MUS&T FY-74

Manned Undersea Science and Technology Fiscal Year 1974 Report

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Robert M. White, Administrator

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Fiscal Year 1974 Report

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Introduction and Summary

This annual report is the third produced by the Manned Undersea Science and Technology (MUS&T) program of the National Oceanic and Atmospheric Administration (NOAA). It describes the purposes, objectives, and results of the technical and scientific endeavors that form the program.

The purpose of the program is primarily to foster those manned underwater scientific investigations that meet the needs and requirements of NOAA and to encourage studies that may increase the safety and versatility of manned undersea operations. Also, the program includes liaison, advice, and support for Federal, State, and academic bodies performing manned undersea work.

Fiscal year 1974 continued the program consolidation begun the previous fiscal year. The major emphasis was on coastal zone problems related to the marine environment and ecology. Funding remained at about $1 million, with most out-of-house expenditures in support of U.S. northeast coast fisheries research and the continuing Bahama Banks research program using saturation diving techniques with the Perry *HYDROLAB* habitat.

To further operations effectiveness and safety, new programs in diver safety and physiology were started, past efforts were updated, and physiological data were collated and prepared for the NOAA Diving Manual, to be issued in fiscal year 1975.

Substantial discussions in the area of sea bottom analysis for heavy metal contaminants were held with the Atomic Energy Commission (AEC), the U.S. Geological Survey, and other agencies. The discussions were followed by detailed planning and organization for a submersible project in the Long Island Sound. The experiment took place in July 1974 and will be described in the fiscal year 1975 annual report.

In the international area, liaison and activities were continued with French and German underwater research groups for mutual participation in underwater habitat programs. The U.S.-French FAMOUS Mid-Atlantic Ridge investigations were planned and coordinated during fiscal year 1974, culminating in a midsummer project involving the *ALVIN* submersible and the French submersibles *ARCHIMEDE* and *CYANA*.

Background

Progress was made in intra- and intergovernmental underwater survey and research endeavors during fiscal year 1974. The resulting plans and programs have laid the basis for future scientific missions on fish and herring ecology, mineral and fossil fuel search, and trace contaminants.

MUS&T policy is the initiation and coordination of various planned and projected underwater research and development and survey missions. The MUS&T office continues to rely on the advice of such bodies as the National Academy of Sciences-National Academy of Engineering (NAS-NAE) and the support and comments of other agencies like the U.S. Navy in technology interchange and transfer.

The MUS&T program includes NOAA support of missions and projects proposed by universities and industry. About 60% of the fiscal year 1974 budget was spent on contract funding and grants.

Managerially, the MUS&T group, while working largely within a coastal zone survey and assessment framework, remained an office under the NOAA Associate Administrator for Marine Resources.

Objectives

The basic objectives of the Manned Undersea Science and Technology (MUS&T) program are as follows:

—Provide manned underwater and operational support to NOAA investigations involving marine resources and environmental problems for which subsurface observations and data collection are required.

—Develop, support, and manage a NOAA diving program to assure safe diving and more efficient operations for prolonged manned missions on or near coastal regions and the Continental Shelf.

—Synthesize the data from MUS&T-supported investigations for dissemination to users in order to improve understanding of the nature and availability of marine resources.

—Foster and coordinate manned undersea science projects with other Federal and State agencies, industry, institutes, and universities and support man-in-the-sea aspects of international programs.

—Develop scientific and technical criteria for characteristics of civilian undersea facilities and platforms through the experience gained by using available habitats and submersibles.

—Encourage and coordinate the transfer of undersea technology, including advances in diver technology, from the U.S. Navy when this is in the best interests of the Navy and NOAA. Also, keep abreast of general scientific and technological developments, both civilian and military, U.S. and foreign.

These objectives were achieved by a small staff of technical personnel with a recognized standing in the marine science and technology community and acquainted with Federal, industrial, and academic institutions.

Operations' effectiveness and safety: NOAA diving program

NOAA DIVING MANUAL

The NOAA Diving Manual has been developed especially for the scientist-diver. It includes information on diving physiology, how to perform biological surveys, how to collect geological samples, and how to dive in kelp beds and fast-moving rivers. Search and recovery operations and underwater photography are also discussed, and new information on saturation diving from shallow-water habitats is presented.

The NOAA Diving Manual is thus designed to provide the diver with the necessary fundamentals for both safe and efficient diving and carrying out useful scientific investigations. The dynamic nature of underwater exploration and development requires that the Manual will need periodic revision, and a format has been selected that lends itself to continual updating. It will be published during fiscal year 1975.

REVISED NOAA DIVING REGULATIONS

Following an extensive review of existing diving regulations, a revised set of regulations was developed and approved. These regulations were developed with the assistance of the NOAA Diving Safety Board and other experts in the field. The new regulations became effective on Aug. 12, 1974.

ESTABLISHMENT OF NOAA DIVING MEDICAL REVIEW BOARD

A Diving Medical Review Board was established by NOAA on Mar. 8, 1974. This Board is chaired by the Chief, Medical Division, Department of Commerce, and includes experts from both in and out of Government. The purpose of the Board is to review selected physical examinations and to make recommendations on the medical qualifications for NOAA divers. These recommendations are forwarded to the NOAA Diving Coordinator for action.

FAA AGREEMENT TO EXAMINE NOAA DIVERS

A formal agreement has been reached with the Federal Aviation Administration (FAA) whereby Senior Medical Examiners with FAA have agreed to conduct physical examinations of NOAA divers. Examinations under this agreement can be arranged by the individual diver contacting a private physician having special qualifications as an aviation medical examiner. The results of these medical examinations are retained by the individual, not processed through FAA. Rather, they are submitted in the same way as examinations from any other private physician. This arrangement went into effect in January 1974.

ASEPTIC BONE NECROSIS

Aseptic bone necrosis may be caused by tiny bubbles forming in the small blood vessels, resulting in reduced blood flow to the bones. This reduction in circulation causes portions of the bone to die. The disease is thought to be associated with the formation of residual bubbles following exposure to increased pressure such as in diving. It can also result from other maladies such as alcoholism and sickle cell anemia.

Surveys in the last 2-3 yr in the U.S. and abroad have revealed a significant incidence of aseptic bone necrosis in caisson workers and commercial divers (30-50%). In most cases there were no symptoms; in some, however, complete disability has resulted.

Liaison has been established with the Navy to participate directly in a long-term study for determining the development, extent, and seriousness of aseptic bone necrosis in divers. The program consists of obtaining repeated X-rays of prescribed bone and joint areas from a large population of NOAA-supported divers over a period of years. The X-rays will be forwarded to an interpretation center designated by the Navy for evaluation and retention. The results of the evaluation will be forwarded to NOAA and become part of the MUS&T records and the individual diver's medical history. Thus far, over 40 sets of long bone X-rays have been analyzed for NOAA by the Navy Submarine Medical Research Laboratory. When the final interpretation of these analyses is complete, individual divers will be informed of the results. This program is to continue, with particular emphasis being placed on those divers taking part in saturation diving programs.

DIRECTIVE ON LEASING AND OPERATING SUBMERSIBLES

This NOAA directive assigns the responsibility for reviewing operational plans and arrangements for leasing of research submersibles to the MUS&T office. It requires that organizations within NOAA prepare advance operational plans for using research submersibles. This directive became effective on Aug. 6, 1974.

UNDERWATER FATALITY STATISTICS

During 1974 the survey of diving accidents involving U.S. citizens by the University of Rhode Island was continued using a clipping service in addition to queries to various Federal, State, and local agencies and to individual scuba divers and instructors in high activity areas. These data are compared with similar figures for the three previous years.

In general, no large changes in accident patterns were detected in 1973. The total of 147 fatal accidents (123 compressed air, 24 skin diving) is slightly higher than 1971 and 1972 totals. Geographic distribution of the fatalities is also similar to past years, with Florida and California contributing almost half the victims. Weather factors were found to contribute to about 25% of the accidents, and Florida cave accidents showed an increase in 1973. Fewer beginning divers were involved in accidents this year, and fewer of the accidents involved training. Most of the divers used the "buddy system," but buddy separation remained a serious problem, with some cases involving the failure of the victim to remain on the surface following a dive, his inability to help himself, or to notify his partner of his problem.

Of the 49 autopsies, most showed "drowning" as cause of death. However, there were nine detected embolisms and six heart attacks, suggesting that a third or more of the fatal group may have suffered an incapacitating injury at some point in their dive. No serious equipment problems were detected, and few of the accidents were equipment caused.

There were approximately 1.5 to 2 million sport divers in the U.S. in 1972, and about 250,000 new sport divers are trained each year. Since the fatality rate (table 1) is essentially constant, it would appear that sport diving is becoming safer.

DIVING POPULATION STUDY

Besides directly supporting NOAA programs through the use of manned undersea techniques, a program like the MUS&T program frequently can support other mission-related manned undersea activities at little or no additional cost. This immediately causes questions regarding the numbers of persons engaged in these other activities, the exact nature of these other activities, and their economic importance. Because this information would permit better program planning, the MUS&T program undertook to develop quantitative information on U.S. civil diving.

During fiscal year 1973 the Technical Analysis Division of the National Bureau of Standards (NBS) helped to perform "An Analysis of the U.S. Civil Diving Population." The Division worked closely with MUS&T personnel to design an analytic methodology and collect basic information. The work begun by the Technical Analysis Division is being completed by MUS&T, with publication planned for fiscal year 1975. However, data from the draft were presented in a technical paper at the 9th Annual Meeting of the Marine Technology Society in September 1973 and cited in an article on commercial diving in the May 1974 issue of *Sea Technology*.

Civil diving was divided into four categories: commercial; scientific, educational, and institutional; nonmilitary governmental; and recreational. These categories were chosen to facilitate data collection through employers. The data were also collected by geographic region using the areas shown in figure 1.

Commercial divers were counted, using a combination of methods, including contacting the largest commercial diving firms and commercial diving firms from "yellow pages" of telephone directories in the

Table 1.—*Summary of diving fatalities, 1970–73*

Activity	1970		1971		1972		1973	
	Male	Female	Male	Female	Male	Female	Male	Female
Scuba diving	104	8	107	7	106	12	115	5
Scuba diving, record attempt	0	0	0	0	1	1	0	0
Skin diving	26	3	17	0	15	1	23	1
Diving with surface-supplied air	4	0	2	0	2	0	3	0
Compressed air explosion	0	0	0	0	1	0	0	0
Total	145		133		139		147	

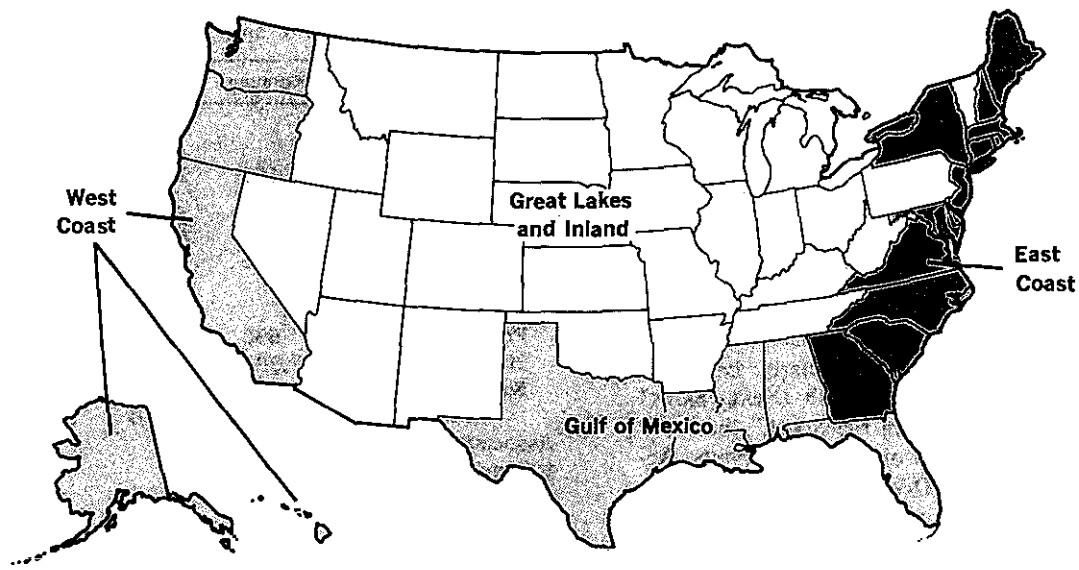

Figure 1.—Geographic regions used in collecting data for diving population study.

Library of Congress' collection. Approximately one-fourth of the 426 firms listed were sampled, and the results extrapolated to estimate the full-time paid employment for the total population. Information from the larger firms and sampling of smaller firms were combined with the information from locals of the United Brotherhood of Carpenters and Joiners Unions of America to develop an estimate of free-lance, part-time employment.

Questionnaires were mailed to colleges, universities, associate degree (2-yr) schools, and research consortiums listed in the August 1971 edition of *University Curricula in the Marine Sciences and Related Fields;* and telephone calls were made to key nonrespondents. Of 100 colleges and universities, 78 reported divers, 9 reported no divers, and 13 did not respond. The following institutions reported at least 100 professional staff and students who dive:

University of California (Berkeley)
University of Hawaii
University of Miami
Scripps Institution of Oceanography
University of Washington

The following reported between 50 and 99 diving staff and students:

University of California (Davis)
Florida Atlantic University
Long Island University (all campuses combined)
University of Michigan
Texas A&M University
U.S. Naval Academy
Virginia Institute of Marine Science
Woods Hole Oceanographic Institution

In nonmilitary Government diving, persons employed by Federal, State, and local organizations were included. Diving was found to be almost exclusively a support for the primary vocation of such persons. The effort was aided immeasurably by an analysis of police departments that the National Bureau of Standards (NBS) was completing for the Department of Justice's Law Enforcement Assistance Administration. NBS contacted 1,400 (of approximately 13,000) police departments in a combination survey and sam pling procedure. Responses enabled NBS to estimate the number of departments that engaged in underwater recoveries. A small sample was taken to determine the number of divers per type or size of department if the department engaged in underwater recoveries, enabling the total number of policemen with additional duties as divers to be computed.

The MUS&T office had completed, for the Interagency Committee on Marine Science and Engineering (ICMSE), a study of the use of manned undersea facilities (submersibles and habitats) by Federal agencies. Source lists from this study and additional information from the regional NOAA diving organizations permitted a rather complete survey of Federal agencies. These agencies with significant numbers of diving personnel (in decreasing order by number) are:

Department of Commerce, NOAA
Army Corps of Engineers (Civil Works Programs)
Environmental Protection Agency
Department of Transportation, USCG
Department of the Interior
Smithsonian Institution

In addition to Federal agencies and police departments, contacts were made with one or more State agencies in each of 25 States and with governmental departments of cities located near major bodies of water. The information obtained was used to extrapolate an estimate of State and local (excluding police and fire departments) employees who use diving in their work. Only a gross estimate of fire department diving was possible after numerous contacts.

In recreational diving, as in many sports, there are a large number of persons with requisite skills, but a lower number who participate regularly. Estimates were developed of "Individuals With Diving Skills" and of "Individuals Practicing the Sport," the latter being individuals with skills minus the dropouts. According to the 1972 Skin Diver Survey, some 86.9% of readers surveyed were certified by one or more of the following five training organizations:

Los Angeles County
National Association of Skin Diving Schools
National Association of Underwater Instructors
Professional Association of Diving Instructors
Young Men's Christian Association

Training statistics were obtained from each organization and used in conjunction with the skin diver statistics to estimate the number of "Individuals With Diving Skills" by virtue of formal or informal training. A similar procedure was followed to determine a "dropout rate" that was used to estimate "Individuals Practicing the Sport." It is interesting to note that all training organizations agree that the dropout rate is decreasing substantially. The decrease is attributed to longer training courses which require a greater commitment to complete training and a greater number of open-water dives during training which build interest.

Table 2 gives the results of the analysis. These estimates are essentially for 1972, and, from trends noted, annual increases can be expected. Additional estimates were developed, such as the "Estimated Percentage of Commercial Diving Services Used by Industries," training levels at nonmilitary commercial diving schools, and of the departments in colleges and universities which use diving. Table 3 shows rather gross estimates of the annual expenditures on diving in each category.

Table 2.—*Estimated U.S. civil diving population*

Diver categories	Minimum	Most likely	Maximum
Commercial:			
Full-time payroll employment	1,450	1,530	1,750
Freelance/part time	650	775	1,000
Total	2,100	2,305	2,750
Scientific/Educational Institutional:			
Colleges and universities:			
Professional staff	590	595	625
Students	1,300	1,360	1,425
Support divers	60	65	75
Total	1,950	2,020	2,125
Associate degree institutions and research consortia:			
Staff	30	45	50
Students	230	250	280
Support divers	15	25	30
Total	275	320	360
Nonmilitary governmental:			
Federal agencies	590	600	650
State and local	300	335	500
Police departments	6,500	8,060	9,700
Fire departments	2,500	5,000	7,500
Recreational:			
Individuals with diving skills.	1,500,000	1,890,000	2,300,000
Individuals practicing in the sport.	375,000	474,000	600,000

Table 3.—*Estimated annual expenditures for civil diving by purpose*

[Millions of dollars]

Marine science and engineering (government and academic):	
Direct diving cost	2.6
Equipment and replacements	0.3
Industrial applications:	
Diving services	63.1
Diver equipment replacement	2.0
Training	0.9
Recreational:	
Basic training equipment	13.0
Advanced equipment and replacements	41.6
Personnel expenditures	186.7
Public safety:	
Direct diving cost	3.3
Equipment and replacement	2.6

Technology studies, development, and transfer

INTRODUCTION

The purpose of the technology program is to review and establish technical criteria for civilian manned underwater activities; provide safe and versatile submersibles, undersea laboratories, and ancillary equipment in support of undersea operations; and to formulate safe and effective procedures for man to operate in the ocean environment.

During fiscal year 1974, two submersibles and three underwater laboratories were used on MUS&T projects. Underwater facilities for these projects were selected from the existing inventory by competitive procurement. No new facility developments were needed to meet the technical requirements of these missions, but assessment of undersea platforms developed by industry and the Navy continued.

Also, the Federal civilian agencies' requirements for these facilities and their use, as recommended by the Interagency Committee on Marine Science and Engineering (ICMSE), are being coordinated in the MUS&T program. The MUS&T office is maintaining close liaison with the Navy to transfer technology from military to civil undersea applications.

This section discusses MUS&T activities in the following five general areas during this period, including technology-oriented projects sponsored or cosponsored by NOAA.

- Diving technology and physiology
  - Evaluation of vertical excursion procedures at PRINUL
  - Doppler bubble detection
  - Portable, inflatable recompression chamber
  - Digital decompression computer
  - MURT-NEFC decompression chamber facility
- Undersea habitats and laboratories
  - Status and utilization
  - *HYDROLAB* system
  - *PRINUL* system
  - *HELGOLAND* system
- Research submersibles (status and utilization)
- Instrumentation
  - Adaptation of scientific instruments for use on the sea bed
  - U.S.-French instrumentation at *HYDROLAB*
  - University of New Hampshire's benthic respirometer evaluation at *HYDROLAB*
  - Nuclear activation analysis
- Technology transfer

DIVING TECHNOLOGY AND PHYSIOLOGY

Evaluation of vertical excursion procedures at Puerto Rico International Underwater Laboratory (PRINUL)

Principal investigator.—J. W. Miller, NOAA, MUS&T office.

Associate investigators.—A. Waterfield, University of New Hampshire; I. Koblick, PRINUL; S. Kohlemainen, Puerto Rico Nuclear Center.

Date.—Mar. 18-29, 1974.

Facilities.—Habitat *LA CHALUPA,* project PRINUL.

Background.—The basic decompression tables developed by the U.S. Navy, other countries, and private organizations are based on computations that assume the diver is already saturated on air at a pressure of 1 atmosphere. The computations further assume that all vertical excursions will be downward and expose the diver to increasing pressures.

The Union Carbide Corporation, Tarrytown, N.Y., under contract to NOAA's Manned Undersea Science and Technology (MUS&T) office, has recently developed new vertical excursion diving tables. These tables are designed for use by aquanauts saturated on air or on a normoxic (a mixture having the same oxygen partial pressure as on the surface) mixture of nitrogen-oxygen and making excursions breathing air. Experiments were conducted in Union Carbide's hyperbaric chambers using subjects saturated at depths of 30, 60, 90, and 120 ft. Extensive medical and psychological experiments were carried out in cooperation with the Navy during these chamber studies.

In March 1974 a series of open sea tests of the downward excursion tables were conducted to further validate the laboratory findings and to determine

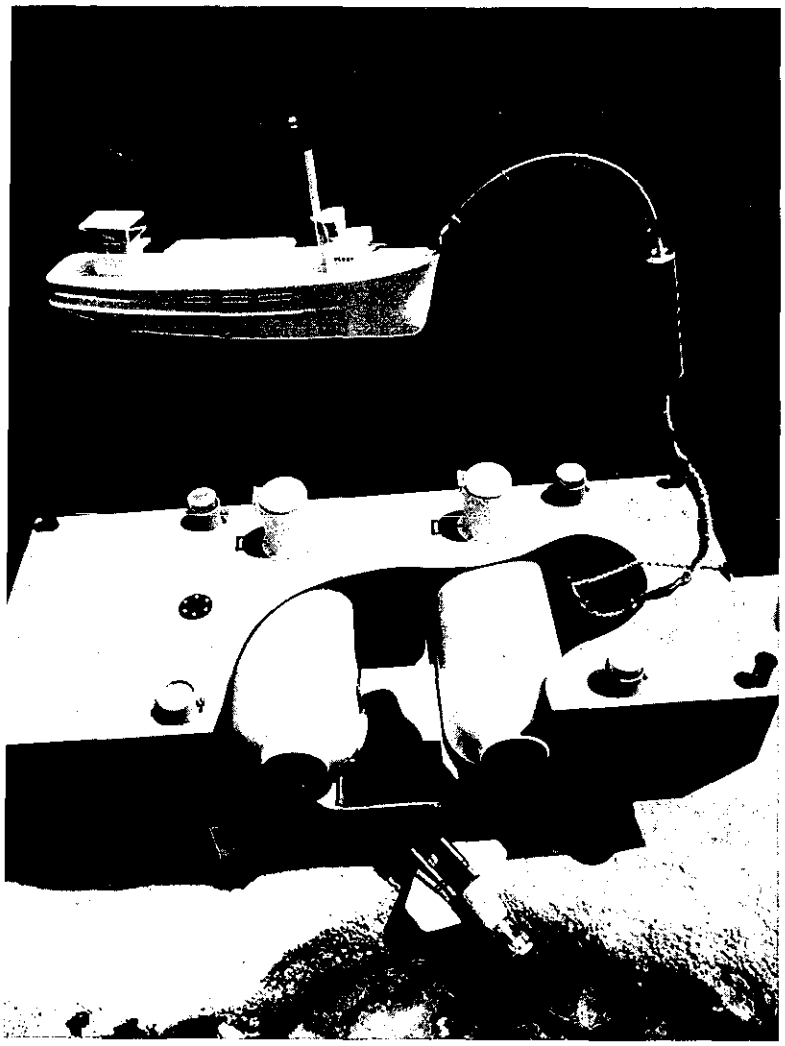

Figure 2.—Model of habitat *LA CHALUPA*, Puerto Rico International Underwater Laboratory (PRINUL), showing surface support.

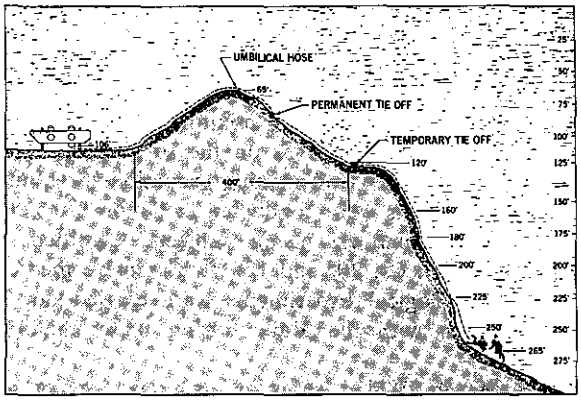

Figure 3.—Site topography, vertical excursion procedures evaluation at PRINUL.

whether these excursions would produce evidence of nitrogen narcosis. Technical support in the form of excursion profiles and treatment tables was provided by Tarrytown Laboratories and the University of Pennsylvania. Additional support was provided by the Naval Medical Research Institute who prepared and analyzed the results of the tests used for assessing nitrogen narcosis.

Dive site.—The habitat (fig. 2) was located approximately 10 miles off the southeast coast of Puerto Rico at a depth of 110 ft (saturation depth was 106 ft).

The topography of the dive site was dominated by three major features: a broad terrace, an uninterrupted buttress reef on the outer edge of the terrace, rising to within 43 ft of the surface, and a relatively steep-terraced dropoff on the outer side of the reef into deep water.

Procedure.—Two divers made each excursion. Air was supplied via a 700-ft hose (hookah) attached to the habitat and was used for all excursions. A single hose was used for the first 550 ft. At this point a T-valve was inserted so that each diver had an individual 15-ft hose. The divers wore full-face diving helmets (Kirby Morgan Band Mask, KMB-8) connected to the air hose. The helmets also contained hard-wire communication to the habitat.

Scuba tanks were used as an emergency backup system. These tanks were manifolded so that the air from both tanks could be shunted directly into the diving helmet or breathed through a separate regulator attached to the scuba tanks. When two divers were making an excursion, the other two were in the habitat manning the communication system, logging times, and recording data.

Because of the length of the hookah, approximately 225 ft of it was permanently anchored to the bottom as shown (fig. 3). Rigid floats and weights were strategically placed along the next 400 ft so the hose formed a long catenary reaching almost to the surface. This arrangement meant the divers had only to pull the final 75 ft across the coral-strewn sea floor. Upon reaching the 120-ft depth, the section of hose forming the catenary was hauled down so as to lie flat on the bottom and was tied to a coral head. The divers then had sufficient hose for making the primary descent. Bottom time began on departure from 120 ft and ended upon leaving the maximum excursion depth.

The excursion profiles are shown in table 4. Because of the required ascent over the 43-ft buttress reef, the excursion times had to be modified. Table 5 shows the depths of each excursion, the times allowed at each depth both with and without the buttress reef, and the times actually spent at depth.

Table 4.—*Excursion profiles from 110 ft*

Excursion No.[1]	Maximum depth	Time to 120 ft	Time at 120 ft	Time to maximum depth	Time at maximum depth	Time to 120 ft	Time at 120 ft	Time to habitat
	Ft	*Min*	*Min*	*Min*	*Min*	*Min*	*Min*	*Min*
1	160	11	2	1	239	3	5	12
2	180	10	2	1	64	3	2	8
3	180	10	2	1	64	4	1	10
4	200	17	2	10	17	4	2	15
5	200	17	2	2	26	6	1	11
6	225	12	1	3	12	3	1	5
7	225	11	2	2	13	5	1	5
8	250	13	13	4	4	5	2	24
9	250	12	8	10	2	6	2	8
10	265	7	8	5	[2]1	13	4	8

[1] Two divers each excursion.
[2] Aborted because of nitrogen narcosis in one diver. Both divers ascended to 200 ft and stayed for 8 min.

Table 5.—*Excursion depths and times*

Excursion No.	Excursion depth	Time allowed, no buttress	Time allowed, with buttress	Time actually spent at depth
	Ft	*Min*	*Min*	*Min*
1	160	360	240	239
2	180	360	65	64
3	180	360	65	64
4	200	262	28	17
5	200	262	28	26
6	225	62	163	12
7	225	62	163	13
8	250	35	9.3	4
9	250	35	9.3	2
10	275	14.7	5.5	[1]

[1] One min at 265 ft where excursion was aborted because of narcosis of one diver. Divers stayed for 8 min at 200 ft.

On each excursion, where time permitted, tests were conducted to detect any manifestation of nitrogen narcosis. The tests were designed to measure the ability to estimate the passage of time and to assess short-term memory. The time estimation test required the diver to estimate the passage of times ranging from 4 to 24 sec. Data were collected on the surface prior to the mission, in the habitat, and on most excursions.

The digit span (short-term memory) test was conducted in a similar fashion. The experimenter read sequences of 4-10 digits to the diver who then repeated them back, either in the same or reverse order.

Results.—A total of 20 man-excursions were completed during the mission. The excursion profiles may be seen by referring back to table 4. Aside from the problems of handling the long hookah hose, the excursions went well with one exception, when a diver's hookah broke and he had to discard his diving helmet and use scuba tanks to return to the habitat from the 120-ft temporary tie-off point. There were no respiratory problems or any symptoms of bends during any of the excursions. One diver experienced nitrogen narcosis at a depth of 265 ft on an excursion scheduled to go to 275 ft. The excursion was aborted at 265 ft. The other diver on this excursion had no symptoms of narcosis.

The results of the digit span memory test were inconclusive because learning was still occurring throughout the mission. No decrement in short-term memory was noted during the excursions. Though statistically inconclusive, the results clearly indicate that the divers could repeat back a series of up to nine digits at depths down to 225 ft.

The results of the time estimation test show a statistically significant trend in the direction of overestimating elapsed time, that is, estimating times to be longer than they really were. Although the underlying cause for this finding is not clear, the trend observed is consistent with results of other studies where time estimation was used as a human performance measure in stressful situations.

Summary.—While the excursion tables were not tested to their limits because of the required ascent over the buttress reef, the feasibility of making such excursions was clearly demonstrated. Narcosis was observed on only one occasion—at a depth of 265 ft by one diver. Time estimation was found to vary significantly with depth, although the cause could not be identified. Short-term memory was apparently not affected to the tested depth of 225 ft. There was no incidence of bends during either excursions or decompression.

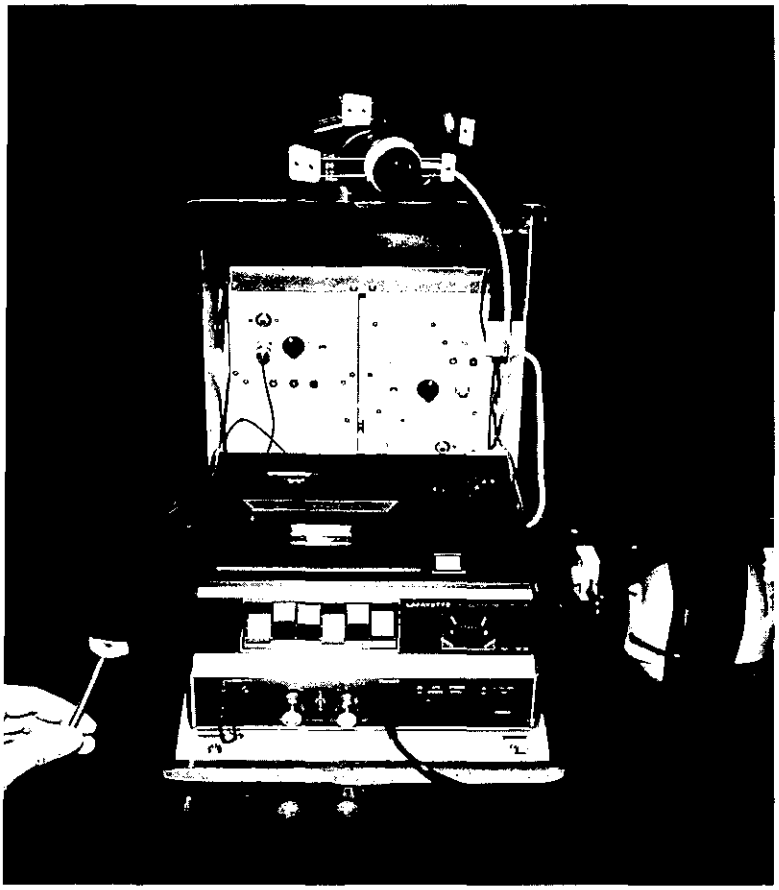

Figure 4.—Doppler bubble detector with chest probe (in hand).

Figure 5.—Portable inflatable recompression chamber.

Doppler bubble detector evaluation

Principal investigator.—D. P. Haugen, Applied Physics Laboratory, University of Washington.

The objective of this project was to evaluate the field performance and utility of a compact, self-contained Doppler bubble detector used to determine the onset of bends symptoms during decompression of saturated divers in the Perry *HYDROLAB* habitat during the Bahama Banks Research Program.

Evaluating diver decompression schedules for safety against both short- and long-term physiological changes is a difficult task. Most schedules are relatively conservative and provide a reasonable margin of safety for most individuals against diving sickness or the "bends." However, because of the wide variability between individuals, a given schedule can be extremely safe for some, but only marginally safe for others. Individual tolerances to decompression vary significantly with time and diving history, so a given schedule may not always have the same results in a given diver. Consequently, an evaluation based upon a small sample of divers and/or upon only a few applications of the schedule may not provide highly reliable results.

Observations of the frequency and severity of diving sickness symptoms alone may not be a particular sensitive way of assessing overall safety. Evidence indicates that bubbles can generally be detected (by ultrasonic Doppler detection means) in the bloodstream prior to, and often with the subsequent absence of, diving sickness symptoms. It is possible that such bubbles are more directly related to causes of long-term effects such as aseptic bone necrosis than are bend symptoms. Monitoring of blood flow for bubbles may consequently prove to be significantly useful in terms of overall evaluation of decompression schedules.

An integrated, self-contained Doppler bubble detector with monitoring and recording equipment (fig. 4) was provided for use by the *HYDROLAB* operational crew. The crew trained the saturated divers to use it to make recordings after excursion dives and during decompression. In this manner, data from a large population of divers were collected, and the

feasibility of the equipment's use in the field was demonstrated. Good recordings were obtained from five teams of divers, and preliminary analysis of this data showed no abnormal bubble signals.

All data derived during the *HYDROLAB* tests are analyzed and reported and subsequently made available to the national decompression bank for archiving.

Portable, Inflatable Recompression Chambers

Principal investigator.—R. L. Seiple, Naval Undersea Center (NUC), Hawaii.

NUC has successfully developed and tested a prototype portable inflatable recompression chamber. NOAA in cooperation with the Marine Corps is providing support to advance the development of this prototype. The fiscal year 1974 effort was to prepare a project plan and a preliminary draft of a specification aimed at obtaining certification. This system is not meant to replace present recompression chambers, but to enable immediate recompression treatment while the victim is being transported to a larger facility.

The prototype chamber (fig. 5) was fabricated from a high-strength, rubber-coated fabric and has been successfully tested to a pressure equivalent to 165 ft of sea water. A viewport was installed in each end for observation of the victim. High-pressure fittings and all other necessary hardware (pressure gages, valves, etc.) are incorporated in these viewports. The unit is sealed by a specially designed leakproof "zipper," which extends along the full length of the chamber to allow rapid entrance and exit. When fully inflated, the chamber will accommodate the victim and a medical observer and will fit through standard double-lock doors so the victim may be transported directly to a larger recompression facility. It is designed to use standard scuba bottles for its inflation and life support. When deflated, it will fit into a 36 × 36 × 8-in carrying case. Future work involves testing of new materials to bring its weight (exclusive of hardware, scuba bottles, and victim) down from its present 150 lb to less than 100 lb. Considerations such as a mask breathing system to reduce air consumption and allow oxygen treatment will be investigated. The final phase of the project would involve construction, testing, and evaluation of several units.

Digital decompression computer

Principal investigator.—R. L. Seiple, Naval Undersea Center (NUC), Hawaii.

NOAA provided partial funding during fiscal year 1974 for the development of a wrist-worn digital decompression computer at NUC in Hawaii. The effort was concerned with developing the electronic circuitry and programming the mathematical model for inert gas tissue saturation. This unit will keep a swimming diver continuously informed of his decompression status through repetitive, multidepth, or mixed-gas dives. The electronic circuits for the decompression computer have already been developed in a preliminary configuration and will be tested in fiscal year 1975. The final package will be smaller and lighter than conventional decompression meters while also being highly accurate.

Conventional decompression meters operate on a mechanical analog principle: Gas is diffused through a membrane or capillary that simulates the saturation characteristics of human tissue. The pressure buildup due to gas diffusion through the membrane is measured and displayed mechanically. Such a package is subject to damage from impacts and prone to error if not properly maintained.

The decompression computer uses a strain gage-type pressure transducer and electronic clock to update the diver's depth-time status every 2 sec. This information is put into an integrated circuit which contains a program for the biological model for tissue saturation. The integrated circuit is easily replaceable if necessary. Light emitting diodes are used to display information on the time and depth of the diver's decompression stops.

Development of MURT-NEFC decompression chamber facility

Principal investigator.—C. D. Newell, Manned Undersea Research and Technology (MURT) program, Northeast Fisheries Center (NEFC).

Associate investigators.—R. A. Cooper, MURT, NEFC; H. Corning and M. Palmer, Falmouth (Mass.) Hospital.

Date.—November 1973 and continuing.

Facilities.—This project involves design and construction of a permanent building at NEFC, Woods Hole, to accommodate for training and operational use a Perry-built 60-in-inside-diameter decompression chamber. The double-lock decompression chamber was purchased by NOAA, MUS&T, as part of supporting equipment for the 1973 herring egg bed survey with the intention that MURT-NEFC maintain it in a ready state for training, emergency treatment of diver accidents, and for periodic use on seagoing missions requiring such backup for divers.

Objectives.—In line with the MUS&T philosophy of establishing fully equipped field-oriented centers of diving expertise, the decompression facility will greatly expand the routine capability of the MURT program and serve as a pilot operation for other NOAA centers of diving expertise.

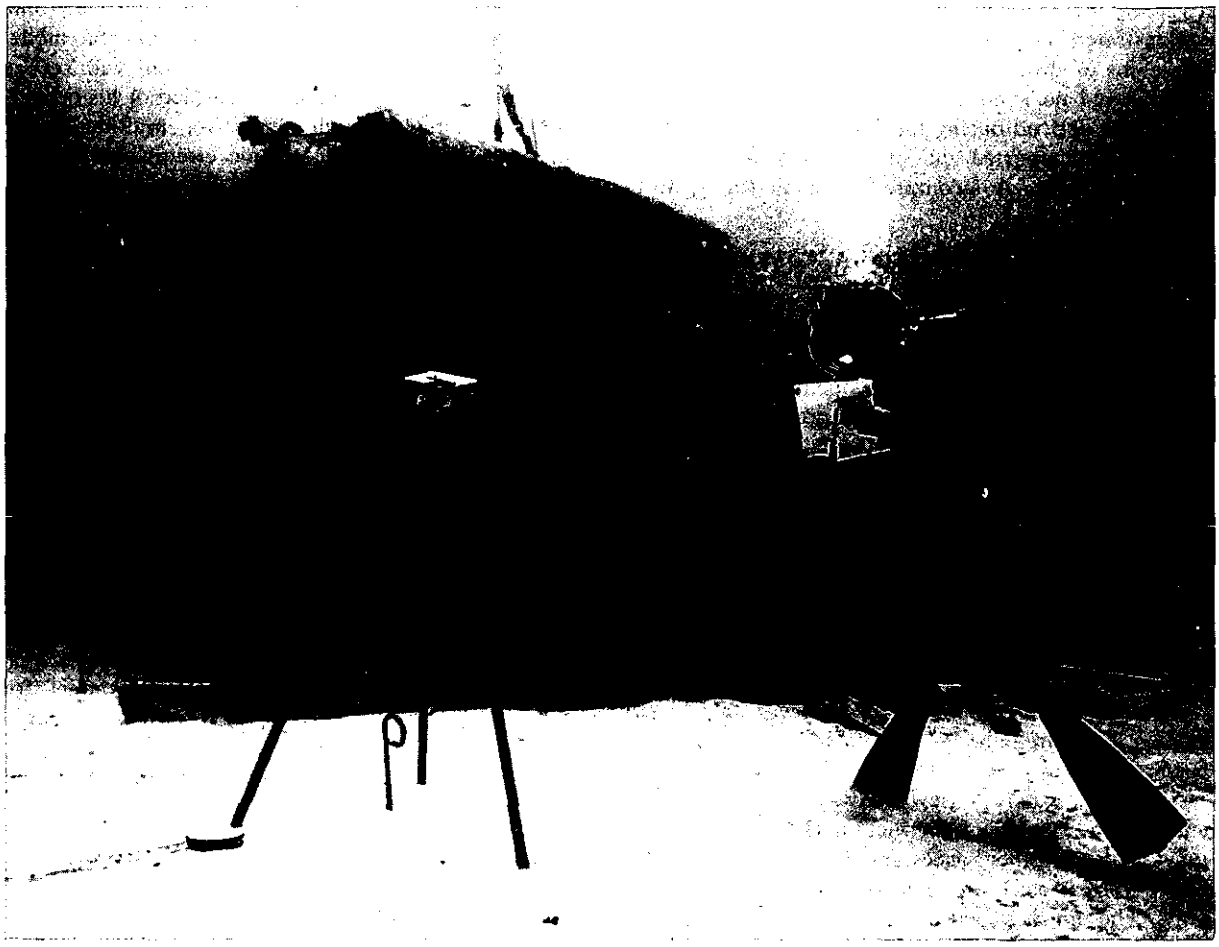

Figure 6.—Underwater laboratory *HYDROLAB* with diver making survey.

Table 6.—*Listing and status of undersea habitats and laboratories, June 30, 1974*

Name	Owner	Operational depth	Status
		Ft	
EDALHAB	University of New Hampshire	45	Inactive; last used in project FLARE, Fla., Jan.-Apr. 1972. Located ashore at Woods Hole.
HYDROLAB	Perry Foundation	50	Used in Bahama Banks research program during FY 1974. Located offshore at Freeport, Bahamas.
TEKTITE	General Electric	80	Inactive; last used in 1970 TEKTITE II project in Virgin Islands. Located ashore at Philadelphia Navy Yard.
LA CHALUPA (PRINUL)	Marine Resources Development Foundation.	100	First mission Nov. 1972 and used through June 1974. Located offshore at Mayaguez, Puerto Rico.
AEGIR	Makai Range	550	Inactive; last used in Hawaii in 1971 by the Navy. Located at Makai Range.
PORTALAB	University of Rhode Island	50	Inactive. Located at the University.
LAKELAB	University of Michigan	50	Tested in FY 1973 in Lake Michigan.

UNDERSEA HABITATS AND LABORATORIES

Status and utilization

The status of available undersea habitats and laboratories, as of June 30, 1974, appears in table 6. Of these seven facilities, *LA CHALUPA* (PRINUL project) and *HYDROLAB* were utilized during fiscal year 1974—to the extent shown in tables 7 and 8. In addition the *HELGOLAND* facility was used in a joint German-U.S. program.

Hydrolab system

NOAA awarded a grant to the Perry Foundation, Riviera Beach, Fla., for the support of the *HYDROLAB* facility for use during fiscal year 1974. The habitat (fig. 6) was refurbished by Perry in 1973 for improved operations. Its characteristics are:

Depth capability .....100 ft
Size .....8 ft diameter × 16 ft long
Total volume .....730 cu ft
Weight .....134,000 lb
Number of divers
accommodated 3–4

The habitat is supported via an umbilical cable to an unmanned surface life support boat providing the following:

7.5 kW, 100 V AC by diesel-electric generator
Compressed air supply
Potable water supply
Habitat vent hose
CB radio link to shore
Emergency battery power, 3-day supply

The *HYDROLAB* facility was used for 21 missions, saturating 101 diver scientists for a total of 613 man-days at a depth of 50 ft about 1 mile off Freeport, Grand Bahama Island. This represents a 20% increase over man-days saturated during fiscal year 1973. It will continue to be used in science projects during fiscal year 1975.

During its period of operation up to September 1974, *HYDROLAB* has compiled some impressive statistics. There have been 262 separate saturation missions involving 182 individuals. NOAA has supported all but 33 of these missions. These dives account for 1,420 days or over 84,000 man-hr spent in saturation in this facility during its 42 months of use.

PRINUL system—*LA CHALUPA* habitat

The *LA CHALUPA* habitat, used in the Puerto Rico International Underwater Laboratory (PRINUL) program managed by the Marine Resources Development Foundation, began operating

Table 7.—*Utilization of PRINUL facility*

Date	Subject	Water depth	Duration	Divers saturated	Man-days saturated
		Ft	*Days*	*No.*	*No.*
July 1973.	Demonstrate water jet embedment anchors and study siltation effects on corals.	60	14	5	70
Aug. 1973.	Metabolism of coral communities.	65	14	5	70
Mar. 1974.	Testing of vertical excursion tables, ecological studies, diver physiology study.	106	10	5	50
May 1974.	Biological survey.	50	14	5	70
Total			52	20	260

Table 8.—*Utilization of HYDROLAB facility*

Date	Depth	Duration	Divers	Man-days
	Ft	*Days*	*No.*	
8/73	45	3	24	72
9/73	45	7	4	28
9/73	45	7	4	28
9/73	45	5	4	20
9/73	45	7	3	21
10/73	45	6	3	18
11/73	60	7	3	21
11/73	45	7	3	21
12/73	45	7	4	28
1/74	45	7	4	28
1/74	45	7	4	28
2/74	45	7	3	21
2/74	45	7	3	21
3/74	45	4	6	24
3/74	45	7	4	28
4/74	45	13	4	62
5/74	45	7	4	28
5/74	45	7	3	21
6/74	45	6	3	18
6/74	45	7	4	28
6/74	45	7	3	21
7/74	45	7	4	28
Total		149	101	613

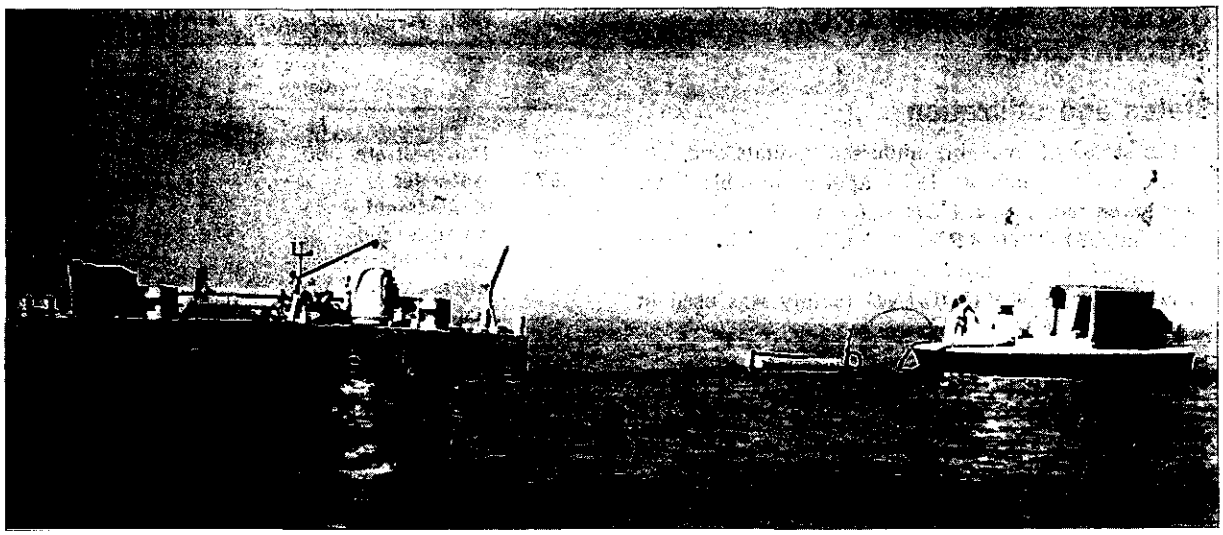

Figure 7.—Underwater laboratory *LA CHALUPA* (PRIN UL) (left). Its support buoy is between the two vessels.

in Puerto Rico in November 1972 and for nine missions during fiscal year 1973 (fig. 7). During fiscal year 1974, it was deployed at several sites at depths from 50 to 100 ft within 10 miles off Mayaguez and used for four missions, saturating 20 diver scientists for a total of 260 man-days.

LA CHALUPA represents the trend from slow-movable underwater habitats to highly transportable underwater laboratories and combines several advancements such as increased laboratory space, improved transportability, deployment, and recovery, capability for dry transfer of personnel from small submersibles, and computer facilities.

LA CHALUPA's characteristics are:

Depth capability	100 ft
Size	(2) 8-ft diameter × 19 ft cylinders with 9×19-ft subpart incorporated into a 20×48-ft barge.
Total volume of living space.	3,150 cu ft
Weight	267,000 lb
No. of divers accommodated.	4
Tow speed	5 knots

The system is supported via an umbilical cable from a 36-ft unmanned life support boat which provides the following:

- Two diesel-powered 20-kW, 110-V AC electric generators
- Compressed air supply
- Potable water supply
- Vent hose
- CB radio link to shore

The system, including the life support boat, is normally equipped to operate for 14 days but under emergency conditions can operate without the life support boat for 3 days.

HELGOLAND system

The concept for the *HELGOLAND* underwater laboratory was conceived in 1966 by the Institute of Flight Medicine and the Biological Institute of Helgoland. The project was funded by the Ministry for Education and Science.[1] The facility was designed and constructed in 9 months in 1968 and was used in its first mission in 1969. It was overhauled and modernized in 1971 and operated in Eckenförde Harbor. In 1972, technological responsibility was transferred to GKSS[2] which operated it at Helgoland in 1973.

The *HELGOLAND* system (figs. 8–10) consists of the underwater laboratory with its energy station buoy, the "Igloo," the "Depot," a personnel transfer capsule (PTC), deck decompression chamber, and one-man rescue chamber. The "Igloo" in an independent underwater station containing compressed air bottles, underwater communications, CO_2 scrubbers, lights, and an acoustic pinger where divers may take refuge for rest periods or emergency. The "Depot" (fig. 11) is an underwater station where divers can stand in a bubble of air, remove their mouthpieces, and converse. The one-man rescue chamber acts as a backup to the PTC and allows one person to be transferred to the surface under pressure and dry.

[1] Federal Republic of Germany (FRG).

[2] Gesellschaft für Kernenergieverwertung in Schiffbau und Schiffahrt, Geesthacht, FRG.

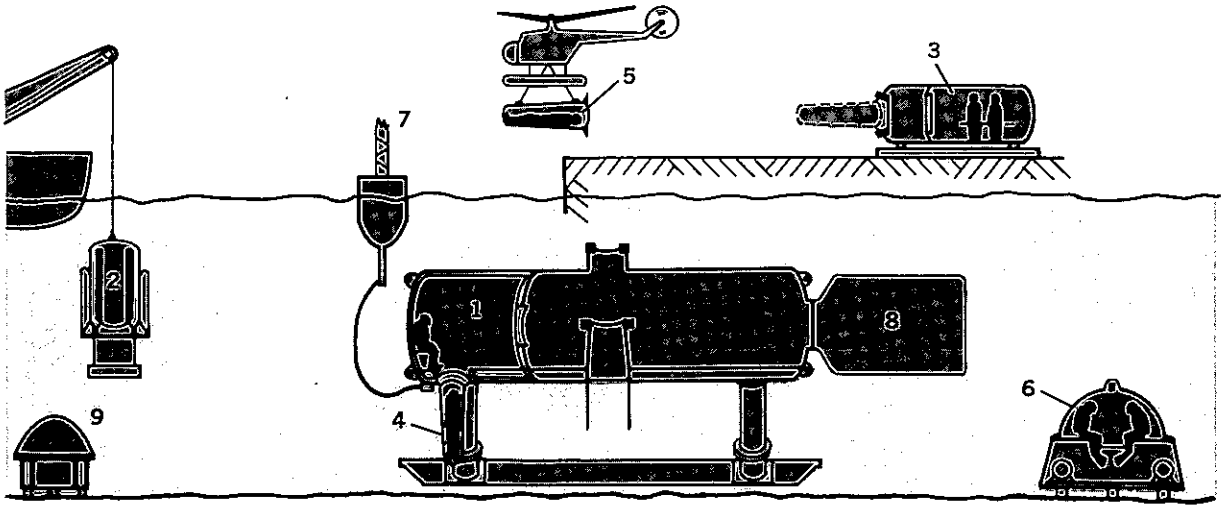

Figure 8.—Components of *HELGOLAND* system: (1) Decompression chamber; (2) lift for transporting persons; (3) stationary decompression chamber; (4) emergency rescue chamber; (5) emergency rescue chamber; (6) underwater igloo; (7) energy buoy; (8) wet room; (9) depot.

Figure 9.—*HELGOLAND* with aquanaut team.

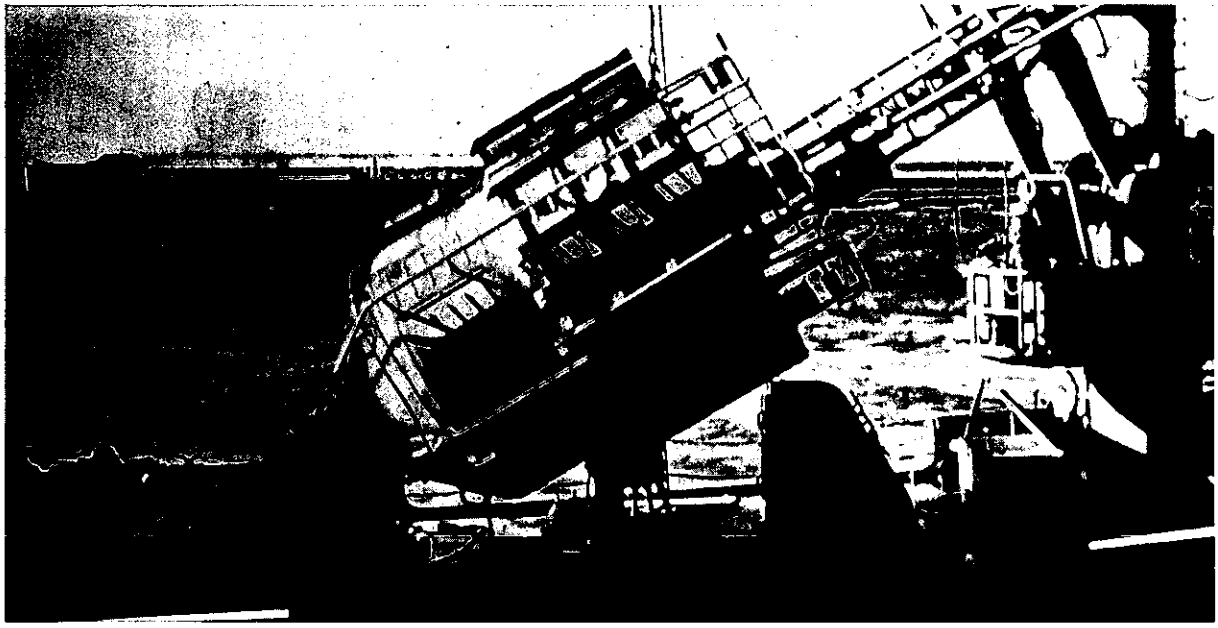

Figure 10.—*HELGOLAND* life support buoy.

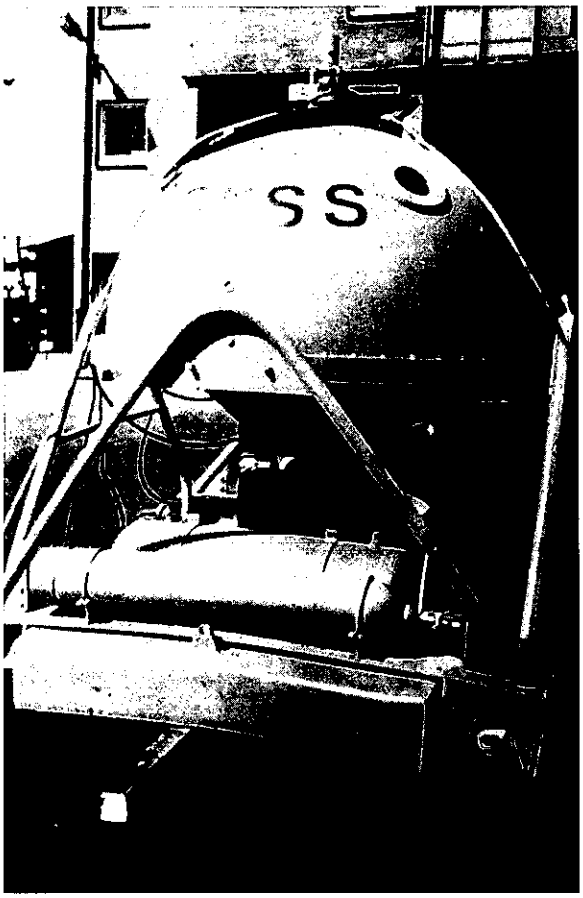

Figure 11.—*HELGOLAND* underwater "depot."

The characteristics of the underwater laboratory *HELGOLAND* are:

- Depth capability:
  - Operational ..... 100 ft
  - Maximum ..... 325 ft (with mooring and life support modifications)
- Size ..... 8 ft diameter × 27 ft cylinder habitat attached to 8 ft diameter by 15 ft cylinder wet room
- Living volume ..... 1,500 cu ft
- No. of divers accommodated. 4
- Towing speed ..... 5 knots
- Weight:
  - Underwater laboratory with wet room. 100 tons
  - Energy buoy ..... 14 tons
  - Batteries ..... 2,000 A-hr, 24 V AC

The habitat is supported by an umbilical cable from an unmanned surface life support buoy which provides the following:

- 25 kVA, 380 V at 50 Hz by diesel-electric generator
- Compressed air supply at 3,000 psi
- Habitat vent hose
- 10-day emergency life support
- Communications:
  - Two radios
  - Closed circuit TV
  - Ship-to-ship system

RESEARCH SUBMERSIBLES—STATUS AND UTILIZATION

Table 9 lists and shows the status of 27 U.S.-owned, civilian-operated research submersible capable of 600 ft or greater during the period July 1, 1973 to June 30, 1974. Seventeen of them are either inactive or on base overseas. The activities of the remaining 10 submersibles are outlined in table 10. Beginning in fiscal year 1973, MUS&T continued its policy to lease only American Bureau of Shipping (ABS)-classed or Navy-certified submersibles for use in its projects. Of the 10 active submersibles, only seven are so classed or certified.

During fiscal year 1974, the MUS&T program utilized two submersibles, *NEKTON BETA* and *ALVIN* (figs. 12 and 13). Their characteristics are included in table 11. The missions employing them are described under "Marine Science Applications."

Table 12 lists the U.S. Navy submersibles and their characteristics.

Table 9.—*Status of U.S.-owned and civilian-operated submersibles, capable of 600-ft depth or greater, July 1, 1973 to June 30, 1974*

Name	Owner	Depth	Active	Certification ABS	ABS pending	Navy	Remarks
		Ft					
ASHERAH	Techoceans	600	No	No	No	No	
TECHDIVER	International Underwater Contractors.	600	No	No	No	No	
SEA RANGER	Verne Engineering	600	Yes	No	No	No	
SUBMANAUT	Submarine Services	600	No	No	No	No	
PC–8B	Northern Offshore Limited	800	Yes	Yes		No	Overseas.
SHELF DIVER [1]	SECT [2]	800	Yes	Yes		No	Do.
GUPPY	Sun Shipbuilding and Drydock Company.	1,000	No	Yes		No	Tethered.
NEKTON ALPHA	General Oceanographics	1,000	Yes	No	No	No	
NEKTON BETA	do	1,000	Yes	Yes		No	
NEKTON GAMMA	do	1,000	Yes	Yes		No	
SNOOPER	Undersea Graphics Inc.	1,000	Yes	No	No	No	
SEA LINK [1]	Smithsonian Institution	1,000	Yes	Yes		No	
BENTHOS V	Garrison Diving and Salvage Co.	1,000	No	No	No	No	
SEA RAY	Submarine Research and Development Company.	1,000	No	No	No	No	
PC–9	Taylor Diving and Salvage Co.	1,200	Yes	Yes		No	Overseas,
STAR II	General Dynamics	1,200	Yes	No	No	No	
OPSUB	Ocean Systems	1,200	No	No	Yes	No	Overseas. tethered.
PC–14	Texas A & M University	1,200	Yes	Yes		No	
DEEP DIVER [1]	Perry Oceanographics	1,250	No	No	No	No	Retired in 1974.
DEEPSTAR 2000	Westinghouse	2,000	No	Yes		No	
STAR III	Scripps Institution of Oceanography	2,000	No	No	No	No	
BEAVER MK IV [1]	International Underwater Contractors.	2,700	Yes	Yes		Yes	
DEEPSTAR 4000	Westinghouse	4,000	No	No		Yes	
DOWB	Santa Barbara City College	6,000	No	No	No	No	
ALVIN	U.S. Navy	12,000	Yes	No	No	Yes	
DEEP QUEST	Lockheed	8,000	Yes	No	No	Yes	
ALUMINAUT	Reynolds International	15,000	No	No	No	No	

[1] Diver lockout.
[2] Service des Equipements de Champs de Tir.

Table 10.—*Activities of U.S. civilian-operated submersibles, July 1, 1973 to Sept. 30, 1974*

Submersible	Date	Mission	Location	No. of dives	Dive days	Depth
						Ft
NEKTON BETA	8/73	Geological	California	13	3	50–375
Do	9/73	Training	do	11	2	50–590
Do	10/73	Geological	do	4	2	300–900
Do	12/73	Biological	Catalina Island, Calif.	14	2	100–550
Do	1/74	Promotion	Long Beach, Calif.	3	1	75
Do	3/74	Training	Catalina Island, Calif.	10	2	25–700
Do	do	Promotion	San Pedro, Calif.	2	1	75
Do	7–10/74	Pipeline inspection	Gulf of Mexico		56	100–360
NEKTON GAMMA	9/73	Herring survey	Gulf of Maine	27	15	10–300
Do	10/73	Salvage	Nova Scotia	3	2	80–320
Do	5/74	Pipeline inspection	Santa Barbara, Calif.	17	6	30–230
Do	do	Salvage	do	3	1	150
Do	do	do	Pt. Mugu, Calif.	17	7	60–1,000
Do	7/74	Lobster survey	Gulf of Maine	39	14	100–1,000
Do	7–8/74	Dump site inspection	New York, Delaware	24	5	80–190
SNOOPER	8/73	Bottom sampling	Redondo Beach, Calif	5	2	550
Do	9/73	Outfall inspection	Palos Verdes, Calif.	4	1	200
Do	10–11/73	do	do	2	1	200
Do	3/74	Biological collecting	Oxnard, Calif.	6	2	200
Do	4/74	Test new equipment	Redondo Beach, Calif.	3	1	360
Do	6/74	Biological collecting	Oxnard, Calif.	7	2	200
Do	do	Outfall inspection	Santa Monica Canyon	7	4	225
SEA LINK	3–5/74	Training	Grand Bahama Island			150
Do	7/74	do	West Palm Beach, Fla.			150
PC 8B	12/73–1/74	Salvage	Greenland	18	12	720
STAR II	7/73–9/74	Research and coral harvesting.	Hawaii	137		1,200
BEAVER IV	6/73	Survey and bury test cable.	Block Island, R.I.	4	4	120
Do	do	Survey trans-Atlantic cable.	do	2	2	150
Do	7/73	Bury trans-Atlantic cable.	do	2	2	150
ALVIN	7/73	Certification	Annapolis chamber	3	3	12,000
Do	8–9/73	Checkout and training	Woods Hole Oceanographic Institution.	11	11	145
Do	10/73	do	Ft. Pierce, Fla.	5	5	3,800
Do	1/74	Navy	Bahamas	2	2	5,500
Do	do	Biology	do	6	6	6,450
Do	do	Training	do	2	2	8,200
Do	2–3/74	Biology	do	7	7	8,400
Do	5–6/74	Test and training	Woods Hole Oceanographic Institution.	4	4	820
Do	6/74	FAMOUS [1]	Mid-Atlantic Ridge	2	2	9,150
DEEP QUEST	do	Testing and sediment research.	Southern Calif.	4	4	500–4,100
Do	8/73	Sediment research	do	1	1	4,000
Do	9/73	Testing and independent research.	do	1	1	4,000
Do	11/73	Geophysical research	do	3	3	4,000
TS–1	5/74	Training	Riviera Beach, Fla.	5	5	120–1,350

[1] French-American Mid-Ocean Undersea Study.

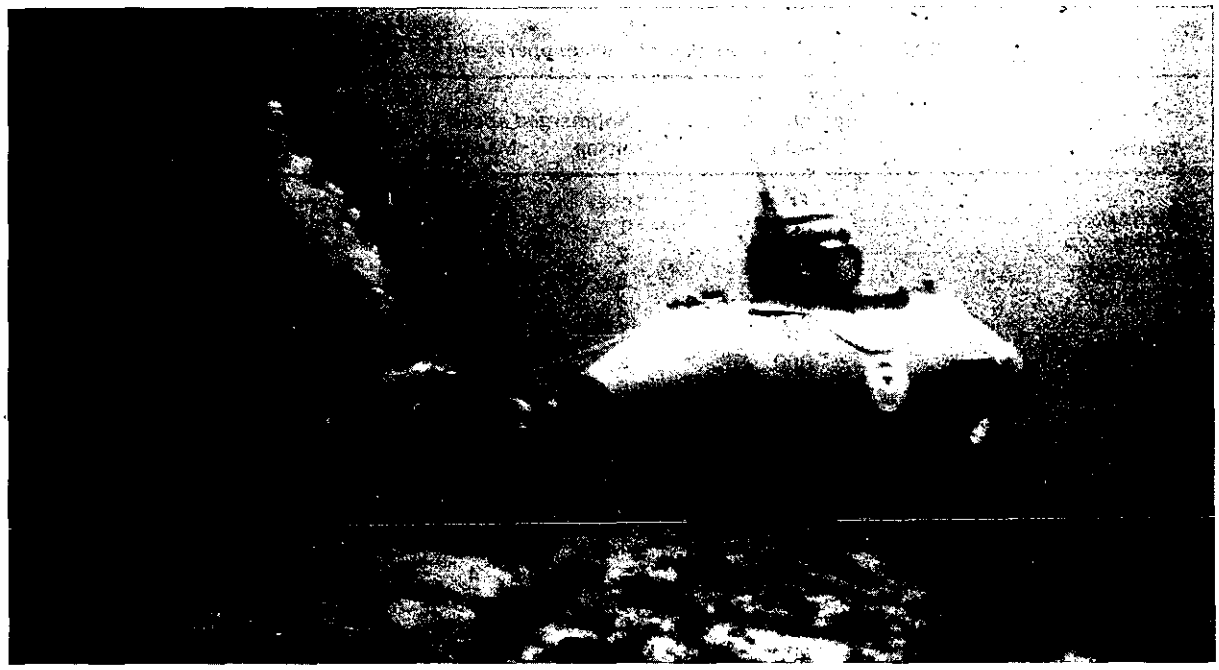

Figure 12.—Research submersible *NEKTON BETA*.

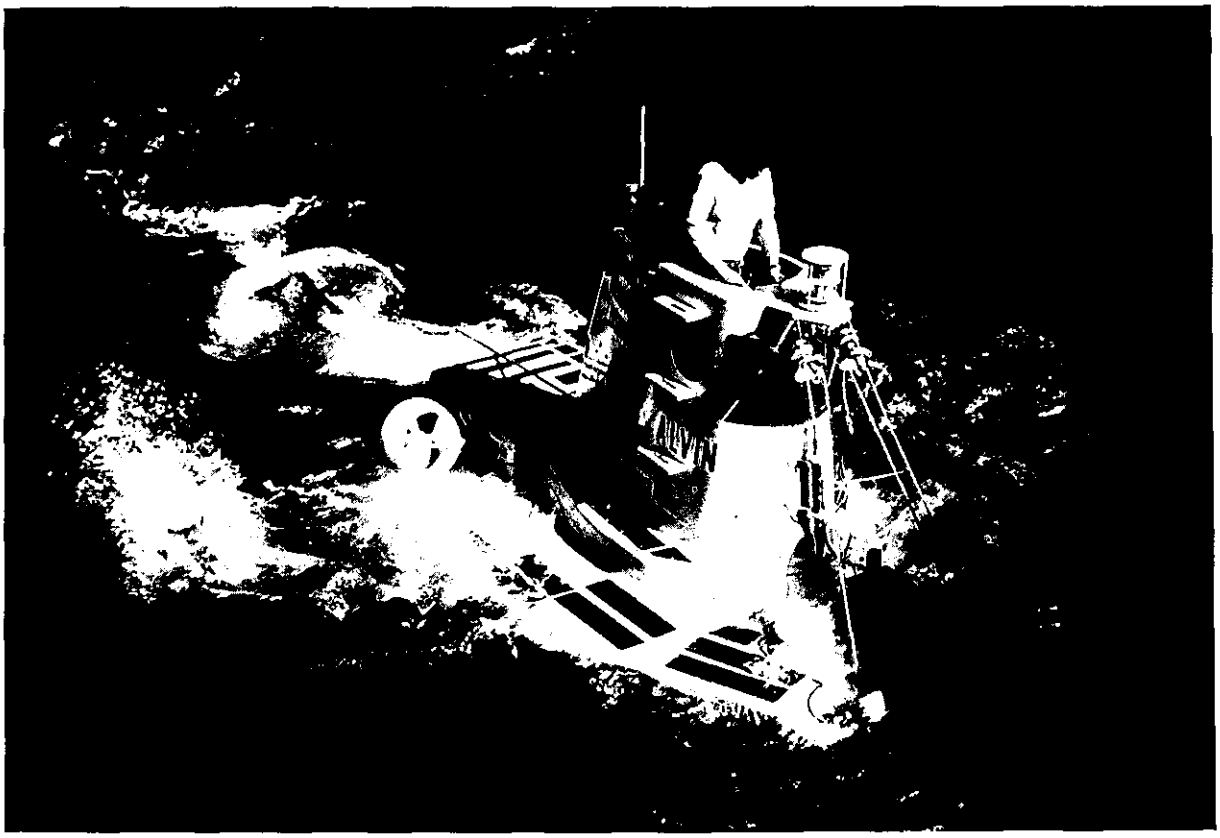

Figure 13.—Research submersible *ALVIN*.

Table 11.—*Characteristics of civilian-operated U.S. submersibles*

Name	Maximum operational depth	Submerged speed Cruising	Submerged speed Maximum	Endurance submerged	Life support Normal
	Ft	*Knots*	*Knots*	*Man-hr*	*hr*
ASHERAH	600	1	3.5	12	48
SEA RANGER	600	2	4	30	60
SUBMANAUT	600	5	10	100	48
TECHDIVER	600	2	4	4	12
PC–8	800	1	3	8	48
SHELF DIVER	800	2	3	6	40
BENTHOS V	1,000	2	3	4	96
GUPPY	1,000	3	3	56	56
NEKTON ALPHA	1,000	2	3.5	6	10
NEKTON BETA and GAMMA	1,000	2	3.5	6	48
SEA LINK	1,000	1	2	8	72
SEA RAY	1,000	2	6	5	16
SNOOPER	1,000	1	3	6	10
PC–9	1,200	—	4	12	72
STAR II	1,200	1	3	8	48
OPSUB	1,200	2	—	—	24
PC–14	1,200	1	2	12	—
DEEP DIVER	[1] 1,250	2	3	4	40
BEAVER IV	2,700	2.5	5	12	120
DEEPSTAR 2000	2,000	1	3	8	36
STAR III	2,000	2	3.5	6	120
DEEPSTAR 4000	4,000	1	3	8	12
DOWB	6,500	0.5	2.5	26	195
DEEP QUEST	8,000	2	4	18	192
ALVIN	[2] 12,000	1	2	8	72
ALUMINAUT	15,000	1.5	3.5	24	336

[1] Now limited to 100 ft.
[2] Titanium sphere, otherwise 7,200.

Table 12.—*Characteristics of U.S. Navy-operated submersibles* [1]

Name	Maximum operational depth	Submerged speed Cruising	Submerged speed Maximum	Endurance submerged	Life support Normal
	Ft	*Knots*	*Knots*	*Man-hr*	*hr*
MAKAKAI	600	1.5	3	6	24
NEMO	600	1	1	8	8
DEEP VIEW	[2] 1,500	1.5	5	6	48
DSRV 1 & 2	5,000	3	5	12	—
SEA CLIFF & TURTLE	6,500	1	2.5	8	100
TRIESTE II	20,000	2	3	12	72

[1] Other Navy-owned and -operated vehicles are *NR-1* and *DOLPHIN*. *NR-1* is a nuclear powered, ocean research and engineering vehicle. *DOLPHIN* is used as an ASW research submarine and is not considered readily applicable to civilian research.
[2] Currently Navy certified to 100 ft.

Table 11.—*Characteristics of civilian-operated U.S. submersibles—Continued*

Life support Maximum	Crew	Observers	Payload	Length	Weight in air	View ports	Manipulators
Man-hr	*No.*	*No.*	*Lb*	*Ft*	*Lb*	*No.*	*No.*
48	1	1	200	17	—	6	0
120	1	3	2,200	17	19,000	11	2
48	2	6	6,000	44	108,000	8	0
18	1	1	200	22	5,500	17	0
48	1	1	200	19	11,000	9	1
60	1	3	1,200	23	17,000	25	0
96	1	1	400	18	4,200	6	1
56	1	1	—	11	5,800	3	1
48	1	1	50	15	4,500	20	1
48	1	1	350	15	4,500	17	1
72	1	4	700	24	17,900	4	0
32	1	1	350	20	8,429	8	1
32	1	1	200	14.5	4,900	10	1
72	1	2	2,000	25	21,000	21	—
48	1	1	500	17	10,000	6	0
26	1	1	—	18	10,400	13	0
—	1	1	225	13	7,000	7	1
60	1	3	1,200	23	16,550	20	0
144	2	2	1,337	24	34,000	9	2
108	1	2	500	20	17,500	2	1
120	1	1	970	25	20,000	5	1
48	1	2	500	18	18,000	3	1
195	2	1	1,050	17	20,000	2	1
204	2	3	7,000	40	115,000	2	2
72	1	2	1,500	23	32,000	3	1
502	3	4	4,000	51	146,000	4	2

Table 12.—*Characteristics of U.S. Navy-operated submersibles* [1]*—Continued*

Life support Maximum	Crew	Observers	Payload	Length	Weight in air	View ports	Manipulators
Man-hr	*No.*	*No.*	*Lb*	*Ft*	*Lb*	*No.*	*No.*
36	1	1	1,200	19	10,600	1	—
16	1	1	—	6	—	1	0
48	1	1	500	16	12,000	1	0
—	3	24	4,300	50	73,900	3	0
107	2	1	700	26	48,000	5	2
108	1	2	2,000	67	100,000	1	2

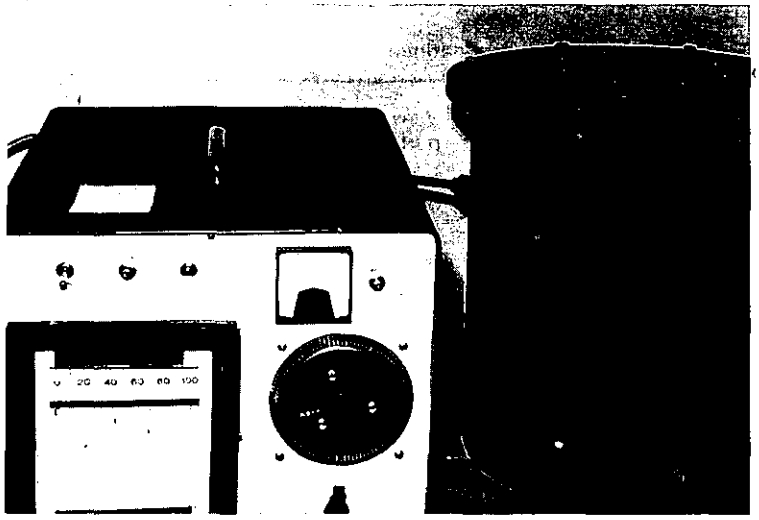

Figure 14.—Sea bed spectroradiometer.

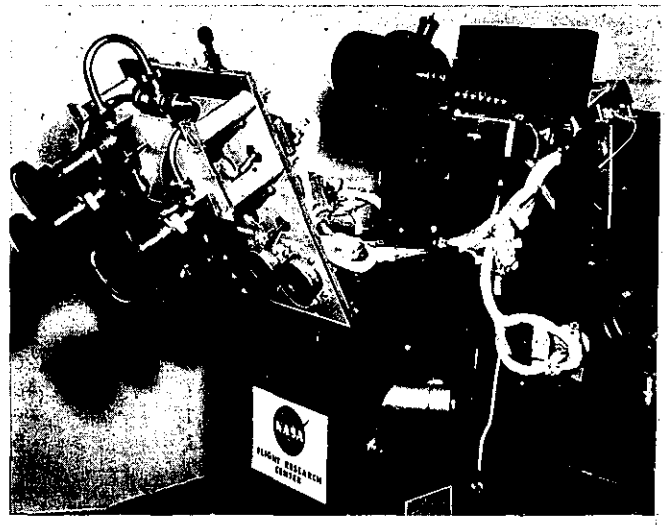

Figure 15.—NASA compact mass spectrometer.

INSTRUMENTATION

Adaptation of scientific instruments for use on the sea bed

Working under a NOAA grant, the University of Miami has adapted two instruments, a spectroradiometer and a NASA mass spectrometer, for use on the sea bed in support of scientific missions from *HYDROLAB*.

The spectroradiometer (fig. 14) was used to measure light energy in watts per square centimeter. Its sensor was packaged in a 12-in diameter by 14-in long cylinder capable of withstanding the pressure at 300 ft. Remote operation of the controls is possible through the lid of the enclosure.

The mass spectrometer (fig. 15) is compact, measuring 10×11×11 in, weighing 28 lb, and can monitor 12 gases with masses ranging from 3 to 11. It has been adapted to monitor a continuous stream of water and is packaged to operate at 300 ft.

The spectroradiometer has been used by the University of Miami in a fisheries resource study off Colombia, South America, in a cooperative effort with that country funded by the National Science Foundation. Deployment of the spectroradiometer was from a surface ship during this operation. Both the spectroradiometer and the mass spectrometer are located at the University of Miami and available to support NOAA missions upon request.

U.S.-French instrumentation at *HYDROLAB*

HYDROLAB mission 18, described under "Marine Science Applications," was a joint U.S.-French mission to study the reef community. The French have done extensive studies on Pacific and Red Sea reefs, but this was their first saturation mission for such a study. They employed an in-situ recording irradiance meter and an electromagnetic current meter, both developed in France, during their study.

The irradiance meter records on an analog strip chart with a capacity for 1 month of continuous operation. It has manually selectable ranges of 0-50 $\mu W/cm^2$, 0-250 $\mu W/cm^2$, 0-2.5 mW/cm^2, and 0-5 nW/cm^2 with an accuracy of 5% of the full scale reading. The sensor is a photovoltaic cell with a flat spectral response from 440-660 nm. The life of the 6-V DC battery that powers the unit is 200 hr, and the package can be placed down to 50 m or 164 ft.

The current meter was designed to measure currents down to 1 mm/sec. It has two ranges, 0-10 cm/sec and 0-50 cm/sec, the output signal being a linear function of speed. Current direction is determined with a vane assembly and electronic compass. Temperature and salinity variations do not seriously affect the accuracy of the unit.

These instruments were deployed on the sea floor near *HYDROLAB* to measure the effects of local environmental parameters (turbidity, light intensity, currents, temperature, and salinity) on the productivity of tropical coral reefs.

University of New Hampshire benthic plant metabolism chamber

Principal investigator.—G. Savage, University of New Hampshire (UNH).

The design and testing of a benthic respirometer was undertaken as a student project at the University of New Hampshire. The testing of the instrumentation was during the German mission at *HYDRO-*

LAB so the UNH team could also provide support for the German team. UNH divers emplaced the respirometer and equipment chambers on the bottom and performed servicing and monitoring functions by making periodic bounce dives from the surface. The chamber (fig. 16) consisted of a Plexiglas half cylinder with a length of 36 in and a radius of 15 in which was mounted on a rectangular base to form a seal to the sea floor sediment. Flow diffusers were placed at each end of the chamber to give a uniform flow through the chamber. This flow was matched to the local currents by timing the dissolution of a sugar candy in order to obtain realistic metabolism measurements and to relate the metabolism to current speed. The chamber was also instrumented to measure such environmental parameters as dissolved oxygen, temperature, salinity, pH, and light intensity. Batteries and recorders were housed in a pressure-compensated housing and deployed with the chamber in 75 ft of water near the *HYDROLAB* facility. The unit remained in place for 1 week, during which it operated continuously. Data on the respiration of Halomentia, a green microalgae found growing on coral, was obtained during this period and correlated with the local light intensity.

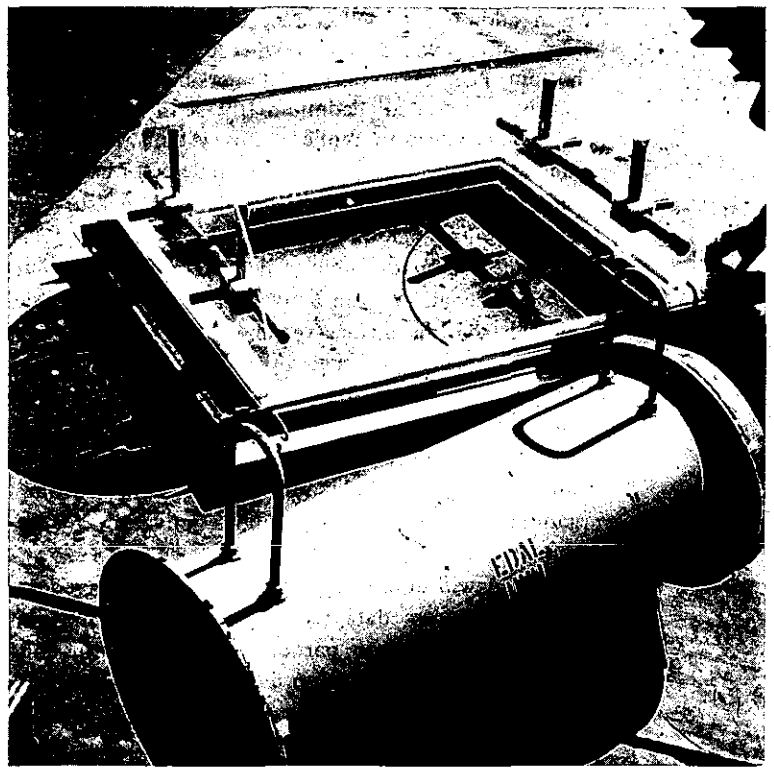

Figure 16.—University of New Hampshire benthic respirometer and (in foreground) instrument package.

Nuclear activation analysis

Several interagency meetings were held during fiscal year 1974 to formulate plans for an undersea mission to compare the in situ capabilities of nuclear activation analysis and X-ray fluorescence to detect and assess heavy metal pollution. This project was called IGUANA (Intra Governmental Undersea Atomic Neutron Activation) because it involved several agencies, viz., Atomic Energy Commission, Geological Survey, Environmental Protection Agency (EPA), National Aeronautics and Space Administration (NASA), and National Oceanic and Atmospheric Administration (NOAA), and the application of several types of activation techniques. The plan was to use a submersible as an undersea platform for evaluating these techniques on the bottom of Long Island Sound during July 1974.

Based on previous data on metal pollutants, a site for project IGUANA was selected in western Long Island Sound between New Rochelle and Sands Point, N.Y. EPA used its ship *CLEAN WATERS* to obtain samples of bottom sediment for preliminary baseline reference data for the mission. NOAA's National Marine Fisheries Service's laboratory at Milford, Conn., analyzed the metal constituents of the samples.

The objectives of this first test will be to evaluate the effectiveness of the two techniques rather than to detect and chart pollution levels in Long Island Sound. X-ray fluorescence and neutron activation techniques both employ a radiation source and a sensor, which will be mounted on the submersibles in these tests. With both techniques, heavy metals that may be present on the seabed are irradiated by the energy source. Each of the metals then emits its own detectable energy signature. The scientists aboard the submersible will compare these signatures to recorded data to identify the metals and will compare the intensity levels to estimate the concentrations of each of the pollutants.

Scientists from the Battelle Memorial Institute, Richland, Wash., under contract by the Atomic Energy Commission, will perform the mission aboard the submersible. The submersible's dual manipulators will be used to implement the delayed gamma neutron activation system. A small californium-252 activation source will be secured to one arm, and the sensitive crystal detector to the other. In operation, the source is forcibly pressed into the bottom sediment, then removed, and the detector pressed into the same spot. The electronic response is detected and recorded.

In addition, Battelle's recently developed in situ X-ray fluorescence system will be appended to the bottom aft section of the submersible. This system consists of a small cadmium-109 X-ray source and a crystal detector. While these systems are simultaneously collecting data, a passive detector externally mounted beneath the submersible will measure the background radiation present in all locations.

While the submersible is deployed below the surface, a second neutron activation system will be deployed from the surface vessel. This system integrates the equipment developed by the Geological Survey with equipment developed by the University of Georgia under a NOAA Sea Grant. In this system, the sensor is in the same housing and very close to a small californium-252 source to detect the prompt gamma emissions derived upon activation by the source.

NASA will utilize advanced data processing equipment to process data recorded during the mission. NASA also plans to participate in future missions applying neutron activation technology developed for space programs.

This mission was conducted in July 1974 and will be reported in the fiscal year 1975 report. Based on the results, additional interagency projects will be planned to assist the participating agencies in fulfilling their own missions concerning metallic pollutants and mineral resources.

TECHNOLOGY TRANSFER

During fiscal year 1973 the MUS&T staff kept abreast of the latest undersea technology developments in the Navy and industry by attending briefings, review meetings, and symposia, reviewing reports and proposals, and continuing surveys and assessments of submersible systems and underwater laboratories and their subsystems and ancillary support systems, diving equipment, physiology, instrumentation, and undersea power sources.

Although considerable knowledge on undersea systems and equipment developed by the Navy has been obtained, utilization of the technology has been limited by the small number and modest scale of MUS&T projects conducted in this period. Nevertheless, part of the technology program is to work closely with the Navy on behalf of the civilian agencies' undersea requirements and needs. Systems and equipment already developed by the Navy and industry will be used or adapted whenever possible.

In addition, MUS&T has participated in undersea science and technology exchange programs with France and the Federal Republic of Germany. These programs have involved direct utilization by visiting scientist and engineer diving teams of equipment designed and built by the host country and have resulted in an exchange of habitat systems technology and operational methods with Germany and seabed instrumentation with French scientists. These international exchanges are expected to continue in fiscal year 1975.

Marine Science Applications

A HERRING EGG BED SURVEY OFF THE U.S. NORTHEAST COAST NEAR JEFFREYS LEDGE (Fig. 17)

Principal investigator.—R. A. Cooper, Manned Undersea Research and Technology (MURT) program, Northeast Fisheries Center (NEFC).

Date.—Sept. 25-Oct. 17, 1973.

Facilities.—Submersible *NEKTON GAMMA* and support vessel *PAUL LANGEVIN II.*

Objectives.—The overall objective of this investigation was to define the ecological factors that affect survival of North Atlantic herring populations.

Procedure and results:

Twenty-five submarine dives were made during the course of the cruise; dives 2 and 3 were on Nantucket Shoals (western end of Georges Bank) in response to a then-current report from fishing industry representatives of herring spawning activity in that area. However, no evidence of herring spawning was found from the dive observations or from associated plankton tows. The remainder of the dives were at locations which were assumed to be likely spawning areas based upon historical catch records of spawning or recently spawned herring.

Suitable spawning substrate was observed over larger or smaller segments of most of the submarine transects. A pronounced lack of herring fishing success in these historically productive areas was evident throughout the time of the cruise. It was earlier evident that abnormally high water temperatures (2-3° F above average) might affect the timing of spawning and therefore decrease the likelihood of achieving the primary mission objectives. Whether or not the unseasonal temperature mitigated against spawning cannot be established, but the fact remains that the cumulative herring catches up to and through the cruise period were little more than 2% of catches in the same period and area in 1972.

Submarine dives ranged in depth from 95 to 300 ft and in duration from 30 min to 2½ hr. Observations were voice recorded on cassette tapes. A portable video recorder was used to document bottom topography, fish fauna, and invertebrate associations.

Forty-one plankton-BT stations were occupied in attempts to locate concentrations of herring larvae and associated temperature relationships. Although 26 of the 41 samples showed larvae, the numbers and pattern of distribution suggested a broadly dispersed hatch of larvae from areas other than the specific localities being sampled. These larvae were probably hatched from small spawnings along inshore coastal New Hampshire and Maine waters. Samples were taken with paired 61-cm-diameter bongo nets, with one of the pair having 0.505-mm mesh and the other 0.333-mm mesh. The experiment was the first submarine and diver-scientist assessment of potential herring spawning grounds with correlated plankton and hydrographic stations in areas of known or probable spawning.

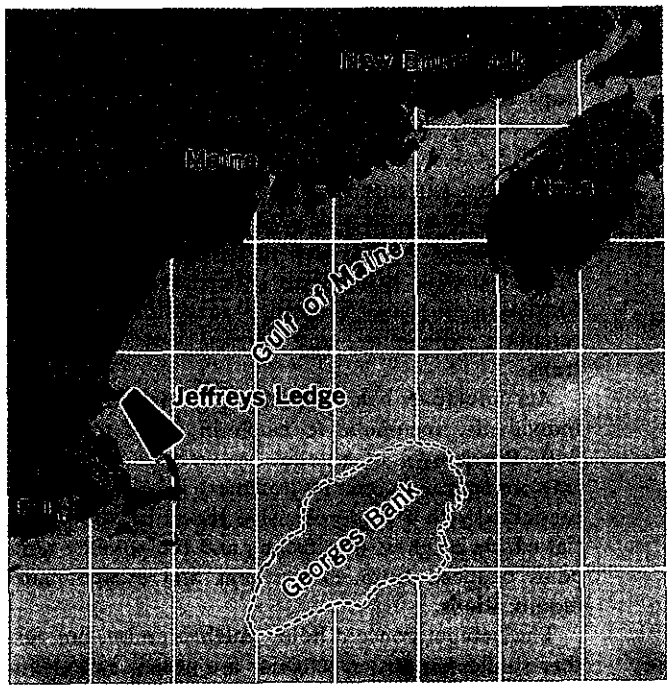

Figure 17.—Jeffreys Ledge dive site.

LOBSTER GHOST POT STUDY, WEEPECKET ISLANDS, WOODS HOLE, MASS.

Principal investigators.—K. J. Pecci, MURT, NEFC; R. J. Smolowitz, NOAA Corps.

Associate investigators.—R. A. Cooper, C. C. Newell, and R. A. Clifford, MURT, NEFC.

Date.—May-August, 1974.

Facilities.—NEFC vessel *BLUEBACK;* MURT-NEFC dive locker facilities; NEFC shop facilities; NEFC engineering program facilities.

Objectives:

—To assess experimentally the continued fishing and holding potential of lobster traps that become lost or irretrievable through loss of surface marker buoys from storm action, severing of buoy lines by boat propellers, or other causes.

—Assessment of the conserving effects of engineering escape vents for escape of sublegal lobsters from traps; assessment of degradable escape panels for escape of entrapped lobsters in ghost pots.

—Evaluation of "habipot" designs; "habipots" are units of variously modified salvage materials such as used tires, sections of tires, lengths of polyvinyl chloride pipe, etc., which might be fished from the surface as are lobster pots, but which offer potential habitat, rather than bait, as their attraction to lobsters.

Results:

Weekly inventory by divers of 20 simulated ghost traps (baited initially, set, thereafter left in situ) was compared with inventory of catches from 20 control traps that were hauled, rebaited, and reset at least once weekly. Size, sex, and condition were recorded for all lobsters caught.

Lobsters entrapped in ghost pots were briefly removed by divers, claw banded with punch- and color-coded rubber bands, and returned immediately to their respective traps. This procedure provided information on escape frequency, recapture frequency, retention probability, and verified mortality within traps.

Accumulative catch in control traps was 1,600 individuals; accumulative catch in ghost traps was 249. Breakdown of catches by weekly periods, by trap configuration, and by treatment is being analyzed preparatory to a comprehensive report on the potential effects of ghost trap fishing and the possible remedies deduced from escape vent and escape panel modifications.

The habipot concept holds much promise, but further studies of lobster behavior are necessary to identify optimum habitat configurations which can be fabricated economically and hauled efficiently.

DUMP SITE SURVEY: PHOTOGRAPHIC AND VISUAL RECONNAISSANCE OF RHODE ISLAND SOUND (BROWNS LEDGE) PROPOSED DREDGE SPOIL DUMP SITE

Principal investigator.—G. F. Chase, U.S. Army Corps of Engineers.

Associate investigators.—R. A. Cooper, MURT program, and dive team personnel, NEFC.

Dates.—June 5, 6, 7, 10, 1974.

Facilities.—Charter vessel RV *GALATEA.*

Objectives.—To assess by direct observation and to document photographically the bottom topography and associated species complex at Browns Ledge, and to determine the implications of proposed large-scale dumping of polluted dredge spoil in study area.

Results.—Thirteen dives (32 man-dives) to depths ranging from 40 to 130 ft were completed during the 5-day study period. Observational results and documentation included bottom classification at dive sites, species counts, and related 35-mm still photographs.

BAHAMA BANKS RESEARCH PROGRAM

Introduction

The Bahama Banks Research Program has been centered around the Perry *HYDROLAB* habitat, an underwater manned facility located off the southern coast of Grand Bahama Island near Freeport.

NOAA/MUS&T has used the *HYDROLAB* to assess coral reef ecology, to establish the effects of pollutants or reef metabolism, to study the various species of extant fauna and flora, and to support marine scientist and diver training and verify the more rigorous diving excursion limits. Extensive tests and evaluation of underwater marine instrumentation and physiological instruments have been performed. Several interesting experiments on cosmic ray radiation intensity, as a function of water depth, have also been conducted from and within the laboratory.

This facility, leased from the Perry Foundation, Riviera Beach, Fla., is unique in the Western Hemisphere, if not the world, as an underwater habitat in continuous operation since 1971. It has drawn international attention and participation, enabling several hundred marine and other scientists from academia, industry, Federal and State governments, and various research institutions to gain useful experience and much new data while participating in the Bahama Banks research program.

Table 13 is a summary of the Bahama Banks *HYDROLAB* missions for fiscal year 1974.

Table 13.—*Summary of HYDROLAB missions, fiscal year 1974*

Mission No.	Principal investigator	Date	Subject
1–6	R. E. Smith, State University System of Florida.	Aug. 2–20, 1973.	Training.
7, 13	J. S. Bunt, University of Miami.	Sept. 5–10, 1973. Nov. 13–19, 1973.	Coral reef ecology.
8, 15, 22, 27	J. T. Enright, Scipps Institution of Oceanography.	Sept. 15–22, 1973. Dec. 9–16, 1973. Mar. 24–31, 1974.	Coral reef metabolism.
9, 17, 26	W. W. Schroeder, University of Alabama.	Sept. 22–27, 1973. Jan. 27–Feb. 3, 1974. June 11–17, 1974.	Shallow water oceanography.
10	B. Pijanowski, NOAA, NOIC.	Sept. 26–Oct. 8, 1973.	Instrument calibration.
11, 21	J. Lord, P. Kotzer, University of Washington.	Oct. 8–12, 1973. Mar. 9–16, 1974.	Cosmic muon study.
12	R. W. Wicklund, Perry Foundation.	Oct. 22–Nov. 2, 1973.	Fish behavior.
14	A. Y. Bryson, NOAA, MUS&T.	Dec. 1–9, 1973.	Engineering transects.
16	M. Heeb, University of North Carolina.	Jan. 4–11, 1974.	Reef metabolism.
18	J. Jaubert, Laboratoire de Biologie Generale; J. Vacelet, Universite D'Aix-Marseille; M. Wells, NOAA, MUS&T.	Mar. 7–20, 1974.	Coral reef studies.
19	L. H. DiSalvo, Naval Biomedical Research Laboratory.	Feb. 16–28, 1974.	Reef metabolism.
20	V. Petriconi, University of Bochum.	Mar. 4–12, 1974.	Benthic studies.
23	M. Wells, NOAA, MUS&T; and others.	Apr. 3–16, 1974.	Coral reef metabolism.
24	T. B. Scanland, Dames and Moore.	May 1–7, 1974.	Oil pollution.
25	A. A. Roth, Loma Linda University.	May 19–31, 1974.	Light studies.

Missions 1–6

Principal investigator.—R. E. Smith, University of Florida, Institute of Oceanography.

Dates.—Aug. 2-20, 1973.

Facilities used.—Habitat *HYDROLAB.*

Objectives:

To train graduate students in ocean diving, underwater habitat operations, and concomitant use of marine science gear and instruments. Also, to study various underwater marine phenomena, ecology, and human physiology. Each of six teams conducted a specific program:

Mission 1: a) Set up housekeeping; b) qualitative and quantitative study of local echinoderm fauna; c) fright reactions of fish to an artificial fish.

Team members.—T. S. Hopkins, G. Francis, E. Meyer, R. Mattlin, University of Florida.

Mission 2: a) Lobster tracking and den residency using *Panulirus argus;* b) Alcyonarian renegeration; c) marine microbiology.

Team members.—W. Eaton, MUS&T; M. Redig, R. Runyan, C. Bigger, Florida State University.

Mission 3: a) Lobster tracking and den residency using *Panulirus argus;* b) colonization of artificial reef; c) efficiency of fish trap design.

Team members.—W. F. Herrnkind, Florida State University; J. Halas, K. Humiston, University of Florida; W. Fable, National Marine Fisheries Service (NMFS).

Mission 4: a) Visual response of divers to pulsed light emitting diodes; b) preliminary evaluation of a low-powered sound source for potential localizing purposes; c) evaluation of a military-type image analyzer for use from habitats or dry submersibles; d) coral transplant experiments; e) evaluation of false color emulsion and high-speed monochrome surveillance emulsions for underwater use.

Team members.—A. J. Llewellyn, University of Southern Florida; A. Smith, R. Morehouse, E. Brown, University of Florida.

Mission 5: a) Physiological effects of a hyperbaric atmosphere on apnea following physical exercise; b) observations of fish fauna near *HYDROLAB.*

Team members.—C. L. Combs, Florida State University; R. Flynn, University of Southern Florida; M. Wertz, University of Massachusetts; F. Wattenburger, University of Florida.

Mission 6: Develop basic mapping grid and techniques for *HYDROLAB.*

Team members.—W. Martin, R. Rohrich, M. Ward, Florida State University; G. Green, MUS&T.

Mission 1

Quantitative observations were made employing a grid-transect system of 5-m squares for a length of

100 m starting at a depth of 14 m and terminating in about 20 m. The grid-transect was laid parallel to the reef channels and as evenly as possible relative to the horizontal plane.

Homing was studied for *Astrophyton* using two colors of brightly colored surveyor's tape of contrasting colors: yellow and pink. Yellow strips were cut in approximately 30-cm lengths and numbered. On a night dive, a numbered yellow strip was placed on the object where *Astrophyton* was spread open for the night. The next day the area was searched carefully and the crevice hiding an *Astrophyton* was marked. The presumable route taken by *Astrophyton* was then measured with a cloth tape measure graduated in centimeters.

Results.—The echinoderm fauna around *HYDROLAB* is remarkably scant in relation to the known West Indian fauna and the biotypic habitat around the facility. Only eight species representing four classes have been confirmed to date.

Of particular note, however, is the apparent absence of *Echinaster*, a rather ubiquitous reef-dwelling asteroid and the total absence of any holothurian fauna. Clypeasteroid fauna were expected in the sand plain areas, but not found.

The quantitative investigations of Crinoids were inconclusive. There did not seem to be a clear-cut relationship between the number of animals and the estimated plan-view surface area. Unfortunately, at the time of the study it was not recognized that at least two species are involved—hence an entirely new question concerning percentage composition and cohabitation.

Within the frame of reference for this study no compelling reason could be found why Crinoids lived the way they did. There was no evidence that space or crevices for hiding were limited. They seemed to prefer an orientation involving "facing" the channels, as opposed to "facing" upward. Since *Astrophyton* feeds exclusively on top of the reef and *Nemaster* on the sides of the reef, it would be interesting to know how the particulate transport in these two areas compares. *Nemaster* showed no marked change in its feeding posture day or night, nor did it respond to dive lights. Very clearly, *Astrophyton* has a nocturnal feeding habit and is reactive to bright lights or flashbulbs. There was no evidence of predators in either case.

Mission 2

Procedure.—Lobsters to be released were measured and their biological condition noted (sex, molt state, reproductive state, degree of fouling, missing appendages); then they were tagged with a coded, three-color sphyrion-type tag. The tag was inserted in the musculature at the juncture of the dorsal cephalothorax and abdomen and was visually identifiable from 1–2 m distance. Some were additionally tagged on the dorsal cephalothorax with a saddle-shaped ultrasonic transmitter pulsing an individually distinguishable 70 kHz signal. An Ametek-Straza Sea Probe and NMFS custom-made directional receiver were used to locate sonically tagged lobsters at ranges of 200 m in open terrain and 10-20 m among the rock clumps.

The lobsters were placed in net bags and transported to the bottom by surface support divers. An aquanaut selected a crevice, then released lobsters individually or in pairs within 1 m of the "den." He then slowly retreated while observing and recording the lobster's behavior until it entered a den and became quiescent. The site was marked by a small, numbered styrofoam float tied 1-2 m above the den. In addition, several lobsters were placed in a simulated reef constructed of cement blocks and located 6 m from the *HYDROLAB* viewport.

Eleven lobsters were released on August 5 and 6 by team 2, 12 lobsters on August 8 and 9 by team 3, and 3 more on August 13 and 14 by the surface support team. Surveys were made daily during August 5-14 except on the 7th and 11th.

Results.—Upon release, 21 lobsters entered the preselected den; four others moved about several metres either around the base of a clump or up its vertical wall before entering a crevice. Only one moved off more than a few metres and was lost from sight and not seen to enter a den. Seven lobsters (27%) were resighted, of which four were resighted in the original, preselected den. The remaining three were found in dens less than 20 m from the original release point. The period of residency of resighted lobsters was 2–9 days with a mean of 4 days. It was presumed that most of the other lobsters not resighted, and certainly the sonic-tagged individuals, left the entire study area. However, the complexity of the area and myriad interstices could have concealed some.

The area characteristically has a small population of lobsters according to other scientists with long-term familiarity with the region. Food scarcity and, especially, predator pressure may be significant. Large black groupers (*Mycteroperca bonaci*) up to 50 lb (estimated), morays (especially the green moray, *Gymnothorax funebris*), and large octopods up to 0.7 m estimated arm spread were observed in the study area.

All lobsters released should be sonically tagged, since this greatly enhances resighting. For example, four of six lobsters with sonic tags were relocated, compared with three of the 20 sphyrion-tagged lob-

sters. The most frequently resighted sonically tagged lobster resided in a deep crevice well up the vertical wall of a large clump. The den was not visible without considerable search and probably would not have been discovered without assistance of telemetry.

Ten colonies of *P. elisabethae* and 5 of *P. flexuosa* were tested. An unknown agent cut some of the tags marking the colonies, which made separation of the auto-grafts and homografts impossible if the colonies were *P. elisabethae*. The xenografts were obvious and could still be scored as a group, though not as reactions to specific individuals.

Mission 3

This experiment evaluated three Plexiglas fish traps identical except for the size and shape of the entrance apertures.

The traps were cylindrical in shape, clear, and had the same overall dimensions. They were approximately 2½ ft long, 1½ ft in diameter, with one flat surface in order to rest steadily on the bottom. Each trap had a different type or size opening for the entrance.

The three traps were placed on the sand beside a coral knoll which could be observed from the main viewport of *HYDROLAB*. During the first day the three traps were left unbaited. Several species of fish made passes at the traps, but their behavior appeared to be more from curiosity than anything else. None entered the traps.

On the second day, lobster meat from a mortality was placed in each of the three traps. Immediately, the fish in the area began to show a greater interest than before. They tried to get to the bait but never entered the trap, except for one bluehead wrasse that entered trap 2. The presence of the wrasse caused a group of yellowtail snapper to go into a frenzy from time to time, but most were too large to enter the opening. Usually the yellowtail snappers would bump into the sides of the trap trying to get to the wrasse.

The traps were rebaited on the third day, but no more fish entered. Several yellowtail, bar-jack, and a couple of small grouper tried unsuccessfully to get to the bait. With the bait settled on the bottom of the trap, the fish would root around the bottom trying to reach it.

Conclusions.—Plexiglas appears to be a good material for fish traps as far as attracting fish is concerned. The size and shape of the trap entrance is important, as is positioning the bait in relation to the trap entrance. Saturation diving techniques enabled prolonged observation of the traps, which would not have been possible otherwise.

Mission 4

These experiments were part of a series designed to evaluate the potential of pulsed light emitting diodes (LEDs) as miniature light signals for divers and perhaps for animal identification. During night operations, divers are frequently working with minimum illumination and attain a visually dark-adapted state. Under these circumstances, when attention has been focused on the experiment, it is often difficult to locate a dark-suited companion diver unless he is illuminated. The problem is to provide an identifying source of illumination which does not destroy the dark adaptation of the diver who is conducting the visual search. Additionally the source should be small, have solid angle coverage, have low power requirements, and be capable of surviving much mechanical abuse.

With these criteria in mind, a series of flashing LED systems for underwater testing was produced which use diodes emitting in the red and green segments of the spectrum. During the *HYDROLAB* phase, five test runs were made, each providing 20 data points.

In the experiments, diver A would act as subject while diver B manipulated the light source. The subject would swim along a tightly moored horizontal line (at night, dark adapted, no artificial lights) until the LED just disappeared from view. He would then place a marker peg on the line at this point and swim until the light became barely visible, placing another marker peg at this point. The data points were measured from pegs to origin and transmitted back to the the habitat. The data were tabulated by an experimenter in the habitat and also logged using a small cassette tape recorder.

SONALERT experiments.—As a parallel system for diver location a sound source was prepared for evaluation. The sound source was a commercial SONALERT unit.

Unfortunately, during the first experimental trials the instrument housing leaked, and the power supply suffered extensive electrolytic corrosion. Because of the pressures of time during the mission it was not possible to restore the modulating circuitry, but instead a CW signal was set up which was used in two experimental series with a total of 40 data points resulting. The experimental methods were essentially those used previously, with a subject diver pegging detection points on a taut range line for subsequent measurement.

In-habitat evaluation of an image intensifier.—During the mission a series of experiments were attempted to evaluate an image intensifier system lent to the Scientists-in-the-Sea (SITS) program by the Harbor Branch Foundation, Ft. Pierce, Fla.

The image intensifier was used under illuminated conditions with the external light fitted to the *HYDROLAB* habitat and also in the presence of natural illumination arising from a 1/3 moon above 50 ft of water. A series of observations were made using various objects at locations up to 30 ft from the habitat, and attempts were made to estimate the narrowest dimension of resolved objects to produce a rough measurement. The comparison standard was the adapted eye at whatever illumination level was present.

In general the results were disappointing. As examples, lobster antennae which could be clearly resolved by the dark-adapted eye under conditions of natural illumination were not discernible using the image intensifier.

Coral transplant experiments.—During SITS II one of the visiting lecturers commented on the extraordinary rate at which some corals were able to recover from severe mechanical damage and presented some preliminary considerations concerning growth rates and natural limiting mechanisms. Because of this, some elementary coral transplant experiments were initiated with the aim of providing isolated corals for which detailed growth and development patterns might be established. Seven specimens of staghorn coral (*Acropora cervicornis*) were transferred to a coral head in the immediate neighborhood of the habitat. Following a procedure used by the Shell Oil Company off Florida and in the Persian Gulf, the specimens were securely anchored to a rigid base, using stainless steel ties. Morphology of each specimen was measured, recording the incidence of branching and branch length so future development could be accurately recorded.

Photographic experiments.—Two emulsions were examined during the mission. The first was Kodak 1-135, a high-speed (400ASA) emulsion used for surveillance. The emulsion gave acceptable images at low light fields but suffered badly from grain deterioration.

The second emulsion tested was Kodak Ektachrome Infrared, a false color, near-infrared sensitive emulsion. This emulsion has been extensively used in crop survey studies to detect ailing vegetation. The emulsion displays differences in near-infrared intensity as changes in visible wavelengths in the processed emulsion. These differences in near-infrared intensity appear to arise from changes in reflectivity associated with changes in chlorophyll and complex pigmented species in the vegetation. The emulsion was used in *HYDROLAB* experiments for two reasons:

—To assess its potential utility for examining chlorophyll-bearing species, especially certain coral types.

—To assess it as an aid to penetrating natural camouflage systems which present problems when inventorying certain components of the benthic ecosystem.

The experiments revealed that the epifauna and epiflora can be successfully photographed using this emulsion but artificial light sources are necessary to replace the missing red light components. Careful control of emulsion temperatures is essential if the false color values are to be reproducible.

Mission 5

The objectives of the first experiment were as follows:

—To study the cardiovascular responses during recovery from induced physical exercise in a hyperbaric environment.

—To study the effects of increased air pressure in the environment on respiratory efficiency during recovery from induced physical exercise.

—To study the effects of the increased partial pressure of oxygen on the resting heart rate and the postexercise recovery rate.

—To study the effects of the hyperbaric environment on blood pressure, during both rest and postexercise recovery periods.

—To study the effects of the dive reflex on physiological recovery from muscular exercise in a hyperbaric environment as measured from postexercise assessments of heart rate and blood.

—To study the different physiological responses during recovery from exercise in a hyperbaric environment while breath holding in air, breath holding with the face immersed in water, breathing normally in air, and breathing through a snorkel with the face immersed in water.

A complete set of control values was taken on land using four of the eight testing periods before the saturation dive in the *HYDROLAB*. Heart rate and blood pressure were recorded for each subject at the beginning of each testing period. After each exercise bout, heart rate was taken with a stethoscope and recorded every 10 sec continuously for a period of 5 min. Blood pressure was recorded with a Taylor sphygmomanometer and stethoscope during each 30-sec interval throughout the 5-min period after exercise.

Because all of the four inhabitants of the habitat were needed as subjects for this study, each was trained to take accurate blood pressure and pulse readings before the onset of the study. Heart rate and blood pressure were shown to be water dependent: each decreased during water submersion.

The purpose of the second experiment was to prepare a list of fishes commonly observed in the vicinity of the *HYDROLAB*.

Mission 6

The purpose of this mission was to develop a mapping grid system and a working map for *HYDROLAB*. Polypropylene lines were used as grid elements. The system as installed kept one person mapping without interruption as the partner moved the lines from areas previously mapped.

Very few problems were encountered in these procedures. Of note, however, is that the buoyancy of the polypropylene line was underestimated for those occasions where the line had to traverse 25 or more metres over open sand suspended between coral heads. In order to remove the "upward drift" and maintain a taut transect line, short (about 1 m) anchor lines using about 3 lb were used.

Mission 7

Principal investigator.—J. S. Bunt, University of Miami.

Associate investigators.—P. Reinholm, J. Wills, D. Nanninga, University of Maryland (habitat team).

Dates.—September 5-10, 1973.

Facilities used.—*HYDROLAB.*

Objectives.—The mission was planned to prepare a grid in a fixed location from which "ground truth" data could be collected for comparison to remote sensing, i.e., aerial photographic survey by NOAA.

Results.—In order to use the grid on a subsequent mission (at 65 ft, with *HYDROLAB* relocated), a trail marker line was run out to a position 300 m east of the original (usual) habitat location and then south until a base depth of 55 ft was reached. From this point, a marked grid was laid out with a base 100 m in length parallel to shore and 10 m wide. Three lines of 100 m length were run out 5 m apart, with additional lines crossing the grid at intervals of 10 m. At each line intersection, a small plastic bottle float marked with a position code was tied down.

With the grid completed, measurements were taken at 1 m intervals along each transect line. This information served to characterize the topographic detail. With time remaining, an attempt was begun to map the locations of all hard and soft corals within the grid.

An aircraft scanning overflight was made during the course of the mission, but conditions were not suitable for high-resolution photography. The topographic information was not usable for interpretation, but will be useful in other studies of coral reef community structure.

Mission 13

Principal investigator.—J. S. Bunt, University of Miami.

Associate investigators.—B. Chalker, University of Miami; P. Widdell, Harbor Branch Foundation.

Dates.—Nov. 13-19, 1973.

Facilities.—Habitat *HYDROLAB.*

Objectives:

—General check on feasibility of using *HYDROLAB* at 65 ft with excursions to 250 ft.

—Associated physiological studies.

—Recording of coral reef associations by mapping.

Results:

The mapped corals were in the immediate vicinity of the habitat. Identification of the specimens collected will provide data to be built into a more extensive account.

Physiological studies.—In order to extend the range and usefulness of the *HYDROLAB*, a mission was planned where the saturated depth would be moved from the standard 45 ft to 60 ft of seawater while maintaining surface air as the breathing gas. The question of possible detrimental physiological effect on the aquanauts at this greater pressure related to the increased partial pressure of oxygen was of primary concern to the director of the *HYDROLAB*. Hence the first mission at the 60-ft depth was to physiologically monitor the aquanauts during the saturation period.

The physiological studies were divided into the following three areas:

—Chronic oxygen toxicity. The inspired partial pressure oxygen was increased from approximately 0.49 atmospheres-absolute (ATA) (375 Torr) at the 45-ft depth to approximately 0.59 ATA (450 Torr) at 60 ft. The first signs of pulmonary oxygen toxicity are substernal distress (pain beneath the sternum, particularly noticeable upon deep inspiration) and a decrease in vital capacity. A Collins water-filled spirometer and a Spirostat spirometer were used to measure vital capacities daily, and the subjective feelings of the aquanauts were logged daily.

—Doppler monitoring. Two types of Doppler ultrasonic bubble detectors were used to check for intravascular bubbles following excursion dives from the habitat to depths as great as 250 ft and also during the 22-hr final decompression. This decompression schedule (from a 60-ft saturated depth) had not been tested at the *HYDROLAB*, and the excursion dive tables had been used on only one other mission, so the Doppler provided a means of evaluating both of these tables.

—Fluid volume regulation. During the saturation period the aquanauts spent an average of 3½-4 hr

per day in the water, and, according to previous physiological studies at the *HYDROLAB*, this state of immersion results in both an osmotic and free water diuresis. In an attempt to repeat these findings, blood samples were drawn during the saturation period and also pre- and postdive. Hematocrit measurements were performed at the shore-based laboratory, and the remaining serum was frozen and mailed to the University of Hawaii for analysis of the hormone aldosterone. Daily body weight losses which are probably related to the immersion time were also recorded.

Doppler Monitoring

Two different models of Doppler ultrasonic bubble detectors were used to evaluate both the excursion dive tables and the final decompression schedule. The first model, the Institute for Environmental Medicine and Physiology Blood Bubble Detector, has a 5 MHz resolution and two available sensors: a large flat probe which focuses 3-7 cm retrosternal for listening over the heart region, and a pencil-shaped probe for monitoring the various peripheral veins and arteries. The second model, the Fairfield Fetone Fetal Blood Flow Detector, has a 2 MHz resolution and one probe used for monitoring the heart region. The lower resolution of this model means that it is not so responsive to blood flow in smaller vessels, but the penetration is very good, and it responds well to large gas emboli. Both Dopplers have jacks for headphones for listening purposes.

The excursion dives from the habitat were made using chamber-tested tables developed by Union Carbide for NOAA. One no-decompression, deep excursion dive was made every morning of the saturation period to depths as great as 250 ft. On two out of four excursion dives the aquanauts were monitored with the Doppler upon re-entering the habitat immediately following the dive. Other work, related to the marine biological aspects of the mission, prevented listening for bubbles after the other two deep excursions until approximately 2 hr past exposure. No unusual sounds or "bubble noises" were heard at any time.

During the final decompression the aquanauts were monitored on the first "pull" from 60 to 30 ft. An experimenter listened several other times after reaching a new depth (i.e., new decompression stop) and detected no bubble sounds at any time.

The results of the Doppler studies indicate that during the period in which the aquanauts were monitored there were no "bubbles" large enough to be picked up by the instruments. This does not exclude the possibility that smaller bubbles beyond the range of the Doppler were present or that bubbles were present when the aquanauts were not being monitored. Within these limitations, the excursion dive tables and decompression tables were both considered safe.

Missions 8, 15, 22, 27

Principal investigator.—J. T. Enright, Scripps Institution of Oceanography.

Associate investigators.—A. O. Flechsig, G. Lewbel, G. B. Smith, J. Davis, W. Reetz, T. Gerrodette, Scripps Institution of Oceanography; A. Wolfson, B. Kobayashi, University of California at San Diego.

Dates.—September 15-22, 1973; December 9-16, 1973; March 24-31, 1974.

Facilities used.—*HYDROLAB.*

Objectives.—Primarily, to measure the effects of sediments on coral reef organisms; secondarily, to investigate the functional roles of selected species in determining community composition, and to study the effects of motile organisms attracted to artificial underwater structures.

Results:

Responses to Sediment

The sediment-clearing responses of corals have been studied by dosing individual coral colonies with measured amounts of inert silt. Responses were measured in situ by placing undamaged colonies inside vertical acetate cylinders, administering uniform suspended silt loads by syringe, and then following the removal of sediment with time. Dosages have approximated 5-100 times the natural background sedimentation rates. The principal mechanism for sediment removal shown by all species was the secretion of mucus. The mucus-sediment mixture was laterally transported off the edges of the colony by coordinated ciliary movements of the polyp surfaces. Eleven common coral species studied showed initial decay constants ranging from —0.003 to —0.008 per min (daylight, silt load 50 mg per cm). After repeated or heavier sediment loading, however, removal rates decreased, and the corals eventually became completely covered with silt. These extreme conditions presumably represent real physiological limits.

Sediment effects on the calcification rates of *Scolyemia lacera* were examined under natural light and water conditions. These rates were measured using a factoral experimental design for coral specimens in both light and dark conditions and without and with sediment. The advantages of this experimental design are that it has a built-in control, and, by running an analysis of variance on the results, the effects of light and dark can be separated from the effects of the sediment. It was found that calcification rates are decreased in the dark and by the presence of sediment in both light and dark animals. Calcification rates in the dark were decreased more by sedimen-

tation. This is reasonable if it is assumed that mucus is a main way of removing sediment since mucus production involves an energy expenditure by the coral. In the daytime, this expense is partly compensated for by the photosynthetic production of glycogen by the symbiotic zooxanthellae. At night, however, the coral itself must supply all energy to replace the mucus and thus less energy is available to make the coral skeleton. Thus, it was shown that sedimentation can decrease coral growth by some means other than light attenuation.

During the saturation dive in March, experiments were begun to determine the effect of sediment on sponges. In situ pumping (filtering) rates of a number of sponge species were measured. One sponge species was chosen for the sediment response experiments.

Sponges were enclosed in specially designed chambers that simultaneously aerated and stirred the water. Various doses of a fine clay silt were injected into the chambers, and the pumping rates of the sponges were monitored afterward for up to 6½ hr. These preliminary experiments have shown:

—The pumping rate of the sponge (assumed to be proportional to its feeding rate) shows a definite reaction to sediment in the water. With a very heavy sediment load in the water, the sponge stops pumping immediately and completely. With more moderate sediment doses (20 mg/l), the pumping rate decelerates over the course of 2–3 hours.

—Over a period of 6 hr or longer, the sponges show a recovery, and pumping rates return to near their former levels.

—Surprisingly, the sponges seem to show an accommodation to the sediment, an effect termed "long-term recovery." This means that a sponge exposed to daily sediment doses for 4 days had higher pumping rates on the fourth day than on the second. That is, instead of a progressive decline in the pumping rate on the second, third, and fourth days, which one might have expected, the pumping rate was most depressed on the second day and thereafter progressively "recovered" to become more similar to the first day.

Functional Role of Grazers in Determining Community Composition

Ten settling plates of asbestos-cement were attached to rocky substrate at various levels above the sedimentary bottom with varying angles of surface exposure to obtain data on the recruitment rates of sessile organisms. After 12 weeks the only recruitment was by a filamentous alga that was kept closely cropped by grazing fish. In that respect the plates closely resembled barren areas on nearby natural outcrops. At that time (December) four plates were enclosed with ½-in wire mesh to exclude the fish and other large organisms. By March the protected plates had several species of plants and animals growing on them, while the uncaged plates were still kept closely cropped by the grazers.

Effects of Artificial Structures

In September a small group of artificial kelp "plants," 35 ft long with 5-ft fronds, were installed at the edge of a sand channel. Additional plants were added in December and March.

Fish were immediately attracted in modest numbers, but as time passed the numbers and kinds increased. Species uncommon or absent from the reef at that location are occasionally seen, and local fishermen have come to regard the spot as a good place for fishing even though most do not know of the plastic kelp.

In addition, and in contrast to results with the settling plates, a variety of sessile organisms are abundant on the plastic, as are a few small motile species. Evidently the grazers that keep the settling plates barren are unable to scrape the unresisting plastic.

In any case, the assemblage of organisms on and around the artificial kelp is quantitatively and, to some extent, qualitatively different from that of the adjacent reef. It remains to be determined, however, whether the influence of this peculiar assemblage will be felt by the nearby reef community and whether the effects, if any, can be measured on another mission.

Missions 9, 17, 26

Principal investigator.—W. W. Schroeder, University of Alabama.

Facilities used.—Habitat *HYDROLAB.*

Date.—Sept. 22-27, 1973 (Mission 9).

Objectives.—To document the circulation patterns and characterize in terms of the basic hydrographic parameters the waters found at the *HYDROLAB* habitat site.

Environmental Measurements With Remote Readout Instruments

Circulation.—Current speed and direction were measured utilizing both remote reading and film recording instruments. The remote readings were made from inside *HYDROLAB* with the sensing unit suspended on an adjustable buoy system in 50 ft of water approximately 60 ft from the habitat. Readings were made at various water depths from 40 ft to the surface.

Hydrography.—Vertical profiles of temperature, conductivity (salinity), and dissolved oxygen were made utilizing a water quality system mounted on a buoyed block and tackle rig. The system was capable of profiling from 47-ft depth to the surface and

located approximately 60 ft from the habitat. It was operated from inside the habitat.

Two multiunit thermometer arrays, located in 50 ft and 90 ft and read as often as visited, provided supplementary data.

Tide measurements.—Readings made from the absolute pressure gage inside *HYDROLAB* will be used to produce a tidal picture for the study area.

Continuous Environmental Measurements (Sept.-June)

An instrument package consisting of an array suspended on a taut-line buoy in 50 ft of water approximately 50 ft from *HYDROLAB* and a single unit located approximately 725 ft south of the habitat at the edge of the wall in 100 ft of water were left in place from September 1973 to June 1974. The components of the array were a combination pressure gage-thermograph attached at the 20-ft level, a current meter at 35 ft, and a thermograph at 50 ft. All units are film recording. The deep unit at the wall is a film recording thermograph.

The package is designed to monitor three physical features: The tides, horizontal water movements (current speed and direction), and thermal structure. After 9 months of continuous recording, these instruments will provide, for the first time, a record of the dynamics and extent of these features as well as seasonal variability.

Results of remote readout measurements:

Circulation.—The observed currents were: (1) 80% tidal with direction varying 360° and speeds 0–0.15 knots, and (2) 20% horizontal unidirectional (wind driven and/or inertia) with a direction of 250° (WSW) with speeds ranging from 0.1 knots to 0.4 knots.

Temperature.—Water column range 28.3°C–29.1°C, average 28.8; no pronounced thermocline; both stable and unstable vertical gradients up to 0.3°C/3 m.

Thermograph data (film recording instrument in 7 m of water recording temperature range every hour):

Date	*Temperature, range (°C)*	*Temperature, average (°C)*
9/23	28.8–29.0	28.9
9/24	28.4–28.9	28.7
9/25	28.6–28.9	28.8
9/26	28.7–29.1	28.9
9/27	28.6–28.9	28.7
9/28	28.4–28.8	28.6

Salinity (conductivity).—Water column range 33.9 o/oo to 34.6 o/oo, average 34.4 o/oo; no halocline; both stable and unstable vertical gradients.

Dissolved oxygen.—Water column range 4.9 ppm to 6.3 ppm. Water column range 6.2-7.4 ppm, average 6.9 ppm.

Date.—Jan. 27-Feb. 3, 1974 (Mission 17).

Objectives.—Continue to document the circulation patterns and characterize in terms of the basic hydrographic parameters the waters found at the *HYDROLAB* habitat site.

Environmental Measurements

(Same as mission 9).

Results of remote readout measurements:

Circulation.—The observed currents appeared to be a confused combination of tidal and horizontal unidirectional (wind driven and/or inertia) flows. Direction varies 360° and speed between 0. and 0.5 knots.

Temperature.—Water column ranges 24.7° to 25.3°C, average 24.9°C; no thermocline.

Salinity (conductivity).—Water column range 30.7–31.2 o/oo, average 31.0 o/oo; no halocline.

Dissolved oxygen.—Water column range 4.9–6.8 ppm.

Date.—June 11-17, 1974 (mission 26).

Objectives.—Continue to document the circulation patterns and characterize in terms of the basic hydrographic parameters the waters found at the *HYDROLAB* habitat site.

Environmental Measurements

(Same as mission 9.)

Results of remote readout measurements:

Circulation.—The observed currents were: (1) 75% horizontal unidirectional with a direction of 250° (WSW) and a speed of 0.1–0.4 knots; and (2) 25% tidal with direction varying 360° and speed of 0–0.25 knots.

Temperature.—Water column range 27.9-28.1°C; average 28.0°C; moderate thermocline near the surface.

Salinity (conductivity).—Water column range 35.2–36.2%; average 35.6%. No halocline.

Dissolved oxygen.—Water column range 5.3–6.8 ppm.

Mission 10

Principal investigator.—B. Pijanowski, NOAA, National Oceanographic Instrumentation Center.

Associate investigators.—J. A. Llewellyn, University of South Florida; M. Sheen, Puerto Rico International Underwater Laboratory.

Dates.—Sept. 26-Oct. 8, 1973.

Facilities.—Habitat *HYDROLAB.*

Objectives.—To evaluate, under field conditions, four water quality systems—*HYDROLAB* Surveyor, Martek Mark 3, Ocean Data Equipment Corp.

(ODEC) Model WQMS–101A, and a Leeds and Northrup Water Quality System—for calibration stability, reliability during continuous use, ease of handling, and effects of pressure.

Results:

The sensor packages were fastened to a support frame anchored to the ocean floor so that they could be observed from the habitat window, and terminal units were placed inside the *HYDROLAB* close by. The instrument systems remained on the ocean floor for 7 days and were monitored from the habitat by divers as various tests were performed. All systems were operational and calibrated before transfer to the habitat.

Actual numerical data as obtained from the systems during the monitoring period were of secondary importance compared with the anticipated identification of problem areas and potential failures.

The systems were transferred to the test site by a small work boat in 6–8-ft seas which subjected the electronic packages to considerable vibration and shock. All terminal units were transferred to the habitat in dry containers. Although most of the cables were designed for underwater use, some connectors were not and required special preparation to keep them dry during the transfer. The Leeds and Northrup cables were not designed for submersion, so these were fed through a rubber hose for protection.

The following problems were encountered during underwater testing:

HYDROLAB Surveyor

The conductivity system was completely inoperative, a result of dislodging the batteries during transfer due to omission of retaining clips. The magnetic stirrer in the dissolved oxygen sensor stopped spinning and required physical manipulation to restart, but operated satisfactorily at surface pressure. This has been a recurring problem on this system and would not have been discovered if divers had not observed the system in use under pressure.

Martek Mark 3

The pH system was inoperative, the result of water leaking under pressure into the sensor housing.

ODEC WQMS-101A

The system was not operational. All output displays indicated unreasonable values. This was caused by a faulty temperature probe and broken wires in the cable, the latter probably a result of strain on the connector from the weight of the cable. Also the dissolved oxygen stirrer was nonfunctional, the result of a leak under pressure into the motor housing. Numerous mounting nuts and washers in the terminal unit had vibrated free during shipping and could have caused some of the electronic component failures pinpointed during posttesting examination.

Leeds and Northrup System

The motor for the stirrer on the dissolved oxygen system was not operational in the habitat; however, it proved to work quite satisfactorily when returned to the surface and has been working ever since. This problem is most likely a result of salt water corrosion on an aluminum connector used to power the motor. Conductivity output remained constant at a value well below the actual level. The sensor appeared to be faulty, probably the result of fouling on the two electrode probes.

Pressure tests were carried out during the field work to a depth of 50 ft, and the Leeds and Northrup system showed no effect of pressure on any parameter. The *HYDROLAB* dissolved oxygen probe showed a negative pressure effect of 0.1 ppm/10 ft for the first 30 ft, then leveled off. The Martek dissolved oxygen system showed 0.2 ppm instability over the pressure range tested.

Missions 11 and 21

Principal investigators.—J. Lord, P. Kotzer, University of Washington at Seattle.

Associate investigator.—K. K. Stehling, NOAA, MUS&T office.

Date.—Oct. 8–12, 1973; Mar. 9–16, 1974.

Facilities.—Habitat *HYDROLAB.*

Objectives.—To retrieve and emplace cosmic ray-sensitive emulsion cassettes under water in order to detect cosmic ray flux, filtered by the water, which could yield new data on nuclear interactions and radiation effects on the water's biota.

Procedures.—Two cosmic ray detectors using nuclear emulsions, X-ray film, and lexan plastic as active elements were prepared in *HYDROLAB* 42 ft under water. The first detector consisted of a solid stack of eight nuclear emulsion pellicles each 400 μm thick and 2.5×4 in in surface area in a sandwich array. The sensitive volume of this array consisted of 20.64 cm^3 of emulsion and, on Friday noon March 15, was placed 200 ft underwater by scuba.

The second package consisted of a sandwich array of many sheets, each 4×5 in in surface area. This array consisted of eight 400-μm-thick nuclear emulsion pellicles, five ⅛-in-thick lead plates, and several sheets each of lexan plastic and X-ray film. The emulsions in this array constituted 41.28 cm^3 of sensitive volume. Assembly of the second package was completed at noon the same day and subsequently transferred by scuba to a storage site 170 ft deep at 3:00 p.m. At 1:00 p.m. on March 27, the

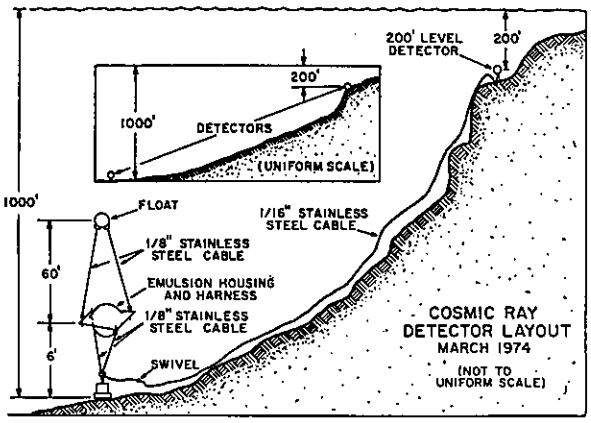

Figure 18.—Site topography, cosmic ray detection study.

detector was successfully transferred to 1,012 ft with the aid of the Johnson Sea Link research submarine. Each emulsion was housed in a glass sphere designed for deep water work (fig. 18).

The packages will be kept for at least 4 months (200 ft) to a year (1,000 ft), after which time the packages will be retrieved, emulsions and X-ray film developed, and data analyzed and presented at the 14th International Conference on Cosmic Rays, Munich, Germany. One of the steel cassettes, recovered in October 1973, had leaked, ruining the emulsion. The other proved intact and was correctly developed. The developed emulsion stacks were then returned to the University of Washington Physics Laboratory and scanned and analyzed for cosmic ray muon tracks.

Several interesting muon-nucleon interactions and collision processes were observed and measured, giving new values for muon stopping as a function of water depth. Further results were retrieved in late 1974 and will be suitably correlated and presented at the Munich Radiation and Cosmic Ray Conference in August 1975.

Mission 12

Principal investigator.—R. Wicklund, Perry Foundation, Inc.

Associate investigators.—R. Clarke, G. Wenz, Perry Foundation, Inc.

Date.—Oct. 22-Nov. 2, 1973.

Facilities.—Habitat *HYDROLAB.*

Objectives.—To study the following:

—Effects of increased pressure on physoclistous reef fishes and its biological significance.

—Distribution of principal grunt and snapper species in the *HYDROLAB* area.

—Twilight migrations of grunts along trails on the south shore, Grand Bahama Island.

—Evening behavior of large adult parrotfish and their nocturnal resting grounds.

—Temperature differentials between ocean bottom water and the top 5 mm of sand sediment during daylight hours off Grand Bahama.

—Pulmonary functions.

—Vertical excursion effects.

Results:

Pressure Effects on Physoclistous Reef Fishes

Experiment I: An adult *H. plumieri* and a juvenile (approximately 100 mm) *L. apodus* were moved to a 100-ft depth. The grunt had been previously captured at 60 ft and acclimated to 45 ft for 1 day. *L. apodus* had previously been acclimated to 35 ft. The increase in pressure (psi) from 45 to 100 ft is 81.6% and from 35 to 100 ft is 95.4%.

A second *H. plumieri* was moved from an acclimation depth of 45 ft to 125 ft 3 min later, an increase in pressure (psi) by 99.3%.

The initial reaction of both specimens of *H. plumieri* to the increased pressure was frantic swimming upwards for about 10 min, after which they lay on their sides on the bottom of the cylinder. The juvenile *L. apodus* displayed the same behavior. All three fish continued their swimming activity for short periods with prompting.

The *H. plumieri* placed at 125 ft had disappeared, the holding cylinder smashed and moved about 100 ft away—most likely by a large predator.

Experiment II: An adult *H. plumieri,* a juvenile French grunt, *Haemulon flavolineatum,* and a juvenile gray snapper, *Lutjanus griseus,* were moved from 45 ft to 125 ft. All three fish displayed frantic swimming behavior and settled to the bottom of their holding cylinders after 8–10 min.

At the same time, an adult *H. plumieri,* a juvenile *L. apodus,* and a juvenile *H. flavolineatum* were moved from 45 ft to 150 ft, an increase in pressure (psi) of 102.6%. Again, these fish swam for several minutes and then lay on their sides.

The following day all of the fish were either gone or half eaten by predators. Some of the cylinders had been smashed.

Experiment III: An adult *H. plumieri* from 60 ft and a juvenile *H. flavolineatum* from 45 ft were moved to 125 ft and placed in a protective cage. The pressure increase (psi) from 60 to 125 ft is 69.8%.

An adult *H. plumieri* from 60 ft and a juvenile *L. apodus,* and a juvenile *H. flavolineatum* were crease in pressure (psi) of 96.6% and 134.5% respectively.

These fish were recovered after 20 hr 45 min. Both *H. plumieri* were lying on their sides with a peculiar curvature—head and tail off the bottom.

The *H. plumieri* and the juvenile *L. apodus* were slightly buoyant upon being returned to their original storage depth. The juvenile *H. flavolineatum* remained negatively buoyant.

Experiment IV: An adult *H. sciurus* was moved from 60 ft to 150 ft. It immediately became heavy and lay on its side.

An *H. plumieri* was moved to 175 ft from 60 ft, a pressure (psi) increase of 123.7%. It escaped from the cylinder but remained trapped in the protective cage.

Later, the *H. sciurus* was still lying on its side but otherwise appeared unstressed. *H. plumieri* appeared very lethargic and died. *H. sciurus* was returned to 45 ft, slightly buoyant.

Distribution of Principal Grunt and Snapper Species (table 14)

The major population of grunts extends along the ledge of the deep reef roughly from a coral cave, 400 ft southwest of the transect line running southeast of *HYDROLAB*, and approximately 800 ft northeast of the same transect point. The area in which the major populations of grunts and some snappers spend the day is characterized by high coral grown in such a way as to create many holes and rather large coral caves. It is quite possible for entire schools of grunts to retreat into the holes and caves to avoid attack by predators.

Table 14.—*Survey of grunt and snapper populations along transect from HYDROLAB southeast to the wall*

Species	Distance from HYDROLAB	Depth	Number
	Ft	*Ft*	
Anisotremus virginicus	300–350	55	7
L. apodus	300–350	55	5
L. apodus	300–350	55	10
H. plumieri	350	55	40
H. plumieri	370	55–57	40
H. sciurus	370	55–57	60
L. apodus	370	57	9
L. apodus	370	57	15
H. plumieri	450	57	35
H. sciurus	450	57	70
H. plumieri	500–525	58	100+
H. sciurus	500–525	58	100+
H. plumieri	600	62	200+
H. sciurus	600	62	400+
H. flavolineatum	600	62	2
L. apodus	600	62	2
L. apodus	600	62	8
H. plumieri	610	68–70	100+
H. sciurus	610	68–70	100+
L. apodus [1]	1,200	180	5
H. plumieri [2]	1,200	225	1

[1] Observed several months before.
[2] Observed on Oct. 31.

Twilight Migrations of Grunts Along Trails

During daylight hours, bluestriped grunt, *Haemulon sciurus*, and white grunt, *Haemulon plumieri*, gather in small schools and are generally inactive. They hover over reefs, moving only to avoid an approaching diver or large fish. At night the grunts disappear from the reef completely.

Evening Behavior of Large Adult Parrotfish and Their Nocturnal Resting Grounds

Large adult rainbow, blue, and midnight parrotfish (*Scarus guacamaia, Scarus coeruleus*, and *Scarus coelestinus*) were sighted shortly before sunset, swimming quickly in a large circle in the area of the caves, ranging between 350 and 600 ft southeast of *HYDROLAB* and extending 500 ft to the northeast and 100 ft to the southwest. This area is characterized by high coral spurs, fused at the top in many places to form labyrinths of caves and narrow gulleys. The group was joined by 25–35 more large parrotfish, including some *S. coeruleus* and *S. coelestinus*.

The parrotfish moved continuously in circles, occasionally breaking the pattern to swim together seaward of the caves, returning a few minutes later. All of the parrotfish within the school appeared to be males.

At the peak of their activity, the parrotfish numbered approximately 75–100. They continued swimming in the wide circle defecating large amounts of the coral debris they had apparently fed on during the day. This defecating reduced the water visibility, which is usually up to 100 ft in this area, to 25–30 ft.

Temperature Differentials Between Ocean Bottom Water and the Top 5 mm of Sand Sediment During Daylight

The primary instrument was a Brooklyn precision mercury hand-held thermometer scaled to read 0.01°C, which was used to measure temperature at 2 ft above the sediment and within the top 3–5 mm of sand. An electronic *HYDROLAB* thermistor unit with remote readout inside the laboratory was also used.

Light intensity was measured with a simple photographic light meter held by the large window of *HYDROLAB* from the inside for relative light intensity data.

Readings in the sand interface on exposed bottom during midday, compared with those in shaded areas, showed as much as 0.1°C higher in the exposed bottom sediment.

Temperatures 6-12 in under the sand interface,

taken on several mornings, indicate higher readings in the deeper sand.

Based on the differential curve, the temperature of the sand interface was higher than the water above from about 0945 to approximately 2130. It started its upward climb at 0800 to a peak at 1230, then dropped rapidly until 1530. As the daylight decreased beyond 1530, the sand apparently held some heat, cooling slowly until the next morning.

The increase and decrease in the temperature differential and the light intensity are compatible, especially in the higher temperature hours of the day. The peak in light intensity is roughly at 1230; the same is true of the temperature curve. For approximately 12 hr at night, the temperature of the sand interface was lower than that of the water above.

Pulmonary Function Studies

Continuing the work performed during previous saturation dives in *HYDROLAB,* a series of dynamic pulmonary measurements were recorded before, during, and after saturation.

Five measurements were taken:

—Forced vital capacity (FVC)

—Maximum voluntary ventilation (MVV)

—Forced expiratory volume in 1 sec (FEV 1.0)

—Forced mid-expiratory flow, 25% to 75% (FEF 25/75%)

—Forced mid-expiratory flow, 200 to 1,200 ml (FEF 2/1,200)

Two divers had pulmonary functions recorded immediately predive, at 24-hr intervals during saturation, immediately following decompression from saturation, and 24 hr following decompression.

The third diver was measured 24 hr predive, 30 min predive, at 12-hr intervals during saturation, and 30 min, 24 hr, and 48 hr post-decompression.

Conforming to past findings, all the measured respiratory functions decreased immediately and significantly upon exposure to the *HYDROLAB's* 2.24-atmosphere pressure. This decrease generally remained in effect throughout the first 96 hr of the dive, after which an increase was observed.

Vertical Excursion Tests

A total of 11 excursion dives deeper than 100 ft of seawater (FSW) were carried out during 7 days of saturation at 42 FSW. These dives were between 120 and 200 FSW.

There were no signs or symptoms of decompression sickness during any of the excursion dives or following decompression from saturation.

The effects of nitrogen narcosis during the deeper dives from a 42 FSW saturation depth were noticeably less than experienced during similar dives from the surface.

Mission 14

Principal investigator.—A. Y. Bryson, NOAA, MUS&T office.

Objectives.—To provide a method for locating specific positions underwater with respect to each other: an underwater horizontal control grid that would enable a diver to return to the same positions up to 5 yr later.

Date.—Dec. 1–9, 1973.

Habitat personnel.—A. Y. Bryson, J. M. Barnhill, T. A. Bergner (all NOAA).

Surface support personnel.—R. F. Dill and J. M. Wells, NOAA; L. T. Bussey, USN.

Procedures and results:

A location close to *HYDROLAB* was selected as the point of origin. A line of bearing (045°), which is parallel to the "drop-off" or "wall," was laid out by using an underwater wrist compass. All positions were determined relative to this point and bearing, using three range poles and a 25-m stainless steel wire. A range pole was set on the point of origin, and another on the line of bearing (045°) at one-half the limit of visibility. A third pole was set on line by using the first two poles as a range. The poles were individually moved ahead, carrying the line forward while measuring the distance with the steel wire. (Fig. 19.)

After the base line, 300 m long, was established on the northeast bearing, two lines perpendicular to the base line were constructed. The perpendiculars were constructed by establishing intermediate positions equidistant on both sides of two base line positions and intersecting two measuring tapes equidistant from each pair of intermediate positions. One range pole was set on the base line position, one pole on the point perpendicular to the base line position, and a third on line by using the first two poles as a range. The line was completed in the same manner as the base line.

Positions were permanently marked every 50 m with a ¾-in-diameter steel pin. Each pin was tagged with a stainless steel strap that had the position number stamped into it. An eye was bent into each pin so that transect lines could be attached. Holes for the pins were drilled into the coral with a pneumatic drill or a star chisel. The hole was then filled with a mixture of seawater and cement, and the pin inserted.

Diagenic cementation in the limestone of the shallower positions made drilling and penetration by the star chisel extremely difficult. A heavy-duty drill to bore holes into calcium carbonate rocks is highly desirable.

The method of cementing the steel pins into the limestone bedrock was highly successful. Grid orien-

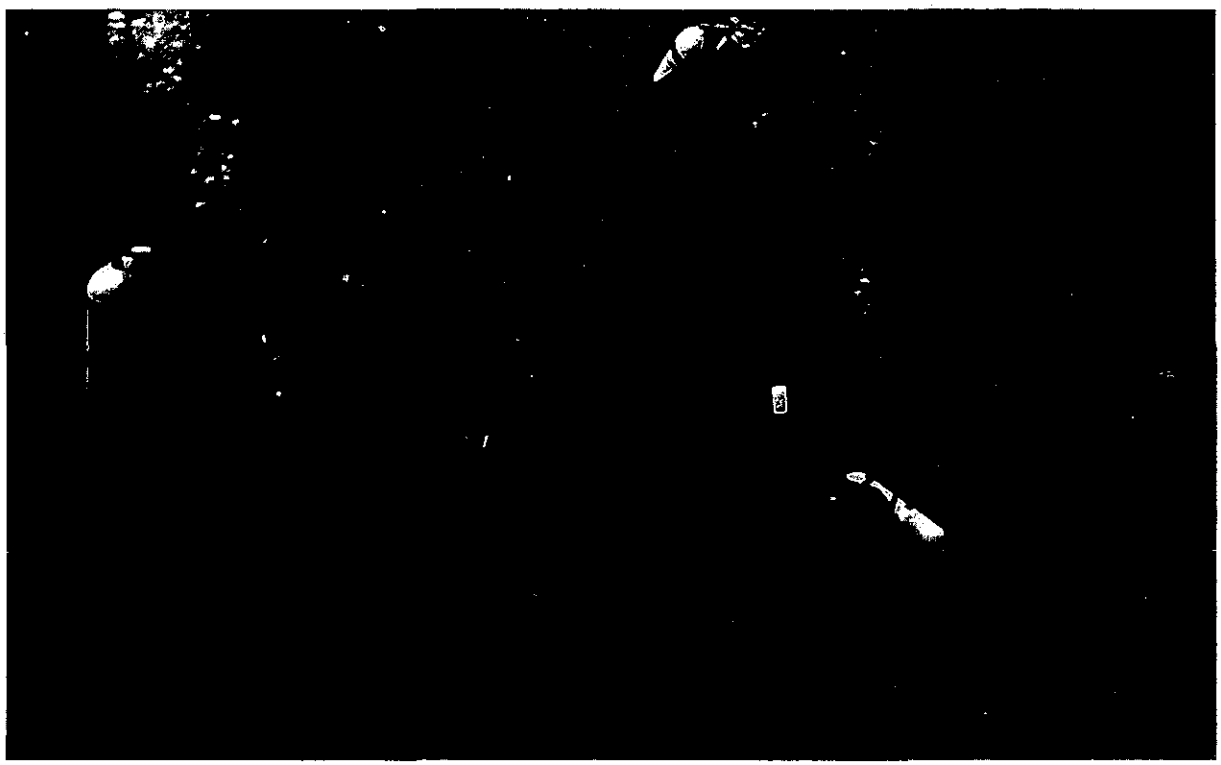

Figure 19.—NOAA Corps officers setting underwater bench marks at *HYDROLAB*.

tation and the position numbering system are shown in figure 20.

Compass bearings on shore landmarks were used to establish the approximate location of the point of origin (position number 34). The following bearings were taken on Dec. 9, 1973, from a boat overhead position number 34, using a diver's hand compass:

Object	*Magnetic bearing (Degrees)*
Xanadu Hotel (apex of the pyramid roof)	265
Lucayan Beach Hotel Lighthouse (center of)	305
Blair House Hotel (west corner of)	045

Range: West jetty light (green) and Lucayan Beach Hotel Lighthouse. Approximate distance from the beach was 1 mile.

Mission 16

Principal investigator.—M. Heeb, University of North Carolina (Wilmington).

Associate investigators.—W. Silver, University of South Florida (Tampa); E. Hipp, Jr., and E. Landis, Nalle Clinic (Charlotte, N.C.).

Dates.—Jan. 4-11, 1974.

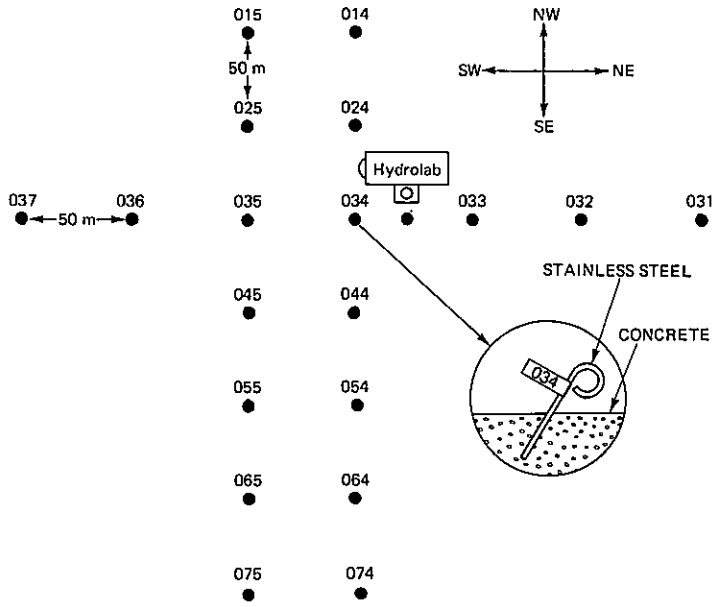

Figure 20.—Underwater grid position marking system, *HYDROLAB*.

Facilities.—Habitat *HYDROLAB*, a scuba scooter.

Objectives:

—To study nitrogen and carbon fixation and turnover of the photosynthetically fixed carbon in a typical Atlantic coral reef.

—To study various physiological factors related to saturation diving.

Procedures:

Coral was collected approximately 800 ft from the habitat at a depth of 100 ft on the edge of the ledge at the second habitat, the Undersea Instrumentation Chamber (USIC). Coral was carried back to the forward pad of the habitat and prepared underneath the plastic dome and underneath a plastic bag. The staghorn coral was isolated in the plastic dome and fed radioactive carbon through a circulating seawater pump. The pump was also connected to an oximeter which indicated active metabolism and release of oxygen by the coral. The plastic bag containing the brain coral was injected with radioactive carbon.

Two identical sets of coral—the staghorn and the brain—were placed on a separate pad and starved by placing plankton nets over them.

After suitable absorption of radioactive carbon by the coral, the domes and plastic bags were removed. The aquanauts then sampled both the brain and staghorn coral at 3-hr intervals day and night. This resulted in approximately 10–20 hr of swimming in the ocean sometimes to depths of 100 ft, but usually to the ambient depth of the habitat about 45–50 ft.

Each aquanaut was checked as he re-entered the habitat, and there was no evidence of microbubble formation in the brachial veins and the region of the pulmonary artery. One aquanaut made a shallow excursion to approximately 20 ft and did not indicate any microbubble formation when he re-entered the habitat.

The distant portions of the reef were visited by the use of an underwater motor-driven Seatech scooter. Daily photographic missions employed both 8 mm movie and 35 mm cameras. On some of the night photographic missions, the topside support physician and topside support diver accompanied the aquanauts.

Results:

Nitrogen Fixation

Sampling included corals, algae, and macrophytes on the reef. Nitrogen fixation was detected in certain macrophytes (species being determined at this time). The macrophyte in question is ubiquitous to the reef, as recorded by extensive photographic coverage. In situ experiments were performed on the bottom, while similar experiments were carried out in the laboratory on shore. In one case samples that did not appear to fix nitrogen on the bottom did so immediately when examined on shore. This indicated an induction process worthy of future investigation.

Carbon Uptake and Oxygen Production

The first day was used searching for and locating stands of coral to be used in the experiments. Selected coral were transferred laterally to a site near the habitat, and four experiments were begun. Two groups of corals, *Acropora cervicornis* and *Siderastrea siderea,* were surrounded with plankton netting in order to starve them for 3 days. Two other groups of corals, *A. cervicornis* and *S. siderea,* were used immediately. The *A. cervicornis* was placed in a plastic dome 2 ft in diameter and 200 μCi of C^{14}-carbonate was added. The respiration was monitored with a polarographic oxygen electrode and submersible recorder during the isotope pulse period.

After about 6 hr the dome was removed and sampling commenced. Sampling was every 2 hr for one day and every 3 hr the following day. The same was done for *S. siderea* except for two differences: the oxygen was not monitored, and a plastic bag was used in place of a dome.

After 3 days of starvation the first two groups of corals were removed from the plankton nets and subjected to exactly the same experimental procedures as were the second two groups mentioned above.

The coral samples were taken in triplicate, extracted with 50 ml of seawater for 20 min, and then transferred to sample jars containing 40 ml of 70% ethyl alcohol for storage and transport back to the home laboratory. At the home laboratory the coral samples were subjected to additional chemical extraction. Each fraction sample (approximately 1,500 total samples) was then prepared for isotopic counting in a Beckman LSC-250 liquid scintillation counter. The output from this instrument needs to be computed. When these computations are completed and the data illustrated, the results will be published.

Behavior of Caranx ruber

During the September 1972 mission, the bar jack *Caranx ruber* displayed unusual behavior patterns around certain bottom-dwelling fish. This unusual behavior was exhibited around goatfish, hog snapper, sting rays, and even an octopus. In the case of the octopus the bar jack's behavior made him a "Judas jack," for every attempt at concealment within the reef by the octopus was betrayed by the distinctive behavior of the particular jack circling overhead.

Doppler Microbubble Detection

The saturation divers were monitored on re-entry to the habitat after each dive and throughout decompression, and the support divers were checked. At no time were bubbles detected.

Mission 18

Principal investigators and habitat personnel.—J. Jaubert, Laboratoire De Biologie Generale, Nice, France; J. Vacelet, Universite D'Aix-Marseille, Station Marine D'Endoume Et Centre D'Oceanographie, Marseille, France; M. Wells, MUS&T office, NOAA.

Dates.—Mar. 7–20, 1974.

Objectives.—International mission involving French and U.S. marine scientists:

—Sample, photograph, and determine the distribution and abundance of sponges.

—Sample the sessile fauna of caves.

—Conduct preliminary measurements of oxygen consumption of sponges with and without symbiotic algae.

—Measure the conditions of light and light flux.

—Study the behavior and activity of fish as a function of light conditions.

—Conduct preliminary experiments on the effects of tropical fish collecting agents on the metabolism of corals.

—Determine baseline levels of benthic metabolism for comparison with Florida, Virgin Islands, Puerto Rico, and Pacific communities.

Procedures and results:

Over 30 different species of sponges were recognized. Before sampling, color photographs were taken and observed and the ecology of each species was recorded.

The oxygen concentrations of ambient water and excurrent water of sponges were recorded to determine the quantity of oxygen removed from the water by sponges. The patterns of distribution of dye drawn in by the sponges were photographed to determine the velocity of water movement. The metabolism of sponges with and without symbiotic algae was determined with the aid of plastic hemispheres and underwater oxygen meters.

Light was measured in situ with a recording irradiance meter in the range of 440-660 nm. Relationships between the light levels at which many diurnal species of fish leave and return to shelters and their levels of activity were established and found to be species specific.

Preliminary experiments on the effects of two tropical fish collecting agents (quinaldine and rotenone) on the metabolism of corals were carried out. No short-term effects of quinaldine on the photosynthetic capacity of several corals could be established at doses which are anesthetic to fish. Rotenone, however, caused a very significant drop in apparent photosynthetic oxygen production by *Acropora cervicornis* and *Montastrea cavernosa* and stimulated extensive mucus production.

The ratios of integrated daily values of photosynthesis and respiration were found to be indistinguishable from those found in the clear waters of the Virgin Islands, but considerably smaller than the same species under stress in Puerto Rico and Florida. The immediate oxygen demand of resuspended sediments was to be much lower than that in areas subjected to organic loading.

Mission 19

Principal investigator.—L. H. DiSalvo, Naval Biomedical Research Laboratory (NBRL), University of California.

Associate investigators.—H. C. Ross, NBRL, University of California.

Dates.—Feb. 16–28, 1974.

Facilities.—Habitat *HYDROLAB.*

Objectives:

—To assess bacterial metabolism in normal and stressed coral head microcosms.

—To determine rates and methods of reef micrograzing by reef infauna using the newly developed film technique.

—To observe tropical fouling on clean and polluted water-immersed glass slides using scanning electron microscopy.

Results:

Oxygen demand results generally were as predicted from published literature. Detailed results were prepared for publication in the *HYDROLAB Journal.*

Data from micrograzing studies have not been analyzed on a quantitative basis. Qualitative observations were as follows:

—Micrograzing was seen on film surfaces at 2 and 3 days. This suggested that bacterial films developed rapidly in the gelatin of the films.

—Films exposed in ambient waters showed little or no clearance in the 2–3-day periods, but films placed within reef spaces were often heavily grazed.

—Films with the gelatin side up were grazed more extensively than films with the gelatin side down, indicating the importance of surface settlement of bacteria and micrograzers due to gravity.

—Diversity of grazing patterns on films was low, compared with results obtained from this method in the western Caribbean.

—Micrograzers were smaller than those of the western Caribbean as determined by size of individual grazing patterns.

Results of viewing by scanning electron microscope of fouled glass slides incubated in the reef and at the shoreside laboratory have been incorporated in an NBRL Technical Progress Report. Further work is continuing. Some photographs were sent to the University of Miami, Institute of Marine Science, for aid in interpretation. The photographs apparently show the in situ precipitation of unidentified crystals on an organic matrix which is precipitated out on glass surfaces placed within the reef. Other photographs show bacterial cells apparently digesting the precipitated organic matter.

Mission 20

Principal investigator.—V. Petriconi, University of Bochum, Federal Republic of Germany (FRG).

Associate investigators.—K. Anger, G. Schriever, C. Valentin, University of Kiel; D. Agerton, P. Lavie, University of New Hampshire; M. Pose, GKSS[3] Company, Geesthacht, FRG; A. Y. Bryson, NOAA.

Dates.—Mar. 4–12, 1974.

Facilities.—Habitat *HYDROLAB*.

Objectives.—To become familiar with U.S. underwater lab *HYDROLAB* technology and operating methods and conduct a saturation diving mission to obtain data on tropical reef communities.

Procedures and results.—A new current meter using the principle of water flow to cool a precisely heated wire was used, but cable problems aborted further tests. Night activity of corals and other animals in symbiosis with the coral were observed and photographed. Local fauna and flora species were photographed, and samples were taken for use in a laboratory. Bottom density was measured.

Much information pertaining to the characteristics of the *HYDROLAB* system and its constituent equipment, operations support, maintenance, diver training and checkout, and mission planning was obtained by the FRG team for comparison with FRG equipment and operational methods.

Mission 23

Principal investigators.—M. Wells, NOAA; D. Olsen, Bitter End Field Station, Virgin Gorda, British Virgin Islands; B. D'Aoust, Virginia Mason Research Center, Seattle, Wash.; R. Dill, NOAA; S. Earle Mead, Natural History Museum, Los Angeles, Calif.; W. Jaap, Marine Research Laboratory, Florida Department of Natural Resources, St. Petersburg, Fla.

Date.—Apr. 3–16, 1974.

Objectives:

—To determine the species composition, distribution, abundance, and diversity of hard corals and algae along an 800-m transect line that extended across the reef tract from a depth of 3 m to a depth of 70 m.

—Evaluate a solid state, absolute gas pressure measuring device for use in metabolic studies and compare it with now-used oxygen electrode techniques.

—Determine the effect of hyperoxic conditions on the rate of photosynthetic oxygen production by coral-algal association.

—Establish dose-response relationships of corals to tropical fish collecting agents in terms of metabolism and mortality.

—Submarine salt water spring studies:

a. Determine the variation in current velocities and relationship to the tidal cycle in order to compute the volume of water interchanged between the porous rock and the sea.

b. Relate the geomorphic feature of the reef tract to lowered stands of sea level during post-ice ages.

Procedures and results:

This 13-day mission was the longest at-sea saturation dive to date using compressed air as a breathing medium. The use of compressed air has several economic and operational advantages over mixed gases. The U.S. Navy Shallow Habitat Air Dive Series (SHAD) I (30 days at 50 ft) and SHAD 2 (28 days at 60 ft) demonstrated that air saturation dives to these depths are possible without ill effects from prolonged exposure to elevated oxygen pressures.

In order to cover the complete 800 m of transect, close coordination of surface-based and saturated scientists was necessary. The shallower portions of the transect were above the upper operational range of saturated divers, and the deeper portions were below the effective working depths of surface-based divers. Both the vertical and horizontal ranges encountered here are required for complete characterization of a reef environment.

A provisional list of over 40 species of Scleractinian corals was prepared. It includes many of the recently described species from Jamaica and several aberrent forms which may be new species or at least subspecific differentiations. The number of Scleractinian corals previously reported from the Bahamas has thus been doubled.

A species checklist of over 200 algae was prepared, and it includes 50 species of algae not previously reported from the area and 1 species previously reported only in a few deep dredge samples from other areas of the world.

Additional information on the corals and algae collected on this mission includes vertical and horizontal distribution patterns and gradients and peaks of diversity and abundance.

[3] See footnote, page 16.

Photosynthetically produced oxygen by coral-algal associations (coral and zooxanthellae) was simultaneously measured by using an oxygen electrode and total gas pressure-measuring device. Whereas patterns of oxygen production and consumption were the same as measured by the respective methods, the absolute values differed significantly.

Preliminary observations reported on a previous dive (French-U.S.) regarding the immediate metabolic response of corals to rotenone and quinaldine (tropical fish collecting agents) were confirmed on this dive. Long exposure to quinaldine in solution caused death, even though no immediate metabolic response could be detected.

Flow in and out of the spring is tidal but delayed by approximately 1–2 hr from surface tides. Flow is greatly affected by the topography of the sea floor opening. Water coming from the spring on the outgoing tide is colder than the surrounding water by about 1°C, indicating some cooling or mixing with colder water when inside the reef. The mouth of the spring is filled with rubble that has been poorly recemented together. The study of the flow of seawater in and out of the reef on this mission was primarily to determine what instrumentation will be necessary to record aging and chemical change in the reef rocks with time. This information is important in comparing present reef environments to conditions of ancient reefs in the attempt to determine why some are rich in petroleum and others not.

The microtopography of the reef around *HYDROLAB* was explored and related to stands of sea level during past ice ages. Distinct glacial-enstatitic stands of sea level were recognized as terraces at 40, 60, 90, 125, and 150 ft. Much of the spur and groove topography between 50 and 90 ft reflects features related to a lowered sea level and subsequently modified by coral growth. The depth distributivity of sea level features corresponds to similar features in Jamaica, British Honduras, Hawaii, and Australia, indicating that they are youthful and have not been modified by recent tectonism.

The primary source of sand-sized sediment in the channels through this region is Halimeda debris. This material is not moved by the prevailing currents of the region and remains in place except when subjected to strong shore surges.

Mission 24

Principal investigator.—T. B. Scanland, Dames and Moore.

Associate investigators.—D. W. Valentine, R. A. deWit, A. Allen, Dames and Moore.

Dates.—May 1–7, 1974.

Facilities.—Habitat *HYDROLAB.*

Objectives.—To determine short-term effects of oil plus sinking agent combination on tropical biota including uptake into tissues by fishes. To determine short-term contribution of biota to degradation of crude oil. To determine long-term effects of oil on recruitment of larvae on solid substrates. To determine long-term gross effects of oil and sinking agent on coral knolls.

Results.—Since most of the experiments were aimed at tissue and water chemistry effects, the results will not be available until completion of the laboratory testing. Gross behavioral effects at knolls that were contaminated with Kuwait crude, Bunker C fuel, or No. 2 fuel oils were observed. In general, neither resident nor transient fishes avoided the settled oil. Several species including wrasses and damselfish appeared to feed on the escaping (rising oil droplets. Most of the hard corals cleaned their upper surfaces of visible quantities of oil within 1 day. The oil-sand mixtures did not adhere to either the soft corals or the upright sponges, but did collect in the bottoms of vase-shaped sponges. Dissolved oxygen measurements of water beneath the domes used in determining the effects of microbiota on oil degradation indicated that active respiratory processes continued in the presence of crude oil.

Mission 25

Principal investigators.—A. A. Roth, Loma Linda University; L. McCloskey, Walla Walla College.

Associate investigators.—C. Clausen, D. Crabtree, and L. Hodges, Loma Linda University.

Dates.—May 19–31, 1974.

Facilities.—Habitat *HYDROLAB.*

Objectives:

The general objectives of the mission were to study the effects of environmental factors on coral. Specifically, study centered around the effects of light and temperature.

The effects of light were studied by:

—Measuring light at various depths and in various environments.

—Measuring the amount of light-absorbing pigment in the coral *Acropora cervicornis* in these various environments.

—Noting the effects of pigmentation on respiration by measuring respiration by coral with varied amounts of pigment in different light environments.

Temperature studies during this mission concentrated on noting the effect of elevated temperatures for varied lengths of time on survival rates of the coral.

Results.—Because the mission was only recently completed, the results as described below are preliminary and tentative.

Figure 21.—Scientist measuring downward irradiance at *HYDROLAB*.

Light Intensity

Light intensity and spectral distribution were obtained by means of a spectroradiometer. For underwater studies the instrument was placed in a Plexiglas container (fig. 21) with the sensing diffuser on the outside and a light pipe connecting to the instrument.

Last year at the same locality, intensity and spectral distribution of light at the surface and at the level of the *HYDROLAB* were obtained. During this mission efforts concentrated on measuring the difference in light intensity between where the coral was growing near the surface, on the top of the spurs, and in the grooves that characterize the reef structure at the location of the *HYDROLAB*.

At noon at a wavelength of 5,000, the ratios of downward irradiance of shallow reef, spur, and groove are roughly 1, 0.5, and 0.125 respectively. Data were obtained at other times of the day, but very unsettled cloud conditions were a serious problem.

Pigment Measurements

Coral samples were collected (fig. 22) at the various localities where light was measured to note the relation of the light intensity to pigment concentration.

Acetone pigment extracts of several hundred samples of *Acropora cervicornis* were analyzed for absorbance at various wavelengths. These values are yet to be related to the surface area of the coral. The measurements necessary to estimate surface area have not been completed, and the only possible conclusion now is that the coral found in the grooves appears to have more pigment than the coral found on the spurs.

Respiration Studies

The relation of pigment concentration to respiration and light intensity was studied using an underwater respirometer.

Acropora cervicornis heads from 75 ft depth were transported to an 8 ft depth, and the production and respiration measured for 24 hr. The reciprocal experiment was also performed with shallow water corals transported to 75 ft and monitored for 24-hr periods. Appropriate control experiments were performed in the deeper water (75 ft), but the control experiment in shallow water was unsuccessful.

An incomplete analysis of the data indicates that the shallow water corals when transported to 75 ft do not photosynthesize fast enough to meet the carbon needs of the coral. Deep corals show a slightly higher photosynthesis rate when transported to shallow water. The relation of these results to pigment concentration awaits further analysis.

Temperature Tolerance Tests

Previous short-term temperature experiments at

Figure 22.—Collecting coral on the top of a spur.

the *HYDROLAB* site with the hermatypic coral *Acropora cervicornis* indicate that it can tolerate temperatures as high as 35°C for 1 hr (MUS&T report, fiscal year 1973). The present research was designed to observe the effect of incubation time on temperature tolerance. The apparatus (fig. 23) consisted of two 15-l incubation chambers—a control and experimental chamber—situated about 3 m from the *HYDROLAB*. Both chambers were isolated from the surrounding water, but had fresh seawater circulating through them at a rate of 0.3 l/min. The desired temperature was maintained in the experimental chamber with a thermoregulator and 10 100-W heaters. Circulation in the chambers was maintained with battery-operated magnetic stirrers.

Because of problems with the apparatus only a single test could be performed. Three racks (each containing nine tips of *A. cervicornis* branches) were placed in the experimental chamber, and one rack in the control chamber. The incubation was at 34°C. Racks were removed from the experimental chamber after 1½, 6, and 24 hr. The control rack was removed at 24 hr. One day after the end of the incubation the control, 1-hr, and 6-hr samples appeared alive and healthy, whereas the 24-hr 34°C samples were dead. In future work, temperatures of 32°–35°C, at different seasons and for longer incubation periods, should provide valuable data for thermal pollution studies.

Figure 23.—Incubation chambers for measuring temperature tolerance.

Interagency and International

ICMSE REPORT ON MANNED UNDERWATER ACTIVITIES

In April 1974, the Interagency Committee on Marine Science and Engineering (ICMSE)-sponsored study, "Manned Undersea Activities of the Federal Agencies and Utilization of Manned Undersea Research Submersibles and Habitats" was released. The findings of the study were presented in the fiscal year 1973 report and will not be repeated. However, the conclusions and recommendations not then reported are included below.

"CONCLUSIONS AND RECOMMENDATIONS"

"Assimilation and analysis of the information from Federal agencies with civil programs generally indicate a substantial body of potential users in addition to the current users. However, the current lack of use of available platforms can be attributed to a combination of reasons including: Short-duration needs for the platforms; their excessive cost due to mobilization and demobilization requirements if used on a project-by-project basis; and the need for a broad appreciation of the capabilities of this technology in some agencies. Therefore, a mechanism is needed to:

"—Coordinate the use of national undersea platforms (present and future) to realize economics of operations and applications and provide continuity of support.

—Identify the need for these platforms and provide support for improvements in platforms as required in support of projects.

—Assist Federal agencies in planning the use of platforms and gaining access to platforms.

—Provide for replacement of platforms and new technological capabilities when needed for programs.

"Of the three alternative methods for accomplishing these—(1) establishing a new coordinating committee; (2) expanding the functions of existing or related interagency groups; and (3) designating a lead agency—the designation of a lead civil agency was adopted by ICMSE. ICMSE also recommended that the lead agency make platform data available to current and potential users, explore the uses with other agencies, continue the accumulation of requirements and utilization data, defer new systems developments until existing platforms are fully utilized or declared technically unsuitable, and transfer available technology to the civil sector whenever possible. The lead agency assignment was to the National Oceanic and Atmospheric Administration, to be performed by its Manned Undersea Science and Technology Office.

"After presentation of the findings and recommendations of the study to ICMSE on October 19, 1972, ICMSE recorded its conclusions on page 33 of its report, entitled "Report of the Annual Review—Federal Ocean Program for Fiscal Year 1974" as follows:

' "*Title: Utilization of Manned Undersea Submersibles and Habitats*

' "*Problem:* Of the 50–60 submersibles produced over the last ten years, only 10–15 remain usable. Utilization of these is estimated at about 30 percent. The role of the Federal Government in assessing the need for submersibles and habitats and in assuring the continued availability of those considered necessary to meet marine research requirements needs to be clarified.

' "A preliminary survey of ICMSE member agencies indicates that many have programs which potentially could benefit from the use of submersibles. However, among the civilian agencies, FY 1973 funds specifically earmarked for leasing them are included only in the NOAA budget as part of the Manned Undersea Science and Technology Program.

' "*Proposed Action:* ICMSE recommends that NOAA, through its Manned Undersea Science and Technology Office, provide a continuing assessment of the Federal civilian agency needs for submersibles and habitats, and coordinate the utilization of available commercial and Navy assets by the civilian Federal agencies." '

INTERNATIONAL

German Program

At the invitation of the GKSS Company of the Federal Republic of Germany (FRG), NOAA's

Manned Undersea Science and Technology office coordinated U.S. participation in a cooperative undersea project in the North Sea during the summer of 1973, using the FRG underwater laboratory *HELGOLAND* off the island of Helgoland. This project involved scientists and engineers from MUS&T, National Marine Fisheries Service, University of New Hampshire, and the Woods Hole Oceanographic Institution.

In the spring of 1974 MUS&T invited a team of five scientists and engineers from the GKSS Company, University of Kiel, and University of Bochum to participate in undersea missions in NOAA's Bahama Banks research program using the *HYDROLAB* facility. Following the Bahamas project the GKSS Company invited MUS&T to assist in formulating plans for a multinational mission (FRG, U.S., France, England) in the Baltic Sea during the summer of 1974. This project will be reported in the fiscal year 1975 report. These cooperative projects in fiscal year 1974 are briefly described below.

German Mission at *HYDROLAB*

Participants.—G. Schriever, K. Anger, and C. Valentin, University of Kiel; V. Petriconi, University of Bochum; M. Pose, GKSS; A. Y. Bryson, MUS&T Office, NOAA.

During *HYDROLAB* mission 20, five German divers were saturated in two groups for 8 days to become familiar with the *HYDROLAB* system and its operation and to make a general survey of tropical reef communities. The German team utilized their time in photographing and collecting samples of the benthic community. Sediment samples were taken at depths from 45 to 150 ft to determine the depth zones of various sediment-dwelling organisms. Several night dives were made to observe the feeding behavior of fish, the night activity of the local corals, and the symbiotic relationships between various reef dwellers.

In addition, the German team obtained information on *HYDROLAB* technology, operational methods, and program management which will be of use in their programs in the western Baltic and North Sea.

U.S. Mission in the *HELGOLAND*

Principal investigator.—R. Cooper, National Marine Fisheries Service.

Date.—July 26-Aug. 2, 1973; Aug. 24-Sept. 10, 1973.

Location.—Helgoland, Federal Republic of Germany.

The objective of this project was the technological and operational assessment of the underwater laboratory *HELGOLAND*, operating in the cold, low-visibility waters of the North Sea. The evaluation was made to determine if this habitat or a similar system would be applicable in conducting projects in the U.S. northeast coastal region and to become familiar with technology developed by the Germans for cold water diving from a habitat. A saturation diving mission was conducted to obtain data on the operation and utilization of the *HELGOLAND* system. For this mission the *HELGOLAND* underwater laboratory was deployed in 75 ft of water approximately 2 miles from the control station on the island of Helgoland in the North Sea.

The evaluation was conducted in two phases. During phase 1, engineers familiarized themselves with the *HELGOLAND* system and equipment technology, diving regulations and procedures, diving equipment, system placement procedures, and day-to-day operating methods. During this phase the habitat was towed and placed at the dive site, and several nonsaturation observation dives were made.

Phase 2 involved conducting a 4-day saturation mission in the habitat. During this mission, three divers were saturated to perform diver physiology experiments, test vertical excursion tables, and generally survey the local biological community and environment. All diving was with an umbilical tether to the habitat to provide safety in the event a diver became lost or disoriented in the low visibility and high currents. In addition, all divers were required to wear full face masks.

The physiology experiments were designed to investigate the effects of normoxic nitrogen-oxygen breathing mixture on the thermal stress of saturated divers during excursions from the habitat. The experiments utilized a four-channel ultrasonic telemetry system (fig. 24) to send data on skin temperature, body core temperature, and heart rate from the divers to the recording equipment.

Vertical excursions from the saturation depth were not attempted due to the high currents ranging from 0.5 to 1.5 knots and the low visibility typically between 1 and 6 ft.

Biological observations were made to compare local marine life to species occurring at similar latitudes off the U.S. Dense populations of crabs and bottom-dwelling fishes were observed, but few lobsters were seen.

The habitat's temperature, humidity, and circulation control system provided a comfortable environment for operations in the cold waters of that latitude and would be adequate for operational use off the coast of New England. The habitat system and its associated life support buoy proved adequate in meeting the requirements of saturation missions in this type of environment.

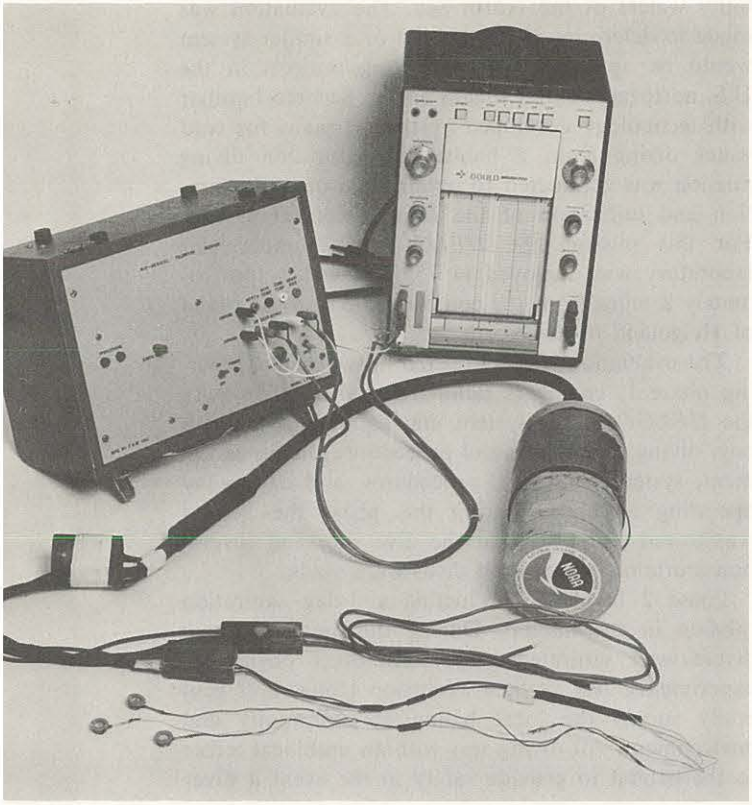

Figure 24.—Diver physiology telemetry system.

French program—FAMOUS

The French-American Mid-Ocean Undersea Study (FAMOUS) was established as a joint project by the governments of France and the United States as part of the U.S.-French Program for Cooperation in Oceanography. The lead agencies under which this agreement is being pursued are the Centre National pour l'Exploitation des Oceans (CNEXO) for France and the National Oceanic and Atmospheric Administration (NOAA) for the United States. FAMOUS project activities of the French are being coordinated at the Centre Oceanographique de Bretagne (COB) at Brest, and U.S. activities at the Woods Hole Oceanographic Institution. Primary Federal agency participation and support for FAMOUS is being provided by the National Science Foundation, NOAA, and the Navy. Others participating include the U.S. Geological Survey, Woods Hole Oceanographic Institution, Scripps Institution of Oceanography, Oregon State University, Dalhousie University (Canada), the Institute of Oceanographic Sciences (England), the Institute of Geological Sciences (England), and Centre Oceanographique de Bretagne (France) and CNEXO (France).

Project FAMOUS focuses on a section of the mid-Atlantic Ridge about 400 miles southwest of the Azores and encompasses two major fracture zones that offset the Ridge. This section of the Ridge is characterized by a well-defined axial rift valley and a symmetrical magnetic anomaly pattern. The overall plan of investigation began with broad regional surveys covering several hundred kilometres, followed by increasingly detailed surveys of features a few kilometres to a few metres wide, using deep-towed sensors, seafloor photography, and bottom stations. Later, research submersibles were used.

In the summer and autumn of 1973 a detailed seismological survey was made of the FAMOUS site. Several research vessels also studied microearthquakes with sonobuoys and bottom heat flow.

Seismographs were placed on the ocean bottom to record seismic events. After the seismographs were retrieved, bottom ocean current meters were deployed and then retrieved for analysis of the deep ocean near-bottom current vectors. The detailed geophysical and oceanographic studies were complemented with large-scale bottom photography and sonar side-scan mosaics of the area.

Preliminary results have already revealed regions of anomalous seismic activity, heat flow, rock types, and morphological characteristics. The followup analysis of geophysical information and rock samples will serve to relate the magnetic and petrologic properties of rock samples obtained by the submersibles to the magnetic and bathymetric profiles and to relate the seismicity and heat flow results to the tectonic structure inferred from the magnetic anomaly and bathymetric observations. The comparison of the various mapping, sampling, and photographic techniques will be one of the important results of this project.

The results of these missions and of the submersible mission of mid- and late summer of 1974 will be summarized in the MUS&T report of fiscal year 1975.

French mission at HYDROLAB.—A separate French-U.S. mission was conducted in March 1974 at the *HYDROLAB* habitat, reported on page 43 as part of the Bahama Banks research program, in order to study sponge metabolism and distribution, other sessile fauna, benthic metabolism, and light conditions.

Japanese Program—JAMSTEC

Principal investigator.—M. Matsuda, University of Hawaii at Manoa.

Date.—July 13-28, 1973.

Facilities.—Japan Marine Science and Technology Center, University of Hawaii (dives were in Japan).

Objectives.—To study the effect of prolonged stay

in a hyperbaric helium-oxygen environment on certain physiological systems such as body temperature regulation, energy exchange, and body fluid volume regulation.

Procedures:

The dive was carried out in Yokosuka, Japan, under the auspices of the Japan Marine Science and Technology Center (JAMSTEC). According to the arrangement between the University of Hawaii and JAMSTEC, four scientists from the University joined Japanese scientists to jointly carry out the physiological portion of the research.

Subjects: From a number of applicants, JAMSTEC selected three subjects for this dive on the basis of rigorous physical and psychological examinations. All three subjects were trained scuba divers, and one had been employed in a 2-day dry saturation dive to 4 atmospheres-absolute (ATA) in 1972. In addition to these subjects, one investigator stayed inside the chamber throughout the experiment in order to serve as a medical officer and to carry out physiological measurements.

Habitat and dive profile: The hyperbaric chamber (11.85 m long, 4.7 m wide, 6.53 m high) consists of three sections—sleeping quarters, laboratory, and shower and toilet—and can be pressurized to 11 ATA. Moreover, the chamber is equipped with temperature and humidity control units as well as other life support systems.

The compression started at 1100 hr and was completed at 1400 hr, July 16. The chamber was first compressed with air to a depth of 4 m at a rate of 1 m per 2.5 min followed by a compression with pure helium to a depth of 60 m at a rate of 1 m per 3 min. Therefore, a total pressure of 7 ATA at depth is attributed to helium (5.5 ATA), nitrogen (1.2 ATA), and oxygen (0.3 ATA).

The chamber pressure was maintained at 7 ATA by continuous supply of oxygen for 7 days. The decompression started at 1400 hr, July 23. The average rate of decompression was approximately 30 m per day. Decompression was not carried out during midnight to 0600 hr and 1400–1600 hr. It thus took 3 days to return to the surface.

Environmental parameters: The chamber temperature was maintained at 28–29°C, except during 2 days (4th and 5th days at 7 ATA) when it was lowered to 25–26°C. The relative humidity was maintained at 60±10%. As stated earlier, the partial pressure oxygen of chamber gas was raised to 0.3 ATA during the dive. Although the original plan was to maintain the level of partial pressure carbon dioxide below 7 mm of mercury inside the chamber, the carbon dioxide scrubber system was not fully satisfactory, and the partial pressure carbon dioxide often increased to nearly 10 mm of mercury. Moreover, the fluctuations in partial pressure carbon dioxide were rather large.

Results.—Profound changes in body heat and fluid balance were found even at the relatively comfortable temperature of 28°C in a hyperbaric heliox environment. This information should help in developing the necessary ameliorative steps for future dives.