The MIT/Marine Industry Collegium
Opportunity Brief #25

Oil Spill Clean-up: An Economic and Regulatory Model

A Project of
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The MIT/Marine Industry Collegium

OIL SPILL CLEAN-UP: AN ECONOMIC AND REGULATORY MODEL

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PREFACE

This Opportunity Brief and the accompanying Workshop held on April 16, 1981 were presented as part of the MIT/Marine Industry Collegium program, which is supported by the NOAA Office of Sea Grant, by MIT and by the more than 100 corporations and government agencies who are members of the Collegium.

Through Opportunity Briefs, Workshops, Symposia, and other interactions the Collegium provides a means for technology transfer among academia, industry and government for mutual profit. For more information, contact the Marine Industry Advisory Services, MIT Sea Grant, at 617-253-4434.

The underlying studies at MIT were carried out under the leadership of Professor J. D. Nyhart and Professor Harilaos N. Psaraftis, but the author remains responsible for the assertions and conclusions presented herein.

John B. Bidwell

July 1, 1981

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1.0 BUSINESS PERSPECTIVE

Accidental oil spills in coastal regions are inevitable. The transport of crude oil by tankers, the conduct of transfer operations, and the operation of offshore wells virtually insure that spills will be matters of recurring concern for the future.

Addressing the problem of oil spill clean-up on an ad-hoc, piecemeal basis has not proved effective. Despite the existence of a national contingency plan, the absence of an overall analysis of the oil spill clean-up problem has been informally acknowledged by government officials and the development of an overall analysis has been informally supported by industry representatives. The clean-up problem is compounded by questions of who is responsible and who is liable, who should bear the clean up costs and how much should be spent, what are the costs to society of environmental damage compared to the costs of cleanup. Oil spill clean-up is, in fact, a problem in systems analysis that requires an integrated solution involving legal, technical and economic issues.

In 1979, MIT Sea Grant initiated such a study which is now also supported by the U.S. Coast Guard, the U.S. Navy, the Spill Control Association of America, JBF Scientific, Texaco, the Doherty Foundation, NOAA's Office of Damage Assessment, and the Commonwealth of Massachusetts. The research team includes industry professionals as well as faculty and students from several MIT departments. An advisory committee is comprised of representatives of oil companies, manufacturers of oil spill clean-up equipment, environmentalists, and interested government agencies.

The broadest objective of the two-year project is to develop a model which will provide policy makers with a strategic tool to analyze options for response to accidental oil pollution under varying sets of assumptions. With it, it will be possible to calculate optimal configurations of cleanup resources in terms of locations, types and quantities of cleanup equipment that should be strategically stockpiled in response to estimates of long term needs. Well before actual need, companies operating in a region in which the model is being used will be able to gain a new, improved perspective on their role and responsibilities in the regional clean-up system. Government will be able to assess the sensitivity of changes in the existing system to changes in assumptions and variables as well as to assess the dollar damages caused by oil spills, and the net cost of oil spills to society under alternative clean-up efforts.

The model, when completed, will also be a valuable tactical tool for all concerned with oil spills: government agencies, the oil spillers, the clean-up industry, fishermen and other coastal interests who may be impacted by the spill. Alternative time-phased responses for combatting a specific hypothetical or actual spill can be simulated on the model.

In addition, the model will suggest business opportunities that exist for manufacturers of clean-up equipment and for suppliers of clean-up related services. Governmental decisions concerning how much clean-up capability is needed will obviously depend on what technology is available or likely to become available in the near term. Similarly, the technology that can or will be available from commercial companies will have to be developed in at least partial response to what policy makers view as the primary needs. The model will help to focus all parties on these interacting issues.

The initial development of the model will be completed in the Summer of 1981. Testing and implementation will begin in the Fall of 1981. This new phase of the project will most probably involve an actual port area, working with the U.S. Naval Facilities Command. The results to date were reported and an opportunity for discussion with the research team was provided in a Workshop of the MIT/Marine Industry Collegium at MIT on April 16, 1981.

This Opportunity Brief is of broader relevance than its topical concern with oil spill clean-up policy. This study in applied research and model building is a concrete instance of how cooperative research action between industry, university, and government can provide important benefits to each simultaneously.

2.0 DESCRIPTION OF THE OIL SPILL PROBLEM

In 1977, on U.S. waters, over 9.8 million gallons of oil were accidently spilled by tanker ships and over 11.6 million gallons were spilled in all kinds of accidents combined. An estimated additional 30 million gallons of oil pollution occurred through operational discharges of ballast, bilges and other oily water from ships.

Accidental spillage was distributed 18% on inland waters, 27% on coastal waters less than three miles from shore, and the balance of 55% on waters three miles or further from shore which would have required a high seas clean-up capability for removal.

By geographical coastal area, the offshore accidental spillage was distributed 11% in the Atlantic, 18% in the Gulf of Mexico and 71% in Pacific waters.

The cost of damages associated with operational discharges is elusive, because these routinely occur at a slow rate and in small concentrations, typically more than fifty miles from shore. The future trend of at-sea oil pollution initially appears to be a function of operational discharge because of the overwhelming quantities of pollutants dispersed during routine operations. But this fact by itself is misleading. Because of the characteristics of these discharges listed above, immediate environmental damage is indiscernable. Also, implementation of load-on-top procedures, crude-washing techniques, and segregated ballast requirements are expected to reduce this source of pollution to 100,000 metric tons per year by 1980.

Accidental spills tend to occur with opposite characteristics to operational discharges, that is, rapidly, in large concentrations and relatively close to shore. The National Academy of Sciences has determined that "the more localized the distribution of the spill, the greater is the mortality." Consequently, one can infer that though accidental spillage is but a small fraction of all at-sea oil pollution, its effects might be more deleterious, and are certainly visibly greater than the damages caused by operational discharges.

Figures do exist for damages sustained in some of the accident incidents and can, to some extent, provide a qualitative appreciation for the problem as a whole. For example, the oil industry has paid over $100,000,000 in costs for cleaning up approximately 60 major oil spills occurring worldwide since 1967. In the United States, the Coast Guard alone expended over $20,000,000 in cleaning up 39 incidents from 1970 to 1976. Of these 39 cases, less than $800,000 has been reimbursed by industry, due to confusion in the interpretation of the governing liability laws. Because of the existing legal complexities in forcing compensation for damages from the spiller, many observers speculate that the $100,000,000 which has been paid by industry actually represents but a small fraction of the total damages arising from the sixty spills. The Argo Merchant accident tends to confirm such speculation. Industry was required to pay only $1,000,000, despite a Coast Guard study placing damages above $5,000,000. Qualified testimony in a Senate hearing stated that "the cost of picking up oil exceeds $1 a pound," or in excess of $8 a gallon, if one divides the amount of money spent trying to clean up oil in the United States by the gallons of oil removed.

Considering the future of accidental spills, much current attention focuses on preventive measures. Preventive measures such as those embodied in the Port Safety and Tank Vessel Safety Act of 1978, coupled with improved capability of the Coast Guard, will certainly reduce future casualty rates. Nonetheless, reduction in this rate is required simply by virtue of the increased oil traffic anticipated in the next decade, if total spillage is not to increase above recent levels. Improvement beyond this goal is foreseeable, but Coast Guard investigations have shown that past accidents were primarily caused by human error (oftentimes the mistake made by one duly qualified in his/her job). Human error may lie outside the scope of any set of rules, regulations, or training programs. A certain amount of oil will continue to be spilled.

As a consequence of this expectation of continued accidental oil spills in the future and despite the efforts being made in the areas of prevention and avoidance, a need still exists to provide and maintain a national capability to clean up accidental spills. Without an offshore clean-up capability, the United States will face extensive rehabilitation of critical environmental areas following oil spillage offshore. Without such a capability, there exists no opportunity to reduce the immediate and overall deleterious effects of oil pollution.

3.0 EVOLUTION OF THE RESEARCH PROJECT

An earlier Opportunity Brief and workshop of the MIT/Marine Industry Collegium addressed the need for oil spill research to improve the ability to gauge the volume and dispersion of oil spilled in accidents. Following the meeting one of the Collegium members in attendance, president of a company that manufactures skimming equipment for oil spill clean-up, pointed out that small-to-moderate spills that occur during normal operations of shipping and of coastal industries need to be considered as well as large ship-load type spills. He stressed the need for accurate, quantitative information concerning the origins and true costs of spills, and he offered to share his experience and business perspective with MIT researchers in a broad systematic study of the spill problem and alternative responses to it.

A project proposal was submitted to the National Sea Grant College Program by Professor J.D. Nyhart of MIT's Sloan School of Management and Department of Ocean Engineering and Professor Harilaos N. Psaraftis, also of the Department of Ocean Engineering, as co-principal investigators. The multidisciplinary system analysis and modelling proposal was funded by Sea Grant for two years beginning July 1979. In accordance with Sea Grant policy, matching funds were raised from other sources, including the U.S. Coast Guard, the Navy, and later Texaco and the Spill Control Association of America.

Next a research team was assembled consisting of the two academic principal investigators, the corporate president whose suggestion triggered the project and who has contributed two days per month to the project, another local corporate president, a biologist and six students. The students included PhD, Masters, and Bachelor's candidates, and together they represented a variety of relevant experience and training. Later a consulting firm from California with experience in environmental damage assessment was added to the team to develop a damage assessment sub-model and to link it to other component sub-models. The work of this firm, and of other damage assessment team members, was supported by a grant from the Damage Assessment Office of NOAA. Dr. Ruthann Corwin, Principle of the consulting firm, was integrated into the research team to lead this portion of the work. About 20 people have worked on the project overall, with an average of 10 people involved at any one time.

The goal of the project is to develop an integrated set of computer models and sub-models that can provide policy makers with the information needed for determining effective responses to accidental oil spills. To do this requires descriptions of present and projected oil spills and their costs, existing clean-up methods and their capabilities and costs, alternative approaches to prevention, and technology for newly integrated clean-up systems and its effectiveness and costs under different assumptions.

The research team as a first task identified individuals and organizations that could serve as sources of information and advice. The intent was to draw upon a representation of interests, including oil companies, environmental groups, govermental agencies, equipment manufacturers, and others. The advisory committee that was assembled includes representatives of the Coast Guard, the Navy, the Massachusetts Office of Environmental Affairs, the Spill Control Association of America, JBF Scientific Corporation, Texaco, Atlantic Richfield, the Oil Spill Intelligence Report, the National Office of Coastal Zone Management, the Sierra Club and the New England Legislative Caucus. In addition, contacts were initiated with various other organizations interested in the project, such as Shell Oil Company, BP England, BP North America, Shell International Labs (Amsterdam), the Intergovernmental Maritime Consultative Organization (IMCO), and the International Tanker Owners' Pollution Federation in London. Various organizations in Canada and Norway have expressed interest in establishing contacts with the project as well.

The research team has met approximately weekly to hear progress reports from individual members and to discuss problems and issues in model development. The advisory committee has met approximately bi-monthly to hear progress reports from the research team, comment on current work, discuss relevant issues from the perspective of their experience and interests, and guide model development.

At this point some of the component models have been formulated while others are still in progress. However, an important result has been to highlight the surprising complexity of the oil spill clean-up problem as indicated by the number of sub-models that are being constructed.

4.0 DESCPIPTION OF THE MODELLING PROJECT

The model being developed is intended as a tool for identifying and evaluating alternatives and trade-offs with respect to oil spill clean-up response. It does not suggest how to weigh objectives against one another, nor does it comment on how to resolve trade-offs and conflicts. Rather, it provides policy makers, and those with operations responsibility for government or for corporations, with information necessary to identify a spill-response system consistent with an explicit objective, however chosen.

4.1 Features of the Model

Several modelling features are important in providing the necessary versatility for analyzing alternative options. These include a hierarchical structure, modularity, and sensitivity analysis of uncertain parameters.

Several sub-problems of the overall oil spill response problem are quite distinct from one another, and hence, should be treated in a hierarchical manner. For instance, decisions on the location of the clean-up equipment are quite different in nature from decisions on dispatching clean-up equipment to a particular spill. In that respect, the study's approach will be to decompose oil spill response decisions into three hierarchical levels: strategic, tactical and operational. Decisions at one level then constitute constraints for the problems at lower levels.

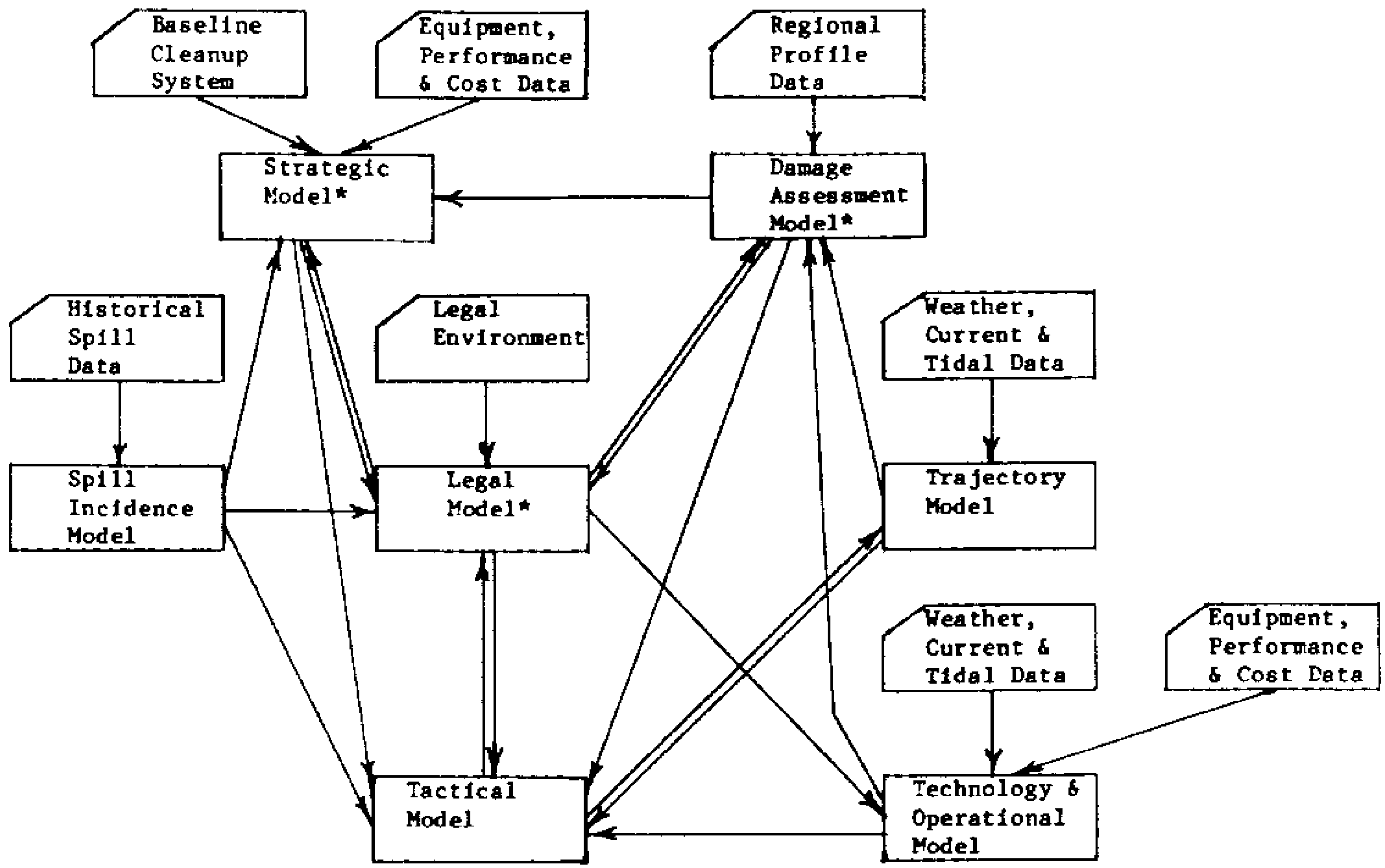
Modularity ensures a maximum degree of flexibility in the model. Various components of the overall model are made in a modular form, so that they can be changed more easily if necessary.

The oil spill response problem is abundant with data and parameters whose values are not well established. This extensive lack of data might suggest that the usefulness of any quantitative study on oil spill response would be extremely limited. It is, however, precisely this factor that makes such a study critically important. A sensitivity analysis on the value of a parameter provides a sound way to establish the importance of that parameter to the overall problem. Sensitivity analysis might reveal trends, show that certain parameters are crucial to the problem and that others are unimportant. The ability to answer "what if" questions of this kind is particularly valuable in providing feedback to determine important areas for additional data collection.

4.2 Description of the Model

The MIT Oil Spill model is schematized in Figure 1. It is a composite of several sub-models. In the discussion that follows, step-by-step references to Figure 1 are helpful in understanding how the components are integrated into an overall model.

Historical Spill Data such as spill frequency, volume, location and type of oil in past spills are used in the Spill Incidence Model to evaluate spill risk in the region under



* Principal Outputs:

- strategic decisions
- tactical and operational decisions (see text)
- evaluation of damages
- policy and regulatory issues

Figure 1

study. The model uses hypothetical probability distributions fitted to historical data. Projections of spill incidence are made on the basis of expected tanker traffic, offshore drilling or production activity.

Weather, Current and Tidal Data and information on the type and volume of oil spilled are used in the Trajectory Model to project the likely movement and spreading of spilled oil. Emphasis is on the hydrodynamics of oil transport and on the change in the characteristics of the oil over time, which allows the user to incorporate current understanding of spill behavior into the decision-making process.

Regional Profile Data, in the form of an inventory of environmentally and economically sensitive resources tabulated in a grid format, are used in the Damage Assessment Model to generate the probable levels of damage at various locations if no effort is made to combat and clean up the spill. The damage potential is evaluated in dollar values for market goods such as tourism, and in natural units for other resources and activities such as marine fisheries and organisms.

The Damage Assessment Model includes environmental and social impact assessment: identification of impacts, projection of their occurrence and magnitude, and evaluation in economic and non-economic terms. The first step involves identification of the categories of damage that result from marine oil spills. Using estimates drawn from literature, case studies, research, and hypothetical analyses of "damage potentials" due to various oils, damages are projected given the environmental conditions and resources of the particular region. Evaluation requires accounting for the damages to the parties affected, either in dollar terms or in other units or descriptors. The model defines damages as any negatively perceived changes in resources that affect social values and they may be quantifiable or non-quantifiable.

The Legal Model takes as inputs the description of the current Legal Environment governing the oil spill system, including some aspects of the social-political environment which may be implemented as law, and relates them to the variables in the strategic, tactical and damage assessment models. It does so by expressing such legal functions as standard-setting, permitting, designating responsibility for planning and acting, assigning of liability, and spending.

Analysis of the questions of liability and compensation illustrate the interconnectedness of the component sub-models. Questions arise of what parties are liable for the many costs arising from oil spills and of what mechanisms exist for remedial payments to those initially bearing the costs by those ultimately held liable. Liability is related to the costs of damages identified in the Damage Assessment Model. Many potential costs, some not presently established in law, are listed in Table 1.

The optimizing decision-making models follow a hierarchical structure which is designed to address three separate questions: 1) the selection and stock-piling of equipment; 2) the equipment levels to be deployed for a

Table 1. PARTIES AND VALUES AFFECTED BY MARINE AND COASTAL OIL SPILLS

Party Affected	Resources Affected
1. Coastal Residents	a) Residential enjoyment b) Health quality of residential environment
2. Commercial Resource Harvestors	a) Fish b) Shellfish & other invertebrates c) Algae d) Research organisms e) Other harvested organisms
3. Marine & Coastal Recreators & Tourists	a) Quality of the natural environment b) Presence of observable organisms c) Non-commercial recreational opportunities
4. Marine & Coastal Recreation & Tourism Industry	a) Commercial recreational opportunity b) Tourism opportunities
5. Marine & Coastal Workers	a) Employment opportunities in resources harvesting, recreation & spill clean-up b) Health quality of working environment
6. Marine & Coastal Property Owners	a) Private property -- real estate b) Private property -- other c) Public property
7. Clean-Up Industry	a) Clean-up opportunities
8. Oil Industry	a) Oil availability b) Company time & expenses related to oil spill responses
9. Consumers of Marine Products	a) Food quality b) Food availability c) Other marine products quality & availability d) Research materials quality & availability
10. Government Agencies -- Spill Respondors	a) Time & funds
11. Citizen Groups	a) Time & funds
12. Non-Localized Recreators (& Potential Tourists)	a) Quality of the natural environment
13. Taxpayers	a) Tax revenues
14. Secondary Consumers	a) Energy source availability b) Oil products c) Other economic indicators
15. Suppliers & Workers -- Secondary Industries	a) Opportunities for revenue b) Opportunities for employment

specific spill; 3) the operational procedures which will govern the use of equipment deployed at a specific spill.

The Strategic Model addresses questions of investment strategy and planning strategy to be directed against accidental oil spills occurring during a future span of years. Three kinds of decision variables are identified. One is on location of pollution response equipment, i.e., where in the region of interest should equipment be stockpiled. Another concerns types of equipment to be stockpiled, i.e., booms, skimmers, pumps, barges, sorbents, dispersants. The third involves the quantities of equipment at each location, i.e., how many feet of boom are enough, how many skimmers are needed and so forth. The Strategic Model thus involves the formulation of global objectives and constraints within the environment of a region of interest. The objective function is to minimize expected total costs from oil spills over the period considered, including fixed investment, specific cleanup costs and damages. Inputs come from the Baseline Cleanup System which describes the current response system for comparison of proposed systems, plus Equipment, Performance and Cost Data, and information from other sub-models.

The Tactical Model addresses the capabilities and quantities of equipment to use in a given spill. This model is constrained by the prior stockpile decisions and receives its inputs from other models as shown in Figure 1. The Tactical Model can also operate independently of the Spill Incidence and

Strategic Models by being given an existing set of equipment. It can then formulate an optimal response to a given spill using local objectives and constraints. The output of this model includes the recovery capability necessary to control the spill in gallons per hour, how to adjust this for changes in outflow and weather, the type and quantity of equipment to be deployed at each successive stage of the spill, as well as when the clean-up effort should terminate.

The Technology and Operational Model is designed to help the On-Scene Coordinator (OSC) configure the equipment in an efficient manner. With inputs from Equipment, Performance and Cost Data and Weather, Current and Tidal Data, it tries to maximize the effectiveness of the deployed configuration. Used in this way it works in conjunction with the Tactical Model which has the option of generating a more detailed level of output, such as length of boom, towing speed or skimming configuration.

In general there are two levels of output from the collection of models. At one level principal outputs are generated in the form of strategic decisions, tactical and operational decisions, evaluation of damages, and policy and regulatory issues. At this level the four models on which attention is focused can be run together with all the others or quasi-independently with only a sub-set of other models. Thus the Strategic Model can be run "alone" supported by Spill Incidence and Damage Assessment, and with or without the Legal Model for impacts of delays or dispersants. The Tactical Model can be run "alone" supported by Damage Assessment, Trajectory, Technology and Operational, and with or without the Legal Model. The Legal Model can be run "alone" or with other supporting models. The Damage Assessment Model can be run "alone" supported by Trajectory with spill information input independently or from Spill Incidence via Tactical, for instance in a "no response" mode.

At another level intermediate outputs can of course be examined during the running of any one of the sub-models, irrespective of whether they represent one of the principal foci or not. In addition the Spill Incidence Model, for instance, can be run independently of any others for other purposes, such as examining statistically a long history of spills.

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6.0 APPENDIX

MIT/MARINE INDUSTRY COLLEGIUM

Workshop #25

OIL SPILL CLEAN-UP:
AN ECONOMIC AND REGULATORY MODEL

April 16, 1981

Marlar Lounge, MIT Building 37, 2nd Floor,
(70 Vassar Street, Cambridge)

8.30 Coffee and Registration

9.15 Welcome

Norman Doelling, Manager, Marine Industry Advisory Service, MIT Sea Grant College Program

9.30 Overview of the Model: Objectives, Uses and Users

Professor J. D. Nyhart, MIT, Sloan School of Management and Ocean Engineering Department
Professor H. N. Psaraftis, MIT, Ocean Engineering Department
Mr. Ralph Bianchi, President, JBF Scientific Co.

10.30 Coffee Break

11.00 Analysis of Decisions in an Individual Oil Spill

B. Ziogas, MIT, Ph.D. candidate, Ocean Engineering Department
Professor H. N. Psaraftis

11.45 Assessing Damages from an Oil Spill

P. Csik, MIT, Research Scientist, Ocean Engineering Department
K. L. Johnson, MIT, M.S. candidate, Ocean Engineering Department
D. Sides, MIT, M.S. candidate, Ocean Engineering Department
Professor J. D. Nyhart
Dr. Ruth Corwin, Consultant

12.30 Lunch

1.30 Projecting 15-Year Need for Clean-Up Capability: Location, Type, Quantity of Equipment

G. G. Tharakan, MIT, Sc.D. candidate, Ocean Engineering Department
Professor H. N. Psaraftis

2.15 Improving the Legal and Economic Environments

W. S. Laird, MIT, M.S. candidate, Ocean Engineering Department
Professor J. D. Nyhart

3.00 Implementation: The Next Phase of the Project

Professor J. D. Nyhart
Professor H. N. Psaraftis

3.20 Closing Remarks

Norman Doelling