NATIONAL UNDERSEA RESEARCH PROGRAM Technical Report 88-1A

REPEX: Development of Repetitive Excursions, Surfacing Techniques, and Oxygen Procedures for Habitat Diving

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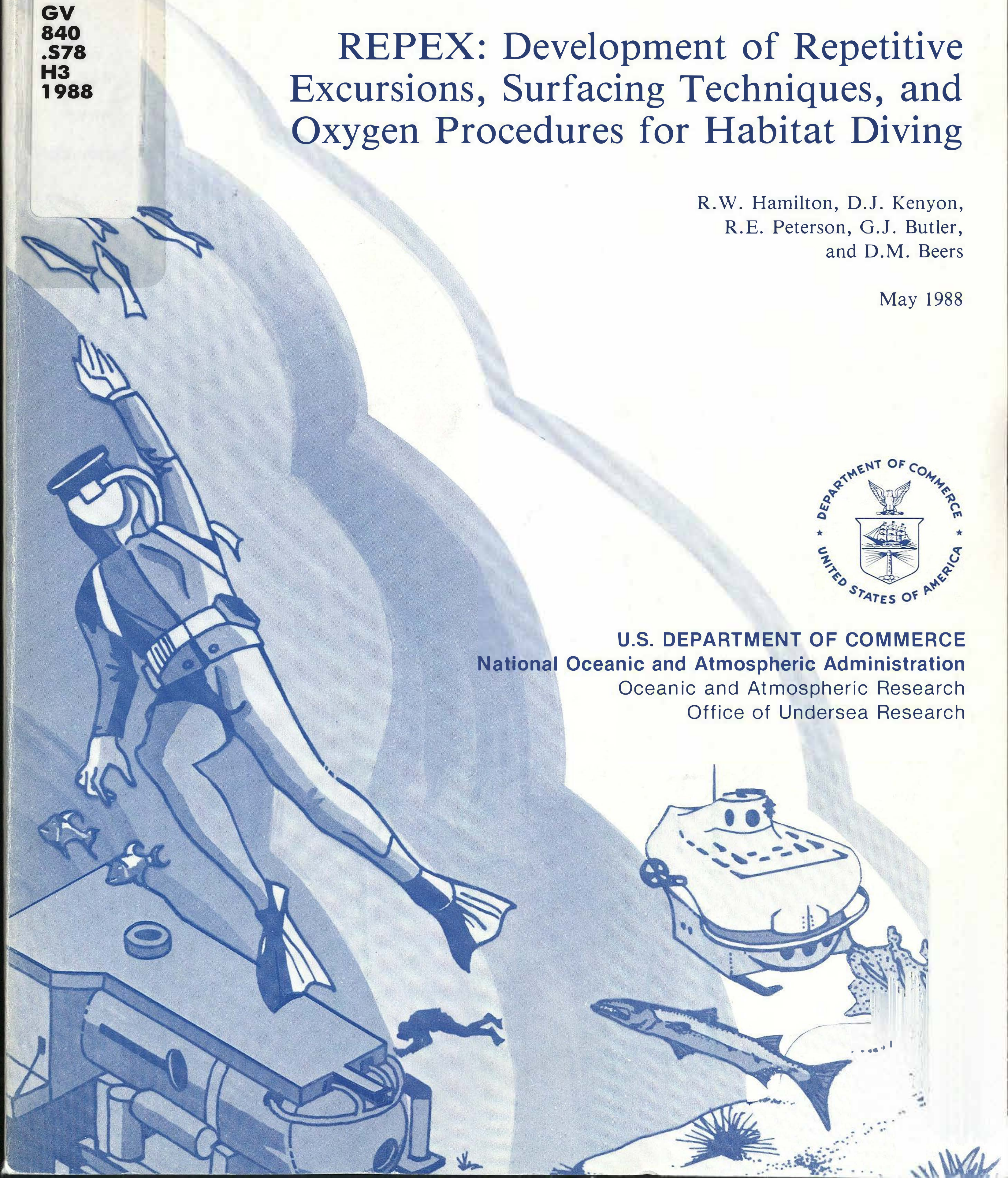
May 1988



U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Oceanic and Atmospheric Research
Office of Undersea Research

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U.S. DEPARTMENT OF COMMERCE
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National Oceanic and Atmospheric Administration
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Office of Undersea Research
David B. Duane, Director

FOREWORD

The National Oceanic and Atmospheric Administration (NOAA) has the largest diving complement of any civilian Federal agency. Under the aegis of NOAA's Undersea Research Program (NURP), the agency also directly assists a large cadre of marine research scientists to conduct their scientific activities under the sea. This research is accomplished using manned submersibles, remotely operated vehicles, and compressed-air scuba, mixed-gas, and saturation mode diving. Additionally, the NURP assists all divers of the nation through research undertaken in accordance with the terms of Sec. 21(e) of the Outer Continental Shelf Lands Act of 1978 (PL 95-372; 43 USC 1331 et seq.). This statute requires NOAA, under authority delegated by the Secretary of Commerce, to "...conduct studies of underwater diving techniques and equipment suitable for protection of human safety and improvement of diver performance. Such studies shall include, but need not be limited to, decompression and excursion table development and improvements and all aspects of diver physiological restraints and protective gear for exposure to hostile environments."

The Technical Report series published by the NURP is intended to provide the marine community with the results of NURP-sponsored research sooner than is normally possible through professional society journals and to do so in greater detail by presenting all of the relevant data developed in the course of the research. Results reported in NURP's Technical Report series may be preliminary or require further development, refinement, or validation, and this additional research may be beyond the scope or mission of NURP. Results of research or development are reported quickly through the Technical Report series to enhance the awareness of members of the marine science and engineering community. Accordingly, the reports in this series do not carry any endorsement or approbation on the part of the NURP, nor can the NURP accept any liability for damage resulting from incorrect or incomplete information.

A research project designed to improve diver performance and safety was recently completed for the NURP by scientists from Hamilton Research, Ltd., of Tarrytown, New York. In that research, the investigators "...focused on decompression aspects of habitat operations, especially excursions, and on breathing mixtures based on nitrogen as the inert gas." A consequence of this research was the development of an improved diving technology, the REPEX tables, for decompression using NITROX gas mixtures in saturation habitat operations. This technology includes both a computational concept (or model) and explicit operating procedures (decompression tables). REPEX has had, in the words of its developers, "modest" validation in hyperbaric chamber tests.

REPEX: Development of Repetitive Excursions, Surfacing Techniques, and Oxygen Procedures for Habitat Diving, a report prepared by R. W. Hamilton, D. J. Kenyon, R. E. Peterson, G. J. Butler, and D. M. Beers and submitted to NURP under the terms of

Contract NA-84-DGC-00152, with Hamilton Research, Ltd., is herein reprinted in its entirety. It is presented in two volumes: REPEX: Development of Repetitive Excursions, Surfacing Techniques, and Oxygen Procedures for Habitat Diving, NURP TR 88-1A; and REPEX Habitat Diving Procedures: Repetitive Vertical Excursions, Oxygen Limits, and Surfacing Techniques, NURP TR 88-1B.

Comments on the report are welcome. They should be directed to:

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May 1988

David B. Duane
Director

PREFACE, Volume 1A

This is a report of a development program to produce a set of new procedures for habitat diving for the Office of Undersea Research, NOAA, U.S. Department of Commerce, under Contract NA-84-DGC-00152. It covers two phases of that program, a narrative of how the Procedures were produced, and a report on the laboratory testing of the new decompression tables.

This report accompanies a companion document[1], referred to here as Volume IB or simply "the Procedures," which contains the tables and procedures whose development and validation are detailed here. The term "detailed" is not chosen casually and needs some explanation. The Procedures are presented as the results of a research program, and that document is not intended to be a manual; it includes much more information and many more details than would be needed by a competent crew. Likewise, this report is intended to be a record of the thought processes as well as specific actions involved in developing and testing the tables and procedures. It too is more detailed than necessary to understand the steps involved. Our objective was to record these details for our client's benefit, for our own, and we hope perhaps for a few others. We beg the indulgence of those who may try to wade through it.

Habitat diving has an intrigue that draws interest well beyond the small group of true users. These findings have implications in other areas, particularly submarine escape/rescue. Perhaps the greatest contribution of the program is something that was necessary in order to accomplish the task but not specified in the Contract, an algorithm (method) for managing long term exposures to high oxygen levels. We feel we have made a good start toward systematizing this problem, which has been with us for many years. Revisions will be needed as experience develops, but the concept should make those relatively straightforward.

During the development process we have drawn on the good offices of many colleagues, for which we are grateful. The Procedures have been the beneficiary of this informal review process. We have tried to report our progress as things have developed, and include the presentations and publications with the references; we have reached small but interested audiences in Europe and the Far East as well as North America.

We acknowledge the help of many for the conduct of the tests and production of the report, in addition to those whose help is mentioned in the preface to the Procedures. Outstanding among all is Andre Galerne, the owner of IUC where the tests were done. Andre truly believed in the project

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[1] Hamilton RW, Kenyon DJ, Peterson RE. Repex habitat diving procedures: Repetitive vertical excursions, oxygen limits, and surfacing techniques. Technical Report 88-1B. Rockville, MD: NOAA Office of Undersea Research, May 1988.

and its sponsors. His staff did a superb job of making this a safe and efficient operation, and for most of us, an enjoyable one as well. Bill Bensky managed the medical and ethical matters with dispatch, and was available at all hours. Dr. Jose-Antonio Amat geared himself up for the doppler monitoring and spent many extra hours going over tapes a third and fourth time before reaching a final decision. The Topside crew at IUC did a good job of managing the chambers and, when necessary, of fixing them (when the ECU failed Bill Crowley returned right away from Boston in case the duty crew could not get it back on line).

But the ones who really did the job were the divers. All were great. They had some little problems among themselves, but were truly professional and effective as far as we were concerned.

We thank CAPT Claude Harvey and Bill Mooney of NSMRL New London for the helpful loan of doppler equipment and Dr. Brian Eatock of DCIEM for essential advice on setting up the protocol. We enjoyed having the NBC TV crew present at the end of Repex II, and were pleased at the quality of the press coverage, including a color photo of the Repex II divers on page one of the Gannett Westchester newspapers.

We appreciated the considerable thought and work put into the proposals of other laboratories; we could not help but benefit from their quality efforts. And we must again thank the NOAA NURP office for their confidence in us, and Deborah Jaquiss in the Contracts Office. And special thanks to all those we forgot to mention.

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The contract report to NURP which has been incorporated into this report is:

Hamilton RW, Kenyon DJ, Peterson RE, Butler GJ, Beers DM. Repex: Development of repetitive excursions, surfacing techniques, and oxygen procedures for habitat diving. Development and validation report to the Office of Undersea Research, NOAA, U.S. Dept. of Commerce, under Contract NA-84-DGC-00152. Tarrytown, NY; Hamilton Research, Ltd.

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I.
ABSTRACT

Hamilton RW, Kenyon DJ, Peterson RE, Butler GJ, Beers DM. Repex: Development of repetitive excursions, surfacing techniques, and oxygen procedures for habitat diving. Technical Report 88-1A. Rockville, MD: NOAA Office of Undersea Research, May 1988.

The Repex program expanded and improved on the basic technology of the NOAA OPS project, which in 1973 opened up nitrox saturation or "habitat" diving by making it possible for divers to excurse to depths both shallower and deeper than their saturation storage depth. From the beginning it was apparent that other capabilities were needed. This program has provided development of these new procedures and a modest chamber validation. Excursion tables were computed using modifications of the NOAA OPS algorithm, adjusted to account for a few decompression problems that have occurred; a new M-value matrix was derived. We justified basing repetitive computations on gas loading because bubble activity depends on gas loading, and ultrasound data has shown no increase, possibly a decrease, in bubbles in the second of repetitive dives having equal stress. We found the dive number in a repetitive sequence and the interval between dives were the important factors, assuming that similar repetitive excursions would be the worst case; tables are based on order and interval. For longer excursions a single stop of up to 1 hr is used, with a preliminary deeper stop of 2 min. Three week-long chamber tests covered the storage depth (50, 80, 110 fsw) and excursion depth (94-240 fsw) ranges in 252 diver-excursions with representative times and intervals. Divers ranged from 19 to 62 yr and from 100 to 235 lb, and included 4 females. No DCS resulted from excursions, and doppler monitoring found bubbles of Grade II or below. We had pain-only DCS at 10 fsw decompressing from 50 fsw after a 12-hr hold following the last excursion, so changed the decompression to start at a "starting depth" deeper than the habitat; it is based on recent excursions. For example, the 80 fsw saturation started at 130 fsw; this is quicker than a 12-hr wait, which would be inadequate anyway. Subsequent saturation decompressions were okay. Two groups of divers were well above the O_2 limit, but had only trivial symptoms, suggesting that the limits are quite good; the daily and total doses depend on the duration of the exposure. The Procedures are ready for provisional use at sea. [Development and validation report to the Office of Undersea Research, NOAA, U.S. Dept. of Commerce, under Contract NA-84-DGC-00152. Tarrytown, NY; Hamilton Research, Ltd., 30 Sep 1987.]

SATURATION DIVING / EXCURSION DIVING / HABITAT / DECOMPRESSION TABLES / CHAMBER / TABLE VALIDATION / NITROGEN / NITROX / DECOMPRESSION SICKNESS / CPTD / OXYGEN EXPOSURE LIMITS / AIR / DOPPLER BUBBLE DETECTION

II.
INTRODUCTION: THE HABITAT DIVING CONCEPT

This chapter discusses the shallow habitat diving concept and the role of this project in enhancing it.

For the sake of simplicity we use the term "habitat diving" to describe the concept under consideration here. It has been referred to as "NOAA OPS" diving, air or "nitrox" or nitrogen-oxygen saturation diving, or saturation-excursion diving, or combinations of these. The concept involves divers living--saturated--in a hyperbaric atmosphere of air or a mixture of nitrogen and oxygen, and excursing from the saturation depth using air as the excursion breathing gas. Excursions are made to depths both shallower and deeper than the depth of the habitat, "storage depth," the pressure with which the divers are saturated. Our interest here is primarily focussed on decompression aspects of habitat operations, especially excursions, and in breathing mixtures based on nitrogen as the inert gas.

A. Background of habitat diving

This section includes a brief review of the history of habitat diving, concentrating mostly on nitrogen-based projects.

1. Early habitat diving

The roots of habitat diving rest on the early Conshelf experiments which began in 1962 (Cousteau, 1964 and 1966; Chouteau, 1969). The first major U.S. program was Tektite (Pauli and Cole, 1970; Beckman and Smith, 1972). These laboratory programs and some undersea habitat operations were all tied together by a common limitation that any excursions performed were of limited (vertical) distance and duration. The U.S. Navy's Sealab program involved two sites and two habitats; both were in the depth range of 200 fsw, both used heliox environments, and both were strictly limited in the amount of vertical excursion distance the aquanauts were allowed to use on excursions.

A laboratory study by the U.S. Naval Submarine Medical Research Laboratory (Larsen and Mazzone, 1967) began to work toward expanding the excursion range. This project, using nitrogen mixes, carried out planned and programmed excursions calculated by the Workman method in use by the Navy at the time (Workman, 1965).

2. Review of habitat operations

Meanwhile quite a number of shallow habitats were installed and used successfully, a large part of the total in Eastern Europe. These are reviewed in detail in a book dedicated to that subject by James W. Miller and Ian G. Koblick (1984). Also, we engaged Dr. Miller to do a survey of information on decompression practices used by these habitats that were not in the book. This is a useful additional reference to these operations; for many it gives details of the final saturation decompression. Most of these are from relatively shallow depths. With regard to techniques for excursions, especially repetitive excursions, the main finding is that the work of the NOAA Repex project is needed. There is a problem in using data of this sort--even if details are available--because of the small number of subjects. If two sport divers make a 24-hr saturation at 30 fsw and surface without problems it adds to our perspective, but it by no means guarantees that the procedure is acceptable.

3. The NOAA OPS program

The NOAA OPS program (for "NOAA OPerationS;" Hamilton, Kenyon, et al, 1973) made vertical air excursions from a nitrogen-oxygen habitat a reality. This laboratory study involved four week-long saturations at 30, 60, 90 and 120 feet of sea water pressure (fsw[1]) with excursions to as deep as 300 fsw. In addition, ascending excursions simulated ascents 30 to 65 fsw shallower than the habitat depth.

The descending excursions used in NOAA OPS were without decompression problems, but divers on ascending excursions noted "niggles" and itching, which indicated that the time limits were none too short. Likewise there was no decompression sickness (DCS) from the saturation decompressions, but one of the tables (NOAA OPS II, which became the "SCORE" table) was later used for other decompressions and eventually was shown to be inadequate.

One thing noted in NOAA OPS was an apparent acclimation to nitrogen narcosis (Schmidt, Hamilton, et al, 1974). This was interpreted as being about the same as if the storage depth (after a few days) were subtracted from the bottom depth in determining the narcotic effect. That is, for divers saturated at 50 fsw excursing to 200 fsw the narcotic effect would be about the same as normally encountered at 150 fsw. Not everyone agrees that this effect exists; Bennett and colleagues did not see any noticeable effect in the SCORE workup dives (Miller, Adams, et al, 1976). This issue was recently reexamined in a NOAA-sponsored workshop on nitrogen narcosis which concluded that there probably was an effect but that one should expect a benefit of about half the storage depth (Hamilton and Kizer, 1985). The effect seems to be more one of learning to cope than a physiological accommodation.

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[1] fsw = feet of sea water. The fsw is defined as 1/33 standard atmosphere, or 3.0705 kPa. See Procedures, p. 13, for details on conversion. English units are required by NOAA.

4. Laboratory and field operations after NOAA OPS

Field operations using the NOAA OPS techniques were begun even before the report was completed. Special tables were provided by the NOAA OPS investigators to Dr. J.W. Miller for use out of the PRINUL habitat in Puerto Rico; these are covered briefly in an appendix to the NOAA OPS report. Only ascending excursions were made; on occasion these caused the same type of "niggles" or indefinite bends symptoms as had been seen in the laboratory.

Both the U.S. Navy and NOAA took definitive early steps to apply the new technology. NOAA used excursions from both the PRINUL and Hydrolab habitats, and the Navy launched a series of experimental dives which began with SHAD and have been continued through Nisat, Airsat, Surex, and Minisat. A major operation involving both laboratory and sea was NOAA's SCORE program, which involved excursions long and deep enough to require decompression stops; these were calculated especially for SCORE by the NOAA OPS laboratory team (Freitag, 1975).

The NOAA activities and the early SHAD dives were compiled in a comprehensive monograph (Miller, Adams, et al., 1976) which covers most developments through early 1975, even including the 10-dive series of Tonofond experiments by De Lara in Spain. These were independent but remarkably similar to NOAA OPS, although excursions were somewhat shallower and longer. There were no bends following excursions, but some after the saturation decompression. De Lara observed the adaptation to narcosis noted in NOAA OPS.

SHAD I and II were saturations conducted at the Naval Submarine Medical Research Laboratory, with air as the habitat atmosphere at 50 and 60 fsw (Hamilton, Adams, et al., 1982). Excursions were performed following the NOAA OPS model. SHAD III divers were saturated at 50 fsw and made 8-hour daily excursions to 100 fsw, all with air. No decompression problems were seen with excursions, but one diver had pain-only DCS at 18 fsw in the saturation decompression that began 16 hr after the last excursion. The divers also showed measurable effects of the oxygen exposures (Adams, 1978; Dougherty et al., 1978). Nisat I involved no excursions, but had divers living at 198 fsw (7 atm) for a week, breathing a nitrogen-oxygen mixture. The divers were sick at first, but recovered on addition of oxygen from 0.21 to 0.3 atm; it is not certain whether the nausea was due to hypoxia or some other factor. Later Nisat exposures involved a switch from nitrogen to helium, resulting in some itching and one clear case of "counterdiffusion" gas lesion disease.

The first Airsat dive at NSMRL was similar to SHAD III but was based at 60 fsw. Later Airsats used longer excursions with decompressions involving stops, and also overnight saturation with air at 132 fsw (Eckenhoff, Hunter, et al., 1981; Eckenhoff, Parker, et al, 1982; Eckenhoff and Vann, 1985). The Surex program confirmed and extended the earlier work on ascending excursions, especially as they involve short duration ascents to the surface from the depth range 45-60 fsw (Eckenhoff and Parker, 1982; 1984). The Minisat series has determined that a direct ascent from 25.5 fsw is not without problems (Eckenhoff, Osborne, et al, 1986).

In the PRUNE operation (Miller, Bachrach, and Walsh, 1976) a number of excursions were carried out at sea to depths as deep as 265 fsw, and though some of them were long, none approached the excursion limits. "Niggles" were felt in ascending excursions, and one diver felt narcosis at 265 fsw, but there were no problems.

The SCORE program involved a 2-week air saturation at Duke University with divers stored at 60 fsw excursing to as deep as 300 fsw. From this it was learned that excursing with air at this depth for up to 60 minutes may result in oxygen convulsions, decompression sickness, and minimal acclimation to nitrogen narcosis (Miller, Adams, et al, 1976). Excursions to 200 and 250 fsw were trouble free. Adjustments to the allowable bottom times were made for the at-sea decompressions (the 60 min table was used for 45 min), and these were carried out successfully despite several operational problems and one postdive precautionary treatment for suspected decompression sickness.

The Swedish Navy carried out a deep nitrox saturation, Nisahex, with divers saturated at 7 bars (200 fsw, like Nisat I), but this involved excursions to as deep as 100 msw with oxygen, helium, and nitrogen "trimix" (Muren, Adolfson, et al, 1984). The exposure was well tolerated despite significant narcosis; there were problems during and after decompressing from saturation, with one diver treated at 11 msw (36 fsw) and DCS symptoms developing in 4 of 6 divers several days after surfacing. In another experiment ("Nosex") carried out at Duke University (Barry, Vann, et al, 1984) 10 subjects were saturated at 165 fsw for 6 days to assess the degree of adaptation to nitrogen. Observations on narcosis are not clear cut and have not been fully reported, but are generally in agreement with the Nisat and Nisahex impressions. Although the decompression profile was improved over that used in Nisahex, DCS was a problem. Four subjects had bends before reaching 20 fsw and another in flying 3 days after leaving the chamber.

5. Initial commercial development

Although they showed great interest from the beginning, commercial diving companies were slow in picking up on the NOAA OPS technology; it is not possible to state their actual activity level accurately because of limited access to information. In due course a commercial adaptation of habitat-type diving began to be seen, wherein the divers live saturated in a living chamber on deck and excurse to and from the worksite in a pressurized diving bell. The work done by commercial divers is substantively different from what marine scientists do. Commercial divers usually work at one location for long hours, while the scientist wants to visit many sites and often wants to do that several times a day. This accounts for the fact that even though the physiology and decompression techniques are readily adapted, it makes more sense for commercial divers to live at the surface. As far as we know there have not been any "commercial" operations that have used seafloor habitats, but there are now published accounts (some quite brief) of numerous "commuter" type operations by Comex (Thornton, 1979), Seaway

Diving (Peterson, Hamilton and Curtsell, 1980), and Oceaneering (Youngblood, 1982), and others.

The general impression is that there have been no problems with decompression from excursions, but as mentioned the commercial excursions have usually been of a different type from those used in at-sea habitat diving operations; the commercial approach is to saturate close enough to the depth of the worksite so that long (8-hr) excursions for work can be performed on a daily basis without decompression. Bends have occasionally been encountered in or after the decompressions from saturation. Storage (i.e., habitat) depths are reported as 35 to 115 fsw, with worksite depths ranging from 72 to 210 fsw. More detail on some of these is given in the section on development of the Repex saturation tables, III.C.1.

The interest in nitrox saturation-excursion diving seems higher than the activity, especially in the U.K. (Thornton, 1979; Walder, 1981). An early publication by the CIRIA Underwater Enggineering Group (Hempleman, Kettle, and Barrett, 1979) concluded that the technique was feasible for commercial work but that not enough was known, especially about repetitive excursions. A resulting British study has looked at this, providing also some data on the interval between the last excursion and the beginning of saturation decompression (Hennessy, Hansen, et al, 1981). Eventually this led to development of a set of commercial nitrox saturation-excursion tables sponsored by the U.K. Department of Energy and published by CIRIA, the British industrial research association (Hennessy, Hansen, et al, 1985). More about these in the discussion.

B. Objectives of this program

A seafloor habitat makes it possible for marine scientists to live close to their work areas, and thus it can improve their efficiency, logistics, and in many ways their personal safety. They can work at locations both deeper and shallower than the habitat by means of vertical excursions. These excursions, however, require correct practices in order to avoid decompression sickness and other problems; this is usually managed with procedures that include time-pressure-gas profiles referred to here as decompression tables, or just "tables." In fact, the problems of decompression and its ramifications are the primary motivation for building an undersea habitat in the first place.

The excursion tables that have been available for habitat diving are included in the Second Edition of the NOAA Diving Manual (Miller, 1979, Section 12). The manual includes tables for both descending and ascending excursions to depths as deep as 250 fsw for habitats situated at from 30 to 120 fsw. Although they have been used effectively, even before they were issued it was apparent that there were some serious limitations. These limitations have been discouraging to eager scientists, and they have made the habitat system much less cost effective than it can be. While the ranges covered are practical, the procedures have been severely limiting primarily with regard to "repetitive" diving; under present rules it is not possible for a diver to perform more than one effective excursion dive each day. There are also unnecessary limitations which were introduced into the excursion tables to avoid oxygen toxicity, and it is not stated clearly in the Manual exactly when or how to use the oxygen procedures. Because habitat diving can result in excessive exposure to oxygen unless proper precautions are followed, practical means are needed for managing oxygen exposure to control both central nervous system and pulmonary/chronic oxygen poisoning.

Also, more reliable choices are needed for the final decompression from saturation at the end of each mission, and for the various patterns of ascent, including emergency ascent. In addition to these needed operational procedures, methods are required for dealing with the treatment of decompression sickness and related diving medical problems that may occur in the habitat as a result of the diving operation.

The Repex procedures (cited in the footnote to the Preface and referred to in this report as "the Procedures.") were prepared by Hamilton Research, Ltd. under Contract NA-84-DGC-00152 to the NOAA Office of Undersea Research. The program had as tasks a means of performing repetitive no-stop excursions, longer excursions using stops, new saturation decompression procedures, emergency and normal surfacing procedures, and treatment procedures.

PART ONE: DEVELOPMENT OF THE REPEX PROCEDURES

CHAPTERS III AND IV.

This chapter and the next discuss methods used for the development of the Procedures. Chapter III covers the methods used, beginning with the development of the computational model and selection of new ascent-limiting M values. It covers the calculation of excursions from nitrox saturation, including no-stop, repetitive, and timed excursions, and procedures for use after excursions shorter than the allowable time. Also described is the calculation method that was used in developing the saturation ascent procedures. Chapter IV rounds out other details, including oxygen management, surfacing, treatment, and an assessment of the efficiencies of the tables.

It is worth reiterating that the Repex Procedures are the product of a research effort to develop new procedures. They are not diving rules, and the Procedures report is not a manual.

III.
DEVELOPMENT OF THE TABLES

A. Methods used in computing the tables

Our method was to apply selected experience using an established computational model operated by a versatile computer program to generate new profiles.

1. Nature of decompression table development

The current state of the art of decompression table development involves a multi-step, iterative process of devising a profile, testing it, revising the profile as a result of the tests, and repeating the process as much as necessary to achieve satisfactory results (Schreiner and Hamilton, 1987). Usually there is a mathematical algorithm used to generate the new profile. Over the years a number of these have been tried, some of them highly touted, highly sophisticated, and at one time some were super secret. But after all the glitter has worn off what has remained has been an iterative, empirical process.

It is now generally recognized that almost any reasonable computational theory can be made to work if there are enough variables that can be adjusted to fit the observed experience (see, for example, Berghage, 1980). It is the "experience" or data base that now becomes the key to the process. (For the record our procedure has for many years recognized this dependence on experience, documented in 1971 as Schreiner's "pragmatic approach.")

While the mechanisms of decompression biophysics are poorly understood, what it takes to make a procedure more conservative is reasonably well established (although it is by no means infallible). The main point is that today's decompression table development is empirical--based on experience--and that it also involves a computational step.

Successful decompression does not fall on one side or the other of a hard line. However, it is taught that if one follows the tables he will not get bends and if he deviates he is certain to be "hit" (it has to be **taught** this way). The human body being decompressed is not so precise. The line, wherever and however it may be drawn, marks an acceptable **probability** of avoiding decompression sickness. Because it is based on probability, there is never certainty one way or the other. The meaning of this is that no **practical** decompression procedure can be counted on to be **100% reliable** under all circumstances of diving and over extensive use.

We use the word "reliable" rather than "safe" to define decompression tables that have a satisfactory level of risk of DCS.

2. The Haldane-Workman-Schreiner model

The computational method used earlier for NOAA OPS was based on the model that Workman derived from Haldane's original concepts, with some modifications by Schreiner and Kelley (1971). This fits the general description of being "Haldanian" or more accurately "neo-Haldanian" because the basic tenets of Haldane's "model" (but not his constraints!) are still used. The Schreiner modifications apply mostly to the use of different inert gases; the methodology is discussed in detail in the NOAA OPS report (Hamilton, Kenyon, et al, 1973). The model assumes that the body takes up and gives off inert gas on an exponential basis, but at a number of different rates. These different rates are considered to apply to different "compartments" (sometimes called "tissues"). A compartment is defined as that part of the body which has the same time constant, or for these calculations the same half time, for gas uptake and elimination. These compartments and their half times are used to do bookkeeping on the "gas loading" of the diver. Decompression is allowed when the gas loadings in all the compartments do not exceed an empirically determined maximum or "M value."

While this method does have a physiological basis, it is not regarded by some as a true "physiological model" (Hills, 1977; Berghage, 1980), its main value is that it can be used to convert previous empirical dive experience into future dives. This is what was done for NOAA OPS. From the analysis of prior dives a new "matrix" of M values was constructed, then this matrix was used with the Haldane-Workman-Schreiner model to compute the NOAA OPS profiles.

Each of the NOAA OPS experiments was calculated as one long continuous profile, such that any effect a previous excursion might have on the gas loading of a subsequent excursion was taken into account. In that sense the excursions were repetitive. The excursions were calculated so a diver could stay at each excursion depth for a definite and limited period of time, but that when the time was up he had to be back at habitat depth; no stops were required during the ascent. For the field tables the diver was assumed to have no "residual" gas at the start of the excursion, and a slight safety factor was included by shortening by five feet the allowable excursion distance. These calculations for repetitive dives did not consider bubble formation or the destruction of bubble nuclei in arriving at the repetitive schedule.

All decompressions in the NOAA OPS project were completed without problems. Some divers during ascending excursions felt itching and "niggles" or indefinite mild symptoms of bends or decompression sickness which went away on return to the habitat.

3. DCAP: Decompression computation and analysis program

This section covers the use of DCAP, Hamilton Research's decompression computation and analysis program.

a. Description of DCAP

DCAP is a comprehensive program written in FORTRAN that enables a user to calculate a wide variety of decompression tables using ordinary language and without the need for conventional computer programing skills (Hamilton and Kenyon, 1982). It functions by interpreting a "Base Case" consisting of a page or more of normal language instructions, setting up a computational scheme using a number of supplementary files, then calculating the table or tables specified in the Base Case.

All of this functions "outside" of the FORTRAN program, and the files can be written in any language; their purpose is to define the terms and provide data for the program. The supplementary DCAP files define organizational things like print formats, error messages, parameter names, "statements" or command categories, comments or instructions to be printed on the tables, etc., and they set up default values for many items. These include definitions of the units to be used; structure of the model with compartment half times, gas names and units to be used; environmental conditions such as barometric pressure and values of CO_2 and water vapor; structure of the table to be produced including staging intervals and the times to be displayed; display of CPTD; and where to put travel time; any of these can be changed in the Base Case.

The Base Case sets up the dive to be done, and can do a single depth-time-mix dive or "families" of many times, depths, and gas mixes. The matrix to be used is either defined or a file containing it is named. Gas mixes are defined in either percentages or partial pressures. Comments (instructions) can be inserted in the table in various ways. "Conditional" functions allow the use of "if" commands that can invoke action as a result of many factors such as depth or time.

The profile of the dive can be defined in terms of depth, travel (as either rate or travel time), and stops. The diver can be "positioned" regardless of gas loadings, or during ascent can be under control of DCAP and the ascent constraints. The Position function allows previous dives to be reconstructed, or--in doing an analysis--a diver can be put through a specific pressure-time-gas history and then the decompression status can be determined. Gas loadings are stored, and can be printed out. The results of running a Base Case become a computer file, but DCAP also keeps an "audit trail" of what has been done in a Notebook file.

For Repex DCAP used the Haldane-Workman-Schreiner "Tonawanda II" model (Schreiner and Kelley, 1971), but other computational models are possible. DCAP's main function is to calculate decompression tables, and is not restricted to any particular approach.

A sample Base Case is shown in Appendix D. This is the printout of a run of the Repex II dive, including all excursions. The Base Case is always kept with the dive output. This one took 3 pages to code all the excursions, but normally a Base Case is less than a page.

b. DCAP configuration for the Repex project

The main calculations were made with DCAP version 4.22, the version that runs on the DEC PDP 11/60 minicomputer. Two new capabilities were added for this program, the calculation of "no-d" or no-stop tables, and the printing of tables in a "multiple-schedule" format whereby a number of time-depth combinations can be output on a single line. Later work with DCAP after the main table calculations was done with version 5.5+, which runs on IBM PC type computers.

The model used was one descended from the NOAA OPS project. It is based on an eight half-time compartments that progress geometrically from 5 to 640 minutes, it considers only nitrogen, and it uses the Initialization file IN08F1.DCP; this defines English units, the half times, and other default values.

The matrix used (MF0805.DCP) was developed as part of the program, and is described in section III.B.c, below.

Parameter, Error, Comment, Statement, and Logicals files were as defined for version 3.+ (Hamilton and Kenyon, 1985).

B. Excursion calculation

1. Development of the model parameters

Traditionally we have considered that the computational "model" for the calculation of decompression tables involves perfusion-limited, exponential gas transport and a set of hypothetical tissue compartments and their half times. In order to carry out calculations it is also necessary to have a "matrix" of ascent-limiting constraints. The combination of **half times** and **matrix** makes up a computational system or **algorithm** that--operating with DCAP or an equivalent system--generates the profiles. The main basis for changing either half times or matrix is to accommodate experience from past dives and dive computations; the experience that served as the basis for the Repex development is reviewed below.

a. Selecting the half times

We developed a new set of half times for these calculations. This was done for two reasons. It was originally begun as an effort to develop a simplified method for calculating repetitive intervals in the field, but this did not prove to be a promising approach. It did, however, lead to the use of a smaller 7-compartment model at first; this developed into the 8-compartment model eventually chosen.

The second reason relates to irregularities in the matrix used for the original NOAA OPS development. We felt that with this model the NOAA OPS matrix was the best available starting point for calculation of new nitrox habitat tables; the NOAA OPS system was developed from dive experience, and the excursion tables generated with it have proven to be quite dependable in field use. Half times for the NOAA OPS matrix, like the Workman matrix before it, were selected in part to make it easier to fit empirical data. We could not differ with that wisdom, but we were concerned about the fact that the gas loading limits of the NOAA OPS matrix were rather uneven (this matrix, 32/02, is given in Miller's 1976 monograph and in the original NOAA OPS report, 1973). Development of the matrix is discussed in more detail later. The requirement to "clean up" the matrix caused us to choose a sequence of half times that progresses smoothly and does not exceed a reasonable maximum half time.

A simple geometric progression of half times was selected. This was consistent with earlier experience in the short compartments, but resulted in fewer middle and long compartments. Our rationale for this was that there is no physiological justification for not expecting the phenomena relating to decompression to behave in a steady and smooth manner. Even if there are discontinuities in specific cases, when the whole system is considered the behavior has to be smooth (but not necessarily linear). The discontinuities found in the NOAA OPS system, for example, are not a representation of biological behavior, they are instead a result of having limited data.

We tried at first to make the shortest compartment 10 minutes, but found right away that this would not allow proper control of short, deep excursions. The traditional 5-min first compartment was used.

The geometric progression of 8 half times starting with 5 min led to a 640-min compartment as the longest. In the old NOAA OPS matrix the next value was 1280 min, and this appears to be incompatible with other aspects of physiology. The value for the longest compartment we have used for some time in our commercial applications of DCAP is 670 min. The long values (1280 min) tested in the original NOAA OPS data analysis were found not to be meaningful, at least for the data base involved there. Half times much beyond those needed to describe established saturation decompression rates have little physiological meaning; at present this is in the neighborhood of 640-670 min. The half times chosen for the present "NOAA Repex" model, designated MF0805, are given in Table III-1.

Table III-1. Comparison of half times

Half times (in min) used in relevant models.

Workman, 1965	5	10	20	40	80	120	160	200	240						
NOAA OPS, Tonawanda II	5	10	20	40	80	120	160	200	240	320	480	640	720	1000	1240
NOAA Repex	5	10	20	40	80		160		240			640			

b. Background of the new matrix

A key ingredient in making decompression calculations with DCAP or other Neo-Haldanian computational models is the "matrix" of ascent limiting M values. Adjusting the matrix is the mechanism for assimilating experience from prior dives.

A matrix is an array of limiting gas loadings for the various compartments, and for each of the depths at which the matrix is evaluated. Whether or not the constraint limits actually represent real world "gas loadings" is not important to the method; the important things are that the matrix affords a workable means of limiting ascent, and that it can be adjusted (in a limited way) to respond to experience.

A matrix may have a separate stored M value in each depth-compartment cell, or it may be defined by a series of linear equations and be calculated each time the matrix is used. Each compartment is represented by a "base" or starting value and a "slope" or differential that defines the increase of the matrix values with increasing depth. If this increase or slope is greater than 1 the matrix is said to "expand." The slope is the "a" in a linear equation of the form $y = ax + b$, where y represents the M value to be determined, x the increment between stop levels, and b the initial value or intercept.

The original NOAA OPS matrix for computing excursions from nitrox saturation was developed by Schreiner and Kenyon as part of the NOAA OPS project. That matrix (designated originally 32/02, currently MF1102 in the 11-compartment version) was based on Workman's original matrix as adjusted for the experience gained from about 200 relevant nitrox dives. These included some saturation and other nitrox sub-saturation dives from a variety of sources; they provided substantial decompression stress and included a significant number of cases of decompression sickness.

The method used for developing a new matrix from an experience data base is described in some detail in the NOAA OPS report. It consists essentially of examining the gas loadings for various depths considered to be significant in the success or failure of the decompression procedures under consideration, then adjusting the M values as a result of the observed loadings. This method was used to produce the matrix that was used to develop the NOAA OPS excursion tables. This method does not have a firm statistical basis, but for the small numbers involved it is an acceptable tradeoff.

The NOAA OPS matrix has proven quite successful in terms of the relative lack of decompression sickness from the use of excursion procedures based on it, but it has some interesting characteristics that for some time have called for further work. During its development the values in the NOAA OPS matrix were adjusted where there was data on which to base an adjustment, but in some areas data was lacking and values the same as or close to Workman's were retained. Thus the matrix has areas where some M values show abrupt and large changes between neighboring depths and compartments, and in other cases M values are relatively constant over several steps in places where they should probably be changing.

It seems intuitively comfortable for the values in the matrix to progress more or less smoothly and constantly, without abrupt changes. Thus if specific data causes a matrix value to be lowered (making it require more decompression to clear the diver to ascend further) then it is reasonable to assume that other matrix values near the one in question should be lowered as well.

The NOAA OPS matrix has undergone smoothing on several occasions since its original development. It was smoothed "slightly" for the calculation of the excursions performed on SHAD I (Hamilton, Adams, et al. 1982) and a distinct smoothing was performed for the calculation of the SCORE excursions (Freitag, 1975). The changes made for the SCORE project consisted of adjusting adjacent values so they would progress evenly, but the changes involved increasing some M values (thus making them less conservative) and decreasing others.

The tests of the SCORE excursions performed at Duke University (Miller, Adams, et al. 1976) are significant in that they represent the only well documented case (that we have been able to find) of decompression sickness resulting from a NOAA OPS type excursion. (There is another anecdotal one from commercial diving, mentioned below.) The task in SCORE was to perform long excursions to as deep as 300 fsw from saturation with air at 60 fsw. To get a useful bottom time at this depth it was necessary to perform some decompression stops on the way back to the habitat. A limited set of staged excursion tables was prepared for the SCORE operation. In tests at Duke University one definitive and one probable case of decompression sickness resulted from a total of 23 diver exposures. To correct this the allowable excursion times were shortened for the at-sea portion of the SCORE operation, but no additional tables were calculated. There was no decompression sickness reported from 47 open sea SCORE excursions, although one diver was given a precautionary treatment after the saturation decompression.

The NOAA OPS matrix was modified again in 1978, to make it possible to incorporate the established values for no-stop excursions into a diver-carried decompression computer (Hamilton and Kenyon, 1978). This modification involved converting to a 9 compartment matrix (39/01), and adjusting the M values down slightly to account for the difficulties mentioned above. This was done to allow the "Decometer" under development by the US Navy to be used for excursions. To our knowledge that computer unit has not been tested in the saturation-excursion mode, but it and its derivatives have been used extensively in other configurations by the Navy (Thalmann, 1983; 1984; 1985).

Another undocumented case reportedly involved a diver who had made a long excursion to 200 fsw from about 100 fsw. Without more facts we could not use this information, but the adjustments that were made changed the tables in this range substantially in a conservative direction, allowing less time in the longest, deepest excursions.

c. Preparing the matrix

A new matrix was prepared for the Repex project. It was based on the NOAA OPS matrix, adjusted and smoothed in the manner discussed above and according to the following criteria.

(a) No M-value limits in the original NOAA OPS matrix were exceeded. (See discussion following.)

(b) Surfacing values (the last stop) were adjusted to produce traditional no-stop dive times.

(c) The increase of M values with depth showed a "break" or change in slope at 70 fsw; this was retained.

(e) An adjustment was made to attempt to account for the decompression sickness seen in the SCORE excursions.

(f) Values for compartments 6, 7, and 8 were lowered (made more conservative) from experience in deep heliox bounce dives that use air in the final part of the decompression.

The first adjustment was to lower the 40 and 80 minute compartments at 80 fsw, the area that appeared to be most likely to be involved with the SCORE problem. The new matrix was converted to a "base-slope" type; the NOAA OPS matrix has a value in every cell, whereas the "NOAA Repex" matrix is the type that is calculated each time it is used. To make this conversion we first adjusted the values at 70 fsw to get rid of the discontinuity between the 5th and 6th compartments and to cause a smooth progression as both stop depths and compartment times increase. This also corrected the discontinuities at 80 fsw and the rather large steps seen between 70 and 80 fsw for all the slow compartments. All these adjustments were in a conservative direction (because the values derived from experience were all lower).

Next we derived a new set of "surfacing" values for the 10 fsw stop. In a table calculation the gas loading is compared with the M value at 10 fsw, and the diver is allowed to ascend to the surface (from the 10-fsw stop) when all his compartments have a gas loading equal to or less than the 10 fsw M value. The 10 fsw values are also used for "no-decompression" or no-stop dives; here the dive time is calculated such that when his time is up the diver can ascend to the surface without exceeding the 10 fsw M value. To get surfacing values we selected M values that would give a set of no-d times slightly more conservative than the USN no-decompression limits. To get these we compared values for the USN limits and those for the new Canadian tables (Nishi and Lauchner, 1984) and took values between them. We did not feel it necessary to go quite as conservative as the Canadian tables, partly because we feel the USN no-d tables are quite good (Thalmann, 1987), and also because the M values at this level play only a small role in calculating excursion tables which require the diver to return to storage, not the surface. The last three compartments were set at values determined in unpublished deep tri-mix table development for commercial diving.

One cell, the value at 10 fsw in the 640 min compartment, was raised from 34 to 35 fsw; this one was not actually tested in NOAA OPS and it remains more conservative than seems necessary in other applications. It would only come into play in a saturation (for which this matrix is **not** intended) or an extremely long decompression. This 35 is consistent with the direct-ascent limit from nitrox saturation of about 24 fsw recently determined by Eckenhoff and colleagues (1986); 24 fsw is 57 fsw absolute, and the PN_2 of air at that pressure is 45, the "surfacing" value in the slowest compartment at 10 fsw.

Using these values--the adjusted 70 fsw values and those derived from the conservative no-d and deep diving limits--we then determined the slopes that would connect them. A further restriction was that the 640 min compartment should have a slope of 1 over all depths in order to be consistent with experience from deep dives that use air breathing at the end (whether or not it is actually valid). We used "expansion" of the matrix for the faster compartments in accordance with established tables for air diving; that is, the slopes have a value greater than 1. For all compartments deeper than 70 fsw we used no expansion, a slope of 1. This is consistent with the more-or-less established NOAA OPS experience, and with results of deep diving.

The actual adjustments on the matrix were obtained by putting all the values into a "spread sheet" computer program (Lotus 1-2-3). This allowed us to make a change at one point and instantly see its effect throughout the matrix.

The resulting NOAA Repex matrix MF0805 is given in Table III-2. Although no-d surfacing values were used in developing this matrix, we do not consider it appropriate for decompression from deep air diving all the way to the surface, and have evidence to support that view (Hamilton, Muren, and Röckert, 1987).

Table III-2. NOAA Repex constraint matrix MF0805

Values in the table are ascent-limiting partial pressures of gas for the respective half-time compartment and depth. When all compartments are cleared at a given depth the diver can ascend to the next shallower one. Slopes are used for calculation of the matrix by the "base-slope" method. 85Jun21

Compartment	1	2	3	4	5	6	7	8
Half time	5	10	20	40	80	160	320	640
Slope 0-70:	1.60	1.45	1.25	1.20	1.13	1.08	1.02	1.00
Slope 70-200:	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Depth	M value							
200	319	295	270	257	248	242	237	235
190	309	285	260	247	238	232	227	225
180	299	275	250	237	228	222	217	215
170	289	265	240	227	218	212	207	205
160	279	255	230	217	208	202	197	195
150	269	245	220	207	198	192	187	185
140	259	235	210	197	188	182	177	175
130	249	225	200	187	178	172	167	165
120	239	215	190	177	168	162	157	155
110	229	205	180	167	158	152	147	145
100	219	195	170	157	148	142	137	135
90	209	185	160	147	138	132	127	125
80	199	175	150	137	128	122	117	115
70	189	165	140	127	118	112	107	105
60	173	151	128	115	107	101	97	95
50	157	136	115	103	95	90	87	85
40	141	122	103	91	84	79	77	75
30	125	107	90	79	73	69	66	65
20	109	93	78	67	61	58	56	55
10	93	78	65	55	50	47	46	45
0	77	64	53	43	39	36	36	35

2. Algorithm for repetitive no-stop excursions

This section covers development of the algorithm for preparing tables for repetitive no-stop excursions from saturation.

a. The dilemma of calculating repetitive dives and the justification for gas loading

From the outset, calculation of repetitive dives presents a dilemma. At least three things about the first dive affect the second dive in a repetitive dive sequence. First, the second dive is affected by an increased gas loading remaining from the first dive. The other two factors have to do with bubbles. We know that a dive can both generate and remove bubble nuclei. What we do not know about this phenomenon is the relative importance of these two factors. That is, we cannot tell whether the first dive is more effective in generating new bubble nuclei or in or removing existing ones. Other possible factors such as effect on platelets or complement are not considered.

To help resolve this question we engaged Mr. Ron Nishi of DCIEM, Toronto, to assist in looking for clues in DCIEM's CANDID Diving Data Base (Kuehn and Sweeney, 1973).

We ran into several problems in attempting to analyze previous repetitive dives with CANDID. First, for the dives coded over the years 1965 to 1979, those most easily accessed at the time of our study, a repetitive dive sequence is logged as one dive. There is a code in CANDID showing which dives involve repetitive sequences, but it is impossible without producing a plot of the dive profile to determine which ones would be relevant. The early experimental diving at DCIEM was dedicated to validating the Kidd-Stubbs pneumatic analog decompression device and the model on which it was based. One of the advantages of this device was that it would permit dives of varying profiles to be performed, presumably with the same degree of conservatism. Because most dives tested this capability with complicated profiles involving a lot of ups and downs, very few done during the early years involve a straight descent to the bottom, work at a specific bottom depth, followed by a decompression and a second similar dive. It was not possible in most of the cases we looked at to make a clean comparison between different dives. Because of the irregular nature of most dives and the fact that we could not easily locate the ones that would have been suitable for analysis, we felt this approach was not worth pursuing further in the limited time available.

The question our analysis was to answer was, "When the repetitive adjustment based on gas loading analysis has been implemented, does the second dive in a sequence have a greater or less probability of decompression sickness than would the first dive performed alone?" That is, is there an effect of bubbles independent of the effect of gas loading? It appears that this cannot be answered without knowing the algorithm for calculating the second dive in a repetitive sequence, so we have a Catch 22.

The case for the formation of bubbles or bubble nuclei by a dive, or by the first dive in a sequence, is illustrated by numerous anecdotal accounts of decompression sickness occurring on flying up to 5 days or 1 week following the end of a nitrox saturation dive in people otherwise without symptoms. It is difficult to explain these instances of classical pain-only decompression sickness as a result of anything other than pre-existing bubbles aggravated by the pressure reduction. The half times that would be required to contain excessive gas in order to create new bubbles from dissolved gas would be far beyond any that can be justified by other types of experimentation and conventional decompression studies. For example, in the NOAA OPS experiment an analysis of half times up to 1280 min was performed, but it could not be demonstrated that any times beyond about 640 min played a role. Another illustration is the phenomenon of delayed treatment of decompression sickness or embolism. Patients with serious or even debilitating symptoms have been successfully treated by recompression therapy for times ranging from several days to two weeks after the initial embolism or pressure exposure. Again it is difficult to explain this by any other method than a persistent bubble. Various models show that bubbles can exist in body tissue well beyond their lifetime in pure water, for example

(Yount, Gillary, and Hoffman, 1984; Tikuisis, Ward, and Tucker, 1985), and they can redistribute (Gait, Miller, et al, 1975).

Bühlmann has recently reported experiments (1987) that show a higher incidence of minor DCS symptoms in the second and third repetitive dives calculated by means of gas loading and presumend to be of equal decompression risk or stress. That is, the excess gas in the first dive was calculated to be just as high as it was in the repetitive dives. This might tend to suggest that gas loading is not the reliable index. However, the excesses were in slower compartments in the later dives, which tends to equate them with longer, deeper dives, and these traditionally are not as reliable as shhorter dives.

We found another approach to the same question. Doppler ultrasonic studies were done at DCIEM on repetitive dives which were performed as part of the testing of their new tables. We were able to review a number of pairs of dives that were generally the same with the second dive calculated as repetitive, and in a non-statistical analysis our **impression** was that the repetitive dives showed fewer or certainly no more bubbles than the first dive in the sequence. Presuming the gas loading calculations treated both dives with the same ascent criteria, this provides some evidence that gas loading analysis is an adequate method for calculating repetitive dives.

A relevant study by Waligora and colleagues (1986) at NASA looked at low pressure exposures--simulated extravehicular activity--performed in the morning and again in the afternoon. The subjects were monitored with doppler bubble detection, and the results showed no difference in incidence of DCS symptoms, but significantly fewer bubbles in the afternoon EVA.

Thus, while the evidence is not strong that there are **fewer** bubbles in the second of an otherwise similar repetitive pair, it seem safe to say that there are usually not **more**.

A further analysis considered the various bubble models involved in decompression theory and led to an interesting conclusion. Different approaches to the use of bubbles in the computation of decompression tables consider bubble size, growth, or number as the important factor. Experimental results with these approaches do not reveal that any one is more correct than the other. However, the role of bubbles can be considered in a more general sense as bubble **activity**, and bubble activity can be shown to be proportional to gas tension. Therefore, regardless of the factors of bubble geometry, skin permeability, crevice formation, etc., etc., the important aspect about bubbles in a decompression computational model is that they act as an "effector" for the gas loading. This can be calculated in a straightforward way (Tikuisis P, DCIEM, personal communication, 1985).

The U.S. Navy method for repetitive dives uses gas loading in the 120 minute compartment, comparing that with the usual limit and adjusting the decompression time of the subsequent dive by a repetitive group classification. The repetitive tables provide, for each repetitive group, a **residual nitrogen time** which represents the theoretical amount of gas resulting from the first dive and affecting the second one. For each repetitive group a fixed number of minutes is added to the bottom time of the subsequent dive, as a function of the residual nitrogen at the time of the repetitive dive and the depth of the second dive; this residual gas is based on the first dive and the duration of the interdive or "surface" interval. In the event of a third or subsequent dive the repetitive group method still continues to work to call for more decompression on successive dives. This is a relatively straightforward approach, and since the choice of the 120 minute compartment is remarkably appropriate for the types of dive in question, the gas loading in that compartment is effective as the controlling gas for a wide variety of dives.

An alternative approach was taken by Nishi and colleagues in developing the DCIEM tables. Here the user again gets a repetitive group, but this time uses it as a multiplicative factor, so as to increase the theoretical bottom time of the second dive and thereby require the use of a more conservative table. The DCIEM procedures were worked out with gas loading techniques by essentially a "brute force" approach which involved multiple calculations of calculated first dive sequences and their effect on subsequent dives. By this tedious procedure Nishi was able to develop a consistent set of repetitive groups and multiplicative factors to use for finding the equivalent bottom time for the second dive. The tables that were developed by this technique have been tested and the results were considered satisfactory (Nishi and Lauchner, 1984). The DCIEM procedures are not limited to a particular compartment but rather consider all the constraints that would normally be used.

Several approaches to calculating repetitive dives have been tried by the Royal British Navy. Some just involve ascent algorithms such as the "combined" dive, which calls for adding the bottom times of the two dives at the deeper depth without regard to the interval. (Leitch, 1971; Leitch and Barnard, 1982). A variation on this by Hempleman adds fractions of the first dive as a function of interval duration. Although a different computational algorithm (diffusion in and out of a slab) is used, the Hempleman method is still one based on gas loadings (Hempleman, 1975).

Nashimoto has proposed a similar gas-loading algorithm for repetitive tables directed primarily at tunnel work, but we do not have results of its application (1970).

Thus we have considerable support for the use of gas loading analysis for the calculation of repetitive dives, and it does not seem necessary to involve bubbles in the model except to recognize their relation to gas loadings. That is, decompression from the second dive is determined on the basis of the gas picked up on that dive, plus the gas remaining in the body from previous dives in the repetitive sequence, and no allowance needs to be made for bubble nucleus formation or destruction. This argument is directed at the repetitive problem; Thalmann has made a good case that bubble (or gas phase) formation needs to be considered in all decompressions with his exponential-linear model (1983, 1984, 1985).

b. <u>Repetitive excursion calculations based on gas loading</u>

Given the choice of gas loading as the decisive factor in a repetitive dive, the next tasks were those of devising an algorithm for calculating repetitive dives and a means of putting them into tables for use.

One premise we began with is the concept that the worst possible repetitive dive is one just like the last one. That is, a dive to the same depth and for a similar bottom time will tend to load the same gas compartments and thus would have the greatest effect on the next dive. To check this premise we computed a number of multiple repetitive dive sequences having the same bottom times and excursion distances from the same storage depth, with the same habitat intervals. We noted that for such a sequence of repetitive dives, the bottom time allowed for a repetitive no-stop excursion seemed to stabilize after a few excursions at a value that did not change with subsequent excursions.

That is, it looked as if the first repetitive dive would normally have a shorter allowable no-stop bottom time than the dive before it in the series, but subsequent repetitive dives would allow the same or only a slightly shorter no-stop bottom time.

At first we thought we had a really simple algorithm, but after more trials we began to find excursions that took a number of sequential excursions tostabilize the time. From this we more or less arbitrarily chose 14 as the maximum number of dives in a repetitive sequence. Some rationale for this choice is that this is more dives than would be done without a break except under exceptional circumstance. In most cases the allowable no-d times stabilize long before 14 excursions, and we can be sure that if there is a change beyond 14 it will be by only a minute or two.

We then modified the DEC version of DCAP to print the results of 14 individual repetitive dives in a single table; the modification did not affect the computation, only the display. From these tables we determined three excursion times for each target excursion depth from each storage depth. The first of these was the time allowed for the fresh diver who has made no other previous excursions and is on the "first" excursion of the day. The "second" time is for divers who have made one previous excursion, and the "third-and-greater" (designated "3+") is the no-stop excursion time allowed after up to 14 excursions.

Next sequences were calculated with the same excursion depth and time, but by varying the habitat interval--the time elapsed since the end of the preceding excursion (this corresponds to the "surface interval" in ordinary diving). From these we concluded that the interval was a second factor--along with the number in the sequence--that had to be considered in the tables, and that most such repetitive excursions could be determined on the basis of the interdive habitat interval without regard for the type of dive that was done before. This was tested with a number of different combinations, and we found that it held up under widely different combinations of dives. The intervals we used ranged from 1/2 to 16 hours. A sample of the table printout used to test the 14 sequential excursions is given in Table III-3.

This sample shows another choice we made. In order to ensure that 16 hours was always enough time to start over with a "1st" excursion, we added a final 16-hr interval after the sequence of 14 and checked the excursion time. In a few cases this time was a few minutes shorter than the initial "1st" excursion. Physiologically the difference between 462 and 466 minutes is not meaningful in decompression terms, but to be strictly correct we used the time of this last excursion as the "1st" excursion time.

As a conservative factor the habitat PO_2 was assumed to be 0.19 atm and the "air" breathed by the divers on excursions was assumed to be 20% oxygen. The 5-fsw "adjustment made for the NOAA OPS tables was not used.

Table III-3. Sample printout of 14 excursions

Table shows two sequences of excursions to 145 and 150 fsw tried for storage depth 85-89 fsw. 14 were done for each interval, but only the 1st, 2nd, and 14th were used. The last column is after a 16-hr interval and the shortest of these (462) is used as the first excursion time. D55R00.H20, MF0805, 85Jul31.

```
Excursion depth 145 fsw:
Stor  1st 2nd 3rd 4th 5th 6th 7th 8th 9th 10t 11t 12t 13t 14t 16hr
intv  exc exc exc exc exc exc exc exc exc exc exc exc exc exc
-------------------------------------------------------------------
  30  466 135  74  65  65  65  65  65  65  65  65  65  65  65  463
  60  466 187 118 118 118 118 118 118 118 114  98  98  98  98  463
 120  466 253 202 202 202 202 202 185 181 181 181 181 181 181  463
 240  466 345 313 313 313 313 313 313 313 313 313 313 313 313  463
 480  466 439 432 431 431 431 431 431 431 431 431 431 431 431  462
 960  466 462 462 462 462 462 462 462 462 462 462 462 462 462  462
```

```
Excursion depth 150 fsw:
Stor  1st 2nd 3rd 4th 5th 6th 7th 8th 9th 10t 11t 12t 13t 14t 16hr
intv  exc exc exc exc exc exc exc exc exc exc exc exc exc exc
-------------------------------------------------------------------
  30  324  86  78  70  46  46  46  46  46  46  46  46  46  46  324
  60  324 136 119  85  85  85  85  85  85  85  85  85  80  73  324
 120  324 200 163 149 149 149 149 149 149 137 137 137 137 137  324
 240  324 265 246 238 238 238 238 238 238 238 238 238 238 238  324
 480  324 314 314 314 314 314 314 314 314 314 314 314 314 314  324
 960  324 324 324 324 324 324 324 324 324 324 324 324 324 324  324
```

Thus, in summary, the method is based on the presumption that the worst impact on a subsequent dive is by a dive of the same type, the same depth-time combination. The prominent effects on repetitive no-stop excursions are the **number a dive is in a sequence**, and the **interval between dives.** In a sequence of repetitive no-stop dives the allowable time tends to stabilize some time after the third dive. Therefore for each excursion distance from a given habitat depth we have a first excursion for the fresh diver who has made no other previous excursions, a second allowable time for the next (2nd) excursion, and a subsequent time (3+) at the point where the times have become stable and no longer change (taken to be 14 consecutive excursions). A second factor, the interdive "habitat" interval between excursions, was found to apply without regard to the type of dive that went before, only to the duration of the interval.

Sets of excursion times covering the desired excursion depths from the desired storage depths and the various intervals (Fig. III-3) were calculated and the appropriate times were selected for the tables. Table samples are given in Appendix C.

One change from NOAA OPS is that Repex no-stop excursions are timed from the beginning of descent to the beginning of ascent, rather than requiring the diver to be back at the habitat by the end of the time.

How these were displayed as useable tables is given in the next chapter (section IV.C), and the "efficiency" of this algorithm compared with repetitive sequences calculated specifically is discussed there as well.

3. "One-stop" excursions for more bottom time

Even with the ability to do repetitive excursions, the time allowed with no-stop techniques is often not adequate to do the required work. A diver can spend a longer time at the work site if he or she can make appropriate decompression stops on the way back to the habitat. Given the calculation setup described above it is a relatively simple and straightforward task to calculate tables with stops for excursions from a given storage depth. But when all the available storage depths, bottom depths, and bottom times are considered it becomes a formidable task to calculate them, and an almost insurmountable one to display them. Further, numerous stops in the water might be difficult to manage operationally. We therefore looked at a relatively simple dive pattern with decompression stops at a single stop depth. Our approach was to try for a single decompression stop, and to supply tables that would give the most possible bottom time with that constraint.

Experimental work at the US Naval Experimental Diving Unit has shown that in at least one type of conventional diving it is acceptable to take the 10-fsw stop at 20 fsw (Thalmann, 1985). This seems entirely reasonable for return to the habitat as well, so we planned the one-stop excursions to use a stop between 10 and 20 fsw deeper than the habitat, with stops calculated for the desired distance of 15 fsw deeper. This could be implemented by having a "way station" at a depth 10 to 20 fsw deeper than the habitat as a stop station for all excursions that need stops. This would give the divers a definite stop depth, some protection from cold and current, easier communications, extra gas, and perhaps other advantages.

We first prepared a set of conventional excursion tables with staged decompression back to the storage depth, to get an idea of what the normal decompression using our standard model and matrix would be, and also to see which bottom times could be accessed with no more than an arbitrary one hour of decompression time. It appeared from available past experience that this would produce bottom times well in excess of most typical requirements.

We then prepared DCAP Base Cases that would hold the diver at a stop depth 15 feet deeper than the storage depth until all compartments had cleared the matrix values for 10 feet deeper than the habitat. [To do this with DCAP we positioned the diver at the 15 foot stop level with a "stage step" of 15 fsw, and held him there until the M values for the 10 foot stop were cleared; this was done by reducing the matrix values by 5 fsw multiplied by the slope for that compartment.]

We chose a specific set of bottom times ranging between 30 and 240 min, then calculated the stop times at the "one-stop" bottom depth and selected only those excursions with required stop times of less than about **one hour**. These were repeated 5 times (like we did 14 times with the no-stops) and followed by a 16-hr interval and another run. This last value was the one used as the 1st excursion, and the 5th one in the run was the time for the 2-16 hr interval. We tried this after a run of 14 no-stops and learned that to be clear in all cases we had to wait some additional time, hence the rule that a one-stop has to follow another by at least 2 hr.

In this process we noted that a number of additional excursions would be possible within these limitations if we could stop for one or two minutes at a stop depth 10 fsw deeper than the "one-stop" depth. Reasoning that an extra 2-minute stop at that point would be operationally easy and beneficial even if not needed, we added the requirement that **all** one-stop dives have a 2-minute stop 10 fsw deeper than the main stop depth. This causes a bit of momentary confusion with terminology (the "one-stop" excursions all have two stops), but is physiologically sound and gives a greatly increased operational capability to the overall set of procedures. Still another advantage is that these procedures can be presented in a relatively simple format.

Only two intervals are allowed, between 2 and 16 hours, and over 16 hours; thus at least 2 hours must elapse before a one-stop excursion. The rule that no more than 4 one-stop dives can be done without a 16-hour break is based on the number of repeats done for each determination (actually 5). In counting the maximum number of dives in a sequence we felt the one-stop excursion could be considered to equal 3 normal no-stop excursions, this is in keeping with the general stress level and the number of runs involved. Arbitrarily each one-stop is considered as a "3+" excursion in determining the sequence; the latter point means that if a one-stop dive is the first one of the day then the second one has to come from the 3+ table. Also, we did not feel the submaximal procedure would be needed with the one-stops since the decompression time is shorter if bottom time is short. Again we say that if finer tuning than this is needed one should use an on-site computer.

4. Adjusting for sub-maximal repetitive excursions

The set of repetitive excursion tables greatly increases the capability of divers working in the nitrox saturation-excursion diving situation. In some cases however, the reduction of allowable time for the second and third dive in a repetitive sequence is significant. While this penalty is quite acceptable when the diver has in fact performed the preceding dive in the sequence, it might seem quite burdensome if the preceding dive used only a small fraction of the time that would otherwise be allowed. In other words, the second excursion in a series could be penalized just as much from a 5 minute as from a 1 hour first excursion, because there is no finer breakdown. Accordingly, we have developed a protocol for adjusting a given excursion for an excursion before it that has used less than the allowable time.

Intuitively one would think that the proportion of allowable time actually used would reduce the allowable time for the following dive in the same proportion of the time that would otherwise be allowed. This is exactly what happens, and although the calculation involves a certain amount of complexity, it is straightforward, linear, and applies throughout the entire range of one-stop excursions.

To facilitate the description of this process we had to select some terms. Three excursions are involved, the **submaximal** excursion, the one **preceding** it, and the one following the submaximal, which we call by the awkward term **post-submaximal**. In order to calculate the time allowed for the post-submaximal dive it is first necessary to figure the **fraction** of time actually used in the submaximal excursion, then figure the extremes possible for the post-submaximal, and use the fraction to determine the allowable time. The extremes mentionedare the times that would be allowed first if the submaximal dive had not taken place at all, then if it had been used to its full allowed time. To make this adjustment the possible excursions have to be looked up in the tables and the calculations performed using the appropriate allowable times. The method is described in detail in the Repex Procedures, and a worksheet is provided in an attempt to facilitate calculations.

We tested this algorithm with calculated excursions for a variety of conditions. The formula does not always get the same answer as a dive calculated directly with DCAP, but it is generally close and so far has been uniformly more conservative. If there is a problem it is in being able to get everything right when making the calculation; this is not easy, and we have demonstrated this by making a couple of such errors in the Repex dives. We strongly recommend that if situations require many of these calculations to be made that a direct computation be used instead.

5. Necessary limits

This section covers some additional items associated with the repetitive algorithm. These include determining the time period to allow a diver to start a new repetitive sequence, the maximum excursion time each day, and the maximum number of dives in a sequence. There is also a strict limit on diving deeper than 200 fsw that is based on CNS oxygen toxicity.

a. The "get-well" interval

According to the US Navy Diving Manual a repetitive dive is a second or subsequent dive during a 12 hour period. The USN procedures assume that after 12 hours a diver is "fresh" again and makes the same decompression that he would on the initial dive. Most other repetitive tables make about the same assumptions. The new Canadian Tables use a "get well" period of 18 hours.

For operational reasons we felt it would be desirable if the start-over time could be 16 hours or less. This would allow a full daily 8-hour work shift with the divers starting out fresh each day.

We tried all the depth-time combinations, and found that for most of the repetitive sequences involved a 16 hour period is sufficient for a diver to begin counting a new sequence of repetitive dives; the 160 min compartment is the longest one that is involved in the no-stop tables. To deal with the few cases where a dive calculated to follow a 16 hour habitat period was a few minutes shorter than one in which there was no previous gas loading, we calculated these tables after a sequence of dives and a 16-hr hold, and included the **shorter** time in the table as the allowable time for the first dive. This made the 16-hr interval proper in all cases (Fig. III-2).

b.e Limits on diving activitye

Two diving activity constraints are imposed on divers using these tables. First, the maximum time a diver is allowed to stay in the water in the "decompression range" in any 24 hour period is 12 hours. The decompression range is any depth enough deeper than the habitat to incur a decompression obligation; details of this are discussed in the next chapter under "oxygen window." The 12 hr limit is a reasonable rule for diver endurance alone, but we require it because we felt that although the tables were conservative enough for the areas where the various computations had been checked, it might still be possible for a diver to get in decompression trouble in areas beyond those we considered.

The other constraint is that no more than 14 excursions may be performed in a sequence without the diver stopping for at least 16 hr to start a new sequence.

c.e Maximum excursion timee

Where the allowable time is greater than 480 min, we consider it as 480 min or 8 hr. This is primarily an endurance limit, but should be somewhat longer than needed for most scientific missions. This was done to limit the scope of the tables to values that would be practical, but it also serves as a further general check like the 12-hr inwater limit to cover situations not covered by the algorithm.

d.e Dives deeper than 200 fswe

There is an additional non-decompression limit. In order to provide short excursion capability beyond 200 fsw but not to deal with the complex issue of narcosis tolerance, we elected to use neurological (CNS) oxygen toxicity as the limiting criterion. This results in fixed limits not dependent on storage depth or decompression status of 29 min at 220 fsw and 16 min at 240 fsw. More about how these were determined and used is in section IV.D.

e. Interval timing

While it may not be a limit as such, we should mention the philosophy for timing excursions and intervals. Strictly speaking the interval should start when a diver has returned to the habitat, and this is the recommended way to do it. However, mission planning can be done more precisely if the ascent can come out of the next interval. We elected to do it this way. For one-stop excursions this is not possible because of the stops. This is discussed further in Chapter VI.

f. Ascending excursion limits

Two limits pertain to ascending excursions. The time after an ascending excursion before another one can be done is 4 hr, and the period after a descending and before an ascending excursion is 24 hr. These are discussed in IV.A.

C. Calculating the saturation decompression tables

R.E. Peterson and R.W. Hamilton

The saturation procedures were developed as a separate task using a computational approach that was somewhat different from the DCAP-oriented methods used for the main tables.

1. Method of calculation

a. Problems with past efforts

The saturation decompression procedures for Repex had to cover a wide range of storage depths. There is a substantial body of nitrox/air saturation decompression experience from operations at shallow depths (see for example Miller, Adams, et al, 1976; Eckenhoff and Vann, 1985), but there is only limited published experience in the deeper range. Further, much of the available very deep experience (>150 fsw) reflects unsuccessful saturation decompression (Barry, Vann, et al, 1984; Muren, Adolfson, et al, 1984); many of these decompressions had such a high incidence of DCS that they are of limited value in preparing a reliable table. This experience with the deep exposures is in keeping with the principle that decompression calculation parameters which are acceptable in some time-depth domains do not produce satisfactory results when the depth (and time, when not saturation) is significantly increased. This is also true in the case of bounce dives, when the time or depth of exposure is increased (Peterson, and Greene, 1976; Peterson, Greene, and Lambertsen, 1978; Hamilton, Kenyon, and Peterson, 1980). Thus an approach had to be found that could be used to calculate reliable schedules for very deep saturation based on experience from shallower depths (since that is where the experience is), but without spoiling the efficiency of new schedules for the shallower storage depth range.

b. Two ascent constraint factors

The approach selected was to use two factors as ascent constraints, an excess nitrogen partial pressure limit (traditional M values), and also a new factor, the nitrogen **delta-P:time integral**. This approach has been employed with satisfactory results to extrapolate from no-stop ascents in one depth domain to ascents requiring decompression stops in a deeper depth domain (Peterson and Greene, 1976; Peterson, Greene, and Lambertsen, 1978). Additionally, the nature of this method is such that decompression schedules from shallower depths will naturally be more efficient than from deeper ones.

The delta-P:time integral, also called the "t:delta-P" integral, is a value equivalent to the area under the curve of excess gas loading or "supersaturation" (sum of inert gases > ambient pressure) plotted against time. This is calculated iteratively over the time of a saturation decompression, so it is larger for longer decompressions.

c. Using empirical data

Two saturation decompression procedures with reliable track records were used to establish ascent constraints for the decompression calculations. One was the Hydro-Lab schedule for storage at a depth of 42 fsw employed extensively in scientific diving operations (Miller, Adams, et al, 1976). The other schedule (Table III-4) was one which has been used for final saturation ascents from depths to 115 fsw following a number of commercial construction and equipment testing operations. A selection of some of the available experience obtained with this schedule and variants of it is given in Table III-5.

Table III-4. Commercial table

Commercial schedule used as basis for computation of nitrox saturation decompression procedures. Breathing gas is air.

Depth (fsw)	Ascent Rate (min/fsw)
165-135	6
135-105	9
105- 75	12
75- 60	18
60- 45	36
45- 35	40
35- 25	44
25- 15	48
15- 5	50
5- 0	56

d. Table computation

For both base schedules, the maximum excess nitrogen pressure and the delta-P:time integral were computed for a series of half-time compartments using ordinary exponential, perfusion-limited inert gas uptake and elimination calculation methods (Workman, 1965). The greater value of each parameter for each compartment was selected to form the set of decompression ascent constraints. These are given in Table III-6. The longest half-time, 1205 minutes, was selected on the basis of a previous analysis of half-times in nitrox saturation decompression procedures (Peterson, Rosowski, and Lambertsen, 1973). Three slow half-times in relatively close proximity, 640, 670 and 720 minutes, were selected because each has been used for the slowest compartment in other air/nitrox decompression computations. The faster half-times are typical of standard perfusion-limited, exponential nitrogen uptake and elimination computations.

In practice, the ascent constraints for the slower compartments came from the longer, deeper schedule while the ascent constraints for the faster compartments came from the shallower Hydro-Lab schedule. This relationship was maintained in the table calculations described here where, although saturation schedules were being derived, the faster compartments had some influence on the formulation of the shallower tables.

Table III-5. Saturation experience

Shows samples of the dives used for developing the saturation criteria. The dives are problem-free unless otherwise noted. I and II refer to different versions of the "commercial" table.

Year	Storage dpth fsw	PO2 atm	Number divers	Excsn range fsw	Dive days	Comments
1979	45	air	10	65-79	6	At sea, (I)
1979	98-121	0.3-0.4	6	98-197	12	Chamber, some pulmonary O_2 toxicity, (I)
1979	98	0.3-0.4	3	164	5	Chamber, (I)
1979	98	0.3-0.4	4	164	5	Chamber, some pulmonary O_2 toxicity, (I)
1979	98	0.3-0.4	4	164	7	Chamber
1980	98-121	0.3-0.4	6	98-197	12	Chamber, (II)
1981	115	0.35-0.4	6	149	12	At sea, (II)
1982	70	0.35	6	96	24	At sea, (II)
1983	100	0.35-0.36	6	120-123	21	At sea, (II)
1983	105	0.36	6	135-140	10	At sea, (II)
1984	110	0.35	8	135	25	At sea, (II)

To compute the decompression schedules, we calculated stop times for holds at 5 fsw intervals starting at the depth 5 fsw shallower than the storage depth. The length of the stops was determined by the inspired oxygen pressure (PO_2) and the value of a constant K, which relates ascent rate and PO_2 (Vann, 1984; Eckenhoff and Vann, 1985):

$$\text{Ascent rate, fsw/hr} = K * PO_2$$

$$\text{or,} \quad \text{Ascent rrate, min/fsw} = (60/PO_2) / K$$

where PO_2 is the inspired value and "rrate" is the inverse rate. A "small" value of K was assumed at the beginning--so that some ascent constraint would be exceeded--and the stops were calculated. Next the maximum delta-P for each half-time compartment and the total delta-P:time integral for the decompression were also computed. If any ascent constraint was exceeded, the value of K was reduced and the process repeated until the fastest schedule satisfying all constraints was arrived at. We wrote a BASIC program to perform these iterations.

Table III-6. Saturation constraints

Compartment half-times and ascent constraints used for saturation decompression computations.

Half time (min)	M value delta-P (fsw)	Maximum delta-P:time (fsw-min)*
5	0.99	0.48
10	0.99	0.96
20	0.99	.88
40	1.35	4.11
80	1.81	14.39
120	1.97	25.32
160	2.05	37.02
200	2.10	83.81
240	4.24	487.38
320	9.55	3508.46
480	16.98	20131.56
640	22.19	41172.85
670	22.97	45090.67
720	24.15	51587.03
960	28.49	82348.32
1205	32.63	113319.14

* These are meaningful to only 3 or possibly 4 significant figures, but more are retained because they are available.

An important difference between this method and those previously used is that different overall ascent rates are calculated for each starting depth.

Other considerations in the calculations of the saturation decompression schedules were the management of oxygen during the decompression, and allowing for the excursion history prior to the start of saturation decompression.

e. Extra conservatism

In order to provide extra reliability for field applications and to deal with diver-scientists who might be older than the young and relatively fit individuals who were divers on the base schedules, we considered it prudent to introduce some conservatism into the decompression schedule computations. In keeping with the successful NOAA OPS excursion computations which have a 5 fsw buffer, an extra nitrogen load was introduced by making the storage PN_2 5 fsw greater than that of the depth for which the computation was being done.

f. Oxygen exposure

An independent but related approach to oxygen toxicity management was taken for the saturation tables. To minimize saturation decompression times and facilitate gas composition logistics, we use air as the decompression gas whenever possible. This approach is limited by exposure to the oxygen in air during the decompression, but is also affected by air excursions prior to the saturation decompression. Although a method for managing the overall oxygen exposure is part of the Repex Procedures, these saturation tables nevertheless are designed to limit the exposure to a tolerable level.

Experience from comparable nitrox saturation-excursion operations gave us some indication of acceptable oxygen doses. Following air excursions to 195 fsw from storage at 115 fsw, six divers undergoing an air saturation decompression employing oxygen breathing were exposed to a cumulative pulmonary toxicity dose (CPTD) of 1420 units in about 41 hours. Four of these men experienced typical, distinct symptoms of pulmonary oxygen poisoning which were generally resolved over the first week postdive. Following air excursions to 165 fsw from storage at 100 fsw, two of eleven divers who underwent saturation decompression on the schedule mentioned above noted severe dyspnea upon heavy exercise after reaching surface. These symptoms occurred after exposure during saturation decompression to a CPTD of 1180 units over a period of about 38 hours, and disappeared over the first 72 hours post-decompression. Because the other nine divers did not engage in as strenuous exercise as the two who reported symptoms, it was not possible to determine whether or not more of the men were affected in a similar way. Following air excursions to 195 fsw from storage at 115 fsw, six divers experienced no symptoms of pulmonary oxygen poisoning after undergoing an air saturation decompression which exposed them to a CPTD of 920 units over 27 hours.

Based on the above and other experience in which saturation decompression CPTD's of less than 920 units have not produced pulmonary distress even though the decompressions were preceded by long, relatively deep air excursions, we felt it was reasonable to allow a CPTD of approximately 850 units for decompressions such as those which have been computed. Thus, whenever the oxygen dose of a schedule computed with air as the breathing gas significantly exceeded this amount, the breathing gas format was changed and the decompression recalculated. The change was to insert periods of 0.5 PO_2 (which is below the CPTD threshold) in decompressions from starting depths 105 fsw and deeper. The method used for reducing the exposure is a period of 4 stops--about 12 hr--early in the decompression (after 2 stops) during which the gas mixture is switched from air to a PO_2 of 0.5 atm. The rates for those 4 stops were recalculated using the same K. As an additional "J-factor," after the "0.5 break" the ascent rate is held constant until it becomes time to change to a lower rate.

The data above are consistent with the Repex oxygen algorithm. The 1420-unit exposure is clearly above the recommended dose line in Figure IV-1 and therefore does not conflict with the criteria of the Procedures as given in Chapter VII of that report. The 1180 and 920 doses are on or slightly below the line; if these had been fresh divers without a previous exposure then symptoms from the 1180-unit exposure over 38 hr would be an argument that the line is perhaps too generous, and the 920-unit exposure would support it. However, these divers had been making daily excursions with air that had no doubt set them up with an unknown but possibly significant exposure. Unfortunately we do not have the details of those exposures.

This method of oxygen toxicity management during saturation decompression--limiting a saturation decompression to no more than 850 units--is consistent with the limits given in the Procedures, but it uses a different method of achieving them and is for the most part more conservative. This is because the saturation decompression is set not to exceed a fixed oxygen exposure but it may be over widely different times. The history of the diver up to the point where the saturation decompression begins is not known for sure, so it is better to be a bit conservative. It would be acceptable on dives calculated in custom form all the way through to manage oxygen exposure during saturation decompression as part of the overall oxygen management algorithm, and in fact this was intended in its design.

We assume that the mission planning takes the predicted exposure during the saturation decompression into account when choosing the average daily oxygen dose. Perhaps we should develop an algorithm that would permit the saturation decompression to be optimized by adjusting the ascent rates according to the oxygen status of the divers as they begin saturation decompression. This could be done, since the K value determining the slope (ascent rate) is known. We advise caution in using a K for ascent rate determinations that involve a lower oxygen level than the typical ones used in determining the K in the first place; these are not as reliable as those with a higher oxygen.

We considered but did not implement an alternative oxygen-limiting gas format that used a fixed PO_2 of 0.6 atm to 60 fsw and air from that depth to the surface.

g. Accounting for the effect of excursions

In the commercial schedule given in Table III-4, a significant descending excursion history (i.e., recent excursion PN_2 exceeded maximum storage PN_2) was managed by starting the saturation decompression immediately after the final excursion at a "starting depth" dependent on the excursion depth but deeper than storage. Thus, the starting depth for saturation decompression after recent excursions will normally be deeper than the storage depth. Although this procedure has proven effective and efficient in commercial and laboratory operations dealing with long, deep excursions prior to saturation ascent, compression to greater than the storage pressure was regarded by NOAA as undesirable for use with seabed habitats.

Accordingly, we tried another approach which has the practical advantage of not requiring compression to pressures greater than the storage depth. This was the common practice of requiring a holding period at the storage depth following the last significant descending excursion and prior to starting the saturation decompression. Unfortunately, little quantitative and no generally applicable data are available upon which to determine the duration of an optimal holding period. In order to retain operational efficiency in the derived procedures, the calculations were done by first computing the worst-case excursion situation as it affects nitrogen loading in the slowest compartments, then recomputing the decompression schedule by the method described following that worst-case sequence of excursions and a holding period of **six hours** at the storage depth after the last excursion. In use during Repex I, however, we doubled the required hold at the storage depth following the last significant excursion to **twelve hours**. This was an attempt to compensate for reduced inert gas elimination should any phase separation occur as a result of an excursion ascent.

This resulted in two sets of saturation decompression tables, one for divers who have been making excursions, the other for those that have not. The K values and resulting ascent times are shown in Table III-7.

2. Results of Repex I and subsequent modifications

In the first trial in Repex I the decompression from storage at 50 fsw resulted in pain-only decompression sickness in one diver on ascent to 5 fsw from 10 fsw (see section VII-C). Although this represents a meager single data point, we felt we had to adjust the saturation tables; two options seemed reasonable.

a. Using a 12-hour hold before decompression

We considered the Repex I hit to be the result of failure of the procedure to deal adequately with bubble formation by the descending excursions. In addressing this problem, extension of the 12-hour holding period was felt to be an inferior solution because, first, there was still no firm basis for selection of the optimal time, and because a significant increase in the holding period would greatly reduce operational efficiency, and because even a relatively large increase in the holding period would give little assurance of success.

b. Using recompression after the last excursion

Thus the best option was to base the starting depth of the saturation decompression on the recent excursion history. Despite the increased operational complexity of compression to depths greater than the storage depth, safety and overall operational efficiency considerations made this approach the most attractive solution.

This method was to begin the saturation decompression at a "starting depth" at or just greater than the PN_2 of the worst-case air excursion depth. The starting depth was determined by a complex iteration process involving all of the significant no-stop excursions from each storage depth, until the "worst case" gas loading for those excursions from that storage depth was determined. A BASIC program ground these things out in many multi-hour runs. These starting depths are displayed in the Procedures with each saturation table. (These calculations had been made before the Repex I hit; they were also used to get the starting rates for the "with excursions" ascent.)

Table III-7. Saturation calculation constants

The K values were calculated using M values and a t:delta-p integral from previous successful tables; those "with" excursions considered worse case effects. Ascent rate, which determines the time for a decompression, is a product of K and PO_2. Storage depths are for the deeper end of a range, such that the values for 80 fsw are given for the storage depth range 75-79 fsw. Only the "with excursions" values were used. Not shown are the slower rates for the last 4 entries (105-120) due to the PO_2 of 0.5.

	Without excursions		With excursions	
Storage depth (fsw)	K	Total time (min)	K	Total time (min)
35	5.9414	95	4.9647	1180
40	5.7851	1145	4.9646	1325
45	5.6536	1275	4.8476	1485
50	5.6267	1400	4.7935	1645
55	5.5605	1520	4.6889	1800
60	5.3954	1670	4.6565	1935
65	5.2574	1810	4.6066	2065
70	5.1739	1940	4.5887	2175
75	5.0931	2060	4.5798	2290
80	5.0015	2180	4.4131	2465
85	4.9517	2295	4.2351	2665
90	4.6935	2495	4.1716	2820
95	4.5207	2690	4.0448	3000
100	4.3282	2895	3.8804	3215
105	4.1679	3105	3.5166	3645
110	3.9784	3325	3.1779	4460
115	3.7664	3920	2.9420	4960
120	3.3820	4505	2.7737	5440
125	3.0816	5100		
130	2.8248	5750		
135	2.6761	6255		
140	2.5308	6800		
145	2.4213	7335		
150	2.3112	7910		

For the decompression back to storage from the starting depth we converted the ascent rates from the original commercial table into the same format based on the K value and current PO_2. This was termed the "precursory" table.

Interestingly, this approach for storage depths deeper than 55 fsw requires less time than the 12-hour hold.

There is no firm basis for the period of 36 hours during which an excursion has to be accounted for; this is a judgement call that seems conservative enough yet operationally tolerable.

This plan was used in two subsequent Repex trials from storage at 80 fsw and 110 fsw. In each case the decompression stops deeper than the storage depth (the "precursory" table) were taken from the commercial schedule given in Table III-4 with air as the breathing gas. Results from these two dives support the concept that such saturation decompressions with an initial recompression produce safe ascents.

3. Final tables with precursory starting depth

Prior to Repex I we had planned to present two sets of tables, with and without excursions. With the decision to start decompression at a deeper starting depth we settled on one single profile, with or without the precursory table as the situation dictates. This requirement applies only to excursions during the 36 hours preceding the start of decompression, which gives a little break to the habitat sitting on a flat seabed where descending excursions are not possible. The 36 hours is arbitrary.

The last stop on the precursory table is calculated from the K used for the main table.

IV.
OTHER PROCEDURES, TABLE DISPLAY, TREATMENT, AND EFFICIENCY

This chapter gathers together the various other aspects of the Repex tables, including ascending excursions, the "oxygen window," means of controlling oxygen toxicity, surfacing procedures, and the development of the treatment procedures. A description and rationale for the display of the tables is given, and an assessment of the "efficiency" of the tables.

A. Ascending excursions

The NOAA OPS program included the development of ascending excursions. These have been used in the field, probably more than the descending excursions. Some reports of vague "awarenesses" of what are probably circulating bubbles were noted originally in the lab and have been reported in some field operations, but generally these procedures have been used without problems.

In another series of experiments designed to determine the amount of time a sailor saturated with air in a distressed submarine might have to make a transfer to a surface chamber, Eckenhoff and Parker (1982; 1984) have performed a number of excursions similar to those of NOAA OPS, but with considerably more decompression stress. He found an incidence of DCS on these excursions of 1 to 10%, which tends to validate the reliability and efficiency of the original NOAA OPS data.

The Contract did not call for any new work on ascending excursions, but in order to make the Repex package as complete as possible the original NOAA OPS ascending excursion values have been included. A new display format has been developed (section IV.C, below).

There are some limits to ascending excursions. The Procedures call for an interval of at least 24 hours following a descending excursion before an ascending excursion can be made, and a period of 4 hours after an ascending excursion before making another one.

These times are somewhat arbitrary, in that we do not have a method for making a precise calculation for this information. The 24 hours is intended to be enough time to allow gas loadings to return to "normal", but to be substantially longer than the period for being able to start with a fresh descending excursion; it is probably not long enough to clear out all bubble nuclei. Making the period a full 24 hours tends to discourage having these two dive types this close together. Any uncertainty here is helped by the fact that an ascending excursion ends with a return to the habitat, and the diver can return early if there are hints that symptoms are developing.

The 4 hr period between ascending excursions is there because an ascending excursion, although it is a decompression and tends to lower the inert gas load, may generate bubble nuclei. Eckenhoff and Parker heard doppler bubbles up to 40 min after an ascending excursion in a diver recompressed 10 fsw deeper than storage (1982); we felt this called for a period significantly longer and chose 4 hr.

B. The oxygen window

A relatively low PO_2 of 0.3 to 0.35 atm is recommended as the gas filling the habitat in situations where pulmonary oxygen toxicity is an issue (see section IV.D). Because air has a higher fraction of oxygen (hence a lower fraction of nitrogen) than the habitat gas, a diver living in this "near-normoxic" mixture and excursing on air may have quite a useful vertical range without adding to his gas loading, and thus without having to be concerned about the effect of the excursion on subsequent decompressions.

This extra range is referred to, after Behnke, as the "oxygen window." It is calculated by converting the PN_2 of air to an absolute depth, and allowing the diver to descend to that depth without restriction. For convenience the range of the oxygen window is displayed with the tables. This ranges from +4 fsw (deeper than the habitat) at 30 fsw to +27 fsw at 115-120 fsw storage.

For shallow air-filled habitats the oxygen window limits are to the same depths as given in the Procedures for a near normoxic habitat at the same storage depth.

The oxygen window does not apply to ascents shallower than the habitat.

C. Method of display

Decompression tables traditionally have included the schedules or profiles from a range of depths on a single page or "table." However, a habitat diving operation is necessarily committed at any one time to a single habitat depth. This affords an opportunity to prepare a more efficient display of the tables by putting all items relevant to each storage depth together. This is what we did; each storage depth covers two pages and includes the various tables used from that storage depth plus some additional information on management of the breathing gases. Sample pages for the 50-54, 80-84, and 110-114 fsw range of storage depths are included in Appendix C.

1. Oxygen management

This section includes unit conversions, recommended oxygen levels in the habitat atmosphere, and oxygen toxicity dosages.

a. Units

The units use the common definitions of 1 fsw (foot of sea water) = 1/33 standard atmosphere or 3.0705 kilopascals, and 1 msw (metre of sea water) = 1/10 bar or 10 kPa. This makes the conversion between fsw and msw slightly different from the equivalent conversions of linear units; 1 msw = 3.2568 fsw whereas 1 metre = 3.2808 feet.

b. Oxygen levels

The recommended oxygen levels for the habitat are slightly lower than might be used under other circumstances. Since long excursions on air are possible at depths deep enough to be a concern with respect to oxygen toxicity, we recommend keeping the oxygen low in the habitat. Operationally the oxygen should be as high as can easily be tolerated in order to minimize the hazard of possible hypoxia situations, but in this case it should be as low as possible to avoid both chronic and CNS oxygen toxicity. A compromise is the habitat PO_2 of 0.3 to 0.35 given here.

As is discussed in section IV.D below, habitat diving requires a constant surveillance of the oxygen exposure. To facilitate this when excursing on air in the oxygen window range, typical PO_2's and CPTU values for this range are given.

2. Ascending excursions

Here the depths that can be accessed from this storage depth range are given in a small chart (thus avoiding the problem of choosing the correct depth for intermediate storage depths). For the absolute target depths in the accessible ranges the allowable times are given.

We considered also displaying a differential depth ("distance") for the ascending excursions. While this might be useful information, we could not find a way to include it without creating a real possibility for confusion; the absolute and the relative values fall in the same range.

3. Oxygen window excursion range

The oxygen window excursion range is given as a differential depth. Here a differential had to be used because the oxygen window is based on the actual habitat depth, not the depth range. As much as 5 fsw of window would be lost in some cases if we used only the range.

4. No-stop excursions

The no-stop repetitive excursion tables have to present an allowable excursion time for each useable target depth (range), and these have to take into account both the number of the excursion in its sequence, and the interval between it and the end of the last excursion. These are in two tables, because one would not fit the page, with the target depths across the top. Below that are three sections for each of the sequence situations--1st, 2nd, and 3+--and within each of these is a set of intervals. For many of the tables the full time of 480 minutes is allowed; rather than fill in all these numbers the whole zone is labelled "all 480."

At the upper right is the date the table was done and the DCAP Base Case filename. This is part of the "audit trail" for the origin of the tables.

5. One-stop excursions

Unfortunately it was necessary to devise yet another type of display for the "one-stop" tables. These involve two intervals, a set of target excursion depths, and several bottom times and stop times for each of the depths. Using a separate table for each interval (2 to 16 hr, or over 16 hr), the stop time is given opposite the bottom time to which it applies; stops are to be made 10 to 20 fsw deeper than the habitat, preferably 15 fsw. Only those excursion times are included that can be reached with a decompression time no greater than about one hour. Of course all these require a 2-minute preliminary stop 10 fsw deeper.

6. Saturation decompression

The saturation tables for each storage depth include a small chart for selecting the precursory starting depth, a precursory table for travel from the starting depth to the storage depth, and a main saturation decompression table for ascent from there to the surface. A small table of summary information is also included. The K value used for calculating the main table is shown with it.

The matter of grouping all information that applies to a given storage depth range on a single pair of pages has created one problem with regard to optimal saturation decompression. A given set covers a 5-fsw range, say from 80 to 84 fsw. This range contains the descending excursion tables for 80 fsw, which is the "worst case" or most conservative table to use for that range. That is, storage at say 83 fsw would be closer to the deeper worksite than storage at 80 fsw, hence would be more conservative. The reverse is true, however, for ascending excursions and saturation decompression; these should use the deeper end of the range. The ascending excursion tables have been adjusted to be appropriate for the storage depth. For saturation, if storage is exactly at an even multiple of 5 fsw, say at 80 fsw, the saturation decompression for the next shallower range can be used, in this example 75 to 79 fsw. This is because the appropriate table for the 75-79 fsw range is the 80 fsw table, and that table is the one included for the 75-79 fsw range. If a storage depth is right on the line, the adjacent shallower table can be used.

E. Controlling oxygen toxicity

1. Defining the oxygen problem

A corollary problem with decompression in air excursion diving is oxygen toxicity. Excursions are made with the diver breathing air to depths and for durations far greater than are possible in air diving from the surface in the usual way. As a result divers can be exposed to levels of oxygen that can be toxic, to the central nervous system specifically, and to other body systems.

CNS oxygen toxicity may be summarized briefly. Humans may have epileptic-type convulsions when exposed to high doses of oxygen partial pressure after a few to many minutes of exposure. The levels necessary to cause CNS O_2 toxicity depend on the duration of exposure; or, conversely, the necessary time for a convulsion is a function of the exposure level. Generally doses over of 1.8 or higher PO_2 may, especially with exercise or an accumulation of CO_2, lead to a convulsion after a number of minutes. Exposures to higher PO_2's may cause convulsions even sooner.

Chronic oxygen toxicity has different manifestations, and generally is caused by longer exposures to higher doses of oxygen. A subset of this is **pulmonary oxygen toxicity**; this is the term generally used in referring to chronic oxygen toxicity, and is the primary symptom in the broader syndrome. Exposures to PO_2's of more than 0.5 atm for one to several days may invoke these symptoms.

This can be dealt with in several ways, mainly by limiting the exposure, but to do this properly and still efficiently requires a good understanding of the effective limits.

2. The dilemma posed by current rules

One set of limits for oxygen exposure dominates all others at this time. This is the set of limits in the U.S. Navy Diving Manual (1981). The same values appear twice in the manual, as Figure 9-20, p. 9-18, and as Table 14-1, p. 14-2, and they have been in several previous editions. Two levels of limit are given, for normal use and for "exceptional exposures." The normal limits start with 30 min at 1.6 atm PO_2, and carry on to 240 min at 1.0 atm. The exceptional exposure limits are more generous, allowing 30 min at 2.0 atm and 240 min at 1.3 atm.

The normal limits present a dilemma. An argument can be made for 30 min at 1.6 atm as a conservative limit, but at PO_2's below this level cases of CNS toxicity are extremely rare (Vann, 1985; Butler and Thalmann, 1986; Young, 1971; Lambertsen, 1965; Shilling, Werts, and Schandelmeier, 1976). The limits in the USN chart extend well into the range where chronic oxygen toxicity is the problem rather than CNS, and the limits are not in keeping with experience--they are much too conservative.

There are other problems with the USN limits. One is that in the same manual another chart, Table 14-1, sets much less restrictive limits for underwater swimmers breathing pure oxygen. Another difficulty is that there is no algorithm for dealing with an exposure to more than one PO_2 level sequentially, nor is there a method given for determining recovery status. The second edition of the NOAA Diving Manual has applied the USN limits to the NOAA OPS excursion tables, but with uncertain directions on how to use them.

Despite these problems the USN limits provide a sound basis for the management of CNS oxygen toxicity in the Repex Procedures.

Another method well suited for the monitoring and bookkeeping of chronic oxygen exposure has been developed largely by Dr. Lambertsen and his colleagues at the University of Pennsylvania. This method introduces and defines the CPTD, Cumulative Pulmonary Toxicity Dose, which is an accumulation of pulmonary toxicity Units, CPTU's. The CPTU is equivalent to an exposure of one minute to a PO_2 of one atmosphere; a formula adjusts the units for exposures at other PO_2 levels, because the effect of oxygen is greater at higher PO_2's and less at lower ones (Wright, 1972; Shilling, Werts, and Schandelmeier, 1976). This method has been derived empirically in much the same way as decompression procedures, by retrospective analysis of documented laboratory and field exposures, and by human exposures dedicated to that purpose.

The problem with CPTD for monitoring chronic oxygen toxicity is that a clear and practical set of limits for its use has not been determined. Another way of stating it is that there is no **denominator**, no time base against which to assess the effect of a dose. Our approach is to provide those limits.

3. Preventing CNS toxicity

Although the NOAA OPS procedures go as deep as 250 fsw, NOAA's request for the procedure development was to be able to excurse to 200 fsw. Another relevant fact is that the PO_2 of air at 200 fsw is 1.5 atm. We combined these points to work out a method of controlling CNS toxicity.

We took the position that below 1.5 atm PO_2 the risk of CNS toxicity is extremely low. Since this is the PO_2 of air at 200 fsw, and since extensive operations deeper than 200 fsw were not requested by NOAA, we chose to apply the USN "normal" toxicity limits deeper than 200 fsw, and to use a different "chronic" technique at 200 fsw and shallower. We elected to prepare tables for short excursions to 220 and 240 fsw, limited by allowable oxygen exposure.

Interpolating the USN table we determined that a diver could breathe air on an excursion for 29 min at 220 fsw and for 16 min at 240 fsw. We then set the computer to limit all excursions not to exceed these times. If decompression requires a shorter excursion time, that time appears in the table, but if the no-stop or one-stop bottom time could be longer than 29 or 16 min, the oxygen-limited time appears in the table.

It is important to note that these times, 29 min at 220 fsw and 16 min at 240 fsw are **not exceptional exposures**, they are **routine** (and quite conservative). By the same token, we take the position that substantially broader limits for air excursions in the range deeper than 200 fsw could be devised, and these given here should not be regarded as any sort of upper limit. They are practical for the circumstances, but not optimized for efficiency.

4. Nature of chronic oxygen toxicity

Although conservative, the CNS limits are beyond the scope of the main tables. For the tables to be of value it was necessary that some efficient means of living with chronic oxygen toxicity be devised. A brief review of chronic oxygen toxicity will help justify the approach we have taken.

First documented in 1899 and henceforth called the "Lorrain Smith effect," the primary component of chronic oxygen toxicity is pulmonary. This consists of irritation to the lung and airways from breathing oxygen at partial pressures above normal for air at sea level. It has been established that normal lungs tolerate oxygen at levels below 0.5 atm PO_2 for indefinite periods (Clark and Lambertsen, 1971), and that even oxygen-injured lungs can recover at that level (Eckenhoff, Dougherty, et al, 1987). Higher levels cause the irritation over many hours or days. It is **hyperoxia** because it is greater than normal, but it is not necessary that the exposure be hyperbaric.

Non-lung symptoms of high oxygen exposure such as headache, paresthesias, fatigue, numb fingertips, and various aches and pains can develop after several days in divers with no detectable lung problems, but chest and airway soreness, coughing, and a reduction in vital capacity are most often noted. There have been many studies of chronic or pulmonary oxygen toxicity, and many of these provide practical data as to tolerance times at different levels, as well as information on the various secondary factors such as temperature or individual sensitivity. A recent notable study is the Predictive Studies 5 series performed at the Institute for Environmental Medicine (Lambertsen, Clark, et al, 1984). Another recent and more relevant series of studies are those by Sterk and colleagues. These have been performed on divers doing diving work, and stress the levels most relevant to the Repex project (Sterk and Schrier, 1984; Sterk, 1986; 1987). Another source of information is a substantial amount of undocumented laboratory and commercial diving experience that may not be valid for statistical analysis but is extremely useful for setting practical limits.

Consideration of all this data permits a few generalizations. Chronic oxygen toxicity--or more properly oxygen poisoning--develops over time and comes on faster at higher exposure levels. Recovery takes place when the level is below about 0.5 atm PO_2, but the rate of recovery at various levels of PO_2 is not as well worked out as the onset rates. When an exposure drops below about 0.5 it is essentially "over" and recovery begins; the part of the exposure of greatest importance is that at levels above 0.5. A certain amount of exposure is necessary to cause symptoms, and this is some sort of integral of exposure level and time.

We concluded from all this that an algorithm for oxygen exposure management would have to consider the average daily exposure "dose" over time intervals on the order of days, and it would have to be related to the total exposure, such as over an entire mission or saturation.

5. Devising a method related to exposure duration

We decided that the traditional CPTD formula would afford us the "integral over time" information that was needed. CPTD has been around a long time, is generally familiar, and considerable O_2 exposure data is reported in those units. DCAP, for example, accumulates CPTD units during a dive. CPTD takes into account the more intense activity of higher PO_2's, and it turns off when PO_2 goes below 0.5.

The problem was to match doses in CPTD terms with various exposure data. We had worked with limits for short exposures such as deep bounce dives or DCS treatments lasting a day or so and accumulating 800 to 1000 or 1200 units. Sterk's total doses over one or two weeks and careful workups of the results provided helpful information in that range, and the SHAD II exposure gave us data for a 27 day exposure (Dougherty, Frayre, et al, 1978).

At first we tried averages for intervals of several days or a week, but this did not work because the tolerable dose is constantly changing. It soon became apparent that to get maximum efficiency and still stay below a toxicity level we would have to account for the whole mission. That is, the number of CPTU's that can be tolerated is a function of the number of days of exposure. It assumes, as mentioned above, that at the end of this period the diver will not be exposed (for a few days at least) to oxygen levels about 0.5 atm PO_2.

After several revisions we ended up with the chart given in Table IV-1, which is the same as Table VII-4 in the Procedures. It is shown graphically in Figure IV-1. The chart has two factors, the total CPTD dose and the average daily dose for missions of different lengths. For a single day of exposure the dose can be 850 units. If the exposure covers 2 days the total goes to 1400, which means an average of 700 CPTU per day, and so on. At some point at about 10 days the diver has to be in a steady state situation and have an average daily dose of no more than 300 units. The column of average daily doses does **not** mean that an individual can have 850 units the first day, 700 the second, and so on. If a mission or exposure has to be extended, say from 8 to 9 days, the difference between the totals, here 170 units, is the correct dose for the 9th day. The dose during saturation decompression should also be considered in planning a dive.

6. Conclusions

We did not invent this information. The information was developed by others it came from experience with oxygen exposure, and was the best that we could find. Our only contribution is to fit it together to show how the daily dose can be determined as a function of mission duration.

Some uncertainties remain. For one, these data are based on results with average, tolerant, people. A sensitive individual may fall well below the line in the figure. We did not try to eliminate these and make the line below all possible cases, for 3 reasons. First, the more sensitive individuals are usually eliminated from diving careers early. Also, to make the line low enough to include all these would make it operationally ineffective, not much better than what we started with. Thirdly, chronic oxygen toxicity develops slowly and can be stopped by reducing the level of oxygen; it has so far been found to be completely reversible (although it may take days or even weeks for complete recovery if allowed to progress. see for example Crosbie, Cumming, and Thomas, 1982; Hyacinthe, Giry, and Broussolle, 1981).

Table IV-1. Allowable daily oxygen doses

This table gives guidelines for management of long-duration oxygen exposure. The daily dose predicted to be tolerable is given in the second column for various mission durations; the tolerable daily level or average daily dose is a function of how many days exposure are involved. Here "mission duration" is the number of days of exposure to increased PO_2. The 3rd column gives the total allowable exposure for the full missions defined in the first two columns. The dose covers the entire period of a dive when $PO_2 > 0.5$ atm. (Same as Table VII-4 in Repex Procedures.)

Exposure (mission) duration, (inc dec)	Avg daily dose	Total this mission
1	850	850
2	700	1400
3	620	1860
4	525	2100
5	460	2300
6	420	2520
7	380	2660
8	350	2800
9	330	2970
10	310	3100
11	300	3300
12	300	3600
13	300	3900
14	300	4200
15-30	300	as req.

The data on which the long exposures (over 14 days) are based is limited to only 2 subjects in SHAD II; we cannot be sure what will happen if the exposure is extended beyond 30 days (this could be needed in, say, tunnel workers). We have not accounted in any way for other environmental and individual variables that might affect the results.

Since oxygen toxicity is very much an individual matter, we expect that tolerant individuals will be able to increase their daily dose in small increments, and that intolerant individuals will have to reduce theirs.

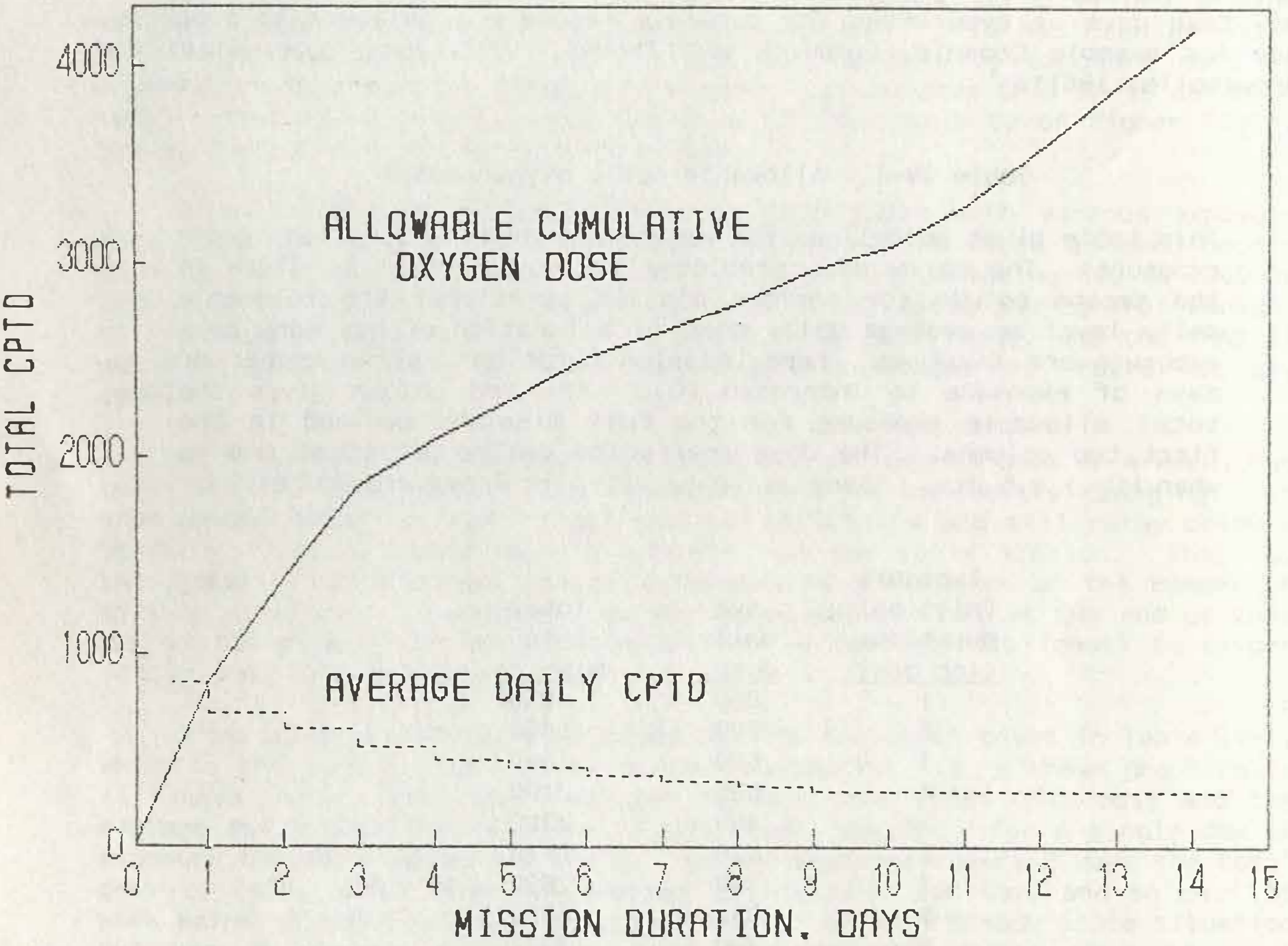


Figure IV-1. Recommended oxygen tolerance limits

The graph shows the allowable dose in both daily doses (dotted) and cumulative totals (solid). The diver is likely to be free of chronic/pulmonary oxygen toxicity symptoms if his total exposure stays below the cumulative dose line.

We feel that a diver could tolerate a full treatment for DCS at any time in one of these missions. However, it could catch him at a point where his tolerance would be exceeded slightly and some symptoms would develop. Since the exposure--at least as it relates to diving activities--

would be over we can expect recovery in plenty of time for decompression or a second treatment.

Although we have directed this algorithm at the habitat diving situation, it could be of value in other types of diving, and it offers a useable alternative in cases where the USN procedures are inappropriate. One possible application is in oxygen decompression of tunnel workers (Kindwall, Edel, and Melton, 1983). Another might be for long treatment with hyperbaric oxygen therapy.

F. Surfacing procedures

The procedures for surfacing divers as given in the Procedures, Chapter V, are more or less standard operational practices for the various situations. This chapter offers rationale for some of the choices.

1. Ascent in pressurized bell and decompression in DDC

This is the standard method used in commercial and navy diving, and offers the most security. The equipment requirements are relatively great in the usual context of scientific diving. An alternative is to decompress in the habitat to sea level or any intermediate pressure, then transfer to the surface or surface chamber to complete the decompression.

2. Surfacing the habitat under pressure

This method was under consideration during habitat design studies at Catalina Marine Science Center, where a marine railway was available for hauling the habitat from the water into a hanger. It is feasible, but only where the appropriate facilities exist, and it balances operational complexity and risk against an easy decompression pattern.

3. Decompression in the habitat followed by swim-up

This procedure is the traditional one for Hydro-Lab operations, where it has worked well. It has been used as deep as 100 fsw in the FISSH mission with the Helgoland habitat. NOAA's Office of Undersea Research has decided that this procedure can be used from storage/habitat depths no greater than 50 fsw.

We are pleased with this method in the range specified, and have no good way to judge its effectiveness from deeper depths, but it appears that the limitations are operational rather than physiological. The divers are unloading gas from the very slowest compartments at the end of the decompression, and the recompression and immediate ascent do not seem to stress the same compartments at all, if an analysis like this has any reliability.

The alternative mentioned in IV.F.1, above, could be a variation on the swimup method, whereby divers transfer to the bell after they have completed decompression and are transferred to the surface without having to recompress. There may be operational advantages in completing the decompression in the habitat for scientists whose equipment and/or specimens would remain in the habitat; they could continue working during decompression.

4. Emergency ascent

a. Seabed decompression and swim-up from deeper than 50 fsw

This is the method just discussed, which is limited to 50 fsw for operational reasons. For it to be used comfortably deeper than this the situation has to be under good control. If there is a decompression consideration it can be assessed by checking if half the time it takes to recompress (after the habitat has reached surface pressure) plus the time to get out of the habitat is less than the no-stop decompression time for that depth; if so, there should be no decompression problem. Even if the limits are exceeded there is no great risk if recompression can be started immediately at the surface. For this type of operation there is ALWAYS a risk of embolism, and this would be exacerbated in a diver at the end of a saturation decompression.

b. The FLARE method: Direct ascent and surface decompression

A great deal more operational risk is involved with this method, which is the habitat equivalent of surface decompression. It requires the diver to make what amounts to an ascending excursion to the surface, enter the surface chamber, and be recompressed to storage depth. If this can be performed within the time allowed for an ascending excursion there is no real decompression risk; this means the chamber has to be nearby, ready, and fully functional. The ascending excursion tables would allow 7 minutes for transfer from a habitat depth of 55 fsw; this could conceivably be done as a normal procedure. If, in an emergency, the times are much longer or depths much greater than those for ascending excursions we have to make an educated guess at the times, because we have no real data to go on. Chances are, much longer times could be tolerated without lasting injury but perhaps with the development of significant symptoms. Again the real physiological risk is embolism, and if the operation can minimize the likelihood of this and deal with it in the most expeditious way, the emergency ascent will invoke relatively little risk to the divers. There is of course the risk that something will go wrong with the chamber and delay recompression.

A relative risk chart is included in section V.D.2.d of the Procedures to indicate possible risk involved with different situations. This is only to give a general picture, and is not to be taken literally. We arrived at these times and risk estimates by comparison with ascending excursion data from NOAA OPS, SHAD/Nisat, and the more recent work at NSMRL (Eckenhoff and Parker, 1982, 1984). They are otherwise guesses. Data from "blowup" experiences is clouded by effects of embolism, but there are stories about successful emergency surfacing from rather deep dives without symptoms by non-saturated divers. Our philosophy in the risk chart is that a situation (depth/time combination) that would cause symptoms in most people would be used only in emergency, but if there is a serious risk in staying in the habitat this is really a small price to pay for a better chance at survival.

c. Speeding up decompression

The method given here is essentially the same one used to get the saturation tables. It allows the operation to trade greater risk of oxygen toxicity for faster ascent. The K values are the same as were used to prepare the saturation decompression tables. They will decompress at least as well at higher oxygen levels as at the levels given in the Procedures, provided the oxygen exposure can be tolerated.

G. Developing treatment procedures

Much of the rationale for the many items in the chapter on treatment of decompression sickness and embolism in habitat diving is contained in the chapter. This section gives additional comments on the procedures, and some indication of where they came from. The comments follow the order of the treatment chapter.

It was not our intent to devise new treatment procedures, but rather to incorporate the best of current techniques into the special situation of habitat diving.

These are not rules or standards, and this is not a manual. This report describes the development of a set of procedures. It is up to the local operation to select and implement the Procedures as rules. When something is "allowed" here it means that it is felt to be physiologically acceptable and in accordance with the limits and limitations of the Procedures.

Our philosophy for managing treatment is to provide the best possible therapy for the affected diver, but otherwise to make the treatment procedure as unobtrusive as possible to the mission and to the work of the other divers. Pain-only DCS is a fact of life in diving, and when it can be established clearly and convincingly that there are no neurological manifestations then the treatment can be accomplished and the mission continued. On the other hand, until **all** residual effects are resolved all efforts will have to be directed to the treatment.

1. Introductory considerations

The equipment, etc., needed to conduct all treatments that can reasonably be anticipated is listed in the Procedures, VI.A.

One thing that has to be in place in anticipation of treatment is an arrangement with a medical doctor trained in diving medicine. Again, it is not our intent to dictate how an organization makes its medical arrangements. The purpose here is to provide procedures in as much detail and with as much authority as possible, but when a situation is clearly a matter of medical judgement, we try to say so and to give guidelines to the responsible medical doctor from that point on. We conceive that a diving operation might have more than one doctor, the first as its advisor or "Facility Doctor," and the second as one or more "Duty Doctors" for a particular mission. In accordance with our "non-invasive" philosophy we consider that a habitat diving operation of this sort--including routine treatments--can be carried out without the need for an on-site doctor as long as it is going well. When problems develop, the advice and possibly on-site service of a diving doctor becomes an essential part of the operation. Throughout the treatment procedures suggestions for involving the doctor or doctors are given.

2. Description of treatment steps

"Treatment" begins with diagnosis of the condition, next involves therapy (mainly with pressure and gases), and then a return to the storage depth for continuation of the mission or to the surface if the mission is over. The steps are discussed, but the main process is covered in charts appearing later.

In diagnosis the important point is to recognize DCS so that it may be treated. Another point is to recognize neurological symptoms; the motto here is that if you have found a little, you have found a lot (CJL). Some tips on separating DCS from chronic oxygen toxicity are included.

The basic treatment pattern for DCS after an excursion is to compress to relief, breathe a session of 6 cycles (20 min on, 5 min off O_2 or treatment mix), decompress if relieved promptly, hold 12 hr and breathe another session if necessary. This pattern has evolved from commercial deep diving experience where divers have had to be treated during long chamber decompressions from deep bounce dives. This pattern is not really in the "navy" envelope, where most treatments are either at the surface or in saturation.

3. Role of other divers, and resuming diving (RWH)

Some of the philosophy on these two points has been mentioned. The criterion for whether companion divers breathe treatment mix is whether or not the return to storage depth or to join a saturation decompression requires it. Certainly, if some deviation in procedures is felt to be the cause of the DCS then all divers affected in the same way might be given a precautionary treatment, but that is a special case. Likewise, any time a diver requires a precautionary treatment it should be given, but breathing treatment mix when another diver has the bends is not the way to make it happen. The "returns" used in this chapter are slow enough for other divers to go through all the pressurizations required on a treatment and still decompress back to storage depth on the return tables without expecting problems.

There also would be a significant operational cost if all divers were required to breathe treatment mix. It would be acceptable to have enough mix on hand for say two treatments of a given sort, provided more can be prepared in a reasonable time. But to have enough for two treatments for the whole crew for each of the possible treatment situations would be a severe logistics burden. This is not to say this procedure should not be done because it is costly or difficult if it is necessary for a safe operation, but to point out that there is a better way. Rather than require companion divers to breathe treatment mix, a better way would be to adjust the return tables as necessary to make such a practice unnecessary. This is the way we believe we have done it.

A desirable alternative to premixed gases is the use of a closed rebreather for administering the right mix to the diver being treated; enough of these will be needed to deal with all divers who might have DCS at the same time.

Regarding the return of a diver to diving after a treatment, this of course is a **policy** matter, and local policy will prevail over these Procedures. Our purpose here is to state that it is physiologically acceptable to allow a diver **promptly and completely** treated for **pain-only** DCS to dive the next day. Our rule is 24 hours, so as to disallow a diver treated in the evening from diving the next morning. Diving the day after treated pain-only DCS is standard practice in commercial diving, and there is no clear evidence to say this is unsafe (Davis, 1980). It is important that there be no neurological involvement, so this should be determined definitively before making a decision to resume diving the next day.

4. Performing a treatment

Treatments are directed by 3 flow charts covering the possible habitat diving situations. The main chart covers DCS/embolism in habitat diving; others cover DCS associated with ascending excursions and handling a diver who has surfaced unexpectedly. The main chart TMT guides the user to the correct treatment chart, which includes two charts for after excursions and two for saturation.

The Procedures deal in some detail with the handling of an inadvertently surfaced saturated diver. There is little actual experience to go on, but we have tried to go through the thought processes in advance of need. As mentioned in IV.F.4, above, the risk factors are guesses based on what experience was available to us.

The Chart ISD for this case contains a principle used elsewhere as well, the requirement for recompression of 30 fsw or 1/3 of the excursion distance (the differential depth) if that is greater than 30 fsw. This is a compromise to limit recompression wherever possible, but to make it fully adequate when the diver's history suggests it may be needed.

Leaving the special cases and going back to TMT, the general philosophy can be seen. Essentially we have two operational situations (after excursion or in saturation) and two classes of symptoms (pain-only or neurological). If a diver has DCS and/or embolism after an excursion it calls for definitive treatment, with adequate recompression based on the symptoms. During saturation it is most unlikely that symptoms will be serious or hard to cure, so less compression is needed. Chart EX1 is used as an example for discussion.

We have tried to deal definitively with a sticky question that comes up in a lot of treatment tables, the statement. "Compress to depth of relief." This is a proper procedure, but it is not always easy to tell when "depth of relief" has been attained. It is easier if treatment is prompt than in divers finally recompressed many hours after onset. If for some reason relief is not apparent and the chamber is pressurized excessively it will invoke a substantial effort in completing the treatment and return, not to mention the added risk, and all this may be unnecessary. These procedures all call for relatively long treatments and slow returns, so an effort is made to keep excess pressurization to a minimum. The means used for stepping down is to take one cycle of treatment mix at each compression step, evaluating during the air breaks. The advantages of linking the cycles with the steps more than overcomes any question about how long to wait before taking another step; even a case that eventually needs many steps of recompression is being given substantial therapy from the first step on.

The Procedures call for the chamber to be switched to air during a treatment. This is to provide a uniform background for the therapy stage and to set both the "treatee" and the other divers up for the return.

Several choices follow from the speed of relief. If relief is prompt the fastest return is used and the intent is to resume the mission. If it takes longer but is complete, a more conservative path (the center one) is followed. This path is not likely to see much use, but it offers an alternative when things are not bad enough for the right path but it is not quite right to follow the left one. If relief is not complete another round of treatment mix is called for, after allowing the diver's lungs to recover for 12 hr or more. At this point there is also a path to follow if it now appears that most likely the diver is not suffering from DCS after all.

As mentioned, it is possible for the treatment to be carried out entirely by the dive crew without the Doctor if all goes well, but the Doctor should be located and advised about the treatment.

The EX2 chart is the heavy one, for the tough situations. The main difference is the 60 fsw of initial recompression as opposed to 30 for EX1. The saturation charts follow the same pattern but call for less recompression and return all the way to the surface.

The charts do not include fluids and drugs as part of the prescribed therapy. These we feel will be the choice of the Facility Doctor, since he/she is the one who will most likely define the contents of the habitat medicine chest and to train the crew in its use. Supportive drugs such as fluid replacement, which is essential for a patient in shock, are of course needed, but the efficacy of many of the popular drugs used in serious DCS/embolism cases are controversial, and since the Doctor will be involved before they are used and will have favorite ones, we leave that up to the operational facility and its Doctor. Further, much of the literature that has developed about treatment of DCS, the really sticky cases, are with divers that are not near a chamber, and there is often more than a few minutes of delay in beginning recompression; the habitat situation should be easier if recompression can be started promptly.

5. The return tables

For the main return table for going back to storage depth we chose to use the Royal British Navy's Table 71 (Ministry of Defence, 1976). This table has a history, and even though it has not been possible for us to get a definitive box score of its experiences, we felt using it would be better than making one up at this point. It has been shown not to be acceptable for full saturation decompression all the way to the surface (Buckingham and Thalmann, 1981). This table uses air.

In presenting the return tables we use the same reciprocal rate used in the Repex saturation tables, designated "RRate." The term may be uninspired, but this is the useful unit to use for timing a decompression, in minutes per depth unit. How does one ascend at 1.93 msw/min?

Another much more conservative table has been derived from commercial experience and modified for these Procedures. This is called the "Contingency return" table. It can be used with air from 105 fsw, and either 0.6 or 0.5 PO_2; the latter enables a diver with pulmonary oxygen toxicity to decompress and recover from the oxygen poisoning at the same time.

One point of terminology. In recent years it has become popular to refer to "saturation therapy" for cases treated and returned via a saturation profile. We prefer to consider that the main part of the therapy takes place during the recompression and breathing of treatment mix, and that the saturation decompression is a **return** technique (often considerable improvement is noted during the saturation decompression, however). One reason why these methods might properly be called saturation therapy is that they are so long only a saturation type decompression can be used.

G. DCAP analysis of the Repex tables

This section deals with two checks we made on the finished tables using the DCAP program. We used the Repex dives (Part Two) for examples. First we looked for places where the repetitive, one-stop, and submaximal algorithms may have broken down. Next we checked the "efficiency" of the tables.

In the process of performing these checks we found a few inconsistencies and errors; these are shown on the worksheets and schedules in the Appendix.

1. Check of table algorithms

The repetitive algorithms used to prepare the tables (Part One of this report) were based on and numerically tested with a number of presumed worst-case trials, but did not (and could not) involve an analysis of all possible situations. As a further check of the repetitive, one-stop, and submaximal algorithms and how they might work in typical habitat missions, we did a minute-by-minute analysis of each of the three Repex dives using the DCAP program. This did not have anything to do with the Repex dives as such, but used them as an example of a field operation that would push the tables to the limit and hence should be a good test of the repetitive algorithms.

By going through each dive from beginning to end, each excursion was calculated for the actual gas loading that would prevail in that situation. Using DCAP the diver was stepped through the complete time-pressure-gas profile from the beginning of the saturation dive up to the end of the bottom time of each excursion, then was decompressed back to storage depth. If, for each specific situation, the diver could not return to storage depth without violating the ascent criteria then DCAP would call for a stop.

This run showed that all actual excursions were at least as conservative as the basic algorithm used for calculating the tables in the first place.

The DCAP runs also serve the purpose of presenting a saturation-excursion dive in a format that might be used for planning a field operation. A sample of the DCAP run of Repex II is given in Appendix D, along with its Base Case, the set of instructions used with DCAP.

2. DCAP check of Repex efficiencies

Normally decompression tables are arranged in groups, a range of depths and a range of times for each table or schedule. This creates a situation in that only tables at the full time and depth are fully "efficient" in terms of the algorithm used to compute them. In practice this adds a conservatism that may be an advantage, so it is a tradeoff. The Repex tables have a number of such built in inefficiencies, for example that the 14th excursion is used for the "3+" dive in the sequence.

To get an idea of how far we were from the algorithm in different types of tables, we computed the three Repex dives with all their excursions, etc., using the "no-d" statement in DCAP. This computes the maximum time an excursion may have without requiring any stops on the way back to storage; it assumes instant compression and decompression. The idea was to check the allowable excursion times prepared with the tables to find out how they would compare with the same excursions done on a "custom" basis.

Since the computed time for an excursion depends on the history of the diver up to that point, we could not check all excursions in a single pass because a different time would affect subsequent excursions. To avoid having to recalculate the whole dive for each excursion we did only one no-d calculation per schedule day, assuming that these small differences would not affect no-d calculations the following day. We made several Base Cases to sequence through each of the three Repex dives.

For no-stop excursions, the **efficiency** is the Repex time (the time taken from the tables) divided by the computed no-d time. Post-submaximal excursion times were also tested, by dividing the time calculated by hand for that excursion by the custom-computed no-d time. There was no point in testing the submaximal dives for efficiency so we assumed these were full and let them serve as additional samples; they were put in as used in Repex for establishing the history of the excursions that followed. The results of this analysis are shown in Table IV-2.

Table IV-2. No-Stop Excursion Efficiency

Using the Repex dives as a sample the dive times taken from the tables are compared with the same dive computed specifically for that exposure history. Submaximal dives were handled as if they were full time for determining efficiency, but were counted as they were done in Repex for computing the post-submaximal. a = depth advanced to compensate for unsaturated divers; * = first dive of day; S = submaximal dive; P = post-submaximal dive

	Repex I				Repex II				Repex III		
Depth	Repex	no-d	Eff%	Depth	Repex	no-d	Eff%	Depth	Repex	no-d	Eff%
143a	54	62	87	200	33 S	37	89	200	105	110	95
140a	62	70	89	140	290 P	480	60	200	52	64	81
130*	one-stop			140	90	360	25	190	57	118	48
145	17	28	61	170	79	90	88	240	12	28	43
125	75	90	83	220	one-stop			180	78	250	31
125	42	74	57	200*	33	37	89	200*	105	110	95
100*	455 S	475	96	180	35	47	74	200	105	110	95
115	149 P	160	96	180	one-stop			240	16	33	48
160	21	32	66	145	43	217	19	190	57	151	38
220	11	11	100	170*	79 S	91	88	200*	one-stop		
160*	one-stop			160	98 P	128	77	180	78 S	269	29
145	45 S	48	94	200	one-stop			200	58 P	101	57
135	55 P	64	86	160	24	87	28	200	22	72	31
95	307	480	64	190	one-stop			200*	one-stop		
115	57	113	50	190	41	46	89	220	29	53	55
155*	one-stop			180*	56	65	86	240	12	28	43
110	189	210	90	140	168 S	458	37	200*	105	110	95
200	14	16	88	155	115 P	154	75	240	16	33	48
110	one-stop			155	147	15	84	220	29	53	55
105*	294 S	322	91	135	69	421	16				
120	57 P	71	80	180*	56	65	86				
170	one-stop			240	13	18	72				
				190	41	46	89				

One-stops were treated a little differently. Here we compared the total decompression time (including the preliminary 2-min stop) from the tables with the time computed for that excursion at that time in the dive. These are shown in Table IV-3.

We did not test the efficiency of dives done at different parts of the interval and depth ranges except as they occurred in Repex. Of course the efficiency would be less for dives later in the interval, since the table time would be the same but the computed time would have the advantage of the longer time since the last dive. Likewise it is not really relevant to compute efficiencies on the first dives of Repex I when the divers were not saturated.

Table IV-3. One-Stop Excursion Efficiency

Bottom time, table time (including 2 min preliminary stop), computed decompression time, and efficiency are shown for each bottom depth. Where the computed time calls for two stops they are both shown. * = 1st dive of day

Repex I					Repex II					Repex III				
Bottm depth	Bot t	Tab t	Dec t	Eff%	Bottm depth	Bot t	Tab t	Dec t	Eff%	Bottm depth	Bot t	Tab t	Dec t	Eff%
130*	120	16	7	44	220	29	6	2	33	200*	150	60	2	3
160*	60	17	1,9	59	180	60	4	0	–	200*	240	35	19	54
155*	45	6	2	33	200	60	41	2,8	24					
110	210	62	4	6	190	60	16	4	25					
170	45	20	1,7	40										

Since the one-stop tables have just two dive interval ranges, >16 hrs and 2-16 hrs, there is a wide spread of calculated efficiencies for these. For example, the first one-stop excursion of Repex III has an efficiency of 3%. The dive interval before that excursion was 8 hrs, placing it in the middle of the 2-16 hr range, and thus it is not as efficient. Also, a one-stop dive forces the next one to be 3+ instead of 2nd, which reduces efficiency. We did not consider this in making the schedule.

PART TWO: VALIDATION TESTING

CHAPTERS V THROUGH VIII.

This Part covers the simulated operational exposures that were conducted as an integral aspect of the overall program. Methods include the planning, facilities, divers and topside personnel, and monitoring that was done. Results cover the dives done, results of the monitoring, and decompression sickness encountered. The discussion concludes that these limited tests were highly successful and support that the Procedures are ready for provisional field use.

V.
THE TEST PROGRAM

The testing reported here was done as an extension of the original contract for preparing the tables. It involved design of a frugal test plan suitable for evaluating the procedures, selection of a facility, planning dive profiles and schedules, preparing monitoring procedures, arranging operational details, conducting, monitoring, and documenting the dives, and preparing this report.

A.e Rationalee

The new tables were produced using the best data available to us. Nevertheless, their basis is empirical and their reliability must therefore depend on the validity of past experience and how closely it relates to the new techniques. The data base used was relevant and appropriate, but it was limited to what had been done and it does not completely cover all aspects of the new procedures. In keeping with the feelings of the professional community knowledgeable in decompression technology, both the Office of Undersea Research and Hamilton Research, Ltd., took the position that a meaningful laboratory validation of these new procedures would be highly desirable. The validation trials were not intended as a "development" program where repeated tests are used to "titrate" the optimal profile, but rather a validation of procedures we presumed would be operationally acceptable to begin with.

B. Objectives

Our objectives were to put the new procedures to as strenuous a test as could be fit into a modest series of exposures. We hoped to test as many different aspects of the decompression procedures as possible, with as many "worst case" situations as could be arranged.

We wanted to cover as well as possible the range of storage depths covered by the procedures, for both the excursions and the saturation decompression. We wanted it to be done with divers having characteristics similar to those of the scientific diver population. Mission durations were intended to be realistic, and we wanted daily schedules as intensive as any eager scientist might conceive, and activity levels to be equivalent to real dives.

Having divers go under water during the excursions would have added some realism and made the testing more valid, but this was judged not to be cost effective. We felt this could be compensated in part by having the divers exercise during excursions. Likewise, we felt that testing of different types of surfacing procedures other than routine saturation decompression would be counterproductive if it were to be at the expense of testing the main procedures.

No new ascending excursion procedures were prepared as part of the Contract, so no plans were made to test ascending excursions. This is just as well for a validation project of this magnitude; to include them would have diluted even further its already limited scope.

Although decompression was the main objective, we wanted the test dives to provide oxygen exposures that would evaluate the limits given in the procedures.

We accepted the default position of letting subjective symptoms of decompression sickness act as the end point, because there does not seem to be a better alternative (see Schreiner and Hamilton, 1987). We also wanted the exposures to be assessed with a somewhat objective and generally accepted monitoring method, doppler ultrasonic bubble detection.

C. Contract arrangements

The original contract called for the development of decompression tables and procedures to be used in habitat-based excursion diving. This resulted in the procedures described in Part One of this report. As this work began to converge on draft procedures ready to be evaluated by NOAA and potential users, it became clear (and it had always been intended) that some sort of operational evaluation would be needed before the tables and procedures could be released for field use.

In response to this need Hamilton Research proposed to arrange for this evaluation. A proposed test plan was prepared and reviewed with the diving simulator facilities in the U.S. that might be able to perform such a test series. Proposals were obtained, reviewed, assessed, and reported by Hamilton Research, and a preferred facility was selected by NOAA. After an additional procurement competition was held by the contracting office the proposal was accepted, and eventually a contract for the testing was issued.

A subcontract was made between Hamilton Research and International Underwater Contractors for performing the test dives at the IUC's North American Hyperbaric Center. Hamilton Research provided overall planning and prepared the profiles to be followed, and handled the analysis and documentation. IUC furnished the facility, set it up with gases and supplies, arranged for "informed" diver-subjects and topside crew, performed medical exams and diver training, carried out the dives, performed the monitoring and logging functions, and carried the necessary insurance. An agreement was made to cover the extra cost of treatment of DCS by shortening the next dive in the schedule; IUC accepted the risk for any extra days should there be a treatment on the last dive, and no contingency fund was used. The divers themselves carried some of the risk for dealing with DCS, since they were paid a flat fee for the dive and nothing additional for any extra time in the chamber due to a treatment.

Originally the plan was to perform 4 saturations each of about 7 days duration, but this was changed later to 3 saturations of about 8 days each. The first plan was to replicate two storage depths twice, and all of the dive days would have had 8 hours of excursions and a 16-hour overnight break. After discussions with NOAA and potential users we concluded that this was much too structured to simulate a real scientific habitat mission, and using only two depths did not cover the depth range well enough. Also, having a 16 hour break every night meant we would not get to test the 8-hour interval. Changing to longer missions made it easier to manipulate the 16 and 8 hour overnight intervals. A further factor in deciding to go from 4 to 3 saturations was due to delays in getting the contract approved, and the resulting requirement to adjust the schedule; 3 dives fit better into the time available.

VI.
METHODS

This chapter tells how the three week-long simulated saturation missions with multiple pressure excursions were performed at IUC, and describes the monitoring that was done.

A. Development of the test profiles

1. Criteria for scheduling the dive profiles

In practice we would expect that work requirements, meals, endurance, daylight, etc., would cause enough breaks in a scientific diver's routine to allow more than the minimum time in the habitat between excursions on most occasions. Our task here, however, was to cram as many dives into each work day as possible, making each interval the minimum duration that it could be and still meet the criteria of the tables, and making each dive as long as possible.

Ground rules were that all excursions would be taken from the Repex tables as printed, following the appropriate methods for selecting the times. Each interval would be for the shortest duration in an interval range that could be used. That is, for the 2-4 hour interval, 2 hours would be used. It was also planned that the ascent time back to the habitat from the no-stop excursions would be taken from the time of the next interval, as the tables call for. That is, timing the interval begins when the diver leaves bottom. Ascent is supposed to be done before the end of bottom time in one-stop excursions; there was a minor deviation on this latter point on the one-stop dives, discussed in section VI.A.3, below.

Each excursion was to be for the longest time allowed in that situation; with the specific exception of those coded as "submaximal," virtually all were done this way.

We tried to test all intervals, and as many different excursion times and depths as possible. We also wanted a few "one-stop" and submaximal excursions in each saturation, and once on each dive the diver was to be held at the depth of the deepest part of the oxygen window range for the duration of the interval. We intended to avoid as much as possible doing dives in the oxygen-limited range deeper than 200 fsw, because these would not be good tests of the decompression algorithm.

There are some constraints imposed by the kinds of excursions that can be done from each of the storage depths; as storage gets deeper the choice of excursion durations diminishes. For example, from 110 fsw there are few choices of target depth because so much time is allowed at all of them; if long excursions are done it reduces the number that can be tested in a given saturation, and it may impose too much oxygen exposure. Also, we did not try to test a full 8-hour excursion in any case. There were just too few days available to spend even one of them on only one excursion. The pattern of doing a single 8-hour excursion each day is more typical of commercial than scientific diving.

Another specification was that we wanted each day to start at 0800 and end at 1600 or 2400, allowing either an 8 or 16 hour day. The idea was to fill the days out to exactly 8 or 16 hours, in order to test both the classical 8 hour work day, and also the traditional 16 hour work day of scientists. Perhaps more appropriate than the work day, was to test both the 16 and 8 hr intervals.

Another parameter which we did **not** try to control when doing the planning was daily or mission oxygen exposure. In Repex III we did avoid some excessively long and deep excursions that would clearly result in excessive oxygen exposure, but generally we just let the oxygen fall where it would and did not try to control or optimize the exposure. In fact, we wanted it to be at least as long as the criteria allowed by the procedures, ideally a little longer. As it turned out this was achieved, with oxygen exposure well over the limit in Repex II and III.

One of the ground rules of the overall plan was that if there was extra time required for treatment that it would be taken off the next dive. This was done, with Repex II shortened by one day due to the treatment in Repex I.

2. Worksheets

To put each dive together and still meet these criteria as much as possible was a bit of a challenge, exacerbated by the difficulty of adding hours and minutes without error. To make it possible we put each dive plan into a computer "spread sheet" (Lotus 1-2-3) programmed to add the appropriate times. It thus became possible to make changes--using times selected from the tables--in excursion depths or bottom times and see the effect on the day's schedule immediately. By switching excursions around we were able to meet the time requirements, and for the most part we were able to get a fair distribution of the various types of excursion. Sample worksheets for the Repex dives are included in Appendix A.

The worksheet columns show the excursion number, the dive day, the "number" of that excursion in its repetitive sequence, the duration of the interval before the excursion in both hours and hours and minutes, the starting time of the excursion, its depth/time, the stop times if a one-stop excursion, and the time the excursion was over. Comments identify submaximal and post-submaximal excursions, and signal when the divers were to remain in the oxygen window during the interval between excursions. The worksheet took care of adding up the times, and a supplemental routine helped to figure the post-submaximal adjustments, but it was still necessary to look up the excursion times and the saturation stops in the tables. Some errors discovered later are shown in bold face within square brackets.

The daily schedules were put together from the 1-2-3 worksheets and issued in the form shown in Appendix B. The schedules also included daily routine items such as meals and the subjective questionnaire, and showed each of the periods of monitoring with doppler ultrasound. Discrepancies that were noted after the dives are shown on the worksheets in square brackets and are detailed in VI.A.5.

3. Scheduling results

It was possible to test at least partially all intervals in each of the three dives, but of course we could not do all the depth/time combinations. However, we were able to distribute the test dives reasonably well among the short, deep and the longer, not-so-deep excursions in all three dives. To show how these dives were distributed we circled the times used for no-stop and submaximal excursions on extracts of the table pages, and have included this as Figure VI-1. The circled dives are full-time no-stop excursions; those done more than once have more circles. Rectangles show depth/sequence/interval combinations that were done as post-submaximal dives for longer times than shown in the tables, and diamonds show the submaximal dives that were for shorter times than the tables.

The one-stops had the same general patterns of distribution, but there are fewer total excursions and we did not do a figure.

On most days the last excursion ended within a few minutes of 8 or 16 hours, depending on which day length was scheduled, so we were able to produce the desired daily patterns.

4. Special first excursions in Repex I

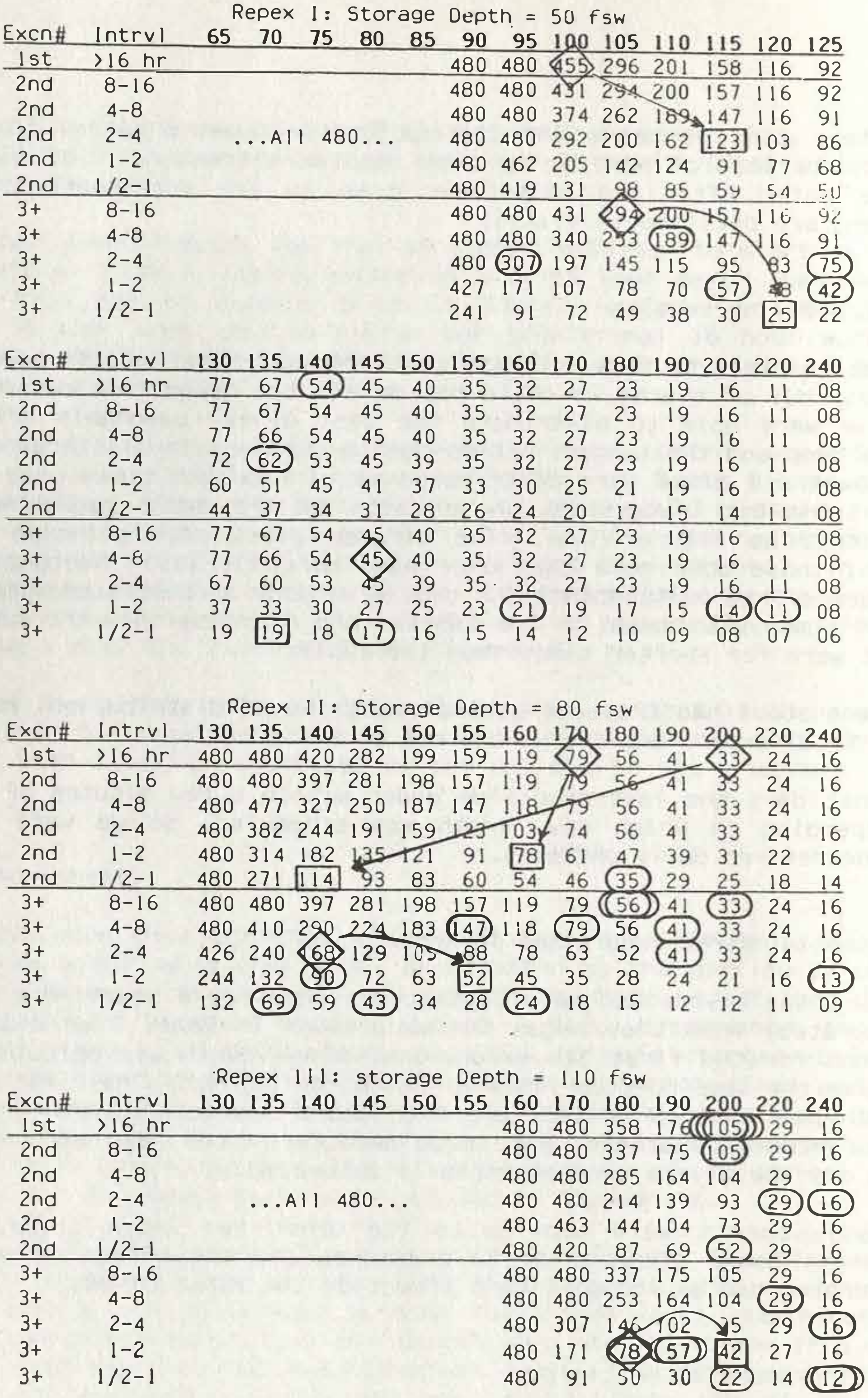
Because the divers had only been at pressure for 4 hours (and were not fully saturated) when they began the excursions in Repex I we did special calculations for the first two excursions. A new depth was calculated with DCAP to give the same no-stop times given in the tables. The first dive was for 143 minutes instead of 140, and the second was for 140 min instead of 135. No further adjustments were made because by the next excursions the following day the divers were essentially saturated.

No adjustments were applied to the other two Repex dives. These started eight hours after going to pressure, and the effect of not being fully saturated had an insignificant effect on the first dives.

5. Discrepancies in timing

In putting together the schedule we had to make some choices that caused the scedules to deviate from the Procedures, and we made some errors in determining the table times.

There was a compromise in timing the one-stop excursions. Normally the ascent from a descending excursion can be absorbed into the interval that follows it (preferred field practice is to start timing the interval on return to the habitat), but to get maximum exposure for the tests we started



Repex I: Storage Depth = 50 fsw

Excn#	Intrvl	65	70	75	80	85	90	95	100	105	110	115	120	125
1st	>16 hr						480	480	455	296	201	158	116	92
2nd	8-16						480	480	431	294	200	157	116	92
2nd	4-8						480	480	374	262	189	147	116	91
2nd	2-4			...All 480...			480	480	292	200	162	123	103	86
2nd	1-2						480	462	205	142	124	91	77	68
2nd	1/2-1						480	419	131	98	85	59	54	50
3+	8-16						480	480	431	294	200	157	116	92
3+	4-8						480	480	340	253	189	147	116	91
3+	2-4						480	307	197	145	115	95	83	75
3+	1-2						427	171	107	78	70	57	48	42
3+	1/2-1						241	91	72	49	38	30	25	22

Excn#	Intrvl	130	135	140	145	150	155	160	170	180	190	200	220	240
1st	>16 hr	77	67	54	45	40	35	32	27	23	19	16	11	08
2nd	8-16	77	67	54	45	40	35	32	27	23	19	16	11	08
2nd	4-8	77	66	54	45	40	35	32	27	23	19	16	11	08
2nd	2-4	72	62	53	45	39	35	32	27	23	19	16	11	08
2nd	1-2	60	51	45	41	37	33	30	25	21	19	16	11	08
2nd	1/2-1	44	37	34	31	28	26	24	20	17	15	14	11	08
3+	8-16	77	67	54	45	40	35	32	27	23	19	16	11	08
3+	4-8	77	66	54	45	40	35	32	27	23	19	16	11	08
3+	2-4	67	60	53	45	39	35	32	27	23	19	16	11	08
3+	1-2	37	33	30	27	25	23	21	19	17	15	14	11	08
3+	1/2-1	19	19	18	17	16	15	14	12	10	09	08	07	06

Repex II: Storage Depth = 80 fsw

Excn#	Intrvl	130	135	140	145	150	155	160	170	180	190	200	220	240
1st	>16 hr	480	480	420	282	199	159	119	79	56	41	33	24	16
2nd	8-16	480	480	397	281	198	157	119	79	56	41	33	24	16
2nd	4-8	480	477	327	250	187	147	118	79	56	41	33	24	16
2nd	2-4	480	382	244	191	159	123	103	74	56	41	33	24	16
2nd	1-2	480	314	182	135	121	91	78	61	47	39	31	22	16
2nd	1/2-1	480	271	114	93	83	60	54	46	35	29	25	18	14
3+	8-16	480	480	397	281	198	157	119	79	56	41	33	24	16
3+	4-8	480	410	290	224	183	147	118	79	56	41	33	24	16
3+	2-4	426	240	168	129	105	88	78	63	52	41	33	24	16
3+	1-2	244	132	90	72	63	52	45	35	28	24	21	16	13
3+	1/2-1	132	69	59	43	34	28	24	18	15	12	12	11	09

Repex III: storage Depth = 110 fsw

Excn#	Intrvl	130	135	140	145	150	155	160	170	180	190	200	220	240
1st	>16 hr							480	480	358	176	105	29	16
2nd	8-16							480	480	337	175	105	29	16
2nd	4-8							480	480	285	164	104	29	16
2nd	2-4			...All 480...				480	480	214	139	93	29	16
2nd	1-2							480	463	144	104	73	29	16
2nd	1/2-1							480	420	87	69	52	29	16
3+	8-16							480	480	337	175	105	29	16
3+	4-8							480	480	253	164	104	29	16
3+	2-4							480	307	146	102	95	29	16
3+	1-2							480	171	78	57	42	27	16
3+	1/2-1							480	91	50	30	22	14	12

Figure VI-1. Coverage of the Repex no-stop dives

The circled times are those tested in the Repex dives; multiple tests show more than one circle. The submaximal dives (run for shorter times) are shown with diamonds, and the following post-submaximals (run for longer times) with rectangles. One-stop dives are not shown.

at the end of the bottom time as the Procedures allow. Therefore, when we planned the original schedules we did not include in the schedule the ascent time back to the habitat from excursions.

That works fine for the no-stop excursions, but there is a problem with the one-stops. The longest part of the ascent time cannot be absorbed into the 2-minute preliminary stop, first because the Procedures require that the **full** 2 minutes be taken, but also because ascent may be longer than the stop. By the time this was discovered some schedules had been firmed up. In order to keep the overall schedule intact we had to consider that the ascent time would be absorbed by the interval that **followed** the decompression stop.

This caused no problem in the schedule or conduct of the dives and only a trivial variance in the criteria for worst-case exposure, but it did force us to have the following interval absorb the travel time. Accordingly, in some cases the **interval** following a one-stop excursion is not for the full time of the interval as stated in the table; it is shorter by the number of minutes of ascent time. It would have been possible to shorten the bottom time of the one-stop excursion instead, but we felt this would cause the least deviation. The sample DCAP run for Repex II in Appendix D shows it this way.

As an example, consider the excursion to 190 fsw for 60 minutes at 1753 on Day 3 of Repex II. The excursion is timed to allow the full 60 minutes on the bottom. Ascent takes 3 minutes to get to 105 fsw for the 2-minute preliminary stop. The stop takes 2 minutes, and this is followed by "instantaneous" ascents to 95 fsw for the 14 minute stop and on to 80 fsw for a "4 hour" interval. In order to make the next dive start at 2309 as scheduled it was necessary to use a time of 237 min instead of 240 for the time at 80 fsw. This is in the right direction for a worst-case exposure, but it sets a bit of a bad example by allowing an interval of 237 min to be considered as a full 240. We do not want to suggest that it is all right to shorten the intervals, even by a few minutes! Consider this a special case for these tests only.

There were also two cases of dives not being calculated correctly, a post-submaximal in Repex I (#21, 120/76, which should be 120/58) and an 8-hr overnight interval being considered as a 16-hr which affected the following dive (#7 in Repex II, 180/35, which should be 180/15).

There was also a discrepancy in the early part of the saturation decompression for Repex III. The ascent "rrate" of 38 min/fsw was used from 110 to 95 fsw, whereas 21, 22, and 23 fsw/min should have been used for those three stops, making the saturation decompression 240 minutes longer than it should have been.

6. Shortened Repex II

Because Repex I took an extra day due to the treatment, we had to take the day off of Repex II.

B. Diver subjects

The divers were selected by IUC from recent graduates of IUC's Professional DIving School of New York and the local diving community. A team for each saturation included 4 primary divers and one standby. All were determined to be medically fit, and all, including the standbys whenever possible, were given the full indoctrination and training.

1. Description of the divers

The individual characteristics of the divers are summarized in Table VI-1. Nine of the 12 were recent graduates of the Professional Diving School of New York, which helped particularly with their familiarity with the chamber system. Some were employed as divers on an occasional basis, some were continuing with other schooling, and others were employed elsewhere. They were uniformly eager to be involved in a special project of this sort. All were in a good to excellent state of physical fitness, but one was somewhat overweight. Most make a practice of regular exercise, but two keep fit primarily by daily hard physical work. They were asked to estimate the number of dives they had done; these were not confirmed, and some did not answer.

2. Medical surveillance and ethics

Candidate divers were given a medical check or their medical records were examined before they were selected for a dive; criteria were essentially the same as for commercial diving work. Because the tests were regarded as operational and the risks of unusual exposure or injury were no different from those encountered in routine commercial diving (actually they were substantially less) it was not considered necessary to perform an unusual neurological or biomedical workup.

Although the dives were considered to be routine operational tests and no special medical workup was needed, the divers were nevertheless experimental subjects and were briefed on the possible risks involved with a saturation exposure in a pressure chamber and on their rights and responsibilities as subjects. Each signed an "informed consent" form indicating that he or she understood and accepted the conditions of the dives. The divers were paid a modest amount for each scheduled day's work, either in training or in the chamber. No extra pay was to be given in the event a dive took longer than scheduled as a result of decompression sickness.

As a group they represent a reasonably good model of the scientific diver population one would expect to find on a habitat diving operation, but are probably a bit younger and possibly more physically active.

Table VI-1. Repex diver descriptions

	Repex I			
Diver	I-1	I-2	I-3	I-4
Initials	RW	JB	MC	PK
Age, yr	23	19	32	23
Weight, lb	200	210	181	135
Height, ft,in	5'9"	5'11"	6'0"	5'8"
Fitness level	Fair	Fair	Good/exc	Exclnt
Daily exercise	Jog 3 mi	Active	Hard work	1 hr+
Smoker?	No	No	No	Yes
Diving experience				
PDSNY graduate?	Yes	Yes	Yes	Yes
Commercial (non-scuba), yr	0	1/2	1/2	1+
Scuba/sport, yr	6	2	3	6
Approx number of dives	40			
Previous DCS?	No	No	Yes	Yes
Previous skin bends	No	Yes	No	No

	Repex II			
Diver	II-1	II-2	II-3	II-4
Initials	HR	KL	VR	KG
Age, yr	22	28	44	27
Weight, lb	128	100	122	138
Height, in	5'4"	5'2"	5'3"	5'7"
Fitness level	Exclnt	Very good	Good	Exclnt
Daily exercise	V. active	1	Active	Active
Smoker?	No	No	No	No
Diving experience				
PDSNY graduate?	Yes	Yes	No	No
Commercial (non-scuba), yr	1	0	0	0
Scuba/sport, yr	3	8	11	1
Approx number of dives	150		400	20
Previous DCS?	No	No	No	No
Previous skin bends	Yes	No	No	No

	Repex III			
Items:	III-1	III-2	III-3	III-4
Initials	JEG	JKG	JG	JL
Age, yr	38	21	28	62
Weight, lb	175	175	235	150
Height, in	5'10"	6'0"	5'9"	5'9"
Fitness level	V good	V good	Fair	Good
Daily exercise	V active	Active	Some	Hard work
Smoker?	No	No	Yes	No
Diving experience				
PDSNY graduate?	Yes	Yes	Yes	No
Commercial (non-scuba), yr	3	3/4	2	0
Scuba/sport, yr	16	1.5	9	30
Approx number of dives			900	
Previous DCS?	No	No	No	No
Previous skin bends	No	No	No	No

C. Facility

The "dives" were performed at the North American Hyperbaric Center, an affiliate of International Underwater Contractors. IUC is a commercial diving and underwater construction company located on City Island, NY. The hyperbaric center serves as a treatment facility for New York City's Emergency Medical Service, handling carbon monoxide and smoke inhalation cases, diving accidents, and more routine cases requiring hyperbaric oxygen therapy. The center has also until a few months before the Repex operation been the locus of a major training school for professional divers.

1. Chambers

The chamber facility consists of two complexes, each having a vertical "wet pot/igloo" chamber 24 feet tall and 10 feet in diameter attached to a horizontal living chamber or DDC 16 feet long and 6.5 feet in diameter. The living chamber has one compartment 10 feet long and a 6-foot lock, and is connected to the igloo by a 3 foot tunnel. One of these complexes was used for Repex. The wet pot remained filled with water, but the overhead igloo chamber was closed off by a plywood and metal floor to reduce the moisture load on the environmental control system and to create a comfortable living-working area 10 feet in diameter. Figure VI-2 shows a cutaway of the chambers in their building; the control panel is on the other side of the chambers from the location shown on the drawing.

The pressure rating is equivalent to 1000 fsw. The complexes are controlled by a fully instrumented control panel having oxygen and carbon dioxide analysis, gas management equipment, lighting, video, and communications. A Kinergetics environmental control unit in the basement maintains comfortable temperature and humidity levels.

During the Repex dives the other chamber complex did business as usual, treating patients on an almost daily basis.

These chambers had belonged for many years to the US Navy's Experimental Diving Unit in the Washington Navy Yard. They were obtained by IUC when the EDU moved to Panama City.

2. Support facilities

The chambers are housed in a 15,000 square foot building, which also contains a wet training tank, welding and shop equipment, a medical office, classrooms, offices, supply storage, a bunk room, and an exercise/weight room. The chamber area is air conditioned. The main offices of IUC are located in an adjacent building. Another large building houses the maintenance facility for IUC's submersibles and ROV's. A barge at the other end of the 7.2 acre yard served as the diving schools outdoor training facility. Helicopters land near the chamber building with emergency cases.

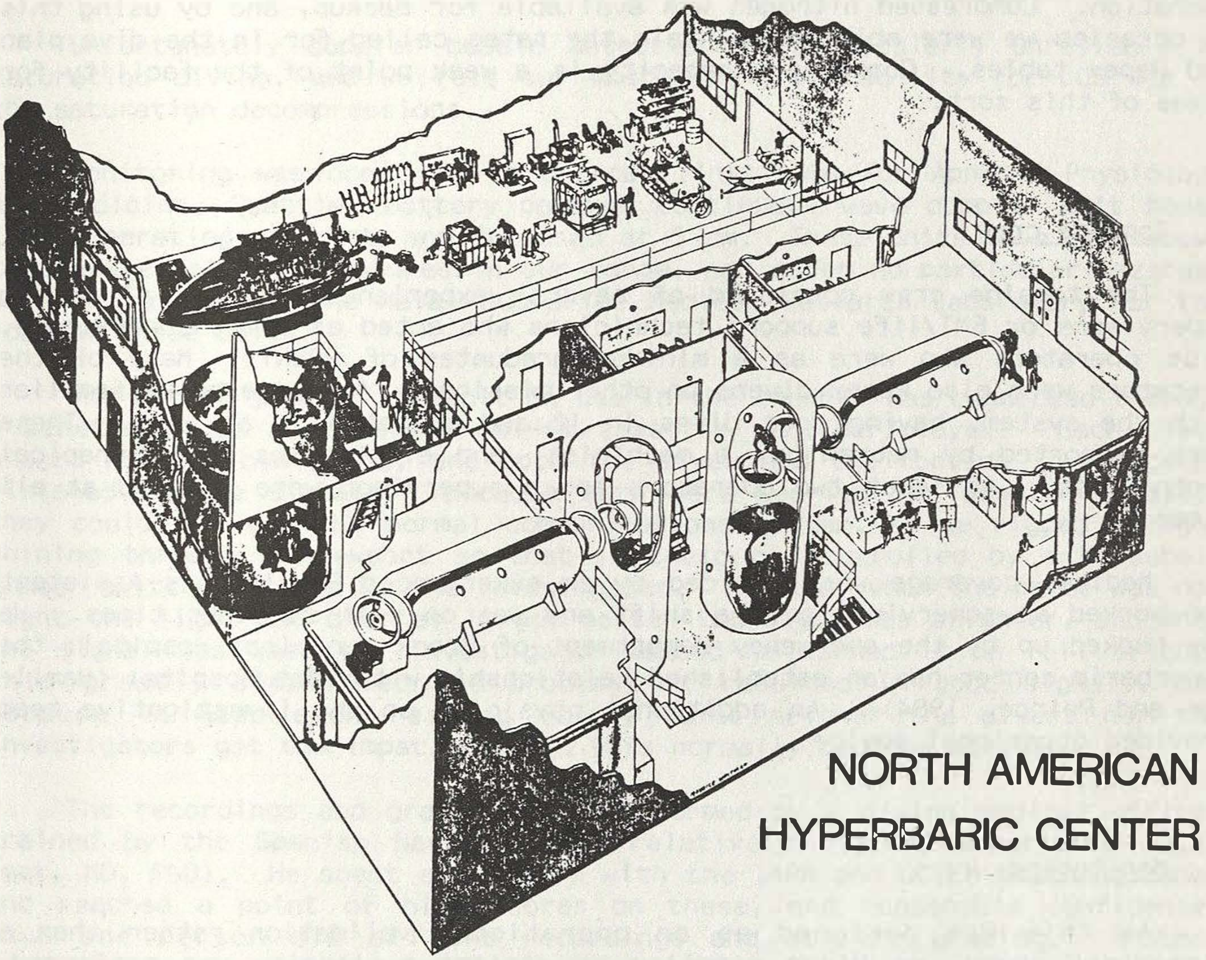


Figure VI-2. Cutaway of the IUC facility

The complex used for Repex is the one on the left, which had the bell simulator lowered out of the igloo and a cover over the water. The control panel is located opposite the DDC's rather than on the lower deck as shown here.

3. Gases

Several high and low pressure compressors supply compressed air to the complex. Several banks of cylinders and a retired diving chamber serve as gas storage. Oxygen was obtained from banks of cylinders. Nitrogen for

Repex was obtained as a liquid in standard dewars. Resupply was planned so as to match boiloff as closely as possible to normal consumption by the operation. Compressed nitrogen was available for backup, and by using this on occasion we were able to maintain the rates called for in the dive plan and Repex tables. Compressor capacity is a weak point of the facility for dives of this sort.

D. Topside crew

The topside crew consisted of several experienced commercial diving supervisors or EMT/life support technicians who acted as shift supervisors, plus operators who were as a minimum graduates of PDSNY. Many of the operators were also Repex divers on other missions. All were quite familiar with the system, having done dives in it and operated it as well. These were supported by mechanics, a machinist, and electronics and mechanical technicians. At least two operators and a supervisor were on hand at all times.

Medical coverage was provided by an experienced Physician's Assistant who worked as supervisor on one shift and was on call at other times. He was backed up by the emergency department of Bronx Municipal Hospital; the hyperbaric center has an established relationship with that hospital (Hamilton and Peirce, 1984). An additional physician on the investigative team provided occasional advice.

E. Monitoring

As this was designed as an operational validation rather than a biomedical study, no blood sampling or similar monitoring was performed. Our main objectives in this area were first to ensure the safety of the divers, then to monitor for decompression sickness, and next to keep track of their general condition and tolerance of the exposure.

1. Doppler ultrasonic bubble detection

The only fully accepted end point of decompression table tests is decompression sickness, DCS. For these excursions we expected few problems with DCS, consequently we needed some means of monitoring decompression stress in asymptomatic divers. While it is by no means a perfect solution, we used doppler ultrasonic bubble detection as a secondary means of assessment. Because it could be managed within the scope of the program we chose precordial detection of venous bubbles in the pulmonary artery. Bubbles detected with this technique do not have good correlation with DCS in the same diver at the same time, but high bubble scores do seem to correlate with tables that have high incidences of DCS. In any case it is non-invasive, could be done reasonably well on these dives, and gives a measure of bubble activity which clearly reflects some measure of decompression stress (Powell, Spencer, and von Ramm, 1982; Thalmann, 1984; Lauckner, Nishi, and Eatock, 1984).

Unfortunately doppler bubble detection is particularly unreliable in saturation diving, and we felt our most likely probability for DCS was in the saturation decompressions.

Monitoring was done with a Spencer (Institute for Applied Physiology and Medicine, Seattle) battery powered continuous wave doppler unit Model 1032G operating at 5 mHz and focussed at 5 cm. These units have been shown to operate well at pressures in our range, and offer no particular hazards. We are grateful to the Naval Submarine Medical Research Laboratory for the loan of these units.

The output jack of the unit in use in the chamber was connected through a penetrator to a commercial hi-fi cassette recorder/player. Each diver placed his/her own probe, and both the diver and the topside investigator listened to the signals. Because both were wearing the doppler headsets they could not use the normal communications system, so we rigged a light shining through a viewport so that it could be controlled by a household dimmer switch operated by the investigator. This way when the probe was not right the light was dim, as it got better the light was brighter, and when the signal was what the investigator wanted he turned it on full bright. This greatly simplified the process; it resulted in good signals, and because it made each reading fairly quick neither the divers nor the investigators got too impatient with this normally tedious activity.

The recordings and grading were performed by a diving medical officer trained by the Spanish Navy, but of relatively limited experience (J.A. Amat, MD, PhD). He spent a few days with the IAPM and DCIEM training tapes and reached a point of high scores on these, and reasonable confidence. Thus one person did all the recordings and all the grading. Another investigator checked many of the scores and had no disagreements with them.

We chose to monitor every 45 minutes after the beginning of decompression. Since 4 divers had to use the same equipment we scheduled readings at 40, 85, and 130 min after the divers left bottom, and took the readings in the next 10 or 15 min following that. The divers took readings in the same order (1, 2, 3, 4) each time. Each held the probe for 30 sec of good recording, then did a deep knee bend and took another "flex" reading. During saturation decompression readings were taken three time a day at 0830, 1430, and 2200. The first impression results of each reading were written on a form and the signals were recorded. Each was rechecked later and a final score given on the subjective judgement of the analyst. We used the Spencer code (Spencer, 1976).

It was not possible to get all three readings on many occasions. The main reason was that in many cases the divers were off on another excursion before the third and in many cases before the second reading could be obtained. On the nights when diving went until midnight with an excursion starting at 0800 the next morning we required only the first two readings. And on a few occasions equipment problems made the readings either impossible or unsatisfactory. After one string of trouble, what we thought was battery problems turned out to be a loose spring clip inside a BNC connector.

We plotted the bubble grades on a scale of 0, 1, 2, or 3 (there were no 4's), showing each measurement and each score on a graph with the entire dive profile.

2. Questionnaires and subjective comments

To get a daily assessment of both the condition and feelings of the divers we used a questionnaire derived from those developed by Vaernes and colleagues (Ellertsen, Hammerborg, et al, 1982). It was given to the divers at supper time and was to be filled out by bedtime. The questions are directed at the types of problems divers have been known to have on long saturation dives. Some questions are directed at high pressure effects, but others cover most of the DCS symptoms likely to be encountered. A sample of the questionnaire used is given in the Results section to facilitate interpreting the answers. No performance tests were done.

Several questions were intended to call attention to any symptoms of pulmonary oxygen toxicity, and we also tried to assess the divers' sleep status. In many complex experimental deep dives the divers have been so exhausted that it has been impossible to segregate effects of the dive environment from those of lack of sleep.

In addition to the questionnaires the divers were encouraged to tell any symptoms to the operators for entry in the log, and there were daily short conversations with the supervisors and the investigators. There was a cursory daily medical check as well.

F. Doing the dives

1. Chamber management

Because there were only two main chambers it was necessary to do some manipulations in order to accomplish all the gas changes, etc., and still be able to look after the safety of the divers. The basic rule was that all time spent at habitat depth should be at a near-normoxic PO_2 of 0.32 atm, and all time spent on excursions should be on air. To be realistic the changes had to be relatively abrupt, as would occur in a seafloor habitat when divers doff and don their breathing gear. This was accomplished with no significant deviations.

Generally the DDC was kept at 0.32 and the igloo was air. The divers would make a quick transfer, then both atmospheres would be corrected if necessary. This was good for short excursions, but for longer ones it was desirable to have more room, so this change was made at first, then the DDC was converted to air (by adding oxygen) and the hatch could be opened making both chambers available. Sometimes the divers used the mask breathing system while changes were being made. Any time there was a possibility of a hypoxic atmosphere or the incorrect mix during a switch they went on mask. At night the igloo was switched to normoxic and both were available.

Typically the temperature ranged between 70 and 78 F, with relative humidity 65-75% (75-85 in Repex I). The divers were comfortable most of the time.

2. Living arrangements

The four divers slept wherever they were comfortable. There was room, theoretically, for four bunks in the DDC, but these were crowded so the igloo was used also. One diver usually used a hammock, and on one dive a diver slept in the tunnel between the chambers.

There was a shower in the igloo, with hot water. A chemical toilet was put in the outer lock on request.

Meals were obtained from local delicatessens and restaurants. This was one aspect of the schedule that was often not done on time. Meals were scheduled to be eaten at a time when the divers could take a break for a few minutes; some were to be eaten during excursions.

No attempt was made to control or monitor diet, but the divers were given all the fluids they wanted and were encouraged to drink as much as they could. One beer was allowed with the evening meal when they were not excursing in the evening.

3. Exercise

Some exercise was performed during all excursions. The exercise consisted of riding an exercise bicycle, or doing situps, chinups, or pushups. A 15-minute session of exercise was performed, more or less, during every full 40-minute period of an excursion.

During a session three divers exercised at one time, one on each exercise, while the fourth maintained communications with Topside. They rotated position every 5 minutes over 20 minutes, such that each could do 15 minutes of exercise during each session.

This is an area where we expected motivational problems, but we got little grumbling and a surprising amount of activity during excursions. We did not attempt to quantify or even to monitor the exercise rigorously, but we are convinced that the activity levels on all excursions was at least equivalent to an observation or sample-collecting dive, and was often a great deal more.

4. Fire drills

To keep divers alert, to remind them constantly of the fire risk in an air-filled chamber, and as a form of entertainment the divers were given periodic (~daily) fire/mask drills. They were to transfer to the other chamber and put on masks as quickly as possible. There was competition, and the last one to get through and get on mask was the goat. The times ranged 10 to 15 seconds. The divers liked this activity.

VII.
RESULTS

A. Saturation-excursion dives performed

This section gives summary data and profiles of the three Repex dives, and specific information on the individual dives and divers.

1. Dive summary

Three week-long saturation dives were done, each with 4 subjects, each with as many excursions as could be done between reaching storage depth and beginning decompression, but allowing reasonable time for sleep. The "statistics" of these saturations are summarized in Table VII-1.

Essentially everything included in the plan was done, with some deviations which are noted in the next section, VII.A.5. The plan gave a representative coverage of the various factors considered in the Repex Habitat Diving Procedures. This included 3 different storage depths spread over the range, excursions scattered over the allowable time-depth range from each storage depth, repetitive dives following all interdive intervals in the tables, submaximal dives followed by repetitive dives adjusted for the unused time, interdive periods spent in the deepest oxygen window range, longer excursions with decompression stops, both 8-hour and 16-hour working days, and a wide range of oxygen exposures. Divers performed moderate exercise on all excursions, doing a 15 minute period of self-paced exercise every 40 minutes. No ascending excursions were done.

Saturation decompression ascent by both 5- and 1-fsw steps was used, and we tried waking the divers every two hours at night or letting them sleep. Two methods of dealing with excursions were used, holding or using a precursory table.

Graphical profiles of the three Repex dives are given in Figure VII-1. Detailed schedules of each saturation are given in Appendixes A and B. The dives were carried out close enough to the schedules that we elected not to include a log; the schedules serve that purpose quite well. Unusual events are covered in the descriptions of the individual dives in section VII.A.2, 3, and 4, below.

The excursions were carried out without significant incident. Compressions were delayed a minute or so on a few occasions for ear clearing or to seal a hatch, but in no case enough to affect the decompression pattern; all bottom times were essentially as planned. No symptoms of DCS were noted following any excursions, but one diver had pain-only symptoms at 10 fsw in the final saturation decompression from Repex 1. The other two saturation decompressions were clean.

Table VII-1. Repex dive summary

Operation:	Repex I	Repex II	Repex III	Total
Saturation depth, fsw pressure:	50	80	110	
Number of divers:	4	4	4	12
Sex:	M	F	M	
Number of hours at depth:	128*	109	112	349
Number of excursions:	22	23	15	60
No-stop	14	16	12	42
One-stop	5	4	2	11
Submaximal	3	3	1	7
Diver-excursions:	88	92	60	240
Excursion decompressions**:	22	22	14	232
Hours on excursions:	27	26	22	75
Diver-hours on excursions:	108	104	88	300
Hrs in saturation decompression:	37.6*	53.4	84.1	
Excursion depth range, fsw:	95-220	140-240	180-240	95-240
Excursion time range, min:	10-307	13-240	12-240	10-307
CPTD, total	1844	2989	3321	
CPTD, daily average (PO_2 >0.5)	326	584	529	
Days exposure for CPTD average	5.7	5.1	6.3	
DCS after excursions	0	0	0	0
DCS, saturation decompression	1	0	0	1

Age range 19 to 62
Weight range 100 to 235 lb, mean 162 lb.

Notes:

* Repex I includes an additional 10.1 hr to complete prescribed DCS treatment regimen.

** On Repex I the divers held at storage depth for 12 hr after the last excursion before beginning decompression; on the last excursions of Repex II and III the divers did not decompress back to habitat depth, but instead started the saturation decompression from the excursion.

Meals were not necessarily served at the times given in the schedule. It was up to the topside crew on duty to arrange for meals, and there always seemed to be some excuse as to why it could not be done on schedule. The divers got to order their meals so were generally pleased with the food once it arrived. The food system got off to a slow start, so there were some rightful complaints during Repex I.

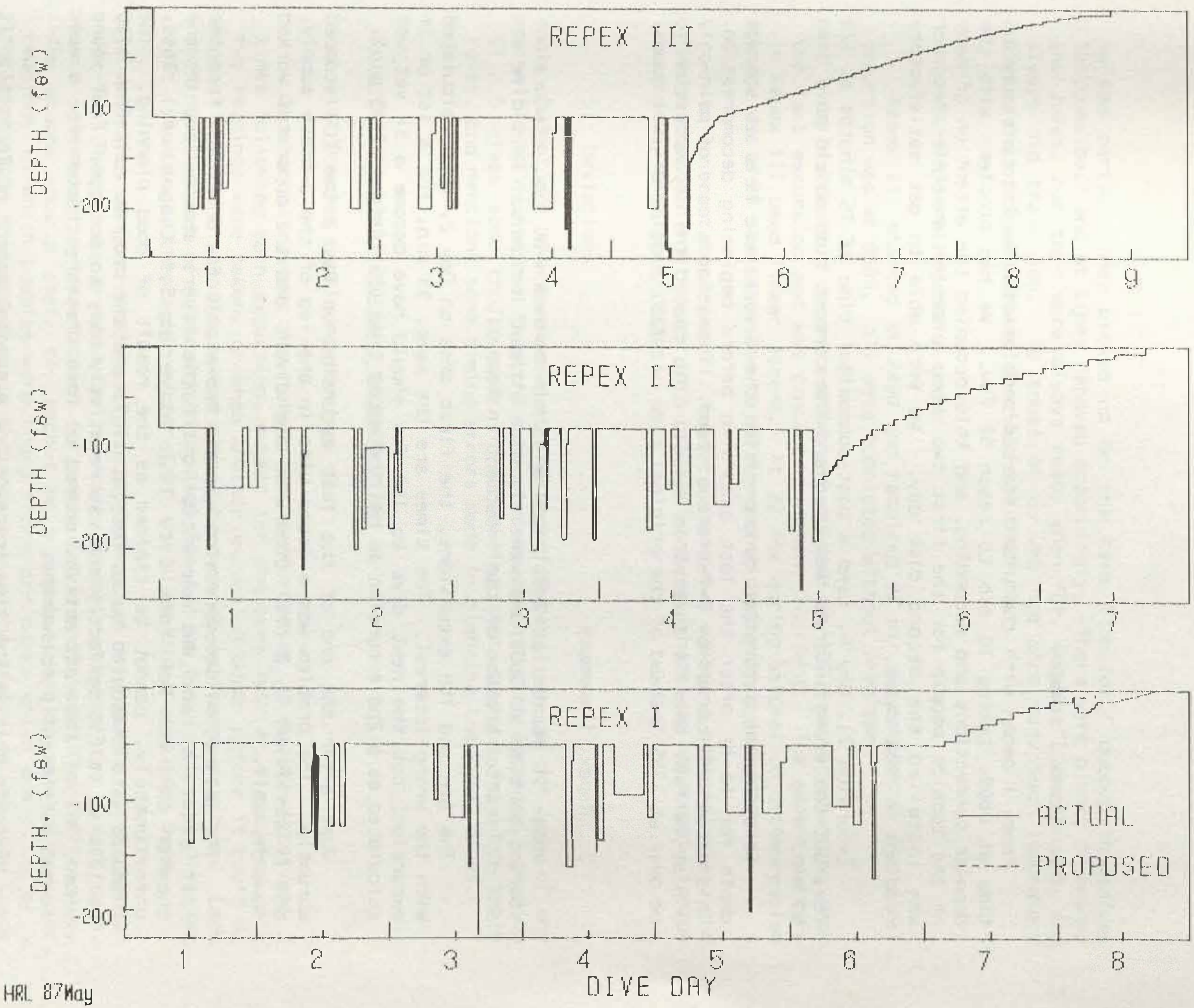


Figure VII-1. Profiles of the Repex dives.

2. Repex I summary

Repex I began with the usual startup problems but went to pressure on time at 0800, taking 10 min to reach 50 fsw. We had problems with the doppler connections and recording, and this occupied the attention of many of the topside people for the first two days; a better amplifier/recorder was installed the second dive day. We were able to get satisfactory readings in most cases.

Excursion 21, Day 6, used a post-submaximal time of 76 minutes at 120 fsw, but the wrong interval was used and the correct time should have been 57 min.

To start the saturation decompression the divers were held at storage depth for 12 hr after the last excursion before beginning decompression. This decompression was by 5-fsw stage steps. There was a case of pain-only DCS at 10 fsw; this is covered in VII.C. This caused the decompression to be over at 1735 instead of the original time of 0725, a delay of 10.1 hours.

3. Repex II summary

Repex II started at 2400, taking 45 min to reach 80 fsw. Excursions started on time at 0800 and were all done without incident. This dive was one day shorter because of the treatment in Repex I.

The 6th and 7th excursions, the first ones on Day 2, were calculated with the wrong interval. The times are the same, 33 min, for a 1st or 3+ excursion, but the next dive to 180 fsw should have become a 3+ yet was calculated as a 2nd excursion so has the wrong time (35 instead of 15 min).

Just after the end of the last excursion on Day 2 the ECU stopped abruptly. The problem was a loose wire in one leg of the 3-phase supply, and it was fixed in 2 hr. Otherwise the divers and the apparatus worked superbly well.

The saturation decompression was started at 130 fsw on return from the last excursion and was uneventful until the divers stepped out of the chamber on live New York City TV, "Alive at 5," Channel 4. This, unfortunately, cannot be claimed as the result of good planning. The chambers were scheduled to surface at 1717, and the program runs from 1700 to 1730 so it fit perfectly and was relatively easy to arrange. Four young women, all of them attractive, cooped up in a pressure chamber for a week seemed sufficiently newsworthy.

Perhaps this is the time to report on a special aspect of Repex II. It was a fortuitous mix of personalities that created a most delightful as well as effective crew. Two of the girls had known each other beforehand, and the other two fit in perfectly with them. They quickly became good friends, and despite the steady string of demands made on them by Topside, the investigators, and the schedule they treated the whole experience as a long pajama party. They picked up on the term "Topside," dubbed themselves "Bottomside," and at times behaved accordingly. There were plenty of pranks and jokes, but they were always ready when "Dr. Doppler" came around, and always did their job. To those of us who had done many such laboratory dives, this one was really special, the best ever.

4.e Repex III summarye

Repex III started at 2400 and required 32 min to compress. The first excursion was at 0800. All were completed without problems.

The saturation decompression was started at 155 fsw on returning from the last excursion and was completed without incident. The ascent pattern in Repex III used linear ascent. At 22 fsw during saturation decompression there was a 30 sec excursion to 18 fsw coincident with a lock change.

In contrast to Repex II, this crew had two clashing personalities, and though they did their work in a professional way there was noticeable inside tension by the later stages.

5.e Deviationse

Except for the treatment at the end of Repex I, we do not know of any significant deviations from the schedules as given in the appendix. Section VI.A.5 gives some choice made in scheduling that deviate from the table rules, and mentions some timing errors made in planning the Repex dives.

B.e Assessment of excursion decompressione

1.e Doppler bubble monitoringe

Doppler ultrasonic monitoring was performed at 45 minute intervals 3 times following each excursion, except for the ones late at night when only two readings were taken, or when another excursion began before it could be done. Occasional readings were missed because of equipment problems. Each reading consisted of listening/recording for 1/2 to 1 min with the diver at rest (standing), then again right after the diver did a deep knee bend.

Results of the doppler monitoring are given in Figures VII-2 through VII-7. The graphs are all in the same format, and show two divers each, with a rest and a "flex" graph for each, and a profile of the entire dive. The graphs show a small tic each time a doppler reading was taken. For readings in which bubbles were heard there are marks which are 1, 2, or 3 "grades" high, measured against the left axis. The graphs do not show Grade IV because this level was not encountered during Repex.

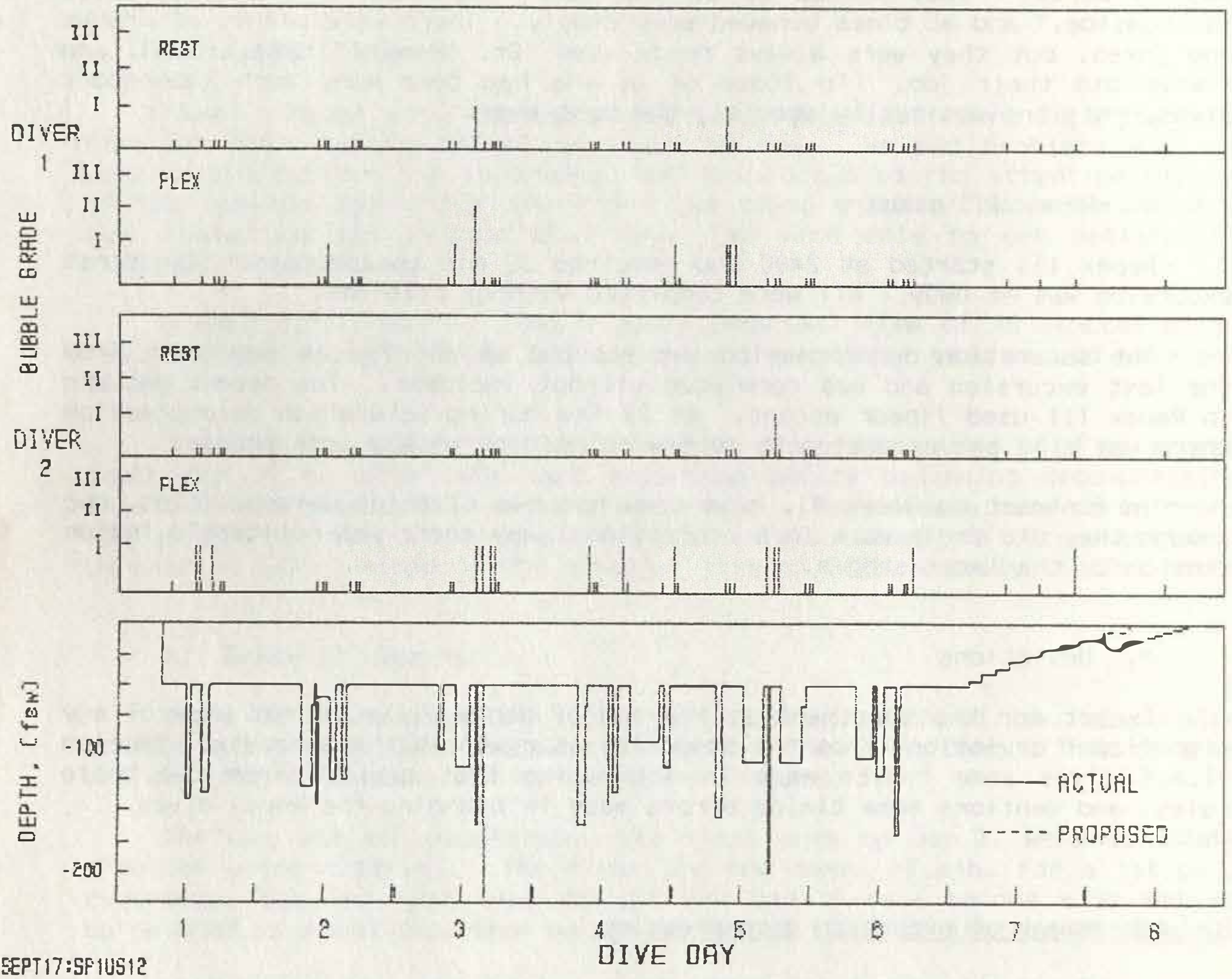


Figure VII-2. Repex 1 doppler scores, Divers 1-1 and 1-2

Only one doppler reading reached a level of III on the Spencer scale, but there were several Grade II's and numerous Grade I's.

There were a few readings during the saturation decompression that resulted in doppler grades of 1 or higher. These were not high or prevalent enough to be of concern, but do indicate that a stressful decompression is in progress.

On inspection these levels were exactly what we had targeted, feeling that significantly lower scores would indicate too conservative tables, and the converse, even if no DCS had been encountered we would not have been happy with excessive bubble scores. Therefore the doppler readings suggest that the excursions are about right in decompression stress.

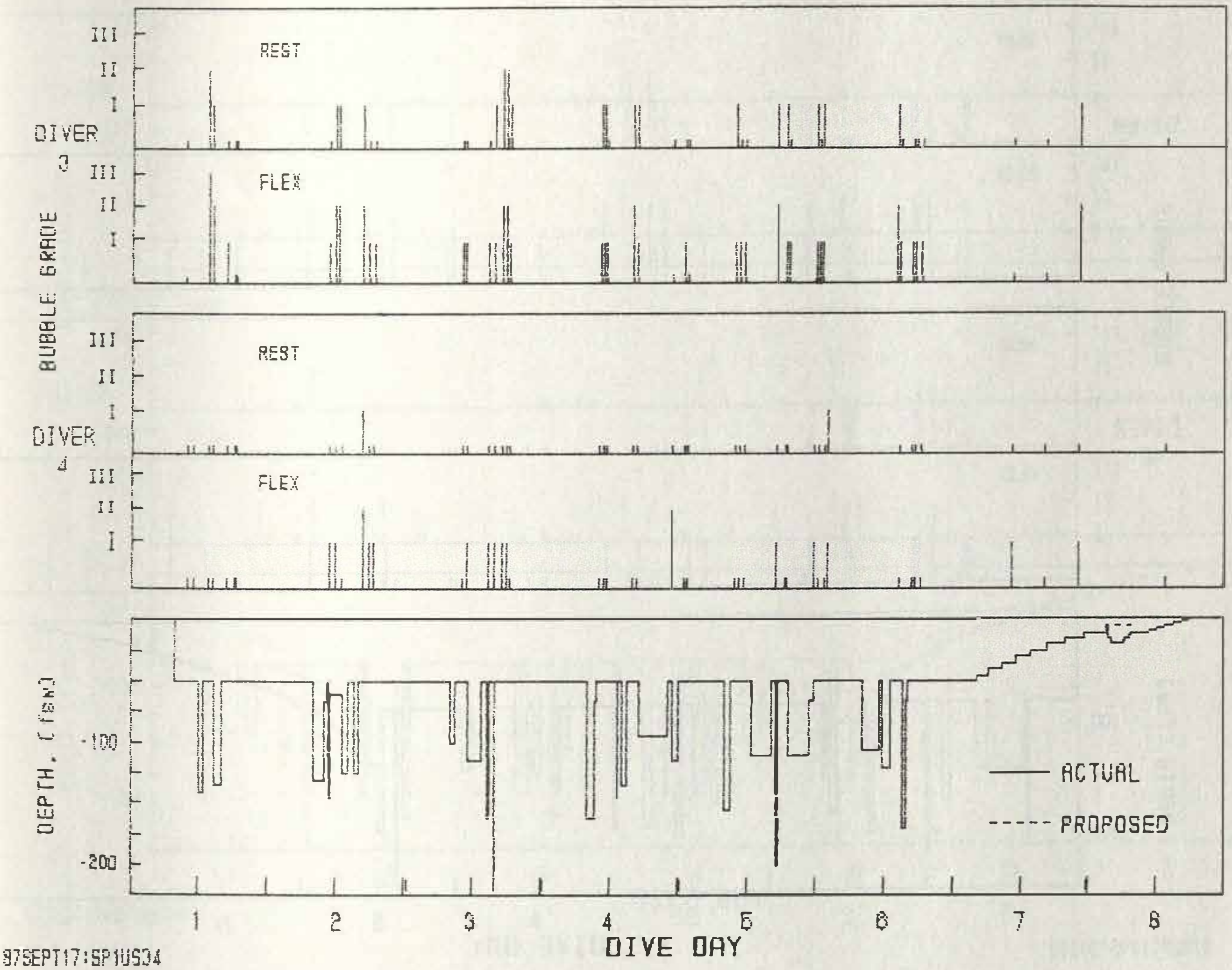


Figure VII-3. Repex I doppler scores, Divers I-3 and I-4

Divers I-3 and II-1 seem to be "bubblers," as they have more and higher scores than the others. Diver I-3 had the DCS at the end of saturation decompression.

No pattern is evident in the doppler data. In an effort to see if there were patterns that could shed some light on the decompression stress of different types of excursion we put the doppler results in a data base program (Reflex, by Borland) for analysis. The scores were grouped by first, second, or third doppler run after the excursions, by Repex dive, and by combinations. These were plotted for interval time, bottom depth, differential depth, and bottom time, all against doppler scores (rest and flex averaged, recognizing that this is considered by some to be statistically invalid; Nishi and Eatock, 1987). Scatter diagrams were produced for a variety of combinations.

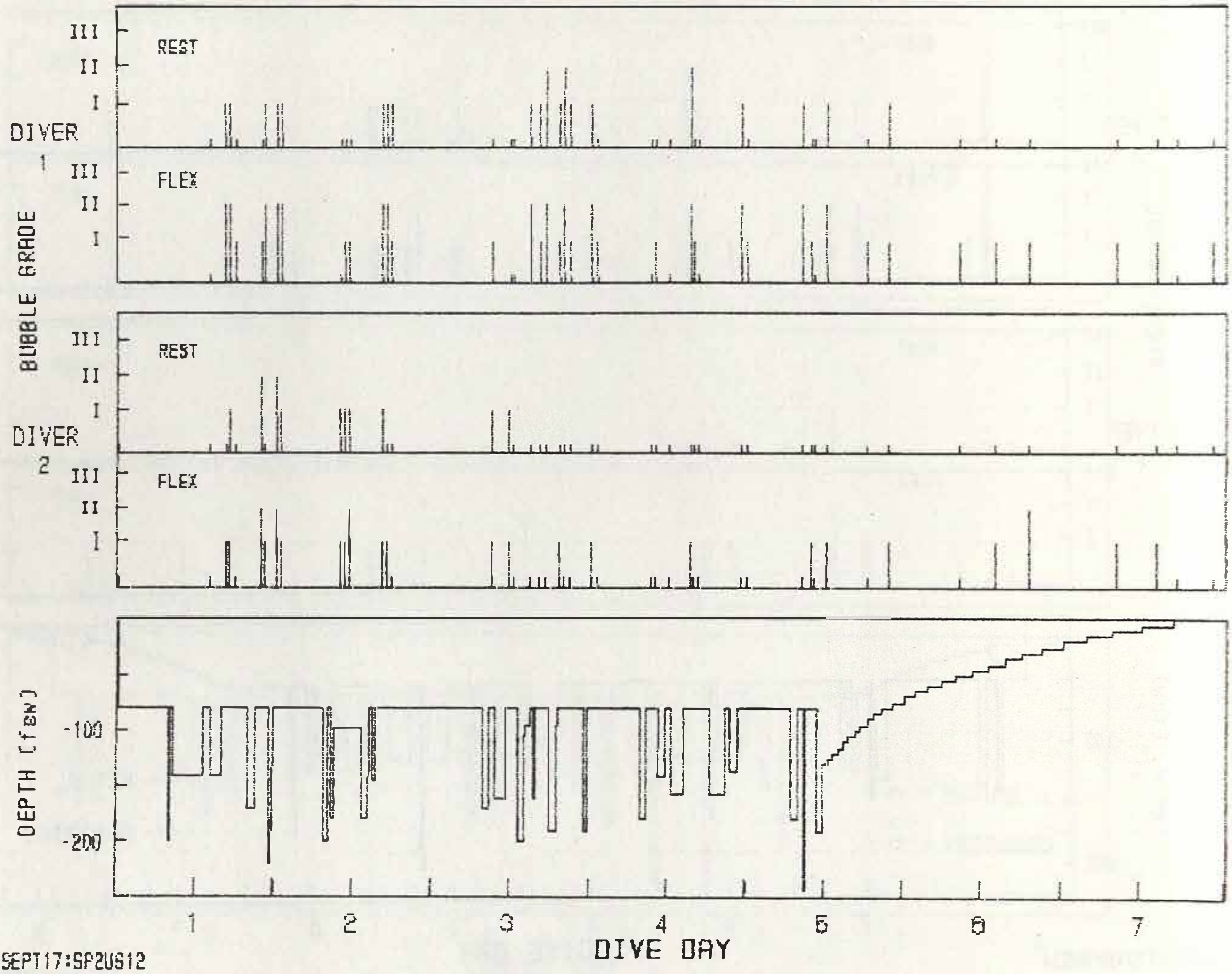


Figure VII-4. Repex II doppler scores, Divers II-1 and II-2

The results of this analysis showed an almost total lack of correlation of any of the plots. There was no point in trying to perform a proper statistical analysis on plots with the types of scatter seen. Part of this is due to the relatively limited amount of data, since there were few high scores. The only plots that showed any hint of a valid relation was a slight negative regression of average score against bottom time. That is, the scores were lower for the longer bottom times. This could be interpreted to say that the higher doppler scores were from the shorter excursions. These would be the deeper ones, ones that showed the problems for which the matrix was adjusted in preparing these new tables.

With practically no grades above II and these well distributed we conclude that the doppler bubble detection supports that these excursions were without significant decompression stress.

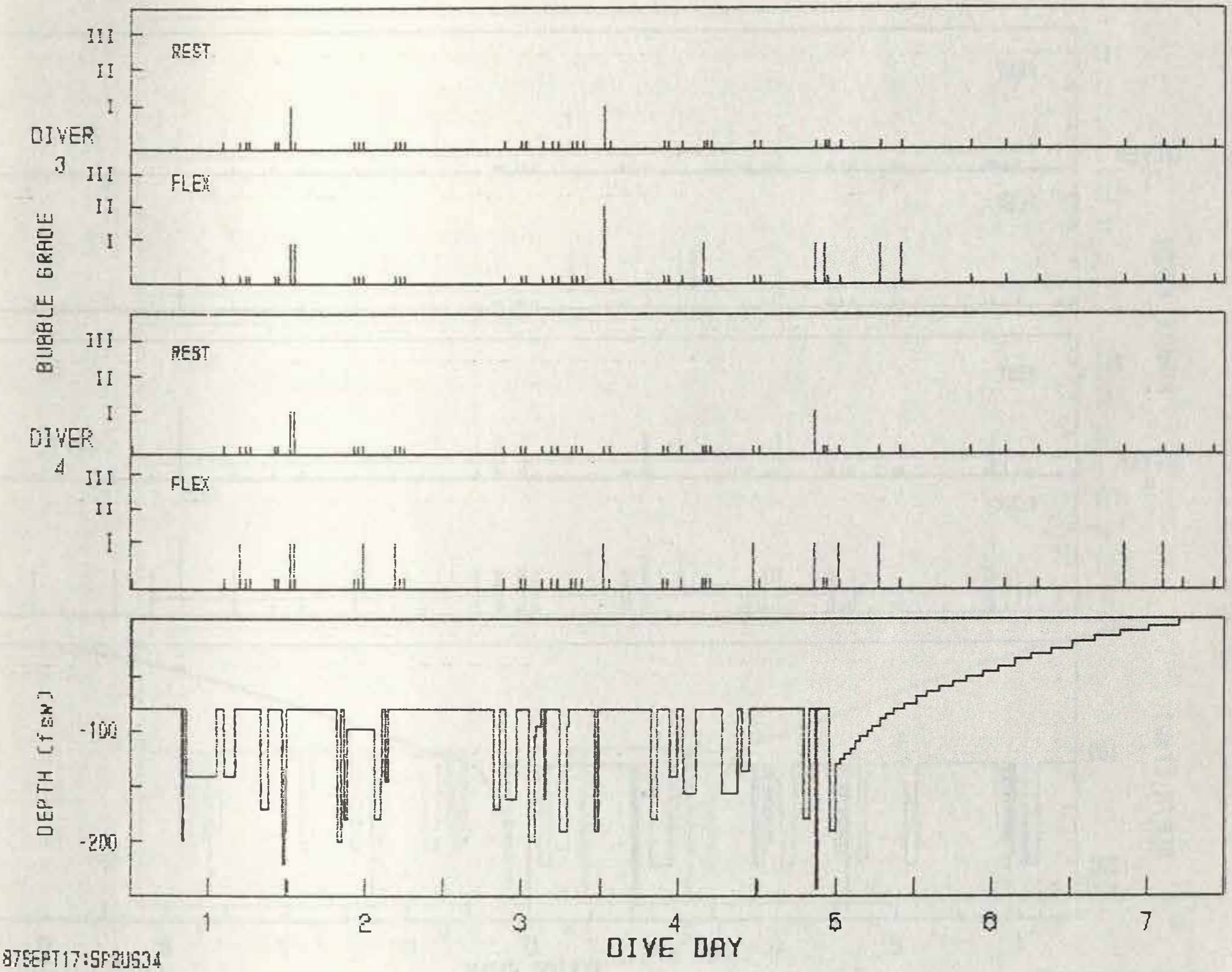


Figure VII-5. Repex II doppler scores, Divers II-3 and II-4

2. Subjective reactions to excursions

With the relative barrage of excursions we were nervous at first about whether the algorithms would work. From the subjective responses of the subjects in all three dives we saw no reason to question the reliability of the excursion profiles. Some mentioned itching after excursions, but it was short-lived and soon forgotten. Some of the pains were not affected by going to pressure on the next excursion, nor were they exacerbated by subsequent decompressions. There were a few aches and pains, some with characteristics of DCS, but none stood up as being DCS. Otherwise none persisted enough to be even seriously suspected of being DCS.

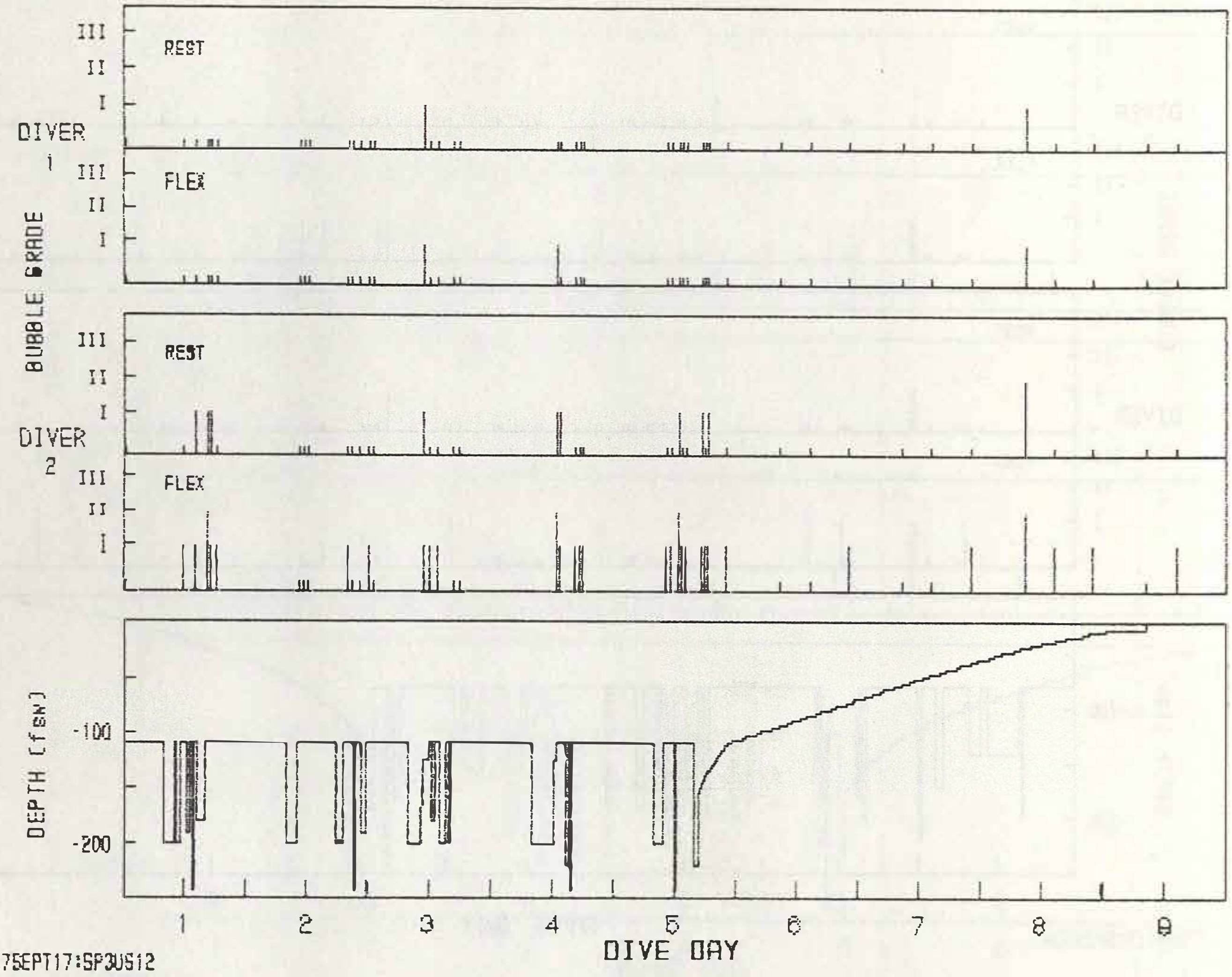


Figure VII-6. Repex III doppler scores, Divers III-1 and III-2

Nor did the subjects feel any of the subclinical characteristics like "niggles" or excessive fatigue. These were not experienced "decompression divers" (who may speak of feeling bubbles in their circulation), but with the intense scene of awareness that prevailed we feel that had these been at all prominent they would have been mentioned. Plenty of other more trivial symptoms and "awarenesses" were not only mentioned but were blown out of proportion.

No one reported the "extreme fatigue" that often accompanies inadequate but asymptomatic decompression.

We could see no other result than that the excursions were well tolerated.

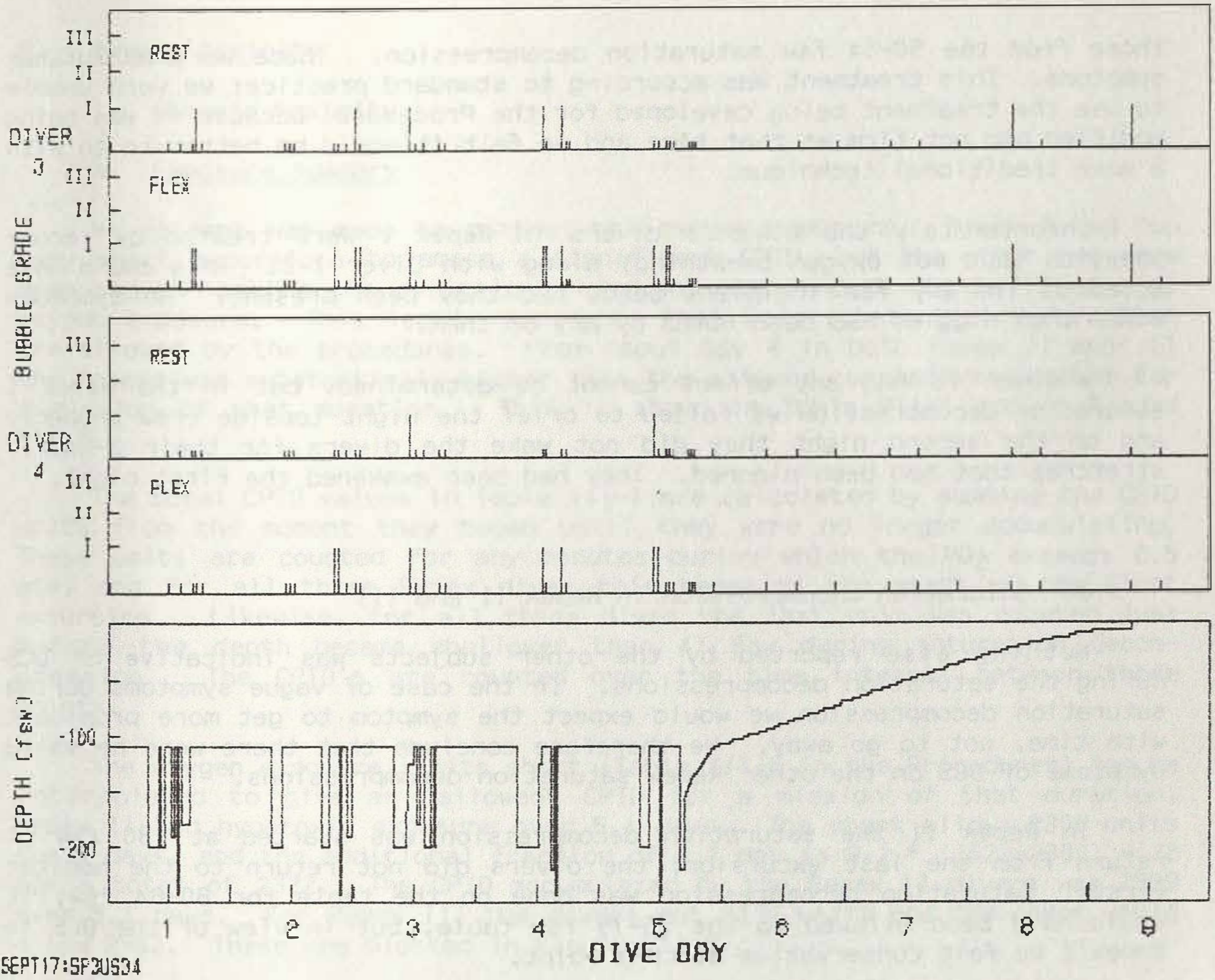


Figure VII-7. Repex III doppler scores, Divers III-3 and III-4

C. Saturation decompression

1. Repex I DCS

On ascent from 10 fsw to 5 fsw Diver I-3 reported bilateral knee pain, with the left knee worse (pain level 4 or 5 out of 10). He was recompressed within 17 minutes to 15 fsw, went on oxygen, and pain was reduced to level 1 within another 16 min. For the second 20-min cycle of oxygen the chamber was compressed further to 20 fsw, and the remainder of the 6 cycles were completed at that depth. Minimal sensations were noted at the end of the 2nd cycle and were completely gone by the end of the third. The chamber was decompressed to 10 fsw at 12 min/fsw, held at 10 fsw for 2 hr, decompressed to 5 fsw at 47 min/fsw, then to the surface at 54 min/fsw. These rates are those from the 50-54 fsw saturation decompression. There were no further symptoms. This treatment was according to standard practice; we were unable to use the treatment being developed for the Procedures because it was being modified and not firm at that time and we felt it would be better to go with a more traditional technique.

Unfortunately the other 3 divers in Repex I were treated by recompression (but not oxygen breathing) along with Diver I-3. This could have acted as therapy for incipient bends had they been present. No symptoms other than niggles had been noted by any of them.

Whether it had any effect cannot be determined, but in the Repex I saturation decompression we failed to brief the night topside crew properly and on the second night they did not wake the divers for their 2-hourly stretches that had been planned. They had been awakened the first night.

2. Saturation decompression in Repex II and III

Nothing else reported by the other subjects was indicative of DCS during the saturation decompressions. In the case of vague symptoms during saturation decompression we would expect the symptom to get more prominent with time, not to go away. We therefore conclude that there were no valid symptoms of DCS on the other Repex saturation decompressions.

In Repex II the saturation decompression was started at 130 fsw on return from the last excursion; the divers did not return to the habitat first. Saturation decompression was done on the table for 80-84 fsw; it would have been allowed to the 75-79 fsw table, but in view of the DCS in Repex I we felt conservative at this point.

Diver II-1 felt "pins and needles" for a while at 10 fsw, which cleared up and was not present the last 3 hr of decompression.

The Repex III saturation decompression was carried out in 1-fsw stages (as an example of linear ascent, the "continuous bleed" method), beginning at 155 fsw on return from the last excursion. It had been intended that this dive would have the divers go back to the habitat for 5 min and then recompress to the starting depth, but we overlooked putting it on the schedule that way. This decompression used the 105-109 storage depth as allowed by the tables; this table is found in Appendix C.

Due to another error in preparing the schedule the 15 fsw of ascent between 110 and 95 fsw was at 38 min/fsw and it should have been at 21, 22, and 23 min/fsw. This added 240 minutes of decompression time to the schedule.

Diver III-3 noted "small aches and pains that come and go" during the final stages of the decompression, and III-1 noted he could feel an old shoulder injury at about 18 fsw. There were a few other niggles.

D. Oxygen toxicity

1. Chronic toxicity

a. Exposure summary

No attempt was made to control the oxygen exposure. Repex I had too many short excursions to amass a significant CPTD, but the other two were deep enough--making the excursions long and deep enough--to build up some oxygen exposure. This led to exposures that were substantially more than are allowed by the procedures. From about Day 4 in both Repex II and III the dosage was substantially higher than the allowed cumulative exposure for a mission of that duration. This is shown in Table VII-1 and in Figure VII-8.

The total CPTD values in Table VII-1 are calculated by summing the CPTD units from the moment they began until they were no longer accumulating. These units are counted for any minutes during which the PO_2 exceeds 0.5 atm, and for all three Repex dives this began at the start of the first excursion. Likewise, for all three dives the last unit was counted just before the depth became shallower than 47 fsw during saturation decompression. The CPTD's are counted over the time interval between those points.

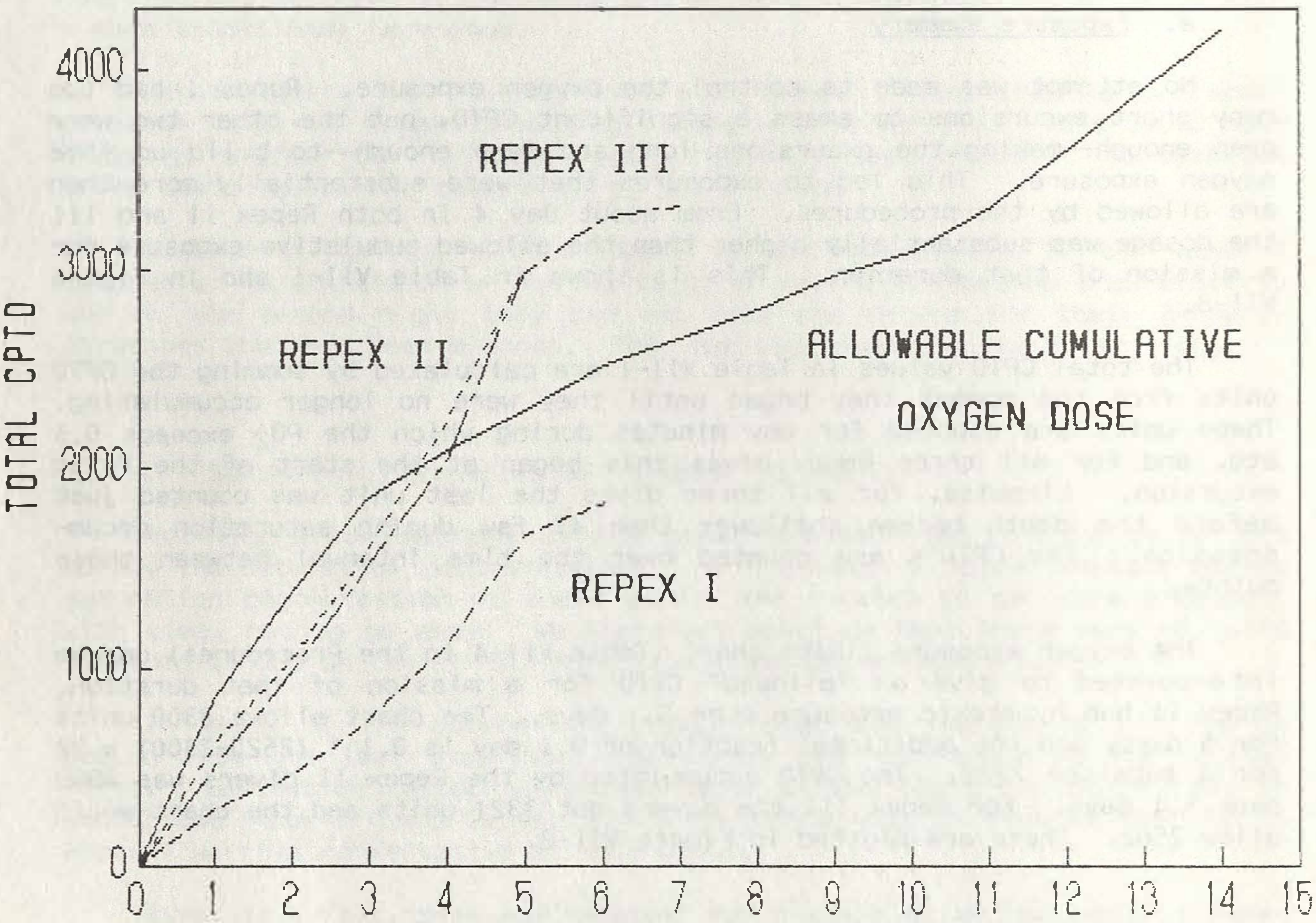
The oxygen exposure limits chart (Table VII-4 in the Procedures) can be interpolated to give an "allowed" CPTD for a mission of that duration. Repex II had hyperoxic exposure over 5.1 days. The chart allows 2300 units for 5 days, and the additional fraction of 0.1 day is 0.1 * (2520-2300) = 22 for a total of 2322. The CPTD accumulated by the Repex II divers was 2989 over 5.1 days. For Repex III the divers got 3321 units and the chart would allow 2562. These are plotted in Figure VII-8.

b. Symptoms and comments

During the early part of the decompression from Repex III Diver III-4 had mild substernal pain when asked to breathe deeply and think about it. He said he "probably would not have noticed it" if he had not been queried. (He probably would have.) Likewise both Divers III-1 and II-2 noted "chest tightness" just before the point where they went from air to the 0.5 nitrox.

Although the Repex II and III divers had mild but definite symptoms of pulmonary oxygen toxicity under examination, these were not the subject of complaints, and in general the divers were completely tolerant of them.

These symptoms we would consider operationally acceptable, and in fact it was the level we were shooting for (we hoped for mild symptoms in perhaps one diver out of four from the most severe exposures, which are well over the limits).



Exposure duration, days

Figure VII-8. Cumulative oxygen exposure of Repex dives

The solid line is the allowable dose from Procedures, Table VII-4.
The dashed lines show the CPTD accumulation of the Repex dives.

2. CNS toxicity

The Repex II divers had three 1-hr exposures in the 180-200 fsw range. The Repex III team spent one 4-hour excursion breathing air at 200 fsw and several others in the 2 to 3 hour range at that depth, providing some good additional evidence that this exposure is tolerable. No symptoms of CNS toxicity were reported.

E. Tolerance of the exposures

The main focus of the program was to develop decompression techniques, but we had the opportunity to assess the physiological effects of the exposures--the saturation/excursion dives--as well. This was done by reports by the divers to the topside control, daily or occasional discussions with the medical director or investigators, or by daily questionnaires, but without blood sampling or performance testing.

The summaries of the subjective questionnaires follow. Those symptoms that belong primarily with the special topics of oxygen toxicity and DCS are mentioned in those sections.

1. Results of questionnaires and comments

Questionnaires were filled out for all dive days by all divers. A sample of the questionnaire is found in Figure VII-9. The questionnaire gives the diver the opportunity to mention a feeling earlier in the day that might not be present at the time the questionnaire was filled out. They did not take advantage of this very much, but it does not really matter because we wanted to know the things they felt and in the long run did not care much when it was present as long as they reported all symptoms.

To display the answers we put the results into miniature bar charts for the four divers on each dive day. These results are given in Figures VII-10 to VII-12, and a legend is given as part of Figure VII-9B. For each question on each dive day there is a place for 4 bars, covering the divers in order from left to right. Each bar has 5 possible responses: None, slight, some, much, a lot. These are shown by bar heights; no bar at all means the question was not answered.

At the end of the second page of the questionnaire are two questions intended to look for lung or airway irritation that might signal pulmonary oxygen toxicity, and two that seek to determine the amount of sleep at night and during the day, plus a question asking if they felt well rested. This latter question has blocks showing a no-yes answer. To save space we left three questions off the charts, ones with only one answer (there was at least one positive answer to all of the questions). These are tremors, difficult urination, and numbness or numb fingertips. Diver I-2 checked slight tremors in the pre-excursion questionnaire on Day 1, numbness on Day 8, and difficult urination on Day 3, all at the "slight" level.

NOAA-HRL-IUC REPEX DIVER STATUS QUESTIONAIRE page 1 of 2

Diver________________ Date__________ Time: scheduled______ done _____

Circle each item describing your status now. If your condition was different during the last 24 hr, please underline the term and tell when it was most extreme. If the choices are not sufficient, write-in votes are acceptable. If there are two parts to the question please circle the one that applies. "Some" means present but not of operational significance.

Do you **now** feel...	**Euphoric**	none	slight	some	much	a lot	When did you?________
	Narcotized	none	slight	some	much	a lot	When did you?________
	Dizziness or faintness	none	slight	some	much	a lot	When did you?________
	Headache	none	slight	some	much	a lot	When did you?________
	Nasal congestion	none	slight	some	much	a lot	When did you?________
	Upset or unsettled stomach	none	slight	some	much	a lot	When did you?________
	Skin itch	none	slight	some	much	a lot	When did you?________
	Difficulty concentrating	none	slight	some	much	a lot	When did you?________
	Unusual tiredness or fatigue	none	slight	some	much	a lot	When did you?________
	Appetite	none	slight	some	much	a lot	When did you?________
	Itching or pain in an ear	none	slight	some	much	a lot	When did you?________
	Malaise or lack of incentive	none	slight	some	much	a lot	When did you?________
	Nausea	none	slight	some	much	a lot	When did you?________
	Coughing spells	none	slight	some	much	a lot	When did you?________
	Dyspnea or breathlessness	none	slight	some	much	a lot	When did you?________
	Visual disturbances	none	slight	some	much	a lot	When did you?________
	Weakness	none	slight	some	much	a lot	When did you?________
	Sore or dry throat	none	slight	some	much	a lot	When did you?________
	Chest tightness	none	slight	some	much	a lot	When did you?________
	Pain in a joint	none	slight	some	much	a lot	When did you?________
	Pain, not in a joint	none	slight	some	much	a lot	When did you?________
	Tremors	none	slight	some	much	a lot	When did you?________
	Sleepiness	none	slight	some	much	a lot	When did you?________
	Sweatiness	none	slight	some	much	a lot	When did you?________

Figure VII-9A. Sample questionnaire, first page

Cramps or muscle aches none slight some much a lot When did you?________

Diarrhea or constipation none slight some much a lot When did you?________

Temperature discomfort (C H) none slight some much a lot When did you?________

Arthralgia in joints none slight some much a lot When did you?________

Skin tingling or paresthesia none slight some much a lot When did you?________

Irritability none slight some much a lot When did you?________

Difficult urination none slight some much a lot When did you?________

Boredom none slight some much a lot When did you?________

Happiness none slight some much a lot When did you?________

Numbness or numb fingertips none slight some much a lot When did you?________

After a full exhalation, take a **deep** breath and blow it out rapidly; does this cause pain? none slight some much a lot

Or coughing (more than it normally would) none slight some much a lot

How much sleep did you get last night? none slight some much a lot

Did you sleep during the day today? Y N How many hours?____ Are you well rested? Y N

Do you have any other problems, comments, or additional information?

LEGEND for questionaire summary

Each diver answered a subjecive questionaire every day. These are displayed on the charts in Figures VII-11, 12, 13. Each question on the chart has a miniature bar graph for each dive day, and these show the responses of all four divers (divers 1-4 from left to right). The five possible responses (for all but the last two questions) are; none, slight, some, much, a lot and these are represented as bars of unit heights of 1 through 5 respectfully. For example, a bar of height 1 says diver answered question with a "none" answer. No bar indicates that diver did not answer question.


Diver 1 answered "slight"


Diver 2 answered "some"


Diver 3 answered "much"


Diver 4 answered "a lot"

The second to last question asks for daytime hours slept. The possible answers are, for bar heights of 1 through 5; 0 hours (did not nap during the day), up to 1 hr, up to 2 hrs, up to 3 hrs and 4 hrs or more. Thus a bar of height 4 says that diver slept up to 3 hrs. Times given by the divers were rounded to nearest hour. Again, no bar indicates diver did not answer question. The last question asked whether they felt rested, and the possible responses were Yes or No. No bar indicates the question was not answered.

Figure VII-9B. Sample questionnaire, Second page, with legend

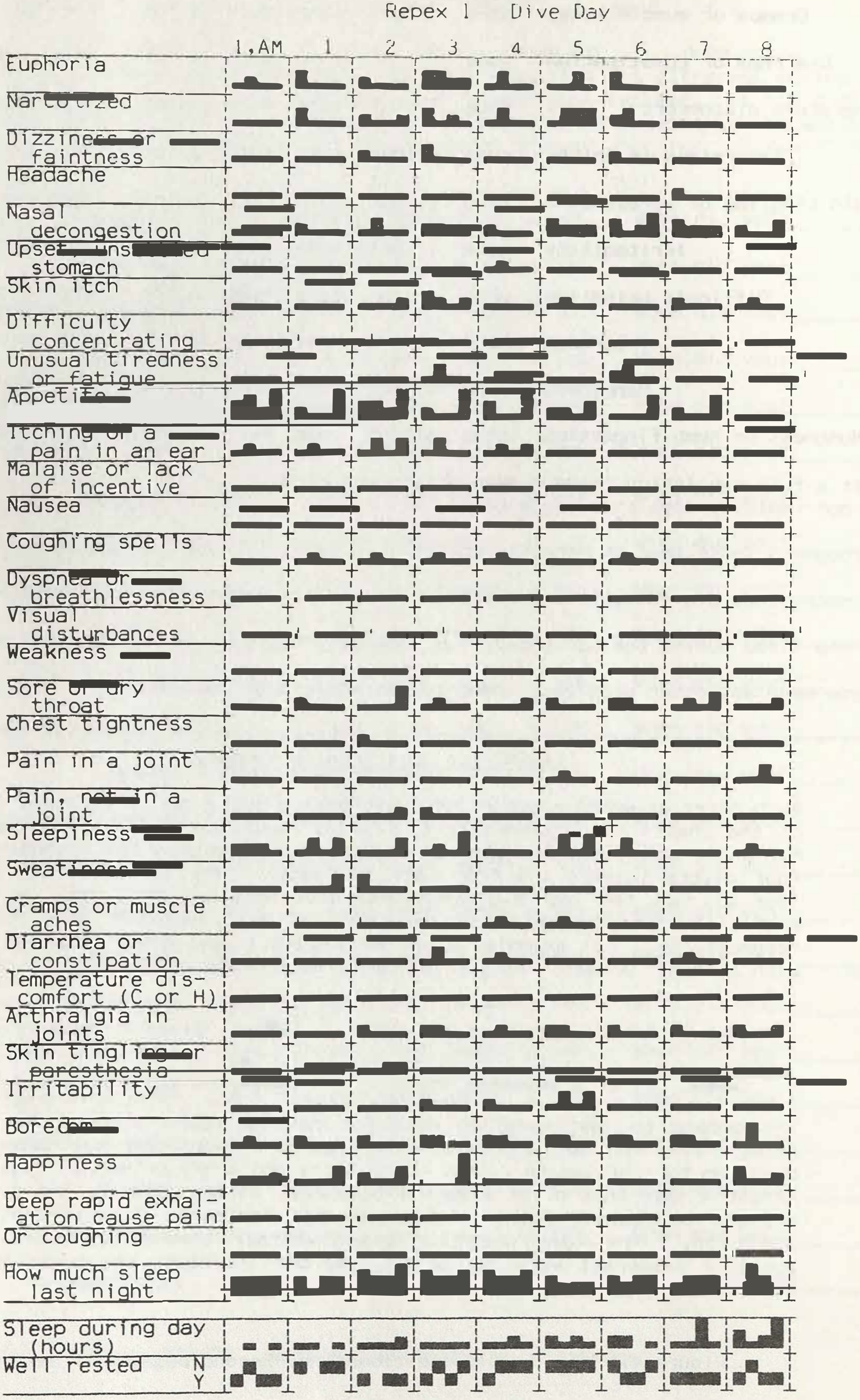


Figure VII-10. Questionnaire results, Repex I

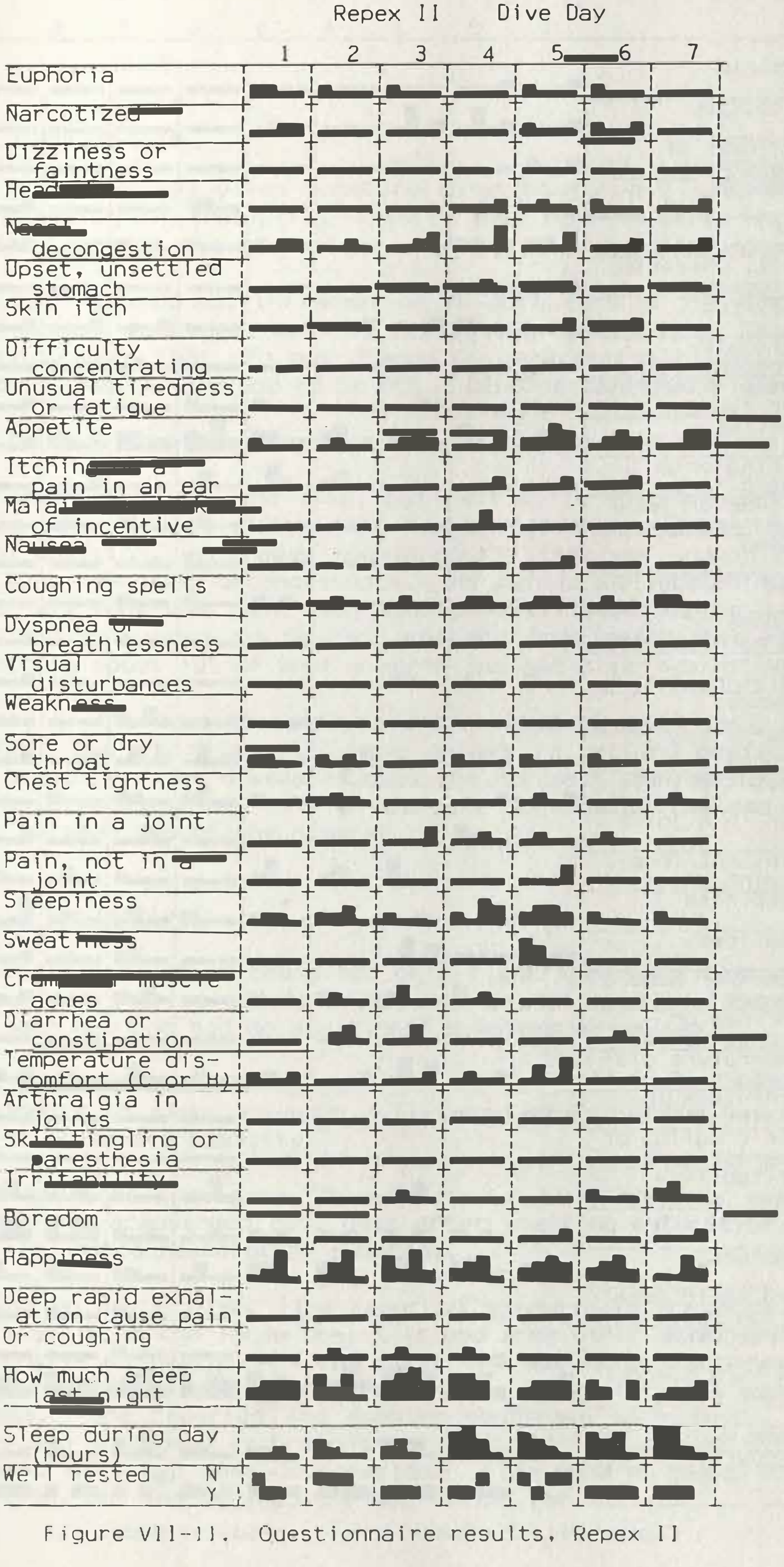


Figure VII-11. Questionnaire results, Repex II

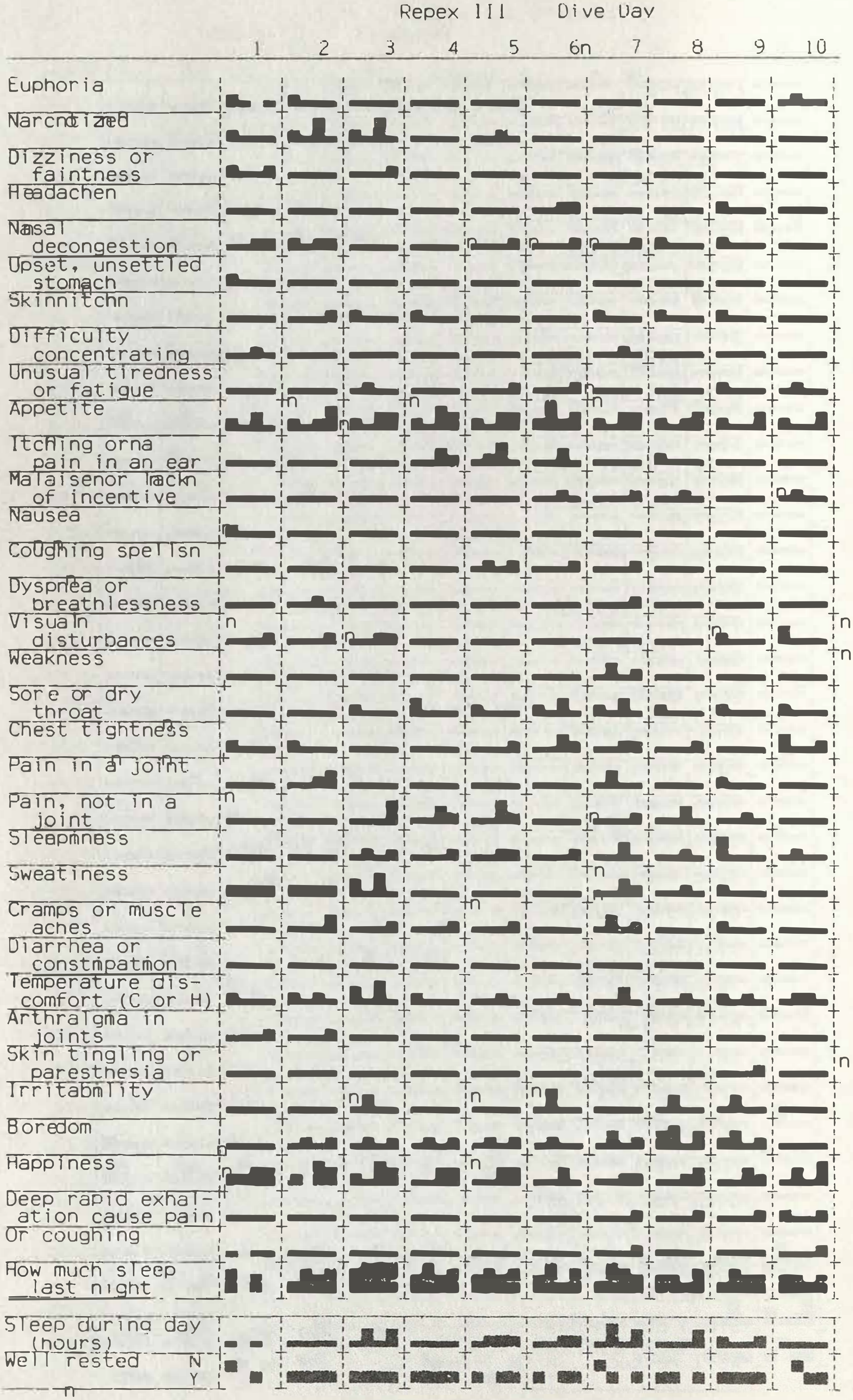


Figure VII-12. Questionnaire results. Repex III

a. Repex I subjective

On Day 6 Diver I-1 was given Domeboro solution for his left ear. He mentioned "tightness" in shoulders, wrists, and legs lasting for 2 min about 10 min after some of the excursions.

Diver I-2 had redness and inflammation in both ears at the beginning, was given Cortisporin, recovered well by Day 4. On awakening on Day 4 this diver had an elbow pain that did not change on compression to 160 fsw; it lasted a few hours, was judged not to be DCS. Decongestants were used.

Diver I-3 had few complaints except that he did not like the music.

Diver I-4 was hungry all the time, but felt quite good throughout the dive. Following Excursion #6 (125/42) he had pain 3 inches above the knee, it responded to position, went away spontaneously, and was judged to be a cramp and not DCS. He used decongestants. He mentioned a "dull ache" on the side of his left foot that went away spontaneously after surfacing. He likes "sat diving" but wants to be paid more (a most reasonable request, since he was getting about 10% of what a North Sea sat diver would).

The comments on the questionnaires are dominated by appetite. This is partly individual, but is related to some delays in getting meals to the Repex I divers promptly. The divers enjoyed the narcosis seen at 160 to 220 fsw. All had nasal congestion. There was some boredom at the end, and a bit of conflict between two of the divers.

b. Repex II subjective

On Day 4 at 1830 Diver 1 complained of a right knee pain that did not persist (an excursion started 15 min later). She also mentioned burping up some fluid the same day but had no additional symptoms or nausea.

Diver II-2 had pain over her eye on compression on the first and second days, due presumably to sinus squeeze. II-2 had dry coughing Day 3, not characteristic of pulmonary toxicity.

Diver II-3 had some problems with muscles due to unfamiliar exercises and more than she was accustomed to. Just after starting saturation decompression Diver II-3 noted respiratory symptoms.

On awakening on Day 2 diver II-4 reported soreness in the arch of her right foot and knuckle of the large toe; this and some other aches and pains were due to exercise at depth. On the first few excursions she described cracking joints typical of hyperbaric narcosis. She also had some ear-clearing problems. She reported and doppler confirmed tachycardia during doppler readings and on a deep excursion; she felt this was due to difficult breathing by mask, also had nasal congestion. (The problem might not have been the congestion, but the Sudafed she was taking for it!)

They felt good, were mildly narcotized, after initial compression to 80 fsw.

The temperament of Repex II is illustrated by this extract from the investigator's log: "Aug 10: The divers are in excellent spirits, laughing and joking among themselves and teasing the topside team. They are cooperative. They slept during the 4-hr break, such that they were slow to awaken; but they did get up and exercise during the last excursion."

There were general complaints of tiredness, lack of sleep, and requests for sleeping late. Some of this was due to the jovial atmosphere which kept things active when they could have been sleeping. They called the igloo the "sauna" during the ECU breakdown. Generally, however, both the questionnaires and comments were favorable; they all took the time to say they were comfortable, happy, and getting along fine.

c. Repex III subjective

Diver III-1 had light headedness the first couple of days, consistent with narcosis; he also mentioned numbness in the lips. Day 2 at 2036 he reported itching on the back of his left hand (1 hr after returning from 200/105). He noted also "the air is thick," and he had a dry, sore throat. He mentioned "nasal congestion" occasionally, which he attributed to the gas density. He mentioned a history of having had a chest tube once for pleurisy. This diver noted chest tightness early in the dive (evidently from the density) and at the end of the last day of saturation decompression, which he called "fatigue" and compared it with exhaustion. His "visual disturbances" were eye strain.

Diver III-2 complained of "heartburn" early on the second day, and this condition persisted throughout most of the dive. On Day 5 he was given Alka Seltzer, then Mylanta, finally had to be taken off food for a day; with only cold water and then milk. This was effective.

Diver III-3 mentioned "happiness" on the deep excursions but did not feel he had narcosis; he even wrote, "not a bit." Later he called it narcosis. He had some ear pain; at first he thought it was due to so many pressure changes, later attributed it to a tooth. He had some intermittent vague aches, and triceps pain that disappeared after movement.

At 1422 on Day 2 Diver III-4 notes a level 1/10 dull pain in his right foot, with numbness, later throbbing; when the foot was elevated throbbing stopped, and pain was aggravated by use. This seems like classical hyperbaric arthralgia, and was clearly not DCS. He had a toothache on Day 2, and exacerbation of chronic neck pain probably due to sleeping arrangements; this he also felt on initial compression. He felt some dyspnea just before going onto 0.5 PO_2. This diver did more exercise during the dive than he normally does.

In general they were happy a lot of the time despite some personal conflicts. They checked happiness frequently, appetites were good, but they were occasionally bored. They all felt sleep was easy during the excursion period; they dreamed more during decompression, and several had nightmares. They could do more chinups and pushups early in the exposure than at the end, so there was some deconditioning. The temperature was too high on Day 2, and they noted that the igloo was more humid than the DDC. They requested better lighting because there is a lot of time for reading but it was difficult; they said this exacerbated the boredom. More planned activity would have helped here.

2. Narcosis

The Repex I divers felt some narcosis on excursions, but there was no real feeling that it disappeared later in the dive. One Repex I diver said he felt more narked on the longer, shallower dives.

The Repex II divers exhibited all sorts of narcotic behavior but did not consider that they were narcotized; "I'm still waiting to be narked." They laughed and giggled so much all the time it was hard to see changes.

Divers in III scored more narcosis early, then it disappeared by Day 4. It did not seem to be a problem, and except for some euphoria they seemed to perform well during the excursions. It looks as if they became acclimated.

The divers had narcosis on excursions. They noted some acclimation, but not much; according to the opinions at the narcosis workshop there was not enough time for the full acclimation, which takes 5 days or so (Hamilton and Kizer, 1985).

The visual disturbances reported were usually related to narcosis or tiredness; no one had anything serious.

3. General subjective summary

The divers all said they would do it again if there were a reason.

VIII.
DISCUSSION AND CRITIQUE

Many conclusions have been given earlier with the data. This is a general assessment of the products of the program, the development and testing of the Procedures.

A. The Repex Procedures: How well did they work in the lab?

1. Excursion tables

In general we feel comfortable that the excursion procedures stood up well under the limited test program. The total of 252 diver-excursions is a fair test; it should be noted that 8 of these (Repex II and III) did not involve excursion decompressions back to storage. The tests are somewhat diluted by covering the whole range of storage and excursion depths, but they serve the purpose to expose any serious defects in the function of the tables. The coverage was quite representative, covering the different types of procedure as well as the ranges.

Since the excursions that were done were all taken from the tables at face value, with minimal intervals, this provides reasonable support to the algorithms used to develop the repetitive, one-stop, and post-submaximal procedures. The analysis with DCAP also supports that these algorithms for grouping and generalizing are valid. Two calculation errors were in a non-conservative direction and therefore made the testing more sensitive.

One unknown that remains is the matter of mixing ascending and descending excursions on the same mission. Fortunately, the threat here is to the ascending excursions, and more uncertainty can safely be tolerated in provisional field use with them than with descending excursions.

2. Saturation decompression

Saturation decompression is still the weak spot in the system. However, we feel we have made good progress and that the procedures are sound and reasonably efficient. Only 8 data points were obtained on the final saturation algorithm, but in view of the problem in Repex I--which should have been the "easy" one--the success of the deeper decompressions is meaningful.

The saturation decompression from Repex I used a 12-hour hold after the end of the last excursion. This decompression resulted in pain-only DCS in Diver 3 on ascending from 10 fsw. This hit at 10 fsw was rather deep and early, and this called for a substantial correction. We implemented the precursory table with Repex II, and because we were somewhat impressed by the Repex I hit we chose to use the 80-85 fsw table. The divers emerged from Repex II in excellent shape, and the results from Repex III were equally good from an even deeper depth. We feel the tests support the new tables quite well.

The new saturation tables have K values becoming progressively smaller and decompression times getting relatively longer as the storage depth increases. As was intended, the computed schedules are conservative with respect to others used previously for practical air/nitrox operations.

The method of starting the saturation decompression immediately at a depth dependent on the recent excursion history appears to be more efficient than employing a post-excursion holding period at the storage depth; a good method of determining a valid but efficient holding period is not yet available.

There was a discrepancy in the planning of the Repex III saturation decompression, where the last three air stops (110, 105, and 100 fsw; 110 fsw is the last stop in the precursory table) before the switch to a PO_2 of 0.5 atm were inadvertently scheduled using the stop times for 0.5 atm rather than those for air. The extra time totalled 240 minutes; we nevertheless consider the test as supporting the table, but the argument is slightly weakened. It clearly would have been preferable to run these decompressions at the absolute minimum time that could have been used. The extra time, less than 1/2 %, would not be likely to cause an unacceptable table to show up without problems. It does not invalidate these trials any more than 4 decompressions would be considered to prove that the tables are totally reliable.

The divers in Repex I were not waked up on the second night to stretch and move around. No one can tell if this had any effect, but this dive did have DCS. Throughout the saturation decompressions the divers were awakened two or three times during the night; this was not done strictly every two hours, but it was done adequately. This practice seems to be a matter of taste. Some operators do not allow divers to sleep during saturation decompression (e.g., USN inserts sleep stops). Others encourage it. We (except REP) take a middle position that keeping up the circulation more than offsets the inconvenience and sleep disturbance, and recommend sleep with movement every two hours. In retrospect, this should have been included on the schedule at specific times, in which case it would have been more likely to have been followed correctly.

Another point we overlooked including was the return to storage and then recompressing back to the first precursory stop, one of the options for starting decompression following excursions. As it was, we got good results with the straight decompression, an important step that had to be taken. In view of the reliability of the excursions from saturation and the "latency" in ascending excursions conducted to the surface and therefore more stressful (Eckenhoff and Parker, 1984), it seems that these short excursions from a greater depth to the original storage depth should be quite easily tolerated if kept within the 5-minute interval recommended.

Another point not covered properly in the Procedures and not tested is starting saturation decompression following a one-stop excursion. It would probably be all right to simply begin at the starting depth and ignore the stops, but the only acceptable way is to finish by making a no-stop as the last excursion. Only no-stop worst case gas loadings were used for calculating the starting depths, and because no testing was done we have no other choice here.

3. Oxygen toxicity limits

Repex II and III gave us a good test overall of one zone of the proposed oxygen exposure algorithm. The same limitations to interpretation apply here as to the decompression data; this is too few subjects, and the range tested is narrow (albeit in the center of the curve). The slight symptoms noted by Divers II-2, III-1, and III-4 would be tolerable on a planned operation, and our subjects were significantly above the limit.

This strongly suggests that as far as this small number of subjects and this narrow exposure range can tell us that the oxygen exposure algorithm might prove to be acceptable. When we began we felt that if perhaps one subject out of four had minor symptoms like these for a dose higher than the allowable level then we would be in the right range. The doses incurred by these divers are enough above the line to allow for a Table 6 treatment.

Interestingly, no divers reported things like numb fingertips that characterize **chronic** high oxygen exposures.

It seems clear, to the extent that these tests are representative, that the proposed oxygen limits are acceptable.

An oxygen dose with a CPTD in the 800-900 UPTD range has proven to be acceptable for air saturation decompression from nitrox storage, even when preceded by an excursion program presenting significant oxygen exposure in its own right. This stands on its own, but in future programs it would make sense to plan the overall oxygen exposure to include the saturation decompression.

Oxygen tolerance is highly individual. As a result the oxygen limits may need to be changed to suit the requirements of different dive teams or operations, reducing the dose if symptoms develop, or in small steps increasing it if conditions warrant (under medical supervision).

4. Treatment and surfacing procedures

Unfortunately we did not have the treatment procedures ready to test at the time of the DCS that occurred. However, that "test" would have only been of academic interest because adequate procedures are already available for this situation. The treatment procedures will likely never be tested in a true sense, certainly not prospectively.

There is a lot of discussion (if not controversy) going on currently about the efficacy of different treatment regimens. As these develop and hard data becomes available changes in the present procedures may be indicated. One thing likely to come to pass will be the reduction of the magnitude of the compression steps.

Nothing was learned about the surfacing procedures in Repex.

5. Tolerance of the exposures

The exposures were well tolerated. Some divers had a few aches, pains, and complaints, but no one had any real problems (except the DCS). There was a significant amount of "nasal congestion." Some of this no doubt is due to breathing gas 3 or 4 times as dense as normal. Dryness in the throat can come from mouth breathing, which most were doing because of the nasal congestion.

Diver I-2 had an ear infection at the beginning of the dive. It was judged acceptable for this situation by the medical director and it turned out to be, but starting with an infection would never be done in an at-sea operation.

The narcosis was about what was expected. They noted it on initial compression to the deeper of the storage depths, and on the excursions deeper than 150 fsw or so. They enjoyed it. Those in Repex III seemed to mention it less later in the dive, suggesting acclimation of some sort, but the observations were subjective and not really directed at this question. It did seem possible for these divers to perform, both at storage and on excursions. We saw nothing to throw doubt on the capabilities of divers in this type of operation.

B. Critique of the Procedures: How will they work at sea?

The question always comes up at about this stage in a development program as to whether the tables are ready to go to sea. The tests were limited, they were not without some problems, and there will of course be differences in conditions. Before we tackle this issue consider some comparisons and critique.

1. Comparison with other tables

There are only two tables for comparison with these, the original NOAA OPS procedures on which these were based, and the independently developed British nitrox tables.

Busch (1987) has compared the envelopes of the Repex tables with NOAA OPS. His findings are generally what we have discussed in Part One, that the deep excursions are shortened and longer shallow ones are now allowed, with a general expansion of the work envelope.

Hennessy et al's tables (Hennessy, Hanson, et al, 1985) take a different, more commercial approach in their presentation. Their no-stop excursion times are comfortably close to ours, and the saturation decompression rates of 36 and 48 min/fsw (with PO_2 of 0.5 and air, respectively, changing at 15 msw) are workable. Their approach to repetitive excursions provides a post-excursion waiting period that depends on the storage and work depths and shift (bottom) durations. Like ours, they were computed using gas loadings. The oxygen algorithm specifies 615 units per day, which the work of Sterk and others shows is clearly too much. Hennessy uses his own definition of the foot of sea water, but the difference is not important physiologically. Their tables lack some of the features of ours such as submaximal and one-stop procedures, but in return they are far less complex to use.

2.e Complexitye

Perhaps we are complimenting the genius of our intended users, marine scientists, but we have made these tables relatively complicated to use. The submaximal calculations are tedious and loaded with places to go wrong, and the normal use of intervals in selecting no-stop times has its share of confusing points. To help get this message across we included three errors in the Repex schedules.

3.e Efficienciese

We did an analysis of the "efficiency" of the various table algorithms, to see how well the tables let a diver do what his gas loading will allow (section IV.G). We did not try to build any conservatism in at this point, but wanted the tables to stay below the gas loading limit in all cases, but as little below as could be practically done. For the most part these were quite good, ranging above 80%. In some cases they are lousy, below 10%. We are not quite sure why all of these happen, but do know that there are parts of the tables where a small change in say, excursion depth or time, can make a big change in the allowable time. This is the nature of the model. In other cases the low efficiency is due to an inefficient relation to an interval. In still other cases, there may be discrepancies in calculation that we did not locate.

4.e Validity of the Procedures for field usee

The limited results of the Repex tests indicate that all aspects of the new procedures will be found to be physiologically acceptable.

A responsible decompression development plan will follow this type of testing with an ongoing "provisional" program covering the use of the new procedures in the field. Such a program should consist of expert supervision, qualified crews, adequate equipment, and careful documentation of the dives done under field conditions, and should be accompanied by periodic analysis of the results. Revisions of both procedures and tables can then be performed when needed. It is not reasonable to expect a new set of tables to be considered fully "operational" until they have the equivalent of several years of field use. During this time some revisions may be needed. In fact, a set of decompression tables should be thought of as a living thing, constantly being modified and improved as the experience base grows.

The treatment procedures are reasonable, based on previous experience, and should be put in service.

The surfacing procedures were not tested, but in view of past experience and considering that the normal ones do not involve physiological "exposures" then they can be used (or, for some, **continue** to be used). The surfacing and emergency procedures should be assessed by experienced habitat operators and revised to fit local equipment, operational capabilities, and philosophies.

5. These are interim tables: The computerized approach

As has been mentioned before, it is important to note that although these procedures fill an operational need and will serve to expand habitat diving capabilities, they are by no means the last word. As data and experience accumulate the algorithm will continue to be improved, and other models will be brought into use.

It has been possible to fit all these decompression requirements into a few tables (actually there are 36 pages of tables, plus the instructions) that can be readily adapted to a manual for field operations. However, putting these tables together has required a number of groupings, many intervals, and more than a few approximations and assumptions. Using the tables, and especially the calculation of the time allowed in the excursion following a submaximal one, can result in errors. There are some operational limitations that could be improved with better methods of displaying the known data. There are some notable inefficiencies. All this can best be handled by an on-site computer. This could begin with being able to calculate upcoming excursions, but it will soon grow to include data monitoring, emergency management, and real-time control. Small "pico" or "laptop" computers are available in 1987 that can perform all the calculations needed for these dives, in a package the size of a large notebook. They are tolerant of pressure and can be made fire safe. We strongly recommend that this be implemented in habitat diving operations.

With the present computational model and constraints and before getting a new laptop, however, it is possible to improve performance by developing "custom" excursions for the special missions that do not fit these tables precisely. The limited validation testing reported in Part Two was close to this type of exposure, so the concept can be considered as ready for **provisional** operational use. This means no further laboratory tests should be needed, but the at-sea use should have extra care, supervision, and safeguards.

There is a restriction in the relevance of the Repex dives as a test of the **algorithm** for excursion diving. The tables were calculated with PO_2 levels of 0.19 in the habitat and 0.20 for air during the excursions. These differences were inserted as a conservatism factor. The experimental dives stand alone as validation of the Procedures as used (given the limited number of subjects and trials). What they do not do is validate the algorithm at face value. That is, to be strict in calculating "custom" dives we must use the PO_2 values as they were tested, with computation at one level and actual use at another. If these work well in practice, as they should, then under provisional conditions they could later be moved in small steps toward the correct PO_2 levels.

A feature of the Procedures until Repex I was two saturation decompression tables, including one for divers who have done no excursions at all. This does make sense since a habitat may be on a flat sea floor where deeper excursions are not possible. We consider this approach valid and could implement it with additional tables, but it would call for testing or at least some controlled use (as "provisional" tables) as it is placed into service.

IX.
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B. Publications and presentations resulting from the Contract

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7. Paper presented, proceedings in press:

Hamilton RW. Review and assessment of NOAA's habitat diving development project. Presented at UJNR meeting, Yokosuka, Japan, 1987 Nov.

APPENDIXES

APPENDIX A: REPEX WORKSHEETS

APPENDIX B. REPEX SCHEDULES

APPENDIX C. SAMPLE TABLE PAGES

APPENDIX D. REPEX DCAP DIVE PROFILE

APPENDIX A.

Repex worksheets

These pages are the output of the spreadsheet program, and were used to prepare the dive schedules in Appendix B.

A sample output of a post-submaximal excursion calculation done with the spreadsheet is given at the end of the Repex III worksheet.

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Repex worksheet: General notes:

This is a worksheet for calculating excursion times according to the tables; it is not a dive profile.

Decompression from excursion depth or last stop begins at time shown under "End t." Travel time is taken from the next stop (except 1-stops).

Notes in last column (numbers apply to Repex I only):

1. The first two dives are calculated specifically rather than taken off the tables, to account for the diver's not being fully saturated and to get maximum stress on all dives. The nominal dive is shown under remarks.

2. The overnight time interval may vary by a few minutes to get dives starting at exactly 0800; however, the interval is not shortened, instead the next dive may start a few minutes after 0800.

3. Dives that follow "one-stop" excursions are considered to be "3+" dives even if they are the second dive in a sequence.

4. "One-stop" excursions show the decompression time in the "Stops" column. All one-stop excursions have a 2 min stop 10 fsw deeper (here 75 fsw) than the main stop, which is 15 fsw deeper (here 65 fsw) than the storage depth.

5. To test the "oxygen window" the divers are to remain at 60 fsw breathing air during this 2-hr interval. This is the maximum O2 window depth; the 10 is the maximum O2 window excursion range:

50 + 10 (from the 50-55 fsw page set in the manual) = 60.

6. Days 4 and 5 test the use of a 16-hour day.

7. Submaximal excursions ("Submax") are followed by excursions ("postsubmx") that have extra time because they follow a submaximal dive.

8. Saturation decompression is in 5 fsw stages, with times (as given here) taken from the 45-49 fsw storage depth page set. After a 12-hr hold, begin decompression by a descent to 45 fsw.

86Jul24 NOAA-HRL-IUC REPEX I SATURATION AT 50 FSW

Excn#	Day	Seq	Int	Int,m	Start t	Excn D	Ex t	Stops	End t	Remarks	Notes
	1				0800	Begin compression to 50 fsw					
1	1	1st	16		1200	145 /	54		1254	(140/54)	1
2	1	2nd	2	120	1454	140 /	62		1556	(135/62)	1
3	2	1st	16	964	0800	130 /	120	+ 2 + 14	1016		2,4
4	2	3+*	0.5	30	1046	145 /	17		1103		3
5	2	3+	2	120	1303	125 /	75		1418	O2 window	5
6	2	3+	1	60	1518	125 /	42		1600		
7	3	1st	16	960	0800	100 /	59		0859	Submax	7
8	3	2nd	2	120	1059	115 /	149		1328	Postsubmx	7
9	3	3+	1	60	1428	160 /	21		1449		
10	3	3+	1	60	1549	220 /	11		1600		
11	4	1st	16	960	0800	160 /	60	+ 2 + 15	0917		4
12	4	3+*	4	240	1317	145 /	10		1327	Submax	3,7
13	4	3+	0.5	30	1357	135 /	55		1452	Postsubmx	7
14	4	3+	2	120	1652	95 /	307		2159		
15	4	3+	1	60	2259	115 /	57		2356		6
16	5	3+	8	484	0800	155 /	45	+ 2 + 4	0851		4
17	5	3+	4	240	1251	110 /	189		1600		
18	5	3+	1	60	1700	200 /	14		1714		
19	5	3+	2	120	1914	110 /	210	+ 2 + 60	2346		4,6
20	6	3+	8	494	0800	105 /	189		1109	Submax	7
21	6	3+	0.5	30	1139	120 /	76		1255	Postsubmx **	7
22	6	3+	2	120	1455	170 /	45	+ 2 + 18	1600		4
	7		12	720	0400	45 /	130		0610	Begin dec	8
	7				0610	40 /	140		0830		
	7				0830	35 /	150		1100		
	7				1100	30 /	160		1340		
	7				1340	25 /	175		1635		
	7				1635	20 /	190		1945		
	7				1945	15 /	210		2315		
	7				2315	10 /	230		0305		
	8				0305	5 /	260		0725	Surface	
	8				0725	Reach surface					

Total saturation time 140 hours
Total excursion time 31.1 hours + Decomp of 2.0 hr on excursions
Total decompression time 27 hours 25 min

* This excursion 3+ because it is after a one-stop excursion

[** Note: Excursion 21 is in error, should be 58 min instead of 76.]

WORKSHEET: NOAA-HRL-IUC REPEX II SATURATION AT 80 FSW

Rev B

Excn#	Day	Seq	Int	Int,m	Start t	Excn D	Ex t	Stops	End t	Remarks
	-1				2400	Begin compression to 80 fsw				
1	1	1st	(16)		0800	200 /	14		0814	Submax
2	1	2nd	0.5	30	0844	140 /	290		1334	Postsubmx
3	1	3+	1	60	1434	140 /	90		1604	
4	1	3+	4	240	2004	170 /	79		2123	
5	1	3+	2	120	2323	220 /	29	+ 2 + 4	2358	
6	2	3+	8	482	0800	200 /	33		0833	
7	2	3+	0.5	30	0903	180 /	35 *		0938	
8	2	3+	4	240	1338	180 /	60	+ 2 + 2	1442	O2 window
9	2	3+	0.5	30	1512	145 /	43		1555	
10	3	1st	16	965	0800	170 /	40		0840	Submax
11	3	2nd	1	60	0940	160 /	98		1118	Postsubmx
12	3	3+	2	120	1318	200 /	60	+ 2 + 39	1459	
13	3	3+	0.5	30	1529	160 /	24		1553	
14	3	3+	2	120	1753	190 /	60	+ 2 + 14	1909	
15	3	3+	4	240	2309	190 /	41		2350	
16	4	3+	8	490	0800	180 /	56		0856	
17	4	3+	2	120	1056	140 /	55		1151	Submax
18	4	3+	1	60	1251	155 /	115		1446	Postsubmx
19	4	3+	4	240	1846	155 /	147		2113	
20	4	3+	0.5	30	2143	135 /	69		2252	
21	5	3+	8	488	0700	180 /	56		0756	
22	5	3+	1	60	0856	240 /	13		0909	
23	5	3+	2	120	1109	190 /	41		1150	
	5			10	1200	130 /	45		1245	Begin dec
	5				1245	125 /	45		1330	
	5				1330	120 /	45		1415	
	5				1415	115 /	45		1500	
	5				1500	110 /	45		1545	
	5				1545	105 /	60		1645	
	5				1645	100 /	60		1745	
	5				1745	95 /	60		1845	
	5				1845	90 /	60		1945	
	5				1945	85 /	60		2045	
	5				2045	80 /	100		2225	
	5				2225	75 /	105		0010	
	6				0010	70 /	110		0200	
	6				0200	65 /	115		0355	
	6				0355	60 /	125		0600	
	6				0600	55 /	130		0810	
	6				0810	50 /	135		1025	
	6				1025	45 /	145		1250	
	6				1250	40 /	155		1525	
	6				1525	35 /	165		1810	
	6				1810	30 /	180		2110	
	6				2110	25 /	195		2425	
	7				0025	20 /	215		0400	
	7				0400	15 /	235		0353	
	7				0755	10 /	260		1215	
	7				1215	5 /	295		1710	Surface
	7				1710	Reach surface				

Total saturation time 153 hours 10 min
Total excursion time 25.9 hours + Decomp of 1.2 hours
Total decompression time 53 hours 10 min

[* Note: Excn 7 should be 15 min.]

WORKSHEET: NOAA-HRL-IUC REPEX III SATURATION AT 110 FSW

Excn#	Day	Seq	Int	Int,m	Start t	Excn D	Ex t	Stops	End t	Remarks	CPTD
	1				0000	Begin compression to 110 fsw					
1	1	1st	16		0800	200 /	105		0945		184
2	1	2nd	0.5	30	1015	200 /	52		1107		275
3	1	3+	1	60	1207	190 /	57		1304		369
4	1	3+	0.5	30	1334	240 /	12		1346		394
5	1	3+	1	60	1446	180 /	78		1604		516*
6	2	1st	16	960	0804	200 /	105		0949		184
7	2	2nd	8	480	1749	200 /	105		1934		368
8	2	3+	2	120	2134	240 /	16		2150		402
9	2	3+	1	60	2250	190 /	57		2347		496
10	3	3+	8	493	0800	200 /	150	+ 2 + 58	1130		263
11	3	3+	1	60	1230	180 /	40		1310	Submax	325
12	3	3+	1	60	1410	200 /	58		1508	Postsubmx	427
13	3	3+	0.5	30	1538	200 /	22		1600		466
14	4	1st	16	960	0800	200 /	240	+ 2 + 33	1235		421
15	4	2nd	2	120	1435	220 /	29		1504		477
16	4	3+	0.5	30	1534	240 /	12		1546		502
17	5	1st	16	974	0800	200 /	105		0945		184
18	5	2nd	2	120	1145	240 /	16		1201		218
19	5	3+	4	240	1601	220 /	29		1630		274
	5				1630	155 /	6		1636		282
	5				1636	154 /	6		1642		290
	5				1642	153 /	6		1648		298
	5				1648	152 /	6		1654		306
	5				1654	151 /	6		1700		314
	5				1700	150 /	6		1706		322
	5				1706	149 /	6		1712		330
	5				1712	148 /	6		1718		337
	5				1718	147 /	6		1724		344
	5				1724	146 /	6		1730		351
	5				1730	145 /	6		1736		351
	5				1736	144 /	6		1742		351
	5				1742	143 /	6		1748		351
	5				1748	142 /	6		1754		351
	5				1754	141 /	6		1800		358
	5				1800	140 /	6		1806		365
	5				1806	139 /	6		1812		372
	5				1812	138 /	6		1818		379
	5				1818	137 /	6		1824		386
	5				1824	136 /	6		1830		393
	5				1830	135 /	9		1839		403
	5				1839	134 /	9		1848		413**
	5				1848	133 /	9		1857		413
	5				1857	132 /	9		1906		413
	5				1906	131 /	9		1915		413
	5				1915	130 /	9		1924		413
	5				1924	129 /	9		1933		413
	5				1933	128 /	9		1942		413
	5				1942	127	9		1951		413
	5				1951	126	9		2000		413

NOAA-HRL-IUC REPEX III SATURATION AT 110 FSW

Excn#	Day	Seq	Int	Int.m	Start t	Excn D	Ex t	Stops	End t	Remarks	CPTD
	5				2000	125	9		2009		413
	5				2009	124	9		2018		413
	5				2018	123	9		2027		422
	5				2027	122	9		2036		431
	5				2036	121	9		2045		440
	5				2045	120	9		2054		449
	5				2054	119	9		2103		458
	5				2103	118	9		2112		466
	5				2112	117	9		2121		474
	5				2121	116	9		2130		482
	5				2130	115	9		2139		490
	5				2139	114	9		2148		498
	5				2148	113	9		2157		506
	5				2157	112	9		2206		514
	5				2206	111	9		2215		522
	5				2215	110	38***		2253		554
	5				2253	109	38		2331		586
	5				2331	108	38		0009		617
	6				0009	107	38		0047		31
	6				0047	106	38		0125		62
	6				0125	105	38		0203		92
	6				0203	104	38		0241		122
	6				0241	103	38		0319		151
	6				0319	102	38		0357		180
	6				0357	101	38		0435		208
	6				0435	100	38		0513		208
	6				0513	99	38		0551		208
	6				0551	98	38		0629		208
	6				0629	97	38		0707		208
	6				0707	96	38		0745		208
	6				0745	95	38		0823		208
	6				0823	94	38		0901		208
	6				0901	93	38		0939		208
	6				0939	92	38		1017		208
	6				1017	91	38		1055		208
	6				1055	90	38		1133		208
	6				1133	89	38		1211		208
	6				1211	88	38		1249		208
	6				1249	87	38		1327		208
	6				1327	86	38		1405		208
	6				1405	85	38		1443		208
	6				1443	84	38		1521		208
	6				1521	83	38		1559		208
	6				1559	82	38		1637		208
	6				1637	81	38		1715		208
	6				1715	80	38		1753		227
	6				1753	79	38		1831		246
	6				1831	78	38		1909		264
	6				1909	77	38		1947		282
	6				1947	76	38		2025		299

NOAA-HRL-IUC REPEX III SATURATION AT 110 FSW

Excn#	Day	Seq	Int	Int,m	Start t	Excn D	Ex t	Stops	End t	Remarks	CPTD
	6				2025	75	38		2103		316
	6				2103	74	38		2141		332
	6				2141	73	38		2219		348
	6				2219	72	38		2257		363
	6				2257	71	38		2335		378
	6				2335	70	38		0013		392
	7				0013	69	38		0051		14
	7				0051	68	38		0129		27
	7				0129	67	38		0207		40
	7				0207	66	38		0245		52
	7				0245	65	38		0323		64
	7				0323	64	38		0401		75
	7				0401	63	38		0439		86
	7				0439	62	38		0517		96
	7				0517	61	38		0555		106
	7				0555	60	38		0633		115
	7				0633	59	38		0711		124
	7				0711	58	38		0749		132
	7				0749	57	38		0827		140
	7				0827	56	38		0905		147
	7				0905	55	38		0943		154
	7				0943	54	38		1021		160
	7				1021	53	38		1059		165
	7				1059	52	38		1137		170
	7				1137	51	38		1215		174
	7				1215	50	38		1253		177
	7				1253	49	38		1331		180
	7				1331	48	38		1409		182
	7				1409	47	38		1447		183
	7				1447	46	38		1525		184
	7				1525	45	39		1604		184
	7				1604	44	39		1643		184
	7				1643	43	39		1722		184
	7				1722	42	39		1801		184
	7				1801	41	39		1840		184
	7				1840	40	41		1921		184
	7				1921	39	41		2002		184
	7				2002	38	41		2043		184
	7				2043	37	41		2124		184
	7				2124	36	41		2205		184
	7				2205	35	44		2249		184
	7				2249	34	44		2333		184
	7				2333	33	44		0017		184
	8				0017	32	44		0101		0
	8				0101	31	44		0145		0
	8				0145	30	48		0233		0
	8				0233	29	48		0321		0
	8				0321	28	48		0409		0
	8				0409	27	48		0457		0
	8				0457	26	48		0545		0

NOAA-HRL-IUC REPEX III SATURATION AT 110 FSW

Excn#	Day	Seq	Int	Int,m	Start t	Excn D	Ex t	Stops	End t	Remarks	CPTD
	8				0545	25	52		0637		0
	8				0637	24	52		0729		0
	8				0729	23	52		0821		0
	8				0821	22	52		0913		0
	8				0913	21	52		1005		0
	8				1005	20	57		1102		0
	8				1102	19	57		1159		0
	8				1159	18	57		1256		0
	8				1256	17	57		1353		0
	8				1353	16	57		1450		0
	8				1450	15	62		1552		0
	8				1552	14	62		1654		0
	8				1654	13	62		1756		0
	8				1756	12	62		1858		0
	8				1858	11	62		2000		0
	8				2000	10	70		2110		0
	8				2110	9	70		2220		0
	8				2220	8	70		2330		0
	8				2330	7	70		2440		0
	9				0040	6	70		0150		0
	9				0150	5	395		0825		0
	9				0825	0			0825	Surface	

Total decompression time 87 hours 55 min
Total excursion time 21.5 hours + decompression
Total time in saturation 200 hours 25 min; 8 days 8.4 hours

* Daily CPTD totals are underlined.

[** It looks as if the CPTD calculation over the depth range 134 to 124 was not made, making the calculated total about 40 units low.]
[* The ascent rate between 110 and 95 fsw was at 38 min/fsw and should have been 21, 22, and 23 fsw.]**

Calculation of Post-submaximal times

Submax t: t:adj = t:min + ((t:max - t:min) * (1-(t:used/t:allowed)))
Postsubmaximal = A + ((B - A)*(1-D/C))

Postsubmax: 1 hr at 180/40 (78). Post: 200/58 (42-75; 1 hr becomes 2 hr)
Normal time = t:min A = 42 Time from table for seq and intvl
Time w/o excn = t:max B = 75 Time w/o preceding (submax) dive
Time allowed = t:allowed C = 78 Time allowed in submax dive
Time used = t:used D = 40 Time used in submax dive
Modified time = 58

APPENDIX B.

Schedules for Repex dives

These schedules are the ones used to run the dives. Each of the dives followed the schedules accurately, with minor exceptions. These are shown in brackets, at the right margin. Repex I had a treatment at the end. See section VI.A for scheduling criteria and Chapter VII for comments on the conduct of the dives and the changes to the profile for Repex I due to the treatment.

NOAA-HRL-IUC REPEX I SATURATION AT 50 FSW

SCHEDULE OF EVENTS

Day	Excn#	Time	Event	Remarks
-1			1986 July 28, Monday	
-1		0800	Familiarization and habitability	
-1		1100	General briefing	
-1		1330	Doppler training, Diver RW	
-1		1400	Doppler training, Diver JB	
-1		1430	Doppler training, Diver MC	
-1		1500	Doppler training, Diver MS	
-1		1530	Doppler training, Diver JG	
1			1986 July 29, Tuesday	
1		0700	Diver last-minute medical checks	
1		0745	Divers enter chamber	
1		0800	Begin compression to 50 fsw, adjust PO2 to 0.3 atm	
1		1030	Control u/s (doppler readings on all divers)	
1		1100	Divers fill out subjective questionaire	
1		1130	Lunch	
1	1	1200	Excurse to 143 fsw for 54 min. Rate 30 fsw/min	
1	1	1254	Decompress to storage depth at 30 fsw/min	
1	1	1334	U/s	
1	1	1419	U/s	
1	2	1454	Excursion: 140/62	
1	2	1556	Decompress	
1	2	1636	U/s	
1	2	1721	U/s	
1	2	1806	U/s	
1		1900	Dinner	
1		2000	Questionaire	
1		2200	LIGHTS OUT	
2			1986 July 30, Wednesday	
2		0600	Divers awakened	
2		0630	Breakfast	
2	3	0800	One-stop excursion: 130/120 + 2 + 14	
2	3	1000	Decompress to 75 fsw	
2	3	1002	Stop at 75 fsw for 2 min	
2	3	1004	Decompress to 65 fsw, stop 14 min	
2	3	1018	Decompress to storage	
2	3	1030	U/s	(u/s early)
2	4	1046	Excursion: 145/17	
2	4	1103	Decompress to O2 window depth, 60 fsw, remain on air	
2	4	1143	U/s	
2	4	1228	U/s	
2	5	1303	Excursion: 125/75	
2	5	1310	Lunch	
2	5	1418	Decompress	
2	5	1458	U/s	
2	6	1518	Excursion: 125/42	
2	6	1600	Decompress	

NOAA-HRL-IUC Repex I SATURATION AT 50 FSW

Day	Excn#	Time	Event	Remarks
2			1986 July 30, continued	
2	6	1640	U/s	
2	6	1725	U/s	
2	6	1810	U/s	
2		1900	Dinner	
2		2000	Questionaire	
2		2200	LIGHTS OUT	
3			1986 July 31, Thursday	
3		0600	Divers awakened	
3		0630	Breakfast	
3	7	0800	Excursion: 100/59	(submaximal)
3	7	0859	Decompress	
3	7	0939	U/s	
3	7	1024	U/s	
3	8	1059	Excursion: 115/149	(postsubmaximal)
3	8	1215	Lunch	
3	8	1328	Decompress	
3	8	1408	U/s	
3	9	1428	Excursion: 160/21	
3	9	1449	Decompress	
3	9	1529	U/s	
3	10	1549	Excursion: 220/11	
3	10	1600	Decompress	
3	10	1640	U/s	
3	10	1725	U/s	
3	10	1810	U/s	
3		1900	Dinner	
3		2000	Questionaire	
3		2200	LIGHTS OUT	
4			1986 August 1, Friday	
4		0600	Divers awakened	
4		0630	Breakfast	
4	11	0800	One-stop excursion: 160/60 + 2 + 15	
4	11	0900	Decompress to 75 fsw	
4	11	0903	Stop at 75 fsw for 2 min	
4	11	0905	Decompress to 65 fsw, stop 15 min	
4	11	0920	Decompress to storage	
4	11	0940	U/s	
4	11	1025	U/s	
4	11	1110	U/s	
4		1215	Lunch	
4	12	1317	Excursion: 145/10	(submaximal)
4	12	1327	Decompress	(no u/s)
4	13	1357	Excursion: 135/55	(postsubmaximal)
4	13	1452	Decompress	
4	13	1532	U/s	
4	13	1617	U/s	
4	14	1652	Excursion: 95/307	Entire system at 95 fsw

NOAA-HRL-IUC Repex I SATURATION AT 50 FSW

Day	Excn#	Time	Event	Remarks
4			1986 August 1, continued	
4	14	1900	Dinner	Maintain fire safety
4	14	2159	Decompress	
4	14	2239	U/s	
4	15	2259	Excursion: 115/57	
4	15	2356	Decompress	
5	15		1986 August 2, Saturday	
5	15	0010	Questionaire	Divers remain active
5	15	0036	U/s	
5	15	0121	U/s	
5		0135	LIGHTS OUT	
5		0630	Divers awakened	
5		0715	Breakfast	
5	16	0800	One-stop excursion: 155/45 + 2 + 4	
5	16	0845	Decompress to 75 fsw	
5	16	0848	Stop at 75 fsw for 2 min	
5	16	0850	Decompress to 65 fsw, stop 4 min	
5	16	0854	Decompress to storage	
5	16	0925	U/s	
5	16	1010	U/s	
5	16	1055	U/s	
5		1215	Lunch	
5	17	1251	Excursion: 110/189	Whole system at 110 fsw
5	17	1600	Decompress	Maintain fire safety
5	17	1640	U/s	
5	18	1700	Excursion: 200/14	
5	18	1714	Decompress	
5	18	1754	U/s	
5	18	1839	U/s	
5	19	1914	Excursion: 110/210 + 2 + 60	Whole system at 110
5	19	1930	Dinner	Maintain fire safety
5	19	2244	Decompress to 75 fsw	
5	19	2245	Stop at 75 fsw for 2 min	
5	19	2247	Decompress to 65 fsw, stop 60 min	
5	19	2324	U/s	
5	19	2347	Decompress to storage	
6			1986 August 3, Sunday	
6	19	0009	U/s	Divers remain active
6		0030	Questionaire	
6	19	0054	U/s	
6		0115	LIGHTS OUT	
6		0630	Divers awakened	
6		0715	Breakfast	
6	20	0800	Excursion: 105/189	(submaximal) Whole system at 105
6	20	1109	Decompress	No time for u/s; keep fire safe
6	21	1139	Excursion: 120/76	(postsubmaximal) **[Should be 120/58]**
6		1215	Lunch	

NOAA-HRL-IUC Repex I SATURATION AT 50 FSW

Day	Excn#	Time	Event	Remarks
6			1986 August 3, continued	
6	21	1255	Decompress	
6	21	1335	U/s	
6	21	1420	U/s	
6	22	1455	One-stop excursion: 170/45 + 2 + 18	
6	22	1540	Decompress to 75 fsw	
6	22	1543	Stop at 75 fsw for 2 min	
6	22	1545	Decompress to 65 fsw, stop 18 min	
6		1600	Begin 12-hr hold (this procedure for this test only)	
6		1603	Decompress to storage	
6	22	1620	U/s	
6	22	1705	U/s	
6	22	1750	U/s	
6		1900	Dinner	
6		2000	Questionaire	
6		2030	Clean up chamber for fire safety; review procedures	
6		2200	LIGHTS OUT	
7			1986 August 4, Monday	
7		0145	Change chamber atmosphere to air	
7		0400	Begin saturation decompression; decompress to 45 fsw	
7			Diver wake-up optional	
7		0610	Decompress to 40 fsw	
7		0830	Decompress to 35 fsw	
7		0900	Breakfast	
7		1000	U/s	
7		1100	Decompress to 30 fsw	
7		1215	Lunch	
7		1340	Decompress to 25 fsw	
7		1600	U/s	
7		1635	Decompress to 20 fsw	
7		1900	Dinner	
7		1945	Decompress to 15 fsw	
7		2000	Questionaire	
7		2200	U/s	
7		2315	Decompress to 10 fsw	
8			1986 August 5, Tuesday	
8		0305	Decompress to 5 fsw	**[Recompressed to treat Diver I-3]**
8		0725	Decompress to surface; divers stay in IUC area all day	
8		0730	U/s	
8		0800	Medical check, clean up	
8		0900	Crew debriefing	
8		0930	Brunch for divers and crew with RWH	
8		1130	Questionaire	
8		1330	Final scheduled U/s	
8		1830	Dinner; divers stay on City Island overnight, in contact for 48 hours	

Day 10, 1986 August 7: Divers call in to RWH or BB to report condition.

NOAA-HRL-IUC REPEX II SATURATION AT 80 FSW

Rev B

SCHEDULE OF EVENTS

Day	Excn#	Time	Events and Remarks
-1			1986 August 7, Thursday
-1		1300	Familiarization, habitability, and general briefing of divers.
-1		2000	Dinner for divers
-1		2130	Doppler training
-1		2300	Final outfitting of chamber
-1		2330	Divers enter chamber
-1		2400	Begin compression to 80 fsw ...continued
1			1986 August 8, Friday
1		0015	Control doppler ultrasound (u/s)
1		0030	Divers fill out subjective questionaire
1		0045	LIGHTS OUT.
1		0630	Divers awakened
1		0700	Breakfast
1	1	0800	Excurse to 200 fsw for 14 min (submaximal)
1	1	0814	Decompress to storage depth at 30 fsw/min, hold 1/2 hr
1	2	0844	Excursion: 140/290 (postsubmaximal)
1	2	1215	Lunch (during excursion)
1	2	1334	Decompress; hold 1 hour
1	2	1414	U/s
1	3	1434	Excursion: 140/90
1	3	1604	Decompress; hold 4 hr
1	3	1644	U/s
1	3	1729	U/s
1	3	1745	Dinner
1	3	1814	U/s
1		1830	Divers sleep
1	4	2004	Excursion: 170/79
1	4	2123	Decompress; hold 2 hr
1	4	2203	U/s
1	4	2248	U/s
1	5	2323	One-stop excursion: 220/29 + 2 + 4
1	5	2352	Decompress to 105 fsw
1	5	2355	Stop at 105 fsw for 2 min
1	5	2357	Decompress to 95 fsw, stop 4 min ...continued
2			1986 August 9, Saturday
2	5	0001	Decompress to storage depth
2	5	0032	U/s
2	5	0045	Questionaire
2	5	0117	U/s
2		0130	LIGHTS OUT
2		0630	Divers awakened
2		0700	Breakfast

NOAA-HRL-IUC REPEX II SATURATION AT 80 FSW

Day	Excn#	Time	Events and Remarks
2			1986 August 9, continued
2	6	0800	Excursion: 200/33 [Should be 8 hr, 3+]
2	6	0833	Decompress; hold 1/2 hr
2	7	0903	Excursion: 180/35 [Should be 180/15]
2	7	0938	Decompress to 98 fsw on air, hold 4 hr (O2 window)
2	7	1018	U/s (98 fsw)
2	7	1103	U/s (98 fsw)
2	7	1115	Lunch (98 fsw)
2	7	1148	U/s (98 fsw)
2		1200	Lights out, divers sleep (98 fsw)
2	8	1338	One-stop excursion: 180/60 + 2 + 2
2	8	1438	Decompress to 105 fsw
2	8	1440	Stop at 105 fsw for 2 min
2	8	1442	Decompress to 95 fsw, stop 2 min
2	8	1444	Decompress to storage; hold 28 min
2	9	1512	Excursion: 145/43
2	9	1555	Decompress; hold 16 hr
2	9	1635	U/s
2	9	1720	U/s
2	9	1805	U/s
2		1830	Dinner
2		2000	Questionaire
2		2200	LIGHTS OUT
3			<u>1986 August 10, Sunday</u>
3		0630	Divers awakened
3		0700	Breakfast
3	10	0800	Excursion: 170/40 (submaximal)
3	10	0840	Decompress; hold 1 hr
3	10	0920	U/s
3	11	0940	Excursion: 160/98 (postsubmaximal)
3	11	1118	Decompress; hold 2 hr
3	11	1158	U/s
3	11	1215	Lunch
3	11	1243	U/s
3	12	1318	One-stop excursion: 200/60 + 2 + 39
3	12	1418	Decompress to 105 fsw
3	12	1421	Stop at 105 fsw for 2 min
3	12	1423	Decompress to 95 fsw, stop 39 min
3	12	1502	Decompress to storage; hold 27 min
3	12	1503	U/s
3	13	1529	Excursion: 160/24
3	13	1553	Decompress; hold 2 hr
3	13	1633	U/s
3	13	1718	U/s
3		1730	Dinner
3	14	1753	Excursion: 190/60 + 2 + 14
3	14	1853	Decompress to 105 fsw
3	14	1856	Stop at 105 fsw for 2 min
3	14	1858	Decompress to 95 fsw, stop 14 min
3	14	1912	Decompress to storage; hold 4 hr

NOAA-HRL-IUC REPEX II SATURATION AT 80 FSW

Day	Excn#	Time	Events and Remarks
3			1986 August 10, continued
3	14	1933	U/s
3	14	2018	U/s
3	14	2103	U/s
3		2115	Divers optional nap time
3	15	2309	Excursion: 190/41
3	15	2350	Decompress; hold 8 hr ...continued
4			1986 August 11, Monday
4	15	0030	U/s
4	15	0045	Questionaire
4	15	0115	U/s
4	15	0130	LIGHTS OUT
4		0630	Divers awakened
4		0700	Breakfast
4	16	0800	Excursion: 180/56
4	16	0856	Decompress; hold 2 hr
4	16	0936	U/s
4	16	1021	U/s
4	17	1056	Excursion: 140/55 (submaximal)
4	17	1151	Decompress; hold 1 hr
4	17	1215	Lunch
4	17	1231	U/s
4	18	1251	Excursion: 155/115 (postsubmaximal)
4	18	1446	Decompress; hold 4 hr
4	18	1526	U/s
4	18	1611	U/s
4	18	1656	U/s. Divers sleep.
4		1830	Dinner
4	19	1846	Excursion: 155/147
4	19	2113	Decompress; hold 1/2 hr
4	20	2143	Excursion: 135/69
4	20	2252	Decompress; hold 8 hr
4	20	2332	U/s
4	20	2345	Questionaire ...continued
5			1986 August 12, Tuesday
5	20	0017	U/s
5		0030	LIGHTS OUT
5		0530	Divers awakened
5		0615	Breakfast
5	21	0700	Excursion: 180/56
5	21	0756	Decompress; hold 1 hr
5	21	0836	U/s
5	22	0856	Excursion: 240/13
5	22	0909	Decompress; hold 2 hr
5	22	0954	U/s

NOAA-HRL-IUC REPEX II SATURATION AT 80 FSW

Day	Excn#	Time	Events and Remarks
5			1986 August 12, continued
5	22	1039	U/s
5	23	1109	Excursion: 190/41. Change atmosphere to air.
5	23	1150	Decompress to 130 fsw
5	23	1152	Hold at 130 fsw for 8 + 45 min
5	23	1200	Begin saturation decompression. Lunch.
5	23	1230	U/s
5		1245	Decompress to 125 fsw
5		1330	Decompress to 120 fsw
5		1415	Decompress to 115 fsw
5		1500	Decompress to 110 fsw
5		1545	Decompress to 105 fsw
5		1645	Decompress to 100 fsw
5		1730	Dinner
5		1745	Decompress to 95 fsw
5		1830	U/s
5		1845	Decompress to 90 fsw
5		1945	Decompress to 85 fsw
5		2045	Decompress to 80 fsw
5		2100	Questionaire
5		2200	U/s.
5		2225	Decompress to 75 fsw
5		2230	Lights out. Divers wake up every hour to move and stretch.
6			<u>1986 August 13, Wednesday</u>
6		0010	Decompress to 70 fsw
6		0200	Decompress to 65 fsw
6		0355	Decompress to 60 fsw
6		0600	Decompress to 55 fsw
6		0700	Divers awakened
6		0745	Breakfast
6		0810	Decompress to 50 fsw
6		0830	U/s
6		1025	Decompress to 45 fsw
6		1200	Lunch
6		1250	Decompress to 40 fsw
6		1400	U/s
6		1525	Decompress to 35 fsw
6		1730	Dinner
6		1810	Decompress to 30 fsw
6		2100	Questionaire
6		2110	Decompress to 25 fsw
6		2200	U/s
6		2230	Lights out. Divers wake up every hour to move and stretch.
7			<u>1986 August 14, Thursday</u>
7		0025	Decompress to 20 fsw
7		0400	Decompress to 15 fsw
7		0755	Decompress to 10 fsw
7		0800	Divers awakened.

NOAA-HRL-IUC REPEX II SATURATION AT 80 FSW

Day	Excn#	Time	Events and Remarks
7			1986 August 14, continued
7		0830	U/s
7		0845	Breakfast
7		1215	Decompress to 5 fsw
7		1430	U/s
7		1650	Final questionaire
7		1710	Decompress to surface
7		1715	U/s
7		1730	Medical check, clean up
7		1800	Crew debriefing
7		1930	Dinner for divers and crew with RWH
7		2230	Final scheduled U/s
7			Divers remain overnight.

<u>Day 9, 1986 August 16:</u> Divers call in to report condition.

NOAA-HRL-IUC REPEX III SATURATION AT 110 FSW

SCHEDULE OF EVENTS

Day	Excn#	Time	Events and Remarks
-1			1986 August 17, Sunday
-1		1500	Familiarization, habitability, and briefing of divers.
-1		1900	Dinner for divers
-1		2130	Doppler training
-1		2300	Final outfitting of chamber
-1		2350	Divers enter chamber
-1		2400	Begin compression to 110 fsw ...continued
1			1986 August 18, Monday
1		0015	Control doppler ultrasound (u/s)
1		0030	Divers fill out subjective questionaire
1		0045	LIGHTS OUT.
1		0630	Divers awakened
1		0700	Breakfast
1	1	0800	Excurse to 200 fsw for 105 min
1	1	0945	Decompress to storage depth at 30 fsw/min, hold 1/2 hr
1	2	1015	Excursion: 200/52
1	2	1107	Decompress; hold 1 hour
1	2	1125	Lunch
1	2	1147	U/s
1	3	1207	Excursion: 190/57
1	3	1304	Decompress; hold 1/2 hr
1	4	1334	Excursion: 240/12
1	4	1346	Decompress; hold 1 hr
1	4	1426	U/s
1	5	1446	Excursion: 180/78
1	5	1604	Decompress; hold 16 hr
1	5	1644	U/s
1	5	1729	U/s
1	5	1745	Dinner
1	5	1814	U/s
1		2000	Questionaire
1		2200	Lights out.
2			1986 August 19, Tuesday
2		0634	Divers awakened
2		0704	Breakfast
2	6	0804	Excursion: 200/105
2	6	0949	Decompress; hold 8 hours
2	6	1029	U/s
2	6	1114	U/s
2	6	1154	U/s
2		1215	Lunch
2	7	1749	Excursion: 200/105
2	7	1815	Dinner

NOAA-HRL-IUC Repex III SATURATION AT 110 FSW

Day	Excn#	Time	Event	Remarks
2			1986 August 19, continued	
2	7	1934	Decompress; hold 2 hours	
2	7	2014	U/s	
2	7	2059	U/s	
2	8	2134	Excursion: 240/16	
2	9	2150	Decompress; hold 1 hour	
2	8	2230	U/s	
2	9	2250	Excursion: 190/57	
2	9	2347	Decompress; hold 8 hours	
3			1986 August 20, Wednesday	
3	9	0015	Questionaire	
3	9	0027	U/s	
3	9	0112	U/s	
3		0130	LIGHTS OUT	
3		0630	Divers awakened	
3		0700	Breakfast	
3	10	0800	One-stop excursion: 200/150 + 2 + 58	
3	10	1030	Decompress to 135 fsw	
3	10	1032	Stop at 135 fsw for 2 min	
3	10	1034	Decompress to 125 fsw, stop 58 min	
3	10	1110	U/s	
3	10	1132	Decompress to storage; hold 1 hour	
3	10	1155	U/s	
3		1210	Lunch	
3	11	1230	Excursion: 180/40 (submaximal)	
3	11	1310	Decompress; hold 1 hr	
3	11	1350	U/s	
3	12	1410	Excursion: 200/58 (postsubmaximal)	
3	12	1508	Decompress; hold 1/2 hour	
3	13	1538	Excursion: 200/22	
3	13	1600	Decompress; hold 16 hours	
3	13	1640	U/s	
3	13	1725	U/s	
3	13	1740	Dinner	
3	13	1810	U/s	
3		2000	Questionaire	
3		2200	LIGHTS OUT.	
4			1986 August 21, Thursday	
4		0630	Divers awakened	
4		0700	Breakfast	
4	14	0800	One-stop excursion: 200/240 + 2 + 33	
4	14	1200	Decompress to 135 fsw	
4	14	1202	Stop at 135 fsw for 2 min	
4	14	1204	Decompress to 125 fsw, stop 33 min	
4	14	1210	Lunch	
4	14	1237	Decompress to storage; hold 2 hours	
4	14	1240	U/s	

NOAA-HRL-IUC Repex III SATURATION AT 110 FSW

Day	Excn#	Time	Event	Remarks
4			1986 August 21, continued	
4	14	1325	U/s	
4	15	1435	Excursion: 220/29	
4	15	1504	Decompress; hold 1/2 hr	
4	16	1534	Excursion: 240/12	
4	16	1546	Decompress; hold 16 hours	
4	16	1626	U/s	
4	16	1711	U/s	
4	16	1756	U/s.	
4		1830	Dinner	
4		2000	Questionaire	
4		2200	LIGHTS OUT	
5			<u>1986 August 22, Friday</u>	
5		0630	Divers awakened	
5		0715	Breakfast	
5	17	0800	Excursion: 200/105	
5	17	0945	Decompress; hold 2 hours	
5	17	1025	U/s	
5	17	1110	U/s	
5	18	1145	Excursion: 240/16	
5	18	1201	Decompress; hold 4 hr	
5	18	1210	Lunch	
5	18	1241	U/s	
5	18	1326	U/s	
5	18	1411	U/s	
5	19	1601	Excursion: 220/29.	
5	19	1630	Decompress to 155 fsw.	Begin saturation decompression.
5		1636	Decompress to 154 fsw.	Remain on air.
5		1642	Decompress to 153 fsw	
5		1648	Decompress to 152 fsw	
5		1654	Decompress to 151 fsw	
5		1700	Decompress to 150 fsw	
5		1706	Decompress to 149 fsw	
5		1710	U/s	
5		1712	Decompress to 148 fsw	
5		1718	Decompress to 147 fsw	
5		1724	Decompress to 146 fsw	
5		1730	Decompress to 145 fsw	
5		1736	Decompress to 144 fsw	
5		1742	Decompress to 143 fsw	
5		1748	Decompress to 142 fsw	
5		1754	Decompress to 141 fsw	
5		1755	U/s.	
5		1800	Decompress to 140 fsw.	Dinner.
5		1806	Decompress to 139 fsw	
5		1812	Decompress to 138 fsw	
5		1818	Decompress to 137 fsw	
5		1824	Decompress to 136 fsw	
5		1830	Decompress to 135 fsw	
5		1839	Decompress to 134 fsw	

NOAA-HRL-IUC Repex III SATURATION AT 110 FSW

Day	Excn#	Time	Event	Remarks
5			1986 August 22, continued	
5		1840	U/s	
5		1848	Decompress to 133 fsw	
5		1857	Decompress to 132 fsw	
5		1906	Decompress to 131 fsw	
5		1915	Decompress to 130 fsw	
5		1924	Decompress to 129 fsw	
5		1933	Decompress to 128 fsw	
5		1942	Decompress to 127 fsw	
5		1951	Decompress to 126 fsw	
5		2000	Decompress to 125 fsw	
5		2009	Decompress to 124 fsw	
5		2018	Decompress to 123 fsw	
5		2027	Decompress to 122 fsw	
5		2036	Decompress to 121 fsw	
5		2045	Decompress to 120 fsw	
5		2054	Decompress to 119 fsw	
5		2103	Decompress to 118 fsw	
5		2112	Decompress to 117 fsw	
5		2121	Decompress to 116 fsw	
5		2130	Decompress to 115 fsw	
5		2139	Decompress to 114 fsw	
5		2148	Decompress to 113 fsw	
5		2157	Decompress to 112 fsw	
5		2200	U/s	
5		2206	Decompress to 111 fsw	
5		2215	Decompress to 110 fsw	**[Ascent rrate 38 min/fsw, should be 21 min/fsw from 110 to 105 fsw, 22 min/fsw from 105 to 100, 23 from 100 to 95]**
5		2230	Lights out.	
5		2253	Decompress to 109 fsw	
5		2331	Decompress to 108 fsw	
6			1986 August 23, Saturday	
6		0009	Decompress to 107 fsw	
6		0047	Decompress to 106 fsw	
6		0125	Decompress to 105 fsw	
6		0203	Decompress to 104 fsw	
6		0241	Decompress to 103 fsw	
6		0319	Decompress to 102 fsw	
6		0357	Decompress to 101 fsw	
6		0435	Decompress to 100 fsw	Adjust chamber PO_2 to 0.5 atm.
6		0513	Decompress to 99 fsw	
6		0551	Decompress to 98 fsw	
6		0629	Decompress to 97 fsw	
6		0707	Decompress to 96 fsw	
6		0745	Decompress to 95 fsw	
6		0815	Divers awakened	
6		0823	Decompress to 94 fsw	
6		0830	U/s	
6		0901	Decompress to 93 fsw	
6		0902	Breakfast	
6		0939	Decompress to 92 fsw	

NOAA-HRL-IUC Repex III SATURATION AT 110 FSW

Day	Excn#	Time	Event	Remarks
6			1986 August 23, continued	
6		1017	Decompress to 91 fsw	
6		1055	Decompress to 90 fsw	
6		1133	Decompress to 89 fsw	
6		1211	Decompress to 88 fsw	
6		1215	Lunch	
6		1249	Decompress to 87 fsw	
6		1327	Decompress to 86 fsw	
6		1405	Decompress to 85 fsw	
6		1430	U/s	
6		1443	Decompress to 84 fsw	
6		1521	Decompress to 83 fsw	
6		1559	Decompress to 82 fsw	
6		1637	Decompress to 81 fsw	
6		1715	Decompress to 80 fsw	Change chamber mix back to air.
6		1730	Dinner	
6		1753	Decompress to 79 fsw	
6		1831	Decompress to 78 fsw	
6		1909	Decompress to 77 fsw	
6		1947	Decompress to 76 fsw	
6		2000	Questionaire	
6		2025	Decompress to 75 fsw	
6		2103	Decompress to 74 fsw	
6		2141	Decompress to 73 fsw	
6		2200	U/s	
6		2219	Decompress to 72 fsw	
6		2257	Decompress to 71 fsw	
6		2300	Lights out	
6		2335	Decompress to 70 fsw	
7			1986 August 24, Sunday	
7		0013	Decompress to 69 fsw	
7		0051	Decompress to 68 fsw	
7		0129	Decompress to 67 fsw	
7		0207	Decompress to 66 fsw	
7		0245	Decompress to 65 fsw	
7		0323	Decompress to 64 fsw	
7		0401	Decompress to 63 fsw	
7		0439	Decompress to 62 fsw	
7		0517	Decompress to 61 fsw	
7		0555	Decompress to 60 fsw	
7		0633	Decompress to 59 fsw	
7		0711	Decompress to 58 fsw	
7		0749	Decompress to 57 fsw	
7		0815	Divers awakened	
7		0827	Decompress to 56 fsw	
7		0830	U/s	
7		0900	Breakfast	
7		0905	Decompress to 55 fsw	
7		0943	Decompress to 54 fsw	
7		1021	Decompress to 53 fsw	

NOAA-HRL-IUC Repex III SATURATION AT 110 FSW

Day	Excn#	Time	Event	Remarks
7			1986 August 24, continued	
7		1059	Decompress to 52 fsw	
7		1137	Decompress to 51 fsw	
7		1215	Decompress to 50 fsw	
7		1230	Lunch	
7		1253	Decompress to 49 fsw	
7		1331	Decompress to 48 fsw	
7		1409	Decompress to 47 fsw	
7		1430	U/s	
7		1447	Decompress to 46 fsw	
7		1525	Decompress to 45 fsw	
7		1604	Decompress to 44 fsw	
7		1643	Decompress to 43 fsw	
7		1722	Decompress to 42 fsw	
7		1730	Dinner	
7		1801	Decompress to 41 fsw	
7		1840	Decompress to 40 fsw	
7		1921	Decompress to 39 fsw	
7		2000	Questionaire	
7		2002	Decompress to 38 fsw	
7		2043	Decompress to 37 fsw	
7		2124	Decompress to 36 fsw	
7		2200	U/s	
7		2205	Decompress to 35 fsw	
7		2230	Lights out	
7		2249	Decompress to 34 fsw	
7		2333	Decompress to 33 fsw	
8			1986 August 25, Monday	
8		0017	Decompress to 32 fsw	
8		0101	Decompress to 31 fsw	
8		0145	Decompress to 30 fsw	
8		0233	Decompress to 29 fsw	
8		0321	Decompress to 28 fsw	
8		0409	Decompress to 27 fsw	
8		0457	Decompress to 26 fsw	
8		0545	Decompress to 25 fsw	
8		0637	Decompress to 24 fsw	
8		0729	Decompress to 23 fsw	
8		0815	Divers awakened	
8		0821	Decompress to 22 fsw	
8		0830	U/s	
8		0845	Breakfast	
8		0913	Decompress to 21 fsw	
8		1005	Decompress to 20 fsw	
8		1102	Decompress to 19 fsw	
8		1159	Decompress to 18 fsw	
8		1230	Lunch	
8		1256	Decompress to 17 fsw	
8		1353	Decompress to 16 fsw	
8		1430	U/s	

NOAA-HRL-IUC Repex III SATURATION AT 110 FSW

Day	Excn#	Time	Event	Remarks
8			1986 August 25, continued	
8		1450	Decompress to 15 fsw	
8		1552	Decompress to 14 fsw	
8		1654	Decompress to 13 fsw	
8		1730	Dinner	
8		1756	Decompress to 12 fsw	
8		1848	Decompress to 11 fsw	
8		2000	Decompress to 10 fsw. Questionaire	
8		2110	Decompress to 9 fsw	
8		2200	U/s	
8		2220	Decompress to 8 fsw	
8		2230	Lights out	
8		2330	Decompress to 7 fsw	
9			1986 August 26, Tuesday	
9		0040	Decompress to 6 fsw	
9		0150	Decompress to 5 fsw. Hold at 5 fsw for 395 min.	
9		0800	If necessary, divers awakened.	
9		0825	Decompress to 0 fsw. Surface	
9		0830	U/s	
9		0845	Medical check	
9		0900	Debriefing, all divers and crew.	
9		1000	Brunch, divers and available crew.	
9		1400	Questionaire	
9		1430	U/s	
9		2000	Divers may leave IUC, stay in contact.	

Day 11,1986 August 28: Divers report condition to RWH, GJB, or BB.

APPENDIX C.

Sample table pages

Storage depth 50-54 fsw was used for Repex I. The saturation decompression was taken from an earlier version of the 45-49 fsw table, which was changed as a result of this decompression.

Storage depth 80-84 fsw was used for both Repex II excursions and saturation decompression.

Storage depth 110-114 fsw was used for Repex III excursions, and 105-109 fsw for saturation decompression. The "break" at $PO_2=0.5$ was done at a different time from the one in the final table set.

REPEX Habitat Diving Procedures

STORAGE DEPTH 50-54 FSW
Page 1 of 2

OXYGEN MANAGEMENT AT 50-54 FSW

Pressure: 50 fsw = 15.35 msw = 153.52 kilopascals = 2.52 atm abs

Habitat gas = 0.3 to 0.35 atm oxygen partial pressure
= 11.9 to 13.9 percent oxygen at 50 fsw

PO_2 of air at			CPTU/hr at		
	50 fsw=	0.53		**50 fsw=**	6
	54 fsw=	0.55		**54 fsw=**	9
	60 fsw=	0.59		**60 fsw=**	14
	64 fsw=	0.61		**64 fsw=**	18

ASCENDING EXCURSIONS FROM 50-54 FSW

Target depth range, fsw:	**0-5**	**5-10**	**10-15**	**15-20**	**20-25**	**25-30**	**30-35**	**>=35**
Time allowed:	7	13	18	25	32	42	60	no limit

OXYGEN WINDOW EXCURSION RANGE

Breathing air: **Storage depth + 10 fsw**

NO-STOP EXCURSIONS FROM 50-54 FSW

85Aug D55R00.K08; .K09

Allowable time (min) at each excursion depth **(fsw)**

Excn#	Intrvl	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**	**105**	**110**	**115**	**120**	**125**
1st	>16 hr						480	480	455	296	201	158	116	92
2nd	8-16						480	480	431	294	200	157	116	92
2nd	4-8						480	480	374	262	189	147	116	91
2nd	2-4			...All 480...			480	480	292	200	162	123	103	86
2nd	1-2						480	462	205	142	124	91	77	68
2nd	1/2-1						480	419	131	98	85	59	54	50
3+	8-16						480	480	431	294	200	157	116	92
3+	4-8						480	480	340	253	189	147	116	91
3+	2-4						480	307	197	145	115	95	83	75
3+	1-2						427	171	107	78	70	57	48	42
3+	1/2-1						241	91	72	49	38	30	25	22

Excn#	Intrvl	**130**	**135**	**140**	**145**	**150**	**155**	**160**	**170**	**180**	**190**	**200**	**220**	**240**
1st	>16 hr	77	67	54	45	40	35	32	27	23	19	16	11	08
2nd	8-16	77	67	54	45	40	35	32	27	23	19	16	11	08
2nd	4-8	77	66	54	45	40	35	32	27	23	19	16	11	08
2nd	2-4	72	62	53	45	39	35	32	27	23	19	16	11	08
2nd	1-2	60	51	45	41	37	33	30	25	21	19	16	11	08
2nd	1/2-1	44	37	34	31	28	26	24	20	17	15	14	11	08
3+	8-16	77	67	54	45	40	35	32	27	23	19	16	11	08
3+	4-8	77	66	54	45	40	35	32	27	23	19	16	11	08
3+	2-4	67	60	53	45	39	35	32	27	23	19	16	11	08
3+	1-2	37	33	30	27	25	23	21	19	17	15	14	11	08
3+	1/2-1	19	19	18	17	16	15	14	12	10	09	08	07	06

ONE-STOP EXCURSIONS FROM 50-54 FSW

85Aug D58400.K08; .K09

Interval >16 hr

Excursion depths (fsw) with bottom and stop times (min)

105		**110**		**115**		**120**		**125**		**130**		**135**		**140**		**145**	
296	0	201	0	158	0	116	0	92	0	77	0	67	0	54	0	45	0
		210	2	180	7	120	1	120	6	90	5	90	9	60	2	60	5
		240	8	210	15	150	8	150	19	120	14	120	22	90	13	90	17
				240	20	180	19	180	29	150	28	150	37	120	31	120	38
						210	26	210	37	180	38	180	50	150	45		
						240	36										

150		**155**		**160**		**170**		**180**		**190**		**200**		**220**		**240**	
40	0	35	0	32	0	27	0	23	0	19	0	16	0	11	0	8	0
45	2	45	4	45	5	30	2	30	5	20	1	20	2	20	6	10	1
60	8	60	12	60	15	45	10	45	15	30	7	30	10			16	10
90	24	90	31	90	37	60	21			45	20						
120	45																

Interval 2-16 hr

Excursion depths (fsw) with bottom and stop times (min)

100		**105**		**110**		**115**		**120**		**125**		**130**		**135**		**140**	
197	0	145	0	115	0	95	0	83	0	75	0	67	0	60	0	53	0
240	4	210	29	180	41	150	44	120	33	90	7	90	22	90	46	60	3
		240	44	210	60	180	68	150	67	120	57					90	66

145		**150**		**155**		**160**		**170**		**180**		**190**		**200**		**220**	
45	0	39	0	35	0	32	0	27	0	23	0	19	0	16	0	11	0
60	9	45	2	45	4	45	7	30	2	30	5	20	1	20	2	20	6
		60	19	60	27	60	40	45	18	45	32	30	8	30	11		
								60	71			45	48				

240	
8	0
10	1
16	10

SATURATION DECOMPRESSION FROM STORAGE AT 50-54 FSW

86Dec

Selecting precursory starting depth:

Max excn last 36 hr	70	75	80	85	90	95	100	105	110	115	>115
Starting depth to use	55	60	65	70	75	80	85	90	95	100	100

Precursory table:

Depth fsw	Time togo	Stop time	RRat mn/f	Gas mix	PO2, atm	CPTD stop
100	2595	60	12	air	0.85	44
95	2535	60	12	air	0.81	41
90	2475	60	12	air	0.78	37
85	2415	60	12	air	0.75	34
80	2355	60	12	air	0.72	30
75	2295	95	19	air	0.69	42
70	2200	95	19	air	0.66	36
65	2105	95	19	air	0.62	30
60	2010	95	19	air	0.59	23
55	1915	115	23	air	0.56	20

Main Table: k = 4.6889

Depth fsw	Time togo	Stop time	RRat mn/f	Gas mix	PO2, atm	CPTD stop
50	1800	125	25	air	0.53	11
45	1675	130	26	air	0.50	0
40	1545	140	28	air	0.46	0
35	1405	150	30	air	0.43	0
30	1255	165	33	air	0.40	0
25	1090	175	35	air	0.37	0
20	915	195	39	air	0.34	0
15	720	215	43	air	0.31	0
10	505	235	47	air	0.27	0
5	270	270	54	air	0.24	0

Precursory	13.3 hr	CPTD	337
Main	1 d + 6.0 hr	CPTD	11
Total	1 d + 19.3 hr	CPTD	348

OXYGEN MANAGEMENT AT 80-84 FSW

Pressure: 80 fsw = 24.56 msw = 245.64 kilopascals = 3.42 atm abs

Habitat gas = 0.3 to 0.35 atm oxygen partial pressure
= 8.8 to 10.2 percent oxygen at 80 fsw

PO_2 of air at	**80 fsw=**	0.72	CPTU/hr at	**80 fsw=**	30
	84 fsw=	0.74		**84 fsw=**	33
	98 fsw=	0.83		**98 fsw=**	43
	102 fsw=	0.86		**102 fsw=**	45

ASCENDING EXCURSIONS FROM 80-84 FSW

Target depth range, fsw:	<25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	>=65
Time allowed:	0	5	10	16	23	30	37	48	60	no limit

OXYGEN WINDOW EXCURSION RANGE Breathing air: Storage depth + 18 fsw

NO-STOP EXCURSIONS FROM 80-84 FSW

85Aug D55R00.K19

		Allowable time (min) at each excursion depth (fsw)												
Excn#	Intrvl	65	70	75	80	85	90	95	100	105	110	115	120	125
1st	>16 hr													
2nd	8-16													
2nd	4-8													
2nd	2-4							...All 480...						
2nd	1-2													
2nd	1/2-1													
3+	8-16													
3+	4-8													
3+	2-4													
3+	1-2													
3+	1/2-1													

Excn#	Intrvl	130	135	140	145	150	155	160	170	180	190	200	220	240
1st	>16 hr	480	480	420	282	199	159	119	79	56	41	33	24	16
2nd	8-16	480	480	397	281	198	157	119	79	56	41	33	24	16
2nd	4-8	480	477	327	250	187	147	118	79	56	41	33	24	16
2nd	2-4	480	382	244	191	159	123	103	74	56	41	33	24	16
2nd	1-2	480	314	182	135	121	91	78	61	47	39	31	22	16
2nd	1/2-1	480	271	114	93	83	60	54	46	35	29	25	18	14
3+	8-16	480	480	397	281	198	157	119	79	56	41	33	24	16
3+	4-8	480	410	290	224	183	147	118	79	56	41	33	24	16
3+	2-4	426	240	168	129	105	88	78	63	52	41	33	24	16
3+	1-2	244	132	90	72	63	52	45	35	28	24	21	16	13
3+	1/2-1	132	69	59	43	34	28	24	18	15	12	12	11	09

ONE-STOP EXCURSIONS FROM 80-84 FSW

85Aug D58400.K20

Interval >16 hr

Excursion depths (fsw) with bottom and stop times (min)

150		155		160		170		180		190		200		220		240	
199	0	159	0	119	0	79	0	56	0	41	0	33	0	24	0	16	0
210	2	180	6	120	1	90	3	60	1	45	1	45	4	29	4		
240	7	210	12	150	7	120	11	90	10	60	6	60	12	29	12		
		240	17	180	15	150	23	120	24	90	18	90	29	29	22		
				210	21	180	31	150	37	120	37						
				240	30	210	46										

Interval 2-16 hr

Excursion depths (fsw) with bottom and stop times (min)

140		145		150		155		160		170		180		190		200	
168	0	129	0	105	0	88	0	78	0	63	0	52	0	41	0	33	0
210	8	180	21	150	25	120	19	120	37	90	30	60	2	45	2	45	5
240	20	210	35	180	43	150	44	150	61	120	66	90	57	60	14	60	39
		240	47			180	63										

220		240	
24	0	16	0
29	4		
29	25		

SATURATION DECOMPRESSION FROM STORAGE AT 80-84 FSW

86Dec

Selecting precursory starting depth:

Max excn last 36 hr	105	110	115	120	125	130	135	140	145	150	>150
Starting depth to use	85	90	95	100	105	110	115	120	125	130	130

Precursory table:

Depth fsw	Time togo	Stop time	RRat mn/f	Gas mix	PO2, atm	CPTD stop
130	3225	45	9	air	1.04	48
125	3180	45	9	air	1.01	45
120	3135	45	9	air	0.97	43
115	3090	45	9	air	0.94	41
110	3045	45	9	air	0.91	38
105	3000	60	12	air	0.88	48
100	2940	60	12	air	0.85	44
95	2880	60	12	air	0.81	41
90	2820	60	12	air	0.78	37
85	2760	95	19	air	0.75	54

Main Table: k = 4.2351

Depth fsw	Time togo	Stop time	RRat mn/f	Gas mix	PO2, atm	CPTD stop
80	2665	100	20	air	0.72	50
75	2565	105	21	air	0.69	46
70	2460	110	22	air	0.66	42
65	2350	115	23	air	0.62	36
60	2235	125	25	air	0.59	31
55	2110	130	26	air	0.56	22
50	1980	135	27	air	0.53	12
45	1845	145	29	air	0.50	0
40	1700	155	31	air	0.46	0
35	1545	165	33	air	0.43	0
30	1380	180	36	air	0.40	0
25	1200	195	39	air	0.37	0
20	1005	215	43	air	0.34	0
15	790	235	47	air	0.31	0
10	555	260	52	air	0.27	0
5	295	295	59	air	0.24	0

Precursory	9.3 hr	CPTD	439
Main	1 d + 20.4 hr	CPTD	239
Total	2 d + 5.8 hr	CPTD	678

ONE-STOP EXCURSIONS FROM 105-109 FSW

85Aug D58400.K26

Interval >16 hr

Excursion depths (fsw) with bottom and stop times (min)

170		180		190		200		220		240	
463	0	214	0	128	0	83	0	29	0	16	0
		240	4	150	4	90	2				
				180	12	120	8				
				210	17	150	19				
				240	23	180	26				
						210	37				

Interval 2-16 hr

Excursion depths (fsw) with bottom and stop times (min)

170		180		190		200		220		240	
181	0	110	0	79	0	65	0	29	0	16	0
240	11	150	17	120	28	90	20				
		180	32	150	48	120	53				
		210	44	180	66						
		240	56								

SATURATION DECOMPRESSION FROM STORAGE AT 105-109 FSW

86Dec

Selecting precursory starting depth:

Max excn last 36 hr	140	145	150	155	160	170	180	>180
Starting depth to use	110	115	120	125	135	145	155	155

Precursory table:

Depth fsw	Time togo	Stop time	RRat mn/f	Gas mix	PO2, atm	CPTD stop
155	5035	30	6	air	1.20	39
150	5005	30	6	air	1.16	38
145	4975	30	6	air	1.13	36
140	4945	30	6	air	1.10	35
135	4915	45	9	air	1.07	50
130	4870	45	9	air	1.04	48
125	4825	45	9	air	1.01	45
120	4780	45	9	air	0.97	43
115	4735	45	9	air	0.94	41
110	4690	105	21	air	0.91	89

Precursory		7.5 hr	CPTD	464
Main	3 d +	4.4 hr	CPTD	485
Total	3 d +	11.9 hr	CPTD	949

Main Table: k = 3.1779

Depth fsw	Time togo	Stop time	RRat mn/f	Gas mix	PO2, atm	CPTD stop
105	4585	110	22	air	0.88	87
100	4475	115	23	air	0.85	85
95	4360	190	38	air	0.50	0
90	4170	190	38	0.5	0.50	0
85	3980	190	38	0.5	0.50	0
80	3790	190	38	0.5	0.50	0
75	3600	190	38	0.5	0.69	84
70	3410	190	38	air	0.66	72
65	3220	190	38	air	0.62	60
60	3030	190	38	air	0.59	47
55	2840	190	38	air	0.56	33
50	2650	190	38	air	0.53	17
45	2460	195	39	air	0.50	0
40	2265	205	41	air	0.46	0
35	2060	220	44	air	0.43	0
30	1840	240	48	air	0.40	0
25	1600	260	52	air	0.37	0
20	1340	285	57	air	0.34	0
15	1055	310	62	air	0.31	0
10	745	350	70	air	0.27	0
5	395	395	79	air	0.24	0

REPEX Habitat Diving Procedures **STORAGE DEPTH 110-114 FSW**
Page 1 of 2

OXYGEN MANAGEMENT AT 110-114 FSW

Pressure: 110 fsw = 33.78 msw = 337.75 kilopascals = 4.33 atm abs

Habitat gas = 0.3 to 0.35 atm oxygen partial pressure
= 6.9 to 8.1 percent oxygen at 110 fsw

PO_2 of air at	**110 fsw=**	0.91	CPTU/hr at **110 fsw=**	51
	114 fsw=	0.94	**114 fsw=**	53
	135 fsw=	1.07	**135 fsw=**	67
	139 fsw=	1.10	**139 fsw=**	70

ASCENDING EXCURSIONS FROM 110-114 FSW

Target depth range, fsw:	<55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	>=90
Time allowed:	0	7	13	18	25	32	42	60	no limit

OXYGEN WINDOW EXCURSION RANGE

Breathing air: **Storage depth + 25 fsw**

NO-STOP EXCURSIONS FROM 110-114 FSW

85Aug D55R00.H25

Allowable time (min) at each excursion depth **(fsw)**

Excn#	Intrvl	**85**	**90**	**95**	**100**	**105**	**110**	**115**	**120**	**125**
1st	>16 hr									
2nd	8-16									
2nd	4-8									
2nd	2-4				...All 480...					
2nd	1-2									
2nd	1/2-1									
3+	8-16									
3+	4-8									
3+	2-4									
3+	1-2									
3+	1/2-1									

Excn#	Intrvl	**130**	**135**	**140**	**145**	**150**	**155**	**160**	**170**	**180**	**190**	**200**	**220**	**240**
1st	>16 hr							480	480	358	176	105	29	16
2nd	8-16							480	480	337	175	105	29	16
2nd	4-8							480	480	285	164	104	29	16
2nd	2-4			...All 480...				480	480	214	139	93	29	16
2nd	1-2							480	463	144	104	73	29	16
2nd	1/2-1							480	420	87	69	52	29	16
3+	8-16							480	480	337	175	105	29	16
3+	4-8							480	480	253	164	104	29	16
3+	2-4							480	307	146	102	75	29	16
3+	1-2							480	171	78	57	42	27	16
3+	1/2-1							480	91	50	30	22	14	12

REPEX Habitat Diving Procedures

STORAGE DEPTH 110-114 FSW
Page 2 of 2

ONE-STOP EXCURSIONS FROM 110-114 FSW

85Aug D58400.K27

Interval >16 hr

Excursion depths (fsw) with bottom and stop times (min)									
180		**190**		**200**		**220**		**240**	
358	0	176	0	105	0	29	0	16	0
		180	1	120	3				
		210	7	150	10				
		240	10	180	17				
				210	23				
				240	33				

Interval 2-16 hr

Excursion depths (fsw) with bottom and stop times (min)											
170		**180**		**190**		**200**		**220**		**240**	
307	0	146	0	102	0	75	0	29	0	16	0
		180	3	120	2	120	37				
		210	18	150	28	150	58				
		240	28	180	44						

SATURATION DECOMPRESSION FROM STORAGE AT 110-114 FSW

86Dec

Selecting precursory starting depth:

Max excn last 36 hr	145	150	155	160	170	180	>180
Starting depth to use	115	120	125	135	145	155	155

Precursory table:

Depth fsw	Time togo	Stop time	RRat mn/f	Gas mix	PO2, atm	CPTD stop
155	5555	30	6	air	1.20	39
150	5525	30	6	air	1.16	38
145	5495	30	6	air	1.13	36
140	5465	30	6	air	1.10	35
135	5435	45	9	air	1.07	50
130	5390	45	9	air	1.04	48
125	5345	45	9	air	1.01	45
120	5300	45	9	air	0.97	43
115	5255	110	22	air	0.94	99

Precursory	6.8 hr	CPTD	433
Main	3 d + 13.8 hr	CPTD	633
Total	3 d + 20.6 hr	CPTD	1066

Main Table: k = 2.9420

Depth fsw	Time togo	Stop time	RRat mn/f	Gas mix	PO2, atm	CPTD stop
110	5145	115	23	air	0.91	98
105	5030	120	24	air	0.88	95
100	4910	205	41	0.5	0.50	0
95	4705	205	41	0.5	0.50	0
90	4500	205	41	0.5	0.50	0
85	4295	205	41	0.5	0.50	0
80	4090	205	41	air	0.72	103
75	3885	205	41	air	0.69	91
70	3680	205	41	air	0.66	78
65	3475	205	41	air	0.62	64
60	3270	205	41	air	0.59	50
55	3065	205	41	air	0.56	35
50	2860	205	41	air	0.53	19
45	2655	210	42	air	0.50	0
40	2445	225	45	air	0.46	0
35	2220	240	48	air	0.43	0
30	1980	260	52	air	0.40	0
25	1720	280	56	air	0.37	0
20	1440	305	61	air	0.34	0
15	1135	335	67	air	0.31	0
10	800	375	75	air	0.27	0
5	425	425	85	air	0.24	0

APPENDIX D.

Repex DCAP dive profile

A sample DCAP Base Case (table file for Base Case D78002.B20) for Repex II is shown. This is the procedure that could be used to calculate a "custom" dive using DCAP. Actually, the Repex dives were constructed from the tables, using a spreadsheet program to adjust and optimize the daily schedules. This Base Case and variations on it were used to check that the tables did not violate the decompression algorithm. (See section III.A.3)

```
 DCAP VERSION 5.506 87Jun12 RUN ON 87Aug28    AT 14:14:11

  C
   BASE.CASE   D78002.B20
  C            <--------------------51------------------------>
   REVISION    REPEX II 80 FSW SATURATION. RATES= +-0
               COMPLETE SCHEDULE. USING CODING FORMAT ADOPTED FOR
               ALL REPEX DIVES.  PROPER SYNTAX FOR 1-STOPs
               USING AN EXACT RATE INSTEAD OF A TRAVEL TO SORT
               OUT ONE MINUTE DISCEPENCY ON 1-STOP END OF DAY 1
  C
   SET         FILE=IN08F1.DCP
               TITLE=NOAA REPEX II, 80 FSW PROFILE
               AUTHOR=RWH/DJK/DMB
               TIME.HEADING=5
               STOP.TIME.INCR=1
               BOTTOM.DEPTH=80
               BOTTOM.MIX=2
               CPTD.PRINT=ON
               STORAGE.DEPTH=80
               SATURATION_MIX=3
   NOTEBOOK    FILE=DNBREPEX.DCP
  C
   MATRIX      FILE=MF0805.DCP
  C MF0805  NOAA Repex, for nitrox excursions
   DB=70 BASE=189 165 140 127 118 112 107 105
   DS=70 SLOPE=1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0
   DB=0 BASE=77 64 53 43 39 36 36 35
   DS=0 SLOPE=1.6 1.45 1.25 1.2 1.13 1.08 1.02 1.0
  C               <--8--->
   MIX         1=BELLMIX
               2=AIR O2=21 % N2=100 BALANCE% COMMENT=32
               3=.32_PO2 O2=0.32 ATM N2=100 BALANCE% COMMENT=27
               4=AIR O2=21 % N2=100 BALANCE%
               5=.32_PO2 O2=0.32 ATM N2=100 BALANCE%
  C              <------------------40------------------>
   COMMENT     FILE=CMNT03.DCP
  C
   POSITION    DEPTH=0 STOP=0 MIX=4 COMMENT=22 2ND.COMMENT=25 3RD.COMMENT=33
   SET         DAY=1986:220
               CLOCK=0:00
   POSITION    DEPTH=0 TRAVEL=0 STOP=0 RATE=0 MIX=4 COMMENT=30
   POSITION    DEPTH=80 CLOCK.STOP=08:00 MIX=5 COMMENT=38
   POSITION    DEPTH=200 STOP=14 MIX=4 COMMENT=28
   DECOMPRESS  DEPTH=80 STAGE.STEP=10
   POSITION    DEPTH=80 STOP=30 MIX=3
   POSITION    DEPTH=140 STOP=290 MIX=4 COMMENT=29
   DECOMPRESS  DEPTH=80
   POSITION    DEPTH=80 STOP=60 MIX=3
   POSITION    DEPTH=140 STOP=90 MIX=2
   DECOMPRESS  DEPTH=80
   POSITION    DEPTH=80 STOP=240 MIX=3
   POSITION    DEPTH=170 STOP=79 MIX=2
```

```
 DECOMPRESS DEPTH=80
  POSITION   DEPTH=80 STOP=120 MIX=3
  POSITION   DEPTH=220 STOP=29 MIX=2
 DECOMPRESS DEPTH=105 RATE=38.33 TRAVEL=0
  POSITION   DEPTH=105 STOP=2 RATE=0 TRAVEL=0 COMMENT=36
 DECOMPRESS DEPTH=95
  POSITION   DEPTH=95 STOP=4 COMMENT=37
 DECOMPRESS DEPTH=80
  POSITION   DEPTH=80 MIX=5 COMMENT=26
C        BEGIN DAY 2
  SET        CPTD=0
  POSITION   DEPTH=80 DAY.STOP= 1986:221 CLOCK.STOP=08:00
  POSITION   DEPTH=200 STOP=33 MIX=2
 DECOMPRESS DEPTH=80
  POSITION   DEPTH=80 STOP=30 MIX=3
  POSITION   DEPTH=180 STOP=35 MIX=2
 DECOMPRESS DEPTH=98
  POSITION   DEPTH=98 STOP=240 COMMENT=31
  POSITION   DEPTH=180 STOP=60 COMMENT=32
 DECOMPRESS DEPTH=105 RATE=0 TRAVEL=2
  POSITION   DEPTH=105 STOP=2 TRAVEL=0 COMMENT=36
 DECOMPRESS DEPTH=95
  POSITION   DEPTH=95 STOP=2 COMMENT=37
 DECOMPRESS DEPTH=80
  POSITION   DEPTH=80 STOP=28 MIX=3
  POSITION   DEPTH=145 STOP=43 MIX=2
 DECOMPRESS DEPTH=80
  POSITION   DEPTH=80 MIX=5 COMMENT=26
C        BEGIN DAY 3
  SET        CPTD=0
  POSITION   DEPTH=80 DAY.STOP=1986:222 CLOCK.STOP=08:00
  POSITION   DEPTH=170 STOP=40 MIX=4 COMMENT=28
 DECOMPRESS DEPTH=80
  POSITION   DEPTH=80 STOP=60 MIX=3
  POSITION   DEPTH=160 STOP=98 MIX=4 COMMENT=29
 DECOMPRESS DEPTH=80
  POSITION   DEPTH=80 STOP=120 MIX=3
  POSITION   DEPTH=200 STOP=60 MIX=2
 DECOMPRESS DEPTH=105 RATE=0 TRAVEL=3
  POSITION   DEPTH=105 STOP=2 TRAVEL=0 COMMENT=36
 DECOMPRESS DEPTH=95
  POSITION   DEPTH=95 STOP=39 COMMENT=37
 DECOMPRESS DEPTH=80
  POSITION   DEPTH=80 STOP=27 MIX=3
  POSITION   DEPTH=160 STOP=24 MIX=2
 DECOMPRESS DEPTH=80
  POSITION   DEPTH=80 STOP=120 MIX=3
  POSITION   DEPTH=190 STOP=60 MIX=2
 DECOMPRESS DEPTH=105 RATE=0 TRAVEL=3
  POSITION   DEPTH=105 STOP=2 TRAVEL=0 COMMENT=36
 DECOMPRESS DEPTH=95
  POSITION   DEPTH=95 STOP=14 COMMENT=37
 DECOMPRESS DEPTH=80
```

```
 POSITION   DEPTH=80 STOP=237 MIX=3
 POSITION   DEPTH=190 STOP=41 MIX=2
 DECOMPRESS DEPTH=80
 POSITION   DEPTH=80 MIX=5 COMMENT=26
C        BEGIN DAY 4
 SET        CPTD=0
 POSITION   DEPTH=80 DAY.STOP= 1986:223 CLOCK.STOP=08:00
 POSITION   DEPTH=180 STOP=56 MIX=2
 DECOMPRESS DEPTH=80
 POSITION   DEPTH=80 STOP=120 MIX=3
 POSITION   DEPTH=140 STOP=55 MIX=4 COMMENT=28
 DECOMPRESS DEPTH=80
 POSITION   DEPTH=80 STOP=60 MIX=3
 POSITION   DEPTH=155 STOP=115 MIX=4 COMMENT=29
 DECOMPRESS DEPTH=80
 POSITION   DEPTH=80 STOP=240 MIX=3
 POSITION   DEPTH=155 STOP=147 MIX=2
 DECOMPRESS DEPTH=80
 POSITION   DEPTH=80 STOP=30 MIX=3
 POSITION   DEPTH=135 STOP=69 MIX=2
 DECOMPRESS DEPTH=80
 POSITION   DEPTH=80 MIX=5 COMMENT=26
C        BEGIN DAY 5
 SET        CPTD=0
 POSITION   DEPTH=80 DAY.STOP= 1986:224 CLOCK.STOP=07:00
 POSITION   DEPTH=180 STOP=56 MIX=2
 DECOMPRESS DEPTH=80
 POSITION   DEPTH=80 STOP=60 MIX=3
 POSITION   DEPTH=240 STOP=13 MIX=2
 DECOMPRESS DEPTH=80
 POSITION   DEPTH=80 STOP=120 MIX=3
 POSITION   DEPTH=190 STOP=41 MIX=2 COMMENT=35
 DECOMPRESS DEPTH=130 TRAVEL=2 RATE=0
 POSITION   DEPTH=130 STOP=53 TRAVEL=0 MIX=4 COMMENT=34
C
 END
```

```
 NOAA REPEX II, 80 FSW PROFILE                       DEPTH            80. FSW
                                                     BOTTOM TIME       0. MIN
 RWH/DJK/DMB      87Aug28                            BOTTOM MIX    AIR
 D78002.B20
                CLOCK                                BOTTOM PO2      .7 ATM
 DEPTH   STOP   TIME            PO2
  FSW    TIME  HR:MIN MIXTURE ATM           COMMENTS
 ---------------------------------------------------------------------------
   00     00   00:00  AIR     0.21 ALL ASCENTS AND DESCENTS AT 30 FSW/MIN.
                                   HABITAT ATMOSPHERE PO2 = 0.32-0.33.
                                   BREATHE AIR ON ALL EXCURSIONS.             00
                                   DAY 220 1986
          00   00:00  AIR     0.21 COMPRESS TO 80 FSW IN HABITAT              00
   80    480   08:00  .32_PO2 0.32 ADJUST ATMOSPHERE TO PO2 = 0.32-0.33 ATM.  00
  200     14   08:14  AIR     1.48 EXCURSION: 200 FSW FOR  14 MIN:SUBMAXIMAL  24
   80     30   08:44  .32_PO2 0.32 _REMAIN IN HABITAT FOR  30 MIN             24
  140    290   13:34  AIR     1.10 EXCURSION: 140 FSW FOR 290 MIN:POSTSUBMAX 357
   80     60   14:34  .32_PO2 0.32 _REMAIN IN HABITAT FOR  60 MIN            357
  140     90   16:04  AIR     1.10 EXCURSION: 140 FSW FOR  90 MIN            461
   80    240   20:04  .32_PO2 0.32 _REMAIN IN HABITAT FOR 240 MIN            461
  170     79   21:23  AIR     1.29 EXCURSION: 170 FSW FOR  79 MIN            575
   80    120   23:23  .32_PO2 0.32 _REMAIN IN HABITAT FOR 120 MIN            575
  220     29   23:52  AIR     1.61 EXCURSION: 220 FSW FOR  29 MIN            631
  105     02   23:57  AIR     0.88 STOP AT 105 FOR  02 MINS                  637
                                   DAY 221 1986
   95     04   00:01  AIR     0.81 STOP AT  95 FOR  04 MINS                  639
   80     00   00:01  .32_PO2 0.32 RETURN TO HABITAT OVERNIGHT               639
         479   08:00  .32_PO2 0.32                                            00
  200     33   08:33  AIR     1.48 EXCURSION: 200 FSW FOR  33 MIN             57
   80     30   09:03  .32_PO2 0.32 _REMAIN IN HABITAT FOR  30 MIN             57
  180     35   09:38  AIR     1.36 EXCURSION: 180 FSW FOR  35 MIN            111
   98    240   13:38  AIR     0.83 REMAIN IN O2 WINDOW INSTEAD OF HABITAT    279
  180     60   14:38  AIR     1.36 EXCURSION: 180 FSW FOR  60 MIN            371
  105     02   14:42  AIR     0.88 STOP AT 105 FOR  02 MINS                  375
   95     02   14:44  AIR     0.81 STOP AT  95 FOR  02 MINS                  377
   80     28   15:12  .32_PO2 0.32 _REMAIN IN HABITAT FOR  28 MIN            377
  145     43   15:55  AIR     1.13 EXCURSION: 145 FSW FOR  43 MIN            428
   80     00   15:55  .32_PO2 0.32 RETURN TO HABITAT OVERNIGHT               428
                                   DAY 222 1986
         965   08:00  .32_PO2 0.32                                            00
  170     40   08:40  AIR     1.29 EXCURSION: 170 FSW FOR  40 MIN:SUBMAXIMAL  58
   80     60   09:40  .32_PO2 0.32 _REMAIN IN HABITAT FOR  60 MIN             58
  160     98   11:18  AIR     1.23 EXCURSION: 160 FSW FOR  98 MIN:POSTSUBMAX 190
   80    120   13:18  .32_PO2 0.32 _REMAIN IN HABITAT FOR 120 MIN            190
  200     60   14:18  AIR     1.48 EXCURSION: 200 FSW FOR  60 MIN            295
  105     02   14:23  AIR     0.88 STOP AT 105 FOR  02 MINS                  300
   95     39   15:02  AIR     0.81 STOP AT  95 FOR  39 MINS                  326
   80     27   15:29  .32_PO2 0.32 _REMAIN IN HABITAT FOR  27 MIN            326
```

```
NOAA REPEX II, 80 FSW PROFILE                         DEPTH           80. FSW
                                                      BOTTOM TIME      0. MIN
RWH/DJK/DMB          87Aug28                          BOTTOM MIX    AIR
D78002.B20
             CLOCK                                    BOTTOM PO2      .7 ATM
DEPTH  STOP  TIME              PO2
 FSW   TIME HR:MIN MIXTURE ATM          COMMENTS
-----------------------------------------------------------------------------
 160    24  15:53  AIR      1.23 EXCURSION: 160 FSW FOR  24 MIN              358
  80   120  17:53  .32_PO2 0.32 _REMAIN IN HABITAT FOR 120 MIN               358
 190    60  18:53  AIR      1.42 EXCURSION: 190 FSW FOR  60 MIN              457
 105    02  18:58  AIR      0.88 STOP AT 105 FOR  02 MINS                    462
  95    14  19:12  AIR      0.81 STOP AT  95 FOR  14 MINS                    471
  80   237  23:09  .32_PO2 0.32 _REMAIN IN HABITAT FOR 237 MIN               471
 190    41  23:50  AIR      1.42 EXCURSION: 190 FSW FOR  41 MIN              538
  80    00  23:50  .32_PO2 0.32 RETURN TO HABITAT OVERNIGHT                  538
                                DAY 223 1986
       490  08:00  .32_PO2 0.32                                               00
 180    56  08:56  AIR      1.36 EXCURSION: 180 FSW FOR  56 MIN               87
  80   120  10:56  .32_PO2 0.32 _REMAIN IN HABITAT FOR 120 MIN                87
 140    55  11:51  AIR      1.10 EXCURSION: 140 FSW FOR  55 MIN:SUBMAXIMAL   150
  80    60  12:51  .32_PO2 0.32 _REMAIN IN HABITAT FOR  60 MIN               150
 155   115  14:46  AIR      1.20 EXCURSION: 155 FSW FOR 115 MIN:POSTSUBMAX   299
  80   240  18:46  .32_PO2 0.32 _REMAIN IN HABITAT FOR 240 MIN               299
 155   147  21:13  AIR      1.20 EXCURSION: 155 FSW FOR 147 MIN              490
  80    30  21:43  .32_PO2 0.32 _REMAIN IN HABITAT FOR  30 MIN               490
 135    69  22:52  AIR      1.07 EXCURSION: 135 FSW FOR  69 MIN              566
  80    00  22:52  .32_PO2 0.32 RETURN TO HABITAT OVERNIGHT                  566
                                DAY 224 1986
       488  07:00  .32_PO2 0.32                                               00
 180    56  07:56  AIR      1.36 EXCURSION: 180 FSW FOR  56 MIN               87
  80    60  08:56  .32_PO2 0.32 _REMAIN IN HABITAT FOR  60 MIN                87
 240    13  09:09  AIR      1.74 EXCURSION: 240 FSW FOR  13 MIN              114
  80   120  11:09  .32_PO2 0.32 _REMAIN IN HABITAT FOR 120 MIN               114
 190    41  11:50  AIR      1.42 SWITCH HABITAT MIX TO AIR
                                EXCURSION: 190 FSW FOR  41 MIN               181
 130    53  12:45  AIR      1.04 BEGIN ASCENT TO SURFACE                     239

                                TOTAL TIME = 108 HRS 45 MINS
                                DECOM TIME =   0 HRS 13 MINS
                                     CPTD =  239.
```

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