90 | 0.163 | 0.677 | - | 0.42 | 2 |
| 20/1/90 | 0.681 | 9.032 | 0.711 | 3.475 | 3 |
| 21/1/90 | 0.922 | 9.212 | 0.839 | 3.658 | 3 |
| 22/1/90 | 0.953 | 0.933 | 0.667 | 0.851 | 3 |
| 23/1/90 | 0.796 | 0.259 | 0.344 | 0.466 | 3 |
| 24/1/90 | 1.154 | 1.791 | 0.468 | 1.138 | 3 |
| 25/1/90 | 0.866 | 0.902 | 0.279 | 0.682 | 3 |
| 26/1/90 | 0.617 | 0.448 | - | 0.533 | 2 |
| 27/1/90 | 0.717 | 0.179 | - | 0.448 | 2 |
| 28/1/90 | 0.249 | 0.979 | 0.179 | 0.469 | 3 |
| 29/1/90 | 0.199 | 0.657 | 0.159 | 0.338 | 3 |
| 30/1/90 | 0.320 | 0.486 | 0.105 | 0.304 | 3 |
| 31/1/90 | 0.553 | 0.701 | 0.398 | 0.551 | 3 |
| Monthly Mean | 0.637 | 1.266 | 0.723 | 0.889 | 85 |
| S.d.± | 0.424 | 2.165 | 0.960 | 1.437 | |

Source: Environment Protection Council/Environment Protection Department, Kuwait

جـدول رقـم ( 6 - 1 )

Distribution of Settled Daily Dust
JUNE (1990)
(grams/square meter/day)

| Date | Locations | | | Daily Mean | Total No. of Sample |
|---|---|---|---|---|---|
| | Shuwaikh Industrial Area | Kuwait City | Al-Jahra | | |
| 1/ 6/90 | 0.478 | 0.458 | ----- | 0.468 | 2 |
| 2/ 6/90 | 0.826 | 0.756 | 0.687 | 0.756 | 3 |
| 3/ 6/90 | 3.613 | 3.065 | 8.877 | 5.185 | 3 |
| 4/ 6/90 | 5.245 | 4.723 | 18.650 | 9.539 | 3 |
| 5/ 6/90 | 3.394 | 3.658 | 13.057 | 6.703 | 3 |
| 6/ 6/90 | 20.232 | 20.740 | 60.150 | 33.707 | 3 |
| 7/ 6/90 | 25.527 | 34.131 | ----- | 29.829 | 2 |
| 8/ 6/90 | 0.587 | 0.736 | ----- | 0.662 | 2 |
| 9/ 6/90 | 0.816 | 0.677 | 1.035 | 0.843 | 3 |
| 10/ 6/90 | 2.189 | 1.270 | 3.115 | 2.191 | 3 |
| 11/ 6/90 | 0.627 | 0.577 | 1.334 | 0.846 | 3 |
| 12/ 6/90 | 0.916 | 0.846 | 1.234 | 0.999 | 3 |
| 13/ 6/90 | 0.557 | 0.468 | 1.015 | 0.680 | 3 |
| 14/ 6/90 | 4.498 | 2.816 | ----- | 3.657 | 2 |
| 15/ 6/90 | 1.065 | 0.806 | ----- | 0.936 | 2 |
| 16/ 6/90 | 1.334 | 1.373 | 1.483 | 1.397 | 3 |
| 17/ 6/90 | 1.509 | 1.015 | 2.185 | 1.570 | 3 |
| 18/ 6/90 | 0.876 | 0.587 | 1.980 | 1.148 | 3 |
| 19/ 6/90 | 2.787 | 2.249 | 1.821 | 2.286 | 3 |
| 20/ 6/90 | 2.528 | 1.742 | 6.071 | 3.447 | 3 |
| 21/ 6/90 | 6.747 | 5.792 | ----- | 6.270 | 2 |
| 22/ 6/90 | 10.251 | 12.749 | ----- | 11.500 | 2 |
| 23/ 6/90 | 31.349 | 47.829 | 98.499 | 59.226 | 3 |
| 24/ 6/90 | 2.757 | 2.249 | 5.892 | 3.633 | 3 |
| 25/ 6/90 | 0.796 | 0.617 | 1.921 | 1.111 | 3 |
| 26/ 6/90 | 0.587 | 0.518 | 0.969 | 0.691 | 3 |
| 27/ 6/90 | 0.806 | 0.717 | 1.188 | 0.762 | 3 |
| 28/ 6/90 | 5.304 | 4.429 | ----- | 4.867 | 2 |
| 29/ 6/90 | 6.081 | 7.583 | ----- | 6.832 | 2 |
| 30/ 6/90 | 0.916 | 0.766 | ----- | 0.841 | 2 |
| 31/ 6/90 | ----- | ----- | ----- | ----- | - |
| Mean | 4.840 | 5.531 | 11.558 | 6.779 | 80 |
| S.D.± | 7.583 | 10.691 | 24.444 | 14.648 | |

جدول رقم ( ١ - ١ )

Table 5

Concentration of Suspended Particulate Matter in daily samples
....January..1990....
(micrograms per cubic meter)

| Date | Location | | | | Daily Mean | Total Samples |
|---|---|---|---|---|---|---|
| | Shuwaikh | Kuwait City | Shamieh | Jahra | | |
| 1 | - | - | - | - | | |
| 2 | - | - | - | - | | |
| 3 | 208.24 | 267.93 | - | | 238.09 | 2 |
| 4 | - | - | 292.13 | 280.60 | 286.37 | 2 |
| 5 | - | 258.78 | - | - | 258.78 | 1 |
| 6 | - | - | 139.02 | 166.79 | 152.91 | 2 |
| 7 | 185.01 | 329.79 | - | - | 257.4 | 2 |
| 8 | - | - | 336.77 | 528.94 | 432.86 | 2 |
| 9 | 133.42 | 118.69 | - | - | 126.06 | 2 |
| 10 | - | - | 89.71 | 150.47 | 120.09 | 2 |
| 11 | 334.02 | 150.54 | - | - | 242.28 | 2 |
| 12 | - | - | 121.12 | 193.57 | 157.35 | 2 |
| 13 | - | 135.27 | - | - | 135.27 | 1 |
| 14 | - | - | 70.45 | 63.01 | 66.73 | 2 |
| 15 | 92.22 | 106.46 | - | - | 99.34 | 2 |
| 16 | - | - | 64.18 | 65.68 | 64.93 | 2 |
| 17 | - | 135.27 | - | - | 135.27 | 1 |
| 18 | - | - | 113.69 | 304.65 | 209.17 | 2 |
| 19 | 159.69 | 107.07 | - | - | 133.38 | 2 |
| 20 | - | - | 139.40 | 135.00 | 137.2 | 2 |
| 21 | - | 261.97 | - | - | 261.97 | 1 |
| 22 | - | - | 146.33 | 177.70 | 162.02 | 2 |
| 23 | 257.15 | 238.69 | - | - | 247.92 | 2 |
| 24 | - | - | 144.79 | 190.09 | 167.44 | 2 |
| 25 | 174.17 | 262.62 | - | - | 218.39 | 2 |
| 26 | - | - | 78.15 | 144.21 | 111.18 | 2 |
| 27 | 110.56 | 82.71 | - | - | 96.64 | 2 |
| 28 | - | - | 49.93 | 38.81 | 44.37 | 2 |
| 29 | 116.43 | 175.58 | - | - | 146.01 | 2 |
| 30 | - | - | 79.14 | 59.72 | 69.43 | 2 |
| 31 | - | - | - | - | - | |
| Monthly Mean | 177.09 | 187.96 | 133.20 | 178.52 | 168.58 | 52 |
| S.d.$\pm$ | 74.23 | 79.09 | 83.70 | 128.06 | 94.98 | |

Source: Environment Protection Council/Environment Protection Department, Kuwait

Table 5

جـدول رقـم ( 7 - 1 )

Concentration of Suspended Particulate Matter in daily samples
June (1990)
(micrograms/cubic meter)

| Date | Locations | | | | Daily Mean | Total Samples |
|---|---|---|---|---|---|---|
| | Shuwaikh | Kuwait City | Shamiah | Al-Jahra | | |
| 1/ 6/90 | ----- | ----- | ----- | ----- | ----- | - |
| 2/ 6/90 | ----- | ----- | ----- | ----- | ----- | - |
| 3/ 6/90 | ----- | ----- | 616.9 | 1089.1 | 853.0 | 2 |
| 4/ 6/90 | 903.1 | 710.3 | ----- | ----- | 806.7 | 2 |
| 5/ 6/90 | ----- | ----- | 606.9 | 753.3 | 680.1 | 2 |
| 6/ 6/90 | ----- | 1355.2 | ----- | ----- | 1355.2 | 1 |
| 7/ 6/90 | ----- | ----- | 2228.3 | 1780.6 | 2004.5 | 2 |
| 8/ 6/90 | 328.0 | 235.2 | ----- | ----- | 281.6 | 2 |
| 9/ 6/90 | ----- | ----- | 229.1 | 456.1 | 342.6 | 2 |
| 10/ 6/90 | 323.9 | 302.2 | ----- | ----- | 313.1 | 2 |
| 11/ 6/90 | ----- | ----- | 235.4 | 297.6 | 266.5 | 2 |
| 12/ 6/90 | 382.7 | 226.9 | ----- | ----- | 304.8 | 2 |
| 13/ 6/90 | ----- | ----- | 214.0 | 318.3 | 266.2 | 2 |
| 14/ 6/90 | 447.4 | 387.6 | ----- | ----- | 417.5 | 2 |
| 15/ 6/90 | ----- | ----- | 304.9 | 374.6 | 339.8 | 2 |
| 16/ 6/90 | 552.5 | 390.3 | ----- | ----- | 471.4 | 2 |
| 17/ 6/90 | ----- | ----- | 288.0 | 365.3 | 326.7 | 2 |
| 18/ 6/90 | ----- | ----- | ----- | ----- | ----- | - |
| 19/ 6/90 | ----- | ----- | 345.9 | 356.7 | 351.3 | 2 |
| 20/ 6/90 | 492.0 | 349.7 | ----- | ----- | 420.9 | 2 |
| 21/ 6/90 | ----- | ----- | 796.8 | 730.8 | 763.8 | 2 |
| 22/ 6/90 | 1375.4 | 1266.9 | ----- | ----- | 1321.2 | 2 |
| 23/ 6/90 | ----- | ----- | 1443.5 | 1853.3 | 1648.4 | 2 |
| 24/ 6/90 | 887.7 | 767.2 | ----- | ----- | 827.5 | 2 |
| 25/ 6/90 | ----- | ----- | 261.4 | 360.5 | 310.9 | 2 |
| 26/ 6/90 | 408.9 | 310.9 | ----- | ----- | 359.9 | 2 |
| 27/ 6/90 | ----- | ----- | ----- | ----- | ----- | - |
| 28/ 6/90 | ----- | ----- | ----- | ----- | ----- | - |
| 29/ 6/90 | ----- | ----- | 1042.9 | ----- | 1042.9 | 1 |
| 30/ 6/90 | 432.9 | 353.8 | ----- | ----- | 393.4 | 2 |
| Mean | 594.0 | 554.7 | 662.6 | 728.0 | 636.3 | 48 |
| S.D.± | 327.8 | 391.7 | 600.7 | 560.9 | 478.6 | |

جدول رقم (7 - ب)

Size Distribution of Suspended Particulate Matter

......January 1990...........

| Particle Size | Size Range (Micron) | Shuwaikh (n=1) | | | Kuwait City (n=3) | | | Shamieh (n=3) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean Conc. (ug/m$^3$) | % in Size Range | Cumul. Freq. % | Mean Conc. (ug/m$^3$) | % in Size Range | Cumul. Freq. % | Mean Conc. (ug/m$^3$) | % in Size Range | Cumul. Freq. % |
| Respirable | 0.1-1.1 | 34.2 | 17.7 | 17.7 | 57.8 | 23.2 | 23.2 | 33.8 | 26.0 | 26.0 |
| | 1.1-2.0 | 10.4 | 5.3 | 23.0 | 12.0 | 4.8 | 28.0 | 8.2 | 6.3 | 32.3 |
| | 2.0-3.3 | 13.1 | 6.8 | 29.8 | 15.4 | 6.2 | 34.2 | 11.5 | 8.8 | 41.1 |
| | 3.3-7.0 | 42.0 | 21.7 | 51.5 | 43.3 | 17.4 | 51.6 | 23.5 | 18.0 | 59.1 |
| Non-respirable | > 7.0 | 39.7 | 48.5 | 100.0 | 120.6 | 48.4 | 100.0 | 53.3 | 40.9 | 100.0 |
| Total | - | 193.4 | 100.0 | - | 249.1 | 100.0 | - | 130.2 | 100.0 | - |

Source: Environment Protection Council/Environment Protection Department, Kuwait

جـدول رقم ( 7 - ب )

## Size Distribution of Suspended Particulate Matter
## June (1990)

| Particle Size | Size Range (micron) | Shuwaikh (n=2) Mean Conc. ug/m3 | Shuwaikh (n=2) % in Size Range | Shuwaikh (n=2) Cumul Freq. % | kuwait City (n=3) Mean Conc. ug/m3 | kuwait City (n=3) % in Size Range | kuwait City (n=3) Cumul Freq. % | Shamiah (n=3) Mean Conc. ug/m3 | Shamiah (n=3) % in Size Range | Shamiah (n=3) Cumul Freq. % |
|---|---|---|---|---|---|---|---|---|---|---|
| RESPIRABLE | 0.1-1.1 | 282.7 | 30.3 | 30.3 | 793.9 | 50.6 | 50.6 | 273.6 | 31.82 | 31.8 |
| | 1.1-2.0 | 57.8 | 6.2 | 36.5 | 75.6 | 4.8 | 55.4 | 43.0 | 05.00 | 36.8 |
| | 2.0-3.3 | 107.0 | 11.4 | 47.9 | 126.7 | 8.1 | 63.5 | 97.4 | 11.33 | 48.2 |
| | 3.3-7.0 | 162.1 | 17.4 | 65.3 | 158.8 | 10.1 | 73.6 | 129.3 | 15.04 | 63.2 |
| Non Re-spirable | > 7.0 | 323.9 | 34.7 | 100.0 | 413.7 | 26.4 | 100.0 | 316.5 | 36.81 | 100.0 |
| Total | | 933.5 | 100.0 | — | 1568.7 | 100.0 | — | 859.8 | 100.0 | — |

## REPORTABLE COMMUNICABLE DISEASES
## KUWAIT 1988 - 1991

Amebic Dysentry
Enteropathic _Escherchia coli_
Notified Diarrhea
Lead Poisoning
Upper Respiratory Infection
Leprosy
Exanthem Subitum
Cutaneous Leismaniasis (imported)
Mycoplasma pneumonia
Erysipelas
Staphylococcal Carrier
]Giardiasis
shigellosis
Shigella Carrier
Aseptic Meningitis
Encephalitis
Mononucleosis Infectious
Scarlet Fever
Herpes Zoster
Meningococcal Meningitis (not specified)
Meningococcal Meningigits (Group A)
Meningococcal meningitis (Group B)
_Neisseria meningitidis_ carrier (not Group A)
_Neisseria meningitidis_ carrier (Group A)
Septic Meningitis
Rocky Mountain Spotted Fever
Brucellosis
Anthrax
Toxoplasmosis
Relapsing Fever (imported)
Hepatitis (not specified)
Food Poisoning
Malaria (imported)
Filariasis (imported)
Endemic Typhus
Chickenpox
Rabies (imported)
Viral Hepatitis A
Viral Hepatitis B
Viral Hepatitis non-A, non-B
Tetanus Neonatorum
Poliomyelitis
Measles
Rubella
Mumps
Salmonella Carrier
DLiphtheria
Diphtheria Carrier
Whooping Cough
Tetanus

Table 7 (continued)

Paratyphoid (A) Carrier
Paratyphoid (B) Fever
Paratyphoid (B) Carrier
Paratyphoid (C) Fever
Salmonella Enteritis
Cholera
Non 0-1 Vibrio cholera
Typhoid Fever
Typhoid Carrier
Paratyphoid (A) Fever

Source: Ministry of Public Health, Kuwait

Table 8

REPORTED COMMUNICABLE DISEASES

KUWAIT - 1988

| Diseases | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S. typhi carrier | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 3 |
| Typhoid Fever | 4 | 7 | 9 | 9 | 16 | 12 | 24 | 38 | 43 | 31 | 7 | 7 | 207 |
| Non 0-1 V. cholerae | 0 | 0 | 0 | 0 | 5 | 3 | 7 | 21 | 9 | 1 | 0 | 0 | 46 |
| Cholera (imported) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 2 |
| Paratyphoid (A) Fever | 2 | 0 | 2 | 1 | 2 | 4 | 2 | 7 | 7 | 3 | 1 | 2 | 33 |
| Paratyphoid (A) Carrier | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 2 | 0 | 0 | 0 | 4 |
| Paratyphoid (B) Fever | 1 | 0 | 0 | 2 | 0 | 1 | 1 | 1 | 2 | 0 | 0 | 0 | 8 |
| Paratyphoid (B) Carrier | 0 | 0 | 0 | 2 | 2 | 2 | 1 | 2 | 0 | 0 | 2 | 1 | 12 |
| Paratyphoid (C) Fever | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| Salmonella Enteritis | 24 | 22 | 38 | 54 | 57 | 68 | 46 | 59 | 74 | 70 | 45 | 39 | 596 |

Table 8

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Salmonella Carrier | 59 | 48 | 69 | 86 | 95 | 117 | 66 | 152 | 192 | 193 | 135 | 86 | 1,298 |
| Shigellosis | 32 | 13 | 17 | 24 | 10 | 21 | 20 | 34 | 25 | 40 | 55 | 33 | 324 |
| Amebic Dysentary | 0 | 1 | 4 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 0 | 1 | 10 |
| Food Poisoning | 10 | 32 | 16 | 3 | 210 | 26 | 35 | 106 | 63 | 8 | 7 | 4 | 520 |
| (A) Viral Hepatitis | 11 | 144 | 173 | 25 | 29 | 31 | 408 | 109 | 251 | 308 | 124 | 93 | 1,706 |
| (B) Viral Hepatitis | 29 | 24 | 24 | 19 | 25 | 16 | 28 | 31 | 44 | 28 | 4 | 32 | 304 |
| (Non A Non B) Viral Hepatitis | 1 | 5 | 5 | 8 | 1 | 2 | 3 | 0 | 3 | 11 | 0 | 2 | 41 |
| Non Specified Viral Hepatitis | 39 | 27 | 35 | 33 | 29 | 17 | 24 | 23 | 41 | 647 | 71 | 45 | 435 |
| Tetanus | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Tetanus Neonatorum | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Whooping Cough | 7 | 17 | 25 | 19 | 47 | 27 | 10 | 78 | 3 | 0 | 0 | 1 | 163 |
| Measles | 8 | 3 | 8 | 18 | 13 | 1 | 3 | 2 | 4 | 5 | 3 | 2 | 70 |
| Rubella | 20 | 39 | 65 | 79 | 48 | 43 | 17 | 20 | 33 | 34 | 23 | 32 | 453 |
| Mumps | 60 | 78 | 105 | 84 | 48 | 35 | 16 | 21 | 33 | 37 | 61 | 76 | 654 |
| Chickenpox | 711 | 547 | 640 | 711 | 558 | 431 | 255 | 183 | 159 | 218 | 296 | 330 | 5,069 |

Table 8

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Endemic Typhus | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| Malaria (Imported) | 38 | 31 | 41 | 71 | 67 | 111 | 111 | 142 | 215 | 183 | 131 | 88 | 1,229 |
| Filariasis (Imported) | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 4 | 9 |
| Brucellosis | 20 | 20 | 56 | 70 | 50 | 39 | 36 | 32 | 23 | 23 | 18 | 7 | 395 |
| Meningococcal (A) Meningitis | 4 | 0 | 0 | 3 | 0 | 3 | 1 | 0 | 0 | 0 | 1 | 2 | 14 |
| Meningococcal (B) Meningitis | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 3 |
| Meningococcal (A) Carrier | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| <u>N. meningitidis</u> Carrier not Grp A | 0 | 23 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 26 |
| Septic Meningitis | 12 | 10 | 10 | 0 | 4 | 6 | 4 | 13 | 10 | 9 | 11 | 12 | 110 |
| Aseptic Meningitis | 4 | 9 | 5 | 3 | 4 | 3 | 2 | 6 | 8 | 6 | 13 | 7 | 70 |
| Encephalitis | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 5 |
| Infectious Mononucleosis | 0 | 1 | 2 | 3 | 0 | 1 | 1 | 3 | 3 | 3 | 1 | 0 | 18 |

Table 8

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Scarlet Fever | 8 | 1 | 3 | 6 | 4 | 2 | 1 | 0 | 1 | 5 | 3 | 5 | 39 |
| Herpes Zoster | 6 | 6 | 5 | 5 | 4 | 5 | 3 | 7 | 3 | 7 | 6 | 7 | 64 |
| Erysipelis | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Upper Respirator y Infection | 15 | 25 | 56 | 20 | 31 | 25 | 18 | 62 | 56 | 85 | 35 | 74 | 502 |
| Leprosy | 0 | 3 | 0 | 1 | 2 | 0 | 2 | 1 | 0 | 1 | 2 | 1 | 13 |
| Staphyloco ccal Carrier | 0 | 22 | 1 | 0 | 4 | 0 | 0 | 2 | 8 | 0 | 0 | 0 | 37 |
| Exanthum subitum | 2 | 1 | 0 | 3 | 1 | 0 | 1 | 0 | 2 | 0 | 1 | 0 | 11 |
| Cutaneous Leishmania sis | 1 | 0, | 3 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| Giardiasis | 14 | 24 | 38 | 22 | 10 | 36 | 9 | 8 | 16 | 28 | 14 | 12 | 231 |
| Notified Diarrhea | 165 | 138 | 188 | 308 | 230 | 259 | 308 | 842 | 498 | 363 | 206 | 268 | 3,773 |
| Lead Poisoning | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |

Source: Ministry of Public Health, Kuwait

Table 9

REPORTED COMMUNICABLE DISEASES

KUWAIT - 1989

| Diseases | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S. typhi carrier | 0 | 0 | 2 | 4 | 1 | 1 | 2 | 0 | 0 | 1 | 6 | 0 | 17 |
| Typhoid Fever | 8 | 11 | 19 | 16 | 13 | 10 | 41 | 20 | 33 | 22 | 15 | 15 | 223 |
| Non 0-1 V. cholerae | 0 | 2 | 0 | 0 | 0 | 0 | 6 | 40 | 268 | 196 | 56 | 6 | 573 |
| Cholera | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 15 | 78 | 34 | 5 | 4 | 136 |
| Paratyphoid (A) Fever | 0 | 0 | 1 | 1 | 4 | 3 | 2 | 1 | 7 | 5 | 5 | 0 | 29 |
| Paratyphoid (A) Carrier | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Paratyphoid (B) Fever | 0 | 0 | 0 | 1 | 2 | 2 | 3 | 2 | 1 | 0 | 0 | 0 | 11 |
| Paratyphoid (B) Carrier | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 4 |
| Paratyphoid (C) Fever | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| Salmonella Enteritis | 33 | 20 | 39 | 41 | 43 | 41 | 30 | 72 | 54 | 42 | 44 | 38 | 497 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Salmonella Carrier | 76 | 56 | 82 | 107 | 120 | 122 | 114 | 174 | 192 | 203 | 166 | 110 | 1,522 |
| Shigellosis | 11 | 7 | 9 | 30 | 31 | 27 | 25 | 19 | 47 | 40 | 27 | 38 | 311 |
| Shigella Carrier | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 3 |
| Amebic Dysentary | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 1 | 5 | 2 | 1 | 1 | 13 |
| Food Poisoning | 18 | 5 | 10 | 602 | 9 | 34 | 36 | 70 | 12 | 15 | 8 | 10 | 829 |
| (A) Viral Hepatitis | 89 | 101 | 39 | 59 | 36 | 47 | 54 | 96 | 222 | 295 | 129 | 142 | 1,309 |
| (B) Viral Hepatitis | 20 | 17 | 31 | 19 | 24 | 21 | 17 | 43 | 23 | 59 | 23 | 15 | 312 |
| (Non A Non B) Viral Hepatitis | 0 | 2 | 2 | 1 | 1 | 0 | 1 | 7 | 3 | 14 | 6 | 4 | 41 |
| Non Specified Viral Hepatitis | 49 | 27 | 33 | 38 | 36 | 31 | 36 | 33 | 19 | 9 | 29 | 28 | 367 |
| Tetanus | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| Tetanus Neonatorum | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| Whooping Cough | 1 | 0 | 1 | 2 | 2 | 0 | 2 | 0 | 0 | 1 | 1 | 1 | 73 |
| Measles | 4 | 16 | 12 | 19 | 10 | 5 | 4 | 1 | 1 | 0 | 0 | 1 | 11 |
| Rubella | 30 | 49 | 158 | 288 | 222 | 75 | 32 | 33 | 18 | 41 | 31 | 21 | 998 |

Table 9

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mumps | 53 | 84 | 127 | 136 | 90 | 75 | 67 | 17 | 22 | 30 | 24 | 30 | 755 |
| Chickenpox | 375 | 365 | 458 | 501 | 495 | 334 | 217 | 197 | 143 | 182 | 244 | 254 | 3,752 |
| Endemic Typhus | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 4 |
| Malaria (Imported) | 68 | 57 | 62 | 79 | 115 | 163 | 142 | 139 | 122 | 130 | 83 | 67 | 1,227 |
| Filariasis (Imported) | 2 | 0 | 0 | 4 | 7 | 8 | 7 | 3 | 3 | 4 | 8 | 5 | 61 |
| Brucellosis | 18 | 28 | 32 | 32 | 31 | 42 | 21 | 18 | 11 | 14 | 10 | 7 | 264 |
| Meningococcal (A) Meningitis | 2 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 8 |
| Meningococcal (B) Meningitis | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 4 |
| Meningococcal (C) Meningitis | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| *N. meningitidis* Type 135W | 3 | 1 | 2 | 1 | 0 | 1 | 2 | 0 | 1 | 1 | 0 | 0 | 12 |
| *N. meningitidis 135 Carrier* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |

Table 9

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Meningococcal Meningitis Not specified | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| Septic Meningitis | 14 | 14 | 14 | 15 | 13 | 11 | 11 | 5 | 5 | 10 | 16 | 23 | 151 |
| Aseptic Meningitis | 9 | 8 | 13 | 13 | 12 | 13 | 3 | 7 | 9 | 7 | 17 | 27 | 138 |
| Encephalitis | 0 | 0 | 0 | 1 | 0 | 2 | 1 | 0 | 0 | 1 | 1 | 0 | 6 |
| Infectious Mononucleosis | 0 | 2 | 3 | 2 | 4 | 1 | 1 | 3 | 1 | 0 | 0 | 2 | 19 |
| Scarlet Fever | 1 | 3 | 14 | 14 | 8 | 4 | 3 | 3 | 1 | 7 | 9 | 6 | 73 |
| Herpes Zoster | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Erysipelis | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Upper Respiratory Infection | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Leprosy | 1 | 2 | 2 | 1 | 2 | 2 | 1 | 1 | 0 | 1 | 1 | 2 | 16 |
| Staphylococcal Carrier | 0 | 0 | 0 | 23 | 0 | 0 | 0 | 2 | 0 | 0 | 2 | 10 | 37 |
| Exanthum subitum | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 10 | 15 |

Table 9

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cutaneous Leishmania sis | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 4 |
| Giardiasis | 24 | 74 | 82 | 54 | 55 | 41 | 16 | 20 | 77 | 85 | 27 | 28 | 583 |
| Notified Diarrhea | 145 | 236 | 206 | 223 | 272 | 255 | 276 | 377 | 789 | 389 | 327 | 236 | 3,729 |
| Lead Poisoning | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Strept Throat | 67 | 30 | 47 | 54 | 44 | 39 | 60 | 50 | 69 | 104 | 51 | 34 | 649 |
| Herpex Simplex | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 7 |

Source: Ministry of Public Health, Kuwait

Table 10

REPORTED COMMUNICABLE DISEASES

KUWAIT - 1990

| Diseases | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug - Dec | Total |
|---|---|---|---|---|---|---|---|---|---|
| S. typhi carrier | 0 | 1 | 4 | 0 | 0 | - | - | 0 | 5 |
| Typhoid Fever | 3 | 9 | 8 | 8 | 16 | - | - | - | 44 |
| Non 0-1 V. cholerae | - | - | - | - | - | - | - | - | - |
| Cholera (imported) | - | - | - | - | - | - | - | - | - |
| Paratyphoid (A) Fever | 1 | 3 | 0 | 1 | 1 | - | - | 0 | 6 |
| Paratyphoid (A) Carrier | - | - | - | - | - | - | - | - | - |
| Paratyphoid (B) Fever | 0 | 3 | 0 | 1 | 0 | - | - | 0 | 4 |
| Paratyphoid (B) Carrier | 0 | 0 | 1 | 2 | 0 | - | - | 0 | 3 |
| Paratyphoid (C) Fever | 0 | 0 | 0 | 0 | 0 | - | - | 0 | 0 |
| Salmonella Enteritis | 29 | 16 | 36 | 46 | 53 | - | - | 2 | 182 |
| Salmonella Carrier | 74 | 76 | 106 | 138 | 148 | - | - | 0 | 542 |
| Shigellosis | 16 | 20 | 25 | 21 | 20 | - | - | 0 | 102 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Shigella Carrier | 0 | 0 | 0 | 0 | 1 | – | – | 0 | 1 |
| Amebic Dysentary | 0 | 0 | 2 | 0 | 0 | – | – | 1 | 3 |
| Food Poisoning | 5 | 4 | 6 | 21 | 46 | – | – | 0 | 82 |
| (A) Viral Hepatitis | 231 | 166 | 248 | 106 | 327 | – | – | – | 1,078 |
| (B) Viral Hepatitis | 35 | 20 | 27 | 28 | 15 | – | – | – | 125 |
| (Non A Non B) Viral Hepatitis | 7 | 3 | 4 | 2 | 1 | – | – | – | 17 |
| Non Specified Viral Hepatitis | 36 | 45 | 33 | 34 | 36 | – | – | 130 | 314 |
| Tetanus | 0 | 0 | 0 | 1 | 1 | – | – | 0 | 2 |
| Tetanus Neonatorum | 0 | 0 | 0 | 0 | 0 | – | – | 0 | 0 |
| Whooping Cough | 25 | 0 | 2 | 0 | 0 | – | – | 0 | 27 |
| Measles | 6 | 9 | 13 | 16 | 12 | – | – | – | 66 |
| Rubella | 31 | 46 | 101 | 76 | 122 | – | – | 1 | 377 |
| Mumps | 56 | 91 | 105 | 99 | 189 | – | – | 1 | 541 |
| Chickenpox | 289 | 284 | 3[illegible]4 | 401 | 751 | – | – | 3 | 2,079 |
| Endemic Typhus | 0 | 0 | 0 | 1 | 0 | – | – | 0 | 1 |

Table 10

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Malaria (Imported) | 49 | 51 | 59 | 83 | 94 | - | - | 2 | 338 |
| Filariasis (Imported) | 1 | 1 | 1 | 1 | 13 | - | - | 0 | 17 |
| Brucellosis | 10 | 12 | 22 | 40 | 60 | - | - | 0 | 148 |
| Meningococcal (A) Meningitis | 2 | 0 | 0 | 0 | 0 | - | - | 0 | 2 |
| Meningococcal (B) Meningitis | 2 | 1 | 1 | 2 | 1 | - | - | 0 | 7 |
| Meningococcal (C) Meningitis | 0 | 1 | 0 | 1 | 0 | - | - | 0 | 2 |
| Meningococcal W135 Meningitis | 1 | 0 | 0 | 2 | 1 | - | - | 0 | 4 |
| Meningococcal Meningitis Not Specified | 0 | 0 | 1 | 0 | 0 | - | - | 0 | 1 |
| Meningococcal (A) Carrier | 0 | 0 | 0 | 0 | 0 | - | - | 0 | 0 |
| Meningococcal (B) Carrier | 4 | 0 | 0 | 0 | 0 | - | - | 0 | 4 |
| Meningococcal (C) Carrier | 1 | 0 | 0 | 0 | 0 | - | - | 0 | 1 |
| <u>N. meningitidis</u> W135 Carrier | 1 | 0 | 0 | 0 | 0 | - | - | 0 | 1 |

Table 10

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Meningococcal Carrier Not specified | 17 | 0 | 0 | 0 | 0 | - | - | 0 | 17 |
| Septic Meningitis | 17 | 15 | 11 | 10 | 10 | - | - | 3 | 66 |
| Aseptic Meningitis | 11 | 5 | 10 | 15 | 15 | - | - | 1 | 57 |
| Encephalitis | 1 | 1 | 1 | 0 | 1 | - | - | 0 | 4 |
| Infectious Mononucleosis | 1 | 0 | 0 | 1 | 0 | - | - | 0 | 2 |
| Scarlet Fever | 11 | 1 | 11 | 11 | 15 | - | - | 0 | 49 |
| Herpes Zoster | 4 | 3 | 0 | 0 | 0 | - | - | 0 | 7 |
| Erysipelis | - | - | - | - | - | - | - | - | - |
| Upper Respiratory Infection | 63 | 39 | 46 | 27 | 41 | - | - | - | 216 |
| Leprosy | 1 | 1 | 3 | 0 | 3 | - | - | 0 | 8 |
| Staphylococcal Carrier | 1 | 52 | 0 | 0 | 4 | - | - | 0 | 10 |
| Exanthum subitum | 1 | 0 | 0 | 0 | 0 | - | - | 0 | 2 |
| Cutaneous Leishmaniasis | 2 | 0 | 0 | 0 | 0 | - | - | 0 | 2 |
| Giardiasis | 11 | 19 | 17 | 17 | 17 | - | - | 1 | 82 |
| Notified Diarrhea | 158 | 220 | 180 | 238 | 372 | - | - | 39 | 1,207 |
| Lead Poisoning | 0 | 0 | 0 | 0 | 0 | - | - | 0 | 0 |

Table 10

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| HIV | 0 | 0 | 0 | 0 | 0 | - | - | 1 | 1 |
| Sore Throat | 0 | 0 | 0 | 0 | 0 | - | - | 1 | 1 |
| Fever for Investigation | 0 | 0 | 0 | 0 | 0 | - | - | 1 | 1 |
| Animal Bites | 0 | 0 | 0 | 0 | 0 | - | - | 1 | 1 |

Source: Ministry of Public Health, Kuwait

## SCHEDULE OF IMMUNIZATION IN KUWAIT FOR CHILDREN UP TO FIVE YEARS OF AGE

| Age | Immunization | Location |
|---|---|---|
| Pregnant Women last trimester) | Tetanus Toxoid | PHC, Hospitals, MCH |
| 2nd day | OPV (Type I)<br>HBV (1st dose) | PHC, Hospitals |
| 3rd month | OPV (Type I)<br>HBV (2nd dose)<br>DPT (1st dose) | PHC |
| 4th month | OPV (Types I,II,III)<br>DPT (2nd dose) | PHC |
| 5th month | OPV (Types I,II,III)<br>DPT (3rd dose) | PHC |
| 6th month | OPV (Types I,II,III)<br>HBV (3rd dose) | PHC |
| 12 months | Measles vaccine | PHC |
| 18 months | OPV (Types I,II,III)<br>DPT (booster dose) | PHC |
| 2-4 years | Mumps, rubella | PHC |
| 2.5 years | OPV (Types I,II,III) | PHC |
| 3.5 years | OPV (Types I,II,III)<br>DPT (booster dose) | PHC |
| 3-6 years | BCG | SMV, BCG Centers |
| 4.5 to 5 years | OPV (Types I,II,III) | PHC |

PHC = Preventive Health Center
MCH = Maternal and Child Health Center
SMV = School Mass Vaccination Survey

Source: Ministry of Public Health, Kuwait

IMMUNIZATION IN KUWAIT (1977 - 1989)

Table 12

| Vaccination | Number | 1989 | 1988 | 1987 | 1986 | 1985 | 1984 | 1983 | 1982 | 1981 | 1980 | 1979 | 1978 | 1977 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DTP | 1st Dos | 60294 | 58265 | 60993 | 63506 | 65392 | 63157 | 56520 | 59896 | 58406 | 56669 | 52239 | 67241 | 68263 |
| | 2nd Dos | 61746 | 58438 | 62049 | 61139 | 61881 | 59309 | 53645 | 57700 | 56479 | 52769 | 46219 | 54793 | 65567 |
| | 3rd Dos | 64008 | 59879 | 93214 | 62678 | 62727 | 60757 | 55132 | 59330 | 55544 | 52530 | 46954 | 56003 | 73018 |
| | Booster | 105286 | 94134 | 97836 | 96634 | 95121 | 90903 | 75199 | 76360 | 60089 | 58088 | 47067 | 61158 | 42941 |
| Polio | 1st Dos | 60422 | 58902 | 61901 | 64432 | 67555 | 65906 | 59681 | 64404 | 65099 | 69699 | 65425 | 83536 | 91029 |
| | 2nd Dos | 61943 | 58665 | 62786 | 61781 | 63766 | 60501 | 55146 | 60530 | 62433 | 63776 | 57588 | 66512 | 87563 |
| | 3rd Dos | 64207 | 59962 | 63555 | 63018 | 63422 | 61626 | 55948 | 62028 | 66072 | 67254 | 46079 | 86387 | 108086 |
| | 4th Dos | 68899 | 63601 | 73053 | 73808 | 74007 | 68073 | 59940 | 67809 | 72357 | 69243 | 50981 | 3043 | |
| | Booster | 184055 | 167600 | 189042 | 188224 | 208502 | 191463 | 178965 | 199554 | 185958 | 170635 | 125077 | 139398 | 89983 |
| Measles | | 53434 | 50205 | 59911 | 63555 | 66841 | 70469 | 61172 | 54346 | 36528 | 32099 | 31155 | 56790 | 30085 |
| Tetanus | 1st Dos | 44247 | 40804 | 30685 | 29444 | 31263 | 56105 | 36003 | 47123 | 39002 | 58545 | 41589 | 50523 | 30104 |
| | 2nd Dos | 17173 | 17394 | 19562 | 16858 | 24179 | 21555 | 14694 | 22147 | 22572 | 22960 | 22502 | 22343 | 16505 |
| | 3rd Dos | 13716 | 11495 | 11000 | 16237 | 12924 | 7407 | 7197 | 7001 | 297 | 4326 | 5362 | 4750 | 3598 |
| | Booster | 32373 | 9082 | 10329 | 7302 | 3599 | 1900 | 2969 | 1622 | 4988 | 1241 | 1022 | 3745 | 242 |

Source: Ministry of Public Health, Kuwait

# Immunization in Kuwait, 1989 (By Months)

Table 13

| | Number | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DPT | 1st Dos | 5661 | 5022 | 5763 | 4361 | 5038 | 4459 | 4510 | 4885 | 4752 | 5098 | 5159 | 5086 | 60294 |
| | 2nd Dos | 5678 | 4916 | 6066 | 5266 | 5235 | 4886 | 4461 | 4740 | 4630 | 5221 | 5254 | 5393 | 61746 |
| | 3rd Dos | 5758 | 5186 | 6274 | 5508 | 5690 | 5288 | 4567 | 4611 | 4047 | 5394 | 5448 | 5517 | 64080 |
| | Booster | 9196 | 7801 | 10082 | 8717 | 8716 | 8485 | 7004 | 7137 | 7994 | 9142 | 9740 | 10072 | 104006 |
| Polio | 1st Dos | 5686 | 5027 | 5763 | 4879 | 5041 | 4473 | 4510 | 4884 | 4760 | 5104 | 5176 | 5119 | 60422 |
| | 2nd Dos | 5698 | 4933 | 6080 | 5279 | 5247 | 4893 | 4450 | 4743 | 4630 | 5208 | 5339 | 5443 | 61943 |
| | 3rd Dos | 5765 | 5205 | 6275 | 5508 | 5691 | 5289 | 4586 | 4604 | 4043 | 5406 | 5475 | 5560 | 64207 |
| | 4th Dos | 6311 | 5544 | 6599 | 5852 | 6116 | 5648 | 5137 | 5083 | 5257 | 5758 | 5748 | 5846 | 68899 |
| | Booster | 16201 | 14243 | 18099 | 15571 | 15116 | 14273 | 11558 | 12743 | 13408 | 15886 | 18194 | 18603 | 184055 |
| Polio (NB) | | 3023 | 3054 | 3009 | 2742 | 2718 | 2766 | 2921 | 2677 | 3073 | 3751 | 3748 | 3019 | 36501 |
| Measles | | 4760 | 3066 | 5330 | 4034 | 4267 | 3635 | 3601 | 3784 | 5281 | 4831 | 5231 | 4814 | 53434 |
| DT | | 190 | 168 | 286 | 146 | 128 | 109 | 101 | 105 | 257 | 212 | 433 | 217 | 2352 |
| MR | | 3028 | 2970 | 4230 | 3956 | 4020 | 3520 | 3306 | 3703 | 4243 | 4542 | 4035 | 4000 | 47233 |
| Meningococcal A+B | | 20154 | 21000 | 22210 | 17735 | 25156 | 46723 | 24427 | 19185 | 24680 | 22030 | 24434 | 21724 | 289458 |
| Yellow Fever | | 38 | 61 | 13 | 74 | 107 | 52 | 31 | 41 | 203 | 38 | 26 | 25 | 709 |
| Rabies IG | | 38 | 35 | 36 | 40 | 17 | 32 | 35 | 37 | 32 | 35 | 34 | 39 | 410 |
| Gamma Globulin | | 604 | 505 | 556 | 431 | 440 | 509 | 454 | 805 | 838 | 829 | 741 | 700 | 7412 |
| Tetabulin | | 83 | 60 | 91 | 66 | 68 | 83 | 62 | 101 | 89 | 75 | 57 | 29 | 864 |
| Pertussis I G | | | | | | 4 | | | | | 2 | 4 | | 10 |
| Tetanus | 1st Dos | 3934 | 4007 | 3405 | 2652 | 4285 | 4008 | 3487 | 4652 | 4490 | 3829 | 3536 | 1882 | 44247 |
| | 2nd Dos | 2045 | 1329 | 2762 | 1471 | 858 | 944 | 1276 | 872 | 1527 | 944 | 1110 | 2055 | 17193 |
| | 3rd Dos | 950 | 867 | 1475 | 1162 | 1355 | 1611 | 1138 | 1440 | 1232 | 185 | 1901 | 392 | 13716 |
| | Booster | 2923 | 3117 | 3245 | 3462 | 3901 | 3455 | 2774 | 3001 | 2837 | 1963 | 740 | 955 | 32373 |
| Typhoid | 1st Dos | 1173 | 1245 | 1718 | 472 | 1474 | 1732 | 1122 | 1825 | 1543 | 1635 | 1209 | 1491 | 16719 |
| | 2nd Dos | 840 | 988 | 1371 | 511 | 629 | 874 | 971 | 1707 | 1730 | 1209 | 1274 | 1553 | 13025 |
| | Booster | [illegible] | 1050 | 1182 | 375 | 1069 | 1190 | 1020 | 1696 | 1420 | 1324 | 1454 | 1662 | 14449 |
| Cholera | | 4986 | 4462 | 5267 | 2947 | 6503 | 8985 | 5040 | 4490 | 5921 | 6042 | 5795 | 6134 | 65900 |
| Rabies | | 271 | 294 | 290 | 325 | 316 | 322 | 300 | 384 | 272 | 297 | 300 | 324 | 3733 |
| Hepatitis B | | 91 | 97 | 174 | 27 | 127 | 80 | 39 | 26 | 60 | 101 | 59 | 82 | 1021 |
| Rubella | | 6 | 11 | 9 | 2 | 2 | 6 | 3 | 3 | 5 | 3 | 35 | 109 | 194 |
| Mumps | | | | | | | | | | | 1 | 500 | | 501 |

Immunization in Kuwait, 1990 (By Months) Table 14

| | Number | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DPT | 1st Dos | 4981 | 4447 | 5105 | 3884 | 4922 | 4055 | | 1116 | 1127 | 1503 | 1661 | 1351 | 34152 |
| | 2nd Dos | 5047 | 4263 | 5189 | 4191 | 5085 | 4420 | | 1174 | 907 | 1449 | 1490 | 1121 | 34426 |
| | 3rd Dos | 5026 | 4290 | 5144 | 4313 | 5525 | 4519 | | 1191 | 1003 | 1661 | 1532 | 1054 | 35550 |
| | Booster | 8475 | 7181 | 8685 | 6142 | 9289 | 7690 | | 1361 | 1607 | 2045 | 2134 | 1406 | 56015 |
| Polio Vaccine | 1st Dos | 5017 | 4480 | 5124 | 3894 | 4939 | 4066 | | 1121 | 1126 | 1514 | 1661 | 1351 | 34293 |
| | 2nd Dos | 5060 | 4282 | 5198 | 4198 | 5139 | 4420 | | 1175 | 1004 | 1150 | 1495 | 1121 | 34242 |
| | 3rd Dos | 5042 | 4208 | 5139 | 4208 | 5535 | 4523 | | 1191 | 1006 | 1323 | 1462 | 1054 | 34771 |
| | 4th Dos | 5647 | 4561 | 5305 | 4205 | 5574 | 4699 | | 1177 | 811 | 1100 | 1317 | 1073 | 35469 |
| | Booster | 16200 | 13651 | 14946 | 10160 | 10314 | 12517 | | 2052 | 2420 | 3556 | 4329 | 3008 | 93241 |
| Polio (New Born) | | 4027 | 3681 | 4132 | 4027 | 4310 | 3902 | | 27 | 349 | 936 | 1059 | 371 | 26021 |
| Measles | | 4230 | 3943 | 4559 | 3503 | 5067 | 3772 | | 801 | 742 | 1064 | 1194 | 1100 | 29975 |
| D.T. Vaccine | | 250 | 164 | 152 | 281 | 217 | 105 | | 26 | 14 | 8 | 13 | 2 | 1232 |
| M.R. Vaccine | | 4284 | 3562 | 4252 | 2863 | 4583 | 3496 | | 861 | 727 | 1010 | 1353 | 1003 | 27994 |
| Meningococcal A+B | | 19317 | 16368 | 21564 | 14490 | 34981 | 88184 | | 1001 | 1027 | 1906 | 1101 | | 199947 |
| Yellow Fever | | 58 | 43 | 63 | 17 | 90 | 61 | | | | | | | 332 |
| Rabies I G | | | | | 16 | 16 | 33 | | | | 3 | | | 68 |
| Gamma Globulin | | 1404 | 1107 | 1305 | 1169 | 2199 | 1760 | | 44 | 30 | 49 | 80 | 408 | 9635 |
| Tetabulin | | 56 | 64 | 65 | 36 | 64 | 62 | | 1 | 3 | 1 | 26 | | 378 |
| Pertussis I G | | | | | 5 | 10 | 3 | | | | | | | 18 |
| Tetanus | 1st Dos | 6416 | 5706 | 6543 | 4522 | 5673 | 4483 | | 66 | 71 | 25 | 39 | 16 | 33640 |
| | 2nd Dos | 1483 | 1109 | 2585 | 1068 | 1120 | 650 | | 1 | 19 | 14 | 6 | 2 | 8057 |
| | 3rd Dos | 332 | 511 | 266 | 76 | 36 | 332 | | | 10 | 5 | 1 | | 1629 |
| | Booster | 794 | 511 | 1494 | 984 | 1328 | 748 | | | 4 | 2 | 1 | | 5866 |
| Typhoid | 1st Dos | 1502 | 1296 | 1691 | 1096 | 1830 | 1496 | | 63 | 71 | 49 | 15 | 5 | 9194 |
| | 2nd Dos | 1200 | 1022 | 1213 | 1295 | 1237 | 1324 | | 10 | 60 | 32 | 3 | 4 | 7400 |
| | Booster | 1796 | 1680 | 1680 | 640 | 2308 | 1740 | | 10 | 31 | | | | 9893 |
| Cholera | | 5600 | 4307 | 4009 | 1904 | 6264 | 8235 | | 45 | 38 | 15 | 297 | | 31834 |
| Rabies | | 320 | 242 | 302 | 292 | 434 | 318 | | 15 | 31 | 34 | 54 | 48 | 2090 |
| Hepatitis B | Peds | 3567 | 3695 | 4121 | 6251 | | | | | | | 21 | 130 | 17785 |
| | Adult | 803 | 1963 | 1270 | 1012 | | | | | | | 8 | 19 | 5155 |
| | | | | | | | | | | | | | | 0 |
| Rubella | | 71 | 11 | 5 | 2 | 4 | 9 | | 103 | | 147 | 30 | 92 | 474 |
| Mumps | | 321 | | 365 | 8 | 6 | | | | | | 1 | | 701 |

[illegible] Public Health, Kuwait

REPORTED COMMUNICABLE DISEASES
KUWAIT JANUARY - MARCH 9, 1991

| Diseases | January | February | March | Total |
|---|---|---|---|---|
| Hepatitis A | 144 | 9 | 22 | 175 |
| Hepatitis B | 0 | 0 | 1 | 1 |
| Mumps | 1 | 1 | 0 | 2 |
| Meningitis | 0 | 1 | 0 | 1 |
| Dog Bites | 1 | 0 | 0 | 1 |
| Diarrhea | 0 | 0 | 5 | 5 |
| Fever | 0 | 0 | 1 | 1 |

Source: Ministry of Public Health, Kuwait

## HEPATITIS A
## KUWAIT BY YEAR 1988 - MARCH 9, 1991

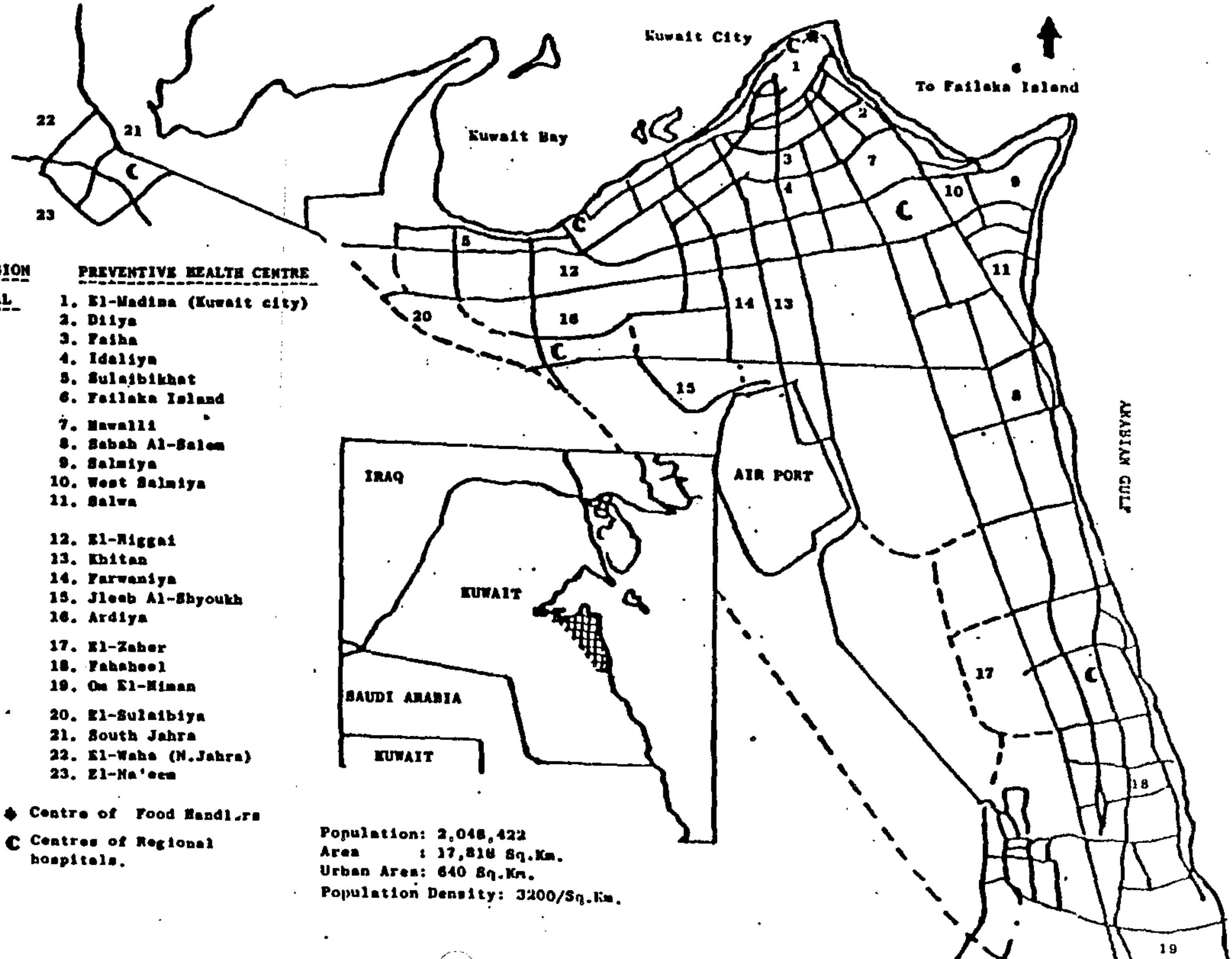
| YR | J | F | M | A | M | J | J | A | S | O | N | D | TOT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 88 | 11 | 144 | 173 | 25 | 29 | 31 | 408 | 109 | 251 | 308 | 124 | 93 | 1706 |
| 89 | 89 | 101 | 39 | 59 | 36 | 47 | 54 | 96 | 222 | 295 | 129 | 142 | 1309 |
| 90 | 231 | 166 | 248 | 106 | 327 | - | - | | | 130 | | | 1208 |
| 91 | 144 | 9 | 22 | | | | | | | | | | |

## HEPATITIS B
## KUWAIT BY YEAR 1988 - MARCH 9, 1991

| YR | J | F | M | A | M | J | J | A | S | O | N | D | TOT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 88 | 29 | 24 | 24 | 19 | 25 | 16 | 28 | 31 | 44 | 28 | 4 | 32 | 304 |
| 89 | 20 | 17 | 31 | 19 | 24 | 21 | 12 | 43 | 23 | 59 | 23 | 15 | 312 |
| 90 | 35 | 30 | 27 | 28 | 15 | - | - | 0 | 0 | 0 | 0 | 0 | 125 |
| 91 | 0 | 0 | 1 | | | | | | | | | | |

Source: Ministry of Public Health, Kuwait

Figure 1




| HEALTH REGION | PREVENTIVE HEALTH CENTRE |
|---|---|
| THE CAPITAL | 1. El-Madina (Kuwait city) |
| | 2. Diiya |
| | 3. Faiha |
| | 4. Idaliya |
| | 5. Sulaibikhat |
| | 6. Failaka Island |
| HAWALLI | 7. Hawalli |
| | 8. Sabah Al-Salem |
| | 9. Salmiya |
| | 10. West Salmiya |
| | 11. Salwa |
| FARWANIYA | 12. El-Riggai |
| | 13. Khitan |
| | 14. Farwaniya |
| | 15. Jleeb Al-Shyoukh |
| | 16. Ardiya |
| AL-AHMADI | 17. El-Zaher |
| | 18. Fahaheel |
| | 19. Om El-Himan |
| AL-JAHRA | 20. El-Sulaibiya |
| | 21. South Jahra |
| | 22. El-Waha (N.Jahra) |
| | 23. El-Na'eem |

◆ Centre of Food Handlers

C Centres of Regional hospitals.

Population: 2,048,422
Area : 17,818 Sq.Km.
Urban Area: 640 Sq.Km.
Population Density: 3200/Sq.Km.

FIGURE 2

## ORGANIZATION OF PUBLIC HEALTH DURING THE IRAQI OCCUPATION, AUGUST 1990 - JANUARY 1991

- PUBLIC HEALTH GENERAL
  - Section of Technical Affairs
  - Section of Administrative Affairs
  - Section of Preventive Health and Environmental Protection
    - Unit of Environmental and Radiation Protection
    - Unit of Communicable Diseases
    - Unit of Occupational Health
    - Unit of Public Health Laboratories
    - Unit of Health Education
    - Unit of Primary Health Care
  - Section of Financial Affairs
  - Section of Pharmaceuticals and Medical Equipment

FIGURE 3

## ORGANIZATION OF KUWAIT MINISTRY OF PUBLIC HEALTH AS OF MARCH 16, 1991

Minister of Public Health (Dr. Abul Wahab AL-Fozan)

Undersecretary of The Ministry of Public Health (Vacant)

Assistant Secretary for Public Health Affairs (Dr. Ali AL-Saif)

- Department of Environmental Health
  Director: Mr. Ibrahim Hadi
  Assistant: Dr. Mohammed Yousif
- Department of Public Health
  Director: Dr. Rashed AL-Owaish
- Department of Health Education
  Director: Dr. Yousif AL-Moumen
- Department of International Health
  Director: Dr. Abul Latif AL-Zaid

FIGURE 4

# ORGANIZATION OF THE DEPARTMENT OF PUBLIC HEALTH

**Department of Public Health**
Director: Dr. Rached AL-Owaish

- **Radiation Protection Division**
  Chief: Dr. Yousif Bagen
- **Public Health Laboratories**
  Chief: Mr. Yagoob AL-Motaweh
- **Port Health Division**
  Chief: Dr. Rached AL-Owaish
- **Preventive Medicine Division**
  Chief: Dr. Jaffar Dawood
  Assistant Dr. Adnan AL-Garabaly
  - **Epidemiology Unit**
    Chief: Dr. Abdul Amir
  - **Environmental Unit**
    Chief: Dr. Tareq AL-Dowesan
  - **Nutrition Unit**
    Chief: Dr. Zamzam AL-Kalidar
- **International Health Division**
  Chief: Dr. Abul Latif AL-Zaid
- **Rodent and Insect Control Division**
  Chief: Dr. Mohammed Balbah

FIGURE 5

## HEALTH DISTRICTS AND DISTRICT DIRECTORS

| DISTRICT | DISTRICT DIRECTOR |
|---|---|
| Capital (Amiri District) | Dr. Ahmamed AL-Aiaf |
| AL-Ahmadi District | Dr. Abdulla Hamadi |
| Hawalli District | Dr. Abdul-Razak AL-Bahar |
| Farwaniya District | Dr. Suliman AL-Fallah |
| AL-Jahra District | Dr. Rashid AL-Roshood |
| AL-Sabah Region for Specialized Services | Dr. Salah AL-Ategi |

FIGURE 6

## HOSPITALS AND HOSPITAL DIRECTORS BY DISTRICT

| DISTRICT | HOSPITAL | DIRECTOR |
|---|---|---|
| Capital (Amiri) | Amiri Hospital | Dr. Ahdy AL-Ghanim |
| AL-Ahmadi | Adaan Hospital | Dr. Adnan AL-Edan |
| Hawalli | Mubarek Hospital | Dr. Yousef AL-Nasif |
| Farwaniya | Farwania Hospital | Dr. Ali AL-Fowderi |
| AL-Jahra | Jahra Hospital | Dr. Abdul Raoof AL-Jahari |
| AL-Sabah | Specialty Hospitals<br>Allergy Center<br>Audiology Center<br>Burns and Plastic Surgery Center<br>Cancer Control Center<br>Chest Hospital<br>Gynecology-Maternity Hospital<br>Infectious Disease Hospital<br>Islamic Medicine Center<br>Neurosurgery Center<br>Ophthalmology Hospital<br>Orthopedic Hospital<br>Pediatric Hospital<br>Physiotherapy Center<br>Psychiatric Hospital<br>Transplantation Center | Dr. Salah AL-Ategi |

## Water Team Accomplishments

1. Accompanied Army Engineers to assess damage to the Schwaiyk Desalination Water Treatment Plane.

2. Met with Mr. Nasser, Deputy of the Ministry of Electricity and Water, and Dr. Fatima AL-Awad, Director of the Water Resource Development Centre. A plan was established to test all of the existing reservoirs which provide water to Kuwait City and surrounding communities. The water would be tested for lewesite, mustard, cyanide, nerve agent, and arsenic. Samples were collected at the following reservoirs:

   Mutla Low, Mutla High, West Finatas, Doha, Subhan

   One positive lewesite sample came from Mutla High. It was thought to be an error in sampling and was retested the following day and found to be negative.

3. The Navy and Army Water Team visited the water testing laboratory at the Water Resources Development Centre (WRDC). The staff of the WRDC was taught how to use the M-272 water chemical test kit and the Millipore Filter Water Bacteriological Field Test Kit. Seven (7) M-272 kits, one (1) Field Bacti kit from the Navy team, and one (1) Field Bacti kit from the Army, along with the bulk of the Navy Millipore Water Testing supplies were transferred to the Director, WRDC, for use in conducting water analysis. Humanitarian efforts by the Navy Water Team were concluded at this point.

<u>Assessment</u>

Given the equipment and training provided the WRDC, adequate water testing may be accomplished until such time as the WRDC is r.supplied and returns to normal operation.

Attachment 2

Vector Control Report of 5 March 1991

1. LTC Lambrinos, LCDR Schultz, LT Lluberas, Cpt Leonard, and several vector control technicians met with Osama Omar EL-Ruby (head of Rodent Control) and Dr. Ibrahim Hadi, Director of the Environment Protection Department, Ministry of Public Health. The meeting took place at the Pest Control Garage main office in the Industrial Area near AL-Mina and the 4th ring road.

2. Mr. EL-Ruby described their limited work during the occupation as mainly supporting five hospitals in rodent and cockroach control. Most of their vehicles and nearly all of their pesticides were stolen. He described how all of their pesticide mixing equipment was carefully removed and flown to Iraq.

3. A tour of the facility was then conducted. Areas such as record keeping, which were of no use to the trespassers, was badly trashed. The pesticide storage garage was empty with the exception of a small amount of rat bait. Several vehicles were present but had their tires removed or were damaged in some way. They had six truck-mounted ultra-low volume machines.

4. They reported that on 9 March about 116-120 previous employees would be returning to work. Most of these people had 15 years experience in pest control. By that date, Mr. EL-Ruby said they should have completed their assessment on how much equipment and supplies were available for their use.

5. We discussed with them the amounts and kinds of pesticides and equipment we brought and was available for them to use. The pesticides would be enough for a 14-day supply for their teams until additional pesticides could be purchased. Most of the equipment in our inventory is similar to that which they used before the invasion, so only refresher training would be needed.

6. Mr. EL-Ruby said that there were no immediate vector control problems that needed spraying by our team. He mentioned that they had a 3-month plan for resuming operations.

## Entomology Team Accomplishments

1. Visited hospitals and interviewed doctors on prevalence of vector-borne diseases. No vector-borne diseases were reported in Kuwait during the occupation and they gave no indication that any would be a likely problem.

2. Acquired body bags and delivered them to several hospitals in which morgue storage facilities had been exceeded.

3. Provided vector control in morgues for flies, and at the U.S. Embassy and airport for mosquitos.

4. Visited pesticide distributors in Damman; got availability and price information. Developed a suggested list of pesticides with amounts that the contractor should purchase to restock the Kuwait Pesticide Garage.

5. Performed assessment of the Pest Control Garage. Reviewed their activities for the past 7 months. Of special note was removal of their pesticide mixing equipment which was flown to Iraq. Also noted was the nearly complete removal of their pesticide supplies and vehicles used for spraying.

6. Assisted the Ministry of Health in an overall assessment of the pest and vector situation. Overall conclusion is that although there are minor local fly and mosquito problems, the city is in very good shape.

7. An extensive amount of pesticides, pesticide spraying equipment, and general laboratory equipment has been transferred from our team to the Kuwait Pest Control Garage.

<u>Assessment</u>

Mr. Osama EL-Ruby, head of the rodent control division, reported that on 9 March about 120 previous employees would be returning to work. These are experiences pest control workers averaging about 15 years on the job. Since during the occupation most of the pesticides and equipment were stolen, we felt that the greatest help we could provide was to transfer our pest control supplies and equipment to them. We discussed pest control priorities and agreed that there should be fly control in areas where garbage had been previously piled. Mosquito, roach, and rodent control would be responded to on the basis of public complaint. Sanitation was stressed as the key to returning things back to normal. We feel confident that the pest control garage, with their experienced workers and the addition of our pesticides and equipment, will quickly return to the effective service that it previously provided.

# Epidemiology Team Accomplishments

1. Hospitals were visited and needs were assessed.

2. Arrangements were coordinated for the delivery of water to the hospitals. In some cases, supplies of bottled water were delivered to the outlying hospitals such as the Infectious Disease Hospital which had a small in-patient population (five persons).

3. Meetings were held at the Ministry of Public Health and their disease surveillance program was discussed.,

4. Delivery of some supplies requested by the hospitals was accomplished.

5. Epidemiology Team members participated in other activities of the 352nd Civil Affairs Command, such as the identification of sites where animal herds were without water, assessment of displaced civilians returning from Iraq, and evaluation of problem areas, such as refuse disposal.

## Assessment

The overall health of the population of Kuwait City was good as a result of optimal health care during the period preceding the occupation. The relatively short duration of the occupation and the ground war was a factor in the minimal degradation of the health and nutritional status of the population. The cool season of the year, which limited the opportunity for vector breeding, helped to minimize the potential for vector-borne disease. Although the ability to conduct surveillance had been degraded during recent months due to severe limitations on communication and transportation, the basic reporting mechanisms were still intact. The efforts to keep up with immunization and basic public health services were impressive.

It is apparent that as soon as the basic services of electricity, water, and communication are restored, that mechanisms are in place for resuming health care and public health service at a high level. The Ministry officials and physicians are among the most highly training professionals in the world. Probably one of the more difficult challenges will be to obtain adequate numbers of service personnel who can restore systems, orderliness, and cleanliness to the hospitals, clinics, and other public institutions.

15 MARCH, 1991

RESULTS OF INFECTIOUS DISEASE SURVEILLANCE IN KUWAIT CITY, 5 MARCH - 15 MARCH, 1991 CONDUCTED JOINTLY BY MUBARAK HOSPITAL LABORATORY (DR KAMAL ELHAG AND DR AWAD EL-MEKKI) AND NAVY FORWARD LABORATORY

BACKGROUND:

DURING THE PERIOD OF 5 MARCH - 15 MARCH, 1991 MUBARAK HOSPITAL LABORATORY (DR KAMAL ELHAG AND DR AWAD EL-MEKKI) IN COLLABORATION WITH THE NAVY FORWARD LABORATORY CONDUCTED INFECTIOUS DISEASE SURVEILLANCE IN MAJOR, KUWAIT CITY HOSPITALS TO DETERMINE THE POST-WAR ETIOLOGY AND INCIDENCE OF ACUTE DIARRHEA AND HEPATITIS.

METHODS:

DIARRHEAL STOOL SPECIMENS AND SERA FROM PATIENTS WITH SYMPTOMS OF ACUTE HEPATITIS WERE COLLECTED DAILY FROM ALAMIRI HOSPITAL, SABAH HOSPITAL, PEDIATRIC HOSPITAL, THE INFECTIOUS DISEASES HOSPITAL AND MUBARAK HOSPITAL (SOME DIARRHEAL STOOL SPECIMENS WERE FROM KUWAITI DETAINEES HELD IN IRAQ). DIARRHEAL STOOL SPECIMENS WERE CULTURED FOR SHIGELLA SP., SALMONELLA SP., CAMPYLOBACTER SP., AND VIBRIO CHOLERAE 01. LT PRODUCING ENTEROTOXIGENIC E. COLI WERE IDENTIFIED USING A DNA PROBE. DIARRHEAL STOOLS WERE ALSO EXAMINED FOR PATHOGENIC PARASITES. SERA FROM PATIENTS WITH CLINICAL SYMPTOMS OF ACUTE HEPATITIS WERE TESTED FOR THE PRESENCE OF IgM ANTIBODY TO HEPATITIS A VIRUS AND IgM ANTIBODY TO HEPATITIS B VIRUS CORE ANTIGEN.

RESULTS:

A TOTAL OF 49 DIARRHEAL STOOL SPECIMENS WERE COLLECTED. THERE WERE 13 SHIGELLA SP., 8 CAMPYLOBACTER SP., 2 SALMONELLA SP., AND 7 VIBRIO CHOLERAE 01 OGAWA ISOLATES. THE SPECIES OF THE SHIGELLA ISOLATES ARE SHOWN IN TABLE 1.

OF THE 7 PATIENTS WITH VIBRIO CHOLERAE 01, OGAWA ISOLATED FROM THEIR STOOL, 4 PATIENTS HAD LEUCOCYTES IN THEIR STOOL. CAMPYLOBACTER SP. AND SHIGELLA DYSENTERIAE WERE ISOLATED FROM TWO OF THE PATIENTS WITH LEUCOCYTES IN THEIR STOOLS. THESE PATIENTS WERE LIKELY VIBRIO CHOLERAE 01, OGAWA CARRIERS. OF THE REMAINING

3 PATIENTS, 1 PATIENT HAD 100,000,000 VIBRIO CHOLERAE 01, OGAWA ORGANISMS PER ML OF STOOL AND WAS LIKELY A CASE OF CHOLERA DIARRHEA. THERE WAS NO EVIDENCE OF PATHOGENIC PARASITES. THESE RESULTS ARE SUMMARIZED IN TABLE 1.

NINE SERA WERE OBTAINED FROM PATIENTS WITH CLINICAL SYMPTOMS OF ACUTE HEPATITIS. OF THESE SERA, 8 WERE POSITIVE FOR IgM ANTIBODY TO HEPATITIS A VIRUS AND 1 PATIENT HAD NON A, NON B HEPATITIS. THESE RESULTS ARE SUMMARIZED IN TABLE 1.

FIGURE 1 COMPARES NUMBERS OF ENTERIC ISOLATES BY SPECIES BETWEEN MARCH, 1990 AND 5 MARCH - 15 MARCH, 1991. THERE IS AN APPARENT INCREASE IN THE NUMBER OF ENTERIC PATHOGEN ISOLATES WHICH IS NOT OF EPIDEMIC PROPORTIONS AND WOULD BE EXPECTED DUE TO CURRENT CONDITIONS IN KUWAIT CITY.

TABLE 2 SHOWS THE ANTIBIOTIC SENSITIVITY PROFILE OF BACTERIAL ISOLATES FROM DIARRHEAL STOOLS. SHIGELLA GROUP A ISOLATES WERE SENSITIVE TO ALL ANTIBIOTICS TESTED IN VITRO. THE SHIGELLA GROUP B ISOLATES WERE ALL RESISTANT TO AMPICILLIN AND 8 OF 9 ISOLATES WERE RESISTANT TO CHLORAMPHENICOL, DOXYCYCLINE AND SULFATRIMETHOPRIM. ALL SHIGELLA GROUP B ISOLATES WERE SENSITIVE TO THE QUINOLONE, NORFLOXACIN. THE 7, VIBRIO CHOLERAE 01, OGAWA ISOLATES WERE SENSITIVE TO ALL ANTIBIOTICS TESTED. ALL BACTERIAL PATHOGENS ISOLATED FROM DIARRHEAL STOOLS WERE SENSITIVE IN VITRO TO THE QUINOLONE ANTIBIOTIC, NORFLOXACIN.

SPECIAL NOTE !!!

EXTREME CARE SHOULD BE TAKEN IN THE INTERPRETATION OF THE ISOLATION OF VIBRIO CHOLERAE 01, OGAWA FROM STOOLS. IT IS LIKELY THAT 4 OF THE 7 PATIENTS FROM WHICH VIBRIO CHOLERAE 01 WAS ISOLATED WERE CARRIERS SINCE THEY HAD LEUCOCYTES IN THEIR STOOL AND ANOTHER ENTERIC PATHOGEN CAUSING INVASIVE DIARRHEA WAS ISOLATED. IN AT LEAST ONE OF THE PATIENTS WHERE A HIGH NUMBER OF VIBRIO CHOLERAE 01, OGAWA (100,000,000 ORGANISMS PER ML OF STOOL CONSISTANT WITH CHOLERA DIARRHEA) ORGANISMS WAS ISOLATED IT WAS LIKELY THAT THIS ORGANISM WAS THE CAUSE OF THE RESULTANT DIARRHEA. THE ISOLATION OF VIBRIO CHOLERAE 01, OGAWA DOES NOT SIGNIFY AN EPIDEMIC OR THE START OF AN EPIDEMIC HOWEVER, CONTINUED SURVEILLANCE IS IMPORTANT.

DR KAMAL ELHAG — LCDR JAMES BURANS

DR AWAD EL-MEKKI — LT SCOTT THORNTON

TABLE I

# RESULTS OF DISEASE SURVEILLANCE IN KUWAIT CITY HOSPITALS, 5 MARCH - 15 MARCH, 1991

NUMBER OF DIARRHEAL STOOL SPECIMENS COLLECTED = 49

| SPECIES | # OF ISOLATES |
|---|---|
| SHIGELLA GR A | 2 |
| SHIGELLA GR B | 10 |
| SHIGELLA GR C | 0 |
| SHIGELLA GR D | 1 |
| CAMPYLOBACTER SP. | 6 |
| SALMONELLA SP. | 2 |
| VIBRIO CHOLERAE 01, OGAWA | 7 |

NUMBER OF SERA COLLECTED FOR HEPATITIS SEROLOGIES = 9

| SEROLOGICAL ASSAY | # POSITIVE |
|---|---|
| HEPATITIS A IgM | 8 |
| HEPATITIS B CORE IgM | 0 |

* 1 SERUM PROBABLE NON A, NON B HEPATITIS

MUBARAK HOSPITAL LAB AND NAVY FORWARD LAB

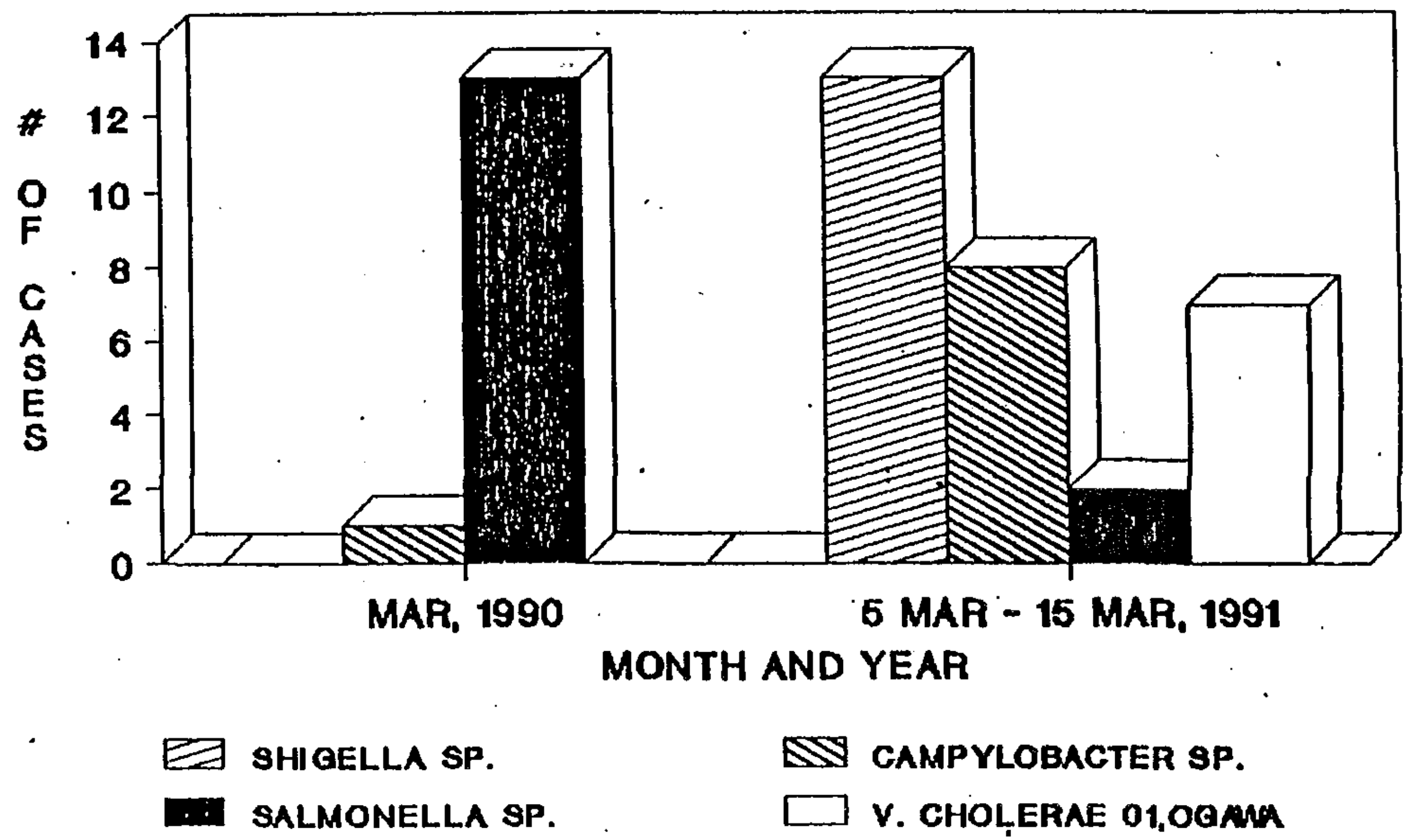
# ANTIBIOTIC RESISTANCE PROFILES OF ENTERIC PATHOGENS FROM KUWAIT CITY 5-15 MAR, 1991

| ISOLATE | # OF ISOLATES | NOR | C | ANTIBIOTIC AM | DOX | SXT |
|---|---|---|---|---|---|---|
| SHIGELLA GROUP A | 2 | 0 | 0 | 0 | 0 | 0 |
| SHIGELLA GROUP B | 9 | 0 | 8 | 9 | 8 | 8 |
| SHIGELLA GROUP D | 1 | 0 | 0 | 0 | 1 | 0 |
| CAMPYLO-BACTER SP. | 6 | 0 | 0 | 1 | 0 | 5 |
| SALMONELLA SP. | 2 | 0 | 0 | 0 | 2 | 0 |
| V. CHOLERAE O1, OGAWA | 7 | 0 | 0 | 0 | 0 | 0 |

NOR=NORFLOXACIN, C=CHLORAMPHENICOL, AM=AMPICILLIN
DOX=DOXYCYCLINE, SXT=SULFATRIMETHOPRIM

FIGURE 1

# RESULTS OF DIARRHEAL STOOL CULTURE AT MUBARAK HOSPITAL



Attachment 6

15 MARCH, 1991

MEMO

FROM: NAVY FORWARD LABORATORY

SUBJECT: DAILY REPORT

ENCL: PROTOCOL FOR IDENTIFICATION OF V. CHOLERAE 01 CARRIERS

1. 1 DIARRHEAL STOOL SPECIMEN FOR CULTURE AND NO SERA FOR HEPATITIS SEROLOGIES WERE RECEIVED.

2. THERE IS NO EPIDEMIC INFECTIOUS DISEASE IN KUWAIT CITY AT THE CURRENT TIME.

3. THE NAVY FORWARD LABORATORY TEAM HAS DRAFTED A PROTOCOL WITH DR KAMAL ALHAG, DIRECTOR LABORATORY SERVICES, MUBARAK HOSPITAL FOR THE IDENTIFICATION OF VIBRIO CHOLERAE 01 CARRIERS TO SIMPLIFY LABORATORY WORKUP AT MUBARAK HOSPITAL (ENCL 1). MEDIA AND REAGENTS FOR PROCESSING 400 SPECIMENS HAVE BEEN PROVIDED AND PREPARED.

4. THE NAVY FORWARD LABORATORY TEAM WILL DEPART KUWAIT CITY ON SUNDAY, 17 MARCH, 1991 TO AL JUBAIL, SAUDIA ARABIA.

5. A FINAL REPORT OF THE JOINT INFECTIOUS DISEASE SURVEILLANCE CONDUCTED BY THE NAVY FORWARD LABORATORY AND MUBARAK HOSPITAL LABORATORY HAS BEEN PREPARED. THIS REPORT HAS BEEN PROVIDED TO DR KAMAL ELHAG, DIRECTOR OF LABORATORY SERVICES, MUBARAK HOSPITAL, DR ALKHANDARI, EPIDEMIOLOGIST, KUWAITI TASK FORCE, DR BASHIR, DIRECTOR OF LABORATORY SERVICES, KUWAIT MINISTRY OF HEALTH, CAPT JOHN ANDREWS, USPHS, KUWAITI TASK FORCE AND LTC MCNAUGHER.

6. IF A SITUATION DEVELOPES THE NAVY FORWARD LABORATORY CAN BE CONTACTED IN AL JUBAIL, SAUDIA ARABIA, THROUGH 24 MARCH, 1991 AT:

AL JUBAIL COMMERCIAL TEL # 341-0912

AFTER THIS TIME INFECTIOUS DISEASE LABORATORY SUPPORT CAN BE OBTAINED THROUGH CONTACTING:

CAPT MICHAEL KILPATRICK, MC, USN
COMMANDING OFFICER
NAVAL MEDICAL RESEARCH UNIT No. 3
CAIRO, EGYPT

COMMERCIAL TEL # 00202-284-1375
TELEX 23035 NAMRU UN

OR CABLE THROUGH US EMBASSY TO US EMBASSY, CAIRO

James Burans
LCDR JAMES BURANS

Scott Thornton
LT SCOTT THORNTON

ENCL(1)

# PROCEDURE FOR THE IDENTIFICATION OF VIBRIO CHOLERAE 01 CARRIERS

STOOL SPECIMEN
OR RECTAL SWAB
INNOCULATE ALKALINE
PEPTONE WATER, PH 8.5

↓ INCUBATE 6 HR, 37 C

SUBCULTURE ON TCBS AGAR

↓ INCUBATE 16 - 18 HR, 37

SUBCULTURE SUCROSE POSITIVE
COLONIES ON GRIDDED TSA

↓ INCUBATE 3 - 4 HR, 37 C

PERFORM OXIDASE TEST ON EACH
EACH COLONY

↓

OXIDASE POSITIVE COLONY
SEROTYPE WITH VIBRIO CHOLERAE 01
POLYVALENT TYPING SERA

Ministry of Public Health
Kuwait-Arabian Gulf

World Health Organization

# EMERGENCY HEALTH
# PLAN OF ACTION
# APRIL-JUNE 1991

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# KUWAIT

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Working document

3 APRIL 1991

## EXECUTIVE SUMMARY

## HEALTH

The health care system in Kuwait had until August 1991 achieved levels of quality and coverage which compared favourably with those of most industrialized countries.

The invasion and subsequent occupation of the country affected it severely in at least two ways. Firstly, it caused the departure of large numbers of health professionals, in particular those who represented the very heart of the health care structure - nurses and other allied health personnel. Their numbers shrunk to about 20% of their initial levels, creating major difficulties in appropriately managing curative and preventive services.

Secondly, it disabled the provision of quality medical investigations and care by crippling the electro-medical equipment, key elements of which were removed, damaged or rendered unusable by the lack of maintenance and repairs.

By the end of the occupation period, only urgent medical and surgical care could be provided by a nucleus of remaining staff who had to rely largely on their clinical skills to diagnose and treat patients, deprived as they were of the solid biomedical and X-ray supports they once had. Generally, health care facilities did not suffer major structural damage but certain facilities, among them the kidney and gastroenterology centres and the Institute of Islamic Medicine, were subjected to complete internal destruction.

The Primary Health Care network, which used to rely on 72 polyclinics in the country, had only 11 of them operating at the time of the visit of the mission. The challenges facing the health structure in providing medical and public health services were compounded by mounting environmental hazards related to air, water and sea pollution and, most critically, the widespread presence of explosives and land mines.

continued

An emergency response plan was elaborated in March 1991, jointly by the Ministry of Public Health and the World Health Organization team. The plan, which covers a period of 3 months from April to June 1991, aims at providing essential health services to the population presently in the country and preparing for the return to Kuwait of displaced nationals.

The following ten programme areas have been identified which require immediate action:

Health Care Infrastructure
Surveillance
Environment Health
Disease Prevention and Control
Psychological Trauma
Essential Drugs
Diagnostic Facilities and Blood Bank
Health Information and Education
Emergency Medical Services
Management and Coordination

During the three month emergency response and rehabilitation period, steps will be taken to formulate a medium term health development plan, as based on policies concerning such issues as the provision of health care and immigration which are under review.

In addition to resources made available by Kuwait, funds are required to begin operations without delays at a time when the national administrative structure does not yet enable these resources to permeate the entire system.

The present plan proposes a set of short term objectives, targets and activities which will require technical support from WHO, other UN agencies, multilateral, bilateral or private groups.

The budget figure of US$ 4 100 000 covers the cost of this technical expertise and of some urgently required supplies and equipment.

## EMERGENCY RESPONSE AND REHABILITATION IN THE HEALTH SECTOR

With a crude death rate at 2.4/1000, an infant mortality rate at 16.3/1000 live births , and a life expectancy at birth of 71.2 years and 75.5. years for males and females, respectively, Kuwait had until August 1990 achieved one of the highest health standards in the world. As communicable diseases and other main contributors to childhood morbidity and mortality were brought under control, the national health, services had gradually expanded their scope by creating diagnostic and treatment facilities for non-communicable diseases which required a constantly increasing level of technical sophistication and amount of resources. This was reflected by the number and the quality of fired health facilities, the efficiency of the emergency medical care and the creation of centres specializing in such areas as oncology, nephrology, organ transplant, open-heart surgery and neonatology. The 6 regional and 9 specialized hospitals, the 72 health centres and several medico-social institutions in the country were providing medical, surgical, dental care and rehabilitation services to the entire population, free of charge. Private health facilities were completing this extensive network. Over 9900 nurses (of which 90% were foreign workers) and more than 3200 physicians (of which 80% were foreigners) were providing these services, with a ratio of physicians and nurses to population which compared favourably with most industrial countries in the world. A large proportion of highly trained manpower is no longer in the country.

It is against this background that the invasion of Kuwait took place. Its immediate effects were the departure from the country of thousands of foreign health workers, followed by the destruction or the removal by the occupying forces of large amounts of equipment and supplies, particularly in hi-tech fields.

At the time of this WHO emergency response and rehabilitation mission, Kuwait was faced with acute difficulties inherent to its prior dependency on expatriate health personnel - a majority of whom had by now left the country, and with challenges created by an adverse environment. Health hazards generated by the pollution of the air, the scarcity of water and the large amount of explosives scattered in and around populated areas were facing a population unprepared for a lifestyle closer to survival than to the secure environment it had known over the past decade. Of the six regional hospitals, one is closed due to shortage of nursing personnel, the non-availability of electricity and water. The others operate at reduced capacity, in the range of 10-20% for most of them. The Mubarak Alkabeer Teaching Hospital which has saved most of its equipment but lost more than 60% of its staff has enroled volunteers and is currently functioning at 48% of its total bed capacity. Only 3 of the 5 operating theatres are used, and only for emergencies, as water is scarce and the maintenance of equipment has been lacking for months. Only one of the six intensive care units is functioning at present. Elsewhere, the damage caused to the infrastructure, the removal of equipment, the reduction in labour force and the lack of electricity and water have severely affected the provision of care. The Centre for Organ Transplant which had a large kidney-dialysis capability has come to a complete stop and will take months and large resources to rehabilitate. The Cancer Centre has had to refer as many patients as it could to foreign countries, suspended surgical activities due to the lack of water and electricity and reduced drastically its provision of chemotherapy as the number of specialists in this field fall from 10 before August 1990 to only one today. The gastroenterology center, highly sophisticated diagnostic and treatment centre adjacent to the Al-Amiri hospital is closed and a large proportion of its initial equipment is damaged or missing.

Of the 72 pre-existing health centres, eleven are functioning with reduced staff, the others are closed. The ambulance services saw their pool of vehicles reduced from 170 to less than 40, newly supplied multi-purpose vans.

The number of dental chairs in the country fell from 350 to 180 at present and the number of dental surgeons from 350 to 110.

In spite of these major difficulties, the existing medical, surgical and dental facilities are coping with the most urgent needs of a population which is temporarily reduced in size, and which has at the moment a lesser demand for health care as a result of competing priorities in the restoration of normal livelihood. In the area of public health, immunization activities continued, albeit at a lower level than required, over the last 7 months. Power failures have however affected the cold chain for the storage of vaccines. Fresh stocks are needed, some of which were supplied together with basic cold chain elements shortly by UNICEF after the liberation of Kuwait. Vector control activities had been maintained for years at a high level of efficiency. They led for example to the dramatic reduction of the rodent population and the absence or low prevalence of certain vector borne diseases (malaria included) which are otherwise present in the region. The access of the population to safe (piped) water supply, sanitation and solid waste disposal was close to 100%, creating a favourable environment. The unprecedented situation created by the burning of oil wells, or the uncontrolled spilling of oil over large areas is a matter of grave concern although preliminary analyses are reported to have shown low levels of acid forming gases in the smog emanating from these fires. The short and long term effects of this pollution call for complementary monitoring systems, some aimed at the measurement of environmental parameters, others at the trend of selected diseases, signs or symptoms. The air and water monitoring stations are not yet operating due to lack of electricity or the loss of equipment. The vast amount of live ammunition scattered throughout the country and the large number of mines in populated areas have resulted in a high number of injuries, particularly among children and adolescents. Reportedly, there are two or more such injuries from this cause every day. The pollution by mines is a particular concern at present but also in the context of the expected return of a large part of the population, mostly unprepared for this risk. Finally, it has been suggested by a UNICEF child psychologists that the violence, stress and anxiety generated by the war have cause childhood trauma and loss which will require both short and long term rehabilitation programmes. Against the background, the Ministry of Public Health and a WHO team elaborated a plan of action for an emergency response period covering three months. During this period, the situation would be reassessed and further plans formulated. The plan can be highlighted as follows:

1. Health Care Infrastructure

While electrical and water supply are being restored gradually, there is an urgent need to verify, repair and put back into operations the electro-medical equipment which has not been maintained or used for an extended period of time. The deficit in health personnel has to be made up for, particularly in the nursing area where it has been estimated that 680 nurses are now required to enable the health care system to meet the need of the population currently present in Kuwait.

2. Surveillance

The health impact of prevailing environmental hazards need to be monitored immediately and continuously. This applies to air pollution related health issues, water borne, food borne and vector borne diseases and those eligible for immunization. Towards this aim, surveillance sentinel sites should be chosen and a simplified, interim surveillance system designed which should produce information on trends of such diseases or syndromes such as fever, acute diarrhoea, respiratory or allergic manifestations.

3. Environmental Health

The restoration of environmental control systems for the protection of community health is a priority task in Kuwait. Activity areas should encompass the monitoring of environmental health impacts, as proposed above, emergency control measures and community education and information. Equipment and supplies including chemicals, are required to assess environmental quality and provide bases for control measures and community information. As a pre-requisite to equipment operation electric generators must be acquired urgently. Control measures are being undertaken vigorously by the Ministries of Electricity and Water, Public Works and Kuwait Municipality.

Community education and information is an important function of the Ministry of Health and the Environmental Protection Council. Emergency funds and staffing must be provided to these in order to carry out information campaigns on environmental hazards and prevention and control methods.

4. Disease Prevention and Control

The health staff and the community must be prepared to face the possible occurrence, or increase of health problems inherent to the current situation. This includes the management of cases of acute diarrhoea, respiratory syndromes, and such other manifestations of environmental health impact as allergies and mucous membrane irritation.

Other diseases requiring close monitoring are those subjected to sustained therapy: cancer, cardiovascular and renal diseases, and diabetes.

Physical injuries caused by mines, explosives burns or traffic accidents demand an enhanced first-aid response capability, an efficient referral system and awareness campaigns.

In the area of maternal and child health, advantage should be taken of the functioning health centres and maternities to re-establish effective pre-per- and post-natal care services. Child growth monitoring and immunization are important elements at a time when vaccination coverage is low and when nutritional disorders may occur.

5. Psychological Trauma

A special programme needs to be established to address and deal with post-war trauma and the consequences of mental stress in the population, with special emphasis on children, repatriated POWs and people who were subjected to atrocities. A special programme for children will be undertaken in cooperation with UNICEF.

6. Essential Drugs

Large amounts of drugs have been received by Kuwait from various sources. The storage and distribution of these drugs was, before the war, monitored by a sophisticated computer system which is currently inoperative. Some of the drugs, reagents or baby-food received are near or beyond expiration date, thus requiring a careful inventory and verification of the shipments which are not always announced. Additional manpower is needed in this area to inventory, stock and distribute medical supplies in a coordinated fashion.

7. Diagnostic Facilities and Blood Bank

In this high-tech area, repair and maintenance skills are lacking. Many sophisticated diagnostic facilities such as X-ray and NMR are non-functional due to lack of maintenance and spare parts. There is an urgent need to establish a coordinating mechanism to undertake these tasks.

Certain diagnostic reagents are lacking which should be supplied on an emergency basis.

The equipment of the Blood Bank has been little affected and most are functional as services are being provided continously. There is however a shortage of diagnostic supplies.

8. Health Information and Education

There is on the part of the general population and professional groups, a high demand for information on the potential health impact of the current environmental health hazards. Education and information communication should be channelled through means currently available: radio, printed medias and taking the opportunity of community gatherings at the Mosques. Some activities have been described earlier in this regard. There is a general need to improve the circulation of valid information to overcome rumours and fears with positive and factual messages.

9. Emergency Medical Services

Of the intensive care units which existed in the country before the occupation only one remains in operation. Personnel should be brought in or redeployed to ensure that these essential services are provided. The ambulance and mobile emergency medical unit system needs to be re-created with an entire fleet of vehicles, effective tele-communication system and trained personnel.

10. Management and Coordination

The country now requires a wide variety of skills to rehabilitate and reconstruct its health infrastructure. The need for tighter management and closer coordination is acute. The secondment of staff on a multilateral or bilateral basis to the Ministry of Public Health and the creation of coordinating committees are needed urgently.

# EMERGENCY HEALTH

# PLAN OF ACTION

# KUWAIT APRIL - JUNE, 1991

EMERGENCY HEALTH PLAN OF ACTION
APRIL - JUNE 1991

*ESTIMATED BUDGET REQUIREMENTS*

(All figures in US Dollars)

| | | |
|---|---|---|
| 1. | Health Care Infrastructure | 220 000 |
| 2. | Surveillance | 60 000 |
| 3. | Environment Health | 1 350 000 |
| 4. | Disease Prevention and Control | 240 000 |
| 5. | Psychological Trauma | 300 000 |
| 6. | Essential Drugs | 200 000 |
| 7. | Diagnostic Facilities and Blood Bank | 570 000 |
| 8. | Health Information and Education | 200 000 |
| 9. | Emergency Medical Services | 840 000* |
| 10. | Management and Coordination | 120 000 |
| | TOTAL | 4 100 000 |

*This represents only a fraction of the cost of restoring ambulance services. Donations in kind will be sought.

# EMERGENCY HEALTH PLAN OF ACTION

## KUWAIT

| OBJECTIVE | TARGET | APPROACHES | ACTIVITIES | RESPONSIBLE | CHRONO | INDICATOR |
|---|---|---|---|---|---|---|
| 1. To rehabilitate the health care infrastructure so as to cope with urgent needs within next 3 months | By the end of 3 months, population present in Kuwait will have access to adequate medical, surgical, dental and rehabilitation care to meet their urgent needs. | - Restore essential equipment | - Provide 2 consultants to help coordinate assessment, repair and maintenance of electro-medical equipment | WHO | April | Consultants in place |
| | | - Assess current availability and needs for for personnel particularly nurses and medical technicians and establish projections | - Human resources assessment and projections to be made | MOPH<br>WHO | May | Human Resources Projection Plan available |
| | | - Regroup available personnel and complement by volunteers and bring in additional staff on emergency basis | - Reach agreement among hospital directors on immediate needs, redeployment and recruitment | MOPH<br>WHO | (in progess) | Reduced number of beds / facilities functioning. Urgent needs in Personnel met |

| OBJECTIVE | TARGET | APPROACHES | ACTIVITIES | RESPONSIBLE | CHRONO | INDICATOR |
|---|---|---|---|---|---|---|
| | | - Design and automate health information system and patients records to optimize personnel use and increase system effectiveness | - Determine timeliness of and plan for consultants to help create the system | Ministry of Public Health/ WHO | June | Project proposal formulated |
| | | - Assess availability of equipment and supplies to operate health facilities | - Inventory to be made by each institution, compiled by Ministry of Public Health | Ministry of Public Health | In progress | Inventory list available |
| | | - Procure essential supplies that may be lacking | - List of needed essential supplies to be made by central medical store | Ministry of Public Health/ CMS | | |
| | | | - Procurement and distribution | Ministry of Public Health/ WHO/UNICEF | In progress | Missing essential supplies available |

| OBJECTIVE | TARGET | APPROACHES | ACTIVITIES | RESPONSIBLE | CHRONO | INDICATOR |
|---|---|---|---|---|---|---|
| | - Improve efficency of hospitals and Health facilities by June. | - Support MOPH decentralized activities through regional Health Departments | - Monitor regional Health Department activities | WHO | May June | Weekly meetings meetings of Regional Directors held |
| | | | - Assign an STC in Hospital Adminstration | | May | Consultants assigned |
| | | - Support individual hospitals | - Determine long term needs in Hospital Management | | June | Needs identified and listed |
| | | | - Estimate cost for 3 months | MOPH WHO UN Agencies Bilateral Agencies | May | . Budget formulated |
| | | | - Identify sources of funds | | | . Resources allocated |
| | | - Formulate to a budget and allocate resources | - Allocate resources | | | |
| | | | - Establish criteria | MOPH/ WHO | April May | Criteria established |
| | | | - Identify needs | MOPH/ WHO | April May | Staffing short term projections and structure |
| | | | - Develop staffing structure | | | |
| | - Operate fully 50% of polyclinics and MCH centres in 3 months time | - Develop criteria for ratios facility/ population and manpower/ facility | - Develop job descriptions | | | |
| | | | - Identify sources of personnel | | | |
| | | - Redeploy Polyclinic staff & secure additional manpower | - Bring in additional staff | MOPH/ Bilateral Agencies | April June | Staff recruited |
| | | | - Conduct in-service retraining | Contractors | May June | In service training conducted |

| OBJECTIVE | TARGET | APPROACHES | ACTIVITIES | RESPONSIBLE | CHRONO | INDICATOR |
|---|---|---|---|---|---|---|
| 2. To restore the surveillance of selected diseases and conditions | By the end of three months : a basic surveillance system for selected conditions will have been established | - Establish and maintain a daily recording and reporting of selected conditions used as indicators of diseases related to environmental hazards<br>- Acute Diarrhoea<br>- Respiratory ailments<br>- Skin/Mucous membranes manifestations<br>- Fever | - Design form<br>- Record information<br>- Collect data daily<br>- Provide data to MOPH for continuous monitoring | MOPH/WHO/US<br>Sentinel hospitals<br>US<br>US | April (in action) | Data collected and reported to MOPH daily |
| | The pre-existing surveillance system will be re-introduced as staff and data processing become available | - Restore a surveillance system for diarrhoeal diseases and other water/ food borne diseases<br>- Vector borne diseases<br>- Diseases elligible for immunization<br>- Overall morbidity and mortality | - Identify sites for information recording and reporting (Health facilities and laboratories)<br>- Train/retrain surveillance personnel<br>- Provide with periodic reports to MOPH<br>- Exploit these reports for public information and action | - MOPH/WHO | May | System designed<br>First report reaching MOPH |

| OBJECTIVE | TARGET | APPROACHES | ACTIVITIES | RESPONSIBLE | CHRONO | INDICATOR |
|---|---|---|---|---|---|---|
| | | - Correlate environmental health data with health information | - Formalize coordinating mechanism between Environmental Protection Council and Directorate of Public Health to correlate data | MOPH | April | - Committee created<br>- Meetings held<br>- Conclusions formulated |
| 3. To undertake and expand monitoring and prevention measures related to environmental hazards. | <u>AIR:</u><br>By the end of April, air quality monitoring stations (3 fixed) will have been put back into operations | | - Provide generators to monitoring stations and supply reagents | MOPH/EPC<br>WHO/UNEP | April | - Monitor reports submitted to MOPH |
| | By the end of April a scale of warning signals and corresponding cautionary statements will have been established | | - Recruit consultants to assist in establishing scale and developping statements | MOPH/EPC<br>WHO/UNEP | April | - Scale end |

| OBJECTIVE | TARGET | APPROACHES | ACTIVITIES | RESPONSIBLE | CHRONO | INDICATOR |
|---|---|---|---|---|---|---|
| | | - Design and undertake monitoring and research project(s) to assess possible short and long term effects of air pollution | -Identify groups in Kuwait with monitoring and research capacity | MOPH/WHO/ UNEP | April | group (s) identifies |
| | | | -Identify groups internationally with such capacity | WHO/UNEP | May | group (s) identified |
| | | | -Establish a coordinating mechanism | MOPH/WHO UNEP | May | Mechanism developed |
| | | - Provide informaton to public on findings and preventative measures | (See No. 2 below) | | | |
| | <u>WATER:</u> By the end of May, safe piped water supply will have been restored and monitored continuously | - Rehabilitation and reconstruction of water supply system | Covered by prviate contractors under Ministry of Electricity and Waters' supervision | | | |

| OBJECTIVE | TARGET | APPROACHES | ACTIVITIES | RESPONSIBLE | CHRONO | INDICATOR |
|---|---|---|---|---|---|---|
| | | - Monitoring of water safety<br>- Public Information | - Provide chemicals and reagents (see No. 8 below) | WHO | April | - Supplies provided<br>- Monitoring done |
| | <u>SEWAGE:</u> | - Restore waste-water system | Covered by private contractor | | April | |
| | | - Monitor marine pollution | Covered by Ministry of Public Works EPC and UNEP | | April | - Sewage system in operation |
| | <u>SOLID WASTES DISPOSAL</u> | - Clear garbage from the city<br>- Re-establish a solid waste disposal system | Under the responsibility of Kuwait Municipality and covered by 5 private firms | | April | - solid water disposal in operation |
| | <u>MINES/EXPLOSIVES</u> | - Appeal to international solidarity to enhance demining operatings | - Increase and sustain the level of international awareness about need for mine sweeping in Kuwait<br>- Increase public awareness through information campaigns (see No. 8 below) | MOPH other Ministries WHO | April - June | - Appeal launched |

| OBJECTIVE | TARGET | APPROACHES | ACTIVITIES | RESPONSIBLE | CHRONO | INDICATOR |
|---|---|---|---|---|---|---|
| 4. To prevent and control selected diseases | <u>Diarrhoeal Diseases:</u><br>By mid-April, health staff and facilities will be prepared to respond to the possible spread of diarrhoeal diseases | - Staff will be alerted to the rise of spread of diarrhoeal diseases and to the methods of case management | - Disseminate guidelines in case management | - MOPH/ Department of Public Health | Now | - Guidelines available in all facilities |
| | | | - Plan a referral system | - MOPH/ Dept. of Public Health | Now | - ORS available in all facilities |
| | | - Supplies will be available to health facilities for diagnosis and treatment | - Verify the availability of ORS, ensure availability of transport medium (Cary Blair) for stool samples at all facilities | - Central Medical Store<br>Public Health Laboratory and Mobarak Hospital | Now<br>Now | Transport Mediuim avail. at all levels<br>Diagnosis Capability in place |
| | | | - Verify/ensure capability of at least one laboratory to diagnose Shigellas and v. cholera | - Public Health Laboratory and Mobarak Hospital | | |
| | | | - Public information of prevention/ treatment (see No. 8) | | | |
| | <u>Diseases elligible for immunization</u><br>By end April & continuously | | | | | |

| OBJECTIVE | TARGET | APPROACHES | ACTIVITIES | RESPONSIBLE | CHRONO | INDICATOR |
|---|---|---|---|---|---|---|
| | <u>Diseases elligible for immunization</u><br>By end April & continuously the immunization coverage of children and pregnant women will be above 95% | - Continue and reinforce immunization activities through polyclinics and private facilities according to national immunization strategies | - Restore the cold chain as electiricty returns | MOPH/ UNICEF/WHO | APRIL | Effective cold chain in operation |
| | | | - Use cold boxes for the transport and short storage of vaccines | UNICEF | DONE IN MARCH | Cold Boxes available |
| | | | - discard old stock of vaccines and replenish by fresh ones | UNICEF | DONE IN MARCH | Fresh vaccines available |
| | | | - Reestablish immunization recording and reporting systems | MOPH | MAY | - Records available<br>- Reports submitted |
| | <u>Air Pollution Hazards</u><br>- By end- April Respiratory and allergic manifestations attributable to air pollution will be attended to according to set guidelines | - Provide treatment to o respiratory and allergic manifestations | - Formulate guidelines | MOPH/ Internists | APRIL | Guidelines formulated |
| | | | - Disseminate these guidelines to all facilities | MOPH | MAY | Guidelines distributed |
| | | | - Provide recommend drugs to facilities | Central Medical Store | MAY | Drugs available |
| | | | - Provide STC for seminar on air pollution | WHO | APRIL | Seminar conducted |

| OBJECTIVE | TARGET | APPROACHES | ACTIVITIES | RESPONSIBLE | CHRONO | INDICATOR |
|---|---|---|---|---|---|---|
| | Maternal and Child Health<br>Operate 50% of MCH centres as well as child by June | - Provide Maternal and Child Health (MCH) Services and strengthen Primary Health Care | - Provide standby generator to MCH centres with no electricity<br>- Install water tank on roof of MCH centres and bring drinking water to 50% health centres<br>- Supply distilled water and reagents to peripheral laboratories | Government of Kuwait, bilateral Agencies, Civil Administration | April<br>April<br>April | Percentage of Health Centre with adequate water/power supplies |
| | Non-communicable diseases<br>Ensure sustained therapies to chronically ill populations | - Provide drugs to specific cases | - Order and supply drugs for Diabetes, Hypertension and Cancer<br>- Supply skin ointments, Family planning pills and disposables | Central medical store, WHO | April | Percentage of treatment prescriptions filled<br><br>Percentage of treatment prescriptions filled |

| OBJECTIVE | TARGET | APPROACHES | ACTIVITIES | RESPONSIBLE | CHRONO | INDICATOR |
|---|---|---|---|---|---|---|
| 5. To create and sustain services for adults and children suffering from violence-related psychological traumas | By June, psychological diagnostic and support services will be provided to adults and children suffering from psychological traumas related to violence and incarceration (POWs) | - Assess needs and develop a plan of action | - Assess needs in qualitative and quantitative terms among children (Psychologists) | MOPH/UNICEF/WHO | April | Status report available |
| | | - Establish services through formal (MOPH) and informal services (religious and social groups) | - Establish diagnostic, counselling and therapy services for children | MOPH/WHO | May | Services operating |
| | | | and for adults | MOPH/WHO | June | Services operating |

| OBJECTIVE | TARGET | APPROACHES | ACTIVITIES | RESPONSIBLE | CHRONO | INDICATOR |
|---|---|---|---|---|---|---|
| 6. To ensure availability of essential drugs to meet current needs | - By the end of the 3 months the needs in essential drugs will have been met continuously | - Rehabilitate the stock management system and coordinate supply to health facilities | - Restore software and assign computer technicians to Central Medical Store | MOPH/Central Medical Store (CMS) | April (ongoing) | Computer based management system in operation |
| | | | - Sort out present stocks of drugs | CMS | April (ongoing) | |
| | | | - Distribute to facilities | CMS | April (ongoing) | Drugs available on request at health facilit. |
| | - By the end of April, specialized drugs will have been made available to treatment centres | - Ensure the continuous availability of drugs for the treatment of diabetes, cancer, cardio-vascular diseases, other chronic diseases | - Locate and distribute specialized drugs available in country | CMS | April | Specialized drugs available |
| | | | - Order drugs not present in stock | CMS/WHO | April | Specialized drugs available |
| | - By the end of June, plans will have been made for the rehabilitation of the drug quality control laboratory | - Convene a task force to propose plan for rehabilitation | - Convene Task Force<br>- Elaborate proposal | Drug quality control laboratory staff | June | Task Force established<br>Proposal elaborated |

| OBJECTIVE | TARGET | APPROACHES | ACTIVITIES | RESPONSIBLE | CHRONO | INDICATOR |
|---|---|---|---|---|---|---|
| 7. To meet current needs in laboratory diagnosis, other electro-medical equipment and blood supply | By the end of three months immediate needs in laboratory diagnosis and blood supply will have been met | Formulate plan and gradually undertake rehabilitation and reconstruction of PHC and relocate different exfaculty of medicine laboratories | Complete inventory of the existing equipment and estimate required supplies and personnel | MOPH/WHO (MOPH laboratory staff) | May | Inventory completed |
| | | | Formulate plan of action for restoring laboratory services to health facilities | MOPH/WHO | June | Plan formulated |
| | | | Provide specific support to operating laboratories to meet the immediate demand | MOPH/WHO Bilateral agencies | April (ongoing) | Critical needs met |

| OBJECTIVE | TARGET | APPROACHES | ACTIVITIES | RESPONSIBLE | CHRONO | INDICATOR |
|---|---|---|---|---|---|---|
| | | | - Ensure maintenance and repair through firm representatives with WHO's coordination (2 consultants) | MOPH/WHO | May | Two WHO consultants in coordinating position |
| | | | - Procure spare parts, reagents and supplies | MOPH/WHO | May | Procurement effected |
| | | | - Identify and procure new equipment | MOPH | June | List prepared |
| | By the end of June restore self-sufficiency in blood supply | Meet current needs to restore self-sufficiency of Central Blood Bank | - Expand donor recruitment to meet demand | MOPH/Military | June | Donors recruited |
| | | | - Procure small supply of blood to restore reserve | WHO/LRCS | May | Procurement effected |
| | | | - Procure diagnostic reagents for HIV and Hepatitis tests | MOPH/WHO | April | Procurement effected |

| OBJECTIVE | TARGET | APPROACHES | ACTIVITIES | RESPONSIBLE | CHRONO | INDICATOR |
|---|---|---|---|---|---|---|
| 8. To provide health and other professional groups, children and the population at large, with information on prevailing health hazards and means of prevention and treatment | By the end of April, factual messages will have been disseminated on air, water, sea and mine/explosives pollution | - Strengthen the roles and functions of health education/information/communication committees through regular meetings | - Conduct periodic meetings<br>- Produce reports and messages<br>- Develop action plan | MOPH, WHO, UNEP | April | Regular meeting held |
| | | - Reestablish a department for health information education and communication | - Identify/assign personnel<br>- Reestablish audio-visual capability | MOPH, WHO | May | Health Information/Education/Communication operational |
| | | - Produce factual messages and disseminate them through medias and alternate channels (social and religious groups) | - Disseminate messages through radio, TV, newspapers and through social groups (neighbourhoods) and mosques | MOPH, WHO, UNEP | April | Messages periodically released |
| | | - Evaluate levels of awareness of health staff, other relevant staff on prevailing health hazards | - Conduct assessment | MOPH, WHO, UNEP | May | 100% health and other personnel aware of message contents |
| | | - Evaluate level of population awareness of message contents | - Conduct assessment | MOPH, WHO, UNEP | May | 80% of population aware of message contents |

| OBJECTIVE | TARGET | APPROACHES | ACTIVITIES | RESPONSIBLE | CHRONO | INDICATOR |
|---|---|---|---|---|---|---|
| 9. To provide emergency medical services to the population present in Kuwait | By the end of May, the emergency medical services will have been rehabilitated to meet the current population needs and, by June, the needs of twice this population | - Inventory ambulance and MCU's needs | - Conduct inventory and formulate needs projections | MOPH | May | Inventory conducted |
| | | - Assess staff training or retraining needs | - Identify personnal and skills needs and undertake retraining | MOPH | June | Training plan formulated |
| | | - Restore short wave communication system | - Procure and assign equipment | MOPH | May | Equipment provided |
| | | - Redeploy/ recruit staff needed in intensive care units | - Redeploy or recruit ICU staff as a matter of urgency to operate 1 ICU by April, 3 by May, 4 by June | MOPH | April (in progress) | 4 ICUs operating by June |

# PLAN OF ACTION FOR PROTECTING PUBLIC HEALTH

Prepared by

THE KUWAIT WORKING PARTY

convened by

United States Public Health Service

Department of Health and Human Services

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Contents

# I. Executive Summary

During the 1991 war to liberate Kuwait, several events occurred that damaged the environment and created concern about the occurrence of adverse human health effects. These events included the spilling of oil from an oil pipeline into the Persian Gulf, setting approximately 530 of Kuwait's 1,000 oil wells on fire, and creating pools of oil in the desert. The Policy Coordinating Committee, convened by the Department of State, delegated to the U.S. Environmental Protection Agency (EPA) responsibility for developing a plan to address the health and environmental consequences of the oil well fires in Kuwait. The EPA, at the request of the Department of State, sent teams to Kuwait to assess the environmental impact from the oil spills and from the oil well fires. The U.S. Interagency Air Assessment Team (USIAAT), made up of personnel from the EPA, the National Oceanic and Atmospheric Administration, and the U.S. Public Health Service (PHS) drafted a proposed program in three broad areas: Air Monitoring, Development of a Forecast Capability, and Human Health Surveillance and Risk Assessment. The EPA asked the PHS to assist it with developing a list of the human health surveillance and risk assessment issues, strategies, and approaches that should be used to address the concern about possible adverse health effects associated with the oil pools and the oil well fires in Kuwait.

Therefore, at the request of EPA and the Department of Health and Human Services' (DHHS) Committee to Coordinate Environmental Health and Related Programs (CCEHRP), the Kuwait Working Party (KWP) met to identify public health issues, strategies, and approaches, related to the oil pools and oil well fires burning in Kuwait in 1991. KWP, which consists of participants from PHS agencies and other governmental agencies, developed a plan of action. This plan of action encompasses the range of issues, strategies, and approaches that should be addressed to explore the potential acute and chronic risks from the oil pools and the oil well fires in Kuwait. This document considers exposures to multiple environmental media including air, water, food and seafood, and soil. This plan of action will be provided to the Interagency Team chaired by the EPA for incorporation into its overall plan of action related to the oil pools and oil well fires in Kuwait.

The issues, strategies, and approaches can be divided into specific areas of action for individual U.S. agencies, foreign countries (Kuwait or other), or international organizations (World Health Organization).

The six priority public health issues defined by the KWP include:

1) Are there acute or chronic health hazards from the oil pools and oil well fires in Kuwait?

2) Who is exposed to the oil pools and oil well fires in Kuwait?

3) What is the nature and extent of the exposure?

4) What public health infrastructure should be developed so that possible adverse health effects associated with exposure to the oil pools or the oil well fires can be identified and evaluated?

5) What risk management and disease prevention policies need to be set up for persons exposed (already or in the future) to the oil pools and oil well fires?

6) What new knowledge about the possible adverse health effects associated with exposure to the oil pools and oil well fires needs to be obtained?

As a follow-up action, the public health issues, strategies, and approaches identified in this plan of action need to be subjected to more detailed analysis and prioritized into "plans of action." To carry out plans of action (whether by PHS or other U.S. governmental agencies, agencies from Kuwait or another country, or international agencies), resources need to be identified so that specific public health activities can be undertaken.

## II. Background

During the war to liberate Kuwait, an oil pipeline was opened, spilling millions of gallons of crude oil into the Persian Gulf and creating an oil slick many miles in length. During the final days of the war, approximately 530 oil wells in Kuwait were set on fire. Other wells that were not set on fire were damaged by explosives and were found to be creating pools of oil in the desert. An estimated six million barrels of oil are being burned each day. Oil well fire fighters responsible for putting out the fires and capping the wells estimate that it will take them 1-2 years to put out all of the fires and to cap all of the wells. Never have so many oil wells been burning for so long. These burning and uncapped wells have created concern among the world community as to the damage being done to the environment (air, water, food, and soil) and the resulting potential adverse health effects.

The U.S. Environmental Protection Agency (EPA), the coordinating agency, and the Coast Guard, sent teams to investigate the oil that had been spilled into the Persian Gulf from the oil pipeline. The EPA also sent two other teams to collect information on the constituents of the oil pools and the oil well fires. They have also carried out air sampling in populated areas. At the request of EPA a PHS medical epidemiologist accompanied one of their air monitoring teams to the Persian Gulf to provide medical interpretations to the monitoring data.

At the request of the Department of State, the EPA's U.S. Interagency Air Assessment Team (USIAAT) made up of personnel from the EPA, the National Oceanic and Atmospheric Administration, and the Department of Health and Human Services (U.S. Public Health Service or PHS) prepared a draft proposed program in three broad areas: Air Monitoring, Development of a Forecast Capability, and Human Health Surveillance and Risk Assessment. The EPA requested that the PHS develop a list of strategies and approaches that should be used to answer the important human health surveillance and risk assessment questions.

The Plan of Action to Protect Public Health encompass all of the issues, strategies, and approaches that should be addressed without regard to what agency or agencies, national, foreign, or international, will develop action plans and carry out specific activities. All of the listed issues, strategies, and approaches can be divided up into specific actions, parts of which can be carried out by individual agencies.

This plan of action was written from a generic viewpoint. Although American citizens living or working in or traveling to Kuwait, U.S. military personnel, and U.S. citizens working for contractors in Kuwait, are of prime responsibility of the PHS, other U.S. agencies, foreign nations (Kuwait or other), or international agencies (World Health Organization) may find this document useful.

At the request of the EPA and the DHHS Committee to Coordinate Environmental Health and Related Programs (CCEHRP), the Kuwait Working Party (KWP) met to identify public health issues, strategies, and approaches, related to the oil pools and oil well fires burning in Kuwait in 1991. The Kuwait Working Party (KWP) consists of participants from various PHS and other governmental agencies.

While in the Arabian Gulf the PHS medical epidemiologist who was assisting the interagency air assessment team collaborated with the Kuwait Ministry of Public Health to develop a health plan for protecting individuals from the hazards associated with exposure to the burning oil wells in Kuwait. The Kuwaiti plan is consistant with the plan of action developed by the KWP. Key provisions of the Kuwait plan are: 1. The initiation of a health alert system to warn the population when potentially dangerous concentrations of air pollutants are reached, 2. Provide medical information and advice to physicians regarding environmental health concerns, 3. Provide general information and advice to the public regarding environmental health concerns, 4. The collection and comparison of recent mortality data with the same months in 1990, 5. The initiation of an emergency room surveillance system to monitor respiratory diseases, 6. The design and implementation of a longitudinal study of asthmatic patients registered at the Kuwait Center for Allergic Diseases, 7. The design and implementation of a cohort study of presumably highly exposed population, and 8. Implementation of the Human Exposure Assessment Locations (HEAL) Program.

## III. Kuwait Working Party

### A. PURPOSE

The purpose of the KWP is

To develop a plan of action that encompasses the range of public health issues, strategies, and approaches that should be addressed to identify and prevent acute and chronic adverse health effects associated with all routes of exposure to spilled oil and oil well fires in Kuwait. This plan of action should make it possible in the future to look back to 1991 and see that the priority health issues associated with oil spills and the oil well fires were identified.

### B. OBJECTIVES

The specific objectives of the KWP are

To prepare jointly with all interested federal agencies, a plan of action that describes the public health issues, strategies, and approaches that should be addressed to identify and prevent or mitigate potential acute and chronic adverse health effects associated with exposure to oil pools and oil well fires in Kuwait.

To identify issues, strategies, and approaches that should be used by federal agencies so that they can coordinate their efforts in identifying and preventing or mitigating potential acute and chronic adverse health effects associated with exposure to spilled oil and oil well fires in Kuwait.

To develop jointly with other federal agencies, a list of issues, strategies, and approaches that will support the "human health surveillance and risk assessment" part of the Proposed Program of the Interagency Team chaired by the EPA.

To share this plan of action with United States legislators, Kuwait, other countries, and the World Health Organization, so that priorities can be determined, action plans developed, and resources obtained to carry out specific activities to prevent potential acute and chronic adverse health effects.

### C. INTERRELATIONSHIP OF FEDERAL AGENCIES

Many PHS offices and agencies (Agency for Toxic Substances and Disease Registry, Centers for Disease Control, Food and Drug Administration, Indian Health Service, National Institutes of Health, Office of International Health, and Office of the Surgeon General), and other federal agencies (Department of Agriculture, Department of Defense, Department of Energy, Department of Commerce, Department of State, and EPA) are concerned about the potential public health issues associated with the oil pools and oil well fires in Kuwait. However, there are also personnel from Kuwait, other nations, international organizations who are also concerned about the potential public health effects of the oil pools and the oil well fires. These potential effects include exposure from inhalation, skin contact, and ingestion of food (such as seafood and crops) that may be contaminated with oil products. For example, the World Health Organization has had a team in Kuwait assessing the public health needs. A United Nations Environmental Team is scheduled to travel to Kuwait to assess the environmental situation.

This plan of action has attempted to address the priority public health issues from the perspective of the United States agencies participating in the KWP. A list of background documents is attached.

## IV. Assessment In Kuwait

### A. ENVIRONMENTAL ASSESSMENT IN KUWAIT

1. The EPA's U.S. Interagency Air Assessment Team (USIAAT) collected measurements of $H_2S$, $SO_2$, oxygen, and total particulate at 13 locations in Kuwait and Saudi Arabia during March 1991. The highest readings were taken in the smoke plumes in the oil fields. The highest levels were: total suspended particulates - 5.4 mg/$m^3$, volatile organic compounds (VOCs) - 2.5 parts per million (ppm) adjacent to large pools of oil, $H_2S$ - 42 parts per billion (ppb), and $SO_2$ - 2 ppm (The $SO_2$ reading may be high because a different $SO_2$ monitor with a detection limit of 0.1 ppm did not indicate any $SO_2$ and field personnel did not detect any sulfur odors at any of the locations.). The only elevated level observed in populated areas was for particulates, with a reading of 480 ug/$m^3$ in Dhahran, Saudi Arabia which was thought to be due to a combination of smoke from the fires and sand. Baseline particulate levels due to blowing sand in Saudi Arabia and Kuwait usually range from 200 - 3,000 ug/$m^3$.

   The results from this monitoring indicate that particulates are the primary acute potential health threat. The results did not indicate an acute health threat from $SO_2$ and $H_2S$. However, a change in conditions (such as the extinguishing of an oil well fire without capping) could cause an acute threat near the wells to occur. An inversion or touchdown of the plume in populated areas could result in an acute health threat.

   These results were obtained with limited equipment, irregularly placed monitors that were not positioned near the plumes, and with the use of short averaging times. These results should be considered to be preliminary and must require a more detailed evaluation.

2. Gases and particulate byproducts associated with the burning oil wells were identified. Air samples from 10 locations were measured for: volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs, i.e., naphthalene, benzo[a]pyrene), heavy metals, $SO_2$, and inorganic acids (i.e., sulfuric, nitric). Some samples were collected for $H_2S$, formaldehyde, CO, and total nuisance dust.

3. Although a number of samples were taken from a variety of locations, the monitoring was done at a small number of locations, over a relatively short period (one month), in a relatively cool month (March), for a limited number of compounds. Respiratory particulates less than 10 microns ($PM_{10}$) were not measured. Mercury and lead, thought to be present in some of the oil wells were not measured. Other substances not measured include uranium, ozone, benzene, elemental carbon, other metals, and nitropyrenes. In addition, the constituents of oil droplets were not characterized.

## B. POSSIBLE HEALTH EFFECTS IN PERSONS EXPOSED TO OIL WELL FIRES

1. The oil fields are located away from Kuwait City where most of the Kuwait population lives. The direction traveled by the plumes is variable and dependent on the local meteorological conditions. Based on National Oceanic and Atmospheric Administration models and on personal observations (Dr. John Andrews), on most days, Kuwait City is not noticeably affected by the oil well plumes. Continuous exposure to the oil well fire plumes in Kuwait City for a period greater than forty-eight hours occurs infrequently. Any risk assessment that is carried out must take into consideration the number of persons in the path of the plumes for various local meteorological conditions and the duration of exposure.

2. The main health effects predicted to occur from exposure to the oil well fires depend on the assumptions that are made regarding the constituents of the plumes.

3. Persons with asthma or preexisting pulmonary disease (chronic bronchitis, chronic obstructive pulmonary disease), and possibly infants, children, and elderly adults would be at risk of exacerbation of their conditions due to exposure to the oil well fires. It is not known if chronic exposure to oil well fires will be associated with an increased incidence or prevalence of pulmonary disease.

## C. HUMAN HEALTH SURVEILLANCE

1. Information obtained from two Kuwaiti physicians and one asthmatic by Dr. John Andrews, indicated that asthmatics were reporting acute asthma attacks when the plumes from the oil well fires were present. One physician reported to Dr. John Andrews that three of his patients with chronic lung disease had died on one of the days when the plumes from the oil well fires were severe. Visits to

seven hospitals by Drs. Andrews and Seligman and reports of visits to all hospitals in Kuwait by the U.S. Army Disaster Area Survey Teams indicated that there were no report of large numbers of persons becoming ill on days when the plumes from the oil well fires were severe. Neither were there reports from Kuwaiti physicians of adverse health effects in infants, children, or the elderly. The absence of reports does not necessarily mean that such effects were not occurring, only that they had not been observed by the physicians and hospital personnel interviewed.

2. The main symptoms experienced by Drs. Andrews and Seligman and by U.S. Army personnel when plumes from the oil well were present were burning eyes (mild to moderate), increased postnasal discharge (mild to moderate), increased cough (mild), throat irritation (mild to moderate), and an acrid smell to the air (mild to moderate). Estimates of the prevalence of these or other symptoms among U.S. Army and U.S. Marine personnel may be available from the Department of Defense.

## D. INFRASTRUCTURE IN KUWAIT

1. The public health infrastructure, including the disease reporting system, public health laboratory, environmental laboratory, continued to operate in limited fashion from the beginning of the Iraqi occupation (August 2, 1990) until January 15, 1991. Beginning with the start of the war of liberation (January 17, 1991), public health functions essentially ceased. Through late March 1991, telephones were not working and transportation was difficult. By late April, telephones and transportation were available. Despite these terrible conditions the Kuwaiti medical community has done an excellent job.

2. During the Iraqi occupation, safe water continued to be available through the municipal distribution system. Water quality continued to be checked (The Iraqis were extremely concerned about the possibility of waterborne disease in their troops.). Only during the ground war (February 22 - 26), and in the initial liberation period (February 27 - late March), after the desalination plants had been made inoperable by explosives, did people have to rely on water stored in cisterns or on rooftops.

3. During the Iraqi occupation, most people who stayed in Kuwait had adequate supplies of food, including grain, rice, and staples; fresh milk from cows; and fruits and vegetables from Iraq and Jordan. Only during the ground war (February 22 - 26) and during the initial period of liberation (February 27 - late March) were fresh milk,

fruits, and vegetables unavailable or in limited supply. As of late April, fruits, vegetables, and milk were available, although some Palestinians and third country nationals without financial resources, may not be able to purchase adequate amounts of these foods.

4. A number of U.S. Army Civil Affairs personnel, U.S. Army Corps of Engineers, and private contractors have been in Kuwait since early March assisting with restoring the infrastructure in Kuwait. By late April, electricity is available, a chlorinated municipal water system is operational (93-97% of water comes from desalination plants and the rest is supplied from wells), sewage treatment is functioning, garbage trucks and waste disposal sites are operational, and hospitals and clinics are functioning. Ministry of Public Health personnel have been meeting in their offices since March 8.

5. Despite the availability of senior Kuwaiti Ministry of Public Health personnel, a number of the workers are no longer in Kuwait. Many were Iraqi, Jordanian, or Palestinian. There will be a need to identify new personnel and train them to carry out the various public health activities.

6. It is estimated that 450,000 people are now living in Kuwait. Prior to the Iraqi occupation, the Kuwait population was approximately 2.1 million, 600,000 (28%) of whom were Kuwaiti. The government of Kuwait has stated its intention to have Kuwait's population grow to approximately 1 million. Various Government of Kuwait ministries (including the Ministry of Public Health) are planning to downsize. This will involve decreasing the number of hospitals and clinics.

7. The disease reporting system in Kuwait was not functional as of late March. However, visits to all hospitals by U.S. Army Disaster Survey Team personnel and to seven hospitals by Drs. Andrews and Seligman, found no evidence of any widespread epidemics. Although several physicians believed that they were seeing increased numbers of persons with hepatitis A, a review of hepatitis surveillance records by Dr. Andrews from 1988 through March 9, 1991, did not verify that there was an increase. Also several Kuwaitis returning after being detained in Iraq were found to have Vibrio cholerae in their stools. Several children with diarrhea were admitted to the hospital, there was no evidence of an epidemic of gastrointestinal disease.

## V. Risk Assessment and Risk Management

In this document, risk assessment and risk management are used as described in the report "Risk Assessment and Risk Management of Toxic Substances" (A Report to the Secretary, Department of Health and Human Services [DHHS], from the Executive Committee DHHS Committee to Coordinate Environmental and Related Programs [CCERP], April 1985). The material below is quoted from this document.

Risk - The probability of an adverse health effect as a result of exposure to a hazardous substance(s).

Risk Assessment - The use of available information to evaluate and estimate exposure to a substance(s) and its consequent adverse health effects. Risk assessment consists of one or more of the following four elements:

- Hazard Identification - The qualitative evaluation of the adverse health effects of a substance(s) in animals or in humans....Hazard identification is largely a judgmental process that requires the expert knowledge and experience of scientists from a variety of disciplines in interpreting the best available information....Hazard identification relies primarily on results generated from clinical and epidemiologic studies and from animal toxicologic experiments. Other types of information that may, when available, contribute to the hazard identification process include: short-term in-vivo and in-vitro test results; comparative metabolism and kinetic information; and when available data on the physiologic, pharmacologic, biochemical, chemical, and physical properties of the chemical of interest.

- Exposure Assessment - The evaluation of the types (routes and media), magnitudes, time, and duration of actual or anticipated exposures and of doses, when known; and, when appropriate, the number of persons who are likely to be exposed....Exposure assessment deals primarily with estimating the types, magnitudes, and durations of actual or anticipated exposures to hazardous agents....Exposure assessment is typically based on monitoring studies that involve direct measurement of exposures, mathematical modeling, and the study of microcosms of mini-environments, or some combination of these approaches.

- Dose-response Assessment - The process of estimating the relation between the dose of a substance(s) and the incidence of an adverse health effect....Dose-response Assessment is concerned with the evaluation and quantitative characterization of the relationship or association between the level of exposure to the agent under study and the toxicologic response or responses that are elicited by such exposure, particularly as it applies to humans. The techniques most frequently used in this quantification process are the safety-factor approach, margin-of-safety procedure, and mathematical modeling.

- Risk Characterization - The process of estimating the probable incidence of an adverse health effect to humans under various conditions of exposure, including a description of the uncertainties involved....Risk Characterization, the final step in the risk-assessment process, involves a multidisciplinary evaluation of all relevant data on hazard identification, exposure assessment, dose-response, and species extrapolation to reach an overall determination of the health risk posed by anticipated or known exposures to a given agent. Because of differences in human susceptibility and exposure corditions, some consideration should be given, when possible, to the identification of high-risk subgroups in the general population at this phase in the process.

Risk Management - The process of integrating risk-assessment results with engineering data and social, economic, and political concerns, then weighing alternatives to select the most appropriate public health action, ranging from public education to interdiction, that will lead to reduction or elimination of the identified risk.

## VI. Assumptions

A number of assumptions were made by the KWP based on information available to KWP participants, information available from the news media, or information reported from federal agencies who have had personnel in Kuwait. Assumptions are being listed below to document that these issues were considered.

A. This document assumes that basic medical services (clinics and hospitals) are functioning, and that electricity, water supply, garbage collection, and vector control programs are functioning in Kuwait.

B. The priority public health issues, strategies, and approaches identified in this plan of action are designed to explore acute and chronic adverse health effects due to spilled oil and oil well fires in Kuwait. However, some of these strategies and approaches are equally applicable to other areas of public health.

C. The priority public health issues apply to a variety of persons exposed to spilled oil and oil well fires including fire fighters, oil well workers, persons living or working in Kuwait, and tourists.

D. As additional information is obtained, the situation in Kuwait should be reassessed. With the availability of additional data, priority issues, strategies, and approaches can be re-evaluated.

E. This plan of action is a technical document. It is written to be an encompassing document that describes the issues, strategies, and approaches that should be explored from a technical viewpoint.

## VII. Public Health Issues

### A. IS THERE A HEALTH HAZARD FROM THE OIL POOLS AND OIL WELL FIRES IN KUWAIT? (Hazard Identification)

It is essential to identify whether or not there are current hazards associated with oil pools and oil well fires. However, there is not much information on the constituents of these oil pools and oil well fires. Measurements for $H_2S$ and some polyaromatic hydrocarbons (PAHs) have been positive near wells. However, there are a variety of additional contaminants that may be present in the oil or the oil well fires. Specifically, KWP personnel suggest that sampling in populated areas be carried out for the following substances: benzene, elemental carbon, ozone, nitropyrenes, lead, arsenic, total respiratory particulates, uranium, other metals, and mercury. After the levels of these substances are known, then other decisions can be made on the frequency that the oil, oil well plumes, air, food, water, or soil should be retested.

As different oil well fields (and even different oil wells) may have different amounts of one or more of these substances, individual wells as well as plumes need to be sampled enough times so that environmental personnel believe they have a reliable estimate of the total emissions of smoke particulate and chemical species from the fires to which people (and their food, water, crops and livestock) may be exposed. In addition, as the oil well fires are extinguished and the oil wells capped, the pollutants released into the atmosphere will decrease.

Strategies and approaches should include

1. Measuring contaminants listed above in environmental media and generating population specific data.

    a. Carrying out a chemical characterization of particulates and oil droplets and comparing the substances found against standards such as EPA Reference Doses.

    b. Determining the size fractionation of particles in plumes from the oil well fires.

    c. Measuring contaminants in oil, in plumes of oil well fires, and at ground level in populated areas, areas where animals graze, and in areas where food is produced, processed, stored, or sold.

d. Measuring the levels of respiratory pollutants including total suspended particulates, respirable particulates, dust, pollen, hydrocarbons, $SO_2$, and $O_3$, and acid aerosols.

e. Identifying contaminants in well water and water coming from desalination plants.

f. Identifying contaminants in soil in populated areas, in areas predicted to have high cumulative soil contaminants from plume models, and in areas where children spend a great deal of time (school).

2. Measuring contaminants in food and water

a. Identifying and measuring contaminants in food and milk produced or stored in the open.

b. Identifying and measuring contaminants in the food supply of grazing animals and chickens.

c. Identifying and measuring contaminants in seafood.

d. Identifying contaminants in drinking water and reservoirs.

3. In vivo and in vitro tests

a. Carrying out in vivo studies in animals or in animal models for human disease by analyzing animals grazing in affected areas.

b. Carrying out in vitro immunogenicity, mutagenicity, and cytogenetic studies with substances produced by the oil well fires or on specimens collected from exposed persons.

B. **WHO IS EXPOSED TO THE OIL POOLS AND OIL WELL FIRES IN KUWAIT? (Exposure Assessment)**

The extent of exposure to the oil pools and the plumes of oil well fires depends on the local meteorological conditions which are extremely dynamic and which vary from hour to hour. If information was available to identify where the plume was located at specific times of the day, this would assist greatly in determining who is exposed. Analysis of plume migration, therefore, will be a critical factor in establishing who was exposed.

An important issue related to the oil pools and oil fires in Kuwait is to determine who has been exposed. It is important to identify areas where persons were likely to be exposed and to identify the nature and probable level of exposure in those areas. In several situations, substances thought to be safe were later found to be hazardous. Also, in the past, even when the presence of a hazardous substances could be documented, without information on who had been exposed, the association or lack of association of adverse health effects with a substance could not be studied easily.

In Kuwait, the exposure of a variety of individuals to oil pools and oil well fires needs to be determined (Kuwaitis, third country nationals, Palestinians, oil well fire fighters, oil well workers, other persons living or working in Kuwait, and persons transiently exposed).

If specific hazardous substances are identified in the oil or oil well plumes, and risk assessments show that people are exposed to enough of one or more of these substances to be associated with acute or chronic adverse health effects, then it is even more important to identify potentially exposed persons.

Strategies and approaches should include

1. Population Information

   a. Determining the number of persons living or working in each area of Kuwait by age and sex (using a geocoding system if possible) so that amount of exposure based on oil well plume measurements or oil well plume modelling can be determined.

   b. Identify representative populations or subpopulations who may have had differing exposures to the oil pools or the oil well fires.

2. Highly exposed individuals

   a. Identifying potentially highly exposed individuals to oil pools or oil well fires.

   b. Setting up a registry of the most highly exposed persons (e.g., oil fire fighters, military, persons working close to the oil fires).

   c. Tracking the more highly exposed persons so they can be given information on health effects (adverse or not adverse) in the future or so that additional information on adverse health effects can be obtained from these persons.

d. Obtaining baseline information on more highly exposed persons, including biological monitoring of exposure (blood and urine), monitoring of different microenvironments, such as homes, work places, and outdoor areas, personal monitoring, and the use of questionnaires.

e. Determination of the most reliable biological markers for establishment of the extent of exposure.

C. **WHAT IS THE NATURE AND EXTENT OF EXPOSURE? (Dose-Response Assessment)**

The dose-response assessment human data as well as animal and in vitro studies is a critical aspect of risk assessment. Namely, the amount of exposure via various routes must be quantified so that acute and chronic risk can be estimated.

Strategies and approaches should include

1. Obtaining information on the relationship of forest fire (western United States and other countries) or urban air pollution (Mexico City, Lima, Los Angeles) to the air pollutants in Kuwait including known health effects from these sources of pollution. Health data from smaller oil fires will be particularly relevant.

2. Reviewing information on the relationship of forest fire and urban air pollution to acute and chronic adverse health effects.

3. Identifying by time, place, duration of exposure, level of exposure, various groups of individuals including oil well fire fighters, oil well workers, military personnel, and citizens.

4. Using plume measurements and plume modelling to estimate individual exposure to oil pools and the oil well fires.

D. **WHAT PUBLIC HEALTH INFRASTRUCTURE NEEDS TO BE DEVELOPED SO THAT POSSIBLE ADVERSE HEALTH EFFECTS ASSOCIATED WITH EXPOSURE TO THE OIL POOLS OR THE OIL WELL FIRES CAN BE IDENTIFIED AND EVALUATED? (Risk Characterization)**

The ability to identify acute or chronic adverse health effects is necessary to determine if unexpected adverse effects are occurring or if predicted adverse health effects did not occur. An active and well functioning infrastructure is necessary to assure that vital information is collected.

Strategies and approaches to strengthen the infrastructure should include

1. Surveys

   Surveys of the general health status of subpopulations living or working in Kuwait are needed so that information will be available on the existing adverse health conditions.

2. Surveillance

   a. Reinstating a communicable disease surveillance system in Kuwait.

   b. Reinstating public health programs such as well-baby clinics, immunizations, health education, and injury control.

   c. Reinstating vital statistics recording to include births, deaths, and fetal loss beyond 28 weeks.

   d. Beginning surveillance for respiratory and chronic diseases including chronic obstructive pulmonary disease, and asthma.

   e. Beginning registries of birth defects, fetal loss (beyond 28 weeks), and cancer.

3. Standard Methods and Quality Assurance

   a. Instituting the use of standard definitions of diseases (World Health Organization standards) and standardized forms.

   b. Instituting a quality assurance/quality control program in the public health laboratory, environmental health laboratory, hospital laboratories, and clinical laboratories.

4. Data Analysis

   a. Beginning computerization of Kuwait's surveillance systems and registries.

   b. Developing the capability to quickly collect, collate, analyze, and distribute data from the various surveillance and registry systems.

5. Personnel

   a. Obtaining the services of trained personnel to carry out pathological examinations on tissues.

   b. Developing an expertise in environmental epidemiology and toxicology.

   c. Training staff so that they can carry out case investigations and epidemiologic investigations.

   d. Obtaining the equipment and training environmental laboratory personnel to be able to identify substances associated with the plumes from oil well fires.

6. Risk Characterization

   The presence of an active and well functioning infrastructure will give rise to disease-specific incidence and incidence rate information. With this information, the numbers and types of acute and chronic adverse health effects that are predicted based on the hazardous substances identified and the amounts of exposure can be compared to the actual amount of disease. Of particular importance will be the modeling of the plume and the verification of the models to establish actual exposure.

**E. WHAT RISK MANAGEMENT AND DISEASE PREVENTION POLICIES NEED TO BE SET UP FOR PERSONS EXPOSED (ALREADY OR IN THE FUTURE) TO THE OIL POOLS AND OIL WELL FIRES?**

Once risks have been characterized, decisions have to be made about how the risks, if any, will be reduced and the adverse health effects, if any, will be prevented.

Strategies and approaches should include

1. For persons with long-term exposures to spilled oil and oil well fire plumes.

   a. Identifying populations at high risk of having adverse health effects if exposed to plumes from oil well fires.

   b. Encouraging Kuwait and other countries to do risk management for their citizens working or traveling to Kuwait.

c. Encouraging Kuwait to test soil for contaminants in areas of new housing, in areas where animals graze, crops are grown, and where children spend time.

d. Having the ability to predict when air quality will deteriorate and to provide sufficient notice that persons at risk of acute or chronic adverse health effects can go to protected buildings or areas of the country until the air quality improves.

e. Identifying buildings or areas of the country where persons at risk of adverse health effects due to exposure to plumes from oil well fires can go until the air quality improves.

2. For persons with short-term exposures to spilled oil and oil well fire plumes.

a. Preparing travel advisories for persons going to Kuwait.

b. Coordinating United States risk management policy with the National Response Team

c. Developing methods to disseminate information and provide health education and training for travelers to Kuwait on such topics as environmental hazards and injury prevention.

d. Prescreening persons going to Kuwait and identifying those with preexisting conditions that might be exacerbated by travelling to Kuwait while the oil well fires are burning.

**F. WHAT NEW KNOWLEDGE ABOUT THE POSSIBLE ADVERSE HEALTH EFFECTS ASSOCIATED WITH EXPOSURE TO THE OIL POOLS AND OIL WELL FIRES NEEDS TO BE OBTAINED?**

The KWP realize that much human suffering has been associated with the oil well fires in Kuwait. Some strategies and approaches listed in this document will provide information that is of importance to persons who have already been exposed to oil or to substances produced by the oil well fires. Other strategies and approaches will provide information that may be of little or no importance to already exposed persons, but may provide much needed information to help persons who may be exposed in the future to oil well fires, other airborne pollutants, or future environmental disasters.

The following is an announcement released by the Public Health Service on June 10, 1991.

## Emergency Room Surveillance -- Kuwait City

This is a summary of the results of emergency room surveillance conducted at two hospitals in Kuwait City from January 1st to April 30th, 1991. During that period, a total of 6,127 visits were recorded. There were 2,373 visits in the period before the oil fires were started (January 1 - February 22) and 3,754 visits in the period afterwards (February 23 - April 30). Since the population of Kuwait was not stable during this period, it is impossible to compute the rates of various diseases treated in the hospital emergency roms before and after the ignition of the oil fires. However, the proportion of total visits for the selected illnesses before and after the fires can be compared. The data are shown below:

| CONDITIONS | Jan 1-Feb 22 | Feb 23-Apr 30 |
|---|---|---|
| | (n = 2,373) | (n = 3,754) |
| Upper/Lower Respiratory | 29.2% | 19.0% |
| Gastrointestinal Illness | 19.6 | 23.2 |
| Muscular Pain | 12.3 | 9.9 |
| Asthma | 7.4 | 7.0 |
| Urinary Tract Infection | 5.5 | 4.4 |
| Skin Diseases | 5.1 | 1.7 |
| Headaches and Migraine | 4.8 | 4.6 |
| Hypertension | 4.1 | 8.3 |
| Heart Disease | 2.8 | 5.2 |
| Diabetes | 1.2 | 3.7 |
| Urticaria/Angioedema | .9 | 2.0 |
| Psychiatric Conditions | .5 | 1.6 |
| Hypotension/Dizziness | .08 | 1.1 |
| Drug Allergy | .04 | .1 |
| Chronic Bronchitis | .04 | .5 |
| Other Illnesses | 6.0 | 7.0 |

It is notable that visits to the emergency room for gastrointestional illnesses, heart diseases, psychiatric illnesses and chronic bronchitis increased during the period after the oil fires were ignited

These data suggest that there was no documented increase in the proportion of persons seeking care in hospital emergency rooms for upper and lower respiratory illnesses and asthma as a result of exposure to the oil fires.

Further data collection underway at additional hospitals and polyclinics will provide a more comprehensive picture of the current situation.

# HARVARD SCHOOL OF PUBLIC HEALTH
# KUWAIT AIR SAMPLING SURVEY
## - April 24 to May 11, 1991 -

**In Conjunction With:**

The Kuwait Ministry of Health: The Environmental Protection Department and the Environmental Protection Council

**In Association With:**

The World Health Organization - The World Meteorological Organization, Dr. David Mage, Project Director

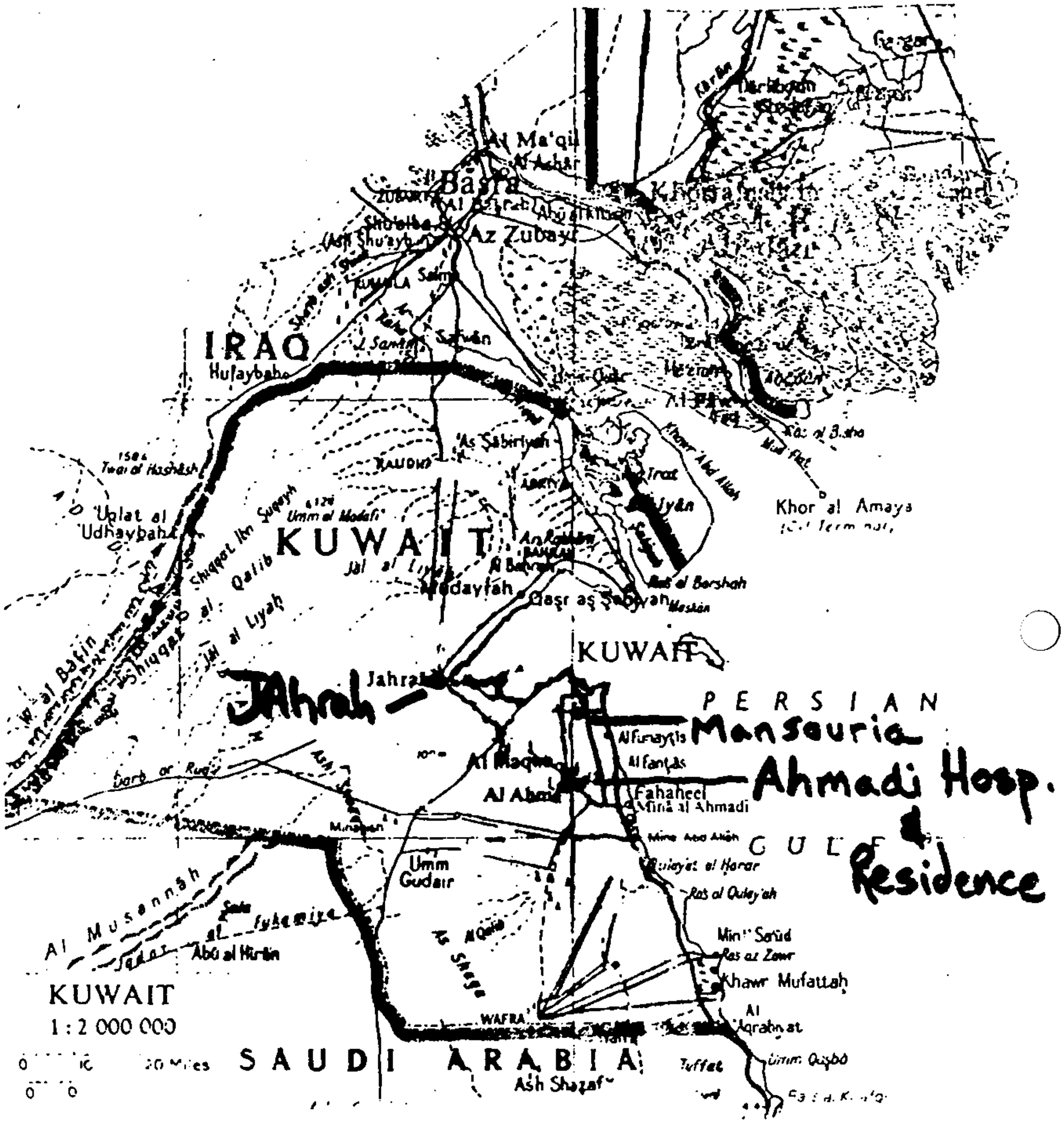

**Harvard University School of Public Health**
**Department of Environmental Health**

| | |
|---|---|
| Dr. John D. Spengler | Professor of Environmental Health |
| Dr. Yukio Yanagisawa | Assistant Prof. of Environmental Health |
| Thomas Dumyahn | Research Engineer |
| David Gilmour | Field and Research Assistant |
| Xiaowei Yan | Research Assistant |

**Collaborators:**

| | |
|---|---|
| MIT --- | Dr. Ilhan Olmez |
| DRI --- | Dr. Judith Chow |
| LBL --- | Dr. Joan Daisey |
| Bell --- | Dr. Charles Weschler |


HSPH KUWAIT



IRAQ
KUWAIT
SAUDI ARABIA
PERSIAN GULF
Basra
Az Zubayr
Jahrah
Al Ahmadi
Fahaheel
Mina al Ahmadi
Umm Gudair
Khor al Amaya
JAhrah -
Mansouria
Ahmadi Hosp. & Residence
KUWAIT
1 : 2 000 000

# HARVARD'S KUWAIT AIR SAMPLING SURVEY

## PARTICULATE SAMPLES - ANALYSIS AGENDA

| PARAMETER | ANALYSIS |
|---|---|
| Bulk / PM3.5 | 1.) Combined Samples for Animal Bio Assays - Dr. J. Brain, HSPH |
| | 2.) Combined Samples for Cell Mutagenicity - Dr. H. Liber, HSPH |
| | 3.) Polcyclic Aromatic Hydrocarbon Analysis - Dr. Joan Daisey, Lawrence Berkeley Labs |
| PM10 | 1.) Mass Concentrations at HSPH |
| | 2.) Elemental Analysis: INAA - Dr. I. Olmez, MIT Nuclear Reactor Laboratory |
| "Quartz Filter" Black Carbon | 1.) Elemental Carbon Analysis & |
| | 2.) Graphic Carbon Analysis - Dr. J. Chow, Desert Research Institute Univ. of Nevada, Reno |
| Particle Acidity | 1.) PH Analysis at HSPH |
| Particle Sulfate | 2.) Ion Chromatography Analysis at HSPH |

# HARVARD'S KUWAIT AIR SAMPLING SURVEY
- Spring 1991 -

## SAMPLE INVENTORY

| AMBIENT PARAMETER | | INSTRUMENT |
|---|---|---|
| Respirable Bulk Mass (3.5 microns and below) | | Harvard Modified Anderson Bulk Sampler with Cyclone Separator |
| PM10 | | Harvard Impactor with Black Box (4LPM Pump); Mounted Pre-Weighed Filters |
| Particulate Carbon | | Harvard Impactor with Mounted Quartz Fiber Filters |
| PM2.5 Acidity | No Acidity | Harvard Impactor with 2.5 Micron Nozzles and Mounted Teflon PH Filters |
| Nitrogen Dioxide | 20 - 30 ppb | Yanagisawa Passive $NO_2$ Badge |
| Carbon Monoxide | 10 ppm | Yanagisawa CO Passive Diffusion Tube |
| Volatile Organic Compounds | | 3M Passive Vapor VOC Badges |
| Hydrogen Sulfide | | DuPont Passive $H_2S$ Badges |

HSPH KUWAIT

# ANALYSIS APPROACH

## Statistical Correlations

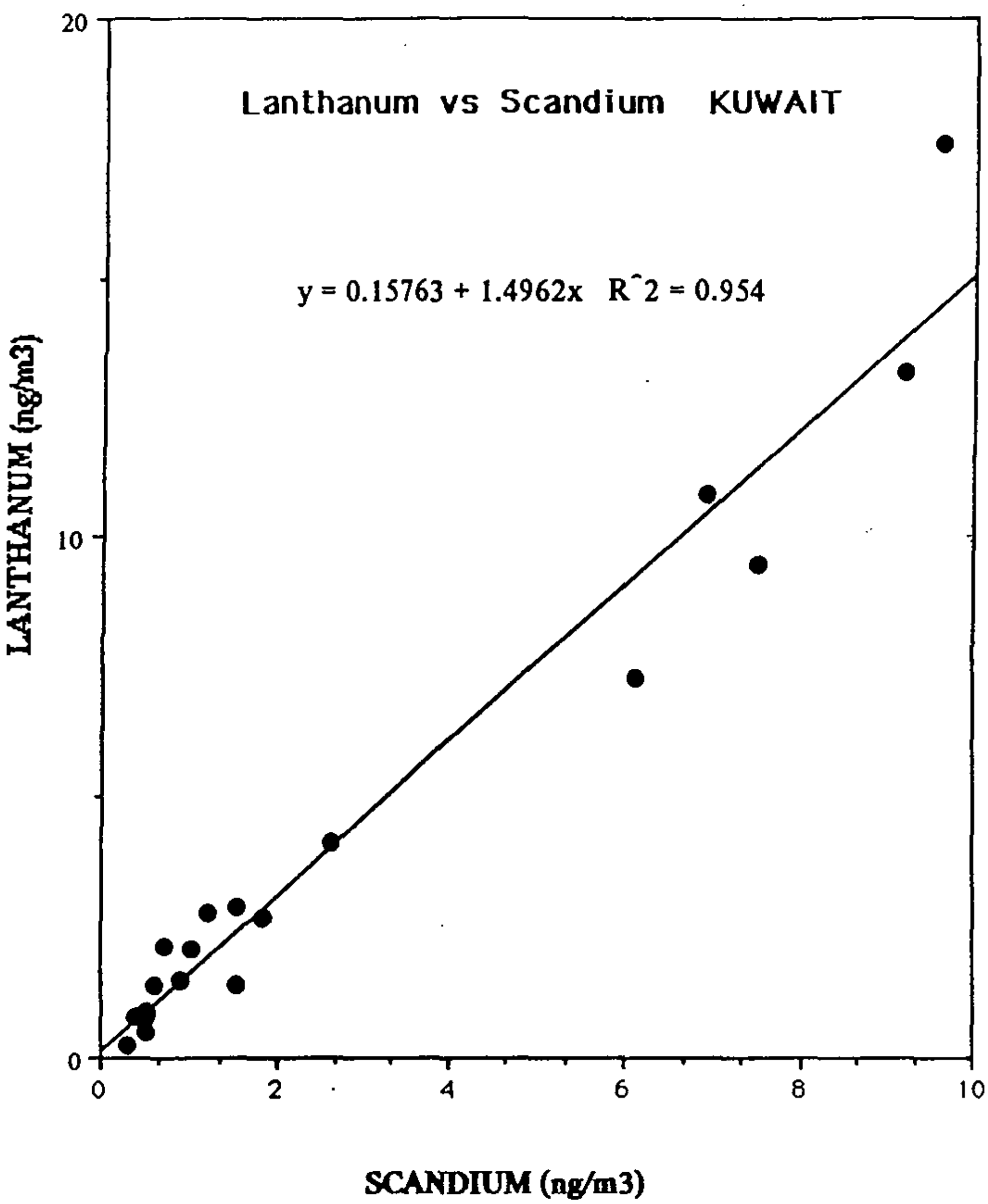
## Enrichment

$$\frac{(\text{Element / Sc})_{\text{sample}}}{(\text{Element / Sc})_{\text{crustal}}}$$

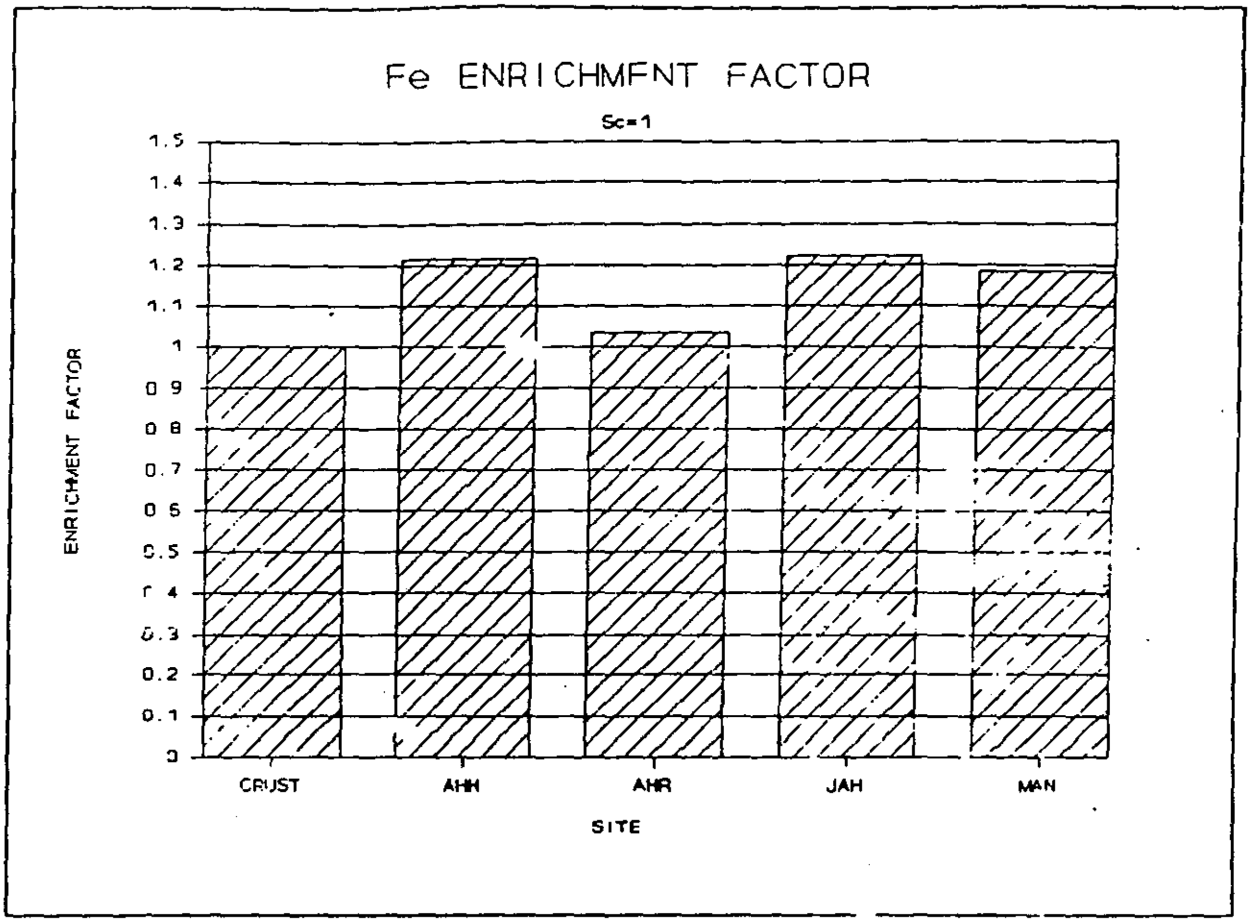
## Factor Analysis

## Regression Analysis

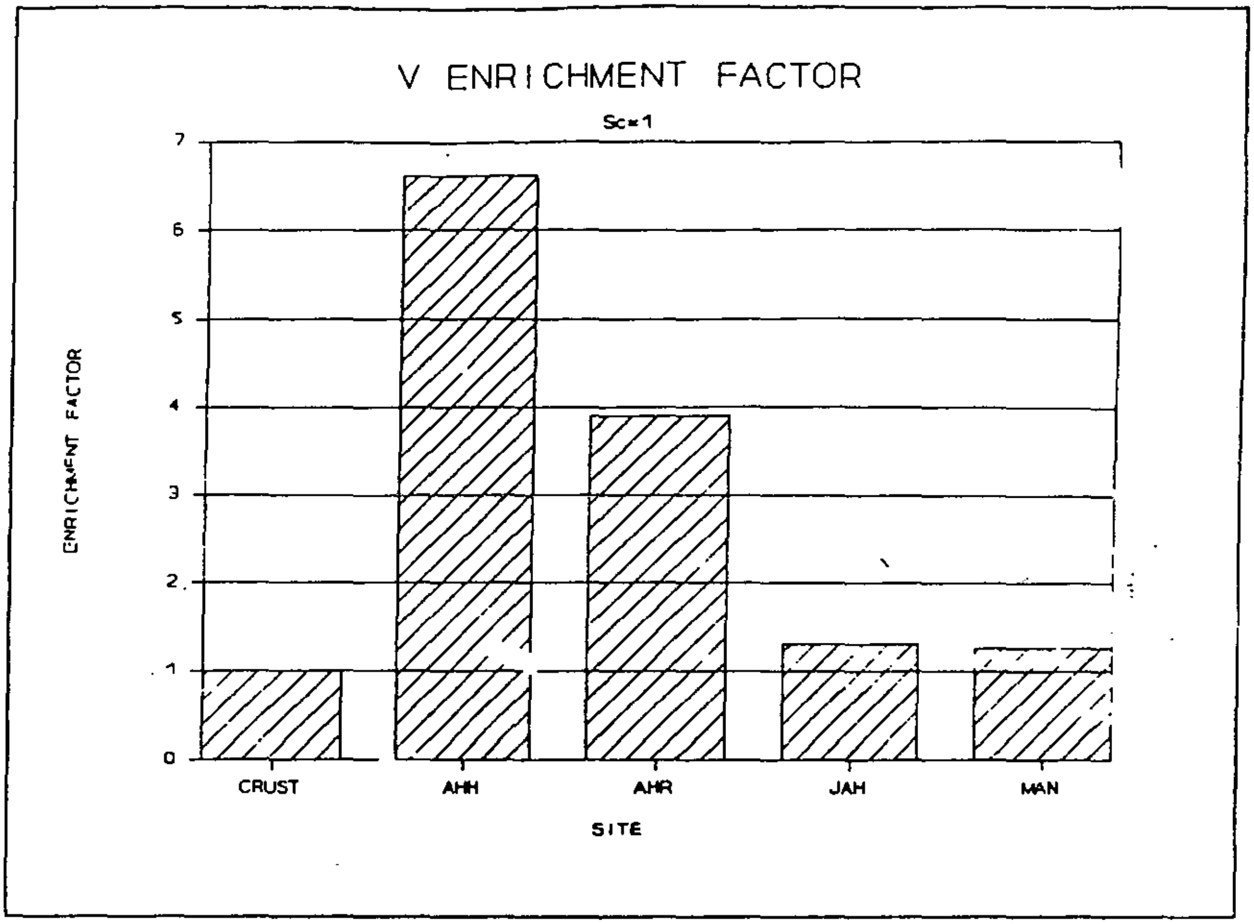
$$\text{mass} = x + \beta_1 X_1 + \beta_2 X_2$$



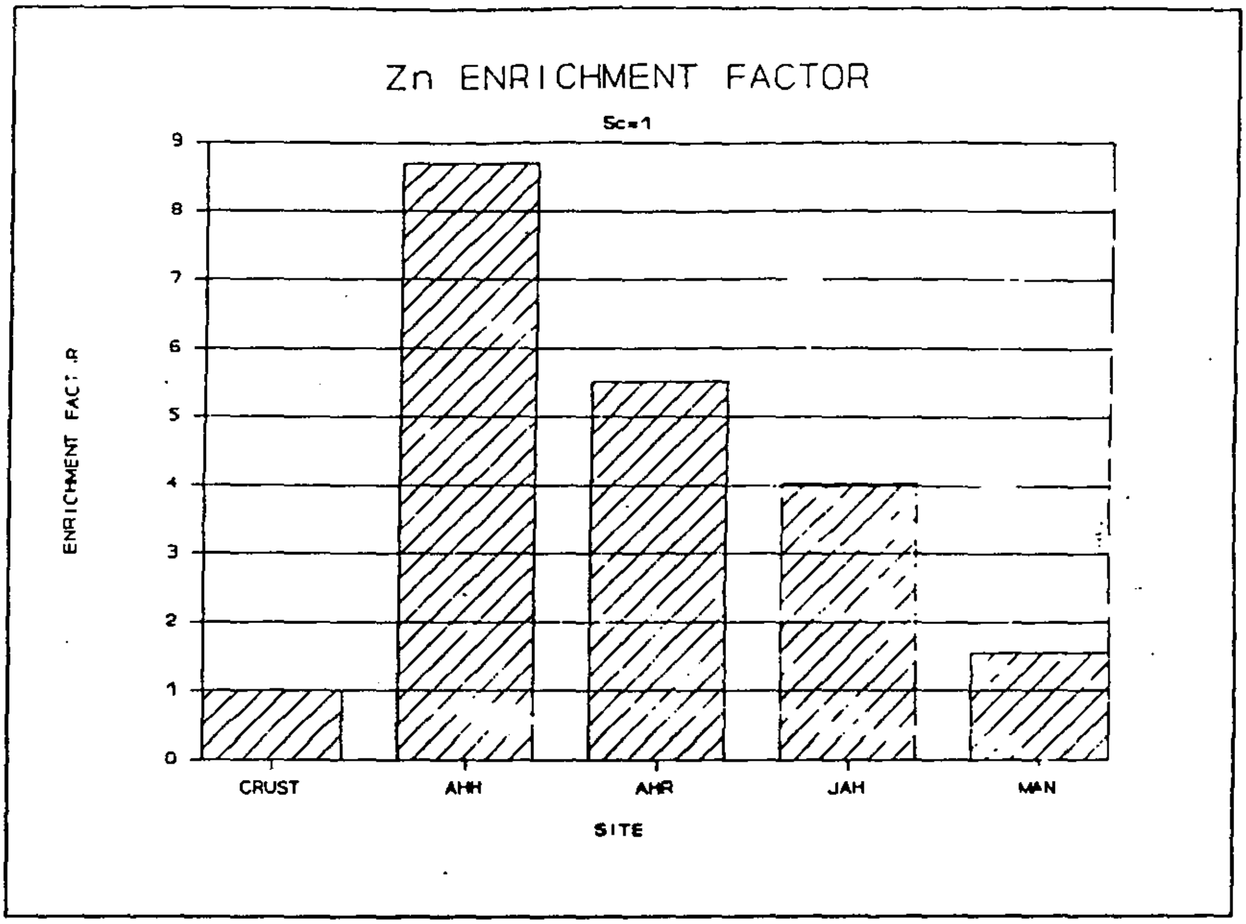
Lanthanum vs Scandium KUWAIT
y = 0.15763 + 1.4962x R^2 = 0.954
LANTHANUM (ng/m3)
SCANDIUM (ng/m3)
20
10
0
0
2
4
6
8
10



Fe ENRICHMENT FACTOR
Sc=1
ENRICHMENT FACTOR
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
CRUST
AHH
AHR
JAH
MAN
SITE



V ENRICHMENT FACTOR
Sc=1
ENRICHMENT FACTOR
0
1
2
3
4
5
6
7
CRUST
AHH
AHR
JAH
MAN
SITE

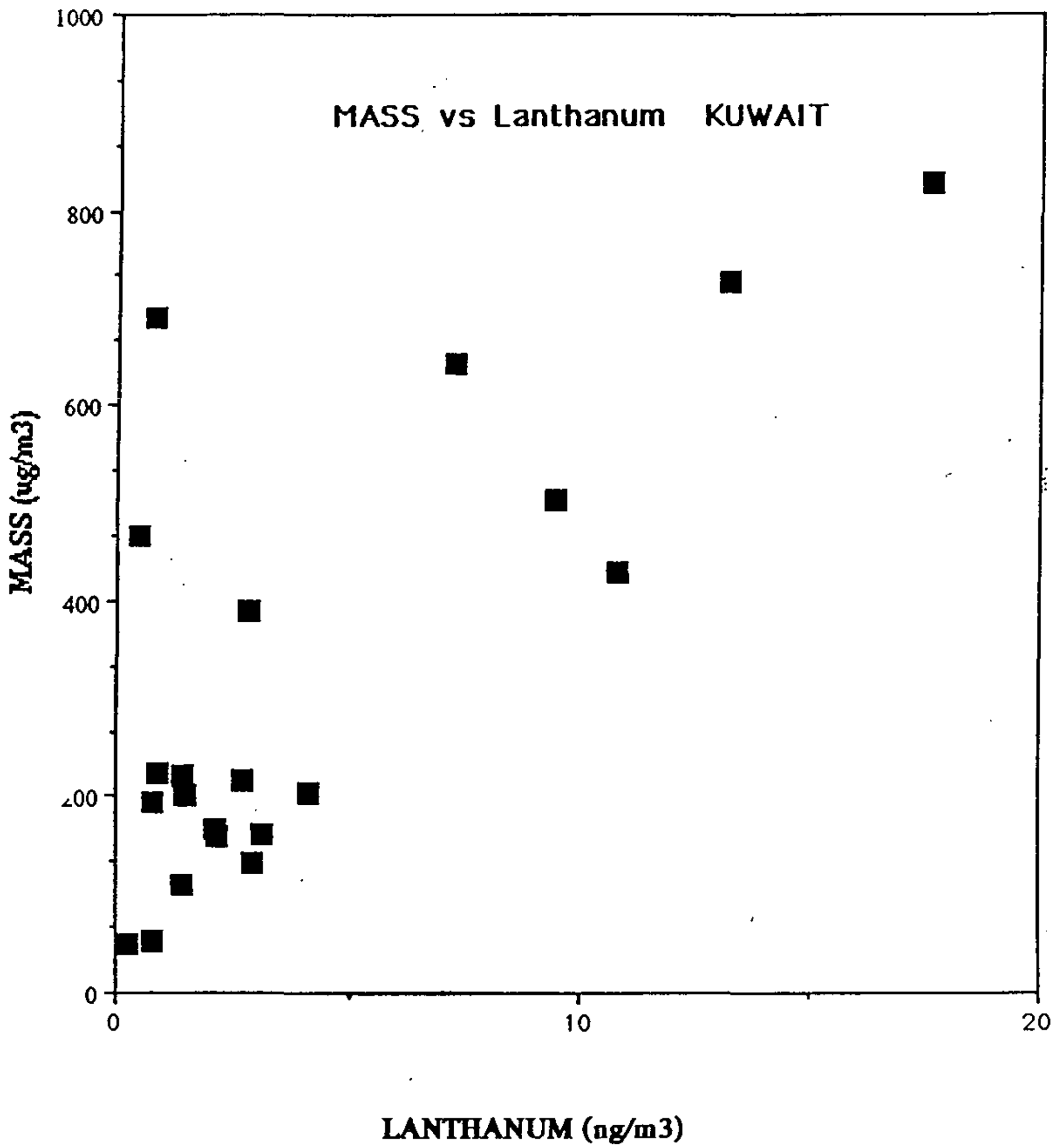

Zn ENRICHMENT FACTOR
Sc=1
ENRICHMENT FACT.R
0
1
2
3
4
5
6
7
8
9
CRUST
AHH
AHR
JAH
MAN
SITE

# ENRICHMENT ANALYSIS

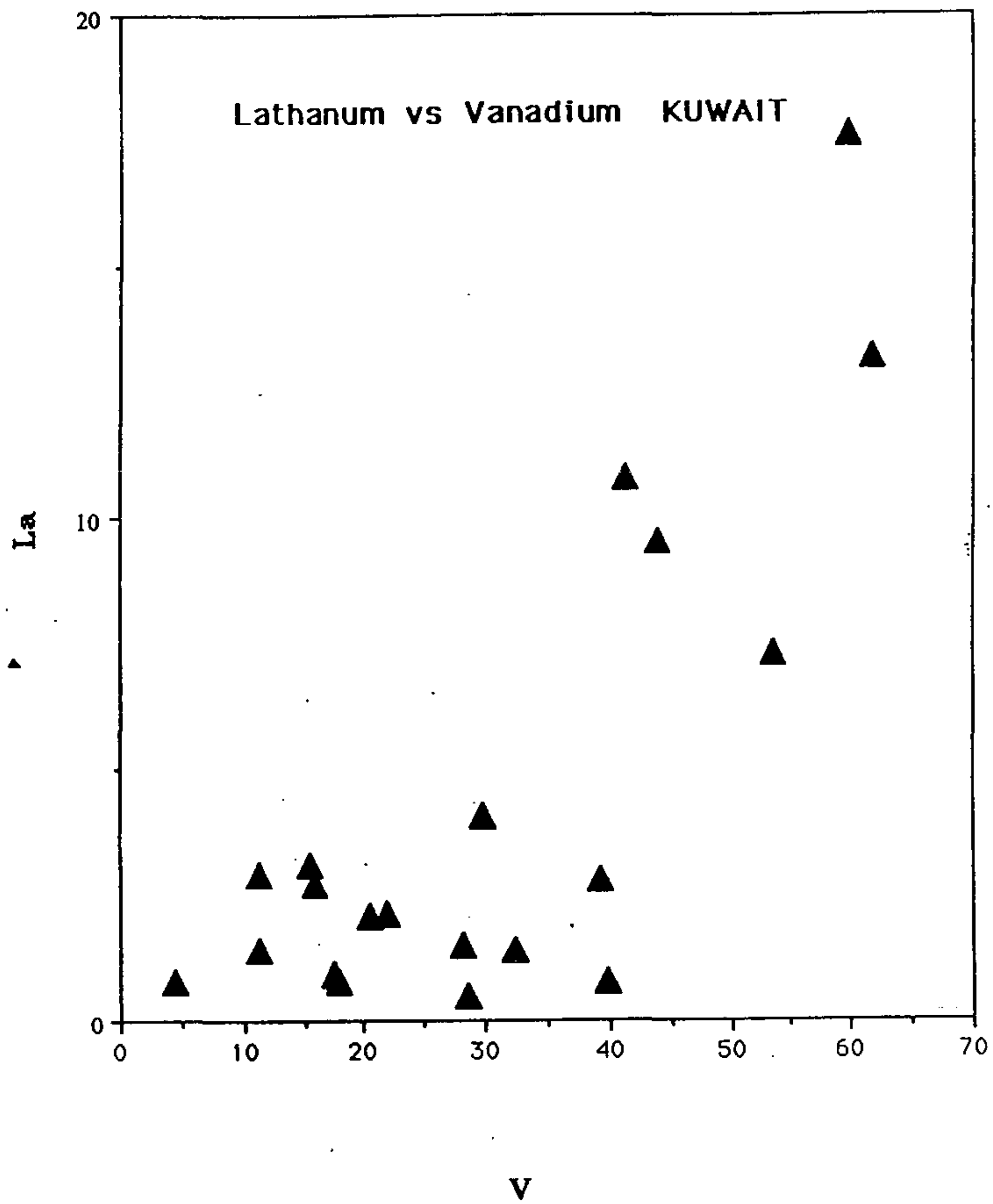
| Oil Related* | Crustal |
|---|---|
| Na | Al |
| Cl | Fe |
| V | La |
| Zn | Sm |
| Br | Th |
| Sb | Sc |

* High Impact Day

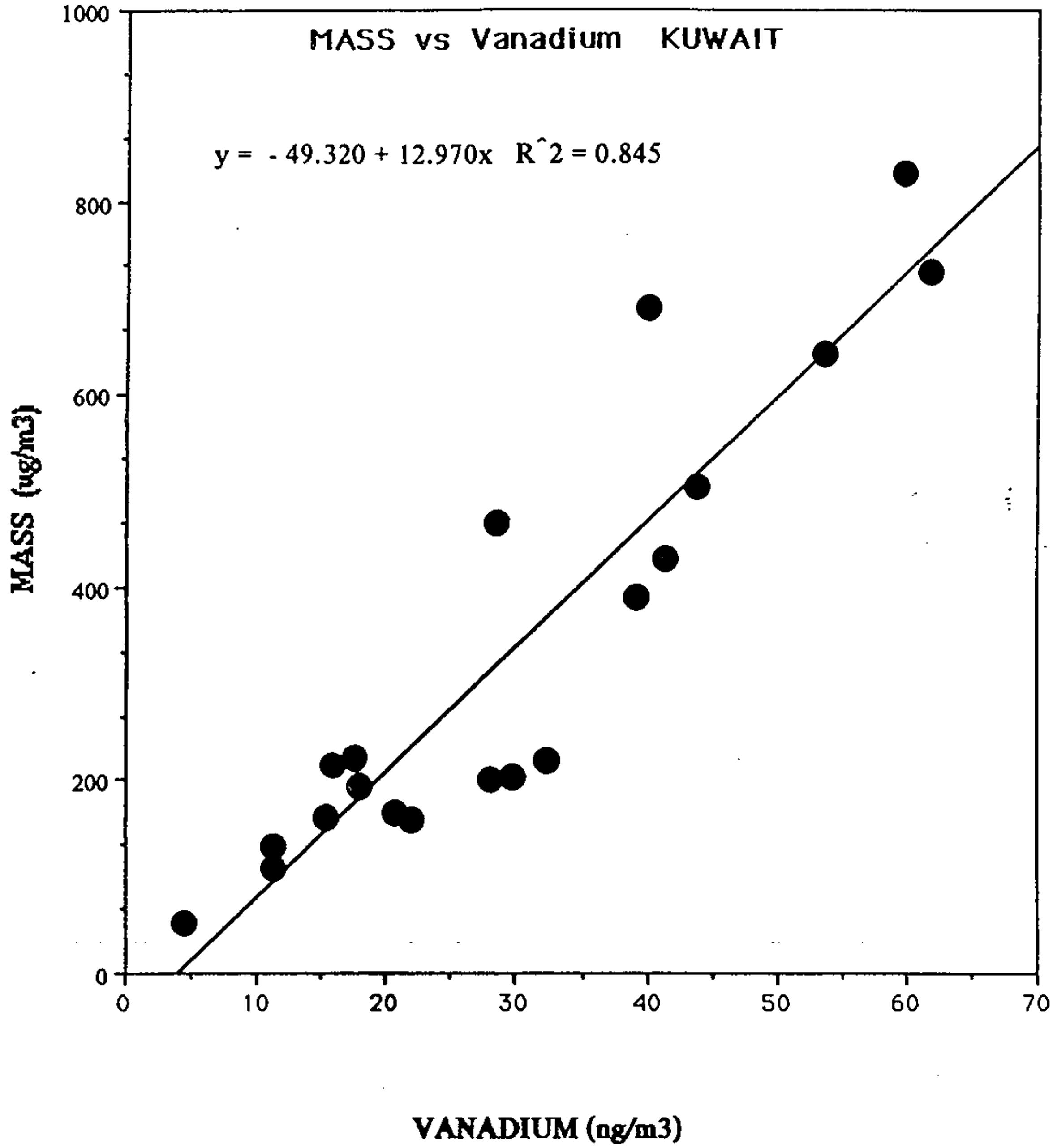
HSPH KUWAIT

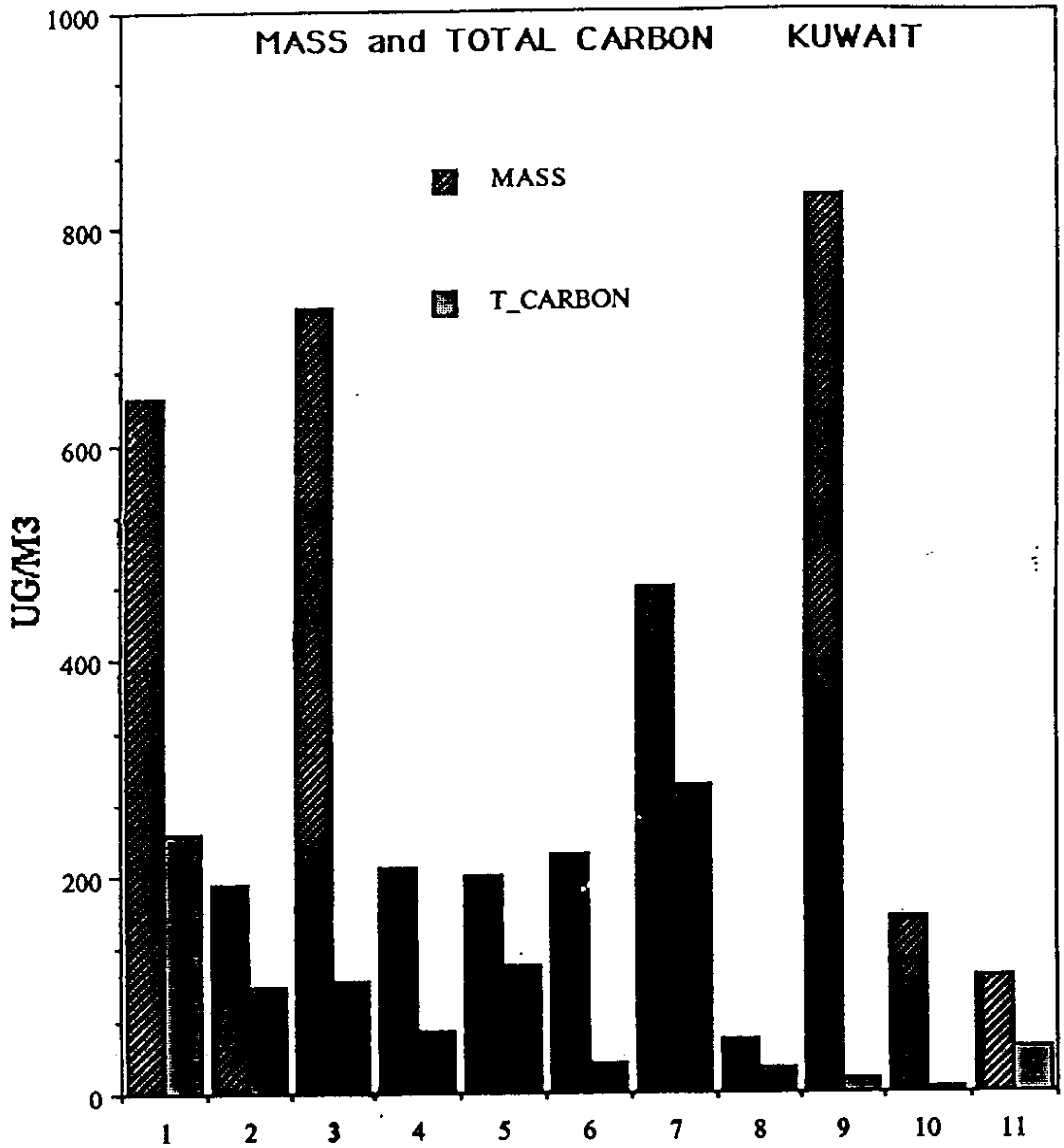


MASS vs Lanthanum KUWAIT
1000
800
600
400
200
0
MASS (ug/m3)
0
10
20
LANTHANUM (ng/m3)

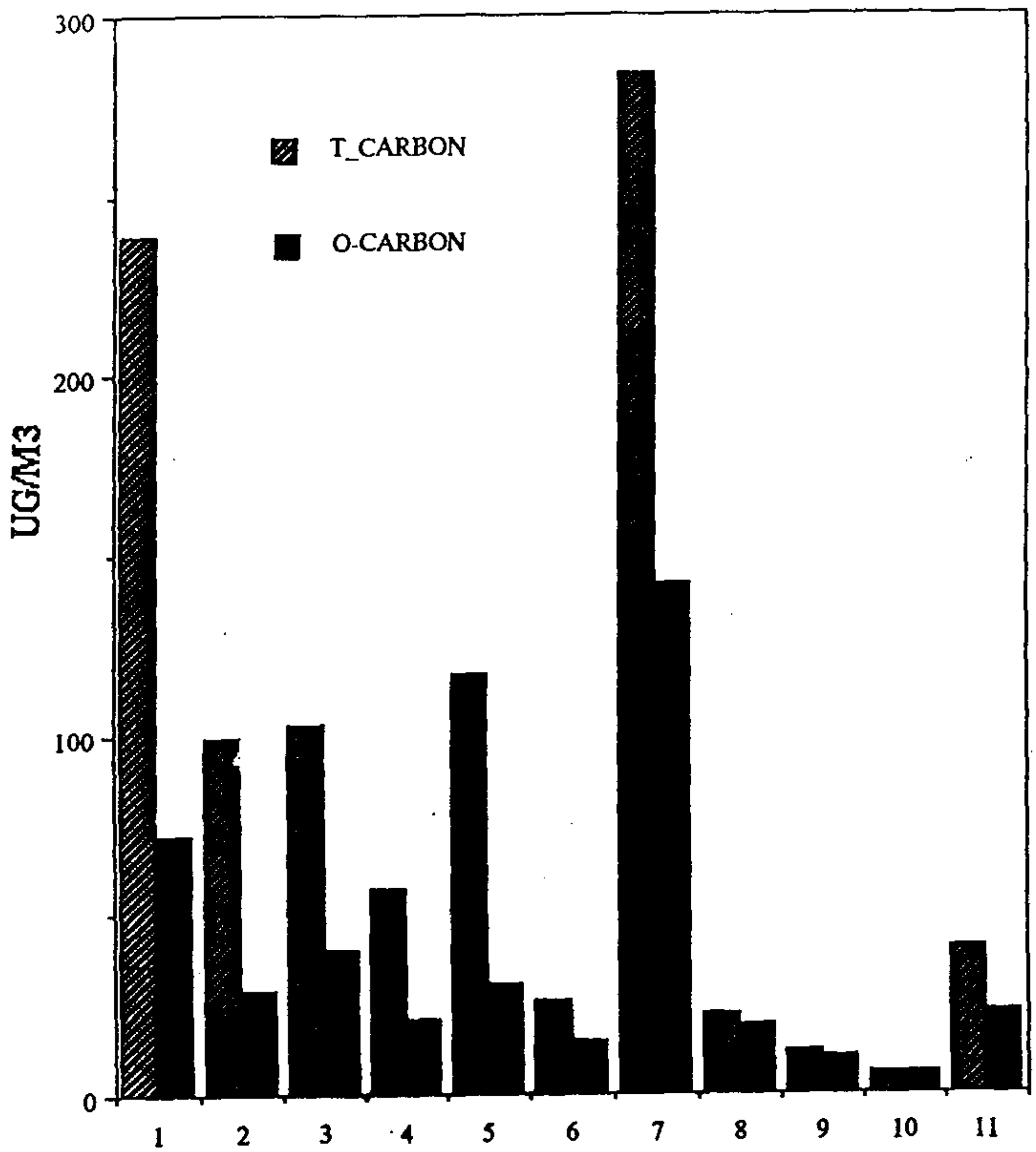


Lathanum vs Vanadium KUWAIT
20
10
0
La
0
10
20
30
40
50
60
70
V


MASS vs Vanadium KUWAIT
y = - 49.320 + 12.970x R^2 = 0.845
MASS (ug/m3)
VANADIUM (ng/m3)
0
200
400
600
800
1000
0
10
20
30
40
50
60
70


MASS and TOTAL CARBON KUWAIT
MASS
T_CARBON
UG/M3
1000
800
600
400
200
0
1
2
3
4
5
6
7
8
9
10
11

# TOTAL and ORGANIC CARBON KUWAIT



# CARBON ANALYSIS

| | |
|---|---|
| Total Carbon | 15 - 450 μg/$m^3$ |
| Organic Carbon | 10 - 315 μg/$m^3$ |
| Elemental Carbon | 0 - 170 μg/$m^3$ |
| % Organic in Carbon | 30% - 90% |
| %OC in Total Mass | 1% - 60% |

# $PM_{10}$ CONCENTRhATIONS

| | |
|---|---|
| Range | 50 - 830 μg/$m^3$ |
| Mean | 328 μg/$m^3$ |
| SD | 239 |

# The Kuwait Oil Fires

***Presentation Abstracts &***
***Speaker Biographies***

Conference Arranged By:
Harvard University School of Public Health
Center for Middle Eastern Studies

Jointly Sponsored By:
The Arab Fund for Economic and Social Development
The United Nations Development Programme

Cosponsored By:
The World Health Organization
The World Meteorological Organization
The United Nations Environment Programme
The International Maritime Organization

**12-14 August 1991**
**American Academy of Arts and Sciences**
**Cambridge, Massachusetts**

# PRESENTATION ABSTRACTS

# EFFECTS OF THE GULF WAR ON THE ENVIRONMENTAL GEOLOGY OF THE REGION

Farouk El-Baz
Center for Remote Sensing
Boston University

Preparations for and conducting the Gulf War resulted in much damage to the environment of the region. Foremost among the irreparable damage are changes to the terrain due to the digging of trenches, building walls of soil, and otherwise disturbing the desert pavement in and around Kuwait. The disruption of the usually one-grain thick layer of pebbles on the desert floor exposes soil to wind action. Furthermore, changing the contours of the normally flat land increases resistance to the wind, and thereby, increases the potential of particle transport until the land is peneplained. This condition will increase the frequency and the ferocity of dust storms in the region (Fig. 1). It will also result in the formation of new sand dunes; sand drifts were observed along roads in northern Kuwait.

The second effect on the geology of the region is that of the oil spill in the Gulf water. Hundreds of miles of the western coastline of the Gulf are already covered by oil. Petroleum "mats" have settled on coral reefs and in other ways have reduced the Gulf water productivity.

The third effect is related to the damage caused by oil well fires in terms of air pollution as well as the potential damage to the petroleum reservoirs. Photographs from the Landsat Thematic Mapper and the NOAA 10 and 11 spacecraft illustrate evidence for the damage to the environment and can help in monitoring environmental change in the future.

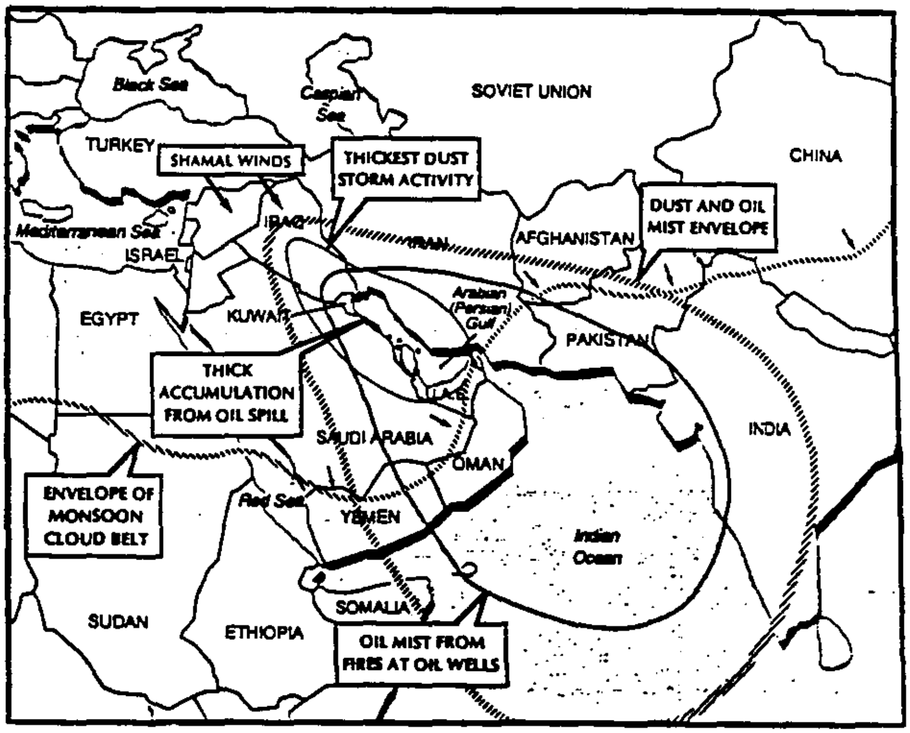



**Figure 1. Schematic illustration of potential regional effects of damage to the environment due to recent Gulf War.**

# SESSION ONE:

## Measurements of Air Pollution from the Fires

# KUWAITI WELL FIRE INVESTIGATION -- MONITORING AND MODELLING

Dr. Abdallah E. Dabbagh
King Fahd University of Petroleum and Minerals

Digitally processed National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) and Landsat Thematic Mapping (TM) data have been successfully used to monitor the Kuwaiti oil fires. Based on the processed information of satellite imagery, the number of burning oil wells and their locations in different oil-fields were identified. Knowing the productivity index of wells, an estimate was made on the amount of oil and associated gases on daily basis.

The total suspended particulates (TSP) using high volume samplers and inhalable particulates using PM-10 samplers were collected at various locations in the Eastern Province of Saudi Arabia. These filters were analyzed for toxic metal concentration and oil hydrocarbons including some carcinogenic organic compounds.

Air particulate samples using PM-10 samplers, collected from Dhahran and Khafji, were analyzed for polycyclic aromatic hydrocarbons (PAHs) and aliphatic hydrocarbon compounds. The concentration levels of PAHs compounds found in Dhahran and Khafji were not significantly high and compare favorably with levels found in urban areas in some parts of the world. However, the concentration of aliphatic hydrocarbons, which are not known to be toxic, were about several times higher than PAHs concentrations in most of the samples analyzed.

Air particulate samples were also analyzed to determine concentrations of aluminum, barium, cadmium, chromium, cobalt, copper, iron, magnesium, molybdenum, manganese, nickel, lead, strontium, vanadium and zinc in the filtrates were determined. Chloride, sulfate and nitrate were also determined.

Real time measurements of various pollutants in the ambient air were carried out in Dhahran, Abqaiq, Rahimah, Jubail, and Tanajib. No significant impact of the burning of oil wells in these areas has been observed. However, the inhalable particulate concentrations have been found to be relatively high.

A number of available air pollution modelling packages were reviewed. RAM Model (a multiple-point and area-source algorithm) within Users' Network for Applied Modeling (UNAMAP) is used to assess the impact of burning of oil wells in the Kuwaiti oil-fields within 100 km radius. For regional transport modeling, ARL-ATAD model is used, to study the behavior of the plume, its movement, decay of the pollutants with time, dispersion, and deposition with the distance and time.

The U.S. Interagency Air Assessment Team in collaboration with the Meteorology and Environmental Protection Administration (MEPA) and Research Institute of the King Fahd University and Petroleum and Minerals (KFUPM/RI) has developed a plan entitled *Gulf Regional Air Monitoring Program (GRAMP)*. A part of the above plan, specially the

# IMPACT OF KUWAITI OIL FIRES AND OTHER WAR ACTIVITIES ON INORGANIC ATMOSPHERIC POLLUTION IN SAUDI ARABIA

Muhammed Sadiq
King Fahd University of Petroleum and Minerals

Multitude of environmental problems has been associated with the Kuwaiti oil fires and other war activities. The Research Institute of King Fahd University of Petroleum and Minerals (KFUPM/RI), in cooperation with the Meteorology and Environment Protection Administration, initiated a research program to assess atmospheric pollution from these events. This presentation will discuss data obtained on inorganic atmospheric pollution as a part of this program.

Air particulates, both TSP (from March 1) and PM10 (from early May), were collected using standard Hi-Vol samplers. The collected samples were extracted with aqua regia and the digests were analyzed for aluminum, arsenic, barium, cadmium, calcium, cobalt, chromium, copper, iron, manganese, magnesium, molybdenum, potassium, lead, nickel, sodium, strontium, vanadium, titanium and zinc. Water soluble concentrations of sulfate, nitrate and chloride were also determined in the selected samples. The analytical data were statistically analyzed to evaluate the impact of Kuwaiti fires on the concentrations of the above parameters.

Soil samples were collected from Hafr Al-Batin area and digested in concentrated nitric acid. Concentrations of the above metals were determined in the digestates using an ICAP. It was found that concentrations of aluminum, cadmium. cobalt, chromium, molybdenum, titanium, nickel and vanadium in the top soil were dependent on the distance from Saudi/Kuwaiti border. These preliminary data suggest that Kuwaiti oil fires and other war activities were responsible for the elevated metal concentrations in the top soils. Distribution of copper and zinc did no follow a similar trend.

Over one hundred scalp hair samples were collected from five cities in Saudi Arabia to obtain first approximation of metal contamination in humans. The samples were thoroughly washed, wet digested and analyzed for about 20 metals. The analytical results were used for inter-city comparison. The data of this investigation were compared with the published information from other countries.

# REVIEW OF THE SURVEY BY JAPANESE TEAM

Toshiichi Okita
Obirin University

From 28 April to 5 May, 1991, a Japanese team has made measurements related with oil fires at nine sites in Kuwait as shown in Table 1.

**Table 1. Pollutants measured at different sites**

| | $NO_2$ | $NO_x$, $NO_2$ | Particu-lates | BaP |
|---|---|---|---|---|
| 1. Ahmadi Hospital | O | O | O | O |
| 2. Ahmadi residential area | O | O | ● | O |
| 3. Riggae Hospital | O | O | | |
| 4. Environment Protection Department | O | O | | O |
| 5. Mansourya Hospital | O | O | | |
| 6. International Hotel NW | O | O | | O |
| 7. International Hotel SE | O | O | ● | |
| O | | | | |
| 8. Jahra Hospital | O | O | | |
| 9. 10 km north of Jahra | O | O | | |

●: Components of particulates such as $SO_4^{2-}$, $Cl^-$, $NO_3^-$, total and elemental carbons, V, Cd, and Pb were determined.

**Table 2. Maximum concentrations of $SO_2$, $NO_x$ and $NO_2$**

| Gases | Concn. (ppb) | Site | Sampling Unit |
|---|---|---|---|
| $SO_2$ | 28 | Ahmadi residential area | $PbO_2$ candle* |
| | 23 | " | Aerosol gas sampling unit |
| $NO_x$ | 54 | Internat'l Hotel NW side | Ogawa sampler |
| $NO_2$ | 33 | " | Filter badge |

* Derived from the sulfation rate ($mgSO_4/100\ cm^2$ day) by multiplying 0.034 according to the Report of Japanese Environment Agency in 1973

The maximum concentrations of $SO_2$, $NO_x$ and $NO_2$ shown in Table 2 were rather low. The concentrations of particulates and their components in residential area of Ahmadi are shown in Table 3.

The mobile laboratory was equipped for automatic measurement of ozone, sulfur dioxide, nitrogen oxides, and carbon monoxide.

- Sampler for black smokes
- Samplings on active charcoal of hydrocarbons analyzed
- Sequential particles, sampler on cellulose acetate filter for measurement of metals (1 hour each sample 1.5 $m^3/h$)
- One sampling cartridge of tenax and glass fiber filter to measure PAH in both gaseous and particulate phases

An automatic data logger stored each fine minute average data from each automatic sensor.

Black smokes and sequential particles samplers take automatic one hour sampling.

The other sampling were made during various times of 4 hours to 14 hours.

The measurements were made both far enough from the burning wells (where a majority of people is living in the city or the suburbs) and close to the fires (underwind) or inside the oil fields.

The main results are following:

- the carbon monoxide and nitrogen oxides levels were always very low and less than in an urban site.
- the sulfur dioxide and black smokes levels were generally medium but with unfavorable weather conditions, very high levels were observed: (2991 $\mu g/m^3$ $SO_2$ on 5 mn, 2030 $\mu g/m^3$ BS on 1 hour). These levels were observed close to the field as well as the city.

The ozone levels were "normal" taking into account the latitude and amount of sunshine.

The heavy paraffinics hydrocarbons levels were relatively high, particularly close to the fields: (decane 58.6 $\mu g/m^3$ on 8 hours).

The light paraffinic hydrocarbons and the aromatics showed relatively low levels (toluene max 46 $\mu g/m^3$ on 7 hours - benzene: 11.9 $\mu g/m^3$ - octane: 51.6 $\mu g/m^3$).

The polycycliques aromatics hydrocarbons (PAH) levels are largely variable depending on the site and on the specific PAH.

High levels are observed for fluoranthene 110 $ng/m^3$, benzo-a-pyrene 30 $ng/m^3$, indeno (123cd) pyrene 49 $ng/m^3$, but generally the levels were lower than the maximum observed in Paris.

## THE GULF REGIONAL AIR MONITORING PLAN (GRAMP)

Andrew E. Bond
Atmospheric Research and Exposure Assessment Laboratory
U.S. Environmental Protection Agency

Timothy R. Gerrity
Health Effects Research Laboratory
U.S. Environmental Protection Agency

The U.S. Interagency Air Assessment Team (USIAAT) developed a 5-phase plan to assess the impact of the oil fires in Kuwait on the gulf region. This plan was jointly developed by the USIAAT, Saudi Meteorology and Environmental Protection Administration (Saudi MEPA), and the Saudi Arabian Oil Company (Saudi ARAMCO) during March and April 1991. The plan includes several objectives: an early warning health advisory system, the capability to track the air pollution emanating from Kuwait, the capability to collect airborne samples for toxicity testing, and the capability to generate a database for model validation. The presentation will focus on the USIAAT recommendations, to the governments of Saudi Arabia, Kuwait, and Bahrain concerning the expansion of their existing air monitoring capability. These recommendations were made to enable these governments to collect a comprehensive database necessary in assessing the long term health risks attributed to fires in Kuwait, on the population centers throughout the region.

## WHO/UNEP GEMS/HEAL STUDY OF EXPOSURES TO PARTICLES IN KUWAIT

Lance Wallace and Mel Kollander
U.S. Environmental Protection Agency

David Mage
World Health Organization

WHO/UNEP, together with the Kuwait Environmental Protection Department (KEPD) of the Kuwait Ministry of Health, is sponsoring a study of personal exposure to inhalable particles (PM-10) and fine particles (PM-2.5) in Kuwait. The study is designed to estimate the frequency distribution of personal exposures to PM-10, and indoor-outdoor concentration of PH-10 and PM-2.5, for all nonsmoking Kuwait citizens above the age of 10, between October 1991 and January, 1992. Additional measurements will be made of vanadium (as a marker of the oil fire contribution to exposure), nicotine (as a marker of cigarette carcinogenic effects).

# SESSION TWO:

## Predictions of Air Pollution Concentrations

# PRE-WAR ASSESSMENT OF THE IMPACTS OF THE USE OF OIL AS A WEAPON IN KUWAIT

B. D. Zak
Sandia National Laboratories

During the closing days of November 1990, Sandia National Laboratories was asked by the Department of Energy to assess the probable impacts of the potential use of oil as a weapon by Iraqi forces in Kuwait. A draft report was needed in a little over three weeks. Impacts on the Kuwaiti oil reservoirs, the health of exposed populations, the optical properties of the atmosphere, global climate, and terrestrial and marine ecology were to be assessed. The request was made of D. Engi, who responded by assembling the multidisciplinary team including H. W. Church, M. W. Edenburn, W. Einfeld, D. Engi, S. A. Felicetti, T. H. Fletcher, G. S. Heffelfinger, K. D. Marx, J. T. McCord, P. W. Moore, D. A. Northrop, L. D. Potter, J. R. Waggoner, and N. R. Warpinski. This paper focuses only upon the atmospheric impacts.

With regard to oil well destruction and ignition, a set of four scenarios was developed to span the range of potential impacts. The scenarios differed in number of wells blown and fraction ignited, covering the range from 100 to 900 blown, and 20 to 80% of the blown wells ignited. In each scenario, the wells presumed blown and ignited were assigned to the three major oil fields (Southeast, West North) into which the existing wells had been grouped.

Using available data, petroleum engineers on the team then estimated flow rates and gas-to-oil ratios for average blown wells in each field. For the presumed average blown well, the two phase flow was modeled, and oil droplet size distributions estimated. Modeling indicated that for the average wells, the output would be a fine oil mist under 15 microns in diameter. Combustion modeling then confirmed that for these conditions, each well would effectively be a blowtorch, with little or no rainout of burning oil drops. Available data on soot, sulfur dioxide, and carbon monoxide emission factors were then used to calculate source strengths for downwind dispersion modeling, but with an allowance made for a small fraction of the oil burning in pools to account for non-ideal venting.

In the interest of time, the burning oil fields were modeled as line sources with no lateral dispersion and no wind shear, but separately for day and night, and using actual climatological wind data from Kuwait City. The results indicated that, except for sensitive populations, the prompt health effects would be modest. Assuming smoke optical properties similar to other carbonaceous soots, impacts on visibility and available light could be very significant during daylight hours at ground level and aloft for a 100 km or more downwind. Regional, but not global climatic effects were expected.

A similar approach was taken for presumed fires associated with oil storage facilities and the system of trenches to be filled with oil and ignited. Downwind of the trenches, extreme conditions were anticipated. However, seepage modeling had identified probably difficulty for the Iraqis in filling the trenches and keeping them full from available pipelines.

defined bounds of the smoke dispersion. While measurements, data reductions, and analysis will continue for some time, early results are significant. Nuclear winter was a poor analog for Kuwaiti fires; crude oil smoke is not as absorbing as previously estimated, nor did self-lofting dominate the cloud dynamics. The smoke readily interacts with moisture and scavenging rates are greater. Analysis of cloud dynamics self-lofting, and definition of cloud properties and environmental damage using multispectral satellite imagery will lead to new models and assessments of smoke physics, nuclear winter, the long-range transport of pollutants, and the impacts of prolonged exposure to persistent smoke fallout.

## THE EFFECT OF MIXING HEIGHT AND WIND SPEED ON THE DISPERSION OF AIR POLLUTION IN KUWAIT

Dr. Dhari N. Al-Ajmi
Kuwait Institute for Scientific Research

The mixing height and wind speed are two important meteorological parameters that affect the dispersion of air pollution. The product of the mixing height and the transport wind speed gives the ventilation factor, which is inversely proportional to the relative pollutant concentration. In this paper, the morning and afternoon mixing height data at Kuwait International Airport have been analyzed. Hourly wind speeds were evaluated. Finally, the relationships between the mixing height, wind speed and dispersion of pollution were discussed.

## SHORT-RANGE AND REGIONAL TRANSPORT MODELING OF POLLUTANTS FROM KUWAITI OIL FIELDS

Tahir Husain
King Faud University of Petroleum and Minerals

The following two types of models were selected to estimate the concentration of the pollutants and to track the smoke plume due to burning of wells in Kuwaiti oil fields:

1. RAM Model within Users' Network for Applied Modeling (UNAMAP) to assess the impact of burning of oil wells in the Kuwaiti oil-fields within a radius of 100-150 km from the source.

2. Air Resources Laboratory, Air Transport and Dispersion Model (ARL-ATAD) to determine the movement of smoke from the Kuwaiti oil fields and regional impact.

## SOME RESULTS OF ARAC'S EFFORTS TO ESTIMATE THE AIR POLLUTION IMPACTS OF THE FIRES

Thomas J. Sullivan, Ph.D.
Lawrence Livermore National Laboratory

The Atmospheric Release Advisory Capability (ARAC) was originally conceived and developed at Lawrence Livermore National Laboratory as a nuclear accident emergency response service. It's purpose is to provide near real-time dose assessment calculations for accident response decision makers. Based on operationally robust three-dimensional atmospheric transport and dispersion models, extensive geophysical databases, real-time meteorological data acquisitions and a highly experienced staff, ARAC responds to U.S. events in the 30-90 minutes time frame. The present ARAC service is supported by a combination of DOE and DoD funding

Beginning with the Chernobyl accident, DOE has on several occasions requested that ARAC calculate the transport and dispersion of pollutants for accidents outside the U.S. and for non-nuclear material. One of the latest such requests was for support of the U.S. aircraft research flight programs measuring the pollutants from the Kuwait oil field fires (5/14-6/15 and 7/29-8/20) and the WMO request for assistance to the region's environmental and meteorological services. Since 14 May ARAC has been calculating the continuous smoke plume dispersion throughout a 3200 km region, using meteorological data sources from the U.S. Air Force Global Weather Central. These calculations have been directed toward optical depth estimates based on the integrated vertical (carbon soot) pollutant impact on visible light. ARAC has also reconstructed the long range pollutant transport on a hemispheric scale, again using AFGWC meteorological data, which depict the most probable far field dispersion and deposition patterns, albeit without washout or particle growth effects. These dispersion patterns provide insight as to where international scientific organizations should perform detailed measurements and analyses.

## WMO ACTIVITIES FOR MONITORING AND ASSESSING THE ATMOSPHERIC EFFECTS OF THE KUWAIT OIL FIRES

Rumen D. Bojkov
World Meteorological Organization

Within the United Nations system of Specialized Agencies the World Meteorological Organization (WMO) has the responsibility of providing authoritative information and advice on the global atmosphere and, because of this, WMO was asked in the joint UN response to the UN Inter-Agency Action Plan to take the lead in the evaluation of atmospheric pollution resulting from the Kuwait oil fires.

none appeared at levels that would suggest a significant health effect. These data in combination with the informal health surveillance lead to the conclusion that short-term health effects, especially in a relatively healthy population, would not be significant. But, that longer term health consequences would not be predictable until better characterization of the emissions had been done. This presentation will focus on several issues including the rationale behind the methodologies employed by the Team and the reasoning behind the preliminary conclusions. Additionally, the roles that monitoring and modeling will play in risk assessment for health effects in the region will be discussed in the context of the National Academy of Sciences risk assessment paradigm.

**This is an abstract of a proposed presentation and does not necessarily represent EPA policy**

# SESSION THREE:

## Risk Assessment and Epidemiology

# MORTALITY RISKS FROM $SO_2$ AND PARTICLES: INSIGHTS FROM THE LONDON FOGS

George D. Thurston, Sc.D.
Kazuhiko Ito, Ph.D.
Institute of Environmental Medicine, New York University Medical Center

Air pollution epidemiology has been able to clearly demonstrate instances were increases in mortality and/or morbidity were associated with elevated concentrations of pollution. Probably the most studied case is that of the 5-9 December, 1952 London, England episode during which the city center levels of daily air pollution reached 1340 ppb (3830 $\mu g/m^3$) sulfur dioxide ($SO_2$) and 4460 $\mu g/m^3$ of British Smoke (BS), and there was an estimated total of 4000 "excess" deaths over a two week period. Other wintertime episodes occurred in following years, especially 4-7 December, 1962 when peak daily center city levels reached 3834 $\mu g/m^3$ $SO_2$, 3144 $\mu g/m^3$ BS, 347 $\mu g/m^3$ particulate acidity (reported as $H_2SO_4$), and some 340 "excess" deaths reportedly occurred. The 1962 data supports the assumption that elevated acid aerosols were also present in 1952.

Quantitative statistical analyses have now been conducted on London's daily wintertime mortality/pollution records (compiled since 1958). We have completed a time-series analysis of these London data during the period when daily acid aerosol records were kept (1965-72). Long-wave trends (e.g., seasonal cycles and influenza epidemics) as well as autocorrelations were first removed from the data, providing robust statistical regression estimates of short-term pollution-mortality associations. The central London pollution during these periods were fairly stable from year to year and less extreme than the past periods (maximum wintertime $SO_2=1076$ $\mu g/m^3$, BS=336 $\mu g/m^3$, $H_2SO_4=30$ $\mu g/m^3$). Although the effects of the individual pollutants could not be separated, the two-day "mean effect" was found to be significant and to range from 7-9 deaths/day in Greater London (depending upon pollutant employed), after controlling for meteorological influences. Normalizing these results with respect to pollution level and population size yields the following coefficient estimates: 0.004($\pm$0.001), 0.015($\pm$0.003), and 0.150($\pm$0.047) in (deaths/day)/($\mu g/m^3$)/million persons for $SO_2$, BS, and $H_2SO_4$, respectively. Converting the BS coefficient to total carbon (TC), based upon a past London calibration (i.e., TC=0.41xBS), yields a 0.037($\pm$0.008) normalized coefficient estimate for TC. Comparable analyses of London summer data gave results not statistically different from these. Care must be taken in applying these estimates at other locations (e.g., where the population age distribution or pollution mix differ substantially from London's).

(2) Repeated high concentration of $SO_2$ reaching to 1.0 ppm at maximum was observed.

(3) The meteorological conditions such as the direction and velocity of wind, had a great contribution on where and to what extent the pollution occurred.

According to the monitoring results by our mission between April 30 and May 8, $SO_2$ concentration was generally at a low level in Kuwait City and other monitoring points; 0.0025-0.0279 ppm (TEA passive sampler). During that period, relatively high pollution reaching 0.35 ppm (detector tube) was recorded only once, when black smokes covered over the city. Therefore, as far as $SO_2$ pollution was concerned, it might not be possible to think that serious acute effect such as the increase of asthma or bronchitis would occur, based on our experiences in Yokkaichi. It seems, however, the meteorological conditions have an important role in the observed level of pollution in residential areas of Kuwait. It seems important to know how frequent that sort of smoke pollution will occur, in order to assess the risk of this pollution problem properly.

# SESSION FOUR:

## Ecological Impacts

# BURNING OF OIL WELLS IN KUWAIT -- NEED FOR PERSPECTIVE

Dr. Fatima Abdali
Kuwait Institute for Scientific Research

The Kuwait action plan (KAP) region is undergoing the world's most extraordinary environmental crisis. More than 600 oil well storage tanks and refineries are currently producing an enormous amount of smoke and other pollutants each day.

Most of the conclusions reached by international teams in Kuwait have been considered suggestive rather than definitive because of the limitation in data collection from limited sites.

The scenario should be oriented to correlate the quantitative characterization of the smoke source with risk assessment. This could be approached by focussing on the feasibility of the sampling sites, types of samples, chemical analysis and environmental and concentration distribution. This scenario should be framed under an Environmental Health Impact Assessment (EHIA) Program, which is directed toward the prediction and identification of the changes in the environmental parameters as a result of any assault, such as the oil well blowouts in Kuwait.

We must not adopt action programs with too little planning, and long-term implications of today's action must always be considered. We are not only concerned with ourselves and today's problem but at the same time, we are carrying out a responsibility to future generations.

# ASSESSMENT OF THE IMPACT OF THE CRISIS ON GROUND-WATER POLLUTION FROM MASSIVE SPILLAGE OF OIL FROM DAMAGED WELLS

Dr. Adnan Akbar
Kuwait Institute for Scientific Research

This article presents the future prospects of the ground water in Kuwait, in light of the tremendous and inhumane damage of the Kuwaiti oil wells, caused by the defeated Iraqi army. Of special and immediate concern are the Kuwait Group and Dammam Aquifers which are considered to be the main source of fresh and brackish ground water in Kuwait. These two aquifers are believed to be hydraulically connected and therefore, the effect on one of them will certainly be reflected on the other. Taking this into consideration, the possibility of contaminating these ground water sources is great - either through direct seepage from ponds of leaked oil, or from the "Acid Rain" generated from the emitted pollutants of the burning oil wells.

# AIRBORNE PETROLEUM CONTAMINATION OF COASTAL FISHERIES' FOOD-WEB

Anitra Thorhaug, Ph.D.
Florida International University

Andrew Oerke
Greater Caribbean Energy and Environment Foundation

The Kuwait oil fires present the world's largest-scale petroleum airborne contamination event. Food chains leading to man (i.e. groundwater, soil, agriculture, livestock and fisheries) may become contaminated with hazardous metals, organic compounds and acids. Fish provide 80% of the protein nutrition for the coastal Iranians. The number of people fishing, selling fish or dependent on fish probably number more than 350,000 with those directly employed by the fishing industry numbering 55,000 (40,000, Iran; 10,000, Saudi Arabia; 2,200, Qatar; 3,000, U.A.E.). It is well-known that fishing was an important historical natural resource in the area, prior to petroleum. Sport-diving and fishing of several types (shoreline and small craft) are popular.

The major fisheries products throughout the Gulf are shrimp snapper, grouper, emperor fish, lobster, crabs, queen fish, needle fish, clams and oysters. The food web has yet to be described for these species with tagging or other tracer techniques. However, clear evidence of Peneus food webs from other similar ocean basin shows early stages migrating into the very shallow seagrass beds where a detrital food web, based on seagrass, is their major food source; adults migrate to spawning grounds. Seagrasses have been shown by Thorhaug & Schroeder (1982) to incorporate metals, either through sediment or water, and to accumulate these, thus becoming an accumulation factor of some of the more toxic contaminants of the food web leading to man.

The nearshore waters and estuaries, particularly in northern Iran, are fisheries nurseries and many of them as well as fishing grounds are close to the fires. The fall-out into large bodies of water from air contaminants has the potential to be a considerable source of pollution. In the U.S.A.'s Great Lakes, more pollutants enter the water from airborne sources than from waterborne sources. If the fallout follows concentric circles around the source and is linear, then a large area of the northern Gulf will receive heavy inputs of contaminants from burning fires. If logarithmic fallout patterns occur, this would be intensified.

The nearshore benthically driven fisheries products include snapper, grouper, clams, oysters, scallops and endangered species of turtles and dugongs. There are also offshore fisheries, some of which have adult stages which feed in coral reefs. There are open-ocean species whose entire life-cycle is spent in the sea -- i.e., tuna. Phytoplankton, which does become contaminated, is the primary producer here.

The marine ecosystems of the Gulf are fragile because of high salinities, being relic at the upper edge of the subtropics and highly restricted in numbers of species. The waters already have 47 times more petroleum than average sea water. It must be understood that the food webs

# SESSION FIVE:

## What Can Be Done? What Can Be Learned?

## THE POTENTIAL ROLE OF ENVIRONMENTAL IMPACT ASSESSMENT (EIA) IN MINIMIZING THE ADVERSE IMPACTS OF THE BURNING OIL FIELDS IN KUWAIT

Dr. Ali Mohammad Khuraibet
Kuwait Institute for Scientific Research

This paper will mainly focus on the approach of the application of Environmental Impact Assessment in terms of the Formulation of a Base Line Study and impact identification, prediction and assessment.

## UN INTER-AGENCY PLAN OF ACTION ADDRESSING THE ENVIRONMENTAL CONSEQUENCES OF THE ARMED CONFLICT OVER KUWAIT

Dr. Makram A. Gerges
United Nations Environment Programme

The UN Inter-agency Plan of Action for the ROPME region, developed by UNEP in co-operation with ROPME, the Regional Organization for the Protection of the Marine Environment of the Kuwait Regional Convention of 1978, was adopted at the Second UN Inter-agency Consultation (Geneva, 14 March 1991).

The Plan of Action is now being implemented by a number of UN and non-UN agencies and organizations under the overall co-ordination of UNEP. Its focus is on four separate but interlinked areas: the coastal and marine environment, the atmosphere, inland terrestrial areas and hazardous wastes. It consists of three distinct phases: the survey phase, the assessment phase and the action plan design phase. Every effort is being made to build on data and information already generated by teams operating in the area, and on initiatives and actions being undertaken by various agencies, organizations and institutions working in the region.

An essential element of the Plan of Action is the establishment of a multi-disciplinary data-base which will contain the data and information collected in the surveys, as well as data from other sources required for the impact assessment.

This presentation reports on the progress achieved so far in the collective UN effort to deal with the environmental consequences of the armed conflict in the region, and describes UNEP's approach to the future development of the plan of action for the mitigation, rehabilitation and protection of the above four environmental areas.

# SPEAKER BIOGRAPHIES

**Mahdi Abdal, Ph.D. and Dhari Al-Ajmi, Ph.D.**
**Kuwait Institute for Scientific Research**

Drs. Abdal and Al-Ajmi have done work in various types of soil in Wisconsin and Tennessee, USA and in Kuwait, focussing mostly on the physical characteristics and soil conservation. They have also managed different projects and tasks related to vegetable production, halophyte, wheat and forges in the avid zone.

**Fatima K. Abdali, Ph.D.**
**Kuwait Institute for Scientific Research**

Dr. Fatima K. Abdali received a Ph.D. in Environmental Health Sciences (majoring in Environmental Chemistry and minoring in Ecological Toxicology & Chemical Oceanography) from the University of Michigan, Ann Arbor in 1990. Dr. Abdali is currently working as an Associate Research Scientist in the Environmental and Earth Sciences Division at the Kuwait Institute for Scientific Research in the Marine Pollution group.

**Adnan Akbar, Ph.D.**
**Kuwait Institute for Scientific Research**

Dr. Adnan Akbar is a Research Associate, Water Resources Division/Hydrology, KISR.

**Dhari Al-Ajmi, Ph.D.**
**Kuwait Institute for Scientific Research**

Dr. Dhari Al-Ajmi has experience in meteorological studies, including the development and utilization of mathematical models to determine dispersion patterns of air pollutants emitted from industrial sources. Dr. Al-Ajmi directed all air pollution and atmospheric studies in the Environmental and Earth Sciences Division in KISR and led several research projects in air pollution modelling, environmental impact assessment, and dispersion of heavy gases.

**Jasem Al-Besharah, Ph.D.**
**Kuwait Institute for Scientific Research**

Dr. Jasem Al-Besharah is the Director of the Petroleum Division at KISR.

**Rumen D. Bojkov, Ph.D.**
**World Meteorological Organization**

Dr. Bojkov has a B.S. in physics from the University of Sofia and a M.Sc. in meteorology and geophysics. He also holds a Ph.D. in physics and mathematics from the University of Moscow and a D.Sc. in atmospheric physics from the University of Rostock.

He began his career as a synoptician in the Bulgarian Meteorological Service (1955-59) and was an assistant and associate professor at the University of Sofia (1960-64). He has held research fellowships in the Canadian Meteorological Service (1960-61, 1965-66) and at the National Center for Atmospheric Research (1966-68). From 1968 to 1969 he was professor of stratospheric physics at the State University of New York at Albany, has served with the World Meteorological Organization as an expert in Egypt on upper-atmosphere research (1969-70) and from 1970 to 1984 was Chief, Atmospheric Sciences Division at the Secretariat in Geneva. From 1984 to 1988 he held the position chief scientist at the Atmospheric Environment Service, Canada and since 1988 has been Chief, Environment Division in the Secretariat of the World Meteorological Organization. In 1988 he was elected secretary of the International Ozone Commission. He is a fellow of the AMS.

Dr. Bojkov has published more than 70 papers on atmospheric circulation and ozone problems, a university text book (1966) and has also initiated and edited dozens of WMO meeting reports, many of which are widely known in the world community of atmospheric sciences.

**Andrew E. Bond**
**U.S. Environmental Protection Agency**

Serves as a chemist on the staff of the Field Measurements and Monitoring Branch, Human Exposure and Field Research Division, of the Atmospheric Research and Exposure Assessment Laboratory, Office of Research and Development, located in Research Triangle Park, North Carolina. Responsible for planning field air pollution monitoring studies, designing and/or modifying air pollution sampling systems, and developing quality assurance techniques for use in the measurement and calibration of a variety of air sampling equipment. A member of the initial eight-member US Interagency Air Assessment Team which visited the Gulf region during March and April 1991, and contributed to the development of the Gulf Regional Air Monitoring Plan (GRAMP).

**Abdallah E. Dabbagh, Ph.D.**
**King Fahd University of Petroleum & Minerals**

Dr. Dabbagh obtained his B.Sc. in Geology, 1968, from the American University of Beirut. His Ph.D. in Geology was obtained in 1975 from the University of North Carolina. He is now an Associate Professor at King Fahd University of Petroleum and Minerals (KFUPM).

exacerbations, the health effects of air pollution and the use of biologic markers of exposure in epidemiologic studies.

**John S. Evans, Sc.D.**
**Harvard University**

Dr. Evans is an associate professor of environmental science and director of the program in environmental health and public policy at Harvard University. He received a B.S.E. in industrial engineering from the University of Michigan, a M.S. in water resources management from the University of Michigan, and a S.M. and Sc.D. in environmental health sciences from Harvard University. Since 1980, he has been involved in efforts to improve the models used to assess the health consequences of nuclear power plant accidents. His other research interests include analysis of the propagation of error in environmental measurements and models, validation of expert scientific judgement, and application of the decision analytic paradigm for assessing the value of information in support of environmental research and control decisions.

Dr. Evans is a member of the American Association for the Advancement of Science, the Society for Risk Analysis, the American Academy of Industrial Hygiene, and Sigma Xi. He serves on the editorial board of Risk Analysis, is past president of the New England Chapter of the Society for Risk Analysis, and was chairman of the Committee on Risk Assessment and Management of the Air Pollution Control Association.

**Nabil M. Fayad, Ph.D.**
**King Fahd University of Petroleum and Minerals**

Dr. Nabil M. Fayad is a research scientist at the Water Resources and Environment Division at the Research Institute of King Fahd University of Petroleum and Minerals. He has a Ph.D. Degree in analytical chemistry in 1979 from Loughborough University of Technology, UK where he had previously obtained his MS degree. His research interests have centered around the investigation of oil pollution, and organic pollutants in the water, marine and air environment.

**Makram Gerges, Ph.D.**
**United Nations Environment Programme**

Dr. Makram Gerges, a Senior Programme Officer at the Oceans and Coastal Areas Programme Activity Centre (OCA/PAC) of the United Nations Environment Programme (UNEP) in Nairobi since 1986, got his M.Sc. in physical oceanography at the Massachusetts Institute of Technology in 1966 and then went on to take a Ph.D. at Moscow State University. Previously, Dr. Gerges worked as field expert and project manager for UNESCO and a long-term consultant to both

**Jerome L. Heffter, Ph.D.**
**NOAA - Air Resources Lab**

Forecasted radioactive fallout from Pacific and Nevada nuclear tests during the 60's to the mid-70's. Researched on long-range transport and dispersion of boundary layer pollutants from the early 70's to the present with emphasis on long-range tracer experiments for model verification, and emergency response modeling procedures for forecasting pollutant and volcanic ash long-range transport and dispersion.

**Tahir Husain, Ph.D.**
**King Fahd University of Petroleum and Minerals**

Dr. Tahir Husain is a Research Engineer-I in the Division of Water Resources and Environment at the Research Institute, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia. He joined the Research Institute in 1979, since then he has been in conducting research in water resources and environmental disciplines. Dr. Husain has also been associated on a part-time basis with the Department of Civil Engineering in graduate teaching and supervision of MS and Ph.D. theses.

Dr. Husain earned his Ph.D. in Civil Engineering from University of British Columbia, Canada in 1979; M.Eng. in Systems Engineering and Management from Asian Institute of Technology, Bangkok, Thailand in 1972, and B.S. in Civil Engineering from Aligarh Muslim University in India in 1969. In 1975, he also completed UNESCO sponsored Postgraduate Certificate Course in Water Resources Management at Water Resources Research Institute (VITUKI) in Budapest, Hungary.

In 1986, Dr. Husain was honored with "Distinguished Researcher" award in recognition of his outstanding performance as the best researcher. In June 1990, the university again honored him with "Distinguished Research Project Leadership" award in recognition of his services as the best project manager at the Research Institute.

**Ali Mohammad Khuraibet, Ph.D.**
**Kuwait Institute for Scientific Research**

Dr. Ali Mohammad Khuraibet received a B.S.C. in zoology from Kuwait University, and went on the receive his M.S.C. and Ph.D. in Environmental Impact Assessment from Aberdeen University, Scotland. Dr. Khuraibet is an Associate Researcher at the Kuwait Institute for Scientific Research and has been listed as an environmental expert with the United Nations Development Program (UNDP) since 1989.

**Prof. Toshiichi Okita**
**Obirin University**

1948: Graduated from Department of Physics, Tohoku University

1948: Assistant, Department of Geophysics, Tohoku University

1952: Assistant Professor, Hokkaido Gakugei University

1961: Head, Laboratory of Industrial Health, National Institute of Public Health

1973: Head, Department of Community Environmental Sciences, National Institute of Public Health

1977: Professor, Department of Sanitary Engineering, Hokkaido University

1983: Director, Division of Atmospheric Environment, National Institute for Environmental Studies

1988: Professor, School of International Studies, Obirin University

**Muhammad Sadiq, Ph.D.**
**King Fahd University of Petroleum and Minerals**

Dr. Sadiq obtained his Ph.D. in Soil Chemistry from Colorado State University in 1977. After graduation, he joined USEPA at Ada, Oklahoma to investigate the movement of sewage-borne metals through soil profiles. He joined the Research Institute of King Fahd University of Petroleum and Minerals in 1979. Since that time, he has been evaluating metal pollution both in the terrestrial and marine environments of Saudi Arabia. Recently, he has been involved in the assessment of metal contamination of air, soil, humans and marine ecosystem from the Gulf War activities. His research interests are metal chemistry, bioaccumulation and toxicity in the terrestrial and marine environments.

**Richard D. Small, Ph.D.**
**Pacific Sierra Research Corporation**

Richard D. Small holds a Ph.D. degree in Aeronautical Engineering (1971) from Rutgers University. He is currently Director of Thermal Sciences and Co-chairman of the Environmental Monitoring and Assessment Program at Pacific-Sierra Research Corporation in Los Angeles, CA. His research interests include fire and smoke physics, dust processes, geography, atmospheric physics, fluid mechanics, and aerodynamics. Dr. Small has written and spoken on environmental impacts of Kuwaiti fires and published extensively on fire effects, smoke in Meteorology from the University of Oklahoma (1970), and a Ph.D. in Atmospheric Sciences from the University of California/Davis in 1982.

**Anitra Thorhaug, Ph.D.**
**Florida International University**

Anitra Thorhaug, Ph.D., C.E.P., Research Professor, Sponsored Program, Florida International University, has received a medal from UNEP for her coastal pollution works in 1981. In 1985, she became one of UNEP's Global 500. For 30 years, she has studied shallow nearshore subtropical and tropical pollution in all regions of the tropics. As an FAO Consultant in 1985-86, in Southeast Asia, she examined fisheries rehabilitation potential. Recently she has studied oil spill and clean up methods in tropical seas. She has worked in the middle east since 1969. Trace metal cycling pollution effects on critical tropical matrix organisms are the subject of a series of her experiments.

**George D. Thurston, Ph.D.**
**New York University**

Dr. Thurston is an Assistant Professor at the New York University Medical Center's Institute of Environmental Medicine. He received his doctorate in Environmental Health Sciences from the Harvard School of Public Health in 1983, and his Bachelor of Sciences degree in Environmental Engineering from Brown University in 1974.

Dr. Thurston's research into the human health effects of ambient air pollution has ranged from field studies of the effects of ambient ozone and acid aerosols on the lung function and health of asthmatic children at summer camps to large-scale epidemiologic studies of cross-sectional associations between particulate matter and U.S. mortality rates. At present, he is the Principal Investigator of a five year NIEHS study of the effects of ambient acidic aerosols on New York State daily hospital admissions for respiratory causes. Prior to joining NYU, Dr. Thurston was a Research Fellow at Harvard's Kennedy School of Government.

**Lance A. Wa[redacted], Ph.D.**
**U.S. Environmental Protection Agency**

Dr. Wallace received his Ph.D. in physics from the City University of New York, following undergraduate work at Caltech and the University of Washington. Since 1977, he has been an environmental scientist at the U.S. Environmental Protection Agency in Washington, DC. His main interest at EPA has been in developing instruments to measure personal exposure and body burden (particularly exhaled breath) for a wide range of environmental pollutants. He conceived and implemented the Total Exposure Assessment Methodology (TEAM) Study, for which he

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October 22, 1991

Dr. Peter C.Hill
United States Department of Commerce
National Oceanic and Atmospheric Administration

Dear Dr. Peter C.Hill

I am a technical officer that have been to the Harvard School of Public Health with Dr. Okita of Obirin University. And I heard that you are collecting data and information about Kuwait Oil Fires.

So, I send our mission's papers and copys which Dr. Okita used for OHP at the conference. The latter is twelve pages(not twenty pages), and used on August 12.

Yours sincerely

立川 裕隆

Hirotaka TACHIKAWA
Unit Chief of Environment Quality Standards
Planning Division
Air Quality Bureau
Environment Agency

# Air Pollution from the Kuwait Oil Fires

August, 1991

Japanese Official Mission

on

the Environmental and Health Effects

of the Oil Fires

## 1. Purpose of Survey

In view of the current situation in Kuwait, where the environmental and health effects of the oil fires there are of great concern, the intent of this survey was to measure air pollution at various sites and to collect related information so as to assist the government of Kuwait in its investigation of countermeasures.

## 2. Duration of Survey

April 25 - May 10, 1991 (Entered Kuwait on April 28, and left on May 6)

## 3. Measurement of Air Pollution

Air pollution was measured by using simplified measuring tools. The items measured and measuring points were as follows. Preliminary measurement of air pollution was performed on April 30. Full-scale measurement was started on May 1, and ended on May 5.

Table 1. Items measured at each measuring point

| Measuring point\Item measured | $SO_2$ | $NO_x$, $NO_2$ | Dust | BaP | CO | $H_2S$ |
|---|---|---|---|---|---|---|
| 1. Ahamadi Hospital | o | o | o | o | o | o |
| 2. Residence in Ahamadi | o | o | * | o | o | o |
| 3. Rigga Hospital | o | o | | | o | |
| 4. Environment preservation dept. | o | o | | o | o | |
| 5. Mansouriya Hospital | o | o | | | o | |
| 6. Northwest side of hotel | o | o | | o | o | |
| 7. Southeast side of hotel | o | o | * | o | o | |
| 8. Jahra Hospital | o | o | | | o | o |
| 9. Northern area of Jahra | o | o | | | o | |

At the points marked with * in the dust column, carbon compounds, anions and heavy metals were also measured.

The measurements revealed that the concentrations of sulfur dioxide and nitrogen dioxide detected by this survey were at levels lower than the environment quality standards of Japan even at their highest values. However, because the measurements were conducted for a short period of time and at a limited number of points, it would be premature to judge that the entire area of Kuwait is at levels free from trouble.

It can be seen from these measurements that the concentration of particle matter is at a considerably high level. The concentration itself is not so high as compared with the concentration level before the war. However, when the constituents of the dust were investigated, it was found that several specimens had concentrations of elementary carbon, which appeared to be soot, exceeding 0.1 $mg/m^3$ (the environment quality standard corresponding to the daily average value for suspended particle matter in Japan). Thus, it is surmised that the crude oil is burning imperfectly. It is known that many of the carbon compounds generated from burning of oil have particle sizes of about 0.5 µm, which easily deposit in the lungs. Therefore, the effects from elementary carbon have to be watched in the future.

It was also observed that the concentration of benz (a) pyrene at Ahamadi was slightly higher than that in major cities in Japan.

Chloride ions and sulfate ions also had high concentrations. If they exist in the form of chloride mist or sulfate mist, their effect on life is of concern. Therefore, it will be necessary to find out in what form they exist.

The concentration of nitrate ions is lower than in Tokyo, while all heavy metals are at less than the lower limits of their detectable values.

Table 2. Measurement results for sulfur dioxide and the like

| | Maximum value [ppm] | Point (measuring and sampling method) | Environment quality standard [ppm] (Japan) | |
|---|---|---|---|---|
| | | | Daily average | Hourly value |
| $SO_2$ | 0.0279 | Residential area in Ahamadi (Lead dioxide method) | 0.04 | 0.1 |
| | 0.0233 | Residential area in Ahamadi (Aerosol sampling unit) | | |
| $NO_x$ | 0.054 | Northwest side of International Hotel 4th floor (Aerosol sampling unit) | - | - |
| $NO_2$ | 0.033 | Southeast side of International Hotel 5th floor (Filter badge) | 0.04 - 0.06 | - |

Table 3. Measurement results for particle matter (at Ahamadi Hospital and residential area in Ahamadi)

| Item | Maximum value | Average value | Geometric mean value | Remarks |
|---|---|---|---|---|
| Total suspended particle (AS) | 1.014 $mg/m^3$ | 0.539 $mg/m^3$ | 0.448 $mg/m^3$ | Environment quality standard in Japan covers particle matter of 10 $\mu m$ or less: Daily average: 0.10 $mg/m^3$ Hourly value : 0.20 $mg/m^3$ |
| Particle matter with particle size of 7 $\mu m$ or less (PD) | 0.952 $mg/m^3$ | 0.514 $mg/m^3$ | 0.444 $mg/m^3$ | |
| Total carbon (AS) | 0.536 $mg/m^3$ | - | | |
| Elementary carbon (AS) | 0.445 $mg/m^3$ | | | |
| Benz(a) pyrene (AS) | 25.5 $ng/m^3$ | 6.3 $ng/m^3$ | 1.2 $ng/m^3$ | Tokyo in 1989 Maximum: 15.2 $ng/m^3$ Average: 2.7 $ng/m^3$ |
| Benz(a) pyrene (PP) | 6.6 $ng/m^3$ | 2.2 $ng/m^3$ | 1.2 $ng/m^3$ | |
| Chloride ion (AS) | 60.1 $\mu g/m^3$ | 12.3 $\mu g/m^3$ | 6.5 $\mu g/m^3$ | Tokyo in 1981 Maximum: 6.2 Average: 3.0 $\mu g/m^3$ |
| Sulfate ion (AS) | 58.2 $\mu g/m^3$ | 16.0 $\mu g/m^3$ | 12.2 $\mu g/m^3$ | Tokyo in 1989 Maximum: 16.1 Average: 6.8 $\mu g/m^3$ |

Note Symbols in ( ) in the item column, which means measuring and sampling method as belows
AS: Aerosol sampling unit
PD: Personal dust sampling set
PP: Personal PAH sampling set

## 4. Situation regarding Damage to Health

According to an analysis of data on emergency outpatients in the three months from January through March, 1991, which was provided by the Health Department, there were 877 and 374 (70.1% : 29.1%) emergency outpatients with asthma, allergic diseases and respiratory diseases before and after the oil fire started on a full scale on February 26. The durations before and after the oil fire were 56 days and 34 days (62.2% : 37.8%), respectively. Thus, it cannot be said that damage to health has increased due to the air pollution from the oil fires.

An investigation of the status of patients at hospitals near the Ahamadi area where the oil wells are burning revealed that the number of patients has not increased significantly as yet after the oil fire.

However, even if there are some effects from air pollution, it may take some time before they are noticed. Therefore, even if the number of patients has not increased as yet, this does not guarantee that the number will not increase in the future. Continuous observation will be required.

Table 4. Comparison of number of emergency outpatients before and after oil fires

| Disease | Asthma and allergic | Respiratory | Digestive | Others | Total |
|---|---|---|---|---|---|
| Before oil fire | 75 | 299 | 268 | 610 | 1,252 (34.5%) |
| After oil fire | 182 | 695 | 465 | 1,031 | 2,373 (65.5%) |
| Subtotal | 257 (7.1%) | 994 (27.4%) | 733 (20.2%) | 1,641 (45.3% ) | 3,625 (100.0%) |

## 5. Suggestions for Future Measures

Based on a comprehensive assessment of the results of the survey, it is strongly recommended that the following measures be put into effect, mainly by the Government of Kuwait.

### (1) Realization of an air pollution monitoring system

It is necessary to ascertain the form of the sulfate ions and the concentrations of volatile organic compounds such as aldehyde and ketone. In addition, a continuous measurement network should be built for fine particle matter and sulfur dioxide, and for sulfate ions, if necessary, and an emergency forecasting system should be instituted based on this network.

Since observations were made at times when the sky was covered with smoke, a wind direction/velocity observation network must be built to study the causes of such conditions.

(2) Implementation of measures against indoor air pollution

Measures to be considered include mounting hoods on ventilation fans at hospitals or households, installing filters, and, if necessary, installing air purification devices with active carbon.

(3) Conducting health surveys of residents

Because the delayed effects of soot or other compounds in the air are a matter of concern in areas near the burning oil wells, it will be necessary to provide a tracing system for observing the progress of the situation for a long period of time, which could include a) preparation of records on hospital outpatients, or b) health surveys of residents near the burning oil wells.

Attachment Table 1. Weather conditions during survey

| Measuring point | Measuring time | Weather | Temperature (°C) | Wind direction | Wind velocity (m/s) |
|---|---|---|---|---|---|
| Southeast side of International Hotel | Apr. 29 15:17 | Clear, but covered with smoke | 34.0 | South-southeast | 2.7 |
| Northwest side of International Hotel | Apr. 29 16:30 | Clear, but covered with smoke | 34.6 | Northwest | 4.7 |
| Southeast side of International Hotel | Apr. 29 17:20 | Clear, but covered with smoke | 34.0 | | |
| | Apr. 29 22:00 | Clear, but covered with smoke | 30.0 | | |
| | Apr. 30 18:30 | Clear, but covered with smoke | 30.6 | | |
| | Apr. 30 18:45 | Clear, but covered with smoke | 30.2 | | |
| | May 1 7:00 | Clear, but covered with smoke | 29.6 | | |
| Environment preservation dept. | May 1 8:40 | Clear, but covered with smoke | 29.2 | Northwest | 1.2 |
| Mansouriye Hospital | May 1 9:15 | Clear, but covered with smoke | 38.6 | Northwest | 1.6 |
| Rigge Hospital | May 1 10:18 | Clear, but covered with smoke | 31.0 | Northwest | 1.2 |
| Residence in Ahamadi area | May 1 12:45 | Clear, but covered with smoke | 32.7 | Northwest | 0.8 |
| | May 1 13:20 | Clear, but covered with smoke | 32.4 | Northwest | 0.8 |
| Ahamadi Hospital | May 1 13:25 | Clear, but covered with smoke | 32.4 | Northwest | 0.6 |
| Jahra Hospital | May 2 9:45 | Covered with smoke (the sun being visible) | 27.8 | Northwest | 3.3 |
| Northern area of Jahra | May 2 11:30 | Clear, but covered with smoke | 28.4 | Northwest | 4.1 |
| Residence in Ahamadi area | May 3 12:00 | Clear, but covered with smoke | 32.4 | Northwest, | 6.0 |
| | May 3 13:00 | Clear, but covered with smoke | 32.0 | Northwest | 4.5 |
| | May 3 14:30 | Clear, but covered with smoke | 32.0 | Northwest | 5.3 |
| | May 3 16:15 | Clear, but covered with smoke | 32.0 | Northwest | 4.8 |
| | May 4 9:30 | Clear, but covered with smoke | 28.8 | Northwest | 4.5 |
| | May 4 10:00 | Clear, but covered with smoke | 28.8 | Northwest | 4.4 |
| | May 4 10:30 | Clear, but covered with smoke | 29.2 | West | 2.7 |
| | May 4 11:00 | Clear, but covered with smoke | 30.9 | West | 2.9 |
| | May 4 11:30 | Clear, but covered with smoke | 31.4 | Northwest | 5.3 |
| | May 4 12:00 | Clear, but covered with smoke | 32.2 | West | 4.2 |
| | May 4 12:30 | Clear, but covered with smoke | 32.8 | West-northwest | 3.3 |
| | May 4 13:00 | Clear, but covered with smoke | 34.0 | Northwest | 3.1 |
| | May 4 13:30 | Clear, but covered with smoke | 33.8 | West | 1.8 |
| | May 4 14:00 | Clear, but covered with smoke | 34.8 | Northwest | 5.1 |
| | May 4 15:49 | Clear, but covered with smoke | 34.6 | West | 4.1 |
| | May 5 12:30 | Clear, but covered with smoke | 36.6 | Northwest | 4.2 |

(Reference)

| Measuring point | Measuring time | Weather | Temperature (°C) | Wind direction | Wind velocity (m/s) |
|---|---|---|---|---|---|
| Dhahran (in running vehicle) | Apr. 28 7:30 | Clear, but with effect of soot | 23.6 | | 5.2 |
| 220 km to Khafji (in running vehicle) | Apr. 28 8:30 | Clear, but with effect of soot | 27.6 | | |
| 150 km to Khafji (in running vehicle) | Apr. 28 9:35 | Clear, but covered with smoke | 29.5 | Northeast | |
| 60 km to Khafji (in running vehicle) | Apr. 28 10:30 | Clear, but covered with smoke | 28.4 | | |
| At Arabian Oil in Khafji, 100 km to inland sea | Apr. 28 11:24 | Clear, but covered with smoke | 27.4 | | |
| At Arabian Oil in Khafji, 100 km to inland sea | Apr. 28 14:00 | Clear, but covered with smoke | 28.0 | Substantially no wind | |

Attachment Table 2. Sulfur dioxide ($SO_2$) measurement results

| Sampling point | Sampling time | Measurement | Measurement results [ppm] |
|---|---|---|---|
| Ahamadi Hospital | 5/ 1 12:45-5/ 5 10:00 | TE | 0.0214 |
| Residence in Ahamadi area | 5/ 1 11:27-5/ 5 9:18 | TE | 0.0062 |
| | 5/ 1 11:20-5/ 5 9:35 | Pb | 0.0279 |
| | 5/ 2 9:59-10:34 | AS | 0.0233 |
| | 5/ 2 10:59-12:01 | AS | 0.0204 |
| | 5/ 2 12:14-13:43 | AS | 0.0182 |
| | 5/ 2 13:57-15:35 | AS | 0.0150 |
| | 5/ 3 9:58-11:48 | AS | 0.0046 |
| | 5/ 3 12:21-14:13 | AS | 0.0060 |
| | 5/ 3 14:30-15:45 | AS | 0.0062 |
| | 5/ 3 16:00-5/ 4 9:20 | AS | 0.0046 |
| | 5/ 4 9:50-12:03 | AS | 0.0084 |
| | 5/ 4 12:30-14:00 | AS | 0.0061 |
| | 5/ 4 14:11-15:41 | AS | 0.0042 |
| | 5/ 4 15:55-5/ 5 9:18 | AS | 0.0025 |
| Rigga Hospital | 5/ 1 10:15-5/ 5 10:55 | TE | 0.0027 |
| Environment reservation dept. | 5/ 1 8:25-5/ 5 8:10 | TE | 0.0014 |
| Mansouriya Hospital | 5/ 1 9:25-5/5 11:50 | TE | 0.0005 |
| Northwest side of International Hotel | 4/29 18:20-5/ 1 7:35 | TE | 0.0005 |
| | 5/ 1 7:35-5/ 5 7:15 | TE | 0.0026 |
| Southeast side of International Hotel | 4/29 17:50-5/ 1 6:55 | TE | <0.0003 |
| | 4/30 15:45-21:45 | AS | 0.0005 |
| | 5/ 1 7:05-5/ 5 6:30 | TE | 0.0110 |
| Jahra Hospital | 5/ 2 9:35-5/ 5 14:33 | TE | 0.0012 |
| Northern area of Jahra | 5/ 2 11:25-5/ 5 14:55 | TE | 0.0004 |

Note: The method of converting measurements by the lead dioxide method (marked with Pb in the measurement column) to ppm yields unfavorable accuracy. However, because the Report by the Environment Agency 1973 suggested multiplying by an average coefficient of 0.032 - 0.036, 0.034 was used here.

Attachment Table 3. Nitrogen oxide ($NO_x$) measurement results

| Sampling point | Sampling time | Measurement | Measurement results [ppm] |
|---|---|---|---|
| Ahamadi Hospital | 5/ 1 12:45-5/ 5 10:00 | TE | 0.044 |
| Residence in Ahamadi area | 5/ 1 11:27-5/ 5 9:18 | TE | 0.003 |
| Rigga Hospital | 5/ 1 10:15-5/ 5 10:55 | TE | 0.008 |
| Environment preservation dept. | 5/ 1 8:25-5/ 5 8:10 | TE | 0.030 |
| Mansouriya Hospital | 5/ 1 9:25-5/ 5 11:50 | TE | 0.041 |
| Northwest side of International Hotel | 4/29 18:20-5/ 1 7:35 | TE | 0.054 |
| | 5/ 1 7:35-5/ 5 7:15 | TE | 0.023 |
| Southeast side of International Hotel | 4/29 17:50-5/ 1 6:55 | TE | 0.040 |
| | 5/ 1 7:05-5/ 5 6:30 | TE | 0.024 |
| Jahra Hospital | 5/ 2 9:35-5/ 5 14:33 | TE | 0.008 |
| Northern area of Jahra | 5/ 2 11:25-5/ 5 14:55 | TE | 0.008 |

Attachment Table 4. Nitrogen dioxide ($NO_2$) measurement result

| Sampling point | Sampling time | Measurement | Measurement results [ppm] |
|---|---|---|---|
| Ahamadi Hospital | 5/ 1 12:45-5/ 3 16:25 | FB | 0.014 |
| | 5/ 3 16:25-5/ 5 10:00 | FB | 0.010 |
| Residence in Ahamadi area | 5/ 1 11:27-5/ 2 10:00 | FB | 0.019 |
| | 5/ 4 10:45-5/ 5 9:34 | FB | 0.003 |
| Rigga Hospital | 5/ 1 10:15-5/ 5 11:50 | FB | 0.022 |
| Environment preservation dept. | 5/ 1 8:35-5/ 5 8:25 | FB | 0.014 |
| Mansouriya Hospital | 5/ 1 8:57-5/ 1 21:27 | FB | 0.024 |
| | 5/ 1 8:57-5/ 2 10:07 | FB | 0.017 |
| | 5/ 1 8:57-5/ 5 13:30 | FB | 0.012 |
| | 5/ 1 9:27-5/ 5 12:30 | FB | 0.015 |
| Northwest side of International Hotel | 5/ 2 7:25-5/ 3 7:30 | FB | 0.003 |
| | 5/ 3 7:10-5/ 4 7:25 | FB | 0.002 |
| | 5/ 4 7:13-5/ 5 7:00 | FB | 0.002 |
| Southeast side of International Hotel | 4/30 19:24-5/ 1 7:10 | FB | 0.002 |
| | 5/ 1 7:10-5/ 2 7:10 | FB | 0.033 |
| | 5/ 2 7:10-5/ 3 7:10 | FB | 0.004 |
| | 5/ 3 7:30-5/ 4 7:13 | FB | 0.001 |
| | 5/ 4 7:25-5/ 5 6:30 | FB | 0.003 |
| Jahra Hospital | 5/ 2 9:35-5/ 5 14:38 | FB | 0.006 |
| Northern area of Jahra | 5/ 2 11:28-5/ 5 14:54 | FB | 0.001 |

(Reference)

| Sampling point | | Sampling time | Measurement | Measurement results [ppm] |
|---|---|---|---|---|
| Individual exposure | Central area in Ahamadi | 5/ 2 10:07-5/ 3 10:30 | FB | 0.012 |
| | Metropolitan area in Kuwait | 5/ 1 10:00-5/ 1 21:00 | FB | 0.034 |
| | | 5/ 1 10:00-5/ 1 21:00 | FB | 0.034 |
| | | 5/ 2 9:00-5/ 2 22:00 | FB | 0.018 |
| | | 5/ 2 9:15-5/ 2 19:20 | FB | 0.014 |
| | | 5/ 2 9:15-5/ 3 7:10 | FB | 0.008 |
| | | 5/ 4 7:30-5/ 5 6:40 | FB | 0.010 |
| Inside (International Hotel) | | 5/ 3 7:18-5/ 4 7:36 | FB | 0.002 |
| Bahrain | | 5/ 6 19:15-5/ 9 7:55 | FB | 0.020 |

Attachment Table 5.  Particle matter measurement results

| Measurement point | Measuring time | Measurement | Dust [mg/m³] | BaP | T-C | I-C | Cl | $SO_4$ | $NO_3$ | V | Cd | Pd |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | [μg/m³] | [μg/m³] | | [μg/m³] | | | [μg/m³] | | |
| Residence in Ahamadi area | 5/ 1 12:07-5/ 2 9:30 | AS | 1.014 | 0.02550 | 536.2 | 445.3 | 20.3 | 25.3 | 3.5 | < 5 | <0.6 | < 6 |
| | 5/ 2 9:59-10:34 | AS | 0.800 | 0.01120 | 394.0 | 311.0 | 60.1 | 58.2 | <11 | <11 | <1.4 | <14 |
| | 5/ 2 10:59-12:01 | AS | 0.387 | 0.00929 | 163.9 | 140.5 | 21.6 | 9.7 | < 6 | < 7 | <0.8 | < 8 |
| | 5/ 2 12:14-13:43 | AS | 0.309 | 0.01230 | 97.9 | 73.4 | 13.8 | 10.0 | < 4 | < 4 | <0.6 | < 6 |
| | 5/ 2 13:57-15:35 | AS | 0.875 | 0.01010 | 151.5 | 92.6 | 16.3 | 20.3 | 4.7 | < 5 | <0.6 | < 6 |
| | 5/ 3 9:58-11:48 | AS | 0.883 | 0.00135 | 51.8 | <42.0 | 3.3 | 15.4 | < 3 | < 3 | <0.3 | < 3 |
| | 5/ 3 12:21-14:13 | AS | 0.463 | <0.00002 | <43.0 | <43.0 | 2.4 | 12.4 | < 3 | < 3 | <0.3 | < 3 |
| | 5/ 3 14:30-15:45 | AS | 0.637 | 0.00600 | <68.0 | <68.0 | 3.6 | 15.2 | < 4 | < 4 | <0.5 | < 5 |
| | 5/ 3 16:00-5/ 4 9:20 | AS | 0.339 | 0.00057 | 51.2 | 44.7 | 2.9 | 9.9 | 0.6 | <0.5 | <0.1 | < 1 |
| | 5/ 4 9:50-12:03 | AS | 0.739 | 0.00500 | 130.0 | <97.0 | 6.5 | 17.0 | < 6 | < 6 | <0.8 | < 8 |
| | 5/ 4 12:30-14:00 | AS | 0.250 | <0.00003 | <72.0 | <72.0 | 6.4 | 6.2 | < 4 | < 4 | <0.6 | < 6 |
| | 5/ 4 14:11-15:41 | AS | 0.211 | <0.00003 | <72.0 | <72.0 | 1.5 | 5.1 | < 4 | < 4 | <0.6 | < 6 |
| | 5/ 4 15:55-5/ 5 9:18 | AS | 0.101 | 0.00045 | 24.8 | 16.4 | 1.1 | 3.1 | 0.2 | < 0.2 | <0.03 | <0.3 |
| Southeast side of International Hotel | 4/30 15:45-21:45 | AS | 1.000 | <0.00010 | <342.0 | <342.0 | 7.0 | 33.7 | <21 | <20 | <2.5 | <25 |
| Ahamadi Hospital | 5/ 3 16:38-5/ 5 9:56 | PP | - | 0.00253 | - | - | - | - | | | | |
| Residence in Ahamadi area | 5/ 1 12:00-5/ 2 10:25 | PP | - | 0.00657 | - | - | - | - | - | - | - | - |
| | 5/ 2 9:44-5/ 3 15:45 | PP | - | 0.00103 | - | - | - | - | - | - | - | - |
| | 5/ 3 10:30-5/ 4 9:35 | PP | - | 0.00074 | - | - | - | - | - | - | - | - |
| | 5/ 3 15:58-5/ 5 9:27 | PP | | 0.00041 | - | - | - | - | - | - | - | - |
| Environment preservation dept. | 5/ 1 8:30-5/ 2 8:35 | PP | - | 0.00003 | - | - | - | - | - | - | - | - |
| | 5/ 3 8:00-5/ 4 8:00 | PP | - | 0.00008 | - | - | - | - | - | - | - | - |
| | 5/ 4 8:08-5/ 5 8:10 | PP | - | 0.00005 | - | - | - | - | - | - | - | - |
| Northwest side of International Hotel | 5/ 1 7:40-15:50 | PP | - | 0.00018 | - | - | - | - | - | - | - | - |
| | 5/ 1 16:10-5/ 2 7:00 | PP | - | 0.00096 | - | - | - | - | - | - | - | - |
| | 5/ 2 7:00-5/ 3 7:25 | PP | - | 0.00032 | - | - | - | - | - | - | - | - |
| | 5/ 3 7:25-5/ 4 7:05 | PP | - | 0.00009 | - | - | - | - | - | - | - | - |
| | 5/ 4 7:10-5/ 5 7:10 | PP | - | 0.00005 | - | - | - | - | - | - | - | - |
| Southeast side of International Hotel | 4/29 15:00-4/30 18:30 | PP | - | 0.00009 | - | - | - | - | - | - | - | - |
| | 4/30 18:45-5/ 1 7:00 | PP | - | 0.00069 | - | - | - | - | - | - | - | - |
| | 5/ 1 7:15-5/ 2 7:15 | PP | - | 0.00011 | - | - | - | - | - | - | - | - |
| | 5/ 2 7:21-5/ 3 7:05 | PP | - | 0.00030 | - | - | - | - | - | - | - | - |
| | 5/ 3 7:05-5/ 4 7:22 | PP | - | 0.00005 | - | - | - | - | - | - | - | - |
| | 5/ 4 7:27-5/ 5 6:30 | PP | - | 0.00004 | - | - | - | - | - | - | - | - |
| Ahamadi Hospital | 5/ 1 9:31-11:07 | PD | 0.151 | - | - | - | - | - | - | - | - | - |
| | 5/ 1 13:30-13:40 | PD | 0.420 | - | - | - | - | - | - | - | - | - |

| | Measuring time | Measure-ment | Dust [mg/m³] | BaP | T-C | I-C | Cl | $SO_4$ | $NO_3$ | V | Cd | Pd |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | [μg/m³] | [μg/m³] | | [μg/m³] | | | [μg/m³] | | |
| Residence in Ahamadi area | 5/ 1 12:11-12:21 | PD | 0.190 | - | - | - | - | - | - | - | - | - |
| | 5/ 1 12:31-12:41 | PD | 0.740 | - | - | - | - | - | - | - | - | - |
| | 5/ 1 12:36-13:34 | PD | 0.300 | - | - | - | - | - | - | - | - | - |
| | 5/ 1 14:03-14:25 | PD | 0.636 | - | - | - | - | - | - | - | - | - |
| | 5/ 1 14:10-15:43 | PD | 0.409 | - | - | - | - | - | - | - | - | - |
| | 5/ 2 9:41-10:03 | PD | 0.952 | - | - | - | - | - | - | - | - | - |
| | 5/ 2 10:08-11:09 | PD | 0.576 | - | - | - | - | - | - | - | - | - |
| | 5/ 2 12:03-12:13 | PD | 0.669 | - | - | - | - | - | - | - | - | - |
| | 5/ 2 12:20-12:31 | PD | 0.706 | - | - | - | - | - | - | - | - | - |
| | 5/ 2 12:45-12:55 | PD | 0.750 | - | - | - | - | - | - | - | - | - |
| | 5/ 2 12:57-13:10 | PD | 0.280 | - | - | - | - | - | - | - | - | - |
| | 5/ 2 13:49-13:59 | PD | 0.302 | - | - | - | - | - | - | - | - | - |
| | 5/ 2 14:12-14:22 | PD | 0.418 | - | - | - | - | - | - | - | - | - |
| | 5/ 2 15:08-15:18 | PD | 0.946 | - | - | - | - | - | - | - | - | - |
| | 5/ 2 15:20-15:31 | PD | 0.756 | - | - | - | - | - | - | - | - | - |
| | 5/ 4 10:30-12:10 | PD | 0.346 | - | - | - | - | - | - | - | - | - |
| | 5/ 4 12:15-15:52 | PD | 0.133 | - | - | - | - | - | - | - | - | - |
| Southeast side of International Hotel | 4/29 10:25-11:25 | PD | 0.000 | - | - | - | - | - | - | | - | - |

(Reference)

| Sampling point | Sampling time | Measurement | Dust [mg/m³] | BaP [μg/m³] |
|---|---|---|---|---|
| Khafji-burning oil well side- metropolitan area in Kuwait | 4/28 14:00-4/29 15:00 | PP | - | 0.00007 |
| On the premises of Arabian Oil in Khafji | 4/28 12:03-13:42 | PP | - | <0.00009 |
| On the premises of Arabian Oil in Khafji | 4/28 11:48-12:05 | PD | 0.035 | - |
| 230 km to Khafji (in running vehicle) | 4/28 8:13- 8:28 | PD | 0.573 | - |
| On the road from Khafji to Dhahran (in running vehicle) | 4/28 7:39- 7:59 | PD | 0.837 | - |
| Inside (residence in Ahamadi area) | 5/ 2 12:07-12:27 | PD | 0.[illegible] | - |
| | 5/ 2 12:42-13:02 | PD | 0.262 | - |
| | 5/ 2 14:16-14:41 | PD | 0.204 | - |
| | 5/ 2 15:13-15:33 | PD | 0.538 | - |
| | 5/ 3 14:53-15:23 | PD | 0.058 | - |

Note 1: BaP represents benz (a) pyrene, T-C total carbon, I-C inorganic carbon.

Note 2: With the personal dust sampling unit method, all dusts with particle sizes of 7 μm or less are eliminated but they remain in other sampling methods.

DRAFT

# IMPACT OF OIL WELL FIRES ON AIR QUALITY IN THE URBAN AREAS OF KUWAIT

## I. POLLUTION BY PARTICULATES LESS THAN 10u


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Ministry of Public Health

Kuwait



August 1991

# IMPACT OF OIL WELL FIRES ON AIR QUALITY IN THE URBAN AREAS OF KUWAIT

## I. POLLUTION BY PARTICULATES LESS THAN 10u

### INTRODUCTION

Particulates in air constitutes a wellknown health hazard. The association of the particulates with the $SO_2$ as the principal pollutant is well documented (WHO, 1990). Kuwait had always suffered of high particulate loads (El Desouky et al, 1985). However a large proportion of the particulates are derived from the soil.

The relation of the particulates load and the health impacts was discussed by the WHO working group on Assessment of Risks to health from Smog Episodes. The level of 24 hour average concentration of 200 $ug/m^3$ particulates is believed to be associated with small, transient decrements in lung function (FVC, $FEV_1$) in children and adults, which may last for 2-4 weeks.

The magnitude of the effect is in the order of 2-4% of the group mean and is classified moderate. When the concentration is 250 $ug/m^3$ (black smoke), the health effect would be increase in respiratory morbidity among susceptible adults (chronic bronchitis) and possibly children. The overall effects are moderate. Increase in mortality among elderly and chronically ill people are associated with levels of 500 $ug/m^3$ and the effect is classified as severe (WHO, 1990).

The US EPA uses slightly different criteria. The national air quality standard is taken as 150 $ug/m^3$ TSP. The alert level is 350 $ug/m^3$. At this level mild aggravation of symptoms is experienced by susceptible persons. Irritation symptoms are reported in the healthy population. Persons with existing heart or respiratory ailments are advised to reduce physical exertion and outdoor activity. The warning level is 420 $ug/m^3$. This is associated with significant aggravation of symptoms and decreased exercise tolerance in persons with heart or lung disease, with widespread symptoms in the healthy population. At this level, elderly and persons with existing heart or lung disease should stay indoors and reduce physical activity.

The level of 600 $ug/m^3$ is classified as being associated with significant harm. At this level, premature death of ill and elderly is seen and healthy people experience adverse symptoms that affect their normal activity. All persons should remain indoors, keeping windows and doors closed and minimize physical exertion. Starting from 1987, the PM-10 reference method, given in the Code of Federal Regulations (40 CFR 50, Appendix J), replaced the total suspended particulate (TSP) standard to focus concern and control from the larger particulates to the more health-threatening, respirable particulates.

In Kuwait, a large volume of information is available as a result of the data collected about the dust. Information about dust fall were collected from 12 sites. TSP samples were collected since 1980 from 4 sites covering the urban areas. The data have been reported to GEMS since 1980. The geographic distribution shows that the commercial residential area had relatively higher particulates load (699.5 $ug/m^3$). However, the correlation between the values reported in the different sites was quite high. It ranged between ($r = .875$ and .966).

Monthly variability was quite evident with very high loads in June (1191.6 $ug/m^3$). The minimum was seen in December (318.6 $ug/m^3$). Friday the weekend had slightly lower mean (574.3 $ug/m^3$). Weather conditions had a marked impact on the particulates load. The mean with the dust storms (1852.0 $ug/m^3$) was much higher than that with rising sand (868 $ug/m^3$), dust in suspension (638 $ug/m^3$) or dust haze (397 $ug/m^3$).

The particle sizes, taken by Andersen head, from different sites showed seasonal variability similar to that seen for the TSP. This was also seen with the weather phenomena. The clear weather had 141.9 ug/m$^3$ of 7 microns or over and 87.2 ug/m$^3$ of <1.1 micron (61.5%). With dust storms, the corresponding values were 910.2 and 698.0 ug/m$^3$ (76.7%).

Starting from 1989, The high volume TSP was replaced by PM10 smaplers. The samplers were used to investigate the particulate loads resulting from the quarries operation and the contribution of offroad vehicles to the particulate loads. They were installed on jeeps and provided with mobile generators to provide the needed power. In Kuwait, the health significance of the particulates and its chemical composition is expected to be quite different from the types seen in Europe, USA, Japan or other industrialised countries (Bennett et al, 1985).

The programme was interrupted on the 2nd of August 1990 when Iraq invaded Kuwait. Two of the 3 PM10 samples were taken away together with the jeeps and the generators. The programme was restarted by the end of April 1991. However we went back to the TSP. The samplers were installed at the general hospitals where power was available. The sites were different from what was used before. The samples were analysed for trace metals and organics at the EPD lab. Some of the samples were sent to the USA & UK for quality control.

Several teams visited Kuwait in the last few months and took air samples in an attempt to assess the pollution problem resulting from the well fires. The US EPA took samples from 2 urban sites, namely the US Embassy and Um Al Heiman. At the Embassy, the levels were 10 and 55 ug/m$^3$. At the other site, 320 ug/m$^3$ was reported. The other sites were mostly in the oil fields. Though a number of samples were taken at Ahmadi Hospital, the levels were variable and ranged from 120 to 935 ug/m$^3$. A group from Harvard School of Public Health and another from Japan took samples, but they were purely interested in toxicity testing rather than assessment of the total particulate load.

MATERIAL & METHODS

The study is designed to examine the distribution of the respirable particulates in the area to the east and north of the Burgan oilfield. The original design included a point to the south east at Al Zoor and another point in the immediate vicinity of the field but no suitable or safe site could be found at the time the investigation started. The sites used for sampling are shown in Fig. (1).

The samplers used are the portable PM10 designed by Dr. John Scheweiss of US EPA. The equipment was given to EPD as a loan by the courtesy of the US EPA as a part of the US Gulf Air Monitoring Programme covering Saudi Arabia, Kuwait, Bahrain, and Qatar. The samplers are battery operated and have a constant rate of 5 liters/min. The air is passed through pretreated, dried, and weighed Whatman Ultrapure quarts filter paper.

The sampling programme covered 10 weeks (1 May - 10 July). The samples were taken daily starting around 9 A.M. and the samplers were run for 24 hours. The samplers are provided by timers and a digital counter for the total volume of air handled by the samplers. The samplers were calibrated by the EPA before being delivered and the behaviour of each of the samplers were cross checked by running each for a fixed time (30 min.) several times and the consistency of the sampler was determined. Two samplers were also run together in the lab. This was also repeated in the field by taking particulate sa ples by rotating one of samplers among the sites.

The investigation is a part of the more extensive one which inc udes running three fixed Sierra PM10s, two TSP, one Andersen head and several dustfall buckets. Almost half of the samples (collected on the even days) were sent to the States for analysis of the trace metals and the organics. The results are not yet a ailable and the local capabilities which were severely crippled as a result of the Iraqi invasion is being upgraded to handle the other

other half of the filters as a quality check. The present report will be limited to the discussion of the weights at the different sites and the factors that probably influenced the results.

RESULTS:

The mean concentration of PM10 reported for the different sampling sites is shown in Table (1). Ahmadi had the highest particulate load (338.3 $ugm/m^3$) followed by Fahaheel (309.9 $ugm/m^3$). The lowest was in Salmiya (249.6 $ugm/m^3$). The levels seen for Farwaniya (256.8 $ugm/m^3$) was slightly lower than that for Andalus (273.9 $ugm/m^3$). It is interesting to note that apart from Ahmadi and Fahaheel the mean for the other sites was lower than the overall mean.

Table (1)

The mean concentration of the PM10
according to the location

| Location | Mean | S.d. | No. |
|---|---|---|---|
| Salmiya | 249.6 | 330.2 | 55 |
| Fahaheel | 309.9 | 257.1 | 66 |
| Ahmadi | 338.3 | 304.3 | 69 |
| Farwaniya | 256.8 | 284.3 | 66 |
| Andalus | 273.9 | 354.8 | 67 |
| Total | 287.4 | 307.3 | 323 |

The correlation between the daily particulates load at the 5 sites is shown in Table (2). The highly significant positive correlation points to the tendency of the values to change in the same direction due to the presence of a number of factors affecting the different sites in a similar way. The proximity of the sites should be considered. It is interesting to note that relatively higher correlation was found between Fahaheel and Ahmadi (r =.929), both in the proximity of the major oil field. The relatively weak correlation between Salmiya and the other sites (.851-.890) could also be explained by the presence of the site on a promontory projecting into the Gulf relatively away from the direct impact of the plume. The correlation between the particulates load between Farwania and Andalus (.929) was also quite high. Both sites are to the north of the Burgan field.

Table (2)

Correlation coefficient matrix between the PM10 recorded at the various sampling sites.

| | Salmia | Fahaheel | Ahmadi | Farwania | Andalus |
|---|---|---|---|---|---|
| Salmia | - | - | - | - | - |
| Fahaheel | .851 | - | - | - | - |
| Ahmadi | .895 | .929 | - | - | - |
| Farwania | .890 | .883 | .924 | - | - |
| Andalus | .895 | .888 | .890 | .933 | - |

The daily mean in micrograms/m$^3$ for the 5 sites is shown in Fig. (2). The data for the individual sites are found in the Appendix. The overall mean for the whole period was 287.4 ugm/m$^3$. Much higher levels were seen on 17 and 22nd May. The level was also higher than the overall mean in the period 20-25 of June and around the 9th of July.

Various factors would influence the daily fluctuations in the particulates concentration. Wind speed is probably the most important. Strong winds are likely to ventilate the plume and thus lower the concentration. It is also known that it would stir up the soil and cause the suspension of soil dust into the air.

The overall mean concentration according to the wind speed is shown in Table (3). With calm wind the concentration (299.4 ugm/$^3$) was slightly higher than the concentration with stronger winds and this was seen up to 4 m/s. The drop was quite steady and persistent, though the difference was quite small.

Table (3)

The mean concentration of the PM10 according to the wind speed

| Wind Speed (m/s) | Mean | S.d. | No. |
|---|---|---|---|
| <2 | 299.4 | 172.9 | 42 |
| 2- | 288.8 | 188.2 | 86 |
| 3- | 278.6 | 440.2 | 107 |
| 4- | 263.9 | 267.3 | 105 |
| 5+ | 367.1 | 267.7 | 29 |

With the strongest winds (5 m/s or more) the concentration was appreciably higher (307.1 ugm/$^3$). These are the days shown as a peak on the graph Fig. (2). Sand storms are frequently seen in the summer months in Kuwait and they are known to be accompanied by heavy particulate loads (El Desouky et al, 1985). The dust storms by definition are accompanied by strong wind and diminished visibility due to the dust obstructing sunlight. Unfortunately no differentiation according to the weather phenomena is possible because the Meteorological Department is not functioining at the time being.

Table (4)

The correlation coefficient between the total particulates load (PM10) and the mean wind speed recorded at the different AQ Stations.

| Location | Total | Exc. 5m/s |
|---|---|---|
| Salmia | .075 | -.047 |
| Fahaheel | -.115 | -.138 |
| Ahmadi | -.097 | -.019 |
| Farwania | -.030 | -.079 |
| Andalus | .017 | -.036 |
| Total | -.029 | -.089 |

The correlation between the wind speed and the overall mean particulate load in the different locations is shown in Table (4). The correlation coefficient was calculated for the total samples and after excluding the days in which the wind speed was 5 m/s or higher the difference is quite clear. With the total, the overall mean gave a week negative correlation (-.029). A week negative correlation is also reported for Fahaheel (-.115), Ahmadi (-.097) and Farwania (-.030). These 3 sites are nearer to the principal oilfield on fire. An insignificant positive correlation was found in the more remote areas (Salmiya = .075 and Andalus = .017).

Excluding the cases in which the wind speed was 5 m/s or over, the picture changed slightly. The correlation was negative and this was seen for all the sites. Relatively stronger coefficient of correlation was seen with Fahaheel (-.138) and Farwania (-.079). This is quite different from what is expected and what was previously reported for the last years. The effect of the plume is influencing the picture to a great extent.

A significant negative correlation was seen between the daily particualte load and the level of the solar radiation reported at the Mansoria air pollution monitoring station (-.350**) and with the UV (-.397). This is an indication of the plume passing over the monitoring site. No solar measurements are available at Reqa station which is more close to the oilfield. The correlation between the intensity of the solar radiation and UV is shown in Fig. (3-A & B). The coefficient with the solar was (-.350) and with the UV (-.397). This is much higher than the correlation between the wind speed. The significant correlation shows clearly the higher concentration of the particulates with the drop in both the UV and solar radiation due to the passing plume.

The other factor that is relevant is the wind direction. The effect will show in the geographical distribution of the particulates. The data for the wind direction is available from the measurement done by the air pollution monitoring stations at Mansoria and Reqa. The prevailing wind direction is not always similar the 2 sites due to the influence of the heat islands. The distribution of the overall concentration reported for the 5 sites according to the wind direction reported for Mansoria is shown in Fig. (4-A).

The concentration was quite low with winds blowing from the west (2.33 ugm/$m^3$), NW (253.7 ugm/$m^3$) or the east (264.7 ugm/$m^3$). The highest was seen with the northerly winds (650.2 ugm/$m^3$). This was significantly higher than the lowest 3 means. With the winds blowing from the SE, and the SW which is the direction of the Burgan oilfield, the concentrations were quite high, though they were not significantly different from the concentration recorded with the west, NW or easterly winds.

A similar picture is seen with the wind direction reported for Reqa (Fig. 4-B). Higher overall mean was seen with winds blowing from the NW (729.3 ugm/$m^3$). This was significantly higher than the means reported with the NW (149.3 ugm/$m^3$), the SW (194.3

ugm/$^3$), the west (280.0 ugm/$m^3$) or the north (313.8 ugm/$m^3$). The NW winds is not likely to bring the plume in the direction of the sites. The southerly winds isthe most likely candidate. The mean with this direction (633.3 ugm/$m^3$) was appreciably higher than that reported with any other wind direction except for the NE.

The concentration of the level at each of the sampling sites with the wind direction recorded at both the Mansoria and Reqa is shown in the Appendix.

The colour of the filter paper is quite important. The smoke coming from the well fires is likely to give the filter papers a black colour. Less heavy loads is likely to give the filter papers a grey colour. The overall mean concentration according to the colour of the filter paper is shown in Fig. (5). The colour of some of the filters was not changed appreciably and these were termed white. These had the lowest overall mean (117.9 ugm/$m^3$). The grey filters came next with almost double the load (257.7 ugm/$m^3$).

The brown filters had the highest particulate load (1388.0 ugm/$m^3$). This was significantly higher than the mean with all the other colours. It is interesting to note that the number of filters with this colour did not exceed 8 cases. The black filters had a mean of 295.2 ugm/$m^3$ and this was significantly higher than that for the white filters. It is interesting to note that the filters which had a light colour that could not be assigned to either grey or brown, had a higher mean (278.8 ugm/$m^3$) compared to the grey (257.7 ugm/$m^3$). The contribution of the soil dust is disturbing the picture very much. It was expected to find the highest loads with the black filters, followed by the grey, the light and the white. However, the colour of the sand is covering up the black tinge of the filters and causing a rather inconsistent distribution pattern.

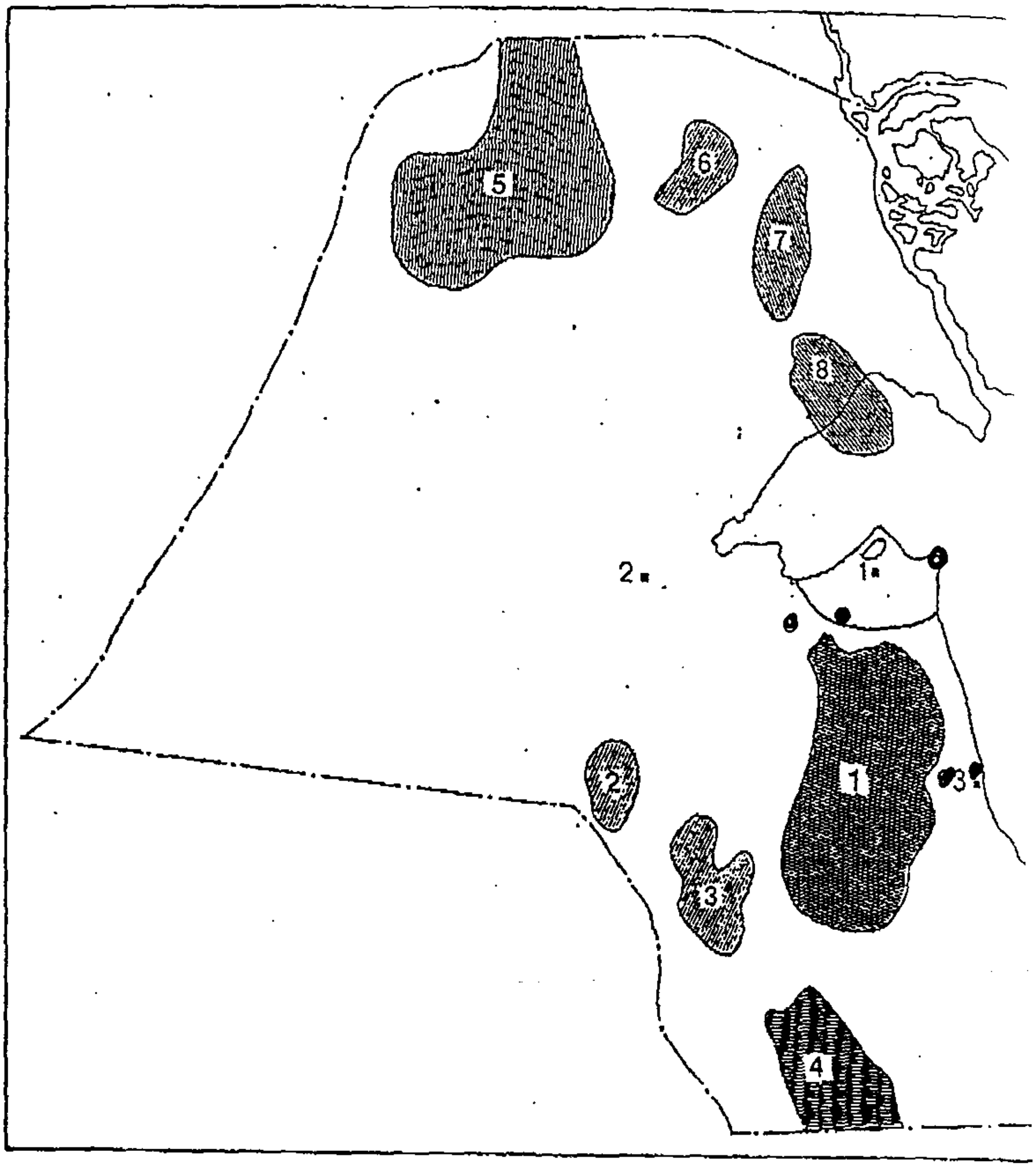
## DISCUSSION:

Kuwait always had a heavy particulates load, mainly due to the prevalence of sand and dust storms. The arid climate, the scorching hot summer, the extensive sand sheets, and the fresh winds are contributing factors. The anthropogenic factors as the overgrassing of sheep, offroad vehicles and quarrying for gravel and sand are disturbing the surface sand making it much more friable and prone to saltation by the wind. Added to this background is the particulates load resulting from the oil well fires.

The magnitude of the problem is not clear, and estimates of the amount of smoke varies widely, according to the quantity of oil burned and the emission rate. The rates range between 5-15 gm/kg of oil burnt. Based on the official figure of 6 m barrels, between 30-90 thousand tons of smoke is being emitted into the air daily. The impact on the level of particulates on the ground level is a matter of speculation. With the plume rising to 2-3,000 of meters, the contribution of the particulates load on the ground is likely to be much smaller than what would be expected.

The samplers used in this investigation are rather new, and have never been tested in a hostile environment and hot climate like that in the summer in Kuwait, but they behaved in a very reliable manner. The variability within the samplers and the consistency of the different samplers and their tolerance is worth mention. The reading taken by the samplers correlated well with the Fixed PM10 and more samples are being taken at the moment.

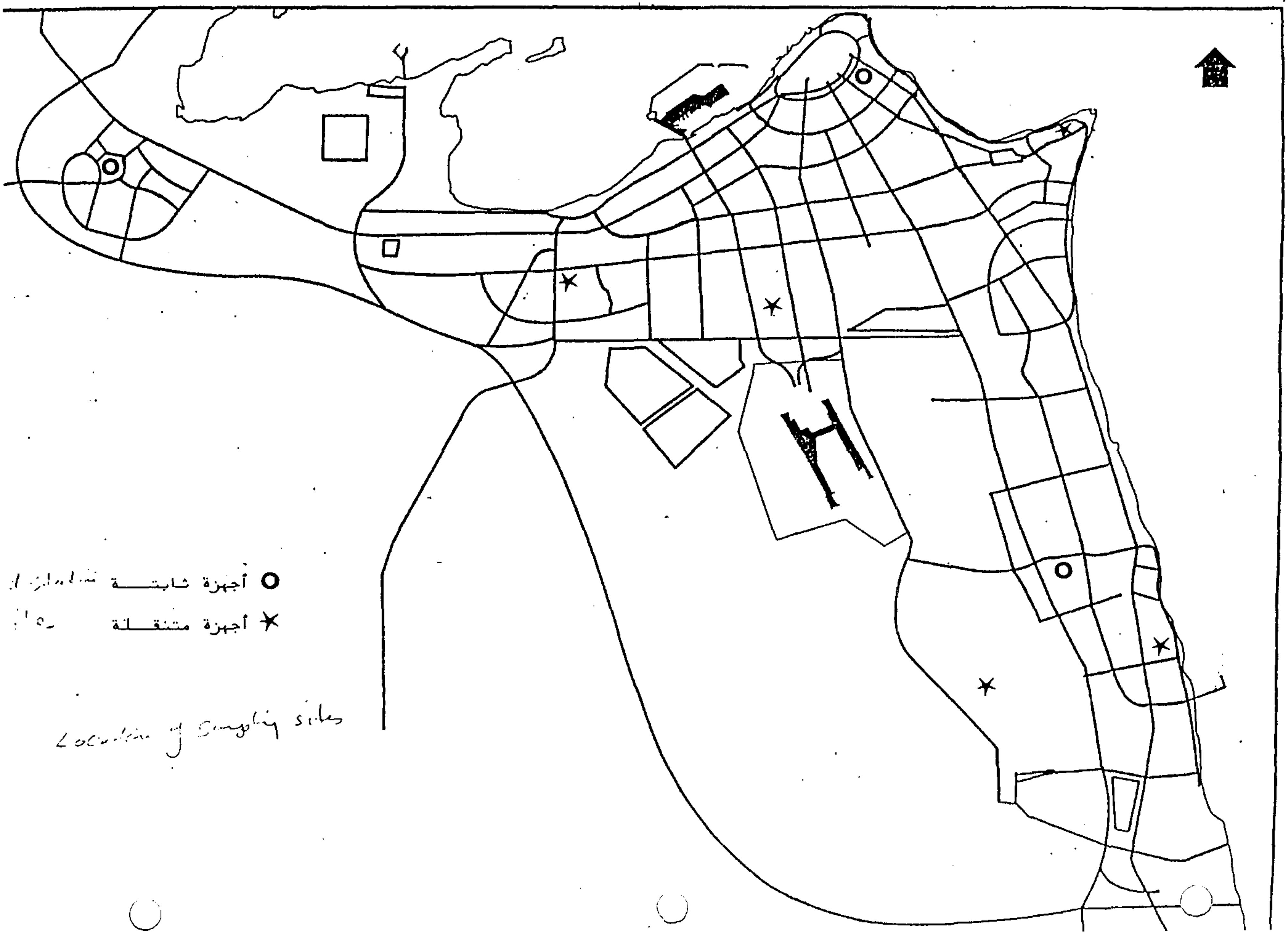
The influence of the well fire on the particulates load is quite substantial. This could be calculated from the negative correlation between the wind speed and the weight of the particulates which is very much different from what was reported in the previous years where a very strong positive correlation was reported (El Desouky et al, 1985). The positive correlation between the particulates load and the drop in the intensity of the solar radiation would further support this point. The levels reported here are within the range found out by the US EPA though they were merely source related.



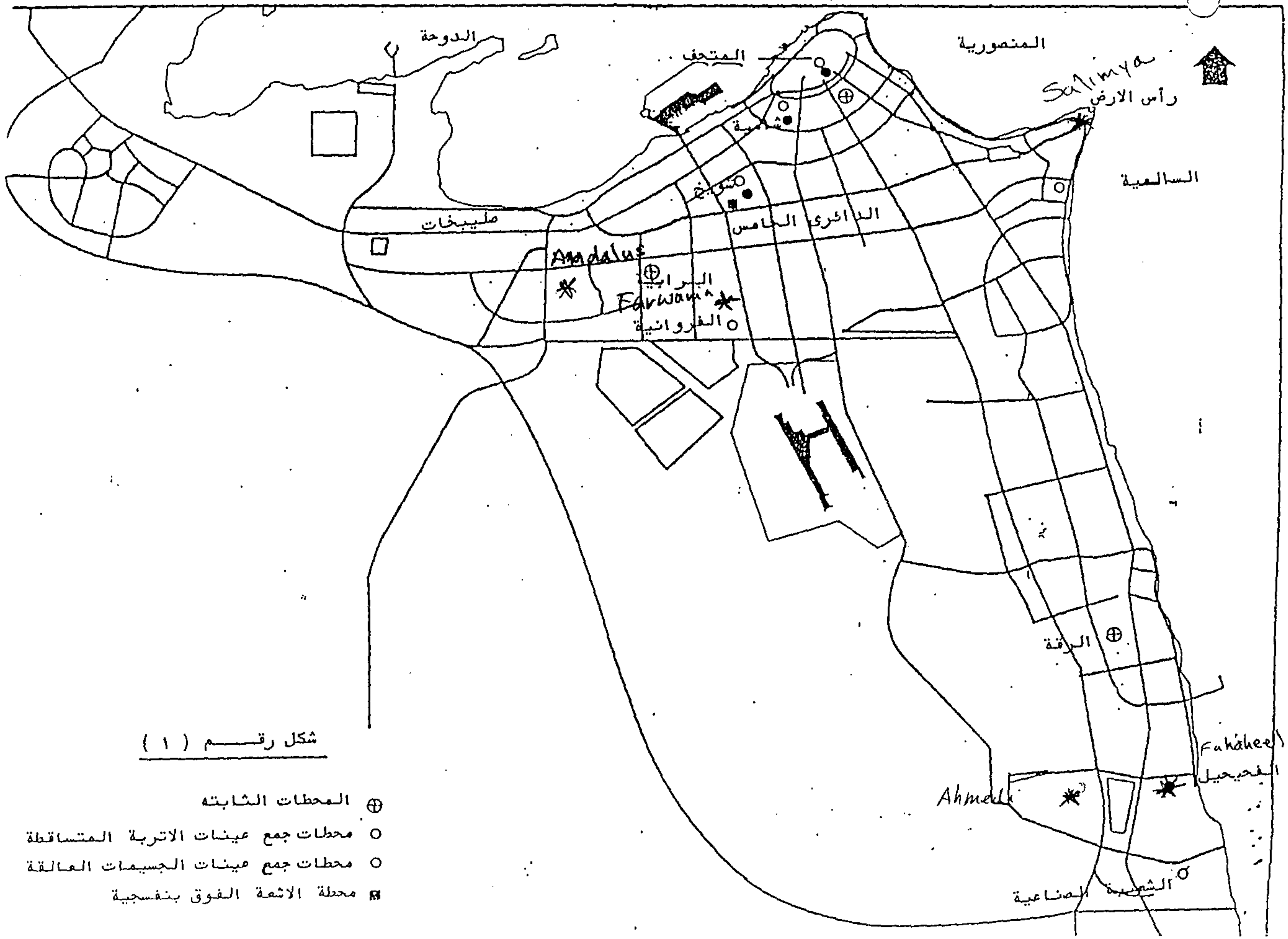
Oil Field
1. Burqan
2. Manakeesh
3. Um-Qudair
4. Wafra
5. Mutreba
6. Rawdatain
7. Sabriya
8. Bahra

Distr
1. Man
2. Jah
3. Faha
4. Khee

Location of sampling sights relative
Burgan field



أجهزة ثابتة
أجهزة متنقلة
Location of Sampling sites

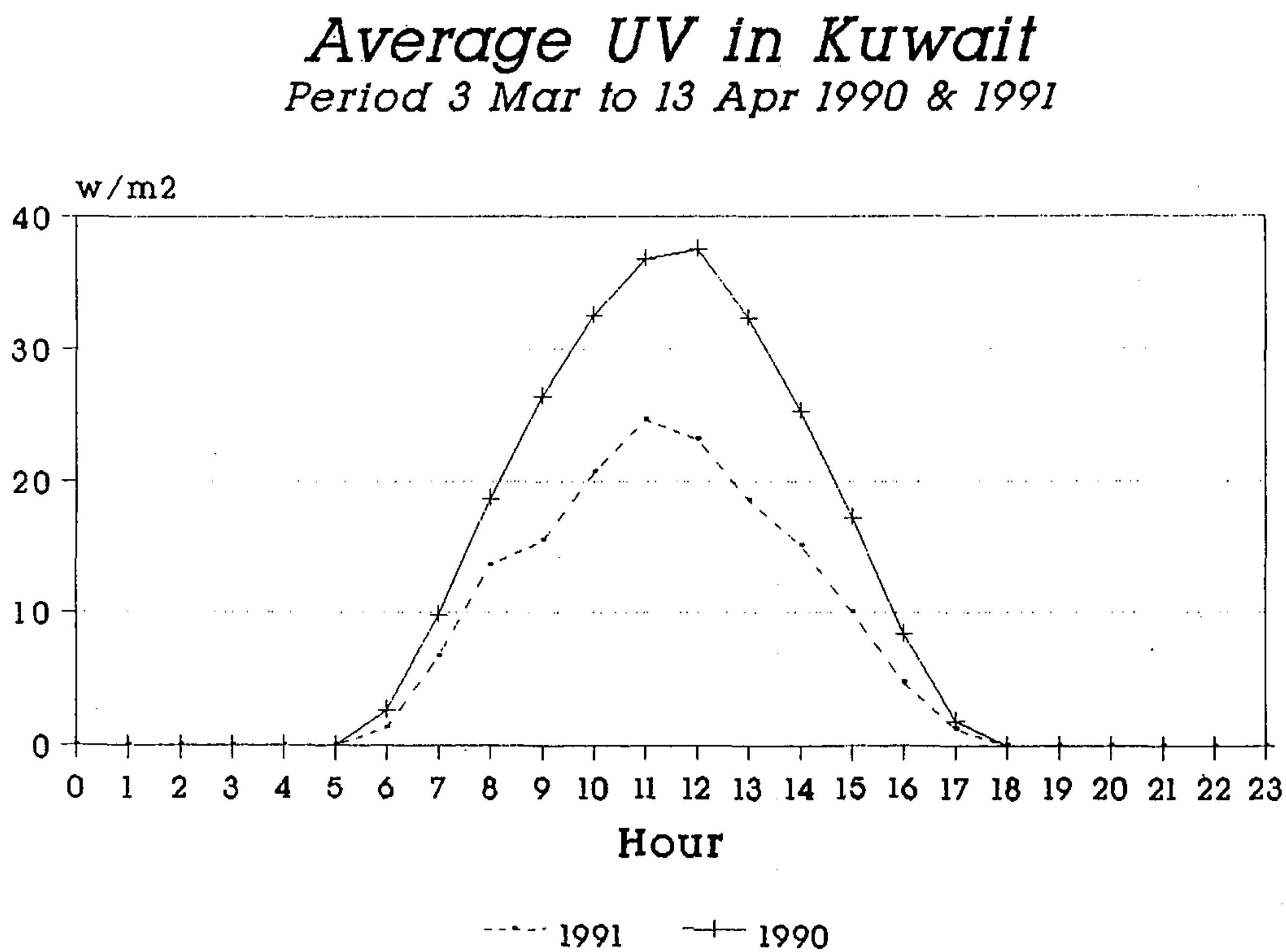


الدوحة
المتحف
المنصورية
Salimya
رأس الارض
السالمية
شامية
شويخ
الدائري الخامس
صليبخات
Andalus
الرابية
Farwania
الفروانية
الرقة
Fahaheel
الفحيحيل
Ahmedi
الشعيبة الصناعية
المحطات الثابته
محطات جمع عينات الاتربة المتساقطة
محطات جمع عينات الجسيمات العالقة
محطة الاشعة الفوق بنفسجية


شكل رقم ( ١ )

Table 1A: Daily mean PM10 loads
May - July 1991.

| Date | May | | June | | July | |
|---|---|---|---|---|---|---|
| | Mean | S.d. | Mean | S.d. | Mean | S.d. |
| 1 | 367.4 | 259.4 | 67.3 | 47.7 | 144.6 | 82.2 |
| 2 | 530.4 | 152.1 | 117.0 | 17.1 | 46.8 | 40.5 |
| 3 | 340.3 | 0.0 | 52.9 | 38.4 | 227.3 | 36.1 |
| 4 | 163.7 | 46.7 | 246.5 | 39.3 | 344.9 | 43.3 |
| 5 | 176.9 | 119.1 | •422.6 | 75.3 | 193.5 | 16.7 |
| 6 | 133.2 | 60.9 | 282.0 | 52.6 | 189.9 | 43.8 |
| 7 | 261.8 | 220.9 | 195.6 | 48.2 | 257.4 | 44.7 |
| 8 | 278.6 | 107.8 | 102.7 | 28.6 | • 675.2 | 115.0 |
| 9 | 167.4 | 184.7 | 105.5 | 50.7 | • 393.6 | 77.0 |
| 10 | 292.0 | 74.3 | 135.8 | 39.0 | 254.3 | 45.3 |
| 11 | 127.3 | 45.7 | 189.9 | 58.7 | | |
| 12 | 255.9 | 114.3 | 117.9 | 16.5 | | |
| 13 | 244.1 | 121.4 | 171.5 | 26.5 | | |
| 14 | 338.5 | 171.6 | 218.1 | 117.4 | | |
| 15 | 136.7 | 15.7 | 174.8 | 50.8 | | |
| 16 | 633.3 | 204.8 | 200.3 | 29.6 | | |
| • 17 | 1329.7 | 275.4 | •631.5 | 344.8 | | |
| 18 | 289.5 | 42.9 | 273.2 | 64.8 | | |
| 19 | 233.3 | 113.7 | 316.5 | 72.6 | | |
| 20 | 177.0 | 116.6 | 366.4 | 119.7 | | |
| 21 | 586.9 | 212.2 | •395.3 | 80.5 | | |
| • 22 | 2029.4 | 291.1 | 257.4 | 0.0 | | |
| 23 | 251.5 | 135.9 | •574.8 | 144.6 | | |
| 24 | 181.2 | 39.5 | •500.1 | 54.3 | | |
| 25 | 34.2 | 14.1 | 362.9 | 169.9 | | |
| 26 | 196.9 | 148.7 | 148.0 | 16.4 | | |
| 27 | 377.7 | 15.4 | 172.2 | 60.0 | | |
| 28 | 142.1 | 52.1 | 281.9 | 76.7 | | |
| 29 | 54.0 | 28.1 | 104.1 | 51.3 | | |
| 30 | 57.3 | 58.4 | 204.6 | 71.3 | | |
| 31 | 28.0 | 26.4 | | | | |
| Mean | 390.2 | 430.7 | 243.2 | 168.5 | 272.7 | 173.4 |
| No. | 132 | | 141 | | 50 | |


Average UV in Kuwait
Period 3 Mar to 13 Apr 1990 & 1991
w/m2
40
30
20
10
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour
1991
1990

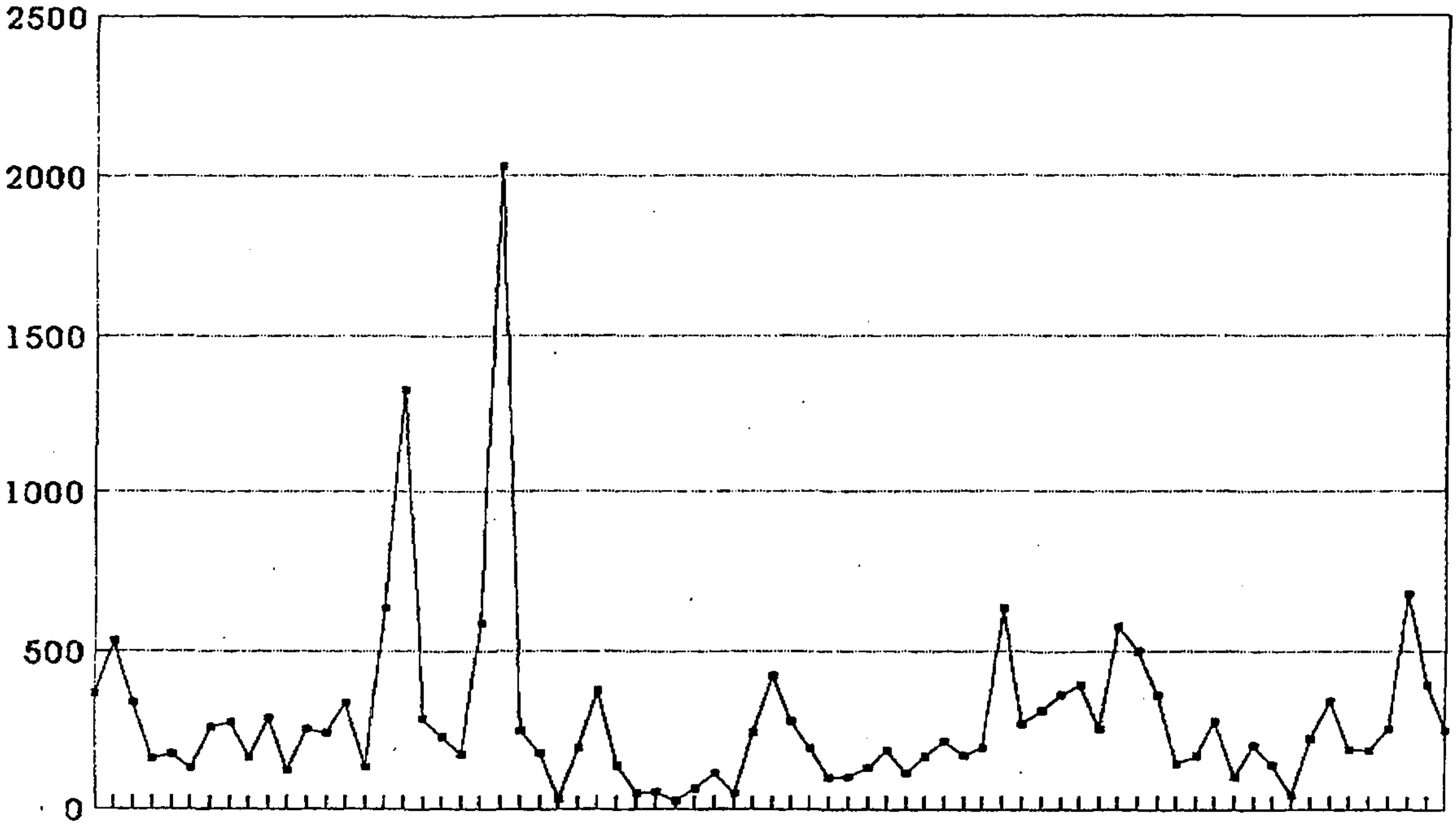
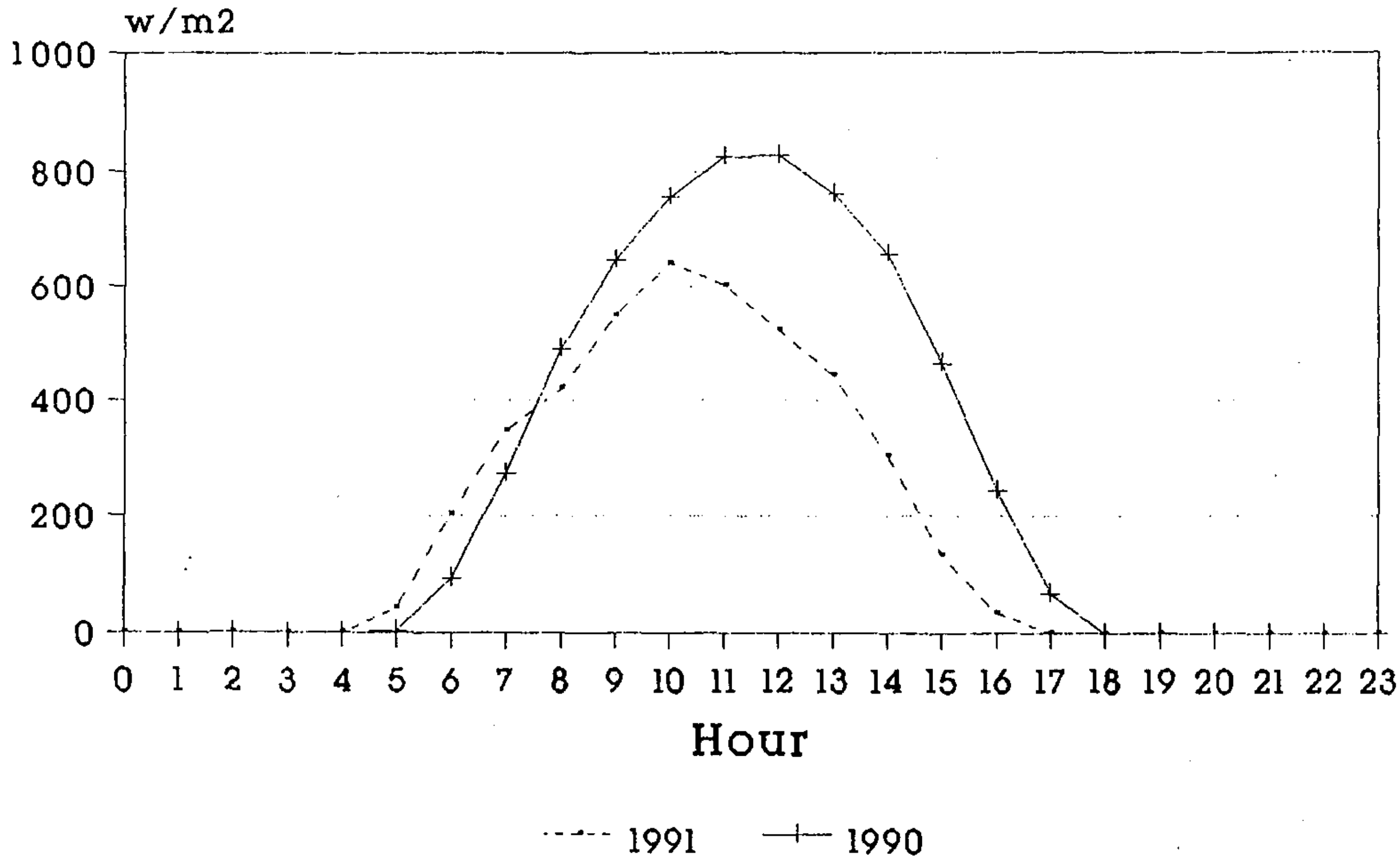



Fig. (2)

The daily mean particulates less than 10 microns recorded at the 5 sites in the residential areas of Kuwait in the period May 1 to July 10, 1991.

# Average Solar Radiation in Kuwait

## Period 3 Mar to 13 Apr 1990 & 1991



Correlation between the measurement taken by the portable and the standard PM10 was highly significant (.949**). The levels measured by the portable are particularly lower than the fixed sampler. The ratio was 74.4%. The scatter between the mean daily values taken by the two samplers is shown in Fig. (6). Another study is in progressing measuring the levels at three sites simultaneously and better correlation will be computed.

No data about the content of the particulates will be discussed at this stage. Further investigation using the same samples have been designed. In addition to the comparison between the particulates and the Fixed AM10, the indoor out door level will be investigated in a number of houses, hospitals and schools. Another study will look into the day and night loads. A third study will use acetate filter to examine for the soot. A short study will be made in the next fall to the north and south of the Burgan oil field to try to locate the site of the impact of the plume, after the fires are extinguished to a large extent, and the plume is likely to be much lower.

Daily mean PM10 loads
May - July 1991.

| Date | May | | June | | July | |
|---|---|---|---|---|---|---|
| | Mean | S.d. | Mean | S.d. | Mean | S.d. |
| 1 | 367.4 | 259.4 | 67.3 | 47.7 | 144.6 | 82.2 |
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| 9 | 167.4 | 184.7 | 105.5 | 50.7 | 393.6 | 77.0 |
| 10 | 292.0 | 74.3 | 135.8 | 39.0 | 254.3 | 45.3 |
| 11 | 127.3 | 45.7 | 189.9 | 58.7 | | |
| 12 | 255.9 | 114.3 | 117.9 | 16.5 | | |
| 13 | 244.1 | 121.4 | 171.5 | 26.5 | | |
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| 23 | 251.5 | 135.9 | 574.8 | 144.6 | | |
| 24 | 181.2 | 39.5 | 500.1 | 54.3 | | |
| 25 | 34.2 | 14.1 | 362.9 | 169.9 | | |
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| 29 | 54.0 | 28.1 | 104.1 | 51.3 | | |
| 30 | 57.3 | 58.4 | 204.6 | 71.3 | | |
| 31 | 28.0 | 26.4 | | | | |
| Mean | 390.2 | 430.7 | 243.2 | 168.5 | 272.7 | 173.4 |
| No. | 132 | | 141 | | 50 | |

DRAFT

# IMPACT OF OIL WELL FIRES ON AIR QUALITY IN THE URBAN AREAS OF KUWAIT

## II. POLLUTION BY NOXIOUS GASES


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- Mr. Ahmed Abu Ghaseba
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Environment Protection Department

Ministry of Public Health

Kuwait



August 1991

# IMPACT OF OIL WELL FIRES ON AIR QUALITY IN THE URBAN AREAS OF KUWAIT

## II. POLLUTION BY NOXIOUS GASES

BACKGROUND:

Before the iraqi troops were forced to pull out from Kuwait, they set fire to all the oil wells, gathering centres and tank farms. The quantity of oil that would have been ignited were estimated by Small (1991) to be around 13 million barrels in the first week based on a storing capacity of 10 days. The real quantity burnt in the first week following the setting of fire is probably much lower than that estimated by Small (1991) since the Iraqis shipped some of the refined products to Iraq. Most of the crude in the Ahmadi tank farm was discharged into the sea exchanging one pollution crime with another. Some of the crude was also pumped in a trench dug along the Saudi/Kuwaiti border to deter the invasion of the allied troops.

The estimates of the quantity of crude burnt daily differed as much as the workers that made them. Small (1991) suggested 1.6 million barrels based on the quantity exported before the war. Schumann (1991) reported that estimates are very uncertain. They may vary between 100 thousand to one million tons/day and that the weak convection seen from space suggest amounts less than 220 thousand barrels/day. MEPA (1991) estimates the quantity of oil burnt at 5 million barrels together with 70 million $m^3$ of associated gas daily from 516 oil wells. The same estimate was made by US Interagency Air Monitoring Team. Another estimate by the Research Institute, King Fahad University in Saudi Arabia, based on productivity puts the burnt crude at 2.4 million barrels and the gas at 34 million $m^3$. Based on data collected from aircraft, UK Meteorological Office (1991) estimated the amount of crude burnt to 4.1 million barrels/day; however an error of 40% was anticipated and a range of 2.5-5.7 million barrels/day was estimated. The official figures announced by the Ministry of Oil in Kuwait in April 1991 is 6 million barrels/day.

The rate of extinguishing the fire is collecting momentum and by now the number of wells that were successfully capped is about 240. Most of the effort is directed to the Burgan field owing to its vicinity to the urban area, the large number of wells on fire an the relatively high quality of the crude extracted from the fields.

The quantity of oil is reflected on the amount of pollutants being emitted. However estimates as regards the rate of emission is not agreed upon by different workers. The percentage of the soot or smoke being generated varied between 5-15% (Schumann, 1991). Small (1991) based on laboratory finding, estimted the smoke to range from 20-98 G/Kg with an average value of 73 $\pm$ 25 G/Kg of crude, with 69% elemental carbon. Mathallad et al (1991) from measurement of smoke collected on filters and $CO_2$ concentration of aeroplane samples estimated the smoke to be 110 G/Kg of crude. However, this is ar upper boundary.

The amount of the sulphur in the crude was also estimated to vary between 2.1-4.1% on the mean. Some of the fields, namely Wafra, Managish and Um Qader are believed to have more sulphur. The estimate of NOx also varies within an order of magnitude. Based on a temp of ignition of 3000$^{o}$ F, the expected quantity of NOx is much higher (30,000 tons/day) than that suggested by the UK Meteorological Office (1991) of 1,400 tons or by Browning et al (1991) (650 tons). The Research Institute, King Fahad University, based on 2.5 million barrels of crude burnt daily estimated that 20,000 tons of $SO_2$, 1500 tons of particulates, 250 tons of CO and 500 tons of NOx are emitted to the atmosphere daily.

The height of the plume is rather critical. Small (1991) expected the plume to rise to 1-3 Km for desert conditions from large pools of oil. From individual wells a height of 700 meter was suggested. However, small (1991) stated that higher and lower heights were probable. Other estimates vary from 1,000 to 5,000 m. Aireal surveys showed a very complex picture. The height of the plume was different from time to time. At times a single plume was seen and at others a number of distinct plumes with clean air in between was reported (Hobbs, 1991). The effect of the heat prevailing in the summer months and the probability of lofting the plume to the stratosphere was discussed by various workers. However the observations do not give support to this hypothesis.

The public health impacts of the well fires is rather complicated. The short term impacts will depend on the level of the pollutants and the length of the exposure. The particulates resulting from the well fires mostly soot have different metallic composition than that resulting from the burning of coal. The contribution of the soot to the particulates load in Kuwait is adding to the complexity of the picture. The level of pollution will be markedly influenced by the weather conditions. The direction of the wind near the ground will determine the site of the i pact. The presence of the oilfields to north and south of the urban area, and the distance of the major fields are rather critical. The height reached by the plume plays a major role in determining the site of the impact.

The colour of the fire coming from the wells was sometimes white and this was thought to be due to the brine being mixed up with the oil jetting from the wells. However, some workers found no water vapour in the plume (Hobbs, 1991). The white colour may be resulting from the atomisation of the oil itself and not due to the water vapour.

Of the different weather phenomena and based on the previous experience from air pollution episodes. Stagnation is probably the most critical (French, 1989). In Kuwait, the radiation ground based thermal inversion is very common (El Desouky & Abdelwahhab, 1985). The top of the layer is 180-220m from the ground. Elevated inversions are also quite common. With the first Km, the percentage of the days in which an inversion in the period of April-September as reported by NOAA (1991) varied between 30 and 40%. Between 1 and

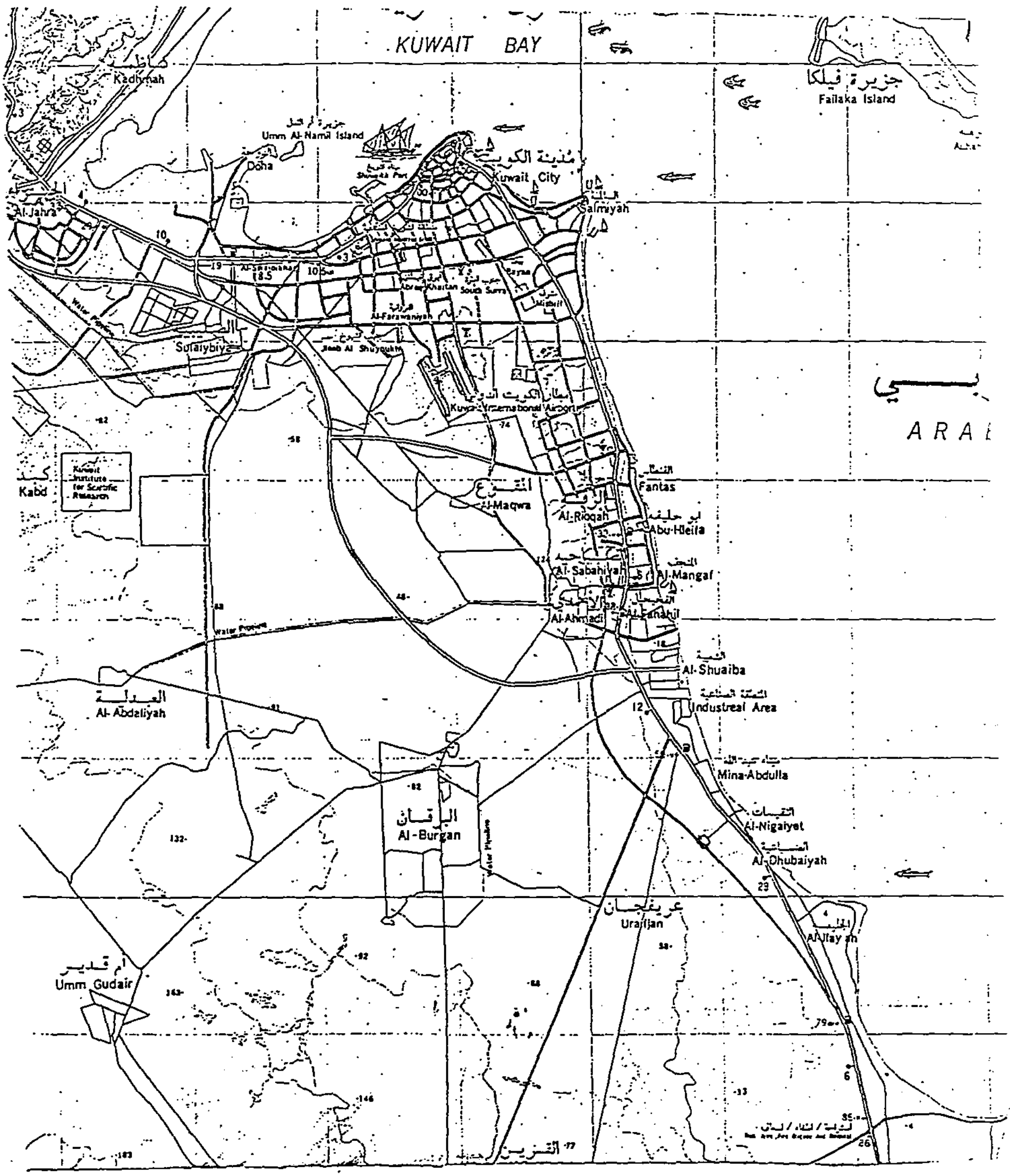



Fig. (1)

The location of the existing air quality monitoring stations and the stations that are decided to be installed next fall.

2 km, the percentage varied between 10 to 15% based on the finding in the period 1988-1990. More detailed information about the height of inversion up to 1500m reported by the Meteorology Department in Kuwait in the 5 years is shown in Table (1).

Previous observations about wind direction are not very useful. The heat islands generated by the intense burning of the oilfields is disturbing the pattern to a great extent. The wind direction at the ground level was seen to blow from the periphery of the fields towards their centres. The plumes from the individual wells were seen to rise up, turn towards the centre of the field and form a single huge plume, before rising up again (Hobbs, 1991). This has a great implication for the prediction of the level of pollution expected in the urban areas based on weather forecasting from synoptic data.

Air quality monitoring in Kuwait started since 1970. Grab samples for the gases and dust fall buckets were used at that time. Three monitoring stations were commissioned in 1985. The sites (Fig. 1) were chosen to look into the pollution by traffic, industry an power plants. Total suspended particulates were sampled and reported to the GEMS since 1980. Apart from the hydrocarbons (methane and non-methane) and the TSP, the level of the noxious gases were generally less than the AAQS adopted in Kuwait. The segregation of the industrial areas and high stacks installed in the power plants helped in the control of the air pollution. Traffic was more difficult to handle and just before the invasion by the Iraqis, the Environment Protection Council was discussing an ambitious plan to control pollution from traffic. The plan included the use of unleaded gasoline, catalytic convertors and setting a programme of inspection and maintenance of the vehicle fleet.

MATERIAL & METHODS

The present report will discuss the finding of the Air Quality Monitoring Stations at both Mansoria and Reqa. The first represent the main urban area, the other is situated in the coastal area extending to the east of the Burgan oilfield. The stations have Horiba equipment which take samples every 5 minutes. The data are stored on cassettes that are picked up every 2-3 days and read by the mainframe at the EPD.

The parameters measured are $H_2S$, $SO_2$, Total Sulphur, NO, $NO_2$, NOX, CO, $O_3$ and methane and non-methane hydrocarbons. The monitors are calibrated automatically every 25 hours and manual checks are done every 2 weeks and whenever the monitoring is interrupted. The two stations are provided with meteorology sensors for temp, RH, wind speed and direction. The Mansoria station has in addition to the standard sensors, total solar and UV measuring devices.

Air pollution monitoring was stopped on the 2nd of August 1991. This included the AQS and the particulates. The Mansoria station was started up by the beginning of April 1991 after the power was made available. The Reqa was started almost one month later. At Reqa, the voltage was not stable and this caused many problems. The third station (Rabia) was cannabalised and used to provide spare parts to keep the other 2 stations running. With international aid, plans were put to fix the Rabia Station and install 2 more with the help from the Norwegian NILU at Jahra and Mina Al-Zoor (Fig.1). The stations are expected to be running by the middle of September.

**RESULTS:**

The mean and maximum level of the principal pollutants measured at both Mansoria and Reqa in the period April to July 1991 is shown in Table (2). Also shown in the Table are similar parameters for the same months in 1990. The most obvious finding is the higher mean level of hydrocarbons in 1991, particularly the non-methane, in Mansoria. The mean $NCH_4$ for 1991 in Reqa was slightly higher than the corresponding figure for 1990. For the methane, the level of Mansoria was slightly higher in 1991. But the maximum was about triple that seen for 1990. Though the means of $CH_4$ in Reqa was comparable the maximum was much higher in 1991. This is rather interesting and is probably due to the emission of methane and non-methane from the extensive crude pools resulting from the oozing wells that were exposed and were not set on fire. The other obvious finding was the much lower mean CO in 1991 compared to last year. The mean for Mansoria (.648 ppm) was about half that for 1990. A similar picture was seen for Reqa. The maximum values however reported in 1991 for Mansoria (38.1 ppm, or Reqa (44.8 ppm) were appreciably higher. These are peak 5 minute value reported in the whole period.

The levels of $SO_2$ in 1991 in Mansoria (2.3 ppb) and Reqa (3 ppb) were within the detection limit of the equipment and are slightly higher than that reported for 1990 (1.8 and 1.4 ppm) for the two stations. NO was lower in 1991 in Mansoria and higher in Reqa. With $NO_2$ it was the other way round. NOx showed the same picture.

Hydrocarbons:

The mean and maximum $CH_4$, $NCH_4$ in 1991 in the four months for which the data were available is shown in Table (3). Higher values were seen for $CH_4$ in April and May, and f r $NCH_4$ in June and July at Mansoria. The maximum behaved in the same manner. The Mansoria generally had much higher means than the Reqa and this was seen for April and May. No data was available from Reqa for June or July due to technical problems resulting from power failure.

Correlation between the $CH_4$ and $NCH_4$ in the period of the study in Mansoria was positive and significant (r =.488). With the Reqa, it was much lower. The sources of $CH_4$ are generally considered natural. However this is not always the case and in Kuwait the geogenic contribution should be considered. The positive correlation shows that the variability of the two compounds are moving in the same direction and that the factors that are influencing the correlation of the methane may be affecting the non-methane in the same direction.

The trend lines for the period of the study in the Mansoria Station where the data were more continuous, is shown in Fig. (2). It could be seen that there is a slight drop in the level of the $CH_4$ and $NCH_4$. It is interesting to note that the slope for the $NCH_4$ (-.0156 ppm/month) was smaller than that seen for $CH_4$ (.0335). It seems that the level of $CH_4$ and $NCH_4$ is coming down. The level in July is lower than that in April. The authorities are doing all they can to extinguish the fires, cap the wells and pump the crude from the pools. The drop may be due to this but the time is too short to draw any conclusion and the meteorology may be playing a more significant role.

The overall mean for both the total hydrocarbons and for $NCH_4$ in Mansoria according to the time of the day is shown in Fig. (3 A & B). The night time is characterized by a marked drop in the anthropogenic activities and hence for the man made sources of the hydrocarbons. Before the present crisis, the major sources of $NCH_4$ were traffic (76.2%) and industry (20%). Both are expected to drop at the night times. The highest mean $CH_4$ was seen between 6-8 AM (2.8 ppm) and the lowest (2.6 ppm) at 3 5 AM. No significant difference was found between the means calculated for any periods ($F = 1.2106$). With the total hydrocarbons, the lowest mean was seen between 3-5 AM and the highest was between 15-17 followed by the 18-20 hours. The mean for the 18-20 was significantly higher than the lowest mean (3-5). The mean for 15-17 was significantly higher than the lowest 3 means. No significant difference was seen between the means for all the other times. A similar picture was seen for the $NCH_4$ (Fig. 3B). The highest overall mean was seen at 15-17 hours (2.3 ppm) followed by that between 18-20 hours. Both were significantly higher than the lowest 4 means seen at 3-5, 0-2, 21-23, and 6-8. The mean for the period 15-17 hours was also significantly higher than that measured between 9-11 AM. With the methane, no significant difference was seen between any of the means and the plot was not computed.

In Reqa, though the data was only available for April and May, the means for $NCH_4$ and $CH_4$ according to the time of the day is shown in Fig. (4 A & B). With $NCH_4$ the highest mean was seen at 3-5 (.869 ppm) followed by that for 6-8 AM (.720 ppm). The lowest means were for 12-14 (.290) and 15-17 (.376 ppm). The difference between the means are tested for and the results are shown in the figure. The means for all the periods are higher than the two lowest means. The mean for the 3-5 AM was also significantly higher than almost all the other means except that for the 6-8 AM

With methane (Fig.4B), the means for 18-20 (1.719 ppm) and 3-5 AM (1.718 ppm) were slightly higher than the lowest two means seen at 12-14 and 15-17. The total hydrocarbons was similr to that seen for the $NCH_4$, with the highest mean for 3-5 AM (2.587 ppm) and the lowest (1.897 ppm) at 12-14 hours. It could be concluded that with the exception of the level of $CH_4$ in Mansoria, the level of hydrocarbons shows significant variability with the time of the day. Factors including the emission and dissipation of the hydrocarbons should be investigated.

The effect of wind speed and wind direction is rather critical. Data for the wind direction may not be very reliable owing to the presence of the heat islands and this has been discussed. The effect of the land and sea breeze and the representation of the wind direction measured inside an urban area should be considered. The data for both the $CH_4$ and $NCH_4$ for the 4 months at Mansoria are shown in Fig. (5 A & B).

With $NCH_4$, the mean reported for the winds blowing from the SE (3.130 ppm) was significantly higher than the means with any directioin. This is the direction of the Burgan field. High mean values were also seen with SW (2.411 ppm) and S (2.380 ppm). The lowest means were seen with the northerly winds (1.208 ppm) and NE winds (1.208 ppm).

With $CH_4$, the highest mean was found with the SE (3.364 pm) followed by the S (3.087 ppm) and SW (3.016 ppm). The lowest mean was found for the NE (2.516 ppm) and W (2.559 ppm). The mean with the SE was significantly higher than the lowest 5 means. The means for the S and SW were significantly higher than that seen with the W and NW.

With Reqa, the mean $NCH_4$ according to the wind direction is shown in Fig. (6A). Higher means were seen with the SW (1.137) and S (1.022 ppm). The lowest values were seen with the NE (.274 ppm) and N (.279 ppm). The two were significantly lower than the means with all the other directions. The S and SW are the directions from which the wind will be blowing from Burgan oilfield. The NE is the direction of the Gulf.

With $CH_4$ (Fig.6B), the SW (1.923 ppm) and SE (1.773) had the highest mean values. It is interesting to note that the westerly winds had the lower means (1.163 ppm). Though the level were significantly higher with the S and SW, the difference in real values was quite small and did not exceed 0.3 ppm.

Different wind speeds are found at different wind directions. Moreover, the dissipating effect of the fresh wind should be considered. The mean $NCH_4$ at Mansoria according to the wind speed is shown in Fig. (7A). A higher mean was seen with winds 4-5 m/s(2.343 ppm) and 5-6 m/s (2.236 ppm). This was higher than the mean seen for the stronger or weaker winds. The lowest mean was found with less than 1 m/s winds (1.854 ppm). The level of significance between the means is shown in the Fig. (8A). With $CH_4$ the mean with winds 2-3 m/s (2.818 ppm) or 1-2 m/s (2.687 ppm) was significantly higher than the mean seen with winds 5-6 m/s which had the lowest (2.395 ppm) (Fig. 8B).

With Reqa the highest mean value of $NCH_4$ was seen with very calm winds (1.434 ppm) followed by 1-2 m/s winds (1.285 ppm). The lowest was that seen with the winds 6 m/s (.075 ppm) or 5 m/s (.156

ppm). The expected pattern of a lower mean with stronger wind due to dissipation is seen. The means that were significantly different are shown in the Fig. (10A). The finding should be taken cautiously since the wind direction at the ground is strongly influenced by the burning oilfields. With $CH_4$ the highest mean was seen with winds 1-2 m/s (1.893 ppm) followed by winds 2-3 m/s (1.787 ppm). Appreciably lower means were seen with winds 5-6 m/s or 6 m/s and over. The cases in which the means were significantly different are shown in Fig. (10B).

Carbon Monoxide:

The other pollutant that behaved in a distinct manner is the Carbon Monoxide (CO). The amount of the CO generated by the fires was estimated to be 250 tons daily (Research Institute, King Fahad University, 1991). The monthly mean CO at both Mansoria and Reqa in 1991 and 1990 was shown in Table (2). The appreciably lower mean CO in 1991 is clear. The principal source for CO in 1990 was traffic. The much lower traffic load in the period covered by the study is clear. Though NO counts are available for this time the absence of the morning rush hour traffic is quite noticeable.

The monthly mean and the maximum reported for the individual sites are shown in Table (4). Traffic load is building up and the effect could be seen from the rise in the mean CO for the 4 months in both Mansoria and Reqa, though a lower mean was seen for Mansoria during May (.253 ppm) compared to that found for either April (.643 ppm) or June (1.0 ppm). A more uniform rise was seen for Reqa. The high level of CO in July compared to April is quite clear and the difference was significant. The rise in the mean CO in July could be attributed to the traffic since a large number of oil well fires have been extinguished since April.

It is interesting to note that the well fires may be a significant source of CO. The incomplete combustion of the oil is quite clear from the droplets that fly around and the black smokes seen rising from a large number of wells. It should be mentioned that generally the mean CO in the summer months particularly July is lower than that seen for the other seasons and this was reported from the previous findings in Kuwait (El Desouky et al, 1988). The trend line calculated for both Mansoria and Reqa for the 4 month period is shown in Fig. (11A & B). The rising trend could be seen.

The hourly mean values for Mansoria is shown in Fig. (12A). The highest mean was seen in the period 18-20 (1.344 ppm) followed by 21-23 (.966 ppm). The lowest mean was seen at 3-5 AM (.221 ppm). The means that differed significantly are shown in the figure.. With Reqa (Fig.12B), a similar picture was seen. The highest mean was also at 18-20 (1.223 ppm) followed by the 21-23 (.983 ppm) and the lowest between 3-5 (.324 ppm). The means that were significantly different are shown in the figure. The virtual absence of any morning peak in the period 6-8 AM was seen for both the stations. The afternoon peak 12-14 was not conspicuous previously (El Desouky et al, 1988) and with the finding in the last 4 months it was persistently lower than the 3 hour periods before or after. The hourly mean values in the period 18-24 hours in the two stations in the 4 months were quite high. This is the time of the evening and night peak for the CO observed in Kuwait in the normal situation.

The mean CO computed from the wind direction at Mansoria and Reqa is shown in Fig. (13A & B). Significantly higher values were seen with the S (1.517 ppm) and SW (1.419 ppm). These are the directions associated with high mean values previously and were explained by the presence of a filling station and the highway network in this direction (El Desouky et al, 1988). The lowest mean was found with the NW wind (.420 ppm) and the W (.626 ppm). These are the prevailing wind directions and are known to be blowing from the Kuwait City with the high traffic load. The level of significance between the means is shown in the figure.

With Reqa (Fig.13B), the wind directions that were having higher mean CO were the S (1.806 ppm), SE (1.097 ppm) followed by the SW (.978 ppm). The lowest means were seen with the N and NE (.431 ppm) and the NW (.433 ppm). It is interesting to note that the directions that were associated with higher CO were not those blowing from the Burgan field in the vicinity of the station. However the station is a few Km from the shore and the wind regime recorded in the last four months has not been the same as that seen in the last years.

The relation with the wind speed showed the normal picture of the high mean values with calm winds. The dissipating effects of the winds is clear. This was seen with the 2 stations (Fig. 14A & B). The difference in the wind speed with the different wind directions should be however taken into consideration.

$SO_2$, NOx:

The sulphur dioxide is probably the most serious of the pollutants resulting from the oil well fire. The sulphur content of the Kuwaiti crude is quite high. The form in which sulphur is found in the crude is usually $H_2S$ and some organic sulphur compounds. The monitors used by the stations measure the two gases and the sum is the total sulphur. Nitrogen oxides measured by the stations are the NO, $NO_2$ and the sum NOx. NO is generated by the heat and is later oxidised to $NO_2$. Near the sources more NO is found being the primary compound. The $NO_2$ is more of a health hazard than the NO. Both the $SO_2$ and $NO_2$ are used for the Health Alert System in Kuwait.

Unlike CO, both the $SO_2$ and NOx have significant sources other than the oil wells on fire. The power plants at Doha started production partially since April and more and more units are producing electricity. The Al-Zoor power plant was not destroyed and was producing the normal load though the power lines were disconnected. Both use crude oil with high sulphur content and are also producing a substantial amount of NO and $NO_2$. The mean $SO_2$, NO and $NO_2$ seen at the two stations in the last 4 months was summarised in Table (5). Shown in the Table is also the finding in the period April-July 1990. $H_2S$ was not included, the level was quite low in general. The major source before the oil well fires was the sewers and this was seen in the Rabia Station which is not functioning now. The sewage treatment plants are not working as the Iraqis destroyed them.

The hourly mean and maximum for the $SO_2$, NO, and $NO_2$ in the individual months is shown in Table (5). The monthly means for $SO_2$ were quite similar with a slightly higher mean in April at Mansoria (3.0 ppb) and for May at Reqa (3.1 ppb). These are well within the limit of detection of the equipment. The maximum was also low. The means for NO and $NO_2$ were higher for Reqa compared to Mansoria and this was seen for the 4 months. The maximum $NO_2$ was quite high in July (771 ppb). It is interesting to note that the proportion of $NO_2$ was higher than NO in Mansoria, whereas with Reqa a larger proportion of the NOx was in the form of NO; also the maximum NO in July exceeded the level reported at any time in Reqa or Mansoria (1108 ppb).

The trend in the four months for both the $SO_2$, NO and $NO_2$ is shown in Fig. (15A & B). A slight insignificant positive trend could be seen. The level of either $SO_2$ or $NO_2$ is not rising in the period covered by the investigation.

The distribution of the $SO_2$ and $NO_2$ according to the hour of the day is shown in Table (6). Very little variability was seen in $SO_2$ in the different times of the day and this was seen for both Mansoria and Reqa. The sources of $SO_2$, wheather the oil well fires or the power plants, do not differ with the hour of the day. The contribution of industry to the $SO_2$ load is not substantial in the time being and most of the measurements are within the detectability of the equipment.

With the NO, at Mansoria high mean values were seen in the period 18-20 and 21-23 (22 ppb) and the lowest mean was seen between 3-5 (1.3 ppb). With $NO_2$, the highest means were also seen at 18 (24.8 ppb) and 21 hours (18.2 ppb). With Reqa, a much higher NO was seen at 18 (73.6 ppb) and 21 hours (67.7 ppb). $NO_2$ showed a similar picture. It could be concluded that the level of both NO and $NO_2$ was higher in the late afternoons and before midnight and this was seen for the 2 stations. The picture was similar to that seen for CO and the contribution of traffic though quite small may explain a part of the fluctuation in the mean NO and $NO_2$. The difference in the proportion of NO and $NO_2$ in the different hours of the day is expected and the complex interaction with ozone and the sunlight should be considered. The role of the maeterological parameters is probably much more important than the fluctuations in the source strength.

The mean $SO_2$ and NOx according to the wind direction is shown in Table (7). A higher level of $SO_2$ was seen with winds blowing from the SE (4.2 ppb) in Mansoria and for SW (5 ppb) and S (6.1 ppb) in case of Reqa. No industrial sources of $SO_2$ are found in the vicinity of Mansoria. However, in April the garbage was not collected by the Municipality and some was burnt inside the residential areas. The fluctuation in the level of $SO_2$ was much higher in Reqa compared to that in Mansoria.

With the NO the fluctuation was appreciably higher with the Reqa. Much higher levels were seen with the NW (94.9 ppb) and w winds (76.5 ppb). With Mansoria a relatively higher means were seen with S (34.4 ppb) and SW (37 ppb) winds. With $NO_2$ the levels at Mansoria were parallel to that of the NO. The maximum was found with the S winds (30.6 ppb) and SW (23.6 ppb). With Reqa a different picture was seen. A relatively higher levels were seen with the S (33.0 ppb) and SW (26.6 ppb). The general picture of a relatively higher NO in Reqa and higher $NO_2$ in Mansoria was preserved except with the SE and SW winds when the $NO_2$ was higher. It is interesting to note that to the NW of Reqa is the Burgan field. The small distance between the station and the major field on fire is likely to cause the relative high level of NOx seen.

Though no similar rise was seen for the $SO_2$, only with the winds from the south were both the NOx and $SO_2$ high.

The relation with the wind speed is shown in Table (8). Very little fluctuation was seen with the $SO_2$ and this was seen for the two station. With NO, the expected picture of the higher mean values with the calm wind and a gradual drop in the means with stronger winds was seen. This was seen with the $NO_2$ though the gradual drop in the means was not as steep as that seen with the NO. A much higher level of NO was seen at Reqa with winds 6+ m/s (100.7 ppb). The probable explanation is the difference in the wind speed with wind direction and probably this reflects with winds coming from a direction with high pollution load.

Solar and U.V.

Total solar and UV are mesured in the Mansoria monitoring station. The effects of the plume will be detected in the drop in the intensity of the solar radiation. The effect of the plume will be independent of the height it reaches since it will obstruct the sunlight regardless of the height. It was however stronger on the days that the plume was moving in the direction of the monitoring station and with the density of the plume. The density is a matter of the wind speed which will determine its capability to disspite the plume. Fig. (16A & B) shows the intensity of solar radiation and the total UV in Watt/$m^2$ at Mansoria with the wind speed. The highest mean (242.6 w/$m^2$) was seen with the 4-5 m/s winds. This was significantly higher than that seen with winds 3-4, 2-3 or less than 2 m/s. The means with wind 3-4 (206.2 w/$m^2$) and 2-3 m/s (183.6 w/$m^2$) were also higher than that with calm winds (104.8 w/$m^2$).

With the UV a similar picture was seen. The highest mean (7.8 w/$m^2$) was seen with the strongest wind. A much lower level (2.3 w/$m^2$) was seen with calm winds. The effect of the wind speed seem to be through ventilation of the plume, and the tiny oil droplets that escape being fired with the main plume. It is worth noting that the days in which the solar and UV readings were quite low, the level of $SO_2$, NO and $NO_2$ were not appreciably higher than the other days. The calm winds will help the plume rise and this seems to play a critical role in determining the level of the pollutants detected at the air quality monitoring stations at Mansoria and Reqa.

CONCLUSION:

The present study is preliminary in nature. There are a lot of uncertainties. The picture of air pollution problem in Kuwait is far from being clear. The level of $SO_2$ and NO, $NO_2$ is very close to what was measured before the air pollution episode to which Kuwait is passing through. The levels of CO was lower than that seen for the same period in 1990. The traffic is building up and we expect the levels to rise soon. The levels of hydrocarbons were quite high. These were high before but the pools of oil in the oilfields are probably causing that rise.

The Ministry of Oil is doing all it can to extinguish the fires and pumping the oil from the ground pools. The plume is rising to relatively great heights at the time being and this may explain the relatively low levels of sulphur and nitrogen oxides. The data are available only for 2 sites and very little information is availiable from the residential areas to the west of the country or the south. Two fixed stations are commissioned at the time being and are planned to be installed in the areas from which the information is valuable. The Norwegian NILU is helping in this respect.

A mobile lab was made available to the EPD by the courtesy of the German Government. The lab was used for the intercalibration of the existing stations. The findings are quite comparable except for $O_3$ where the measurement by the German lab was higher. This was also reported previously from comparing the finding with the French team. The level at Al-Zoor to the south are appreciably higher than those reported in the town. The data for the Al-Zoor and Jahra which is next on the plan will be used to advise the Norwegian NILU as regards the levels expected on the sites the new stations will be installed.

We hope that the existing air pollution episode would not result in any health problem but we should be prepared and with the help and advise we are getting from the international community we are sure the problem will be solved.

The problem of heat island is causing due concern as the prediction of the wind direction on the ground level is not possible. The NOAA was kind enough to help install and run 15 met stations all over the State covering the oil fields and urban area. The data from the met stations and the air quality monitoring stations will be used as an input to the Health Alert System being developed at the time being.

The expection as regards the future are guarded. The wind direction changes in fall and more southerly winds are expected. More calm winds are also anticipated and this together with the rate at which the fires are being extinguished will probably expose the urban area to the north of the Burgan field to higher levels of $SO_2$, NOx and the other pollutants resulting from the oil well fires.

Table (1)

Mean number of cases of Inversions according to the month
Kuwait International Airport 1973-1977 Time 2300 G.M.T.

| Month | Air Layer | | | | |
| --- | --- | --- | --- | --- | --- |
| | Ground 300m | 300m-600m | 600m-900m | 900m-1200m | 1200m-1500m |
| Jan. | 22.6 | 5.6 | 5.0 | 4.0 | 1.8 |
| Feb. | 23.0 | 6.0 | 3.4 | 3.8 | 2.2 |
| Mar. | 27.0 | 6.2 | 2.4 | 1.8 | 1.4 |
| Apr. | 23.8 | 5.8 | 0.8 | 0.8 | 0.6 |
| May | 26.25 | 7.0 | 1.5 | 0.4 | 0.5 |
| Jun. | 26.4 | 6.0 | 0.4 | 0.2 | 0.2 |
| Jul. | 27.4 | 2.6 | 0.2 | 0.2 | 0.4 |
| Aug. | 30.0 | 4.6 | 0.2 | 0.4 | 0.6 |
| Sep. | 28.8 | 6.6 | 0.8 | - | 0.2 |
| Oct. | 27.6 | 8.4 | 1.8 | 1.0 | 0.6 |
| Nov. | 27.0 | 8.2 | 2.8 | 2.0 | 1.2 |
| Dec. | 24.6 | 10.0 | 5.8 | 3.8 | 2.2 |

Table (2)

The overall mean $SO_2$, nitrogen oxides, and hydrocarbons measured at the 2 AQMS in the period April-July in 1990 and 1991.

| Pollutant | | Mansoria | | | | Reqa | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1990 | | 1991 | | 1990 | | 1991 | |
| | | Mean | Max. | Mean | Max. | Mean | Max. | Mean | Max. |
| $SO_2$ | ppb | 1.8 | 52.0 | 2.3 | 38.0 | 1.4 | 28.0 | 3.0 | 38.0 |
| NO- | ppb | 15.0 | 1011.0 | 8.2 | 920.0 | 17.6 | 1436.0 | 60.2 | 1108.0 |
| $NO_2$ | ppm | 23.8 | 370.0 | 13.4 | 496.0 | 24.2 | 456.0 | 20.5 | 771.0 |
| NOx | ppb | 38.8 | 1201.0 | 21.6 | 938.0 | 41.8 | 1470.0 | 80.8 | 1187.0 |
| $NCH_4$ | ppm | 0.449 | 12.8 | 2.030 | 23.4 | 0.417 | 22.2 | 0.619 | 20.0 |
| $CH_4$ | ppm | 1.767 | 6.0 | 2.658 | 19.8 | 1.737 | 4.7 | 1.669 | 10.8 |
| CO | ppm | 1.022 | 22.0 | 0.648 | 33.1 | 0.982 | 24.8 | 0.592 | 44.8 |

Table (3)

The mean and maximum Hydrocarbons ($NCH_4$ and $CH_4$) measured at the 2 AQMS in the period April-July 1991.

| Month | | | Mansoria | | Reqa | |
|---|---|---|---|---|---|---|
| | | | Mean | Max. | Mean | Max. |
| April | $NCH_4$ | ppm | 1.742 | 13.4 | 0.781 | 6.2 |
| | $CH_4$ | " | 4.596 | 19.4 | 1.845 | 3.8 |
| May | $NCH_4$ | " | 1.176 | 10.6 | 0.606 | 20.0 |
| | $CH_4$ | " | 5.743 | 19.8 | 1.875 | 10.9 |
| June | $NCH_4$ | " | 2.254 | 23.0 | -- | -- |
| | $CH_4$ | " | 1.797 | 7.8 | -- | -- |
| July | $NCH_4$ | " | 2.226 | 9.0 | -- | -- |
| | $CH_4$ | " | 1.729 | 3.7 | -- | -- |

Table (4)

The mean together with the maximum Carbon Monoxide (ppm) at the 2 AQMS in the different months.

| Month | Mansoria | | Reqa | |
|---|---|---|---|---|
| | Mean | Max. | Mean | Max. |
| Apr. | .643 | 7.3 | .492 | 32.4 |
| May | .253 | 7.9 | .615 | 30.6 |
| Jun. | 1.000 | 33.1 | .699 | 44.8 |
| Jul. | .655 | 13.3 | .5786 | 27.6 |

Table (5)

The hourly mean and maximum of $SO_2$, NO, and $NO_2$ (ppb) at the 2 AQMS in the different months.

| Month | Mansoria | | | | | | Reqa | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $SO_2$ | | NO | | $NO_2$ | | $SO_2$ | | NO | | $NO_2$ | |
| | Mean | Max. | Mean | Max. | Mean | Max. | Mean | Max. | Mean | Max. | Mean | Max. |
| Apr. | 3.016 | 38.0 | 8.0 | 341.0 | 12.2 | 490.0 | 1.603 | 22.0 | 39.1 | 1006.0 | 19.7 | 167.0 |
| May | 2.132 | 20.0 | 5.6 | 368.0 | 12.5 | 74.0 | 3.116 | 15.0 | 49.0 | 1094.0 | 21.9 | 186.0 |
| Jun. | 2.108 | 17.0 | 17.0 | 420.0 | 16.2 | 287.0 | 2.200 | 22.0 | 16.1 | 737.0 | 16.7 | 317.0 |
| Jul. | 1.945 | 2.0 | 3.8 | 571.0 | 12.9 | 211.0 | 2.620 | 8.0 | 165.3 | 1108.0 | 24.6 | 771.0 |

Table (6)

The mean level of $SO_2$, NO, $NO_2$, and NOx (ppb) measured at the 2 AQMS in the period April-July 1991.

| Time | Mansoria | | | | Reqa | | | |
|---|---|---|---|---|---|---|---|---|
| | $SO_2$ | NO | $NO_2$ | NOx | $SO_2$ | NO | $NO_2$ | NOx |
| 0- | 2.3 | 7.0 | 9.0 | 16.1 | 3.0 | 58.3 | 20.0 | 78.4 |
| 3- | 2.2 | 1.3 | 5.2 | 6.6 | 3.5 | 55.9 | 15.7 | 71.6 |
| 6- | 2.1 | 2.9 | 10.5 | 13.4 | 3.0 | 53.7 | 17.0 | 70.7 |
| 9- | 2.3 | 3.7 | 15.2 | 18.9 | 3.1 | 62.7 | 17.2 | 79.3 |
| 12- | 2.3 | 2.1 | 10.8 | 12.9 | 2.7 | 54.7 | 13.0 | 68.1 |
| 15- | 2.3 | 4.7 | 13.5 | 18.3 | 2.7 | 51.6 | 16.5 | 68.3 |
| 18- | 2.5 | 22.2 | 24.8 | 47.0 | 2.8 | 73.6 | 34.9 | 112.7 |
| 21- | 2.5 | 22.1 | 18.2 | 40.0 | 3.0 | 67.7 | 30.7 | 98.0 |

Table (7)

The mean level (ppm) of $SO_2$, NO, $NO_2$, and NOx measured at the 2 AQMS in the period April-July 1991 according to the wind direction.

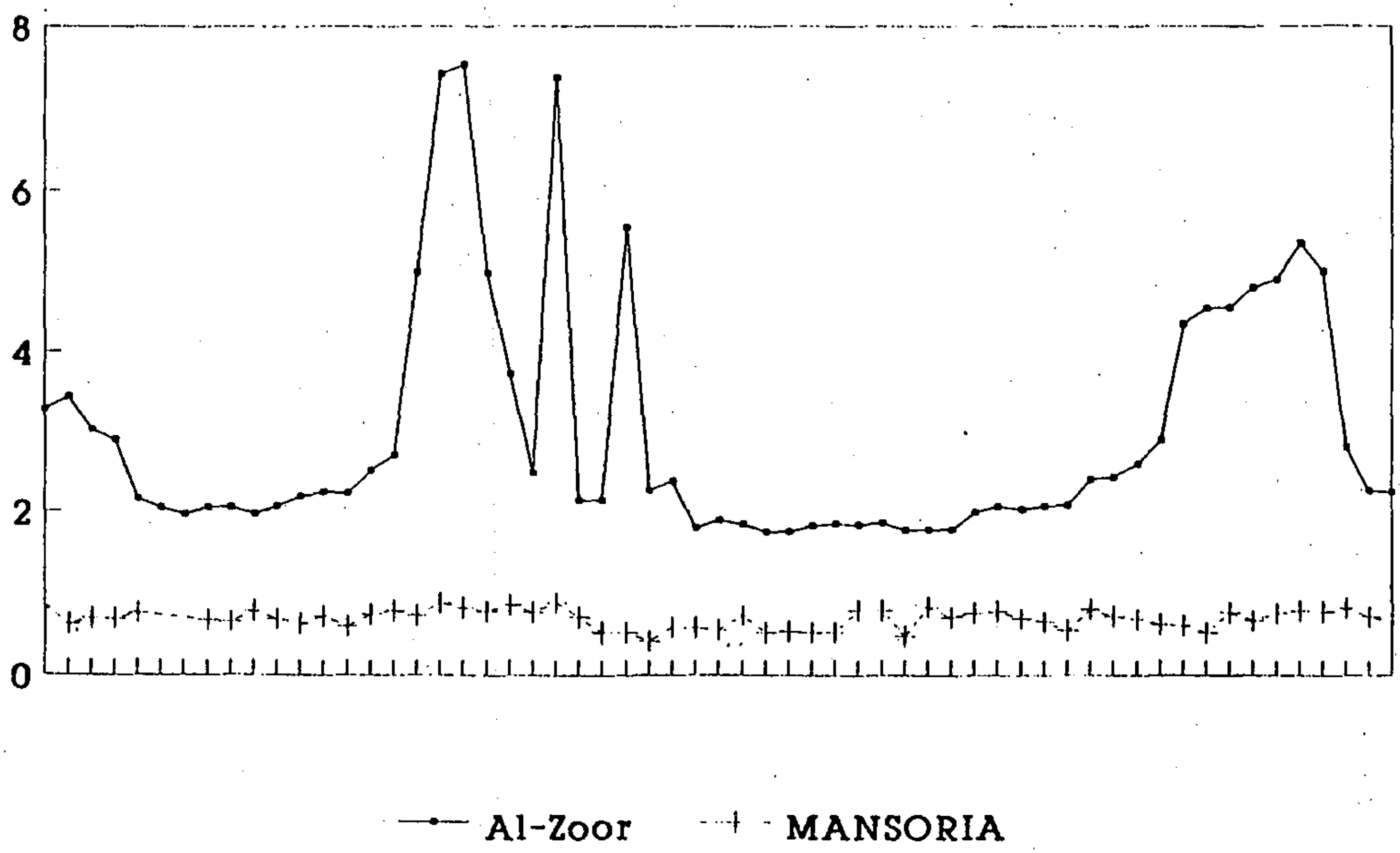
| Wind Direction | Mansoria | | | | Reqa | | | |
|---|---|---|---|---|---|---|---|---|
| | $SO_2$ | NO | $NO_2$ | NOx | $SO_2$ | NO | $NO_2$ | NOx |
| N | 2.0 | 5.3 | 12.2 | 17.4 | 2.7 | 43.1 | 20.0 | 62.9 |
| NE | 2.5 | 5.5 | 13.9 | 19.4 | 2.3 | 10.8 | 15.5 | 26.2 |
| E | 3.2 | 12.1 | 19.3 | 31.5 | 2.2 | 26.5 | 18.6 | 45.2 |
| SE | 4.2 | 9.6 | 23.2 | 32.8 | 3.9 | 21.3 | 25.6 | 47.1 |
| S | 3.1 | 34.4 | 30.6 | 65.1 | 6.1 | 47.5 | 33.0 | 80.7 |
| SW | 2.9 | 37.0 | 23.6 | 60.7 | 5.0 | 20.0 | 26.6 | 46.6 |
| W | 2.0 | 10.0 | 12.2 | 22.2 | 2.6 | 76.5 | 19.5 | 95.9 |
| NW | 2.0 | 2.0 | 9.8 | 11.8 | 3.3 | 94.9 | 20.4 | 115.7 |

Table (8)

The mean level (ppm) of $SO_2$, NO, $NO_2$, and NOx measured at the 2 AQMS in the period April-July 1991 according to the wind speed.

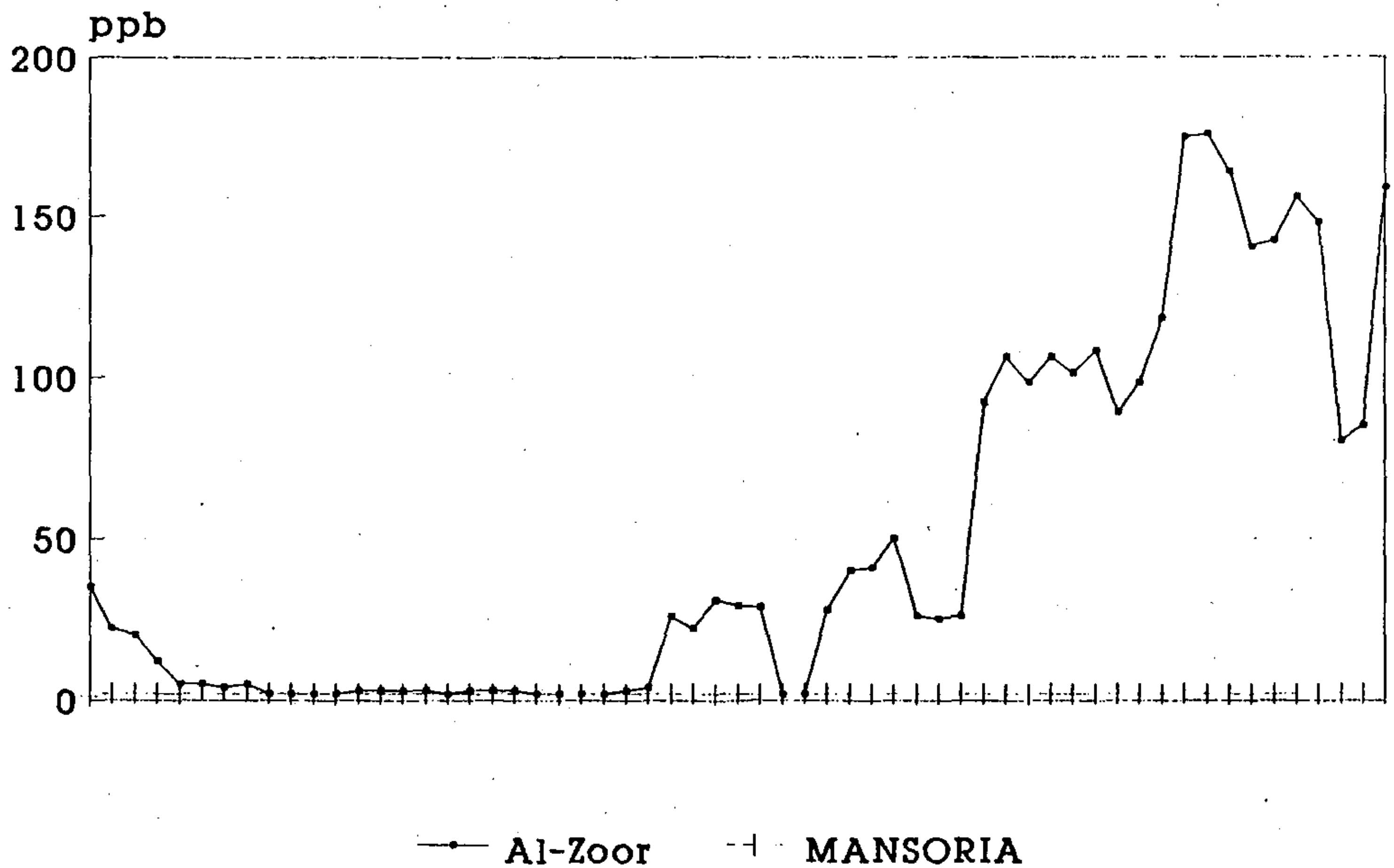
| Wind Speed (m/s) | Mansoria | | | | Reqa | | | |
|---|---|---|---|---|---|---|---|---|
| | $SO_2$ | NO | $NO_2$ | NOx | $SO_2$ | NO | $NO_2$ | NOx |
| <1 | 2.5 | 31.8 | 27.9 | 79.7 | 2.0 | 98.6 | 40.0 | 138.1 |
| 1 | 2.4 | 14.6 | 19.4 | 34.0 | 2.4 | 45.2 | 31.1 | 76.1 |
| 2 | 2.3 | 2.9 | 12.1 | 15.0 | 3.4 | 33.9 | 22.9 | 56.8 |
| 3 | 2.3 | 1.3 | 9.1 | 10.5 | 3.5 | 48.8 | 18.6 | 67.5 |
| 4 | 2.2 | 1.3 | 8.8 | 10.1 | 2.8 | 55.8 | 18.1 | 73.7 |
| 5 | 2.0 | 2.0 | 9.6 | 11.6 | 2.8 | 60.1 | 14.7 | 74.6 |
| 6+ | 2.0 | 2.3 | 10.0 | 12.4 | 3.3 | 100.7 | 16.7 | 118.0 |

# THc MEASURED BY GERMAN LAB
(3/8/1991 11:45 TO 4/8/1991 8:45)



# SO2 MEASURED BY GERMAN LAB

(3/8/1991 11:45 TO 4/8/1991 8:45)



# DARWIN SCIENTIFIC FOUNDATION

Kuwait Oil Fires
and
International Environment Considerations

Washington Conference

28 September 1991

Baird Auditorium
Museum of Natural History
Smithsonian Institution
Constitution Avenue and Tenth Street
Washington DC

# DARWIN SCIENTIFIC FOUNDATION

Kuwait Oil Fires
and
International Environment Considerations

Washington Conference

Presentation Abstracts

and

Speaker Biographies

# EFFECTS OF THE GULF WAR ON THE ENVIRONMENTAL GEOLOGY OF THE REGION

Farouk El-Baz
Center for Remote Sensing
Boston University

Preparations for and conducting the Gulf War resulted in much damage to the environment of the region. Foremost among the irreparable damage are changes to the terrain due to the digging of trenches, building walls of soil, and otherwise disturbing the desert pavement in and around Kuwait. The disruption of the usually one-grain thick layer of pebbles on the desert floor exposes soil to wind action. Furthermore, changing the contours of the normally flat land increases resistance to the wind, and thereby, increases the potential of particle transport until the land is peneplained. This condition will increase the frequency and the ferocity of dust storms in the region (Fig. 1). It will also result in the formation of new sand dunes; sand drifts were observed along roads in northern Kuwait.

The second effect on the geology of the region is that of the oil spill in the Gulf water. Hundreds of miles of the western coastline of the Gulf are already covered by oil. Petroleum "mats" have settled on coral reefs and in other ways have reduced the Gulf water productivity.

The third effect is related to the damage caused by oil well fires in terms of air pollution as well as the potential damage to the petroleum reservoirs. Photographs from the Landsat Thematic Mapper and the NOAA 10 and 11 spacecraft illustrate evidence for the damage to the environment and can help in monitoring environmental change in the future.

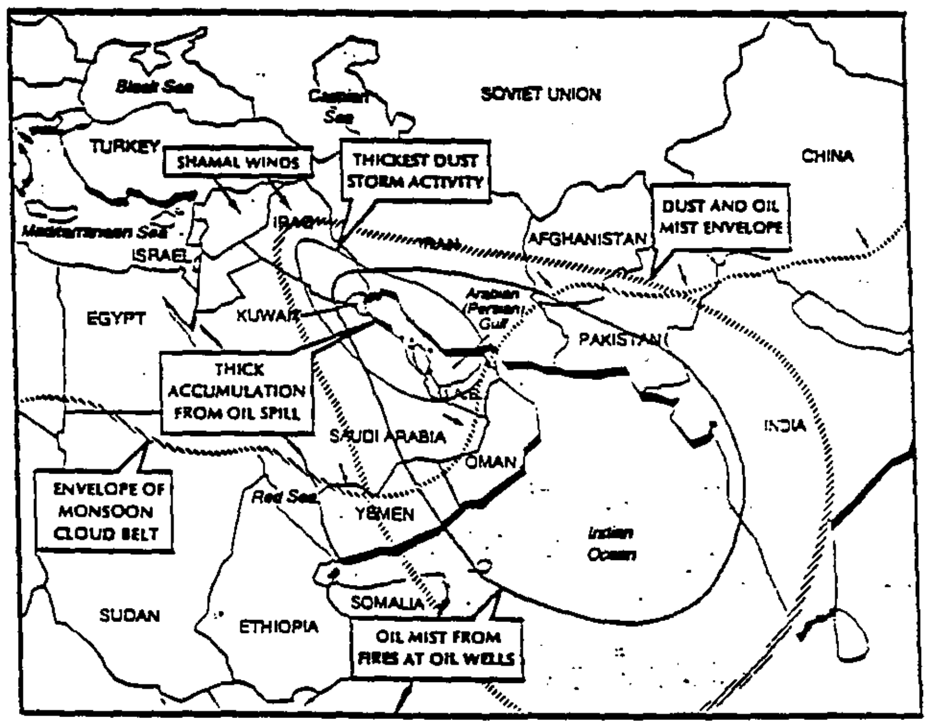



Figure 1. Schematic illustration of potential regional effects of damage to the environment due to recent Gulf War.

# THE IRAQI INVASION OF KUWAIT: AN ENVIRONMENTAL CATASTROPHE

Prof. Jassim Al-Hassan
Kuwait University

Kuwait, an environmentally active country, was rendered the center of the worst environmental disaster ever recorded in history through Iraqi design and execution. The Iraqis threatened to blow up the oil wells as well as other essential services, and they ended up by doing much more than that. In fact, they used the environment as a weapon of mass destruction. The invaders blew up oil installations, laid down and diverted oil pipe lines to dump oil into the Gulf, filled trenches with oil to prevent allied forces from landing, laid down mines on the coast and in the desert, and left huge amounts of ammunition everywhere in Kuwait, thus imposing an instant hazard to human life, indeed an unusual form of pollution. The Iraqi military activities in the desert led to the establishment of a huge network of trenches and bunkers in a land whose top soil is delicate and unstable, thus causing tremendous amounts of sand drifts due to the prevailing winds. The drifting sand buried large areas of trenches, bunkers, mines, ammunition dumps, and even oil lakes. The land, sea, and air pollution resulting from the Iraqi occupation imposed and will continue to impose a constant threat to the environment for many years to come. With very little chemistry done on the nature of the emitted organic and inorganic pollutants from the oil well fires or the oil lakes, it is unsafe to speculate on or minimize the effect of these organic and inorganic pollutants on human and animal health and on marine and desert ecology.

As there is a complex and unprecedented environmental situation in Kuwait, a concerted and integrated international effort involving all related fields of science is needed in order to understand the nature of the Kuwaiti environmental catastrophe and to recommend solutions to the problem.

# SOME RESULTS OF ARAC'S EFFORTS TO ESTIMATE THE AIR POLLUTION IMPACTS OF THE FIRES

Thomas J. Sullivan, Ph.D.
Lawrence Livermore National Laboratory

The Atmospheric Release Advisory Capability (ARAC) was originally conceived and developed at Lawrence Livermore National Laboratory as a nuclear accident emergency response service. It's purpose is to provide near real-time dose assessment calculations for accident response decision makers. Based on operationally robust three-dimensional atmospheric transport and dispersion models, extensive geophysical databases, real-time meteorological data acquisitions and a highly experienced staff, ARAC responds to U.S. events in the 30-90 minutes time frame. The present ARAC service is supported by a combination of DOE and DoD funding

Beginning with the Chernobyl accident, DOE has on several occasions requested that ARAC calculate the transport and dispersion of pollutants for accidents outside the U.S. and for non-nuclear material. One of the latest such requests was for support of the U.S. aircraft research flight programs measuring the pollutants from the Kuwait oil field fires (5/14-6/15 and 7/29-8/20) and the WMO request for assistance to the region's environmental and meteorological services. Since 14 May ARAC has been calculating the continuous smoke plume dispersion throughout a 3200 km region, using meteorological data sources from the U.S. Air Force Global Weather Central. These calculations have been directed toward optical depth estimates based on the integrated vertical (carbon soot) pollutant impact on visible light. ARAC has also reconstructed the long range pollutant transport on a hemispheric scale, again using AFGWC meteorological data, which depict the most probable far field dispersion and deposition patterns, albeit without washout or particle growth effects. These dispersion patterns provide insight as to where international scientific organizations should perform detailed measurements and analyses.

# MEASUREMENTS OF AIR POLLUTION FROM THE FIRES AND THEIR IMPLICATIONS TO HEALTH

Halûk Özkaynak and John D. Spengler
Harvard School of Public Health

In April a team of investigators from the Department of Environmental Health of the Harvard University School of Public Health travelled to Kuwait where they collected ambient air samples for several days in each of four locations in Kuwait (two locations in Ahmadi, Monsouria and Jahara). The field team included Thomas Dumyahn, David Gilmour (Harvard School of Public Health). Xiaowei Yan, Yukio Yanagisawa (Harvard School of Public Health), Ilhan Olmez (Massachusetts Institute of Technology), and Judith Chow (Desert Research Institute, University of Nevada) contributed to laboratory and data analyses. The purpose was to characterize the chemical and elemental composition of particulate mass as well as gases and vapors in locations representative of exposed populations. Bulk mass samples were collected using a modified HiVol with cyclone pre-separator (< 3.5μm). These samples provided the material for animal and cell culture bioassays. Harvard impactors were adapted to collect $PM_{2.5}$ pH samples and black carbon samples, as well as serving their primary function of obtaining $PM_{10}$ concentration data. Four types of passive badges were used to roughly quantify the gases and vapors present and gain a baseline understanding of the concentrations encountered.

Ambient $PM_{10}$ concentrations over 24-hour periods ranged from 50 to 829 $\mu g/m^3$. Mass concentrations do not usually represent the signature of the oil fires alone; rather it is a combination of crustal dust re-suspended by wind and oil fire soot. $PM_{10}$ samples were analyzed through Neutron Activation techniques to obtain a fingerprint of oil fire impacts. Black carbon analysis of quartz filters exposed on days where we have mass concentrations also enables an estimate of the plume/soot impacts.

Scandium was used as an indicator of earth crustal element. V, As, Cr, Cl, Na, Nr, and Ni appear enriched in the particle samples. Al, Fe, La, and Sm appear to be soil related. Preliminary regression analysis shows V is a significant predictor of mass concentration. The carbon is a substantial fraction of the total mass, varying between 2% and 60%. On plume impact days the contribution of carbon to mass was typically greater than 30%. The organic fraction of total carbon ranged from 25% to 90% in Ahmadi.

$PM_{10}$ concentrations measured in Kuwait were often found to be high due to impacts from the oil well fires. The composition of the particle samples collected also showed organic and metal species that are of potential human health concern. Accurate estimates of acute or chronic health effects of plume impacts are not yet available. However, using historic epidemiologic data bases on air pollution and health records, it is possible to make projections of the likely morbidity and mortality effects from exposures to elevated levels of ambient particles. In particular, inferences made by utilizing mortality risk coefficients obtained from the analysis of daily mortality and pollution measurements from New York City and Los Angeles indicate that acute health risk for Kuwait and neighboring countries could be significant (e.g., excess acute mortality could reach 10% in some areas). Chronic health effects are much more difficult to estimate but could be very significant.

# KUWAIT OIL BLOWOUTS AND OIL LAKES FORMATION PERSPECTIVES AND CONSEQUENCES

Dr. Jasem Al-Besharah
Kuwait Institute for Scientific Research

The Kuwaiti oil well blowouts are of different characteristics and structure, depending on their locations, the formations and oil fields, the extent of destruction of the well heads, and finally, the type of crude oils and their impact on the environment. Therefore, these determinant factors helped in setting up priorities for extinguishing and controlling the 600 oil wells on fire.

This paper will concentrate on the extent of the damage that the Kuwait oil fields have been subjected to, the economical and environmental impacts and their consequences, and the priorities of the fire fighting efforts.

Special emphasis will be placed on the formation of the oil lakes in the Kuwaiti desert: their causes, behavior, impact on the environment (air and land), and the methods of oil reclamation and soil cleaning.

**Douglas Dockery**
**Harvard School of Public Health**

Dr. Douglas Dockery, Associate Professor of Environmental Science and Physiology at the Harvard School of Public Health, is Principal Investigator of the Harvard Six Cities Study, a 12 year longitudinal study of the effects of sulfur oxide and particulate air pollution on the development of lung function in children and the development of respiratory disease among adults. He is also Co-Investigator of the Harvard 24 Cities Study, which is measuring the effects of acid air pollution on respiratory health of children in North America. Additionally, he is directing several studies quantifying the acute effects of air pollution episodes on respiratory symptoms and lung function of children, and on increased mortality among adults.

Internationally, Dr. Dockery is collaborating in epidemiologic studies of the effects of air pollution on respiratory health in Mexico City, Beijing, Switzerland, the Netherlands, Germany and Czechoslovakia. He is currently serving as a consultant to the European Community in developing a coordinated program in air pollution epidemiology methods, and is also organizing the efforts at the Harvard School of Public Health to evaluate the respiratory health effects of smoke from the oil fires in Kuwait.

Dr. Dockery received a BS degree in physics from the University of Maryland, an MS degree in meteorology from the Massachusetts Institute of Technology, and an MS and Doctor of Science in Environmental Health from the Harvard School of Public Health.

**Farouk El-Baz, Ph.D.**
**Boston University Center for Remote Sensing**

Dr. Farouk El-Baz is director of the Center for Remote Sensing at Boston University, which he founded in 1986, that deals with applications to archaeology, geography and geology. He contributed to pioneering efforts in this field as supervisor of science planning for the Apollo missions to the moon (1967-1972); founding director of the Center for Earth and Planetary Studies of the Smithsonian Institution (1973-1982); and vice president for science and technology at Itek Optical Systems (1982-1986). He presently serves as president of the Arab Society for Desert Research.

**Michael B. McElroy**
**Harvard University**

Michael B. McElroy received his elementary and graduate education from Queen's University in Belfast, Northern Ireland. After spending a postdoctoral year in the Chemistry Department at the University of Wisconsin, he was appointed staff scientist in 1963 at Kitt Peak National Observatory in Tucson, Arizona. In 1970, Professor McElroy was named Abbott Lawrence Rotch Professor of Atmospheric Sciences at Harvard University, and in 1975 was appointed Director of the Center for Earth and Planetary Physics. He is currently Chairman of the Department of Earth and Planetary Sciences at Harvard. Professor McElroy's research interests range from studies on the origin and evolution of the planets to, more recently, an emphasis on effects of human activity on the global environment of the Earth. He is a fellow of the American Academy of Arts and Sciences and the International Academy of Aeronautics. He was the recipient of the Macelwane Award of the American Geophysical Union in 1968, and the NASA Public Service Medal in 1976.

**Halûk Özkaynak, Ph.D.**
**Harvard School of Public Health**

Halûk Özkaynak is a Research Associate and Lecturer at Harvard School of Public Health, Department of Environmental Health. He has over fifteen years of experience in air pollution data analysis, model development and epidemiologic investigations. His experience includes application of standard air pollution models to infer concentrations, development of state-of-the-art models of long-range transport and visibility, development of detailed indoor air quality models, environmental risk analysis, investigation of biases in air pollution epidemiological data and studies on the implications of air pollution on health. Dr. Halûk Özkaynak has worked in both the private and academic settings conducting research on technical and policy-oriented environmental problems. He has been responsible in the management of large scientific investigations involving monitoring and modeling of human exposures and performing multimedia risk assessment for environmental contaminants. He has several publications in the field of exposure and risk assessment. Dr. Halûk Özkaynak holds degrees in Mathematical Physics and Air Pollution Control.

**Thomas J. Sullivan, Ph.D.**
**Lawrence Livermore National Laboratory**

Tom Sullivan is Group Leader for the Atmospheric Release Advisory Capability (ARAC). He has been with the ARAC Program since 1979 and at LLNL since 1974. Prior to his LLNL employment he was an U.S. Air Force weather officer for 11 years, providing a range of weather support services including six years of operations and development of automated support. Tom received his A.B. in Mathematics from College of the Holy Cross (1963), M.S. in Meteorology from the University of Oklahoma (1970), and a Ph.D. in Atmospheric Sciences from the University of California/Davis in 1982.

Environment Crisis
Persian Gulf
1991

# International Environment and Peace Funds

## International Environment Strategy

Darwin Scientific Foundation

Kuwait Oil Fires

and

International Environment Considerations

Washington Conference

28 September 1991

John M. Eaton

# DARWIN SCIENTIFIC FOUNDATION



Kuwait Oil Fires
and
International Environment Considerations

Washington Conference

28 September 1991

The health effects of the Kuwait oil fires and international environment issues will be considered. Environment damage and dispersion of pollutants will be explained. Satellite imagery, satellite photographs and other satellite obtained data including meteorological information will be presented.

Benzene, polycyclic aromatic hydrocarbons and other potential carcinogenic and toxic compounds contained in the plume from the oil well fires and from the evaporating oil lakes will be described. Hydrophilic carbon pollutants which may be rain seeding and the effects therefrom will be explained.

Acccountability and compensation for damage to the environment will be discussed. Mobilization of people to assure that similar environment damage will not occur in the future will be considered.

The Washington conference follows the conference to consider health effects of the Kuwait oil fires held from 12 to 14 August 1991 at the American Academy of Arts and Sciences, Cambridge, Massachusetts and arranged by the Harvard University School of Public Health and the Harvard Center for Middle Eastern Studies. The Cambridge Conference was jointly sponsored by the Arab Fund for Economic and Social Development and the United Nations Development Programme and co-sponsored by the World Health Organization, the World Meteorological Organization, the United Nations Environment Programme and the International Maritime Organization.

Room 336 • Museum of Natural History • Smithsonian Institution • Washington, DC 20560
FAX (202) 357-1628 • Voice (202) 357-2383

# DARWIN SCIENTIFIC FOUNDATION

Kuwait Oil Fires
and
International Environment Considerations

Washington Conference

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Agenda - Saturday, 28 September 1991

| | | |
|---|---|---|
| 9:00 | Welcome | S. Dillon Ripley<br>John M. Eaton |
| | Man's Impact on the Global Environment | Prof. Michael McElroy |
| | Effects of the Gulf War on the Land, Air and Sea | Dr. Farouk El-Baz |
| | The Iraqi Occupation of Kuwait - An Environmental Catastrophe | Prof. Jassim Al-Hassan |
| 10:15 | Break | |
| 10:30 | Kuwait Oil Fires Pollution Dispersion | Dr. Thomas J. Sullivan |
| | Air Pollution Incidents | Dr. Douglas Dockery |
| 12:00 | Discussion | |
| 12:30 | Lunch Break | |

# DARWIN SCIENTIFIC FOUNDATION

Kuwait Oil Fires
and
International Environment Considerations

Washington Conference

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Agenda - Saturday, 28 September 1991

| | | |
|---|---|---|
| 2:00 | Measurements of Air Pollution from the Fires And Their Implications to Health | Dr. Haluk Ozkaynak |
| | International Environment Issues | John M. Eaton |
| | Kuwait Oil Blowouts and Oil Lakes: Perspectives and Consequences | Dr. Jasem Al-Besharrah |
| 3:30 | Discussion | |
| 4:00 | Conference Adjournment | |

Speakers Committee

S. Dillon Ripley
Darwin Scientific Foundation, Chairman
Smithsonian Institution, Secretary Emeritus
Washington, DC

John M. Eaton
Darwin Scientific Foundation, Secretary
Washington, DC

Professor Jassim M. Al-Hassan
Biochemistry Department
Faculty of Science
Kuwait University
Kuwait City, Kuwait

Dr. Jasem Al-Besharrah
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Scientific Research
Safat, Kuwait

Dr. Douglas Dockery
Associate Professor of Environmenal Science
Department of Environmental Health
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Professor Michael McElroy
Chairman
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Dr. Haluk Ozkaynak
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Dr. Thomas Sullivan
Lawrence Livermore National Laboratories
Livermore, CA

**Conference Chairman**

Dr. Farouk El-Baz
UN Development Programme
Representative and Director, Center for Remote Sensing
Boston University
Boston, MA

# International Environment and Peace Funds

## International Environment Strategy

# Environment Crisis
# Persian Gulf
# 1991

## International Environment Strategy

**Basis --**

- Arab contributions to world civilization
- War presents an environmental threat to world civilization
- Environment is a global concern and the ultimate deterrent of conflict
- Environment provides the catalyst for the new era

**Strategy --**

- Strategy for the environment and peace in the Middle East
- Strategy for a new security framework in the Middle East
  - Environment Corps and Peacekeeping force under United Nations
  - Available world-wide
  - Financed by a percentage of oil revenues
- Strategy for a world-wide peace and security framework
  - Administered by representatives from the five permanent members of the Security Council
  - Financed by a percentage of oil revenues
- Strategy for a world-wide environment preservation framework
  - Administered by representatives from the five permanent members of the Security Council
  - Financed by a percentage of oil revenues
- Strategy for international environment research and scholarship
  - Financed by a percentage of oil revenues

ENVIRONMENT CRISIS
PERSIAN GULF
1991

INTERNATIONAL ENVIRONMENT AND PEACE FUNDS

**Immediate Goal**

Perpetuate Arab contributions to civilization. Address threat to the Environment. Preserve major source of oil production. Major international environment and peace programs commence activities.

**Important Arab Contributions to Civilization**

- Law
- Mathematics
- Philosophy
- Medicine
- Astronomy
- Islam

**Historic Models**

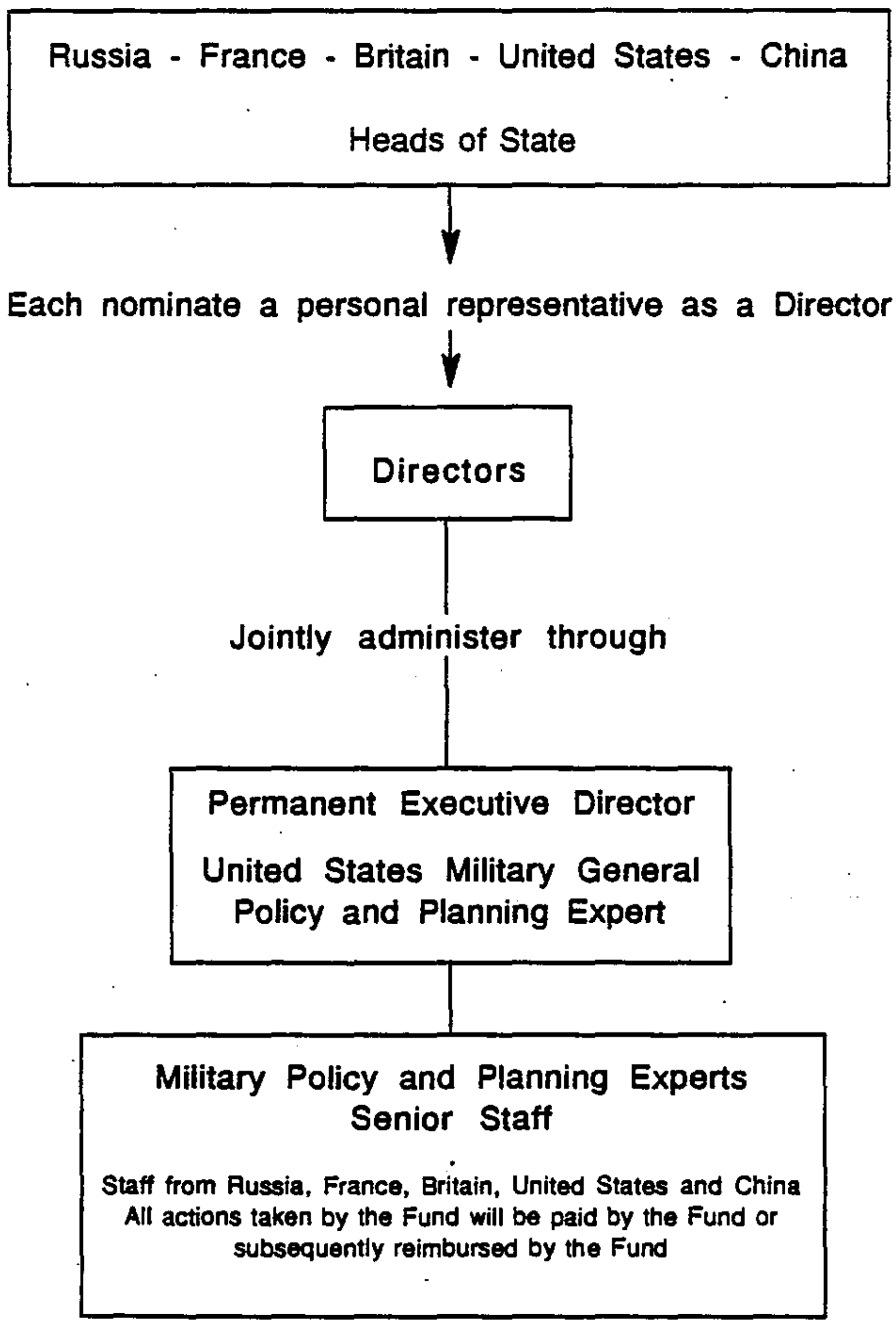
- League of Nations and United Nations in the aftermath of World War I and World War II, respectively.
- Rhodes Scholars
- Nobel Prizes

**International Environment and Peace Funds**

The International Environment and Peace Funds will be viewed in history as following the last war just as the United Nations is viewed as arising out of World War II.

- International Peace Fund for the maintenance of peace. The International Peace Fund will be administered by five personal representatives of the heads of state of the five permanent members of the United Nations Security Council. The immediate effort of the Peace Fund will be the elimination of pollution from the oil wells and oil lakes.
- Darwin Scholars for environmental research and education throughout the World.
- International Environment Fund for environmental preservation and elimination of environmental damage throughout the World. The International Environment Fund will be administered by five personal representatives of the heads of state of the five permanent members of the United Nations Security Council. The immediate effort of the International Environment Fund will be the commencement of an environment impact study and the removal of toxics from Kuwait.
- United Nations Environment Corps for the protection of the environment and for the maintenance of peace. United Nations Environment Corps will protect oil fields and oil production and transportation facilities of Kuwait. United Nations Environment Corps will assure that the oil under the territory of Kuwait and rhe revenues from such oil will belong to, and be for the account of, the government of Kuwait. United Nations Environment Corps will immediately administer all border crossings, ports and airports in Kuwait.

# INTERNATIONAL PEACE FUND




(A)

# INTERNATIONAL ENVIRONMENT SCHOLARSHIP

# DARWIN SCHOLARS

Darwin Scholars:

- Select Darwin Scholar recipients who will be the best and brightest scientists, professors and other scholars in the World working to preserve the environment and survival of species.
- Fund scholars, environmental programs and environmental studies throughout the World.
- Assist in developing and in funding environmental education.
- Award Darwin Prizes for outstanding environmental achievement.
- Publish environmental research reports.

Darwin Scholars immediately awards Darwin Prizes to outstanding environment scientists, professors and other scholars.

# INTERNATIONAL ENVIRONMENT FUND

Russia - France - Britain - United States - China

Heads of State

↓

Each nominate a personal representative as a Director

↓

Directors

Jointly administer through

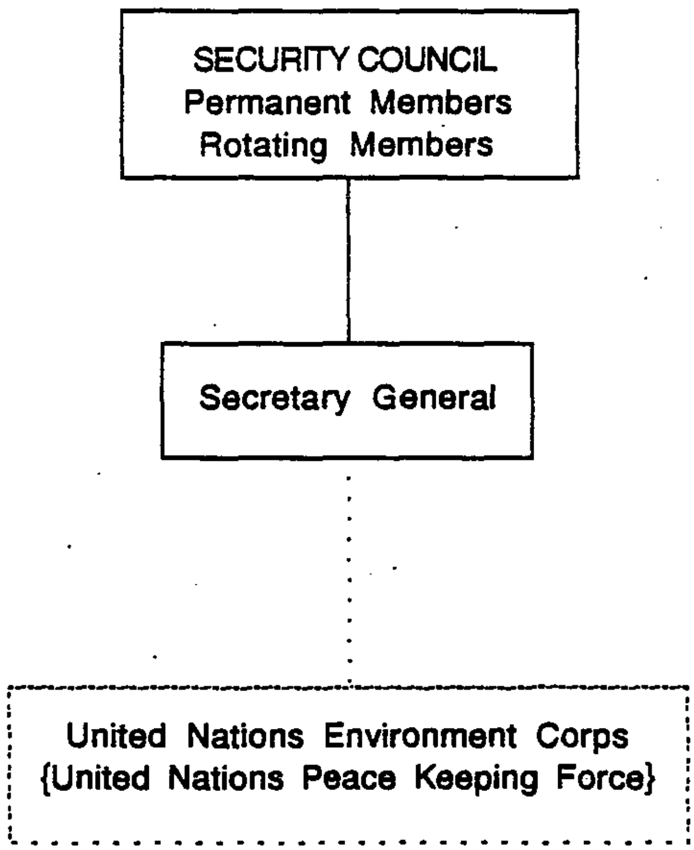
Permanent Executive Director

United States Environment Protection Expert

Environment Protection Experts
Senior Staff

Staff from Russia, France, Britain, United States and China
All actions taken by the Fund will be paid by the Fund or subsequently reimbursed by the Fund

UNITED NATIONS




(D)

## CONTRIBUTION TO WORLD CIVILIZATION

The contribution of a percentage of future oil revenues assures for future world civilization and for the environment supra-national coordination of education, research, planning and action targeting on the environment.

Education, research and planning targets natural disasters and manmade disasters including natural events and war.

In the context of oil production, the cost of the contribution to world civilization is not great.

Conceptually the contribution to world civilization and to humanity includes present funding and assignment of future revenues.

The International Peace Fund receives ten to twenty-five million dollars and a permanent assignment of five percent of oil revenues.

The Darwin Scholars receives ten to twenty-five million dollars and a permanent assignment of one percent of oil revenues.

The International Environment Fund receives ten to twenty-five million dollars and a permanent assignment of five percent of oil revenues.

The United Nations Environment Corps receives a permanent assignment of one percent of oil revenues.

Centers for Disease Control:
National Center for Environmental Health and Injury Control
National Institute for Occupational Safety and Health
and
The Agency for Toxic Substances and Disease Registry

# HEALTH ADVISORY FOR KUWAIT AND SAUDI ARABIA

OCTOBER 8, 1991

**BACKGROUND:**

In February 1991 more than 749 oil wells were damaged or set on fire throughout Kuwait. Efforts to extinguish the fires and end the pooling of oil in the desert have now resulted in the successful capping of over 500 wells. On March 21, 1991, the Public Health Service (PHS) issued a preliminary health advisory related to the burning oil fires which addressed the potential health threats posed by the smoke, the signs and symptoms of exposures, and recommended public health measures. At the time of the preliminary health advisory, no data were available on the levels of airborne pollutants generated by the oil fires. Similarly, no information was available on the health problems being experienced by the civilian and military populations as a result of exposure to the oil fire pollutants. Several United States and international teams of environmental and health experts have visited Kuwait and Saudi Arabia to assess the changing situation. This health advisory is based on the preliminary data generated by these activities.

This update will provide:

1. Results of the air monitoring data collected by the US Interagency Air Assessment team and other international organizations;
2. Summary of the health surveillance findings for civilian and military populations in Kuwait; and
3. Revision of the public health recommendations for US citizens.

**SUMMARY OF AIR MONITORING DATA:**

Since the fires were set in February, the plume of the fire has typically risen 10,000 to 12,000 feet, mixing with the air and then being dispersed for several thousand miles downwind over a period of several weeks. As the plume travels, the particles and gases contained within it become more widely dispersed and also more diluted. The highest concentrations of pollutants are found in the areas nearest the affected oil fields and the areas immediately downwind.

SULFUR DIOXIDE, NITROGEN DIOXIDE, CARBON MONOXIDE:
During April through July the levels of two major air pollutants (sulfur dioxide and nitrogen dioxide) never reached harmful levels based on the U.S. EPA air pollution index (See Appendix). The level of CO exceeded the U.S. alert level on rare occasions, possible due to increased traffic.

| | AVERAGE MONTHLY LEVEL PPM APRIL-JULY | MAXIMUM 5-MIN LEVEL PPM APRIL-JULY | U.S. ALERT LEVEL* |
|---|---|---|---|
| Sulfur Dioxide | 0.002 | 0.038 | 0.3 |
| Nitrogen Dioxide | 0.013 | 0.496 | 0.6 |
| Carbon Monoxide | 0.648 | 33.1 | 15.0 |

*See Appendix for time periods of measurement.

PARTICULATES:

The average level of particulate matter measuring less than 10 microns, that portion of airborne particulate with the greatest health impact on the respiratory system, measured each day between May - July 10 was 308 ug/$m^3$ and the maximum level was 2029 ug/$m^3$. The alert level in the U.S. is 350 ug/$m^3$. It must be remembered that Kuwait, for various reasons including frequent sand and dust storms, has an average annual level of $PM_{10}$ of about 700 ug/$m^3$, the highest in the world (WHO/GEMS). The $PM_{10}$ levels of daily samples exceeded 500 $\mu g/m^3$ on 5 days during May, 3 days during June and 1 day in the first 10 days of July.

HYDROGEN SULFIDE:

For hydrogen sulfide, the highest measured level was 0.042 ppm by the US EPA in a grab sample in a well plume in Sabiriyan. This level is well below levels that can cause mucous membrane and conjunctival irritation (10 ppm), olfactory fatigue (100-500 ppm) or asphyxiation (500 ppm). Levels greater than 1000 ppm can cause apnea within seconds. The peak level of 0.042 ppm is well below the U.S. federal occupational standard for hydrogen sulfide of 20 ppm, the ceiling concentration for an 8-hr workday.

NICKEL AND VANADIUM:

Information about concentrations of metals in the ambient air in Kuwait has been collected by a team of French researchers who visited Kuwait from March 27 to April 4, 1991. The Laboratory of Hygiene of the city of Paris and the French Institute of Petroleum measured vanadium and nickel from 8 samples collected from different parts of the city at different times on several days. The average concentration of nickel in the 8 samples was 221 $ng/m^3$ (values ranged from 20 $ng/m^3$ to 600 $ng/m^3$). The average concentration of vanadium was 32 $ng/m^3$, (values ranged from less than 20 $ng/m^3$ to 200 $ng/m^3$). The Kuwait Environmental Protection Department measured nickel and vanadium using high volume samplers placed at each of three different hospitals in Kuwait City during 10 days between March 16 and April 26, 1991. The average concentration of nickel during the 10 days was 54 ng/m$^3$ (values ranged from 22 to 145 ng/m$^3$). The average concentration of vanadium was 32 ng/m$^3$ (values ranged from 7 to 75 ng/m$^3$). To put these values into perspective, the average nickel concentrations in urban areas of Europe range from 60 to 300 ng/m$^3$ and the average vanadium concentrations range from 7 to 200 ng/m$^3$.

BENZO(A)PYRENE:

The median level of benzo(a)pyrene measured by the French team at the English school in Kuwait city was 4.9 ng/m$^3$. In the village of Ahmadi they measured 7.6 ng/m$^3$. For comparison, the median level measured in Paris in the winter was about 4.6 ng/m$^3$.

It should be stressed that measurements of air pollutants from the Kuwait oil fires are still not complete nor adequate to fully evaluate the potential long-term health effects.

**SUMMARY OF HEALTH SURVEILLANCE FINDINGS:**

All of the substances released by the burning oil wells can cause adverse health effects, which vary depending on the concentration and duration of exposure. These effects were summarized in the Preliminary Public Health Advisory. Surveillance in civilian clinics and emergency rooms, and a survey conducted among U.S. Marines, indicate increases in symptoms of upper respiratory irritation. These observations are consistent with the environmental air sampling results indicating high levels of airborne particulate matter.

EVALUATION OF HEALTH EFFECTS FOLLOWING SHORT-TERM EXPOSURES: Data collection from polyclinics and hospital emergency rooms continues to improve. Preliminary analyses of emergency room surveillance conducted at two hospitals in Kuwait City from January 1 to April 30 showed that 6,127 visits had occurred, 2,373 in the period during occupation before the oil fires were started (Jan 1 - February 22) and 3,754 in the period after liberation (February 23-April 30). Notable findings included the fact that the proportion of visits by residents of Kuwait City to the emergency rooms for gastrointestinal illnesses, heart disease, psychiatric illnesses, chronic bronchitis, emphysema, and bronchiectasis increased during the period after the oil wells were ignited. On the other hand, there was no documented increase in the proportion of visits for acute upper and lower respiratory infections or asthma during the period after the oil wells were ignited.

Department of Defense surveys of Marines stationed in Saudi Arabia and Kuwait showed that Marines in Kuwait reported more frequent symptoms of upper respiratory irritation such as dry cough compared with those who served only in Saudi Arabia. Marines with a history of asthma were more likely to report wheezing in Kuwait compared with Marines in Saudi Arabia.

POSSIBLE HEALTH EFFECTS FOLLOWING PROLONGED EXPOSURES:
At the lower concentration levels of air pollution observed to date, the primary public health concerns are the cumulative effects of prolonged exposure and short term exposure during a pollution episode. Of particular concern are the potential effects of elevated levels of particulates on the respiratory system, such as a decrease in lung function or the development of chronic bronchitis.

Some of the hydrocarbons, measured at low concentrations in the smoke, have been shown to cause cancer in laboratory animals at higher levels of exposure. In addition, epidemiologic studies show that exposure of humans to high concentrations of nickel for many years can cause lung cancer. At an air nickel concentration of 1000 $ng/m^3$ (higher ever measured in Kuwait), a conservative estimate of the lifetime cancer risk is 4 per 10,000. There is no evidence that vanadium concentrations below 1000 $ng/m^3$ have adverse health effects.

Based on risk estimates from coke-oven emissions, about 9 per 100,000 exposed people may die from cancer of the respiratory tract as a result of spending a lifetime in ambient air containing an average of 1 ng benzo(a)pyrene per $m^3$ mixed with all the other polycyclic aromatic hydrocarbons and related substances in coke-oven emissions.

Most epidemiologic studies of health effects following prolonged exposures are based on a lifetime of exposure to the chemical of interest. Thus, it is difficult to extrapolate those results to the current situation, in which exposure levels changes as the wind shifts direction. In addition, most, if not all of the oil fires are expected to be capped by March, 1992, 5 months from now. Thus, individuals are cautioned not to extrapolate these risk estimates to their particular exposure history.

**PUBLIC HEALTH RECOMMENDATIONS FOR US CITIZENS IN KUWAIT AND SAUDI ARABIA:**

These recommendations are slight modifications of the preliminary precautions to protect public health issued in March, 1991:

1. All personnel stationed or working in the immediate vicinity of the burning oil wells (such as firefighters) should be medically evaluated prior to

their assignment for pre-existing cardiac and pulmonary diseases and issued appropriate personal protective equipment. Sufficient training should be provided in the use of this equipment and appropriate safety precautions.

2. US Embassies should consider the initiation of a health alert system during this period of decreasing winds in Kuwait during October, November, and December 1991. During air pollution episodes persons residing in areas with high air pollution should be advised on measures they can take to reduce their exposures. These include staying indoors during air pollution episodes and keeping windows shut, and monitoring changes in their own health status. Persons at risk for experiencing health problems from air pollution, particularly asthmatics, and individuals with underlying respiratory or cardiac conditions, should be educated as to the early warning signs and symptoms of potential serious exposure such as runny nose, sore throat, watery eyes, chest pain, headache, nausea, dizziness, cough, shortness of breath, etc. Persons experiencing even minor symptoms should be instructed to seek medical attention.

3. Persons who smoke should be encouraged to stop smoking. They should be warned about the possible additive effects of exposure to cigarette smoke and air pollution.

4. Persons exposed to the smoke from the oil well fires should thoroughly wash exposed areas of skin each evening, to prevent excessive dermal absorption.

5. Medical personnel should be advised of the potential health hazards posed by the burning oil. Individuals with respiratory complaints should be carefully evaluated and clinical personnel should be educated on the appropriate medical management of acute airway obstruction.

6. Public health authorities should develop and effectively disseminate information to the public covering the above measures in addition to advice concerning and symptoms of potential ill-effects, and steps to follow if such symptoms appear.

**ACTIONS TO FURTHER ASSESS THE SITUATION:**

1. The medical facilities in the affected areas should be prepared to both diagnose and treat medical conditions which may occur as a result of exposure to emissions from the burning oil wells. These include adequate cardiac and respiratory monitoring equipment for patients presenting with chest pain and shortness of breath, oxygen delivery systems, chest x-ray machines, pulmonary function testing equipment, airway management equipment (etc. endotracheal tubes), and medications (eg. beta adrenergic agents).

2. Ambient air monitoring should continue in all major residential areas in Kuwait and Saudi Arabia. Specific pollutants to be measured should include respirable particulates, sulfur dioxides, hydrogen sulfide, nitrogen oxides, and other pollutants. Monitoring activities should be continued in those areas most likely to be affected by the smoke plume.

3. Surveillance systems for adverse health effects should be expanded, to better monitor the health status of persons exposed to the oil fire plumes. In addition, the availability of medical records for long-term follow-up of highly exposed persons should be assessed.

**APPENDIX**

The following table lists current U.S. regulations or other recommendations for environmental levels of selected air pollutants:

| POLLUTANT | STANDARD | AVERAGING TIME | SOURCE |
|---|---|---|---|
| Carbon Monoxide | 9 ppm (10 $mg/m^3$) | 8-hour | EPA |
| | 35 ppm (40 $mg/m^3$) | 1-hour | |
| Particulate Matter | 50 $\mu g/m^3$ | 1-year | EPA |
| ($\leq$ 10 $\mu m$) | 150 $\mu g/m^3$ | 24-hour | |
| Sulfur oxides | 0.03 ppm (80 $\mu g/m^3$) | 1-year | EPA |
| | 0.14 ppm (365 $\mu g/m^3$) | 24-hour | |
| | 0.5 ppm (1300 $\mu g/m^3$) | 3-hour | |
| Ozone | 0.12 ppm (235 $\mu g/m^3$) | 1-hour | EPA |
| Hydrogen sulfide | 0.15 $mg/m^3$ | 24-hour | WHO |
| Nitrogen Oxides | 0.05 ppm (100 $\mu g/m^3$) | Annual | EPA |

NCAR/TN-363+PROC
NCAR TECHNICAL NOTE

August 1991

# Workshop Review: Management of Data Collected in GRAMP (Gulf Region Atmospheric Measurement Program)

## 22-24 July 1991

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# LIST OF ACRONYMS

| | |
|---|---|
| ARAC | The Atmospheric Release Advisory Capability |
| ASAP | A System for Assessment of Pollution |
| BTAB | BUFR Tabular Form |
| BU | Bahrain University |
| BUFR | Binary Universal Form for Data Representation (WMO spec FM 92) |
| CBS | Commission for Basic Systems |
| CD | Compact Disk |
| DAT | Digital Audio Tape |
| DCP | Data Collection Platform |
| DDB | Distributed Databases Concept |
| DM | Data Management |
| DMSP | Defense Meteorological Satellite Program |
| DNA | Defense Nuclear Agency |
| ECMWF | European Climate Modeling Weather Forecast |
| FGGE | First GARP Global Experiment |
| GCOS | Global Climate Observing System |
| GDPS | Global Data Processing System |
| GKS | Graphics Kernel System |
| GMEP | German Ministry of Environmental Protection |
| GOS | Global Observing System |
| GRAMP | Gulf Region Atmospheric Measurement Program |
| GRIB | Grid in Binary (Gridded data format--WMO spec) |
| GTS | Global Telecommunications System |
| IFC | IGOSS Flexible Code |
| ISS | Integrated System Study |
| KFUPM | King Fahd University for Petroleum and Minerals |
| MDD | Meteorological Data Dissemination |
| MEPA | Saudi Arabian Meteorological and Environmental Protection Agency |
| METEOSAT | Meteorological Satellite |
| MTN | Main Telecommunication Network |
| NASA | National Aeronautics and Space Administration |
| NCAR | National Center for Atmospheric Research |
| NIST | National Institute of Standards and Technology |
| NMC | National Meteorological Center |
| NOAA | National Oceanic and Atmospheric Administration |
| NOAA/ARL | NOAA/Atmospheric Research Laboratory |

| | |
|---|---|
| NOAA/AVHRR | NOAA/Advanced Very High Resolution Radiometer |
| NOAA/NESDIS | NOAA/Earth System Data Directory |
| RSMC | Regional Specialized Meteorological Centers |
| RTH | Regional Telecommunications Hubs |
| SPOT | Système Probatoire pour l'Observation de la Terre |
| USAEHA | US Army Environmental Health Agency |
| WGDM | Working Group on Data Management |
| WMO | World Meteorological Organization |
| WWW | World Weather Watch |

# PREFACE

The demolition and subsequent burning of the Kuwait oil fires was a senseless act of destruction that has threatened public health, damaged the environment, and may possibly cause short or longer term changes in regional and global climate. Many nations responded to this disaster by offering aid and by rushing teams into the affected area to make measurements that would assess the impact of the fires.

The following report summarizes a workshop that was held July 24-26, 1991 at the National Center for Atmospheric Research (NCAR) to discuss a plan to gather all the atmospheric measurements that are being made in the Gulf region and make them available for general dissemination. This workshop was initiated by the World Meteorological Organization and co-sponsored by the National Oceanic and Atmospheric Organization.

# ACKNOWLEDGEMENTS

The idea for the workshop was originally discussed in early June but the actual planning effort did not get started in earnest until the end of that month. The fact that the workshop was conducted and well attended can be attributed to the hard work and fast action of a number of people. John Robinson of NOAA deserves special thanks, not only for obtaining financial backing to help underwrite the expenses of the workshop, but also for his relentless enthusiasm and support. Danny Foster of the WMO contacted all the potential participants. Larry Radke, manager of the NCAR Research Aviation Facility and the co-principal investigator of the NCAR effort in the Gulf, provided the necessary resources from the RAF to accomplish this workshop in what might be record time. We would particularly like to thank all the participants who managed to break away from thier already overloaded schedules to attend this workshop and provide their valuable input. Finally, we would like to offer special thanks to Barbara Knowles who made the majority of the meeting room arrangements, took notes, arranged for refreshments, typed the workshop report and managed to keep a big smile on her face the whole time.

# PART I--INTRODUCTION

A large-scale, international effort has been initiated by the World Meteorological Organization to assess the atmospheric effects caused by the man-made pollution that is introduced by the burning of more than 500 oil wells in the Kuwait oil fields. The WMO called a meeting of experts to discuss how to assess the effects and to coordinate an international response for the atmospheric part of the environmental emergency in the gulf.[1] This meeting identified a large number of agencies that had been or would soon be participating in measurement programs in the Arabian Gulf region and focused on the critical environmental issues that needed to be addressed by these measurement programs. All of these programs are being coordinated by the WMO whose responsibility is to ensure that adequate measurements are made and that these measurements are integrated and disseminated to international research organizations in a systematic and timely fashion.

This latter task requires gathering the many measurements from multiple platforms, cataloguing the attributes of each of the data sets, archiving and then disseminating this information. The need for this operation is stated in section 6.5 of the draft report. However, the methodology and mechanisms for accomplishing this task are omitted. A number of factors are involved with establishing a data archive and this task should not be undertaken without careful consideration and utilization of input from the agencies that were involved in the measurement programs. The World Meteorological Organization (WMO), seeing the need to solicit this input, asked the National Center for Atmospheric Research (NCAR, Boulder, Colorado) to organize a workshop that would focus on the salient aspects involved with starting the data archiving process. This workshop was held at the NCAR facilities on July 22-24, 1991.

The urgency of the problem and need to initiate an archiving process as soon as possible made it difficult to obtain representatives from all agencies who had participated in the Gulf Regional Air Monitoring Program (GRAMP) since there was only about a three week period between notification and start of the workshop. Nevertheless, over 45 attendees from more than 20 agencies and five countries participated in the workshop (Appendix C lists all the participants).

The remainder of this document summarizes the workshop proceedings (the agenda may be found in Appendix A).

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[1] Draft Report of the WMO Meeting of Experts on the Atmospheric Part of the Joint U.N. Response to the Kuwait Oil Fields, Geneva, 27-30 April 1991.

# PART II--OVERVIEW AND CONTEXT OF WORKSHOP

There were several objectives to be met by the workshop.

- To identify as many data sources as possible that could be assembled into an archived data set which will assist the scientific community in assessing the impact of the Kuwait oil well fires.

- To identify measurements that are still needed and things that should be done to present data sets for future analysis.

- To make recommendations with regard to how the data should be documented, archived, accessed, and disseminated to achieve maximum accessibility and portability.

## Identification of Data Sources

During the course of the workshop, representatives from a number of agencies summarized the types of measurements that their groups have been making in the Gulf region. The measurements are generally grouped in four categories: ground-based, airborne, satellite, and computer models.

### Ground-based Measurements

Representatives from the King Fahd University for Petroleum and Minerals (KFUPM, Dhahran, Saudi Arabia)[2], National Oceanic and Atmospheric Administration (NOAA), Defense Nuclear Agency (DNA)[3], Environmental Protection Agency (EPA), the National Institute of Standards and Technology (NIST) and the United States Army Environmental Health Agency (USAEHA) presented overviews of their measurement programs. These are summarized as follows:

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[2] KFUPM is one of several facilities that make up the Saudi Arabian Meteorological and Environmental Protection Agency (MEPA).

[3] The representative from this group also discussed measurements made by the University of Bahrain who collaborated with the DNA on radiation measurements.

- MEPA - Atmospheric measurements of PM-10[4], $SO_2$, $O_3$, CO, $H_2S$, Polycyclic Aromatic Hydrocarbon (PAH) analysis, inorganic acids, volatile organic hydrocarbons (VOC) and heavy metals. Soil samples were analyzed for nickel and vanadium. Solar radiation measurements are also being taken at KFUPM.

- NOAA - 16 meteorological towers in Kuwait are telemetering 15 minute averages of temperature, humidity, horizontal winds, and solar radiation into Kuwait City.

- EPA - Measurements of $SO_2$, Polycyclic Aromatic Hydrocarbon (PAH) analysis, inorganic acids, volatile organics and Heavy metals. Single measurements were made at 10 different locations from March 13 - March 20.

- DNA - In Collaboration with Bahrain University (BU), direct, diffuse, and spectral radiation data were taken in Bahrain with DNA and BU radiometers. The university of Bahrain has also been making spectral measurements since 1986 that can serve as useful pre-fire background data.

- NIST - Has made measurements of flame height on five oil wells, heat flux and release rate on one well, and analysis of particulate mass and PAHs from an oil pool fire.

- USAEHA - Soil sample analysis for metals.

In addition to the ground-based measurement programs presented at this workshop, several other agencies were identified either as having made measurements or planning to. Those that were mentioned were groups from Saudi Arabia (Royal Commission, ARAMCO, MODA/MSD), Kuwait, Bahrain (Environmental Protection Committee), France (Air Parif), Germany (Ministry for Environment), Norway (Institute for Air Research), and Japan. The specifics of these measurement programs were not available for further discussion but the archiving process will need to encompass these data sets if they become available.

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[4] PM-10 is the particle mass of all particles less than 10 $\mu m$ diameter. This is a technique whereby particles are deposited on a filter after particles larger than 10 $\mu m$ have been removed from the air.

## Airborne Measurements

The airborne measurements were discussed by the representatives of the German Ministry of Environmental Protection (GMEP) and the National Center for Atmospheric Research (NCAR). The measurements made by these organizations are as follows:

- NCAR - Temperature, pressure, humidity, horizontal and vertical winds, turbulence
  Particle size distributions (0.05 - 600 $\mu m$ diameter)
  Cloud condensation nuclei, condensation nuclei
  Cloud droplet composition
  Soot mass
  $O_3$, CO, $NO_x$, $SO_2$, $H_2S$, OCS, CS2, Methane, Total Sulfur, Speciated and Continuous Peroxides, Formaldehyde, Total Hydrocarbons
  Short Wave, IR, and UV radiation, Surface temperature
  Single particle albedo
  <u>Lidar</u> - 0.5 $\mu m$, 1.06$\mu m$, 10.6$\mu m$
  <u>Dropsondes</u> - vertical profiles of winds, temperature, and humidity
  A total of 15 flights and 100 flight hours were flown covering the time period from May 19 - June 4, 1991.

- GMEP - Temperature, pressure, humidity, horizontal winds
  Particle size distributions (0.1 - 50 $\mu m$ diameter)
  Soot mass
  $O_3$, $NO_x$, $SO_2$, VOC, PAH, Anions, Cations, metals
  UV radiation
  A total of 29 flights were flown from the period May 20 - June 6, 1991.

In addition to these airborne measurement programs, other airborne measurement projects were identified. The British Meteorological Service operated an aircraft and flew 55 hours during seven flights from March 22 to April 2, 1991. The University of Washington aircraft flew during the same period as the NCAR aircraft in a cooperative experiment and its instrumentation was fundamentally the same as NCAR's. The Department of Energy has made airborne measurements during the months of July and August and NASA had plans to fly a helicopter near the plumes to make better estimates of emission factors. There has also been discussions of sending the NOAA P-3 to the Gulf in the October-November time period of 1991.

Satellite Measurements

A number of satellites cover the Gulf region and this data can be obtained from several different sources.

- Meteosat 4 and 5 (Geo-Stationary)
- NOAA 9, 10 and 11 (two passes/day, each satellite)
- Defense Meteorological Satellite Program (DMSP) F8, F9, F10 (two passes /day, each satellite)
- Landsat
- SPOT

**Surface and Upper Air Stations**

The WMO World Weather Watch has 180 surface observing stations and about 40 upper air stations in the countries concerned. The data from those stations that report are archived daily at NCAR.

**Modeling Efforts**

Numerous modeling efforts are presently going on around the world, many of which were identified at the WMO meeting of experts. Three of these models were discussed at the workshop.

- Lawrence Livermore National Laboratory - The Atmospheric Release Advisory Capability (ARAC) is used to model optical density and provides near-real-time assessments of concentration, dose, and deposition of particulate as a function of time and location.

- NOAA/ARL - The ARL (Atmospheric Research Laboratory) runs three models for emergency response smoke plume dispersion forecasts. These models are used for concentration and trajectory forecasts.

- Royal Netherlands Meteorological Institute - "Puff model" provides isopleths of vertically integrated soot concentration and dispersion forecast in 24, 48, and 72 hour time intervals.

## Data Analysis Requirements

One of the primary reasons for archiving large data sets is to provide an easily accessible, centralized database to facilitate extensive analysis. The database will be used to address four major issues:

- What is the composition and amount of gaseous and particulate by-products being produced by the burning oil wells?
- What is the magnitude of the exposure to toxic substances in the Gulf region in relation to human health risks?
- What are the expected effects in areas more remote from the source with regard to additional air pollution and deposition?
- Are there any global effects to be expected and what would be the magnitude and duration?

The analysis of the measurements fall into categories of diagnostic and prognostic. In the first case diagnostic analysis is used:

- To assess the immediate regional impact on public health and the environment.
- To characterize the regional emission rates of smoke particles and trace gases.
- To measure radiative properties of the smoke particles and the radiative effects of the plumes with attention to how radiation affects the altitudes of the plumes and the stability of the atmosphere.
- To measure characteristics of the smoke particles, i.e., size, shape, composition, and optical properties.
- To evaluate the degree to which smoke particles are scavenged in clouds, their subsequent effects on composition and radiative properties of clouds.
- To measure how the properties of the plume change with time.

The prognostic use of the data will be:

- To help in developing emergency response systems to warn the populace of health risks.

- To provide measurements that will aid in better parameterization of turbulent diffusion fields, particulate size distributions, and chemical reaction rates.

- To provide data on smaller scale than available from Radiosonde Observations to initialize dispersion models.

- To validate and help adjust medium, long-range, and global climate models.

## Data Archival Objectives

The primary objectives to be met when archiving data from the atmospheric measurements made in the vicinity of the Kuwait oil fires are as follows:

- To catalogue and document as many atmosphere related measurements as possible that are of relevance to assessing the impact of the fire;

- To assemble as many of these data sets as possible;

- To store these data sets on high density medium that can be easily accessed;

- To maintain these data sets and update them as necessary;

- To provide utility software to allow easy access and perusal, and retrieval of these data sets.

These five objectives formed the focus of the remainder of presentations and discussions the final two days of the workshop.

## Cataloguing and Documenting Measurements

The large quantity and variety of measurements that have been and are being made in the region of the oil fires makes it imperative that a major effort is made to compile comprehensive documentation on these data sets. At the minimum the following information must be included:

- What atmospheric constituents were being measured?

- What sensors were being used to make the measurements?

- What are the ranges, resolutions, sample rates and accuracies of the instruments?

- Where and when were the measurements made?

- Who is the primary contact to whom questions about the dataset should be directed?

Some data cataloging efforts are already underway, one instigated by UNEP and one by the U.S. Public Health Service. The UNEP effort is being developed by the Delft Corporation (The Netherlands) to be delivered to ROPME (Saudi Arabia). This system is called "A System for Assessment of Pollution" (ASAP) and is a PC-based database system that will contain as much information as possible about the measurements efforts taking place in the Gulf region. Information about this system can be obtained by contacting Dr. H.J. Van Zuylen (see Appendix B).

The Public Health Service has developed a database of published literature that pertains to the health effects of the Kuwait oil well fires. This database is presently on-line and can be accessed by computer dial-up. More information on this service may be obtained from Dr. John Andrews (see Appendix B).

Gerald Barton (NOAA/NESDIS) described the NOAA Earth System Data Directory that is a referral service for national environmental data. He suggested that this directory might be a possible place to put the Kuwait data catalogue information once it is assembled.

## Assembling and Accessing Data Sets

Assembling the data sets requires full cooperation of each of the participating agencies. All of the organizations that attended the WMO meeting of experts agreed to participate in the sharing of data. To expedite the archiving process, these data sets will need to be available on commonly available magnetic media (e.g., magnetic tape, CDs, floppy discs) and in a easily readable format (i.e., ASCII, packed integer, etc.). It is critical that each data point is labeled in some manner with the sensor type (e.g., $SO_2$), time (local or UTC) and location (preferably latitude, longitude and, where applicable, altitude). This labeling method will allow rapid retrieval for subsequent analysis.

## Storing Data Sets

The amount of information to be stored in a central archive is enormous. The actual magnitude is difficult to assess at this time; however, it is clear that sufficient space must be planned carefully at the archival center. In addition, since the data must be disseminated on an easily accessible medium, a high density media must also be identified.

A number of agencies routinely archive large data sets that are accessed frequently by large numbers of users. Technology is presently available for storing data in terrabyte quantities. Likewise, recent technology has been developed to store large quantities of data on relatively small devices such as compact optical discs or 8 mm video cartridges. These are but a few of the possibilities that must explored before embarking on a project of this magnitude. Discussions during the workshop concerning long-term storage of magnetic media, especially newer technology such as DATs and Exabytes, emphasized the need to use multiple storage techniques.

## Disseminating, Maintaining and Updating Data Sets

The data taken during the Kuwait oil fires is unique in its breadth and scope. The number of agencies and individuals who will seek access to this data set cannot be fully determined at this time, but is quite likely to be large. This data set is also likely to be accessed over a longer period of time and will continue to evolve as the fires are extinguished or as some of the measurements are modified to account for sensor recalibration or other corrections, and as more baseline measurements become available.

A suggestion was made at the meeting of experts that the center for data archival should be located in either Kuwait or Saudi Arabia. Local impacts of the oil fires will most affect these two countries and it is reasonable that a data dissemination center be located in one of these two nations. Experience has shown, however, that a strategy should be explored in which multiple centers are established to be used as dissemination centers. International communications and computing equipment continues to improve in both speed and reliability. However, there will always be a finite chance that a power or equipment failure will temporarily disable an archive center's ability to function, oftentimes at inopportune moments when data is most needed. Locating centers in the Middle East, Europe, and the US would ensure that the flow of data remain uninterrupted and that a catastrophic failure will not jeopardize an irreplaceable data set.

Establishing three data centers does not mean three archiving centers if, by definition, an archiving center is the one that generates the initial cataloguing and formatting of data sets. The strategy is to maintain a constant line of communication between centers so that any updates or modifications be implemented in the auxiliary centers once they have been certified by the central archiving facility.

The actual dissemination of the data can be accomplished in two ways. One way is to put the complete data set on a portable media such as magnetic tape or optical disc and mail it to the user who reads the data on his own system. An alternative way, to be used with much smaller, selected data sets, is for the user to communicate over the electronic network with one of the data centers and to request the specific information from the centralized mass storage center. This is a technique routinely used at a number of agencies at this time. A representative from NCAR discussed the present electronic network that spans the world. This network continues to expand in size and speed. Branches already stretch into the Middle East, although the coverage is not yet as extensive as found in the United States and Europe.

Some of the measurement systems provide a relatively simple set of data that is easily manipulated and analyzed. However, other measurement platforms such as aircraft can produce a complex set of measurements that is much more difficult to manipulate and interpret. As an example, there are more than 500 possible raw and derived variables available from measurements made by the NCAR Electra alone. Rapid display and manipulation of these data, coordinated with other data such as upper air and satellite measurements will require sophisticated analysis tools if useful information is to be extracted in a minimum amount of time. Some such analysis tools were demonstrated at the workshop that allow easy display of complex data sets from aircraft and for integrating measurements from multiple platforms such as satellite and ground-based measurements.

# PART III--RECOMMENDATIONS

The workshop concluded with a summary session in which a number of recommendations were made concerning the handling of data from the Kuwait oil fires. The workshop has recommended (without assigning specific priorities) that:

- NCAR should be the international archive center for regional datasets which are related to the Kuwaiti oil fires. In fulfilling this function, NCAR should:

  - Identify, collect and store the relevant datasets.
  - Manage the archive.
  - Facilitate access to the datasets.
  - Compile, maintain, and publish an inventory of the data sets.
  - Maintain a set of appropriate software tools for accessing and viewing the datasets.
  - Further develop archival perusal and display tools.
  - Make these software tools available upon request.

- The datasets should be generally available without restrictions except for necessary nominal charges covering handling and shipping of data storage media.

- NCAR should provide special assistance to Gulf Region countries to meet their requirements for accessing the data.

- NCAR should consider appropriate data formats for long-term archiving with a view to supporting efficient access to the data, taking into account the needs of the major disciplines of evaluating groups such as public health agencies, modelers, emergency response teams, etc.

- Relevant archived data should be made available to health agencies as soon as possible.

- An assessment should be made as soon as possible of current measurements to determine what additional measurements should be made and what on-going measurements should be continued.

- An electronic Bulletin board needs to be established for providing archive information to interested users.

- An advisory group should be formed to review the archival process.

- An Internet link to Gulf region should be established.

- WMO should take active role in publicizing Kuwait measurement activities.

- A WMO Gulf coordinator should publish quarterly situation reports.

- Encourage the Public Health Service to continue archiving health-related literature.

- Need of data focal points in the Gulf Region countries with active collaboration by scientists in the archival process.

- There should be a follow-up meeting later this year.

A number of additional measurement and analysis efforts were recommended:

- A climatological summary of the Gulf region should be made available as soon as possible. A Gulf region meteorologist should take a lead role in this effort.

- The Air Force Defense Meteorological Satellite Program (DMSP) local ground-receiving station should remain in operation in Gulf area throughout the duration of the project (5th Weather Wing from Langley AFB, VA).

- Better source term characterization is critically needed.

- Modeling must be continued but with more realistic physics, and measurements must be used to validate these models.

- Data from any classified satellite, airborne, or ground-based measurements pertinent to the problem should be made available as soon as possible.

- Continued archival of Meteosat and NOAA AVHRR data is needed until at least the end of the fires.

- Continued acquisition of higher resolution satellite data by landsat and SPOT is encouraged.

- Encourage NASA to continue hand-held camera photography of Kuwait oil fire plumes during space shuttle missions until oil well fires are extinguished.

# PART IV--APPENDICES

## APPENDIX A--Agenda

Agenda
A Workshop on the Management and Analysis
of Data Relating to the Kuwait Oil Fires
July 22 - 24, 1991
Boulder, Colorado

Workshop Registration

Opening Comments--WMO Representative

Workshop Objectives--*WMO/NCAR*

Review of Available Data Sets--*WMO*

| Ground-Based | Airborne | Other |
|---|---|---|
| MEPA, Saudi Arabia | United Kingdom | Climatological |
| KFUPM, Saudi Arabia | NCAR | Satellite |
| EPC, Bahrain | U. Washington | |
| NOAA | Germany | |
| EPA | | |

WMO Procedures & Formats for Data Exchange--*WMO*

WWW Structures & Capabilities for Data Management--*WMO*

Data Analysis Issues - Who will use the data archive?--*WMO*

Integrating and Analyzing Multiple Data Sets--*Darrel Baumgardner, NCAR/RAF*

Introduction to McIDAS--*Tom Yoksas, UNIDATA, NCAR*

Aircraft Data Analysis, Introduction to WINDS--*Gary Horton/Darrel Baumgardner, NCAR/RAF*

Integrating and Analyzing Multiple Data Sets--*Paul Herzegh, NCAR/RDP*

Archiving and Storing Massive Data Sets--*Dennis Joseph, Scientific Computing Division, NCAR*

Electronic Communications and teleneting--*Joe Choy, Scientific Computing Division, NCAR*

Common Data Formats--*Russ Rew, UNIDATA, NCAR*

Requirements for Data Base Services--*WMO*

Tour of NCAR Computing and Archival facilities

Requirements for Data Base Services-Continued--*WMO*

Review and Summary--*WMO/NCAR*

End of Workshop

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# APPENDIX C--WWW Involvement in Emergency Response to Kuwaiti Oil Fires

*The introduction presented by Dieter Schiessl of the WMO at the onset of the workshop.*

## Reestablishing and Strengthening of the WWW Structures

The WWW operational component consists of the observing network, the telecommunication system, and the data processing facilities, and as an integrating and kind of overhead component, data management. It happens that I am the officer responsible for the WWW data management component. In this capacity, I have been asked to participate on behalf of WMO.

These major components of the WWW are represented in all the member countries in different degrees of sophistication and different degrees of completeness. The facilities in Kuwait have been nearly completely destroyed during the Gulf conflict. It is our major task and our major effort at the moment to assist Kuwait and other countries in the Middle East Region to reconstruct their weather services and improve their facilities to the extent necessary to ensure that the data and products required can be generated, exchanged, or transported to the centers in areas in need. We have noted that the meteorological staff is back to about 70 percent and is well-qualified. The upper-air station in the Kuwait airport will soon receive new Vaisala radiosonde equipment. I am here to report to you that the purchasing and contracting framework have been completed, and we are now only waiting delivery of the system. The existing wind finding radar has been repaired. This allows regular wind soundings at 06 and 18 UTC. Full radiosonde ascents (Pressure, Temperature, Humidity, Wind) will be made daily at 00 and 12 UTC.

Somewhere later in the workshop, I will present to you the latest numbers on monitoring contained we executed last week so you can where we stand in terms of surface observations and upper air observations covering all the countries of interest in the Middle East Region.

Surface observations at regular synoptic hours and, if required, more frequently are needed as input for the local assessment of the pollution situation and as input to forecast models. WMO's plan is to reestablish the five Synop stations of the Regional Basic Synoptic Network. This is considered to be the permanent routine observing system which is supplemented by 15 automatic meteorological stations established already by NOAA.

As a matter of highest priority, the Global Telecommunications System (GTS) link between the Kuwait National Meteorological Center and the Regional Telecommunication Hub (RTH) Jeddah is being established. We have been informed as of the middle of July that a low speed circuit (100 baud) connection between Jeddah to the PTT center in Kuwait has recently been established, and the next step will be to connect the NMC at the Kuwait Airport to the PTT center. An upgrade of the link between kuwait and RTH Jeddah to medium speed, telephone type is necessary to enable the timely transmission of data and products required in Kuwait through the GTS. As an additional measure, WMO installed at the end of July a Data Collection Platform (DCP) at Kuwait Airport which allows the relay of radiosonde data (TEMP and PILOT) as well as surface observations directly through METEOSAT for injection into the GTS.

Now, what I'm saying has been drafted and written around Monday last week, so it's about a week old. As far as I know, these devices I am referring to have been shipped, but they are not through custom clearance.

The reception of satellite data, in particular imagery is of considerable importance. The WMO plan therefore includes the establishment of APT/WEFAX receiving station. In addition, it is planned to establish a ground receiving station for the Meteorological Data Dissemination (MDD) system operated by METEOSAT which will allow direct reception of a broad selection of meteorological products urgently needed in Kuwait, including among others those from the ECMWF, from the World Area Forecast Centre in London (to serve aviation), and from other Global Data Processing System (GDPS) centers in Europe. Those centers took responsibility within the WWW scheme to provide products of a regional or super regional basis, or in some cases, on a global basis.

Apart from the situation in Kuwait, similar attention is being given to improve the operational WWW components in neighboring countries in the down wind area. The improvements of the observing network in Iran, Iraq, and Afghanistan appears to be most urgent. However, our monitoring results indicate that for various reasons, only a small percentage of reports from these stations are routinely available from some countries on the GTS. In particular the implementation of a radiosonde station in the Northwest Iran is a matter of priority. WMO is also making all efforts to improve the timely exchange of all available observational data.

**Data Management Concept**

The WWW structures (Global Observing System [GOS], GDPS, and GTS) have been offered to support the management of atmospheric data generated by various groups in the Gulf region. The Regional Specialized Meteorological Center (RSMC) Jeddah has indicated that it is ready to act as a data center. This workshop in Boulder, Colorado, is expected to develop a concept for the management of air monitoring data from the Gulf collected under the Gulf Air Monitoring Program (GRAMP). WMO will involve all concerned countries and scientific groups to reach agreement on data formats, exchange policy, management and archiving procedures, availability of data sets, etc.

The WMO Members and scientific groups concerned have requested that use should be made of proven methodology (such as NCAR data management systems) and existing WMO formats, procedures and structures, where possible to meet the requirements for data and products within and outside the Gulf Region. This may include the use of GDPS centers to provide specialized analysis and forecast products as well as data base services. It will also involve the use of the GTS for the real-time and nonreal-time exchange of data where required and appropriate.

**Emergency Response**

Several institutes are ready to provide analysis and forecast products to Kuwait, if required on a routine bases to support an appropriate emergency response system. WMO is taking steps to coordinate and organize such support. Although relatively high resolution meteorological (mesoscale) products are available from major GDPS centers, it is not guaranteed that these are always meaningful due to the general lack of data from the region. The products from major centers will therefore have to be interpreted by experienced forecasters before applied on a national scale and used as an input for air quality assessments and forecasts. WMO proposes that this capability be established as a warning center in Kuwait combining the expertise of a meteorologist, an air quality, and a health expert to cooperate routinely in providing analyses and regular advice to decision makers in the countries.

This briefly summarizes the position of WMO in the view of two major tasks we are trying to pursue and which I would like to convey to the workshop as objectives from the point of view of WMO, which is to provide recommendations for the establishment of an Emergency Response Scheme to give the countries in the region a mechanism at hand to warn their population and their economists in appropriate fashions. The second objective is to arrange for a consolidated, consistent, and common data storage and archiving for those centers for either producing or collecting data or who take responsibility in producing dedicated products for the region.

# APPENDIX D--The WWW Data Management Concept of WMO

Dieter Schiessl
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## Background

The World Weather Watch (WWW)--the basic program of WMO--is twenty-five years old. From the start, this program consisted of three components, namely the Global Observing System (GOS), the Global Data Processing System (GDPS) and the Global Telecommunication System (GTS). After the first GARP Global Experiment (FGGE) had revealed a number of serious deficiencies, the WMO Congress initiated in 1979 the WWW Integrated System Study (ISS). As a result of this study, the perception of the three component structure was replaced by a concept of an integrated WWW system, whereby appropriate data-management functions should effectuate the integration. The WWW Data Management Concept was introduced through the WMO Second Long-term Plan (1988-1997) and the WMO Congress (Cg-X 1987) noted its importance as the integrating element in the WWW system and urged its rapid implementation.

## Problems and Opportunities

The volume of data produced and exchanged globally within the WWW system nearly doubles every five years. This in mainly caused by:

1. Progressing introduction of surface-based, automated, remote-sensing systems (Radar, Sodar, Lidar, etc.);

2. Increasing use of automated *in-situ* observing systems (AMDAR, ASDAR, drifting buoys, etc.);

3. Growing volume of satellite data;

4. Expanding data volumes generated by numerical meteorological productions.

The total amount of data is expected to exceed, in many cases, the requirements of individual Members. The widely uncontrolled injection of information sets into the GTS will lead to overloading of many telecommunication links and of national data bases and will hinder the Members' efficient access to those sets of information needed for their daily operations.

The present data exchange system (GTS) shows deficiencies, since it still carries, in many parts, the basic features of a conventional Teletype system (i.e., store and forward of character-based data via many nodes) and is, therefore, no longer capable to render the services needed to cope with growing requirements within a reasonable financial and technical framework. It is necessary to look for appropriate means in terms of Data Management to carry the present data exchange system forward through a transitional phase to a system fully developed for the requirements of the next decade.

But side-by-side with these problems, new opportunities have emerged. Cost-efficient technologies for data processing and telecommunications favor the coordinated design and implementation of automated systems and also facilitate the cooperation of Members within the WWW system at different levels of sophistication. An array of Regional Specialized Meteorological Centers (RSMC) with geographical and activity specialization in concert with the three WMCs and a number of advanced Regional Telecommunications Hubs (RTH) provide an ideal starting point for better coordinated and improved data exchange among each other and with presently 160 National Meteorological Centers worldwide.

The rapidly growing appreciation of and adherence to international standards for telecommunications and data processing technology in the meteorological community, mainly for computer graphics, software management and telecommunication are major assets which open new and promising prospects for the WWW system.

WMO fully recognized these new opportunities for its vast data handling requirements and responded by introducing the Data Management (DM) Concept as an element of WWW.

## Data Management Concept

### Purpose and Scope

Data Management is the component within the WWW system which provides those support functions needed for the orderly overall management of meteorological data and products of the WWW system, the most economical use of the resources of the WWW system components, the monitoring data and product availability and quality, the identification of operational deficiencies and the initiation of remedial activities. It will be realized by implementing DM functions and services in the networks and facilities of GOS, GTS, and

GDPS and in the interfaces between them. In order to enable each member to participate at a level commensurate with its abilities and requirements, it is necessary to allow for suitable interfaces, flexible developed and developing countries. Particularly in the area of data processing and telecommunications, DM will define and design proper procedures and interfaces which will allow Members to obtain the coherent and appropriate sets of data and products required. Hence, the main long-term objectives of DM concept are defined as follows.

1. To fully integrate WWW operations and monitoring activities including methods to correct deficiencies in the WWW System;

2. To establish common procedures for management and handling of data and products within the WWW System in order to meet effectively and efficiently Members' individual requirements;

3. To coordinate and support DM issues for the participation of Members in the technologically advancing WWW System.

**Organization**

The Commission for Basic Systems (CBS-IX 1988) established the Working Group on Data Management (WGDM) to deal with concept and implementation of DM. This group should coordinate with the Working Groups on the GTS, GOS, and GDPS in DM matters as appropriate. The Working Group on Data Management is assisted by the Sub-groups on Data representation and on Codes. As to the technical expertise, the working group relies on expert meetings, workshops, and consultants. This organizational framework is supplemented on the global level by Implementation Coordination Meetings on the DM on the Main Telecommunications Network (MTN), and on the regional level by the Regional Implementation Coordination Meetings on DM and Regional WWW Implementation Coordination Working Groups.

**Current Activities**

Although the DM concept is just beginning to evolve in the long history of WWW, CBS has already embarked on a number of prominent issues:

Distributed Databases Concept (DDBs)

The DDB concept envisages a number of databases, each owned and operated by a center, containing a number of data sets of observational data and products of the WWW system primarily for use in real time or near real time. In entirety, each data set provides all currently available data of a particular type or of a defined scope, e.g., all TEMP data, all satellite soundings at a defined resolution. Each database is intended to relate to a specific sub-set of WWW data, by data type, period of retention, and geographic area. Database centers are distributed in relation to geographic or other requirements recognizing the constraints imposed by telecommunication facilities.

Data from the DDB will be in principle available by routine arrangements. This mechanism will be supplemented by ad hoc request/reply and special arrangements, whereby the assignment of specific responsibilities above national level to individual data centers will be by international agreement through CBS and its working groups.

1. Routine arrangements handle data for exchange on a regular basis on the GTS;

2. Ad hoc requests will occur on an occasional basis and are temporary by nature;

3. Special arrangements handle data which are normally not made available over the GTS, but are exchanged by-lateral agreements such as experimental data or data-related to research projects.

Planning of the data center network should ensure that each set or subset of data provided at a data center to meet the needs of a particular service domain should be available at another center and that in event of failure arrangements are made for supply of required data to/from that domain from/to alternate centers and for the rapid re-establishment of database contents on recovery of the center which has suffered failure.

The logical organization for the DDBs is illustrated Figure 1. Designation of centers with primary and alternate responsibilities must be governed by availability of appropriate telecommunication services. Principally, these will be provided by the improved GTS as illustrated by the scheme in Figure 2. The use of other facilities, e.g., public data networks, for back-up and special purpose access must also be expected. Adequate measures to protect from unauthorized access must be provided.

Complementary to subsets of data of different types, e.g., those provided by different types of observing systems, the DDBs should include added information to original observational data, e.g., quality control information provided by GOS and GDPS services. Such information should be made available as required. Data should also be provided selectively to meet routine or specific requirements, the smallest addressable data entity within the DDB being governed by the ability to represent such data within a single element of a WMO code form, e.g., one BUFR item, one GRIB representation.

The DDB concept is envisaged to extend to data-related to status information on availability and quality of data, including products, to climatological and oceanographic data, and to data in archives.

**Procedures for Monitoring of the Status of WWW System**

The objectives of the monitoring activities are to improve the performance of the WWW on a national, regional and global level through identifying deficiencies and initiating corrective actions as quickly as possible. Efficient monitoring requires close cooperation between all centers concerned, as well as with the WMO Secretariat. To this end, WMO has developed plans which detail procedures and responsibilities for monitoring activities for data availability in real time and non-real time and for data quality.

**Real-Time Monitoring Activities**

Real-time monitoring contains activities carried out quickly enough to allow remedial action to be taken in time to be of value in day-to-day meteorological work. This requires swift exchange of information between centers concerned, e.g.:

1. Bulletins not received by the time specified;

2. Observations not received, or which are incorrect;

3. Inadequacies in receipt of processed information.

**Non-Real-Time Monitoring Activities**

Non-real-time monitoring activities are carried out over a specific time period at an agreed frequency, for instance once per year. Types of data to be monitored include observations such as TEMP, SYNOP, PILOT, AMDAR, CLIMAT, BATHY, TESAC which are marked for global exchange. WWW centers are invited to participate and provide their findings to the WMO Secretariat. The WMO Secretariat coordinates these activities and produces a summary of statistics and evaluates, as far as possible, the deficiencies.

## Non-Real-Time Data Quality Monitoring

The monitoring of the quality of observational data is based on so-called "lead centers." For each type of observation, a lead center will be nominated which a view to taking a leading role in the coordination between participating centers of all monitoring aspects, including common methods and criteria to be used for compiling statistics. Such centers continuously carry out the monitoring activities and compile and distribute reports every six months. For monitoring on global level, the following centers act as lead centers:

1. Upper-air observations--ECMWF Reading;

2. Marine weather observations--RSMC Bracknell;

3. Satellite and aircraft observations--WMC Washington.

The plan for the monitoring the quality of surface observations is to seek lead centers on regional level for carrying out this task. Presently, RSMC Tokyo for Region II and WMC Melbourne for Region V have begun to monitor on regional level. Coordination to find other lead centers is ongoing in the remaining regions.

## Coordination of Exchange of Software

Technical and procedural innovations have forced many Member countries, and in particular the developing ones among them, to look for computer support for handling improving their operations. Although, the computer industry offers higher hardware performance at lower cost, the actual benefit expected from the use of computers can only be attained through complex computer programs which are difficult to obtain, especially in developing countries. Meanwhile, progressing standardization made many basic meteorological functions that need to be performed at the various centers, similar or almost identical and programs for these functions are available in many centers. A free exchange will help others in obtaining software modules, design ideas, or development methodologies without "re-inventing the wheel" many times over and without big financial investment. In view of this, WMO has started to collect information on meteorological applications software which is offered and/or requested by Member countries for exchange, and published a catalogue on such data in early 1991. The main objectives of this activity are to:

1. Encourage and support the free exchange of application software among the WMO Members;

2. Provide an overview of applications software offered and requested by WMO Members.

Promotion of Suitable Standards

It is the view of CBS that the entire sector of software development and maintenance, including efforts to prot software between various hardware platforms could become much more cost-efficient if appropriate standards would be consequently applied. Although, CBS has not yet published firm recommendations it encouraged WMO Members to follow guidelines, such as:

1. The general use of UNIX;

2. The use of GKS in graphical applications;

3. The modular architecture of meteorological computer system with well-defined interfaces;

4. The separation of the telecommunications component from the applications component;

5. The preference of WMO binary formats, wherever this is possible.

Work is underway to look at graphical interfaces best suitable for a meteorological operational environment.

**Data and Product Representation**

**Binary Formatting Systems**

The use of bit-oriented formatting systems FM 92 GRIB and FM 94 BUFR is rapidly progressing in the meteorological community and their range of data representation is steadily expanding. Ten centers are presently capable of exchanging binary data, and this number will double in the near future.

It is the policy of CBS to further develop and promote the binary formats and, at the same time, maintain and improve the WMO character-oriented codes where this is necessary.

For instance, recent improvements of GRIB included:

1. Identification of high precision and mixed precision pressure and sigma layers;

2. Accommodation of vertical coordinate parameters and quasi-regular grids;

3. Revision of the definition of the Mercator grid revised to allow for more precision in the grid length specification;

4. Definition of a space view or "perspective" map projection, with satellite needs in mind;

5. Representation of a matrix of values at each grid point with the freedom to specify the coordinates of the matrix; second order packing can now be done either on a row-by-row basis or by selecting various points in the data to start, or restart, the second order packing. The latter is a variant of "run-length encoding."

BUFR was recently expanded to include:

1. Many new descriptors for aviation, radar, surface observations, radiation, satellites, ship reports, wind profilers, etc.

2. A set of new descriptors to describe information about quality control, replaced values, retained values, the original values, statistics of the measurements, etc; it will now become possible to handle quality control information in BUFR.

3. A feature which allows splitting of large binary data entities into smaller ones, thus facilitating more convenient handling of such data sets at GDPS centers and also allowing transmission of binary data sets that would otherwise exceed the maximum size of a message on the GTS.

## WMO Character Codes

WMO maintains a spectrum of 45 character codes which are needed to represent observational data and products stemming from meteorological, climatological, aeronautical, and oceanographic sources. These codes are published in the WMO Manual on Codes Vol I and Vol II (WMO-No. 306) and kept up-to-date by the Sub-group on Codes.

Given the co-existence of both data representation standards and the adherence to the principle that one and the same should not be exchanged on a given link on the GTS in both formats, it is obvious that some kink of interface is needed between both representation forms. Standardized techniques are being sought for the transformation between bit-oriented and character-oriented formate, e.g., to:

1. Facilitate the human legibility (visualization) of binary coded data;

2. Allow for exchange on those parts of the GTS where centers are not automated or where telecommunication capabilities are insufficient;

3. Overcome the inflexibility inherent to character codes.

At present, two proposals are being discussed, namely the IGOSS Flexible Code (IFC) and the BUFR Tabular Form (BTAB). This is done with a view towards developing a flexible character code which are best described as character codes analog to BUFR in that they share many of the advantages of BUFR, but can be transmitted on low-speed communication lines.

**Extension of DM Principles to Other WMO Programs**

Other WMO programs (e.g., World Climate Program, and in particular the Global Climate Observing System (GCOS), the Global Atmospheric Water, Hydrology and Water Resources Program, the Environmental Program, etc.) will progressively take advantage of the basic services of the WWW systems in order to establish efficient and consistent data handling procedures across the programs. There are, for instance, growing requirements for the use of climatological data in near real time. Such requirements lead to requests from other WMO programs for a timelier, more reliable exchange of growing data volumes. There is a need to include oceanographic data, radioactive radiation data, volcanic activity data, satellite data archives, etc., in the WWW data handling. In this respect, consultations and cooperation are being sought with the relevant WMO technical commissions with other intergovernmental and international organizations.

**Summary**

The integration of the core elements of the WWW system is seen as an essential prerequisite for an efficient operation and should enable the WWW system to cope with the rapid evolution of meteorological requirements and techniques and should ensure that proper WWW data and products subsets are available to Members in a timely and convenient fashion. k The WWW Data Management concept is expected to bring about this important level of integration. The various data-management functions will be introduced progressively over a period of years and all aspects and experiences gained will be closely monitored.

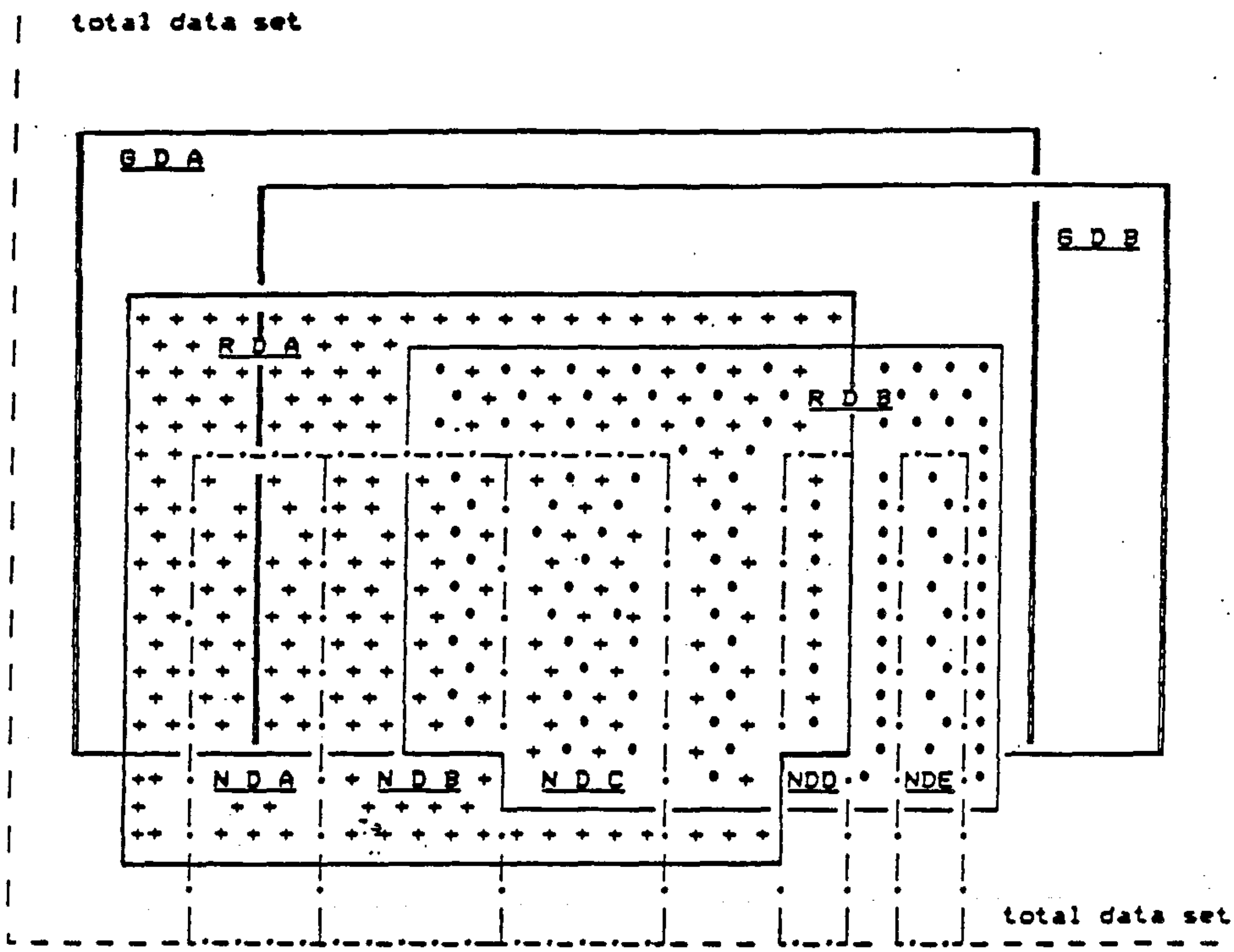
References

Cg-X 1987: Tenth WMO Congress, Geneva, 4-18 May 1987, Abridged Final Report with Resolutions; WMO-No. 681.

SLTP 1987: The World Weather Watch Programme 1988-1997, Second Long-Term Plan, Part II, Vol. 1; WMO-No. 691.

CBS-IX 1988: Commission for Basic Systems, Abridged Final Report of the Ninth Session, Geneva, 25 Jan - 5 Feb 1988; WMO-NO. 699.

[Figure 1]--Domains for one data set



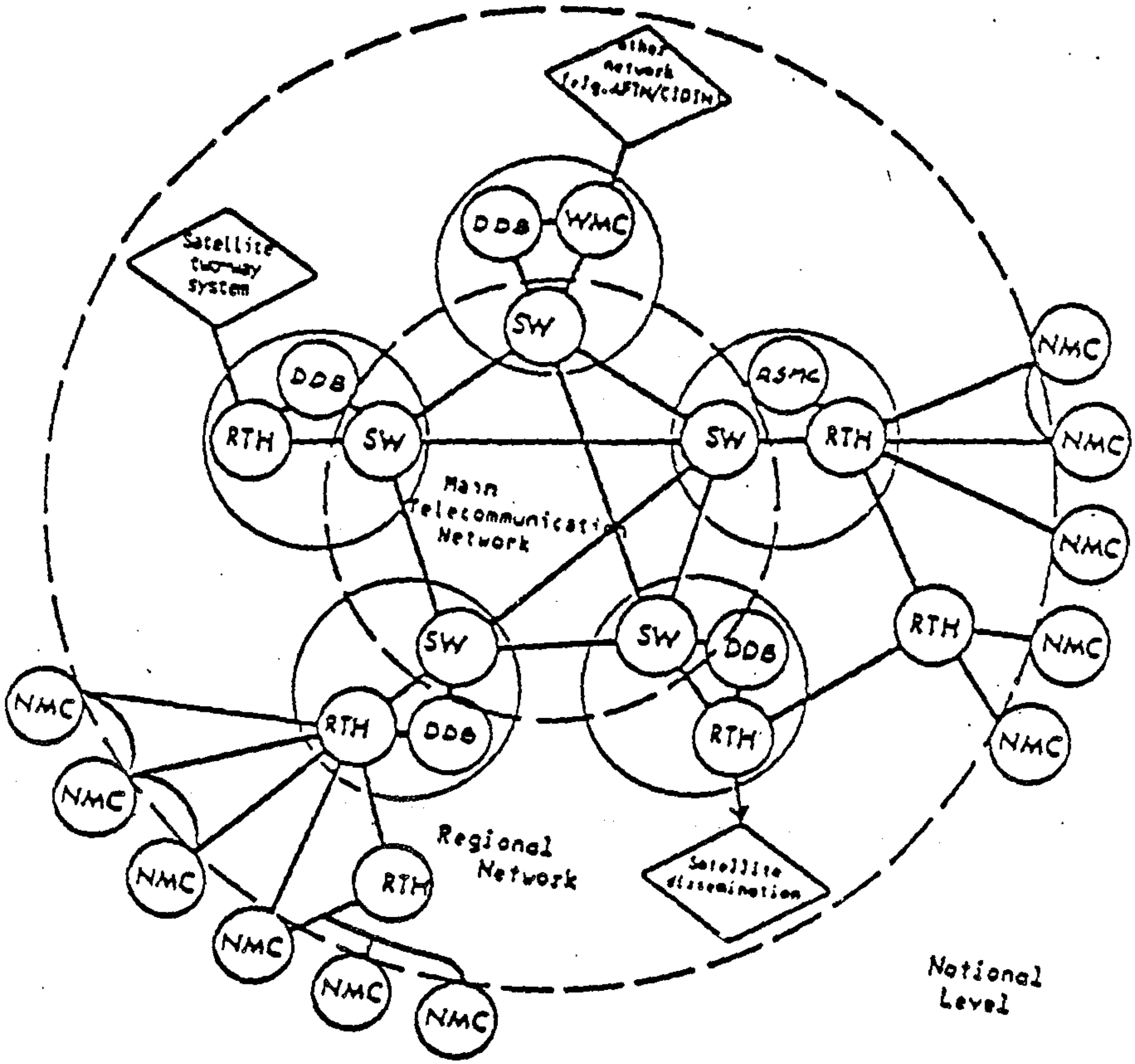

N = National Domain: Includes all national data and the subsets received from other national, regional, and global data centers

R = Regional Domain: Includes data collected from national domains and required sets or subsets from other regional centers and from global centers

G = Global Domain: Includes all required data from global and regional exchange

Note: Required data are those data needed by centers routinely served plus data needed to provide alternate (backup) service in emergency.

# Structure of GTS




[Figure 2]--Switching Node (included in fuctions of RTHs on the MTN)

# Status of Kuwait Data Archive Project

One month after the official approval of the archive project, the status is as follows:

**Equipment**

- The workstation and software for processing and archiving AVHRR, METEOSAT, and DMSP images has been ordered and is expected to arrive within two weeks.
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**Personnel**

- We have closed the advertising for the Associate scientist, programmer, and applications programmer. Interviewing of potential candidates is underway and offers are expected to be made within two weeks.

**Data Catalog**

- We have decided to implement the EMPRESS software package as the database for meta-data describing the data sets available in the archive. This software was selected since it is presently being used at NCAR to archive other massive data sets and because of its extreme flexibility. With this software we are offering the following services to users of Gulf region data:
    - Perusal of all available information on data sets including searches by geographical location, time period, type of measurement, type of measurement platform, type of sensor, etc.
    - Selection of archived data filtered by any of the above combination of parameters; e.g. the user could request all $SO_2$ measurements for the time period May 1-15, in the area bounded from 25°-26° latitude, 48°-49° longitude. Depending upon quantity, the data will be sent to the user on a medium of his choice, i.e. electronic mail, ½ tape, etc.
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  - Environmental Protection Agency (Bahrain)
  - Environmental Protection Agency (United States)
  - National Oceanic and Atmospheric Administration (United States)
  - National Institute for Standards and Technology (United States)
  - German Ministry for Environment

  Airborne Measurements

  - United Kingdom Meteorological Office
  - National Center for Atmospheric Research (United States)
  - University of Washington (United States)
  - German Ministry for Environment
  - National Aeronautics and Space Administration (United States)
  - Department of Energy (United States)

Satellite Measurements

- Meteosat 4 and 5 (Europe)
- NOAA 10 and 11 (United States)
- DMSP
- LANDSAT (United States)
- SPOT

Surface and Upper Air Stations

- The WMO World Weather Watch has 180 surface observing stations and about 40 upper air stations in the countries concerned.

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P.O. Box 3000 • Boulder, Colorado 80307-3000
*Telephone: (303) 497-1000 • Telex: 989764*

October 14, 1991

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We realize the level of effort that this request will require from you and your colleagues and appreciate your cooperation. Please contact us if you have any questions about the questionnaire or any other aspect of our request.

We may be contacted at:

KuDA Archive Office (303) 497-1029
(303) 497-1092 (fax)

Electronic Mail (Internet) kuda@spock.atd.ucar.edu
(OMNET) NCAR.RAF

Send data to Kuwait Data Archive
c/o Research Aviation Facility
10800 West 120
Broomfield, Co 80021

Sincerely,

Darrel Baumgardner
Richard Friesen
KuDA Project Managers

DB/RF/bak

Enclosure

# Kuwait Data Archive (KuDA) Questionnaire

**Agency** ______________________________

**Research Platform(s)** ______________________________

**Data Format (e.g. ASCII)** ______________________________

**Data Structure on Media** ______________________________

**Media Type (e.g ½ Magnetic tape)** ______________________________

**Anticipated Date of Availability of Data** ______________

**Measurement Periods and Locations**

**(Please use additional pages as needed)**

| Date | Time Period | Boundaries (N,S Lat.;E,W Long.; Altitude) |
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**Sensor Description**

**(Please use additional pages as needed)**

| Parameter Measured | Sensor Type | Manufacturer | Technique | Range | Accuracy |
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# Kuwait Data Archive (KuDA)Questionnaire
(Continued)

**Ancillary or related data**

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**Summary of data quality and any significant problems encountered.**

______________________________________________________________________
______________________________________________________________________
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**Primary Contact Person for Further Information** _______________
**Address, telephone #, Fax #, E-mail, Etc.**

# Kuwait Data Archive (KuDA)Questionnaire

## SAMPLE

Agency National Center for Atmospheric Research

Research Platform(s) Aircraft

Data Format (e.g. ASCII) Scaled Integer

Data Structure on Media 1 second blocks of 60 parameters

Media Type (e.g ½ Magnetic tape) Exabyte

Anticipated Date of Availability of Data November 1, 1991

Measurement Periods and Locations

(Please use additional pages as needed)

| Date | Time Period | Boundaries (N,S Lat.;E,W Long.; Altitude) |
|---|---|---|
| 6/19/91 | 0635 - 1132UCT | 25.2°-29.5° ; 48.0° - 50.4° ; 1000-5500 m |
| 6/21/91 | 0852 - 1347UCT | 25.1°-28.1° ; 48.8° - 53.0° ; 900 -3650 m |
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Sensor Description

(Please use additional pages as needed)

| Parameter Type | Sensor Description (Mfg., technique) | Measurement Range and Estimated Accuracy |
|---|---|---|
| Temperature | Rosemount, Platinum Wire | -60°C to +40°C, ±0.5 |
| Pressure | Rosemount, Diaphram | 0 to 1000 mb, ±.3 mb |
| Dew Point | EG&G, Chilled Mirror | -40°C to 40°C, ±0.5°C |
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Kuwait Data Archive (KuDA)Questionnaire
(Continued)

**Ancillary or related data**

Lidar, 0.5, 1.06, 10.6 μm wavelength

Filter Samples

Dropsondes

**Summary of data quality and any significant problems encountered.**

Generally of very high quality. Any data quality problems are included with documentation. Time periods where instrumenation was inoperable or measurements may be questionable are signified with the value -9999 in the data.

**Primary Contact Person for Further Information** Darrel Baumgardner

**Address, telephone #, Fax #, E-mail, Etc.**


NCAR/RAF
Box 3000
Boulder, Colorado 80307

Tel# (303) 497-1054
1092 (fax)

E-mail (Internet) darrel@spock.atd.ucar.edu

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**Sensor Description**

**(Please use additional pages as needed)**

| Parameter Measured | Sensor Type | Manufacturer | Technique | Range | Accuracy |
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Kuwait Data Archive (KuDA)Questionnaire
(Continued)

Ancillary or related data

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Summary of data quality and any significant problems encountered.

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## INFORMATION SOURCES

### INTERNATIONAL COOPERATION

1. "Report of the WMO Meetings of Experts on the Atmospheric Part of the Joint UN Response to the Kuwait Oilfield Fires." Contact: Danny Foster, World Meteorological Organization, 41 Avenue Giuseppe Motta, P.O. Box 2300, 1211 Geneva 2, Switzerland. Phone: 41 222 730-8259.

2. Gulf Regional Air Monitoring Plan (GRAMP)." Contact: Andrew E. Bond, Atmospheric Research and Exposure Assessment Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. Phone: 919 629-4329.

3. Kuwait Oil Fires: Interagency Interim Report." Contact: Gulf Task Force, Environmental Protection Agency, 401 M Street, SW, Washington DC 20460.

4. "UN Interagency Action Plan on the Kuwait Oil Fires." Contact: Gulf Program Office, Office of the Chief Scientist, National Oceanic and Atmospheric Administration, Herbert C. Hoover Bldg, 14th and Constitution, N.W., Washington D.C., 20230. Phone: 202 377-5483, Fax: 202 377-9714.

5. "Statement by Miss Margaret J. Anstee, Director-General, United Nations Office at Vienna, and Personal Representative of the Secretary-General to Coordinate United Nations Efforts to Counter the Impact of the Burning Oil Wells and Other Environmental Consequences of the Gulf Conflict in Kuwait and in the Region." Contact: Gulf Program Office, Office of the Chief Scientist, National Oceanic and Atmospheric Administration, Herbert C. Hoover Bldg, 14th and Constitution, N.W., Washington D.C., 20230. Phone: 202 377-5483, Fax: 202 377-9714.

### OVERVIEWS, ASSESSMENTS

6. "Preliminary Scientific Report - Kuwait Oil Fires,"[NCAR and University of Washington flight team debriefing in Bahrain]. Contact: Gulf Program Office, Office of the Chief Scientist, National Oceanic and Atmospheric Administration, Herbert C. Hoover Bldg, 14th and Constitution, N.W., Washington D.C., 20230. Phone: 202 377-5483, Fax: 202 377-9714.

7. "An Updated Briefing on the Kuwaiti Oil Fire Smoke Experiment (KOFSE)." Contact: Lawrence F. Radke, NCAR Research Aviation Facility, Boulder, Colorado 80307-3000. Phone: 303 497-1030, Fax: 303 497-1092 or contact: Peter V. Hobbs, Atmospheric Sciences Department, AK-40, University of Washington, Seattle, Washington, 98195. Phone: 206 543-6027, Fax: 206 543-0308, Omnet: P. Hobbs.

8. "Statement by Dr. Abdulrahman A. Al Awadi, Chairman of Emergency Committee, Environment Protection Council (EPC), of Kuwait, to the Second Committee, United Nations General Assembly, 20 November 1991." Contact: Gulf Program Office, Office of the Chief Scientist, National Oceanic and Atmospheric Administration, Herbert C. Hoover Bldg, 14th and Constitution, N.W., Washington D.C., 20230. Phone: 202 377-5483, Fax: 202 377-9714.

## KUWAIT OIL FIRE STATUS

9. "Kuwait Oil Well Fires Updated." Contact: Joseph R. Riva. Jr., Congressional Research Service, Science Policy Research Division, The Library of Congress, Washington DC 20540. Phone: 202 707 7040.

10. "Kuwait Oil Fire Extinguishing Chronology." Contact: Gulf Program Office, Office of the Chief Scientist, National Oceanic and Atmospheric Administration, Herbert C. Hoover Bldg, 14th and Constitution, N.W., Washington D.C., 20230. Phone: 202 377-5483, Fax: 202 377-9714.

## AIRCRAFT MONITORING DATA AND INFORMATION

Meteorological Office Mission

11. "Summary of the GULFEX Flights, 23rd - 31st March 1991." Contact: M.A. Gibbs, Meteorological Research Flight, Royal Aerospace Establishment, Farnborough, Hants GU14 6TD, United Kingdom, May 1991.

12. "Observations in March 1991 of the Oil Smoke Plume from Kuwait by the UK Meteorological Office C-130 Aircraft: Preliminary Report." Contact: G.J. Jenkins, Head, Meteorological Research Flight, Royal Aerospace Establishment, Meteorological Office, Farnborough, GU14 6TD, United Kingdom, June 1991.

13. "Airborne Observations of the Physical and Chemical Characteristics of the Kuwait Oil Smoke Plume," Contact: D.W. Johnson, Meteorological

Research Flight, Royal Aerospace Establishment, Meteorological Office, Farnborough, GU14 6TD, United Kingdom.

National Center for Atmospheric Research (NCAR) Mission

14. "Aircraft Research Instrumentation, Electra N308D," [also includes raw data from flight legs]. Contact: Lawrence F. Radke, NCAR Research Aviation Facility, Boulder, Colorado 80307-3000. Phone: 303 497-1030, Fax: 303 497-1092.

15. "NCAR Scientists Release Preliminary Results from Kuwait Oil Fires Study." Contact: Joan Vandiver Frisch, NCAR, P.O. Box 300, Boulder, Colorado 80307-3000.

16. Abstracts of papers submitted to the American Geophysical Union for presentation at the December 1991 meeting in San Francisco, California and at the January 1992 Ocean Sciences meeting in New Orleans, Louisiana. Contact authors at addresses listed in abstracts.

University of Washington Mission

17. "Carbon Budget Data," Contact: Peter V. Hobbs, Atmospheric Sciences Department, AK-40, University of Washington, Seattle, Washington, 98195. Phone: 206 543-6027, Fax: 206 543-0308, Omnet: P.Hobbs.

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