ONR Report ACR-124: Project *Sealab* Report: An Experimental 45-Day Undersea Saturation Dive at 205 Feet, *Sealab II* Project Group

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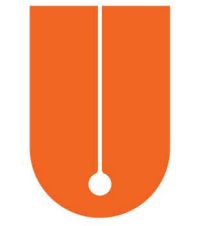

ONR ACR-124

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Project Sealab Report

An Experimental 45-Day Undersea Saturation Dive at 205 Feet

Sealab II Project Group

Edited by

D. C. Pauli and G. P. Clapper
Office of Naval Research

March 8, 1967

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FOREWORD

SEALAB II was the Navy's second major step in a continuing program to increase our ability to live and to perform useful work under the sea. Although the event was well publicized, we have become so accustomed to technological advancement that I doubt if many realized the full significance of this pioneer effort to support human life and useful activity in the earth's most hostile environment.

SEALAB II involved every phase of engineering including the development of new materials and techniques, the fabrication of sophisticated equipment and the solution to unique physiological and psychological problems.

It should be a matter of pride to all of us that the Navy was able to provide the full spectrum of capabilities necessary to insure the success of such an enterprise.

SEALAB's success puts us at the threshold of an expanding capability for military operations on the continental shelf where required. Of equal importance to the welfare of the nation, it increased our capabilities in the extraction of chemicals and minerals from the sea, the tending of pipelines, cables and underwater installations, the culture of marine life for food, and, of course, the extension of geophysical exploration and general advancement of all earth sciences.

I am pleased to present this report in accordance with the Navy's policy of sharing its information with an interested scientific community.

Paul H. Nitze

PAUL H. NITZE
Secretary of the Navy

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CONTENTS

		Page
Foreword		i
Abstract		v
Frontispiece		vi
Chapter		
1	The Man-In-The-Sea Program	1
2	Objectives of Sealab II Project	3
3	Sealab II Project Organization	11
4	Major Program Areas	14
5	The Sealab II Surface-Subsurface Complex	26
6	Project Chronology	30
7	Conclusions and Recommendations	32
	SECTION I—EQUIPMENT AND OPERATIONS	
8	Design of the Sealab II Habitat	39
9	Electrical and Electronic Systems for the Sealab II Habitat	50
10	Umbilical Cord for the Sealab II Habitat	63
11	The Design Construction, and Outfitting of Sealab II	67
12	Modifications and Outfitting of the Sealab II Habitat	87
13	Sealab II Exterior Lighting	91
14	Arawak System on Sealab II	94
15	Handling Characteristics of Sealab II	97
16	Sealab II Atmosphere Control	110
17	The Decompression Complex	112
18	The Support Vessel	121
19	Site Selection	131
20	Staging Vessel Mooring Complex	135
21	Aspects of Communications in Sealab II Project	139
22	Utilities	147
23	Operational and Emergency Bills	149
	SECTION II—AQUANAUTS	
24	Aquanaut Biographies	167
25	Aquanaut Training	177
26	Aquanaut Daily Routines	182
27	Future Selection of Aquanauts	187
	SECTION III—MAN-IN-THE-SEA PROGRAMS	
28	Physiological Studies in Sealab II	203
29	The Telemetering of Human Subjects and Animals Under Water	205
30	Adaptation to Environmental Stress in Sealab II	214
31	Determination of Dissolved Gases in Body Fluids	220
32	Serum Enzyme Study and Hemotological Data	228
33	Physical Fitness Tests	233
34	EEG and EKG Observations in Sealab II	237
35	Neurological, EEG, and Psychophysiological Findings Before and After Sealab II	240

Chapter | Page

36 The Sealab II Human Behavior Program 245
37 Electrically Heated Pressure-Compensated Wet Suits for Sealab II 272
38 Engineering Evaluation of Sealab II 306
39 Oceanographic Investigations 349
40 The Sealab II Biological Program 366
41 Sealab II Underwater Weather Station 369
42 Sealab II Salvage Tests 385
43 The Benthic Laboratory 394
44 Ocean-Bottom Mining Technology 402
45 Utilization of Porpoises in the Man-in-the-Sea Program 407
46 Dietary Program 412
47 Mark-VI Mixed-Gas Breathing Apparatus 417
48 Carbon Monoxide in the Atmosphere of Sealab II 423

ABSTRACT

Sealab II operations conducted by the Office of Naval Research as a part of the man-in-the-sea task of the Deep Submergence Systems Program was an interdisciplinary investigation into the usefulness of ocean floor habitation by the measurement of the ability of man to do useful work while living as a saturated diver in equilibrium with the ocean-floor pressure.

Ocean-floor tasks of the 28 Navy divers and civilian scientists included working dives for studying human physiology and performance, experimental salvage techniques, biological and physical oceanography, and the evaluation of the undersea habitat and associated diving equipment.

The Sealab II operation was conducted between Aug. 28 to Oct. 14, 1965, 3000 ft off Scripps Pier at La Jolla, California, in a depth of water of 205 ft. Using a synthetic breathing gas of helium, oxygen, and nitrogen, each of the three aquanaut teams lived under pressure approximately 15 days in an ocean-floor habitat, making forays into the 48° F, 5 to 30 ft visibility bottom waters for periods ranging from a few minutes to an extended dive of 3 hours. Excursion no-decompression dives to 266 ft and 300 ft were accomplished. Diving from the habitat was accomplished using both semi-closed-circuit breathing apparatus and hookah (habitat-connected-hose) breathing apparatus. A decompression complex new to the Navy consisting of a personnel transfer capsule mating with a deck decompression chamber was used for accomplishing recovery and decompression of aquanauts.

Sealab II demonstrated that:

1. The concept of ocean-floor habitation to accomplish a wide range of salvage and scientific tasks is compatible with man's ability to perform useful work at these depths.

2. No significant short-time physiological changes occur which resulted in deterioration of the aquanauts physical condition.

3. There is a degradation of human performance which increases with the complexity of the task being accomplished.



The U. S. Navy undersea habitat, Sealab II, which housed three ten-man aquanaut teams for 15 days each at a depth of 205 ft off the California coast at La Jolla from Aug. 28 to Oct. 10, 1965

PROJECT SEALAB REPORT

AN EXPERIMENTAL

45-DAY UNDERSEA SATURATION DIVE

AT 205 FEET

Chapter 1

THE MAN-IN-THE-SEA PROGRAM

Sealab II operations had as a backdrop Sealab I, also conducted by the Office of Naval Research, which had been completed just one year previous to Sealab II. In Sealab I, four U.S. Navy divers had performed an 11-day saturation dive at a depth of 193 ft.

Prior to Sealab I, extensive saturation pressure-chamber tests had been conducted at both the Submarine Medical Center, New London, Connecticut, and at the Experimental Diving Unit, Washington, D.C. Principal Investigators at these laboratories included CAPT George Bond, CAPT Walter Mazzone, and CAPT Robert Workman. The results of these chamber tests on test animals as well as human subjects proved that man could be subjected to saturated diving conditions and successfully decompressed without any ill effects.

Sealab I operations resulted from an interest generated within the Office of Naval Research to translate the U.S. Navy's saturated diving capabilities from the diving tank to at-sea operations. Sealab I operations were conducted in ideal ocean waters with respect to visibility, water temperature, and ocean-floor conditions.

The habitat used in Project Sealab I was primitive. A large experimental minesweeping float nine feet in diameter and 40 ft long was modified with ports and openings and equipped with bunks, showers, galley, and gas bottles. This simple habitat was lowered to the ocean floor next to Argus Island, an Office of Naval Research ocean research tower, located 30 miles southwest from Bermuda.

A standard two-man decompression chamber was used as a submersible decompression chamber for Sealab I operations and was handled with the crane installed on Argus Island.

Handling of the Sealab I habitat in even relatively smooth waters proved to be difficult. Many other associated problems were revealed in the Sealab I operation. The project was terminated as a result of an impending tropical storm.

Sealab I did prove to be successful, and for the limited funds available (approximately $150,000) did accomplish the end intended—the first step of translating saturated diving from pressure chambers to at-sea operations.

Sealab II was the second step toward this end (Fig. 1).

However, instead of the clear warm water and hard-bottom conditions of Bermuda, it was desired for Sealab II to face the more realistic environmental conditions existing on the continental shelf surrounding the United States. The site off Scripps Institution of Oceanography at La Jolla, California was selected for these environmental conditions as well as for logistic and scientific support considerations.



Fig. 1. Sealab II on a barge at Long Beach Naval Shipyard shortly before it was placed in the water and towed to La Jolla, California

The Sealab II project, a step in the man-in-the-sea program of DSSP, was initiated in January 1965, at which time a goal was set to place the aquanauts on the ocean floor on Aug. 20, seven months later. Extreme cooperation by all participating Navy, university, and industrial organizations resulted in coming within eight days of this preset goal. During these seven months, the habitat was designed, fabricated, and equipped with specialized atmospheric control, communications, and diver's equipments. During this same period, aquanauts were selected and trained to respond to the equipments, which were to be their primary life support on the ocean floor. The surface-support vessel was modified, and a decompression complex, using a new concept, was designed, built, tested, and installed. The fabrication and testing of a remote maintainable ocean-floor telemetering station (benthic laboratory) was accomplished, as well as the many tasks related to the development of the ocean-floor work programs. Last but not least, Tuffy, the porpoise who proved his capability to find and save lost divers, had to be trained in the special life saving procedures and integrated into the busy, noisy environment surrounding the Sealab II site.

Chapter 2

OBJECTIVES OF SEALAB II PROJECT

The major objectives of Project Sealab II were:

1. Determination of man's general ability to do useful work at a depth of 200 ft in a realistic ocean environment under saturated diving conditions.

2. Determination of physiological changes in man as a result of extended diving.

3. Measurement of performance to determine work degradation or improvement, as compared to surface-diver operations, and as a function of dive time.

4. Determination of stressful conditions and their effects on the group interactions of the aquanauts.

The degree of success of each of the planned work functions varied considerably because of the limited availability of diving time. In general, it can be stated that man's ability to do work under saturated diving conditions at a depth of 205 ft was more than amply proved. Actually, the diversity of tests, while providing a considerable overall project enhancement, tended to limit the measurement of man's capability in each specific field of interest. The determination of man's general ability to do useful work at 205 ft in a realistic ocean environment under saturated diving conditions implies a wide range of work involvement. Such a diversity of work was planned and undertaken in the Sealab Program. The various work assignments were as follows:

All three teams:
- Touch-sensitivity tests
- Arithmetical tests
- Aquasonic intelligibility tests
- Light and form visibility tests
- Stationary target array identification
- Contrast and resolution studies
- Visual acuity tests
- Auditory range studies
- Sound localization studies
- Water clarity meter correlation
- Strength testing
- Triangle assembly tests
- Two-hand coordination tests
- Group assembly tests
- Hookah evaluation
- Time-lapse photography
- Heated wet-suit evaluation
- Plankton studies
- Underwater weather station assembly, Calibration and Inspection
- Fish rake census
- Sediment coring
- Fish cage placement and stocking

Teams 1 and 2 only:
- Sand movement studies
- Portable EEG, EKG recorder evaluation

Teams 2 and 3 only:
Excursion diving

Team 1 only:
Fish migration studies
Fish gas bladder studies

Team 2 only:
Porpoise evaluation

Team 3 only:
Foam-in-salvage evaluation
Salvage tools and equipment evaluation
Geological airlift evaluation
Geological corer evaluation

In addition to the above specifically assigned work assignments, many other assignments had to be accomplished as part of the regular routine. These everyday assignments included:

Watchstanding
Medical observations
Housekeeping
Pressure-pot transfers
MK-VI set-up and check

The investigation of physiological changes in man as a result of the extended saturation diving of Sealab II resulted in a conviction that:

1. No significant short-time physiological changes occur which result in deterioration of the aquanauts' physical condition.

2. Acclimation to stressful temperature changes of Sealab habitat living (85° F) and ocean-floor swimming (47° to 54° F) occurs, with the result that aquanauts can perform better and for longer periods of time in the surrounding ocean waters.

The measurement of work performance to determine work degradation or improvement as compared to surface-diver operations and as a function of dive duration resulted in the following:

1. The results of a lift-and-pull strength test showed a decrease in exertable strength between dry land and Sealab.

2. The individual triangle assembly (manual dexterity) tests revealed a 37-percent decrease in performance between dry land and Sealab.

3. The Two-Hand Coordination Test showed a 17-percent decrement in performance in Sealab.

4. The three-dimensional group assembly task took twice as long in Sealab as on dry land.

5. No decrement was found between predive and Sealab mental arithmetic tests.

Determination of stressful conditions and their effects on the group interactions of the aquanauts leads to the conclusion that there can be little doubt that the Sealab environment was stressful. The conditions which contributed to this stressful environment included the following:

1. The water was cold and visibility poor.

2. The work schedule, requiring long hours of preparation, was very often interrupted, delayed or revised.

3. Communications were difficult because of helium-speech distortion.

4. Sleep was often disrupted for most men by the long hours of work, high humidity, poor air circulation, and physical complaints of headaches, minor ear infections, and skin rashes.

However, in spite of the stressful aspects of the situation, the motivation and morale of the men were extremely high. Group cohesiveness, as measured by the diver's choices of their own team members, increased for each of the three teams from pre- to postexperiment measures. Despite a general feeling of accomplishment, many men were dissatisfied with the amount of work they personally accomplished.

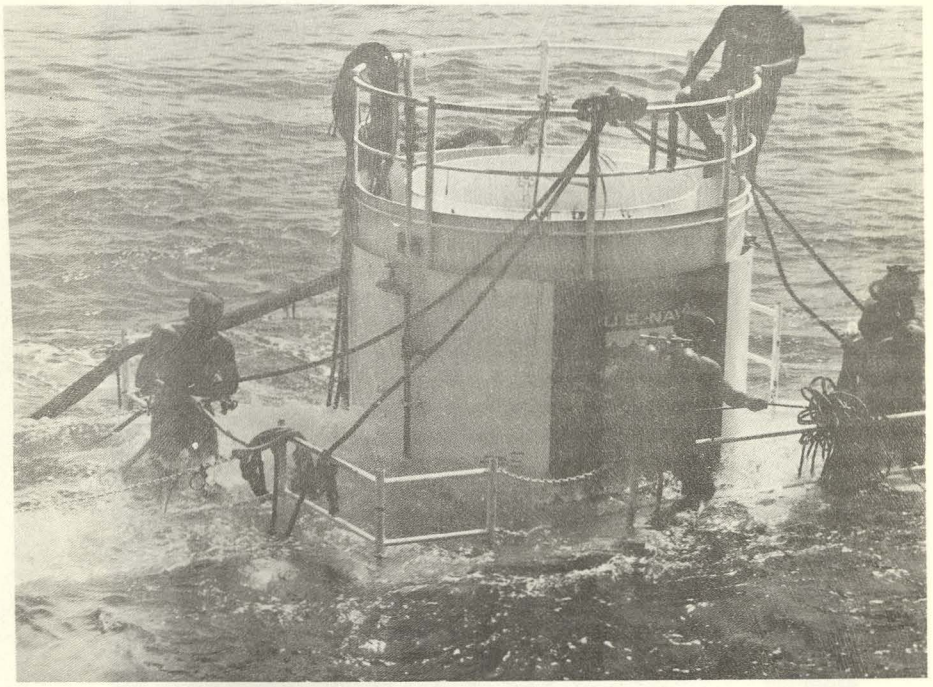


Fig. 2. Aquanauts open the Sealab conning tower flood valve

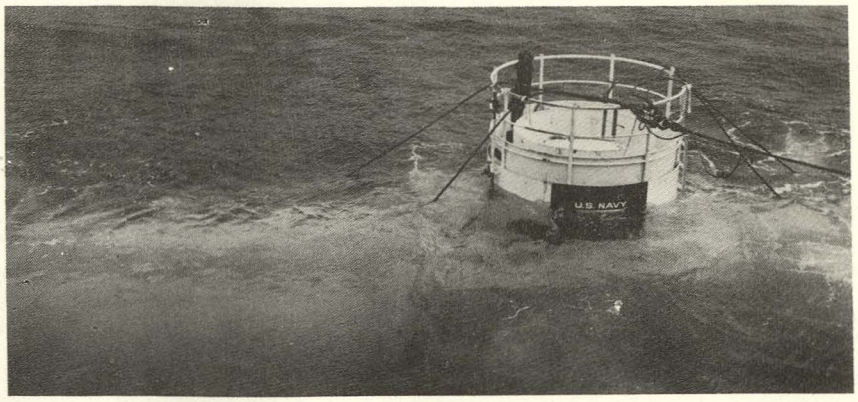


Fig. 3. Sealab II begins its slow descent to the ocean bottom, 205 ft below



Fig. 4. Aquanauts Commander M. Scott Carpenter and Gunner's Mate First Class Wilbur Eaton prepare to enter the water and dive to Sealab II on the bottom

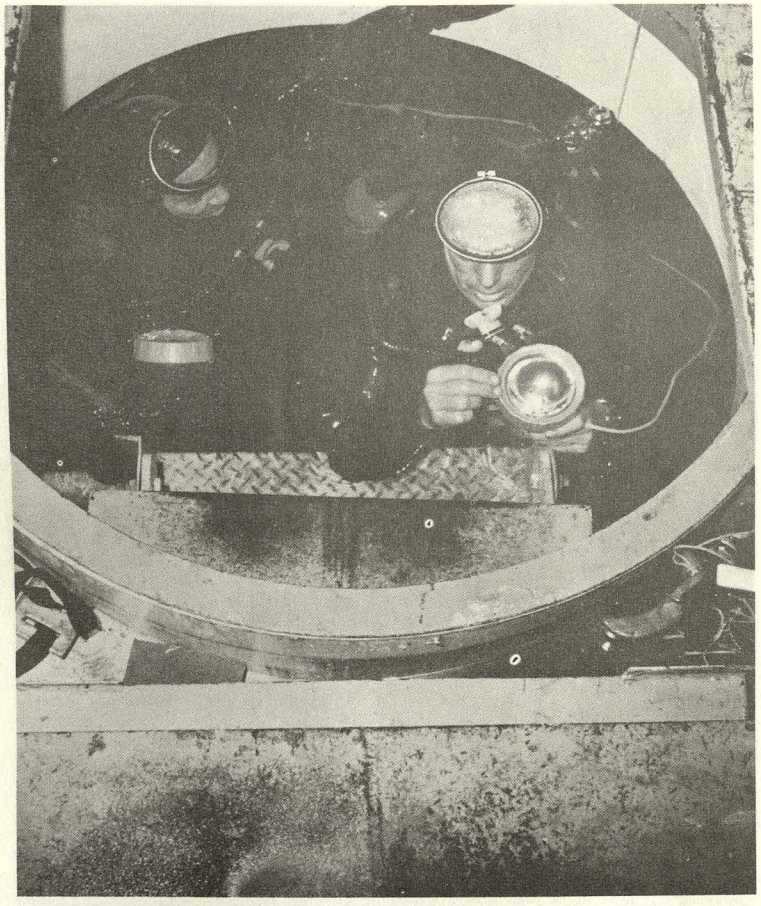


Fig. 5. Commander Carpenter and Eaton enter Sealab II through the four-foot entry hatch

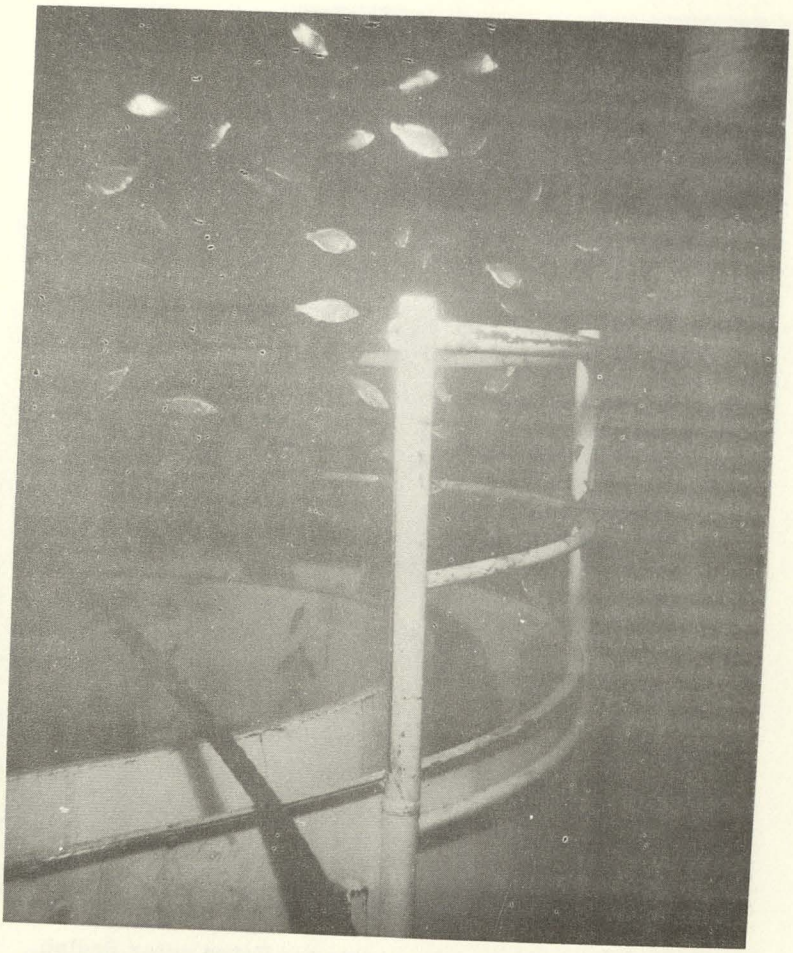


Fig. 6. Marine life around the Sealab II conning tower shortly after the habitat was occupied by Team 1

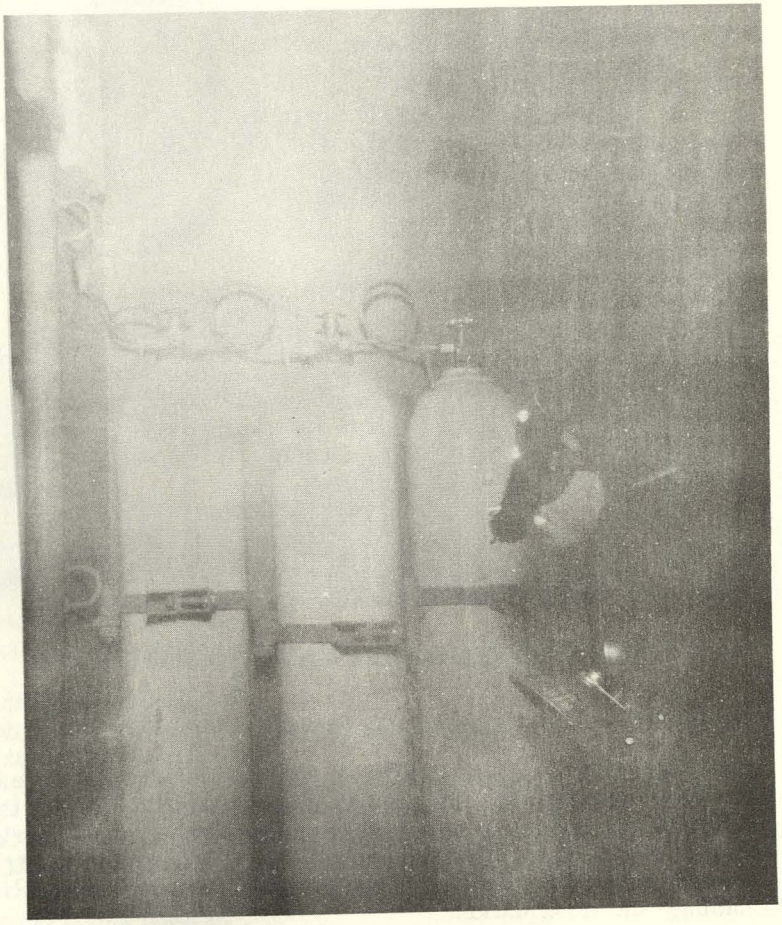


Fig. 7. Aquanaut Grigg inspects the Personnel Transfer Capsule as it sits on the bottom

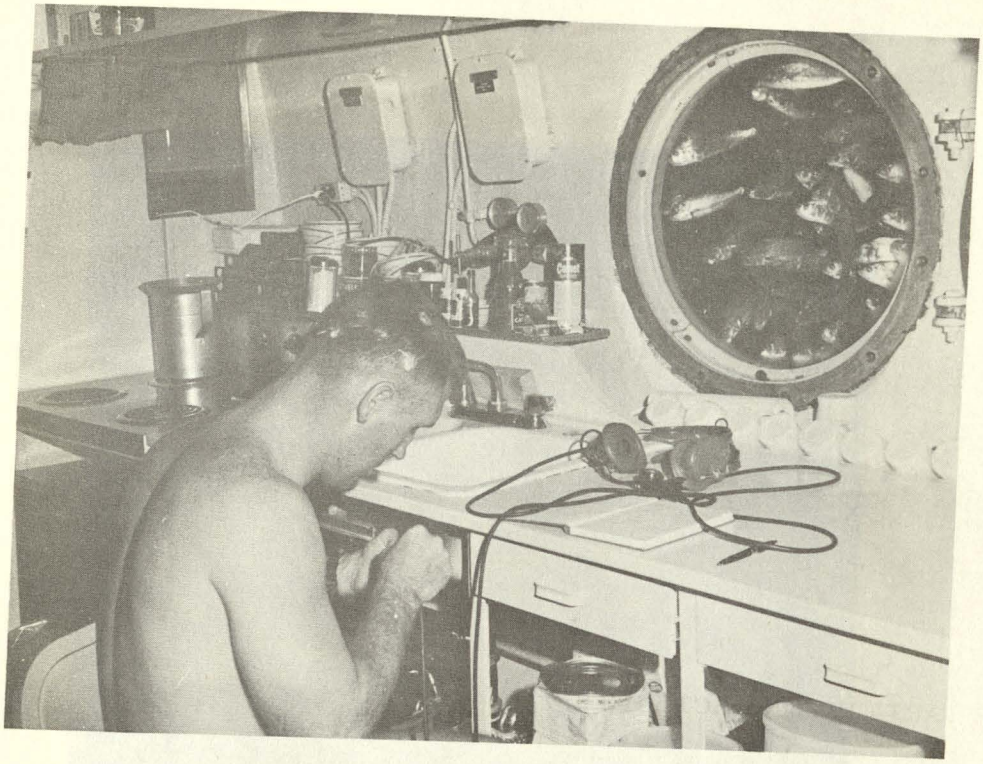


Fig. 8. Aquanaut Cannon repairs a headset inside Sealab II

It should be made clear that in spite of all the obstacles and dangers present during Sealab II, an unprecedented amount of useful work was accomplished (Figs. 2 through 8). The aquanauts' performance of scientific and operational tasks demonstrated clearly that man can live in harmony with the hostile undersea environment. Having again demonstrated the tremendous ability of man to adapt, the future of undersea habitation and exploration should be limited only by technology and imagination.

Chapter 3

SEALAB II PROJECT ORGANIZATION

INTRODUCTION

Sealab II, being the multidiscipline operation that it was, was organized on a task-assignment basis coordinated through a steering committee. Members of the steering committee were selected from the major participating organizations. Steering-committee meetings were called at milestone points to review problem areas, delineate task responsibilities, and make policy decisions related to safety, schedules, and personnel.

It has been estimated that the total number of persons who contributed materially to the success of Project Sealab II is in excess of 400. To attempt to list all support personnel and indicate their contributions to the project would not result in a complete list, and therefore the attempt will not be made. However, listed below are the organizations which, through direct participation or by furnishing equipment and supporting participants, contributed to the overall success of the project.

MAJOR PARTICIPATING ACTIVITIES

Atlantic Fleet Mobile Photographic Unit
Provided documentary photographic coverage of aquanaut training.

Bureau of Medicine and Surgery
Approved physiological qualifications of all aquanauts. Set guidelines for surface support and saturated excursion diving.

Bureau of Ships
Initiated and provided support for salvage programs. Staffed habitat and Decompression Complex Certification Board. Provided ARS for surface support.

Chief of Naval Operations (Op-09)
Supervised overall still and motion picture documentation.

Commander Eleventh Naval District
Provided logistic support and staff personnel during operational phase of the project.

Experimental Diving Unit
Tested diving gear and provided 230-ft He-O_2 decompression tables and technical advice.

Long Beach Naval Shipyard
Provided facilities and technical personnel for final checkout and modification of staging vessel, decompression complex, and habitat.

Marine Physical Laboratory
Designed and constructed benthic laboratory and provided communications equipment and support.

Naval Medical Research Institute
Initiated and monitored heated wet-suit program. Planned and directed psychological observation program during the operational phase.

Naval Operations Support Group, Pacific
Provided surface diving support and transportation from shore to the support vessel.

Naval Ordnance Test Station
Furnished staging vessel and supervisory range personnel. Conducted predive site surveys, provided supervisory personnel for habitat, decompression complex, and staging vessel modification, and provided special equipments and logistic support.

Naval Electronics Laboratory
Provided staging area for logistics support and underwater photometric equipments and special technical support personnel.

Office of Naval Research
Provided overall project management and documentation. Planned and supervised human-performance program, decompression complex construction, and public information program.

Pacific Fleet Mobile Photographic Unit
Provided documentary coverage of outfitting and operational phases.

San Francisco Bay Naval Shipyard, Hunters Point Division
Designed and constructed Sealab II habitat. Provided technical assistance during operational phase. Conducted toxicology study of possible habitat contaminants.

Scripps Institution of Oceanography
Provided local logistic support, shore facilities, and transportation between shore and staging vessel.

Special Projects Office
Selected aquanaut teams. Supervised physiological testing. Aided in public information activities.

Submarine Medical Center
Provided physiological monitoring personnel and equipments. Supervised atmosphere control and aquanaut decompression.

U.S. Naval Research Laboratory
Supervised gas uptake studies. Analyzed atmosphere purification chemicals and atmosphere samples. Conducted CO_2 absorbent efficiency tests.

U.S. Navy Mine Defense Laboratory
Provided specifications and design criteria for habitat, surface diving locker, and decompression complex. Trained aquanauts. Provided technical assistance during operational phase. Made engineering evaluation of habitat and diver's equipments.

ORGANIZATIONS FURNISHING SPECIAL APPARATUS AND SUPPORTING PARTICIPANTS

Battelle Memorial Institute - Underwater power tools and engineering support
Commander Service Force, U.S. Pacific Fleet - Logistics
Dixie Manufacturing Company - Decompression complex
Dunlap and Associates, Inc. - Human performance equipment and test procedures
EEG Laboratory, Gaustad Sykehus, Norway - Portable EEG, EKG recorder, EEG studies
Hennessey Productions - Documentary film producer
International Latex - Experimental wet suits
Marine Mineral Technology Center - Underwater coring and mining equipment experiments
Merrett-Chapman-Scott - Operated USNS gear (ARS-7), participated in salvage experiments
Mine Safety Appliance Company - Salvage tools
Murphy-Pacific Corporation - Foam-in-salvage equipment and experiment support
Philadelphia General Hospital - EEG experimental telemetering equipment tests
Photosonics - Electronic support personnel on staging vessel

U.S. Naval Applied Science Laboratory - Helium speech unscramblers
U.S. Naval Hospital, San Diego - Postdive aquanaut physical examinations
U.S. Naval Missile Center - Porpoise evaluation and audiometric measurements of aquanauts
U.S. Naval Ordnance Laboratory - swimmer knife evaluation, stud gun engineering
U.S. Naval Radiological Defense Laboratory - Radio-isotope studies of possible iron deficiencies
U.S. Naval School of Aviation Medicine - Predive aquanaut physical examinations
U.S. Naval Training Station, San Diego - Provided IBM card coders and observers for psychological monitoring
U.S. Navy Underwater Sound Laboratory - Underwater swimmer auditory test equipment
U.S. Rubber Company - Experimental heated wet suits
University of California, Santa Barbara - Environmental stress studies
University of California Medical School, Berkeley - Blood testing
Westinghouse Electric - Arawak/hookah gear, staging vessel support personnel
Yale University - Data collection, psychological studies, computer coding, and data analysis

The on-site organization is outlined in Fig. 9. It must be emphasized, however, that the principal concern of a test of the nature of Sealab II is that of safety of the aquanauts.

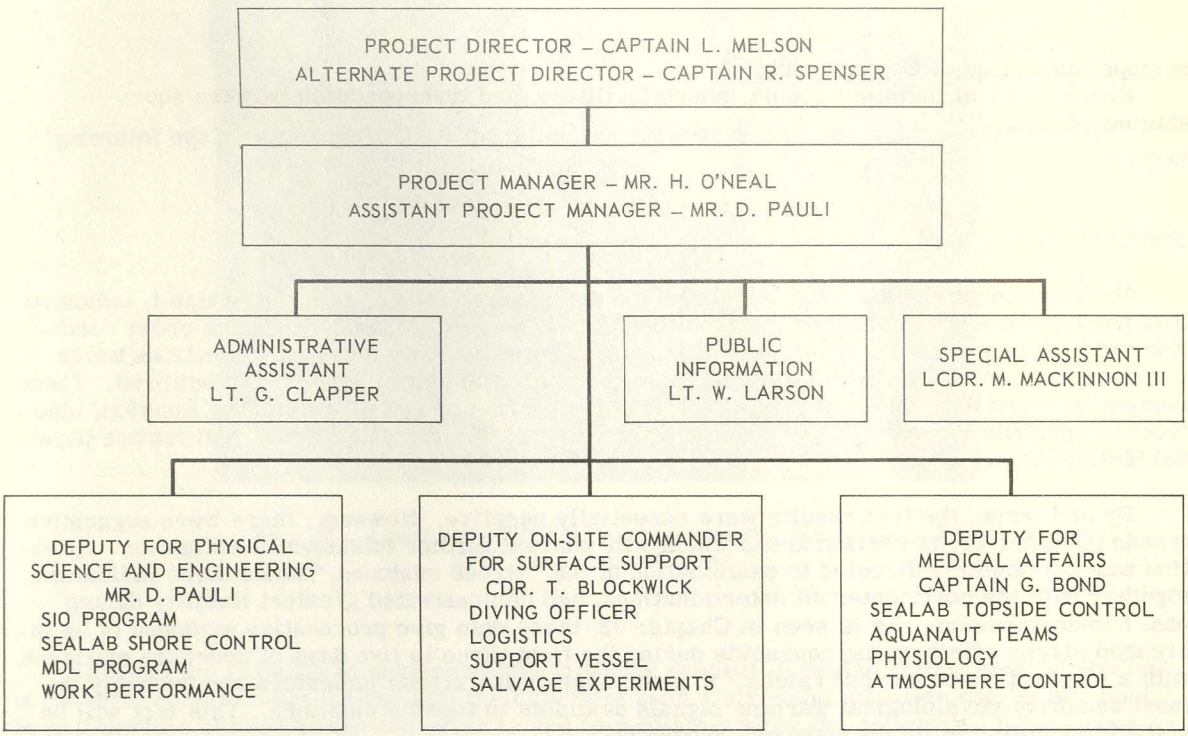


Fig. 9. Sealab II On-Site Organization

Consequently, to a large extent, the ocean-floor work load of the aquanauts was controlled by the Medical Affairs Officer. As this concept of ocean floor habitation moves more toward operational objectives, the external control of the aquanauts' direct work load will be by a topside salvage diving officer. Medical officers will then function in a monitoring and emergency role, as they now do in conventional diving operations.

Chapter 4

MAJOR PROGRAM AREAS

INTRODUCTION

Over forty programs were carried out during Project Sealab II. These programs covered the following major areas:

1. Physiology
2. Human performance
3. Experimental wet suits
4. Habitat engineering evaluation
5. Oceanography
6. Salvage
7. Benthic laboratory
8. Mining technology
9. Porpoise utilization
10. Dietetics
11. Mk-VI semiclosed circuit scuba evaluation
12. Atmosphere contaminants

The general concepts and major results of each program are discussed in the following sections.

PHYSIOLOGY

Previous physiological studies, conducted during Projects Genesis and Sealab I, indicated that most physiological parameters monitored would show no significant change under conditions of high pressure and exotic gas mixtures. Therefore, only those vital functions which might assist topside control in medical management of the experiment were monitored. These studies included daily blood analysis, inspection of urine and saliva, pulmonary function, electrocardiographic recordings, body temperature control, exercise tolerance, and routine physical tests (Chapter 33).

By and large, the test results were essentially negative. However, there were suggestive trends (Chapter 28) in certain areas which will warrant further intensive investigation. Attention was particularly directed to examination of the "stress enzymes," since these indicators, together with the corticosteroid determinations, had demonstrated greatest liability during past human exposure. As is seen in Chapter 32, these data give provocative evidence of an increased stress effect on the aquanauts during the first three to five days of undersea exposure, with a slow return to normal values. It would appear that stress indicators are probably the most sensitive physiological warning signals available to topside monitors. This fact will be suitably exploited in future undersea programs.

Physiologically, the most critical area of the project was decompression. Decompression schedules may be based on mathematical calculation; however, the validity of such schedules can only be established empirically, since there is no simple, accurate method of determining inert-gas tension in tissue.

During Sealab II decompression runs, a test program applying gas chromatography to determine the dissolved gas levels in urine was conducted (Chapter 31). The results indicate that a high correlation exists between the amount of dissolved gas in the urine and the ambient atmospheric concentration. Application of this observation to decompression schedules is under serious consideration.

Another major problem encountered in undersea living is that of recording physiological parameters while the subjects are outside of their undersea habitat. Several approaches to the problem come to mind, two of which were investigated during the experiment. One method was the acoustic underwater telemetering of EKG signals from the swimmer to the habitat and wire transmission to the surface support vessel (Chapter 29). The second method was the use of a miniaturized unit which was carried by the swimmer and recorded EEG and EKG (Chapter 34). In both programs some expected and unexpected artifacts were encountered. However, progress to date shows great promise for the monitoring of vital signs on free swimmers in the future (Fig. 10).



Fig. 10. Aquanaut Coffman has electrodes for EKG and EEG recorder attached

Although the complex of environmental stresses present in Sealab II may best be studied at the site, considerable insight into the effects of such a stressful situation can be obtained by appropriate studies conducted prior to and immediately after the exposure. Nine divers were studied before and again after their 15 days in Sealab (Chapter 30). Studies conducted included modified maximal work capacity and cold-exposure tests. There is a suggestion, based on the data obtained, that some alteration in physiological function may have occurred in men living under the conditions present in Sealab II.

Pre and postdive tests involving neurological, EEG, and psychopsysiological studies were also conducted (Chapter 35). The psychophysiological variables included heart rate, respiration rate, skin resistance, and finger plethysmogram. No significant predive or postdive neurological or EEG changes were found, while the only significant difference in psychophysiological variables was a drop in arousal level from predive to postdive.

HUMAN PERFORMANCE

The purpose of the human-performance program was to make an overall assessment of man's behavior while living in the sea. The program was designed not only to determine how well man can perform scientific tasks, but also to study broader aspects of adaptation to life and work in the hostile undersea environment.

Psychomotor tests used during the program were designed to measure the application of maximum force (strength test), manipulative dexterity, eye-hand coordination, and the cooperative assembly by four divers of a three-dimensional configuration. On most of these tests, data were obtained on dry land, in shallow water, and during submersion in Sealab.

The program also included auditory and visual tests. Predive and postdive hearing tests were administered to each diver. Data were collected in the water on color and form discrimination, and the optical properties of light transmission as well as the observation of underwater lights. Results were also obtained on the ability of the divers to perform mental-arithmetic tests, both before and during the submersion period.

In addition to the specific tests described above, the men were under continual surveillance during submersion by closed-circuit television and open audio channels. The behavior of the men was systematically observed and recorded. These data included eating and sleeping habits, activity levels, variation of mood, morale, motivation, and the general spirit of cooperation. Following the submersion period, each diver completed questionnaires and medical examinations, and was interviewed.

Results showed that in spite of all the obstacles and dangers present during Sealab II, an unprecedented amount of useful work was done. While some of this work possibly could have been performed from the surface, a diver, with his inherent flexibility for on-the-spot decision making and planning, was the essential element in the program. Although some degradation of work performance occurred, the aquanauts' performance of scientific and operational tasks demonstrates clearly that man can live in harmony with the hostile undersea environment.

EXPERIMENTAL WET SUITS

The principal objectives of the experimental wet-suit program, as detailed in Chapter 37, was to evaluate the concept of supplementing body heat with Joule heating to maintain thermal balance during prolonged cold-water exposure. Eight experimental electrically heated pressure-compensated wet suits were provided for Sealab II aquanauts (Fig. 11).

Supplemental heat was generated by resistance wires powered either by a power cable terminating in Sealab II or by silver zinc cells worn around the waist. Pressure compensation was achieved through use of an open-cell natural rubber latex sponge sandwiched between thin layers of solid rubber and injected with gas at depth to maintain normal thickness.

Evaluations indicate conclusively that adequate thermal control can be realized with this approach to protective suits for deep and prolonged cold-water immersion.

HABITAT ENGINEERING EVALUATION

The habitat engineering evaluation program (Chapter 38) presents a brief description of Sealab II and associated systems and facilities, and their evaluation from an engineering standpoint. The evaluation is based on observation, interviews with the aquanauts, and recorded data, and includes hull, umbilical cord, ballast system, electrical system, breathing-gas systems, gas-sampling system, Arawak system, plumbing and sanitary system, communication system, and data-recording system. In general, systems and equipment were satisfactory and in most cases performed their designed functions, with a few notable exceptions. These exceptions include the food freezer, which would not maintain a sufficiently low temperature, the dehumidifiers, which removed water at less than 25 percent of their rated rate, and the CO_2 scrubber, which was only 60 percent efficient.

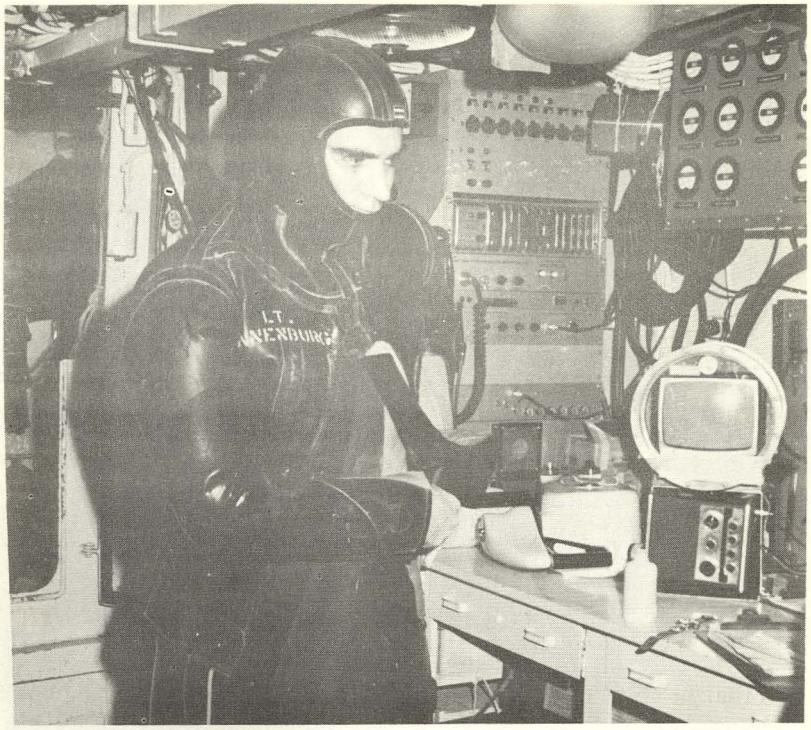


Fig. 11. Aquanaut Sonnenburg in Sealab II wearing an experimental electrically heated pressure-compensated wet suit

OCEANOGRAPHY

Programs in physical oceanography and marine biology were conducted by civilian oceanographer-aquanauts from the U.S. Naval Mine Defense Laboratory and Scripps Institution of Oceanography.

The Mine Defense Laboratory programs (Chapter 39) were slanted toward physical oceanography, with emphasis on those aspects which have potential usefulness for application to naval problems. Major areas covered included a study of general environmental parameters, underwater surveying and mapping, ambient-noise conditions, investigation of the effects of the Sealab II environment on plants, bottom-roughness power spectrum, diffusion studies of bottom boundary layer and near-bottom turbulence, ultraviolet fluorescence, and wave-induced bottom motion (Fig. 12).

The results of these studies indicate that even though Sealab II was not designed primarily as an oceanographic platform, it does provide the capability to attack many significant oceanographic problems, the solution of which would lead to a better understanding of the marine environment and how to exploit it.

The aim of the Scripps Institution of Oceanography biology program (Chapter 40) was to describe the biological activity in, on, and just above the sea floor in the vicinity of the habitat and as far away as divers could operate with safety. The program was designed to describe the normal bottom fauna and to document any qualitative or quantitative changes that took place after Sealab was placed on the bottom. This was done by determining the identities, abundances, and spatial distributions of the organisms attracted to the Sealab site throughout the operation and comparing and contrasting these with the normal sandy-bottom and canyon

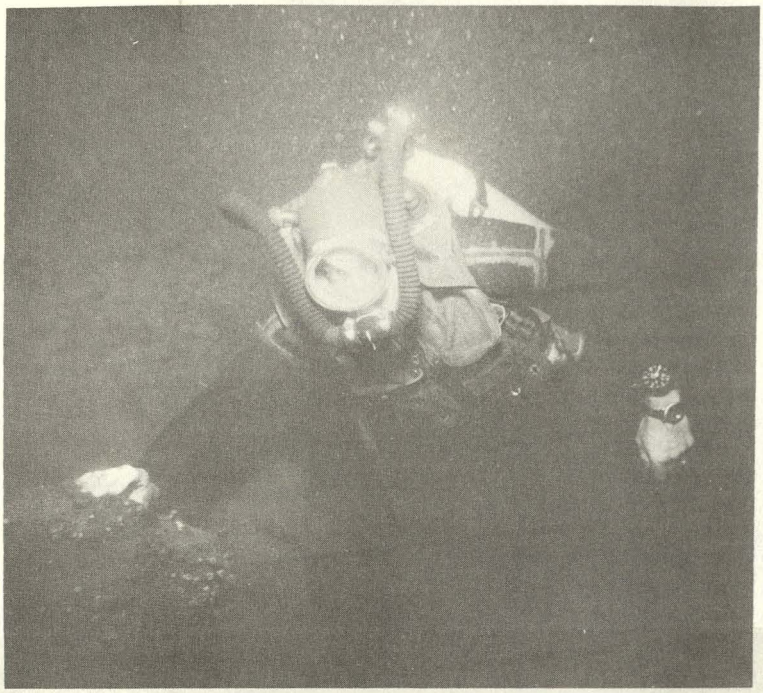


Fig. 12. Aquanaut Meeks holds on to a rock outcropping at the edge of Scripps Canyon, 266 ft below the surface

faunas, and recording the activities of organisms and their relationships with each other and with the physical environment.

It was possible to carry out an extensive survey of the organisms present around Sealab. The data indicate that an object the size of Sealab provided with lights is a very effective fish attractant. Observations of predatory and other behavioral interactions, and of patterns of distribution, have given a preliminary idea of the structure and dynamics of the community of animals, particularly fish, attracted to such artificial substrates.

The oceanographic program conducted by Scripps Institution of Oceanography also included an underwater weather station, which was installed and maintained by the aquanauts (Chapter 41). The weather station provided measurement of current speed and direction, temperature, pressure, and ambient light. The data were recorded in Sealab II for diver use and was transmitted through the benthic laboratory to a shore station where more detailed analysis could be performed.

The data indicate that many phenomena contribute to underwater weather. The identity and relative contributions of the many possible sources of energy will require more extensive measurement and spectral analysis. Weather at this depth could not be predicted by simple manipulation of measured surface parameters, such as waves and tides.

SALVAGE

The Supervisor of Salvage, U.S. Navy, sponsored a number of ship-salvage-oriented projects in Sealab II (Chapter 42). The general objectives of the several tasks were:

1. To demonstrate the feasibility of conducting long-term salvage operations mounted out of a bottom habitat.

2. To determine the capability of divers to accomplish strenuous salvage work during prolonged saturation dives.

3. To perform subjective in situ tests and field evaluation of several new or modified tools, systems, and techniques in 205 ft of water.

4. To determine the feasibility of scuba-equipped divers to use these tools in deep water, as compared with hard-hat divers.

The general objectives were accomplished with considerable success. All assigned tasks were performed during Team 3's tenure on the bottom. Diver tasks in general were performed with dispatch and skill, and consistently in less time than had been programmed (Fig. 13). It was clearly demonstrated that the saturated diver, as a man, could handle the tools employed and accomplish the tasks assigned. This is not, however, to say that the tools in each case were optimum. Nor is it to say that all diver-support systems were satisfactory. On the contrary, the lack of adequate diver-to-diver and diver-to-topside communications, and the inadequate body-heating systems, hampered the divers in the accomplishment of their tasks. That they nonetheless were able to perform satisfactorily further emphasizes the feasibility of scuba-equipped saturated divers, operating from a bottom habitat, performing typical, complicated, strenuous salvage tasks.

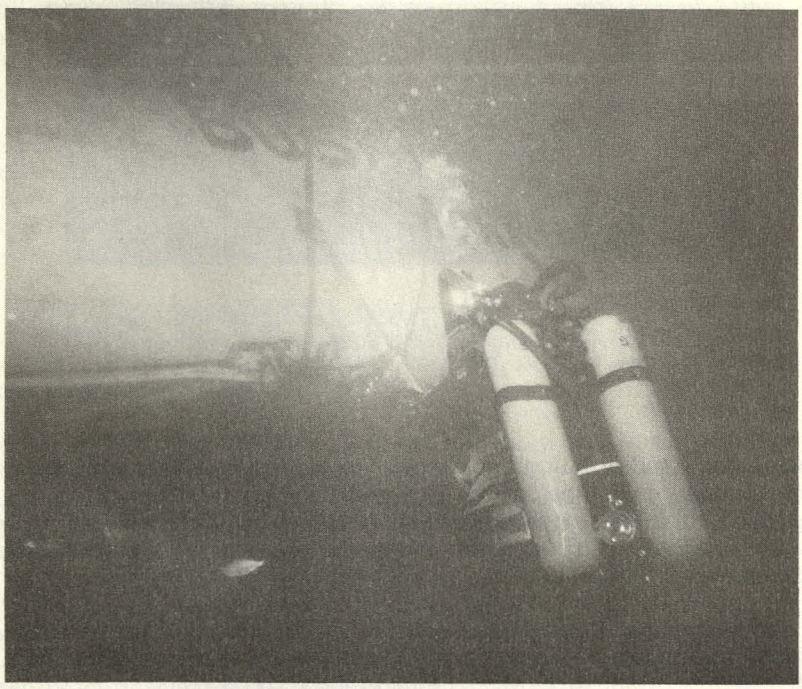


Fig. 13. Aquanaut P. Wells injects buoyancy foam into an aircraft hull during the Sealab II salvage evaluation

BENTHIC LABORATORY

The benthic laboratory (Chapter 43) as used in Sealab II, was an unmanned, remotely operated electronics complex, housed in an oil-filled inverted dome, or "hive," mounted on the sea floor near the Sealab habitat (Fig. 14). This complex was connected through a single coaxial cable to the benthic control console one mile away on shore.

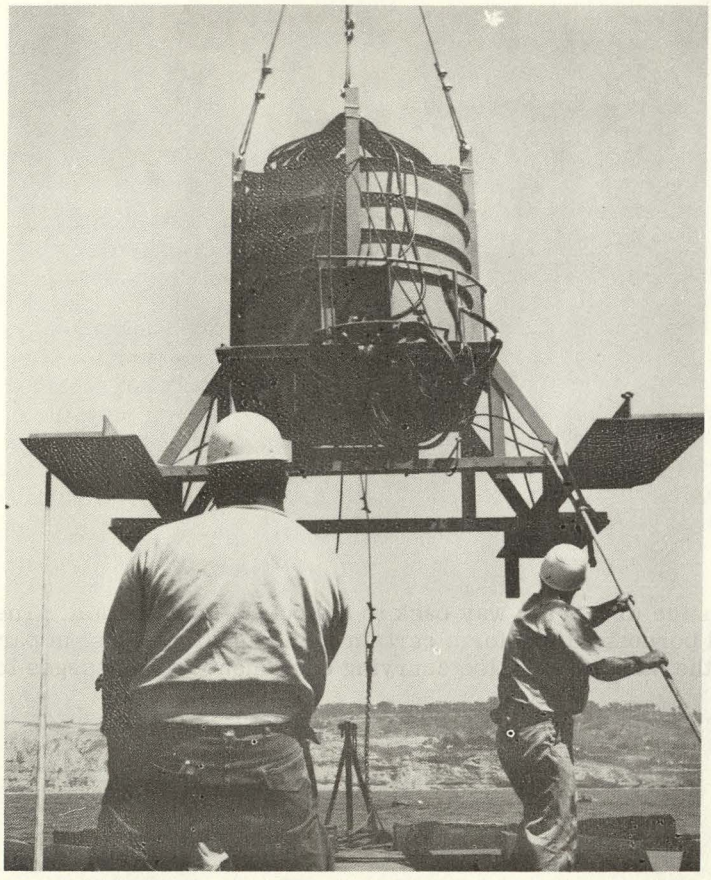


Fig. 14. The benthic laboratory is lowered into the ocean from the Sealab II surface support vessel

In addition to control and monitor functions associated with the operation of the benthic laboratory, the electronics provides for the multiplex and demultiplex of quite a number of television video, audio communication, and digital telemetering channels to and from Sealab over the single coax to shore. The ac power required to operate the benthic laboratory is also transmitted over the same coaxial cable.

The bulk of shore-recorded data from Sealab is of questionable value, because conductors carrying 3 of 18 bits telemetered ashore were intermittent due to connector failure in the Sealab-to-benthic cables. Also, three of the four video coaxial connectors to benthic, along with telemetered signals for focus and sensitivity adjustment, were lost during the initial benthic-to-Sealab hookup as a result of the cable-connector damage.

All audio communication channels performed as expected, and no failures occurred in the 42 days of operation while Sealab was manned.

MINING TECHNOLOGY

Two methods of mining/sample recovery were evaluated during Project Sealab II (Chapter 44). These two methods were airlift and the rotary corer.

In the airlift method, a recovery pipe is suspended from a surface craft to the sea floor. Compressed air is injected into the pipe some distance above the bottom, forming an aerated

froth in the pipe. The reduction in density in the upper portion of the pipe causes water-sediment flow into the bottom. This flow has such velocity that solids are raised to the surface, where they are discharged into recovery barrels.

The rotary coring method involves a coring assembly mounted in a frame with tripod legs. The device sits on the ocean floor and is intended to drill a six-foot-long core of sand, gravel, nodular material, or rock. The unit is lowered and raised from a surface vessel, from which power is supplied to a motor mounted on the device.

Tests of both units indicated promise, but there is still work to do before either become operational. With the airlift method, handling is quite difficult because of the long lengths (over 200 ft) of large-diameter pipe used. The coring-device unit tipped over each time it was placed on the sea floor, indicating a need for adjusting the unit to the topography of the area.

PORPOISE UTILIZATION

Sealab II provided an opportunity to test the feasibility of using porpoises in conjunction with the man-in-the-sea program (Chapter 45). It was planned that Sealab II aquanauts would be tethered at all times while swimming at ranges beyond the visual ranges of the habitat. However, should a failure occur and the diver become disoriented, a strong possibility exists that he would be unable to find his way back to his ocean-floor habitat. Therefore, the availability of a trained porpoise to perform certain vital work functions, in particular guiding a lost diver back to the habitat, and also carrying equipment and messages to divers working some distance from the habitat, would be of great importance.

It was planned that the porpoise would be summoned from the surface by buzzer to an aquanaut at Sealab. That individual would snap a line to one of the rings on the animal's harness, then turn off his buzzer. The "lost" aquanaut would then summon the porpoise by turning on his buzzer. After unsnapping the line that the animal had carried to him, he would have a guide back to Sealab (Figs. 15, 16).

This procedure, using during Sealab, indicated that a porpoise can be trained to perform useful and even vital tasks in programs such as Sealab. It can adapt relatively quickly to a strange and in many ways disturbing environment, and, once trained, will perform with a high degree of precision and reliability.

An unexpected opportunity developed during this study to observe another seagoing mammal, a sea lion that wandered into the Sealab area (Figs. 17, 18). The sea lion was trained to respond to an underwater buzzer and was observed feeding on the fish that gathered around Sealab. On several occasions the sea lion swam into the Sealab entry trunk, breathed the atmosphere, and returned to the surface with no ill effects.

DIETETICS

In the past, too little importance has been placed on food and food preparation as it may affect morale. If man is to be subjected to other than ideal conditions, i.e., living and working on the ocean floor for prolonged periods of time, his motivation must not be stinted by being underfed.

In preparation of the menu (Chapter 46), it was necessary to keep in mind the following considerations:

1. All foods must be easily prepared.

2. Packaging must be compatible with the extreme pressure conditions (at least 110 psia).

3. Most food would be prepared and eaten on an individual basis, rather than as a group of ten men.

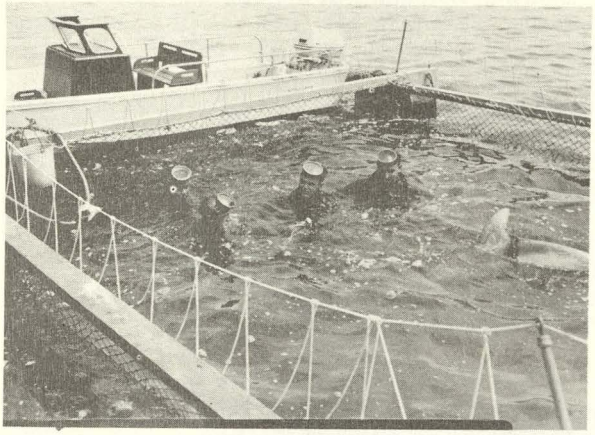


Fig. 15. Sealab II aquanauts work with Tuffy, the trained porpoise, in a floating pen near the Sealab site

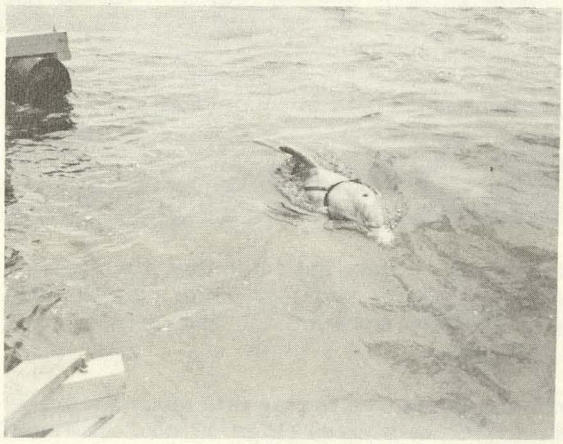


Fig. 16. Tuffy, wearing a harness, swims outside the floating pen

Comments by the aquanauts indicated that meals were considered palatable and generally good, although midway through each of the periods, some of the aquanauts complained about the monotony of the meals.

By general observations via closed-circuit TV, it appeared as though eating became more than just a necessity. On the average, though a specific calorie account was not maintained, the aquanauts were of the opinion that they had consumed at least one-fourth again as much food each day as normal. These opinions were confirmed by observation.

MK-VI SEMI-CLOSED-CIRCUIT SCUBA EVALUATION

The initial preparation of gear and the training of Sealab personnel in the use of the Mk-VI scuba was accomplished under the supervision of the U.S. Naval Mine Defense Laboratory Diving Officer. Training encompassed four weeks and included three weeks of diving in the open sea at depths ranging from 30 to 180 ft.

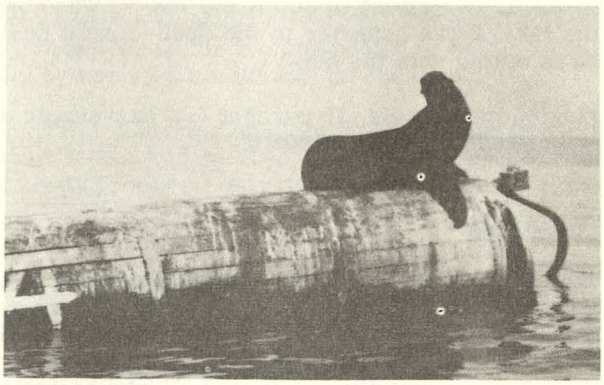


Fig. 17. A wild sea lion rests on a buoy near the Sealab II surface support vessel

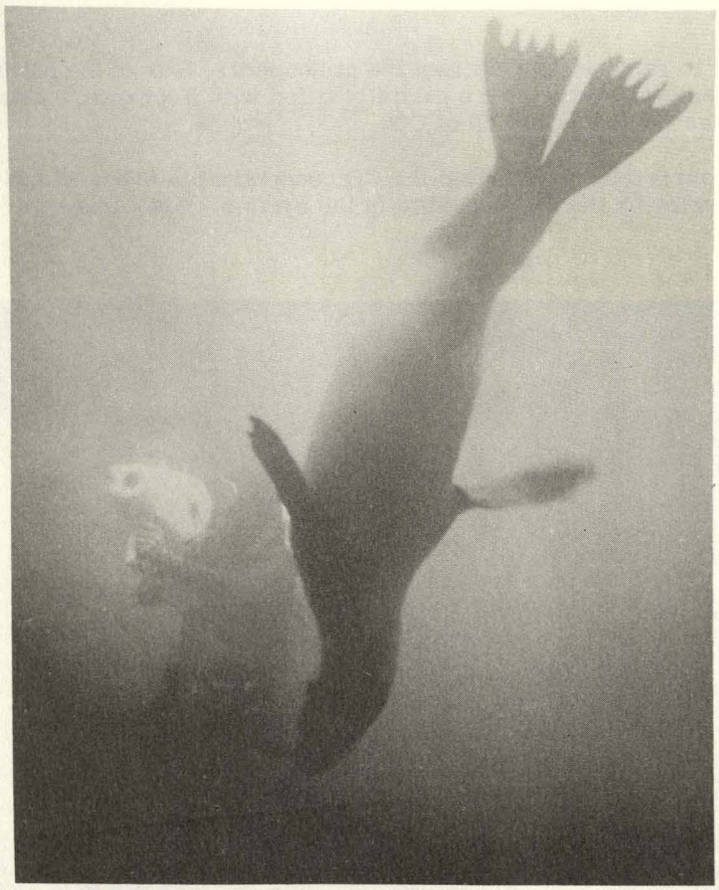


Fig. 18. A wild sea lion dives near the Sealab II site

At the Sealab site, repair and routing maintenance of all diving gear was accomplished in the diving locker on the surface-support vessel. Cylinder charging for Teams 1 and 2 was accomplished in the diving locker, but Team 3 employed a charging line from topside to the inside of the habitat, allowing the empty cylinders to be charged on the bottom.

In general, for deep-excursion diving to 300 ft the Mk-VI was considered outstanding. All aquanauts agreed that the Mk-VI was superior to the open-circuit scuba. The men liked the Arawak, but preferred free diving with the Mk-VI.

With the Mk-VI, using 85 percent He, 15 percent O_2, gas-supply duration was, in many cases, lower than the expected 70 minutes at 205 ft.

ATMOSPHERE CONTAMINANTS

Prior to Sealab II it was expected that some contaminants would be present in the atmosphere. It was thought that the major problems would be presented by hydrocarbons, the majority of which would be produced by cooking. To combat this possibility, any type of frying was prohibited, and a 50-pound charcoal filter was installed in the Sealab air-conditioning system to remove hydrocarbons. Although there was some hydrocarbon buildup, the charcoal proved to be effective and hydrocarbons were no problem.

During the latter part of the operation, however, the aquanauts frequently complained of headaches (Chapter 48). The presence of carbon monoxide in the atmosphere was suspected as the possible cause, and tests were carried out for its detection. Values of approximately 20 ppm CO were reported.

In an attempt to remove the CO from the atmosphere, four of the lithium hydroxide canisters in the CO_2 removal system were partially filled with Hopcalite, a catalyst used aboard nuclear submarines for the oxidation of CO.

Later it was surprising to find that the CO concentration in Sealab had been decreasing for several days prior to placing Hopcalite in the system. Also, there was no noticeable

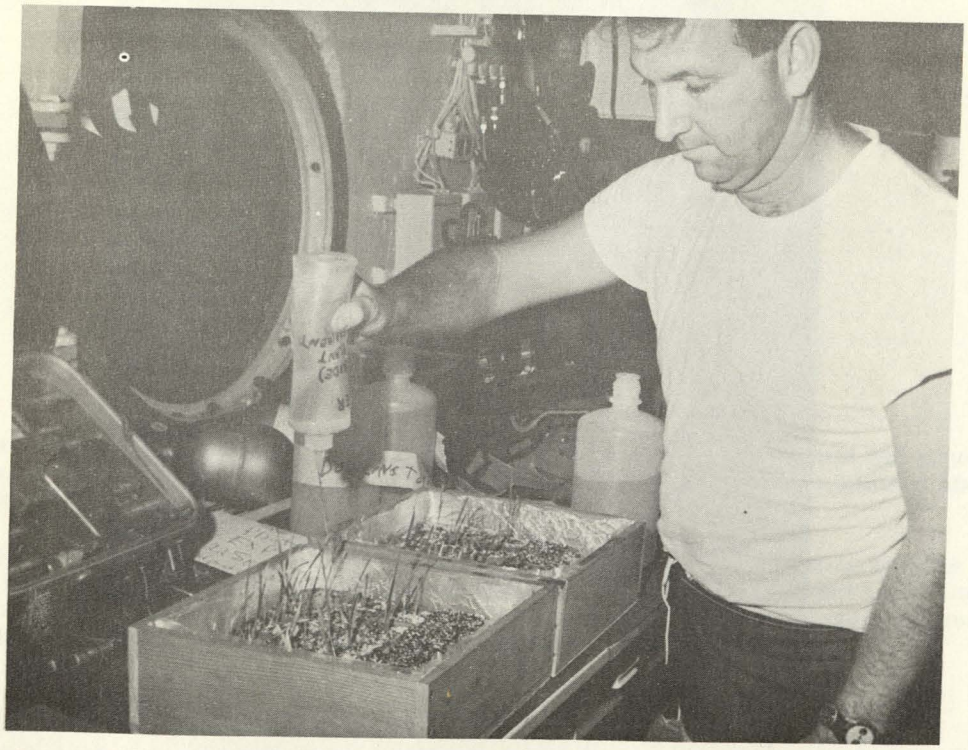


Fig. 19. Aquanaut Tolbert uses a special plant nutrient for plants grown in Sealab II

change in the slope of the curve after the Hopcalite was in place. This observation raises doubts as to whether the Hopcalite was at all effective. Possibly, CO was generated through some process which was stopped when CO was suspected of being a problem. After this, the CO was removed gradually by some still unknown mechanism.

The Sealab II environmental study included an attempt to grow barley and marigold plants from seeds in the Sealab atmosphere (Fig. 19). The barley seedlings did well, and were healthy, but the marigold seeds produced only one sprout. Control plants were grown at Texas A & M College.

Chapter 5

THE SEALAB II SURFACE-SUBSURFACE COMPLEX

INTRODUCTION

While most of the machinery and equipment used in Sealab II were off-the-shelf items, there were four major pieces of equipage which were unique to the project and were not directly associated with the programs of the preceding section. These four were:

1. Sealab II habitat
2. Personnel Transfer Capsule (PTC)
3. Deck Decompression Chamber (DDC)
4. Surface support vessel

These four, with their installed machinery as discussed below, comprised the Sealab II complex.

SEALAB II HABITAT

The Sealab II habitat (Chapters 8, 11, and 12) is a nonpropelled, seagoing craft which can be lowered into the ocean and emplaced on the ocean floor. It served as an underwater habitat wherein ten aquanauts lived for periods of 15 to 30 days in an artificial atmosphere.

When on the ocean bottom, Sealab II's living compartment was at a pressure equal to ambient pressure. In effect, the aquanauts lived in an "air" bubble contained beneath a dome. The boundaries of the compartment were subjected only to the differential pressure between the "air" and the water outside. Therefore, although the habitat was designed as a pressure vessel so that it could be pressurized on the surface, the living compartment was not subjected to total bottom pressure when it was emplaced.

The living compartment is a cylinder 12 ft in diameter and 57 ft long, designed for an internal working pressure of 125 psi, in accordance with the ASME Unfired Pressure Vessel Code. When the habitat was submerged, access was gained through an antishark cage suspended below a four-foot-diameter hatch in the bottom of the hull.

The living compartment was divided into four areas, the aftermost of which was the entry way, into which the access hatch opened. This entry way contained showers and stowage space for diving gear.

Just forward of and separated from the entry way by a waterproof dutch door was the laboratory area. The laboratory area contained a built-in sink and cabinets, a 50-gallon water heater, a 150-gallon emergency fresh-water tank, the breathing-gas control panel (Fig. 20), and the communication station with its associated equipment.

Forward of the laboratory area was the galley area, which contained a built-in sink and cabinets, electric cook top, chill box, freezer, electrical power transformers, and the major components of the habitat air-conditioning system (Fig. 21).

The forwardmost space was the berthing area. It contained bunks for the ten aquanauts, storage lockers, a large drop-leaf table, and at the forward end, a 30-in. emergency escape hatch. A total of eleven 24-in. viewing ports were provided throughout the four spaces.

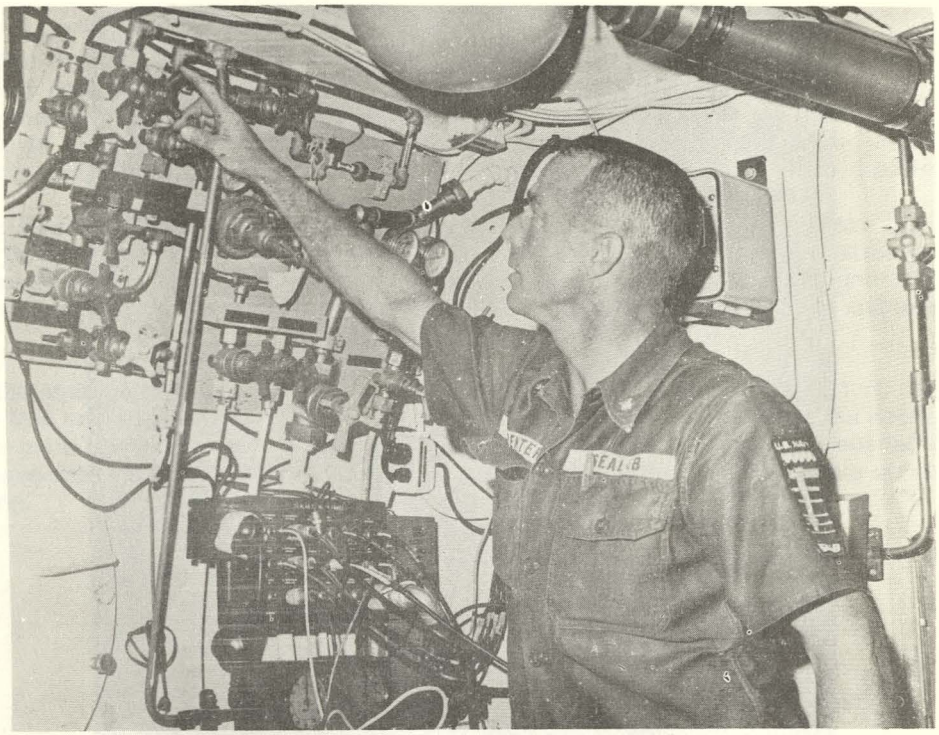


Fig. 20. Aquanaut Carpenter checks the breathing-gas control panel

In the three forward spaces, the overhead was insulated with one-inch cork, the sidewalls with two-inch cork, and the deck was made of solid concrete, which was part of the fixed ballast. The overhead of the living spaces was fitted with three ballast tanks, which were used as variable ballast during raising and lowering operations.

The atmosphere in the living compartment contained approximately 85 percent helium, 11 percent nitrogen and 4 percent oxygen, at approximately 103 psia. The gas in the atmosphere was replinshed from spare bottles of helium and oxygen outside the hull. Also, replenishment gas was available via the umbilical from the surface-support vessel. The umbilical also contained a communication cable, a gas-sampling hose, a compressed-air hose, and an alternate electrical power cable, while primary electrical power and fresh water were supplied via power cable and vinyl pipe from shore.

THE DECOMPRESSION COMPLEX

The at-sea decompression of ten divers saturated at a depth of approximately 200 ft presented a new problem for the U.S. Navy (Chapter 17). First, the men would have to be lifted from the ocean floor in a personnel transfer capsule (PTC), maintaining the ocean-floor pressure, to the surface-support vessel; second, they must be transferred to a larger, more comfortable deck decompression chamber (DDC), where they undergo a lengthy decompression.

The PTC is basically a cylinder 10 ft long and 6 ft in diameter, with a 27-in. entrance hatch on one end. The cylindrical portion sits on a removable stand which provides five feet of clearance for gaining entrance through the hatch. Ballast to provide negative buoyancy is incorporated into the base of the stand and in a lower ballast tray clamped to the stand base. The lower tray can be released from the stand to serve as an anchor in the event that aquanauts in the PTC must make a controlled ascent to the surface, using an escapement mechanism in the stand, rather than being lifted aboard the surface-support vessel by crane.

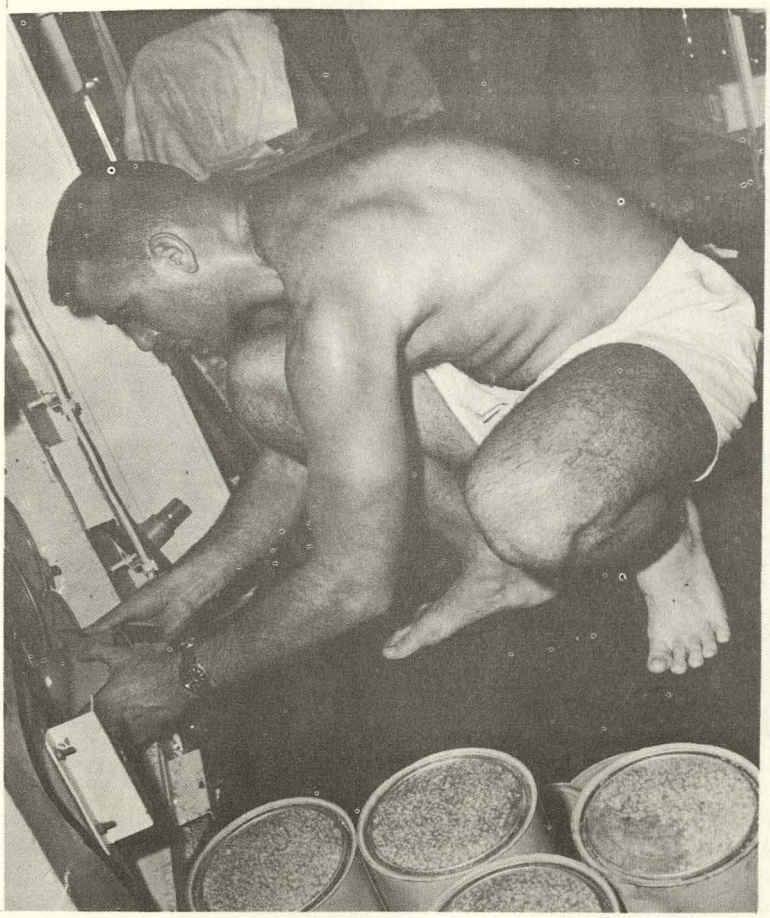


Fig. 21. Aquanaut Sonnenburg replaces lithium hydroxide canisters in the Sealab II air conditioning system. The canisters remove carbon dioxide from the atmosphere.

An emergency, 24-hour life-support system, providing breathing gas and CO_2 removal was self-contained. However, normal operation included an umbilical from the surface-support vessel which provided breathing gas, a communication link, and power for CO_2 removal.

The DDC is another cylindrical structure 23 ft long and 10 ft in diameter. It contains berthing for ten men, an entrance lock, a medical lock, a CO_2 scrubber, a mating hatch for the PTC, and an exhaust manifold with constant-flow regulators.

In normal operations, with the PTC on the ocean floor, the saturated divers enter and close the hatch, sealing themselves at bottom pressure. The PTC is then hoisted aboard the support vessel, where the capsule is removed from the stand and base and placed on the mating hatch of the DDC. After the mated hatches are sealed, the pressures in the PTC and DDC are equalized and the divers enter the DDC from the PTC. The DDC and PTC hatches are then closed and the divers start decompression as the PTC is returned to the ocean floor to serve as the emergency capsule for the next team.

SURFACE-SUPPORT VESSEL

The support vessel (Chapter 18) as configured for the project is made from two 110 x 34 ft YC barges spaced 22 ft apart and connected at one end by a covered structure. This structure

provides a rigid platform with overall dimensions of 110 x 90 ft with a 65 x 22 ft open well at one end. The port barge contains an open bay, a portion of which is roofed over and used as a divers' ready room. The DDC was installed in the remainder of the bay. Principal items of machinery included on the support vessel were three ac generators with a total capacity of 460 kw, two 15,000-pound-pull winches, a high-pressure air compressor, a low pressure air compressor, and a 100-ton lima crane, restricted to a 50-ton working load as mounted.

On the starboard barge, 01 level, two vans with a connecting enclosure were installed for use as the Sealab control center. Included in the vans were communications, atmosphere control, and medical monitoring equipment. Other installations included a counterweighted system for lowering and raising the PTC and Sealab and a breathing-gas storage and distribution system.

With the aquanauts in the habitat, it was necessary that motion of the support vessel be limited so that any given point would remain within a ten-foot circle. This was accomplished with a five-point moor. Tension in four of the five legs was measured and recorded continuously. These data proved to be invaluable in maintaining position without undue strain in any mooring leg.

Chapter 6

PROJECT CHRONOLOGY

The first official Sealab II planning meeting was held on Jan. 21 and 22, 1965. At this meeting, for planning purposes, it was decided that a schedule would be adopted which would result in Sealab II being placed on the bottom at La Jolla on August 15, 1965. Although numerous problems plagued scheduling, the following chronology shows that the original schedule slipped only eleven days throughout the seven months of preparation for the project.

Jan. 13, 1965 - Scripps Canyon selected as the general site for Sealab II.

Jan. 21-22 - First Sealab II planning meeting held at the U.S. Naval Mine Defense Laboratory

Feb. 3 - Sealab II Steering Committee established:

Mr. H. A. O'Neal, Chairman	ONR
CAPT L. B. Melson	ONR
CAPT G. F. Bond	SPO
Mr. S. Hersh	SPO
Mr. T. Odum	MDL
Mr. H. Talkington	NOTS
LCDR M. MacKinnon	SFBNSY(HP)
Dr. V. Anderson	MPL
Dr. E. W. Fager	SCIO

Feb. 10 - Specifications for decompression complex given to bidders.

Feb. 26 - Anchor pull tests conducted at site.

Mar. 1 - TV site survey made with YFU-53
- Dixie Manufacturing Company of Baltimore selected to fabricate the decompression complex.
- Fabrication of Sealab habitat underway at SFBNSY(HP).

Apr. 1 - First twelve-foot-diameter dished head for Sealab habitat formed by explosive methods at SFBNSY(HP).

Apr. 27-28 - Sealab II Steering Committee meeting at SCIO.

May 4-5 - Additional TV site surveys made.

July 1 - Fabrication of Sealab habitat completed at SFBNSY(HP).

July 5 - Sealab II habitat arrives at LBNSY by barge.
- Aquanauts arrive at LBNSY.

July 7 - Structural Certification Board is briefed on Sealab II construction at SFBNSY(HP).

July 8 - Structural Certification Board inspects Sealab II habitat at LBNSY.

July 13-16 - Five-point support vessel moor laid by USNS GEAR at site.

July 15 - Structural Certification Board inspects decompression complex at Dixie Manufacturing Co.

July 23 - Sealab II christened at LBNSY
- PTC completed at Dixie and shipped via truck to LBNSY.

July 29 - DDC completed at Dixie and shipped via rail to LBNSY.

Aug. 4 - PTC arrives at LBNSY.

Aug. 8 - DDC arrives at LBNSY.

Aug. 17 - Completed Sealab II trim tests at LBNSY.

Aug. 21 - Sealab II arrives at La Jolla site.

Aug. 23 - Sealab II and decompression complex certified for use.

Aug. 26 - Sealab II placed on bottom at 205 ft.

Aug. 28 - Team 1 enters Sealab.
CDR M. Scott Carpenter in Sealab II speaks with astronaut Gordon Cooper in GT-5.

Aug. 31 - Benthic laboratory placed on bottom near Sealab.

Sept. 12 - Team 1 comes to surface for decompression in DDC.
Team 2 enters Sealab II.

Sept. 14 - Team 1 completes decompression.

Sept. 26 - Team 2 comes to surface for decompression in DDC.
- Team 3 enters Sealab II.
President L. B. Johnson talks by phone with CDR M. Scott Carpenter who is in the DDC undergoing decompression.

Sept. 28 - Team 2 completes decompression.

Oct. 1 - Aquanauts Sheats and Grigg in Sealab II talk by phone to Oceanauts Lebon and Cousteau in Conshelf III in Mediterranean Sea.

Oct. 5 - First excursion dives made from Sealab II to 300 ft.

Oct. 10 - Team 3 brought to surface to end operations.

Oct. 11 - Sealab II raised to the surface.

Oct. 12 - Team 3 completes decompression.

Oct. 13 - Sealab II towed back to LBNSY and lifted out of water.

Chapter 7

CONCLUSIONS AND RECOMMENDATIONS

Sealab II Steering Committee

INTRODUCTION

On December 9, 1965, the Sealab II Steering Committee met as a group for the last time to formulate conclusions and recommendations for Project Sealab II. The results of this meeting follow.

MAJOR MAN-IN-THE-SEA CONCLUSIONS

1. Reasonably large groups of men can live for protracted periods (15 to 30 days) at 205 ft, have a large degree of autonomy, accomplish useful work, be safely decompressed, and show no apparent serious adverse physiological or psychological effects.

2. The U.S. Navy's first experience with no-decompression excursion dives from a starting depth of 205 ft in a saturated state to a depth of 266 and 300 ft was successful. This experiment represents an important addition to undersea diving technology.

3. There is a clear degree of diver adaptation to cold water, as shown both by interviews with the aquanauts and by predive and postdive cold-water-immersion physiological measurements.

4. Adequate protection against cold water can be obtained for extended periods by the use of heated suits. Swimmers without supplementally heated suits are limited to less than one hour of useful work in 47° to 54° F waters.

5. A degradation of work capability varying between 17 and 37 percent, as compared to the warm, shallow-water capability, occurs as a result of the many adverse factors encountered in the Sealab environment.

6. Improved tools and techniques for the ocean environment show promise for the accomplishment of salvage tasks and other undersea work functions.

7. Based on the analysis of the overall performance of the aquanauts, criteria can be developed to assist in the selection of future aquanauts.

8. The interaction between man and porpoise has shown that to depths of 200 ft, the porpoise can be extremely useful to man-in-the-sea operations.

9. In situ living offers a new and important methodology to scientific, biological, geological, ocean-floor investigations.

10. Although vastly improved over Sealab I, the habitat and much of the diving equipments are still rudimentary and not yet suited for routine operations.

11. Present state-of-the-art deep-water swimmer communications and ocean-floor navigation systems are unacceptable for future man-in-the-sea operations.

12. A completely autonomous habitat is not possible without a reliable underwater power package and complete, integrated life-support system.

13. Explosive forming of 12-ft-diameter dished heads from one-inch mild steel is feasible.

14. Counterweight lowering systems provide a greatly improved technique for lowering large objects where inertial and lowering-vessel motions are critical.

15. Offshore telemetry stations using remote manipulators for accomplishing component replacement are practical and have considerable merit.

COMMENTS AND RECOMMENDATIONS

In general, the Sealab II complex and operations were highly satisfactory. Fast response obtained from the entire U.S. Navy diving community, a number of Navy laboratories and Shipyards, and several selected contractors made possible the project initiation and preparation for field operations within the short, available time span of seven months. A critique of deficiencies of the Sealab II complex yields the following recommendations. These recommendations should be considered in modifying the complex for future undersea experiments. However, they should not be considered as all-encompassing for enabling deeper operations or operations in unprotected areas.

HABITAT

1. A leveling technique and reliable local and remote level-measuring equipment must be provided in future sea habitats.

2. Noise generation should be reduced to a minimum for both comfort and increased communications intelligibility. Both sound and light surveys are recommended.

3. A special oceanograph viewing port should be provided giving an increased angle of observation. The feasibility of bubble-type observation ports should be investigated.

4. More space should be allowed for storage, maintenance, and setup of diving gear. Maximum use of space should be made for storage cabinets for general storage and for scientific sample storage.

5. Improved environmental control is needed. Research should be undertaken to determine the comfort zone for humans in Sealab-type atmospheres.

6. The ballast, flood, and blow system should be re-evaluated. At deeper depths, remote control of valving is a necessity.

7. A re-evaluation of the entire habitat inside arrangement from the human-engineering aspect is desirable.

8. The arrangement of the habitat communications center should be improved.

9. Photographic conditions should be improved by installing special photographic lights.

10. The method of sealing internal port covers should be modified.

11. Outer port covers should be hinged.

12. All inside surfaces should be insulated to prevent condensate drippage.

13. The exit area must be rearranged to provide more space for dressing, etc.

14. Because of the difficulty of entry while wearing flippers, other entry techniques need investigations, i.e., an elevator.

15. The bathtubs in the entry should be either improved (insulated) or removed, as they were not used as presently configured.

16. Investigate the possibility of providing a dry room under the entry trunk to alleviate space problems.

17. A large port is needed so that swimmers can be observed outside near the critical entrance area.

18. Particularly near the entrance area, eliminate as many cables as possible that may cause diver entanglement.

19. If necessary, bottom stabilization should be achieved in the area adjacent to the entrance.

20. Storage racks, hooks, etc. should be provided in the shark cage area for external wet-storage.

21. The lighting in and around the shark cage should be improved.

22. Rearrangement and auxiliary handling gear must be provided so that men do not have to don diving gear to place supplies in or remove supplies from the dumbwaiter.

23. A method of supply that does not block the entry way should be devised.

HANDLING PROCEDURES

1. Facilities must be available for a gas-fill capability and pressure test to lowering pressure on site.

2. Sufficient flexibility in ballasting should be provided to permit changes in raising and lowering procedures and to control trim and level without subjecting the habitat to unstable conditions.

3. The ballasting system should provide the capability of overpressurizing the habitat on the bottom to insure adequate port and hatch seals prior to raising.

4. Flexibility and reliability during handling operations could be improved by obtaining

   a. A cable footage counter
   b. The weights, in air and water, of all equipment to be handled
   c. A dynamometer capable of weighing loads up to 20 tons.

DECOMPRESSION COMPLEX

1. To provide the capability of handling and mating in higher sea states, different handling and mating appurtenances must be provided.

2. The following improvements to the DDC are recommended:

   a. Bunks (at least seating) in the outer lock
   b. Improvement of temperature and humidity control
   c. Provision of charcoal scrubber
   d. Automatic decompression gas controls
   e. Better matching counterbalance spring on top hatch
   f. Future chambers for this purpose should have at least three locks to provide for emergency medical purposes. Gas control of each lock should be independent.

3. Internal gas controls on the PTC, not used extensively during the operation, need redesign and a better gas-analysis system provided.

4. A method should be found to keep fish, attracted by the lighting, from collecting in the PTC. The light is necessary for swimmer guidance.

5. An emergency CO_2 scrubbing technique should be provided for the PTC. The hand-operated scrubber has not been fully evaluated.

TRAINING

1. A continuous aquanaut training program should be established to maintain the excellent level of training attained for Sealab II. The program should include a minimum number of He/O_2 dives on a monthly basis.

2. Mk-VI training classes should be limited to a maximum of 14 people. A four-week course should be adequate for an experienced diver.

3. Aquanauts should be trained in the same groups that will be living together on the bottom.

DIVING PROCEDURES AND EQUIPMENT

1. Safety precautions as outlined in the Diving Manual must be strictly adhered to.

2. The adaptation of the Mk-VI for Sealab-type operations is a necessity. Areas of study should include:

   a. Elimination of nonmagnetic requirements. However, substituted parts should be designed so as to be noninterchangeable with nonmagnetic gear parts.
   b. Revision of the Mk-VI manual.
   c. Quality control to obtain proper part interchangeability.
   d. Relocation and modification of critical control components to prevent snagging.
   e. Compatibility for SPU operations.
   f. Buddy breathing capability.

3. Insure that all necessary diving equipment spare parts are in hand several months before the scheduled start of training and operations.

4. The noise of the Arawak compressors needs suppression.

5. Investigate the incorporation of a self-tending reel, quick-release capability, and "come home" bottles in future Arawak-system design.

6. Arawak hoses should be slightly negatively buoyant.

7. Investigate improvements in the heated suit design to provide greater reliability and improved battery configuration.

8. Positive steps must be taken to prevent pressure-compensated suit buoyancy problems from occurring which result in threat to life.

9. The PPI Pump Manual needs revision.

10. Vehicles for saturated swimmers must be investigated.

11. Diver lights need re-evaluation in terms of available light sources.

12. Investigate the development of new diver pressure gages for the deeper depths expected in the future. Keep in mind the necessity for fail-safe operation when divers are working above their saturation depth.

13. Provide snap hooks for carrying tools and other gear on the diver's belt.

14. Improve the method of coding bottom boundary and tether lines.

COMMUNICATIONS AND INSTRUMENTATION

1. Reliable communications must be developed for swimmer to swimmer, swimmer to habitat, and swimmer to staging vessel.

2. Reduction of ambient background noise will improve communications using existing communications equipment.

3. Direct communications should be available between the Sealab diving station and the staging-vessel diving platform.

4. Provide high-resolution vidicon tubes for accurate TV monitoring of aquanaut activity.

5. Investigate improved methods of sealing habitat TV cameras against penetration by the helium atmosphere.

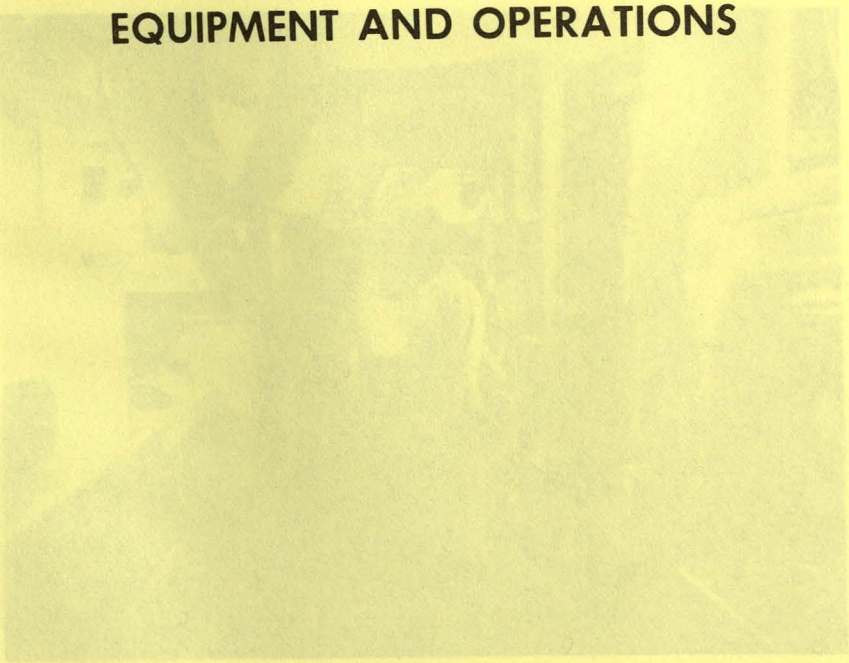
6. At least three stations in the habitat should be monitored by TV continuously. These are the gas station, watch station, and entrance area.

7. Investigate methods of protecting TV tubes against damage by direct light flashes, i.e., photographic flash bulbs. Heat-absorbent glass with absorption characteristics matched to the flash-bulb intensity characteristics should solve this problem.

8. An integrated oceanographic suit of instrumentation should be incorporated in future Sealabs employed for oceanographic purposes.

9. Oceanographic instrumentation read-out should be internal, with external data storage.

Section I
EQUIPMENT AND OPERATIONS



Chapter 8

DESIGN OF THE SEALAB II HABITAT

W. B. Culpepper
U. S. Navy Mine Defense Laboratory
Panama City, Florida

INTRODUCTION

The Sealab II habitat served as an undersea habitat (250 ft maximum depth) for 28 aquanauts for a period of 45 days (Fig. 22, 23). As such, it was equipped with the necessary life-support equipment such as breathing-gas systems, air-conditioning systems, berthing, food-stowage and preparation facilities, sanitary facilities, work space, and communication, and electrical power, and lighting systems. It is capable of maintaining a positive buoyancy adequate for surface tow. Water ballast is used to provide necessary negative buoyancy for lowering and to increase negative buoyancy for stability once it is placed on the sea bottom.



Fig. 22. The kitchen and laboratory areas in the Sealab II habitat

HULL

General

The hull for the Sealab II habitat was designed and fabricated in general accordance with Fig. 24. It is 12 ft O.D., and 57 ft long with a semi-elliptic head at either end. The hull was designed and fabricated in accordance with the ASME boiler code for unfired pressure vessels and is capable of withstanding an internal working pressure of 125 psig.

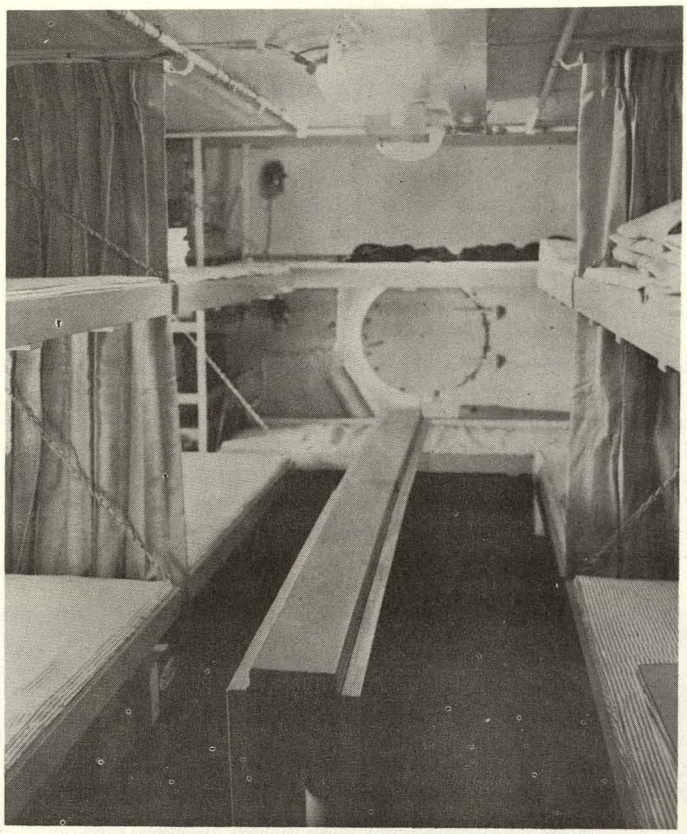


Fig. 23. The berthing area of the Sealab II habitat

Viewing Ports

The hull is provided with eleven viewing ports. These ports are approximately two feet in diameter and capable of withstanding the internal design pressure of 125 psig.

Access Openings

The hull is provided with three access openings. The bottom entry hatch is approximately four feet in diameter and located in the hull bottom in the entryway. The emergency escape hatch is approximately 27 in. in diameter and located in the hull bottom near the bow. The surface access hatch is approximately 27 in. in diameter and located in the top of the hull amidship.

Entry Trunk

The entry trunk is eight feet by eight feet and extends two and one-half feet below the hull bottom. This trunk provides a displacement volume to compensate for the expected bottom-pressure variations due to tidal action in addition to normal internal pressure changes.

Shark Cage

The shark cage is eight feet wide by 12 ft long, and extends from the entry trunk down to a point one foot above the Sealab II support base. A one-foot-high flexible extension is attached around the bottom of the shark cage. This allows conformity with an uneven sea bottom.

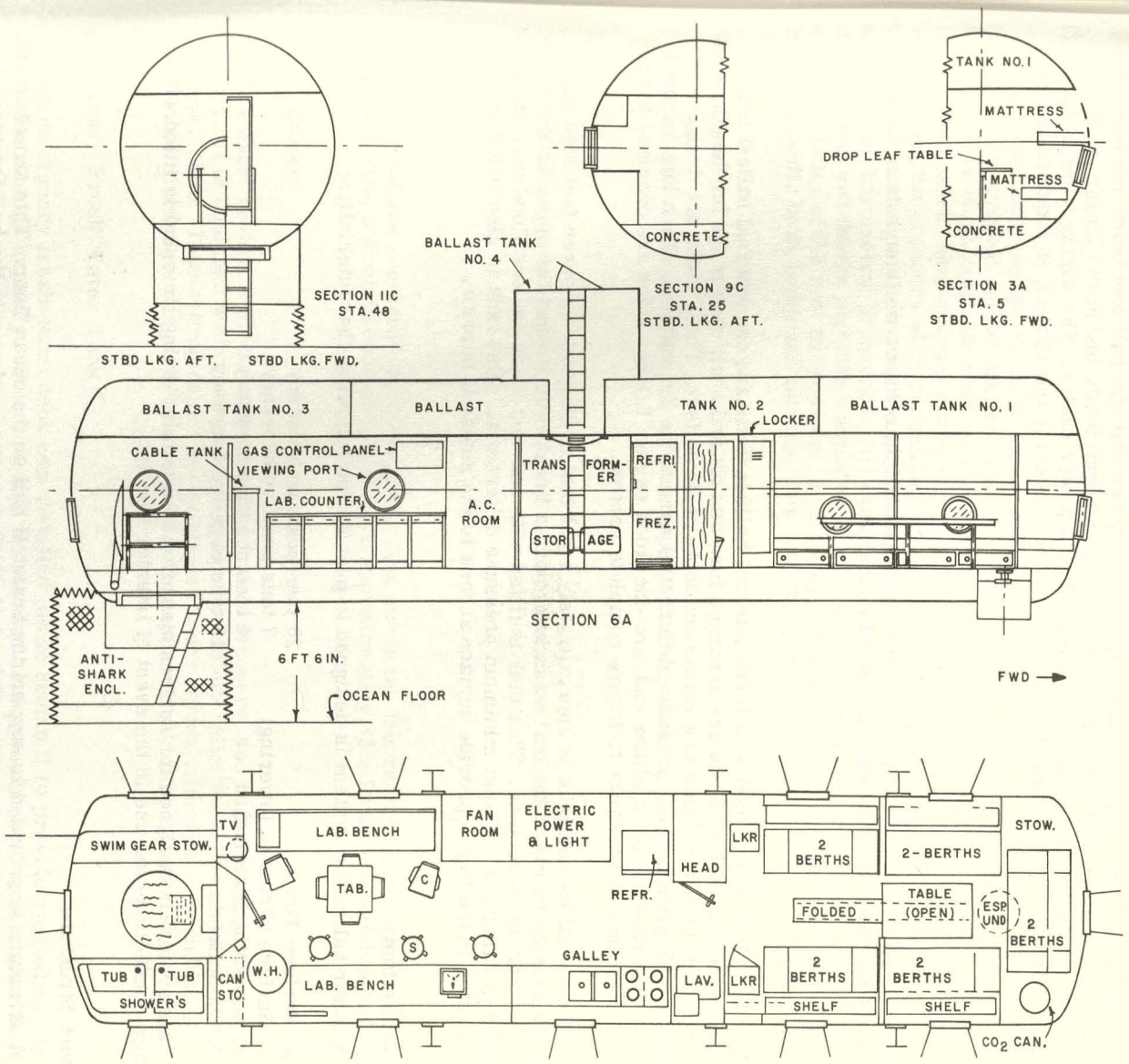


Fig. 24. Sealab II interior arrangement

Hull Penetrations

Hull penetrations for all gas lines, water lines, and sanitary drains are located as low on the hull as possible to minimize flooding or atmosphere loss in the event a line may carry away. All penetrations are optimally located so as to minimize length of pipe runs in Sealab II, in particular, high-pressure gas lines. All penetrations are either double-stuffing tube type or piping direct welded to the hull. A wiring trunk is provided for the benthic lab equipment and outside divers' lights. This trunk is approximately 10 in. I. D. and extends from the horizontal centerline of the hull to a point approximately two and one-half feet below the hull bottom. A smaller three-inch IPS* trunk is installed concentrically inside the larger trunk to provide for electrical shielding of the divers' lights power cables. The wiring trunk is fitted with a pressure-tight cover which may be easily removed for installation of required cables (see Chapter 9).

Bilge Drains

Bilge drains fore and aft are provided for draining bilges to sea while on bottom. These drains are provided with valves for manual operation.

Ballast Tanks

The Sealab II is provided with three internal ballast tanks and one external ballast tank. The three internal ballast tanks are arranged fore and aft and shall contain the full length, upper portion of the hull volume to a maximum depth of three feet. These tanks are designed to withstand a 15-psi minimum pressure differential across the flat bottoms. Each tank is fitted with two vent valves, one at either end, and one flood valve. Limber holes are provided in the internal structure of the tanks to insure complete venting.

The external ballast tank is approximately eight feet in diameter by seven feet high and located amidship on top of the hull so as to provide a breakwater around the upper access hatch while the craft is on surface. This tank is fitted with one vent valve and one flood valve and is designed to withstand a 15-psi minimum pressure differential. This tank is also fitted with an access hatch in the top to provide surface access to the Sealab II interior.

Ballast System

A water ballasting system is designed to provide the following characteristics:

a. Surface Tow	26 tons positive buoyancy
b. Surface (Prior to lowering)	7 tons positive buoyancy
c. Lowering (Raising)	4 tons negative buoyancy
d. On bottom	12 tons negative buoyancy

This system is designed for surface operation to minimize diving time and is fitted with salvage connections for use in the event of interior flooding.

Support Structure

A structure is provided to support the Sealab II hull on the ocean floor. This structure is designed so as to provide approximately six feet of clearance underneath the hull for ease of entry. The base of this structure is designed to provide a maximum bottom bearing stress of 300 lb/ft at maximum negative buoyancy.

*Internal Pipe Size

Fixed Ballast

A concrete deck is installed inside Sealab II from the entryway forward to provide a portion of the fixed ballast. The remainder of the fixed ballast is placed in trays underneath the hull.

EQUIPMENT

General

All mechanical equipment to be installed in Sealab II (Fig. 24) was checked and certified for use in the ambient operational environment. Particular emphasis was placed on eliminating any materials which may introduce toxic fumes into the closed atmosphere. All equipment cavities or enclosures are vented for pressure equalization or are tested to prove a capability of withstanding the pressure of or permeation by the Sealab II atmosphere. Particularly all "aneroid type" sensing elements were eliminated, since they are designed to operate only in standard (air) at barometric pressures. All equipment was performance tested in the Sealab II environment and design capacities adjusted where necessary to compensate for the peculiar characteristics of the new environment, such as hyperbaric pressures, increased density, higher specific heat, increased thermal conductivity, etc.

Water Closet

The water closet is a standard marine type, Wilcox-Crittendon "Senior" model.

Lavatory

The lavatory is vitreous china, 17 $\times$ 20 in. minimum size, and may be wall or cabinet mounted.

Sinks

Two sinks are required, one in the galley and one in the laboratory. The sinks are double basin, self-rim, porcelain enamelled steel and approximately 33 $\times$ 22 in. overall dimensions.

Water Heater

The water heater is electrically powered, quick recovery, and has a 50-gallon storage capacity. It is equipped with a pressure-temperature safety relief valve set at 100 psig relief pressure. Note: This setting can be accomplished under normal atmospheric conditions. The relief valve discharge was piped to a convenient overboard drain (see Chapter 9).

Emergency Fresh Water Tank

An emergency fresh-water tank was installed inside Sealab II to provide approximately 150-gallon storage capacity. This tank will not be used as a pressure tank and is provided with an adequate vent to prevent pressure buildup while filling. It was constructed of CRES and properly sterilized for storage of potable water (see section titled "Plumbing and Sanitary Facilities").

Showers

Two showers are provided in the entryway, starboard side. The showers are drained directly overboard through the main entry hatch.

Hookah Pumps

Two hookah pumping units are suspended from the overhead, aft of the hatch in the entryway. Due to late delivery of these equipments, they were mounted at Long Beach Naval Shipyard. Four hull penetrations, one inch IPS by six inches long, threaded nipples, were installed in the after semi-elliptic head. These penetrations are located approximately six inches above deck level and spaced on four-inch centers horizontally about the longitudinal centerline. All threads are protected with pipe caps.

Refrigerator-Freezer

A combination refrigerator-freezer of approximately 10 cu ft storage capacity (5 cu ft refrigerator - 5 cu ft freezer) was installed in Sealab II. The refrigeration cycle is the conventional Freon gas system. Since the helium-rich Sealab II atmosphere is approximately six times as conductive as air, it is necessary to provide sufficient insulation to reduce heat gain, or an increased cooling capacity is required to compensate for the increased heat gain of a standard commercial insulation system. If mercury type temperature controls are utilized, these should be adequately protected against rupture (see Chapter 9).

Plumbing and Sanitary Facilities

The supply piping is of conventional design for 125 psi service. Fresh water was supplied to Sealab from shore to provide a minimum flow of 10 gpm at a minimum pressure of 40 psi above ambient. Maximum (static) pressure did not exceed 75 psi above ambient. Pressure-relief valves for the supply system and water heater were set at 100 psig. A 50-gallon water heater is installed (see Chapter 9). An emergency fresh-water storage tank of 150 gallon capacity is installed for use in the event of failure of the shore water supply. This tank is provided with a hose bibb for filling and draining and is vented. The emergency water tank is not connected to the Sealab water system, in order to prevent accidental usage of the emergency supply. The emergency tank may be drained and refilled periodically in order to maintain "fresh" tasting water. A hose bibb is installed in the supply system and located in the entryway for this purpose and also for general washdown purposes. A 25-ft length of "garden" hose is provided.

The sanitary system is of conventional design, gravity flow, overboard discharge. A 50-ft length of hose is provided for attachment (external) to the overboard sanitary discharge. This serves to keep the discharge opening below the water level in the entry trunk, thereby preventing gas loss from Sealab, and conveys the effluent away from Sealab. Since it is impossible to vent the sanitary system externally, all vents are fitted with potassium permanganate or charcoal filters to remove odors from the vent gases.

Air-Conditioning System

The air-conditioning system provides the following functions and capabilities:

Dehumidification	-	18 gallons per day
Ventilation	-	1200 cfm
Heat	-	25 kva (see Electrical Specifications)
CO_2 Scrubbers	-	1 lb/hr (approximately 4600 cu in. LiOH)
Charcoal Filter	-	to remove hydrocarbons, odors, and aerosols (approximately 2300 cu in.)
Gas sampling and make-up	-	(see Breathing Gas Systems)

It is desirable to obtain gas flow through the air-conditioning system with a single fan in order to reduce the number of electrical motors in the system. It is further desirable to enclose the one fan motor in a pressure-tight (5 psi over ambient) enclosure to reduce fire or contamination hazard. The distribution and return system is arranged so as to provide complete circulation of the Sealab atmosphere in order to eliminate any stagnant areas which might

create CO_2 pockets or concentrations. Storage space is provided for replacement supplies of charcoal and LiOH.

BREATHING GAS SYSTEMS

General

The breathing gases to be used to make up the Sealab II atmosphere are stored externally in 1,300-cu-ft cylinders (Fig. 25) (approximately 21 ft long and 9-5/8 in. O. D.) Storage pressures are nominally 2400 psi and all high pressure lines are designed for 3000 psi service. All breathing-gas systems are cleaned in accordance with BuShips specifications for breathing-oxygen service. Gases for the emergency make-up systems are supplied through the umbilical cord at a maximum pressure of 400 psi. A gas-control panel is provided and contains all components indicated on each drawing of the individual systems. This panel is located above the counter, port side, aft of the air-conditioning space, and has complete piping-diagram layouts of each gas system properly color-coded for ease of identification. The three pressure regulators plus one spare required in the oxygen, helium, and BIBB systems are of the type used in standard welding equipment. All regulators are identical, so as to provide interchangeability. These regulators are capable of providing the specified low pressure (gage) range by simple external adjustment in an ambient pressure of up to 140 psia.

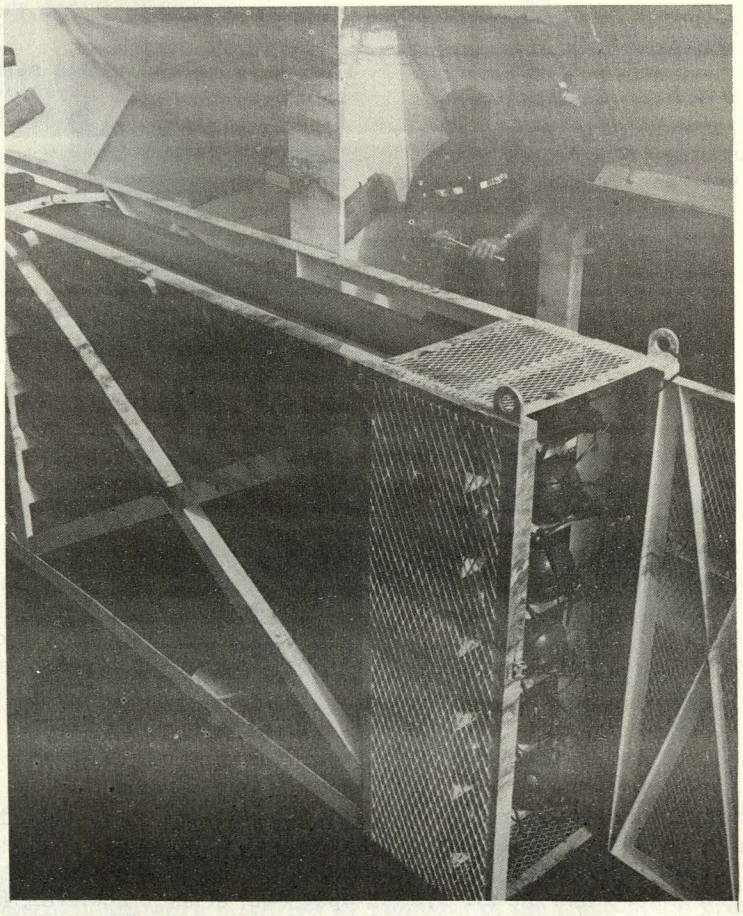


Fig. 25. Aquanaut Sheets checks fittings on the Sealab II externally mounted breathing gas cylinders

Oxygen System

The automatic and manual oxygen systems are in accordance with Fig. 26. This system is designed for automatic (normal) operation utilizing a "Krasberg" PO_2 sensor and servo valve supplied by Westinghouse Corporation. Provisions are also made for bypassing the servo valve for manual operation. The external storage bottles are piped to two separate manifolds of five and six bottles each. During operation, one bottle on each manifold was "on line" at all times, such that in case of failure upstream of the gas-control panel, a backup supply may be selected immediately inside Sealab. Note: Make-up oxygen shall be introduced into the discharge duct of the ventilation system downstream of the gas-sampling line. The oxygen input is downstream of the fan motor to reduce fire hazard and is in a high-velocity or turbulent region to provide complete mixing.

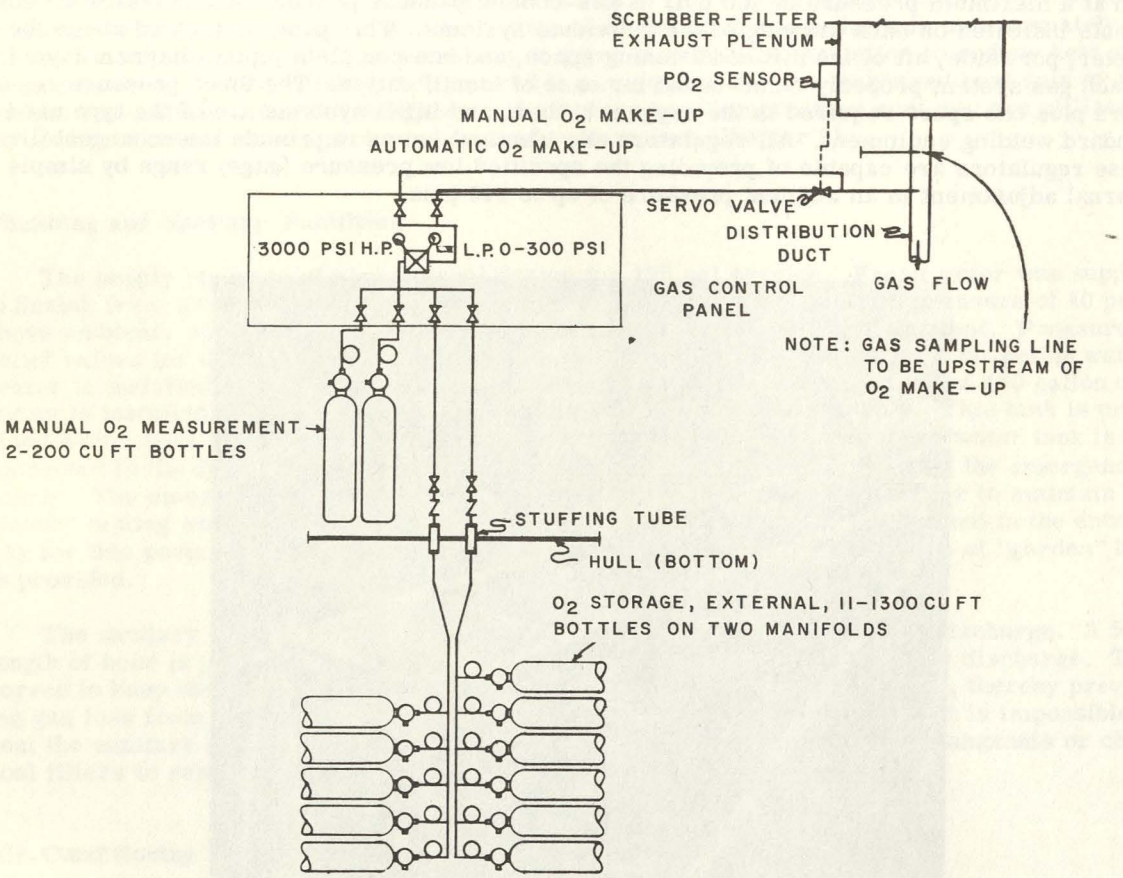


Fig. 26. Sealab II oxygen system

Helium System

The helium system is in accordance with Fig. 27. This system is designed to provide any make-up required in Sealab and is designed for manual operation. The ten external storage bottles are piped to a single manifold. During operation one bottle was "on line" at all times. The helium input is introduced into the air system upstream of the circulating fan to provide adequate mixing.

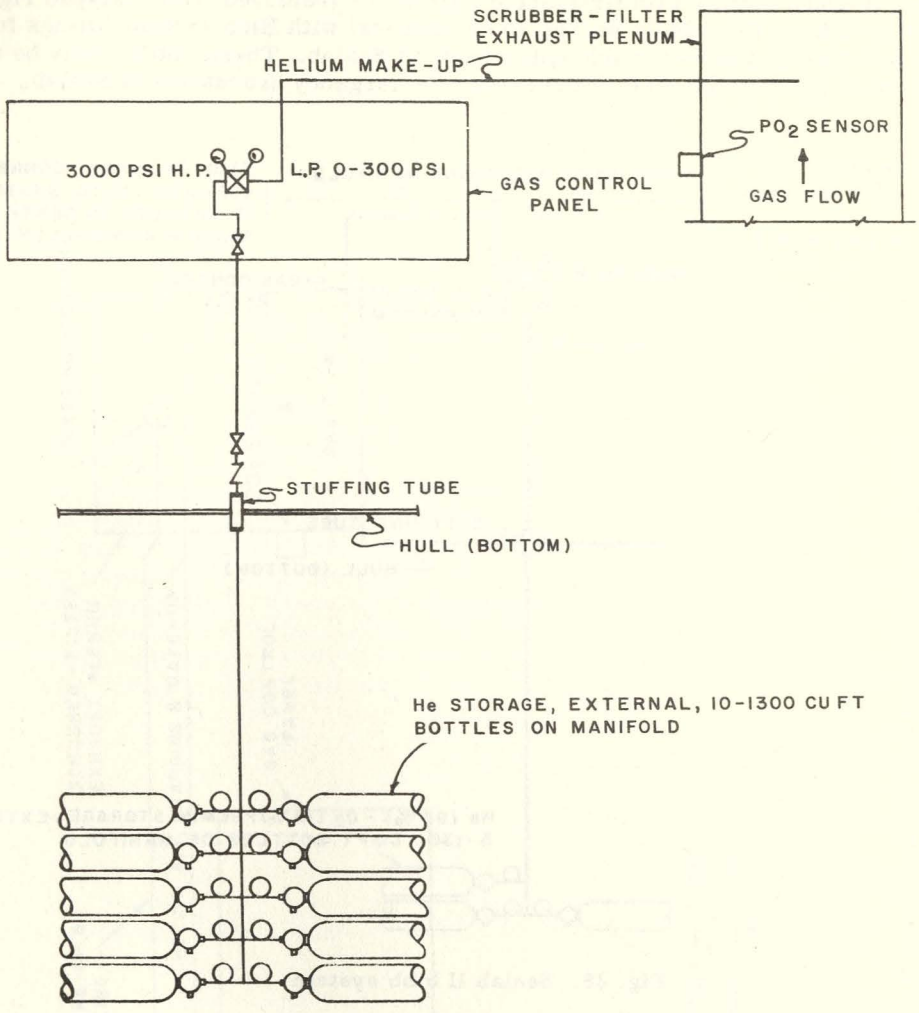


Fig. 27. Sealab II helium system

Bibb System

The Bibb system is in accordance with Fig. 28. The three external storage bottles are piped to a common manifold. During operation all three bottles were "on line" at all times. This system is designed to provide emergency breathing gases (premixed) in the event the Sealab atmosphere becomes contaminated. It will provide approximately 43 minutes breathing time for ten aquanauts. Internal manifolding shall be installed to provide quick-connective outlets (female or socket) as follows:

10 - berthing space
4 - galley space
4 - lab space
10 - entry way

Ten "Calypso" Model No. 1050 single-hose scuba rigs are provided for use with the Bibb system. These equipments were modified by removal of the first-stage pressure regulator and the installation of a quick-connective fitting (male or plug end) to suit quick-connective fittings installed in Sealab. Note: The first-stage regulators removed from the Calypso rigs are to be retained for installation on emergency scuba bottles.

Ten 38-cu-ft scuba bottles with first-stage regulators (removed from Calypso rigs) and quick-connective fittings (female or socket) to be identical with Bibb system fittings installed in Sealab are provided and stored inside entry trunk of Sealab. These bottles may be utilized by the aquanauts to swim to the PTC in the event of emergency evacuation of Sealab.

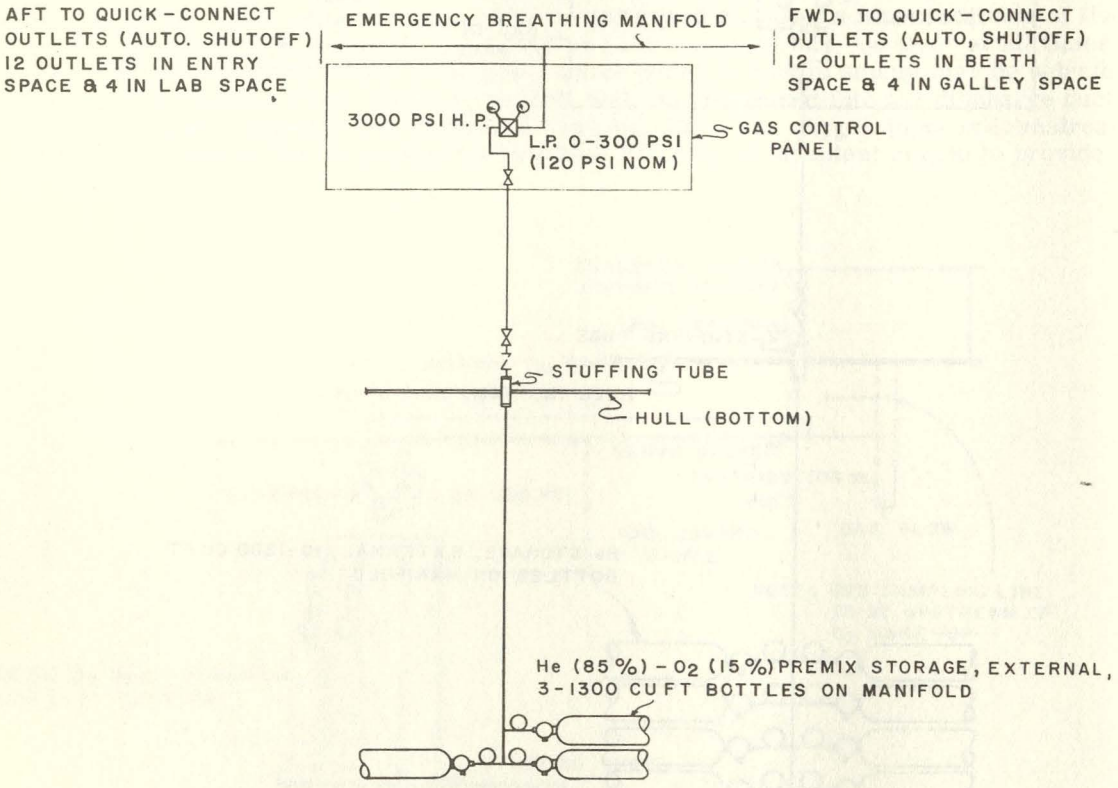


Fig. 28. Sealab II bibb system

Emergency Helium, Air, and Oxygen Systems

These systems are in accordance with Fig. 29. The emergency helium and air system will be utilized to provide helium or air from the surface in the event of failure or exhaustion of the self-contained helium supply. This system is also used for the surface (initial) charging of Sealab. Gases are supplied through the gas-supply hose of the umbilical cord at 400 psig maximum pressure. The emergency oxygen system is utilized to provide oxygen from the surface in the event of failure or exhaustion of the self-contained oxygen system. This system is used as a gas-sampling system for surface monitoring of the Sealab atmosphere. Oxygen is supplied through the gas-sampling hose of umbilical cord of 200 psi maximum pressure. The gas-sampling intake is located in the outlet of the air-conditioning system upstream of the oxygen input in order to obtain sampling of well-mixed and filtered atmosphere. An additional gas sampling intake is provided via a 30-ft length of 1/4-in. I. D. hose for sampling at any desired point inside Sealab.

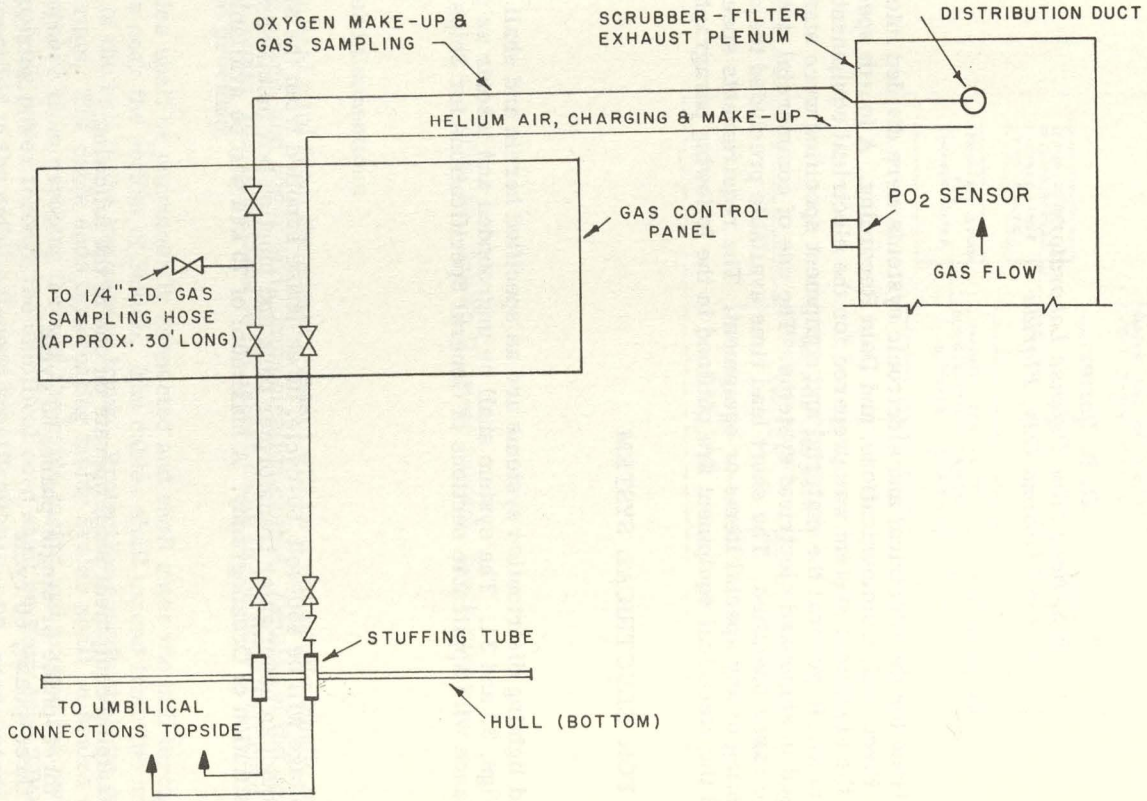


Fig. 29. Sealab II emergency helium, air, and oxygen system

Chapter 9

ELECTRICAL AND ELECTRONIC SYSTEMS FOR THE SEALAB II HABITAT

R. B. Porter
U.S. Navy Mine Defense Laboratory
Panama City, Florida

INTRODUCTION

The specifications for the electrical and electronic systems were divided into three sets of specifications: Electrical, Communications, and Data Recording. A fourth specification closely related to the electrical system was prepared for the electrical equipment to be used in the Sealab II habitat. In general the material and equipment specified were standard Navy items normally used in shipboard electrical systems. The use of commercial items was permitted and in some cases specified. The short lead time available precluded the design, development, and testing of any special items or equipment. The requirements specified for the three systems and the electrical equipment are outlined in the following paragraphs.

REQUIREMENTS FOR ELECTRICAL SYSTEM

General

The power and lighting distribution systems are as specified herein and shall be in general accordance with Figs. 30 and 31. The system shall be ungrounded and insofar as practical shall be in accordance with applicable sections of General Specifications for Ships of the U.S. Navy.

Supply Voltage

The supply voltage will be 450-volt, 60-cycle, three-phase supplied from the staging vessel or from shore through an underwater transformer bank and junction box installed at the test site by Scripps Institution of Oceanography. A maximum of 75 kva will be available.

Utilization Voltage

All power-consuming equipment shall operate on one of the following:

208-volt, three-phase or single-phase, 60 cycle
440-volt, three-phase, 60 cycle
115-volt, three-phase, 60 cycle
115-volt, single-phase, 60 cycle
230/115-volt, single-phase, 60 cycle (alternate for range in case suitable 440-volt range is not available)

Electrical Load

The estimated electrical load requirements as shown in Table 1 shall be used as a guide in designing the electrical system.

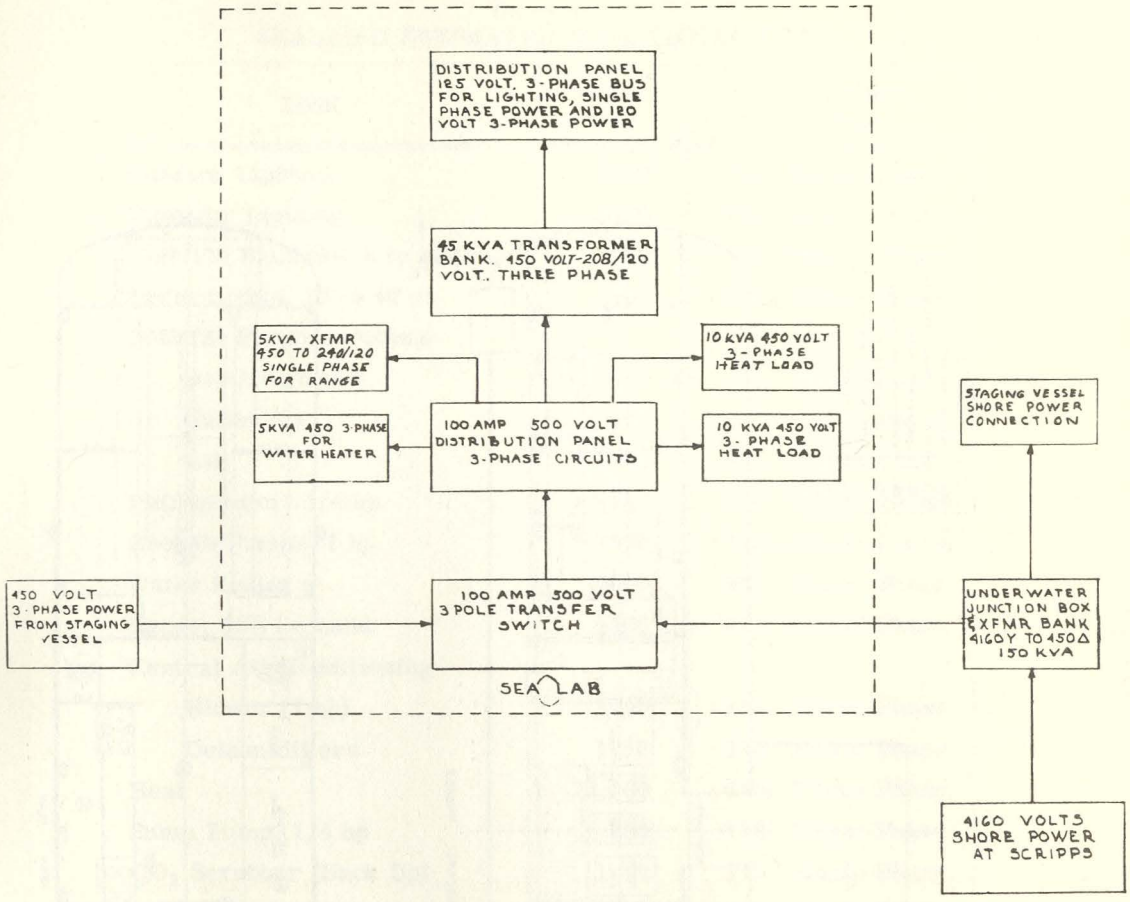


Fig. 30. Sealab II power system, block diagram

Umbilical-Cord Connections

The umbilical cord from the support vessel will be a composite bundle of air, gas, and gas-sampling hoses, and power and communication cables. Details of the umbilical cord are contained in Chapter 10. In addition to the power cable in the umbilical cord, a shore power cable shall be provided.

The cables shall be permanently connected and shall enter the hull through pressure-proof stuffing tubes near the bottom of Sealab. The cables shall extend from the hull penetrations on the exterior of the hull to the top access trunk. Protective guards shall be provided for the exterior cable runs. The cable ends terminating inside Sealab shall be sealed to prevent the Sealab atmosphere from escaping through the cable jacket and around the conductors. The cable for supplying power through the umbilical cord shall be Navy type THOF-42. The length shall be as specified in the umbilical-cord specification.

Shore Power Cable — The cable for supplying power from shore through an underwater transformer shall be Navy type THOF-42. A rod closing type Kellems grip shall be installed on each end of the shore power cable. A waterproof connector shall be installed on the surface end of the cable. The connector shall have a male insert. A mating connector shall be furnished to Scripps Institution of Oceanography for installation on shore power supply cable. The connector shall be capable of sealing on a 1.250-in.-diameter cable. Pin connections for correct phase rotation shall also be supplied.

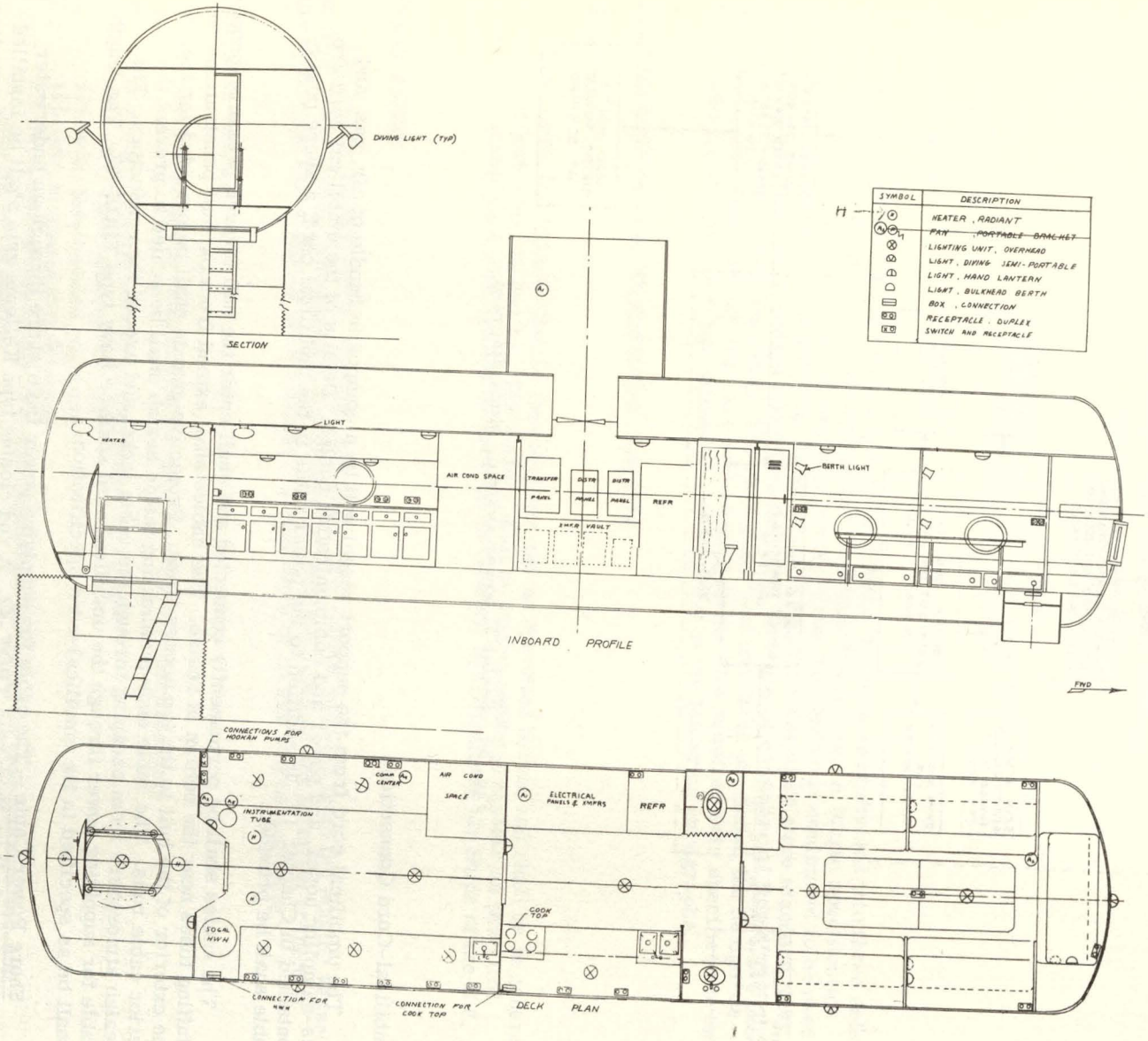


Fig. 31. Sealab II electrical layout guidance plan

Table 1
SEALAB II ESTIMATED ELECTRICAL LOAD

Load	Power (va)	Utilization Voltage
Interior Lighting	1500	115 Single Phase
Exterior Lighting	8000	115 Single Phase
Electric Blankets, 8 to 180 va	1440	115 Single Phase
Berth Lights, 10 to 40 va	400	115 Single Phase
General Purpose Outlets		
Berthing Space	1500	115 Single Phase
Galley (2)	3000	115 Single Phase
Lab	6000	115 Single Phase
Refrigerator, 1/4 hp	700	115 Single Phase
Hookah Pumps, 1 hp	2800	115 Three Phase
Water Heater	4500	440 Three Phase
Range, 80% Demand	5360	220 Single Phase
Central Air Conditioning		
Blower (1 hp)	1400	115 Three Phase
Dehumidifiers	1750	115 Single Phase
Heat	20,000	440 Three Phase
Sump Pump, 1/4 hp	700	115 Single Phase
CO_2 Scrubber (Back Up)	1050	115 Single Phase
Heat (Entrance Area)	5000	115 Single Phase
Total	64,840	

Total 115 volt single- and three-phase load	35.74 kva
Total 220 volt single-phase load	5.36 kva
Total 450 volt three-phase load	24.50 kva
Total to be provided 65.10 × 115%	= 74.9 kva

Illumination Requirements

General – Fluorescent fixtures shall not be used. Commercial 40-watt appliance lamps and 50, 75, and 100-watt rough-service lamps have been tested and have been found to be suitable for the proposed operating depth. Other types may be used provided they are suitable for the proposed operating depth.

Interior Lighting – The number and location of the lighting fixtures for general and detail illumination shall be that required to provide the initial average foot-candle values specified in Table I of Section 9640-2 of General Specifications for Ships of the Navy. The laboratory space shall be considered as a General Workshop for general and detailed lighting requirements.

Interior Lighting Fixtures – The lighting fixtures shall be commercial type Russell and Stroll No. 370 and/or No. 351, or other suitable fixtures. The asbestos leads shall be replaced with Type B wire of Specification MIL-W-16878 or covered with Teflon sleeving. A pressure-equalizing hole shall be provided in each fixture to permit the glass globe to be removed after Sealab is pressurized. All fixtures except fixtures in head and lavatory shall be controlled by

conveniently located switches. Switches shall be Symbol 780.1 listed in NavShips 250-560-3. (Note: 50 and 75-watt bulbs may be used in Fixture No. 370, since the He atmosphere is a better heat conductor than air.)

Low-Level Lighting — A red lighting fixture for low-level lighting shall be installed in the berthing space. The fixture shall be selected from NavShips 250-560-3.

Berth Lights — Incandescent berth lights shall be installed for each berth. The fixture shall be a suitable commercial type which encloses the bulb. The fixtures may connect to a convenience outlet or be permanently connected. Each fixture shall have an off-on switch.

Hand Lanterns — Hand lanterns without relay, Symbol 100.2 of NavShips 250-560-3, shall be installed throughout the interior of Sealab II to provide a limited amount of illumination in the event of a power failure. The minimum number of installed lanterns shall be four, and they shall be located to illuminate the following areas: (a) main entrance trunk (2), (b) electrical power control area, and (c) the berthing area.

Exterior Lighting — The exterior lighting shall consist of six semiportable lighting fixtures. The fixtures shall be Standard Navy diving lights, Symbol 313, as shown on BuShips Dwg. 9000, S6405-7445. Suitable mounting brackets shall be provided at locations shown on MDL Dwg. 8656 to permit the lights to be installed after Sealab is on the ocean floor, or to permit movement to temporary locations. The lights located on the port and starboard side of lab space shall have 150 ft of cable outside the Sealab. The remaining four lights shall have 50 ft of cable outside the Sealab. Suitable stowage shall be provided for the excess cable when the lights are mounted on Sealab. Some convenient means shall be provided to permit the lights to be installed after Sealab is on the ocean floor. Connectors capable of being plugged or unplugged underwater may be used. Cables shall not be run through the entrance trunk.

A switch shall be provided inside Sealab for each exterior light. Each switch shall be clearly labeled. If underwater receptacles are used, switches shall be Symbol 780.1 of NavShips 250-560-3. If an interlocking switch and receptacle is used, it shall be Symbol 900.1 of NavShips 250-560-3.

Equipment and Material

The equipment and material for the electrical system shall be as specified herein. Miscellaneous items not specifically listed shall be Navy or commercial items best suited for the application.

Transformers — The transformers shall be dry, Naval Shipboard type in accordance with MIL-T-15108. Three 450-120 volt transformers of suitable size connected delta-delta, or delta-wye, shall be used to supply power for the lower voltage single- and three-phase loads. A 6-kva transformer bank or transformer shall be provided to supply 240-120 single-phase power for the electrical cook top if the unit will not operate on 440-volt three-phase or the lower voltage of the main transformer bank.

All transformers shall be enclosed in a gastight compartment to prevent contamination of the Sealab atmosphere in case of overheating. Stuffing tubes shall be used for all cables entering the compartment. The compartment should be built so that one side is formed by the shell of the vessel. The shell side shall not be insulated. A pressure-equalizing valve shall be provided to equalize the pressure of the interior of the compartment during pressurizing operations. A temperature-indicating device shall be provided to monitor the inside temperature of the compartment near the center transformer. A circulating fan shall be installed in the transformer compartment to provide forced circulation of the compartment atmosphere through the transformers in case of a temperature buildup. The fan may be manually or automatically controlled.

Transfer Panel and 450-Volt 3-Phase Distribution Panel — The incoming power-transfer panel and 450-volt 3-phase distribution panel shall be similar to NWT Type panel, Symbol 2531, listed in NavShips 250-560-3. The number of circuits required shall be determined by the

detail design. The transfer-switch breakers shall be 100 amp capacity. The power-distribution breakers shall be selected to protect the load served. At the option of the design activity, the transfer switch and the 450-volt, 3-phase distribution panel may be in separate enclosures.

Power and Lighting Distribution Panels — The 115-volt power and lighting distribution panels shall be similar to totally enclosed type Symbol 994.3, 995.3, or 999.3 listed in NavShips 250-560-3. The number and size of the panels required shall be determined in the detail design. The rating of the circuit breakers shall be selected to protect the load served.

Cable — The cable for the electrical system shall be type SGA of MIL-C-2194 and/or types covered in MIL-C-915.

Stuffing Tubes — Stuffing tubes shall be standard Navy stuffing tubes listed in NavShips 250-560-3. Pressure-proof type shall be similar to tubes shown on BuShips Dwg. 815-1197030.

Interior Receptacle — The double receptacles installed throughout the vessel shall be grounded type and shall be Symbol 730.1 (commercial) listed in NavShips 250-560-3. Where receptacles controlled by a switch are required, Symbol 900.1 of NavShips 250-560-3 shall be used. Commercial plugmold or similar may be used in the lab space, providing provisions of Note 7 of BuShips Dwg. 9000 S6202 73980, Section 3, Sheet 57 are met.

Waterproof Connectors — Waterproof connectors shall be any suitable commercial or Navy type. The following companies manufacture waterproof connectors:

Cannon Electric Company, Los Angeles, California
Marsh and Marine, Houston, Texas
D. G. O'Brien, Inc., Natick, Massachusetts

The manufacturer of the connector selected should be consulted for proper installation procedures.

REQUIREMENTS FOR COMMUNICATION SYSTEM

General

Communication between the Sealab and the Communications Command Center (CCC) on the support vessel will be via a communications cable in the umbilical cord. The following modes of communication are to be provided:

1. Helium Speech Unscrambler
2. Electrowriter
3. Television
   a. Closed Circuit Monitors
   b. Entertainment
4. Audio, CCC to Sealab
5. Audio, CCC to shore via Sealab
6. F-M Music

In addition to the communication modes, the following information will also be transmitted via the communication cable:

1. Wedge Spirometer Output
2. Trunk Water Level
3. O_2 Partial Pressure

Unless otherwise specified, all equipment will be installed at Long Beach by U.S. Naval Ordnance Testing Station (NOTS) Pasadena.

Exterior Umbilical Cord Connection

The communication cable shall be permanently connected through the hull with a pressure-proof stuffing tube near the bottom of the hull. The pressure-proof stuffing tube shall be similar to those shown on BuShips Dwg. 815-1197030. The cable shall terminate in a suitable plug at the communication center inside Sealab. The cable end shall be sealed to prevent the Sealab atmosphere from escaping through the cable jacket and around the conductors. The exterior section of the cable shall extend from the hull penetration to the umbilical connection near the top of top access trunk. Protective guards shall be provided for the exterior cable run.

Communication Cable

The communication cable specified for the umbilical cord is Boston Insulated Wire Company No. TV-33N or equal, neoprene jacket, O.D. 0.780 ft ± 0.015 in. Table 2 lists the recommended conductor usage. Cables required for other interior communication circuits shall be Navy or commercial types best suited for the application.

Sealab Communication Center

A section of the lab bench adjacent to the fan cabinet shall be used for the Sealab communication center. A patch panel shall be designed and installed at this location to facilitate connecting the various pieces of equipment at the test site. The panel shall have multi-pin receptacles for all multiconductor circuits and coax receptacles for the TV circuits. Each receptacle shall be labeled. Plugs shall be provided for each receptacle. Table 2 lists suggested receptacles or a particular receptacle if required to mate with an existing plug on the equipment. A panel shall be built and furnished to NOTS, Pasadena, for installation in the CCC van on the support vessel. The panel shall be identical to the Sealab panel, except (a) a switch for the FM speaker is required, and (b) an Amphenol receptacle No. 67-02E14-5S or equal shall replace the two separate receptacles for the audio link to Sealab and shore. A mating plug shall be furnished. A wiring diagram shall also be furnished with the panel.

Helium Speech Unscrambler

The helium speech unscrambler is being provided by the Office of Naval Research (ONR) in cooperation with BuShips. The equipment will be shipped to NOTS, Pasadena. Three headsets are being provided and are to be located as follows: Sealab Communication Center, galley, and berthing space. Cables shall be run to the galley and berthing space and terminated at a convenient location in a receptacle. The conductor and connector requirements are listed in Table 2.

Electrowriter

The electrowriter, consisting of a transmitting unit and a receiving unit, will be shipped to NOTS, Pasadena. The conductor and connector requirements are listed in Table 2.

Television

The TV units for monitoring and entertainment are being furnished by Scripps Institution of Oceanography. The conductor and connector requirements are listed in Table 2.

FM Receiver

The FM receiver and remote speakers will be provided by NOTS, Pasadena. The FM remote speakers shall time share the conductors in Quad 1 of the communication cable with the helium speech unscrambler headset (Table 2). A switch shall be provided on the patch panel

Table 2
SEALAB II COMMUNICATION SYSTEM CONDUCTOR AND CONNECTOR REQUIREMENTS

Item	No. of Cond. Required	Suggested Conductor Usage W/Cable*	Patch Panel Connectors		No. Pins Req'd in Umbilical Plug
			Sealab	Support Vessel	
Helium speech unscrambler	Four conductors for each headset	Sealab Comm. Center - Quad 1 Galley space - 2 from perimeter and 2 from center group Berthing space - 2 from perimeter and 2 from center group	Information not available	Info. not available	4 4†
FM speakers	Two or four	Time share Quad 1	Amphenol series	91 or equal	None
Electrowriter	Two with shield	Two from perimeter	Amphenol series 91 or equal	Same	2†
Television (1) Closed circuit monitor (2) Entertainment (3) Spare	 One coax One coax One coax	 Coax No. 1 Coax No. 2 Coax No. 3	Amphenol series 83 or 31 or equal	Same	2
Audio, CCC to Sealab	Two with shield	Two from Quad 3	Amphenol series 91 or equal	Amphenol No. 67-02E 14-5S	2†
Audio, CCC to shore via Sealab	Two with shield	Two from Quad 3 shield common	Amphenol series 91 or equal		2†
Wedge spirometer	Four with shield Two singles	Four from Quad 2 Two from center group	Amphenol 67-02E14-9P, Do not substitute	Same	4† 2†
O_2 partial pressure	Two singles	Two from center group	Cinch-Jones S-202-CCT or equal	Same	2
Trunk water level	Two singles	Two from center group	Cinch-Jones S-202-CCT or equal	Same	2

*Conductor usage is based on BIW Cable No. TV-33N. Quads and coax conductors have been arbitrarily numbered for identification in this table only

†All shields except coax shields shall be connected to pin 34 of the umbilical connectors.

for the Command Control van to switch off the FM circuit when using the helium speech unscrambler. Receptacles and mating plugs shall be provided on the patch panels. Circuits from the patch panel to the speakers to be located in the berthing space and lab space shall be installed.

Audio, CCC to Sealab

The audio link for two-way communication from the CCC to Sealab shall be a commercial intercom system, Bogen or equal. A two-station master shall be provided for the CCC and a remote unit at the Sealab Communication Center. The conductor and connector requirements are listed in Table 2.

Audio, CCC to Shore via Sealab

The second station on the master station provided in the previous paragraph shall be used for the audio link from the CCC to shore. A remote unit shall be furnished for the shore station. Conductor and connector requirements are listed in Table 2.

Wedge Spirometer

The wedge spirometer is being furnished by the Submarine Medical Center (SMC) and will be shipped to NOTS, Pasadena. Wiring diagrams will be furnished to all concerned at the earliest possible date. NOTS, Pasadena, will provide an extension cable from the patch panel in the CCC to the atmosphere van. An Amphenol plug 67-06J14-9S shall be installed on each end of the cable. The type of cable required will be specified later. Conductor and connector requirements are listed in Table 2.

O_2 Partial Pressure

The Krasberg unit for determining the O_2 partial pressure will be furnished by ONR and Special Projects. The equipment will be shipped to NOTS, Pasadena. Provisions are being made to monitor and record the O_2 partial pressure remotely. The conductor and connector requirements are listed in Table 2. The installation of the unit and connections to the patch panel will be accomplished during the fitting-out period at Long Beach.

Equipment Mounting Strips

To facilitate the installation of communication and monitoring equipment during the fitting-out period, two slotted metal angle strips shall be installed on the overhead in the lab space, galley and berthing space.

The strips shall be installed approximately 2 ft 2 in. on either side of the center line, the entire length of each space. Where interferences exist, the strips may be omitted. The strips shall be on the surface of the cork insulation.

Circuits for Shore Equipment

The following circuits shall be installed from a terminal box located near Scripps electronic rack to the locations indicated for equipment to be installed later.

Equipment	Type Conductor	Location
Open Mike (3)	Shielded Pair (3)	(1) Berthing area (2) Galley (3) Lab

Equipment	Type Conductor	Location
Intercom	Shielded Pair (1)	Sealab Communication Center
Intercom	Shielded Pair (1)	Berthing area

REQUIREMENTS FOR DATA-RECORDING SYSTEM

General

The engineering and the environmental data specified herein will be recorded either in Sealab II proper or on shore through the facilities of the Scripps Benthic Laboratory.

Engineering and Environmental Data to Be Recorded

The following data is to be recorded:

Item	Recorder Location
1. Power Usage	Sealab
2. Equipment Usage	Sealab
(a) Water heater (1)	
(b) Dehumidifiers (4)	
(c) Electric heaters	
(1) Baseboard banks (3)	
(2) Deck (1)	
(3) Radiant (4)	
(d) Refrigerator (1)	
(e) Freezer (1)	
3. Temperature, Interior	Shore
(a) Trunk area	
(b) Lab area	
(c) Galley	
(d) Berthing area	
4. Temperature, Equipment	Shore
(a) Refrigerator, interior	
(b) Freezer, interior	
5. Humidity, Interior	Shore
(a) Trunk area	
(b) Lab area	
(c) Galley	
(d) Berthing area	
6. O_2 Partial Pressure (PO_2)	Shore (monitor on support vessel)
7. Trunk H_2O Level	Shore (monitor on support vessel)

Power Usage Recorder

A standard commercial three-phase watthour meter shall be provided and installed in Sealab and shall be connected on the load side of the transfer switches to record the total power consumed. If more convenient and economical, a watthour meter may be installed on the supply side of each transfer switch.

Equipment Usage Recorders

Commercial, non-resettable, self-starting, synchronous, elapsed-time indicators shall be installed for all equipment listed under Item 2, Equipment Usage. The indicators may be installed on the individual pieces of equipment or grouped at a convenient remote location. If indicators are grouped, they shall be labeled with the name of the equipment to which connected. The indicators shall register in hours and tenths of hours up to 9999.9.

Interior Temperature Sensors

The interior temperature of the Sealab at the locations specified in Item 3, Interior Temperature, will be recorded on shore through the facilities of the Scripps benthic lab. San Francisco Naval Shipyard shall design and/or procure and install the necessary temperature sensors, amplifiers, and interior wiring. The temperature range of each sensor shall be 65°F to 95°F. The benthic lab accepts an 0-7 vdc input with a preferred operating range of 1-6 vdc. The amplifiers shall be designed to produce a degree/volt output that will be within this range. The output cable from each sensor amplifier shall terminate in the terminal box located in the vicinity of the instrumentation cable trunk.

Equipment Temperature Sensors

The interior temperature of the refrigerator and freezer compartment will be recorded on shore through the facilities of the Scripps benthic lab. San Francisco shall design and/or procure and install the necessary temperature sensors, amplifiers, and interior wiring. The temperature range of each sensor shall be approximately -10°F and +20°F of the designed temperature of each compartment. The output of each amplifier shall be designed to produce a degree/volt output that will be in the range of the benthic lab specified in the preceding paragraph. The output cable of each amplifier shall terminate in the temperature terminal box.

Interior Humidity Sensors

The interior humidity of the Sealab at the locations specified in Item 5, Interior Humidity, will be recorded on shore through the facilities of the Scripps benthic lab. San Francisco Naval Shipyard shall design and/or procure and install the necessary humidity sensors, amplifier, and interior wiring. The humidity range of each sensor shall be 50 to 100 percent relative (50 to 90 percent satisfactory if the above range is not available). The amplifiers shall be designed to produce a percent/volt output that will be in the benthic lab range. The cable from each sensor amplifier shall terminate in same terminal box provided for the temperature sensors.

O_2 Partial Pressure (PO_2) Sensor

The PO_2 sensor is being furnished by NOTS. Two spare terminals in the terminal box shall be provided to facilitate connecting equipment at the test site.

Instrumentation Cable Trunk

An eight to ten inch pipe shall be installed through the hull at approximately frame 44 on the port side of the lab space to permit instrumentation cables to be brought in to the Sealab

from the benthic lab and other exterior equipment. The bottom end of the pipe shall extend to the same level as the bottom of the entrance trunk. The top end of the pipe shall be approximately three feet above the deck. A removable watertight cover shall be provided.

REQUIREMENTS FOR ELECTRICAL EQUIPMENT

General

The electrical equipment shall be standard Navy items or commercial items best suited for the application or which can be modified to suit the application.

Electric Motor and Controllers

The electric motors and controllers selected shall be in general accordance with Section 9630-1 of General Specifications for Ships of the U.S. Navy. Commutator type motors shall not be used. Insofar as practical, motors selected shall be three-phase. The necessary manual or magnetic controllers shall be provided for each motor. Thermal overload protection shall be provided for each motor, including those furnished as part of a complete unit, either from the Navy supply system or commercial sources. The thermal protection shall be designed to prevent the motor from becoming overheated and contaminating the atmosphere. Fan motors should be oversized or have the pitch of the fan modified to compensate for the denser atmosphere. Precautions should be exercised in the modification of the pitch of the fan blade of equipment cooling fans.

Water Heater

The water heater shall be a 50 to 52 gallon capacity, quick-recovery type. The preferred voltage is 440 volts, three-phase; however, a lower voltage rating may be used if a 440-volt unit is not available. The insulation shall be fiber glass or rock wool.

Refrigerator

The refrigerator shall have a net capacity of not less than 10 cu ft and not more than 14 cu ft, and shall be divided into a freezer compartment and a refrigerator compartment. The freezer capacity shall not be more than 5 cu ft net. The refrigerator shall be capable of performing its normal function in an 80 percent helium atmosphere at approximately 110 psig.

Cook Top

The cook top shall consist of four electric heating units of approximately 1250 watts each. Each unit shall have a heat-control switch. Thermostatically controlled units are not required. The preferred voltage is 440 volts, three-phase; however, other voltages may be used if 440-volt units are not readily available.

Radiant Heaters

The four radiant heaters for the entrance area, as shown on MDL Dwg. 8656, shall be at least 1250 watts each. Each heater shall be controlled by a double-pole switch or the circuit breaker in the distribution panel.

NOTE: Nutone Model 9290 was used in Sealab I and performed satisfactorily.

Bracket Fans

The two bracket fans for emergency circulation will be furnished. Fans are Robin and Myers Model CG16-1/2-3, Cat. No. CG 16-1/2 361, 110-120 vac, 60 cycle, 0.70 amp. The fans are not to be installed but will be stowed aboard Sealab.

Hookah Pumps

The two hookah pumps will be furnished. The motors will be 1 hp, 440-volt, three-phase.

Miscellaneous

The following equipment will be used in Sealab. All equipment operates from a standard 15-amp grounded receptacle.

1. One rotisserie (1500 watts). (For use in galley.)

2. Two portable electric heaters (1650 watts each). (Back-up heat if part of main system fails.)

3. Bracket fans.

No special circuits are to be installed for the heaters; however, the convenience outlet circuits should have the capacity to accommodate one heater.

Chapter 10

UMBILICAL CORD FOR THE SEALAB II HABITAT

W. B. Culpepper and R. B. Porter
U. S. Navy Mine Defense Laboratory
Panama City, Florida

INTRODUCTION

The purpose of the umbilical cord is to provide utilities to the Sealab II habitat from the support vessel. The power and communication cables were permanently attached to the Sealab and penetrated the hull through pressure-proof stuffing tubes. The hose components were connected to piping installed on the exterior of the hull with two-way shut-off quick-disconnect type connectors. The short lead time available precluded the design and testing of suitable underwater connectors for the power and communication cables which would have permitted the umbilical cord to be completely disconnected from the Sealab. Also, time did not permit the design of a special communication cable with the proper number and type of conductors required. In this case, the best commerical item available was specified. The umbilical-cord requirements specified are outlined in the following paragraphs.

REQUIREMENTS FOR THE UMBILICAL CORD

General

The umbilical cord from the support vessel to the Sealab will contain hoses for compressed air, gas supply, and gas sampling, and cables for power and communications. The compressed-air hose will provide 400 psig air for pneumatic tools. The gas-supply hose will supply, at 400 psig, the initial helium charge, make-up helium, and breathing air. The gas-sampling hose will be used to obtain Sealab atmosphere samples and to supply emergency oxygen. The power cable will supply 450-volt, 3-phase power from the support vessel. The communication cable will provide communication, closed-circuit television, and environment data circuits from Sealab to the communication command center on the support vessel. The power and communication cables will be permanently connected to the Sealab. Each hose component will have a quick-disconnect type connection on each end. All hose connections on the Sealab end will be made in a central location near the top entrance trunk. The connections at the support-vessel end will also be made at at central location on the vessel.

Design

The umbilical cord shall have a nominal length of 350 ft. All components shall be compactly arranged (Fig. 32) to form a compact, easily handled bundle. The bundle shall be covered overall with a woven cotton or nylon braid, a hand-sewed canvas jacket, or bound at sufficient intervals to insure that a compact bundle is maintained. The method of binding shall be such that the individual components are not damaged and a relatively smooth surface is maintained. A Kellems stainless steel single-weave grip, or equal, shall be installed on each end to prevent strain on the connections. A double wrap of cotton canvas shall be placed under each grip to prevent damage to the components. The eye of the grip on the Sealab end of the umbilical cord shall be eight feet from the end. A six foot, 7/16-in stainless steel wire rope pendant shall be provided to connect the grip to the Sealab. A suitable staple or pad eye shall be installed on the top entrance trunk near the umbilical connections. The cable grip on the upper end shall be a Kellems stainless steel Rod Closing Grip, or equal, and shall be placed on the cord near the end for shipping purposes only. Naval Ordnance Test Station (NOTS), Pasadena, will position the grip at the time of lowering. Floats will be attached to cable by NOTS, Pasadena, to obtain a slight positive buoyancy.

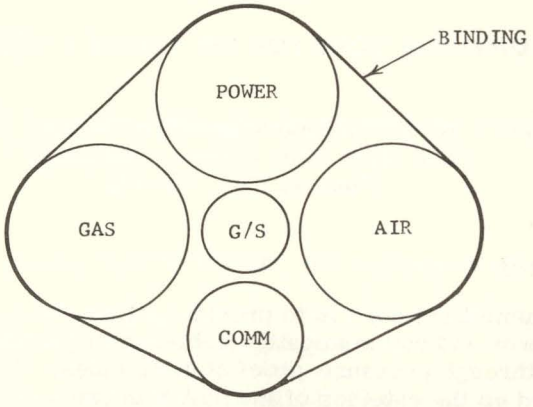


Fig. 32. Cross section of umbilical cord

Details of Components

The individual components of the umbilical cord shall be as specified herein.

1. Electrical Power

a. Cable. The power cable shall be Navy type THOF-42 of MIL-C-915, or a suitable commercial equivalent. The cable shall be 350 ft plus additional length to reach from the top access trunk to the termination point inside Sealab. The cable shall be in one continuous length.

b. Stuffing Tube, Sealab End. The power cable shall be permanently connected and shall enter the hull through pressure-proof stuffing tubes near the bottom of the hull. The pressure-proof stuffing tube shall be similar to tubes shown on BuShips Drawing 815-1197030.

c. Plug, Support-Vessel End. The plug shall be a Crouse-Hinds Catalog No. AP20465. The plug shall have a male insert. A protective cap, Crouse-Hinds Catalog No. CPK-104, shall be provided and secured to the plug with a chain or small stainless steel cable.

2. Communications

a. Cable. The communication cable shall be Boston Insulated Wire Company No. TV-33N or equal. Conductor usage is outlined in the communication specifications. The cable shall be 350 ft, plus additional length to reach from top access trunk to termination point in Sealab. The cable shall be in one continuous length. A 150-ft continuous length of the cable shall be furnished to NOTS, Pasadena.

b. Stuffing Tube, Sealab End. The communication cable shall be permanently connected and shall enter the hull through pressure-proof stuffing tubes near the bottom of the hull. The pressure-proof stuffing tube shall be similar to tubes shown on BuShips Drawing 815-1197030.

c. Plug, Support Vessel End. The plug on support vessel end shall be waterproof with cap and chain or provided with a waterproof boot.

3. Gas Sampling

a. Hose. The gas-sampling hose shall be a 1/4-in. I.D. × 19/32-in. O.D. welding hose for oxygen service, 250 psig working pressure, and shall be Gates No. 16B or equal. The hose shall be in one continuous length.

b. End Fittings. A two-way shut-off quick-connecting fitting shall be installed on each end of the hose. The fittings shall be 1/4-in. Roylyn Incorporated Series 1300, or equal. Material may be brass or corrosion-resistant steel.

The Sealab end shall have a nipple-type fitting.

The support vessel end shall have a coupling-type fitting.

A cap or plug shall be provided for each end of the hose and secured to the hose with a chain or small stainless steel cable. The cap and plug should be of the same material as the end fitting; however, aluminum may be used with corrosion-resistant steel fittings.

c. Cleaning. Upon completion of the installation of the end fittings, the hose shall be thoroughly cleaned for oxygen service. The cap and plug shall be installed to prevent the interior from becoming contaminated during handling.

4. Gas Supply

a. Hose. The gas supply hose shall be 3/4-in. I.D. × 1-1/4-in. O.D. with a minimum working pressure of 400 psig and shall be Weatherhead H-16 or equal. The hose shall be in one continuous length.

b. End Fittings. A two-way shut-off quick-connecting fitting shall be installed on each end of the hose. The fittings shall be 3/4-in. Roylyn Incorporated Series 1300 or equal. Material may be brass or corrosion-resistant steel.

The Sealab end shall have a coupling type fitting.

The support-vessel end shall have a coupling type fitting.

A plug shall be provided for each end of the hose and secured to the hose with a chain or small stainless steel cable. The plugs should be of the same material as the end fitting; however, aluminum may be used with corrosion-resistant steel fittings.

c. Cleaning. Upon completion of the installation of the end fittings, the hose shall be thoroughly cleaned for helium and breathing air service. The plugs shall be installed to prevent the interior from becoming contaminated during handling.

d. Color Coding. Both ends of the hose shall be color coded to distinguish the gas-supply hose from the air-supply hose. The connection on Sealab shall also be color coded.

5. Air Supply

a. Hose. The air-supply hose shall be 3/4-in. I.D. × 1-1/4-in. O.D. with a minimum working pressure of 400 psig and shall be Weatherhead H-16 or equal. The hose shall be in one continuous length.

b. End Fittings. A two-way shut-off quick-connecting fitting shall be installed on each end of the hose. The fittings shall be 3/4-in. Roylyn Incorporated Series 1300 or equal. Material may be brass or corrosion-resistant steel.

The Sealab end shall have a nipple-type fitting.

The support vessel end shall have a nipple-type fitting.

A cap shall be provided for each end of the hose and secured to the hose with a chain or stainless steel cable. The caps should be of the same material as the end fitting; however, aluminum may be used with corrosion-resistant steel fittings.

c. Cleaning. Upon completion of the installation of end fittings, the hose shall be cleaned by purging with compressed air to remove any foreign particles from the interior of the hose. The caps shall be installed upon completion of cleaning.

d. Color Coding. Both ends of the air supply hose shall be color coded to distinguish the air supply hose from the gas supply hose. The connection on Sealab shall also be color coded.

UMBILICAL CONNECTIONS ON SEALAB

Power and Communication

The cable connections for power and communication shall be as specified in the Electrical System and Communication System Specifications.

Gas Sampling and Gas and Air Supply

A quick-connecting coupling type fitting shall be installed on each Sealab gas line. Each coupling shall mate with its respective hose nipple in the umbilical cord. Plugs shall be provided and secured to the gas lines with chain. The plugs should be of the same material as the coupling; however, aluminum may be used with corrosion-resistant steel fittings.

UMBILICAL CONNECTIONS ON SUPPORT VESSEL

Power

NOTS, Pasadena, will provide and install the mating receptacle and circuit breaker on the support vessel. The receptacle and circuit breaker shall be a Crouse-Hinds Catalog No. DVR75-2042-WT125-3. To insure proper phasing, pin-connection information shall be furnished by San Francisco Naval Shipyard (SFNS) to NOTS, Pasadena.

Communications

A mating receptacle for the communication-cable plug with a water-proof cap and chain shall be furnished to NOTS, Pasadena, for installation on the support vessel. The receptacle, or sufficient details for installation plans, should be furnished to NOTS, Pasadena, as early as possible. SFNS shall furnish a pin connection schedule to NOTS, Pasadena.

Gas Sampling and Gas and Air Supply

Quick-connecting nipples which mate with the coupling on the respective hoses, or sufficient details for the installation plans, shall be furnished to NOTS, Pasadena, for installation on the support vessel as early as possible. The couplings furnished shall be suitable for connecting to pipe identical to those in the umbilical. Hose color-code information shall also be provided so that the connections on the support vessel may be coded in the same manner.

NOTE: Hansen Manufacturing Company hose fittings, Series 2-HK and 6-HK as applicable, may be used in lieu of Roylyn type specified.

Chapter 11

THE DESIGN, CONSTRUCTION, AND OUTFITTING OF SEALAB II

Malcolm MacKinnon III
San Francisco Bay Naval Shipyard
San Francisco, California

DESIGN PHILOSOPHY

In the middle of January 1965, Hunters Point Division of the San Francisco Bay Naval Shipyard was approached with an interesting proposal. Could it undertake the design, construction, and outfitting of an underwater habitat to be called Sealab II? Acceptance was given even though it was apparent that this was a marked departure from normal. The normal tasks of a shipyard are the construction, conversion, and repair of Naval Ships. There would be none of the clean-cut, detailed specifications and contract plans a shipyard normally receives when embarking on the construction of a prototype design.

This project was in the realm of applied research and involved a large number of activities and people. Extensive studies in many areas for equipment selection and arrangement were precluded by time and economic reasons, and empirical results of precious tests were relied on and used. Naturally, the most significant of these prior tests was Sealab I.

With the initial proposal came several parameters. Sealab II was to be a habitat capable of housing 10 men at a depth of 250 ft for a period of 30 days. Thus, complement, working depth, and duration were established directly from the basic goals of the project.

In addition, much experience in the hitherto nonexistent field of underwater habitat design and construction was obtained by the Navy's Mine Defense Laboratory through its efforts in support of Sealab I. The assistance and guidance provided by MDL in early design phases were invaluable. Many equipment and installation specifications came directly from MDL.

A great deal of the equipment utilized in Sealab I was "off-the-shelf" and of the mail-order-house variety. The fact that it functioned well in Sealab I, and a tight budget and schedule for Sealab II, influenced selection in many instances.

The effect of feedback from Sealab I on basic design was considerable, and the following major design parameters were obtained, most resulting from operational difficulties experienced in Sealab I.

1. Sealab II was to be a pressure vessel capable of being pressurized prior to submergence to bottom pressure.

Reason: Sealab I was a nonpressure vessel and was flooded more than once while being lowered while keeping internal gas pressure higher than hydrostatic.

2. Submergence and bottom emplacement were to be done with Sealab II in an unoccupied condition.

Reason: There would be less danger of personnel casualty if anything went wrong during pressurization and lowering. The importance of personnel safety was held paramount.

3. The pressure vessel was to be cylindrical, approximately 50 ft long and 12 ft in diameter.

Reason: The size of Sealab I and the already fixed complement of Sealab II indicated that this should be close to an optimum size and shape.

4. The arrangement should include four separate areas: entry, laboratory, galley, and living space.

Reason: This basic arrangement worked well with Sealab I.

5. The atmosphere was to consist of approximately 85 percent helium, 4 percent oxygen, and 11 percent nitrogen.

Reason: Controlled experiments and experience in Sealab I confirmed this to be a proper mixture to minimize narcosis, support life, and preclude complete air purging.

6. Certain effects of helium were to be accounted for, primarily in the heat transfer area; the coefficient of heat transfer of helium being approximately six times that of air. Extra insulation must be provided.

Reason: Heat losses were not calculated in Sealab I, and no controlled tests were run. The refrigerator, a thermal electric type, never operated satisfactorily.

7. Temperature was to be held at 88°F and humidity at 60 percent relative.

Reason: These seemed comfortable in Sealab I.

8. Primary power was to come from the shore, secondary power from the surface staging vessel as part of the umbilical cord. Communications, secondary gas supply and sampling, and compressed air for external tools used were also to come down the umbilical.

Reason: Assuming the integrity of the primary power source, the staging vessel could depart and not cause an immediate abort or dangerous situation. Primary gas supply was from an external bank of bottles. Sealab I was terminated due to impending heavy weather. This development would make Sealab II more independent.

9. There were to be a maximum number of portholes with the capability of seeing the bottom periphery of Sealab II.

Reason: A near-fatal accident occurred in Sealab I. An unconscious man was rescued only when his bottles bumped the side of Sealab I; he was not visible from within.

10. The atmosphere-water interface was to be as close to the bottom as possible.

Reason: With no good data or information as to the extent of excursion dives deeper than saturation pressure, deeper depths could be reached from a higher saturation pressure.

11. Reduction of the interior volume was to be made wherever possible by use of interior tanks, dead spaces, etc.

Reason: Any decrease in interior volume was a decrease in the amount of helium required and thus a cost savings.

12. Sealab II was to be painted white.

Reason: The international orange of Sealab I would not have the acuity that white does underwater; hence easier sighting in marginal visibility conditions.

There were a few other more minor considerations but the afore-mentioned were about the extent of information the shipyard received in the forms of design parameters.

It became apparent very early that the biggest problem area in Sealab I was in the submerging operation. Railroad axles at 300 lb each were used as variable ballast. These were loaded by hand, and when sufficient negative buoyancy was reached, lowering was by a sling and whip arrangement from a crane on the surface. A 9- in. nylon line was used, and the effect was similar to a huge yo-yo on a rubber band. Once on the bottom, additional axles were added

to increase negative buoyancy. To eliminate this unwieldy method of ballasting, Sealab II was designed along submarine principles. The variable ballast would be water, stability would be maintained during all phases of the submerging operation, and negative ballast on the bottom to insure firm seating would also be water. NOTS Pasadena developed a winch-counterweight lowering system (Chapter 18) that made lowering against negative buoyancy feasible and desirable. Flooding had to be controlled simply and externally, since Sealab in this phase of operation was unoccupied and sealed.

The condition requiring full working pressure internally at the surface made the Sealab II cylinder an internally pressured nonfired vessel under the ASME Boiler Code. The code governs the structural design, construction, tests, and inspection. The tables in the code indicated that one-inch-thick mild steel was sufficient for a working pressure of 125 psi, ample for the desired 250 ft. A structural-strength test, hydrostatically, to 1-1/2 times working pressure was also required. The end cappings for the cylinder were required to be ellipsoidal dished heads of proper curvature and depth. Their unique method of fabrication will be discussed later.

The use of water as variable ballast and the desire for reduction in internal volume to save helium combined to provide internal ballast tanks. These were built into the overhead of the cylinder with sufficient capacity to allow proper reserve buoyancy on the surface and adequate negative buoyancy on the bottom, as previously discussed. The structural details necessitated making these tanks "soft", i.e., incapable of withstanding pressure differentials in excess of 15 psi across their lower boundary.

To preclude the necessity for a porthole (viewing port) capable of withstanding full internal pressure and to allow large (24-in.) ports, structural covers were provided internally to constrain the pressure. When opened on the bottom they then exposed the port viewing glass to a pressure differential of slightly over 6 psi. This allowed the use of 1-in. plexiglas as the viewing-glass material.

Previous data on equipment behavior in helium existed only in what could be obtained from Mine Defense Laboratory observations during Sealab I. Many commercially obtainable items functioned well, and this fact was accepted, tempered wherever possible by actual tests prior to any operational certification. As an example, commercial dehumidification units used apparently successfully in Sealab I. The same type units were procured and tested in helium at the Sealab II working pressure. It was noted during operational test that the compressor motor did not function properly. The malfunction was traced to a metallic relay in the motor start circuit that apparently changed its characteristics when operating in helium. Replacement with a sealed-unit relay restored normal operation. The rated capacity of 47 pints/day was never conclusively checked, however. A standard Navy-type refrigerator-freezer was procured, additional insulation added, and the unit was tested in helium at working pressure. The thermal sensors in the refrigeration compartments were of the fluid-filled bulb type and would have crushed under the extreme pressures. Once these were replaced with thermocouple type sensors the refrigerator and freezer functioned properly.

No data were available on heat losses and heat input during Sealab I, although qualitatively the aquanauts seemed comfortable at a temperature of 85° - 90°F at relative humidities between 60 and 70 percent. It was obvious that these observations were all that was readily available to design the heating dehumidification, and insulation systems. A psychrometric chart for a He-N_2 - 0_2 atmosphere was nonexistent. A qualititive analysis indicated that since ambient temperatures for Sealab II would be 20° to 30°F cooler than for Sealab I a much higher heating capacity (needed also to allow for many more men and a larger volume) and more insulation were required. Consequently, 25 kw of heat were provided and 2 in. of cork insulation on the inner surface of the shell were installed. These perforce were based on the most rudimentary qualitative analysis. A concrete deck was used for several reasons:

1. Structurally simple and economical
2. Provided additional ballast
3. Reduced further the internal cubic

4. Provided insulation

5. Enabled the use of radiant heating by embedding several runs of mineral insulated (MI) heating cable in the concrete. Additional heating was installed in the form of household convection baseboard and overhead radiant heaters.

The ventilation system was modeled after a standard submarine system. Atmosphere treatment was determined to be sufficient if lithium hydroxide (LiOH) CO_2 scrubbers and charcoal filtration were used. The major effort in this regard was to properly channel the supply and return atmosphere to optimize treatment.

Thus it is seen that the design philosophy involved in the development of Sealab II was very loose and flexible, based on a few supplied parameters and tempered by empirical data, economics, and time. Since Sealab II was a complex total project, very few design decisions were independent; most affected many other project team members, making this project a good problem in systems engineering. Time and geographic distance precluded lengthy conferences on design decisions. Mostly the decisions were made locally, members of the team informed, and if no objections were heard in a reasonable length of time, production commenced. The results of these philosophies and decisions, the vessel itself and its characteristics, will be discussed in succeeding sections.

DETAILS OF CONSTRUCTION

The construction of Sealab II was generally a routine shipyard task with a few interesting exceptions. The production schedule was extremely tight, but not unlike any other more conventional shipyard project. Standard shipyard organization and practices were used throughout.

The ASME Boiler Code under which the main cylinder was constructed provides for certain procedures to be followed in assuring adequate quality. The steel selected for the main structure was 1-in.-thick mild steel, Grade M, of Military Specification MIL 5-16113 and, as such, received extensive testing at the rolling mill. The plate was ultrasonically inspected locally to check for laminations, and other specifications were spot checked. Welding was performed in accordance with current procedures for mild steel (AISI 1015-1025). All welds were radiographed, and films were evaluated according to the latest standards. All welds were defect-free.

After fabrication of the basic structure, a hydrostatic test to 1-1/2 times working pressure, 190 psi, was applied to test for strength. This was done prior to outfitting with fresh water to minimize any harmful effects. After installation of all piping systems and upon completion of all hull penetrations, a tightness test at working pressure was conducted using air. Helium was not used due to economic and time restrictions.

In general, standard shipyard procedures were used in all phases of construction and testing. Quality-control procedures commensurate with those employed on normal shipyard work were invoked.

As mentioned previously, the schedule was very close and would surely have been missed if it were not for the rapid solution of many production and procurement problems. Fabrication of the large (24 in.) portholes was extremely difficult, since tolerances were very close and hard to maintain in the face of normal welding distortions. Not the least of the procurement problems involved the ellipsoidal dished heads used to cap the main cylinder.

Once design specifications were set, contract bids were let to the normal suppliers of these large dished heads. The production schedule demanded a 30 to 45 day delivery. None of the major steel companies, the normal sources, could begin to touch this time frame. The large size of the heads, coupled with a rash of back orders due to an inpending steel strike, made normal procurement impossible. The earliest delivery that could be expected was five to six months, after the scheduled submergence of Sealab II.

Fortunately the shipyard maintains the Navy's West Coast Shock Testing Facility and thus has had a fair amount of experience in underwater explosions. The use of the energy of an underwater explosion to form metal is a noval idea, used sparingly in the past to form relatively small and simple pieces. The energy of explosion is transmitted as a pressure pulse through the water, forming the steel against a female die. The forming process lasts only a few milliseconds. The employment of this process to form large and complex sections like these dished heads was hitherto never attempted anywhere. Expedience and necessity being the parents of invention, the decision was made to attempt this quantum jump in the technology of metal forming.

Immediately several problems became apparent: die design and construction, including curing of the concrete, handling and rigging, and configuration and size of the explosive charge. Briefly, a large die, 14-1/2 ft in diameter and 5-1/2 ft high, filled with a special-formula quick-curing concrete, was designed and built. A blank of steel was placed over the die and a vacuum drawn under the blank. This vacuum is extremely important, since any entrapped gas would have to vent, wrinkling the edges of the piece. One hundred pounds of C-4 plastic explosive were distributed in two concentric rings and a lumped central charge. The calculations for charge configuration, size, and standoff distance were extremely complex and important, as was the depth of water at detonation.

The entire assembly, weighing 60 tons, was lowered 30 ft beneath the surface of San Francisco Bay using the shipyard's large gunning crane. There the explosive was detonated, and in approximately 0.004 sec the first dished head for Sealab II was formed.

The results were phenomenally good, and only minor straightening in certain areas was required. The heads checked dimensionally within 1/16 in. on the diameter and within 1/4 in. on the contour, well within specifications. The metal did not thin at all, and thickening by approximately 0.075 in. occurred at the rim where stresses were highest.

A detailed metallurgical analysis was conducted, comparing the stock plate, the place after forming, and the plate after stress relieving. As expected, the severe cold working of the explosive forces embrittled and toughened the plate. Stress relieving restored most of the original metallurgical properties.

The expense of die fabrication was considerable, but once made it can be reused. Die life can be made excellent, and once eight heads are formed the process becomes attractively competitive.

The significance of this feat can best be illustrated by excerpts from a UPI story in the Berkeley, California, Gazette, dated Nov 18, 1965.

> "Denver (UPI) - A metal shaping process . . . is being studied by Martin Co. and Denver University scientists for possible use in forming missile domes, side plates for ships, and other large structures.
>
> The technique was demonstrated Wednesday with the production of . . . ash trays.
>
> It involved the placing of a sheet of metal across a die or mold, then submerging the mold and metal in water. An explosive charge was detonated a few inches away, beneath the water, causing a shock wave to blast the metal into the mold.
>
> The experiment is being conducted under a one million dollar government grant by DU's Denver Research Institute and the Denver division of the Martin Company. It is expected to take three years to prove or disprove the process."

Figures 33 through 44 on the succeeding pages illustrate the process.

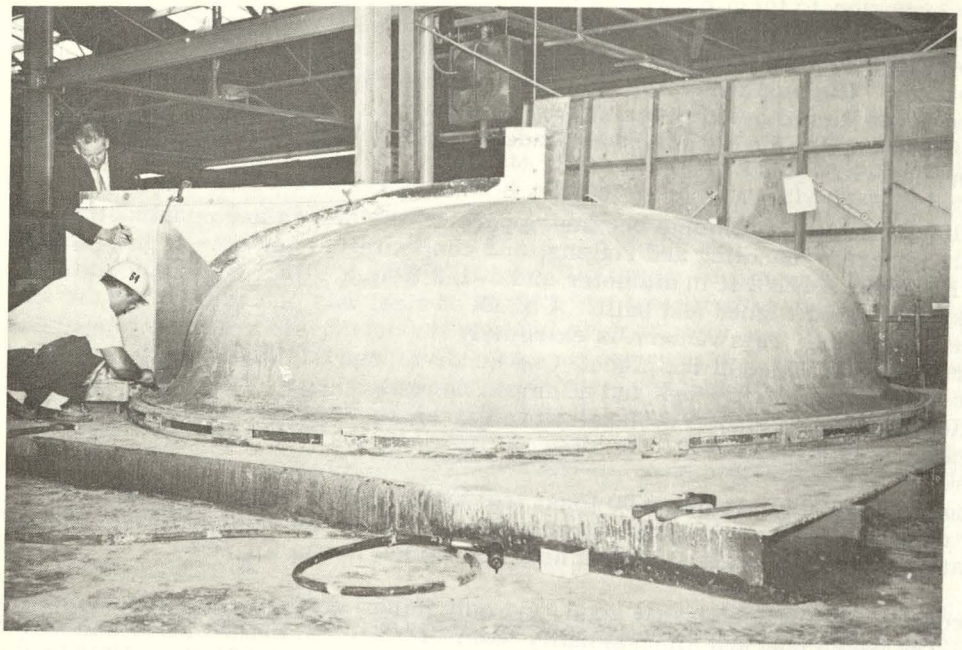


Fig. 33. Plaster of paris male mold being finished

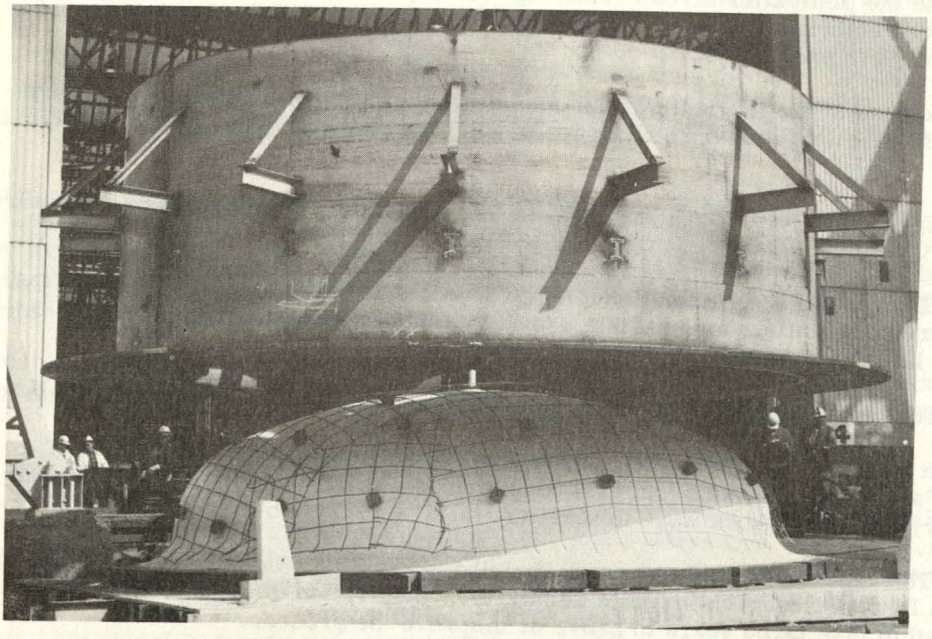


Fig. 34. Steel die casing is lowered onto fiber glass lining

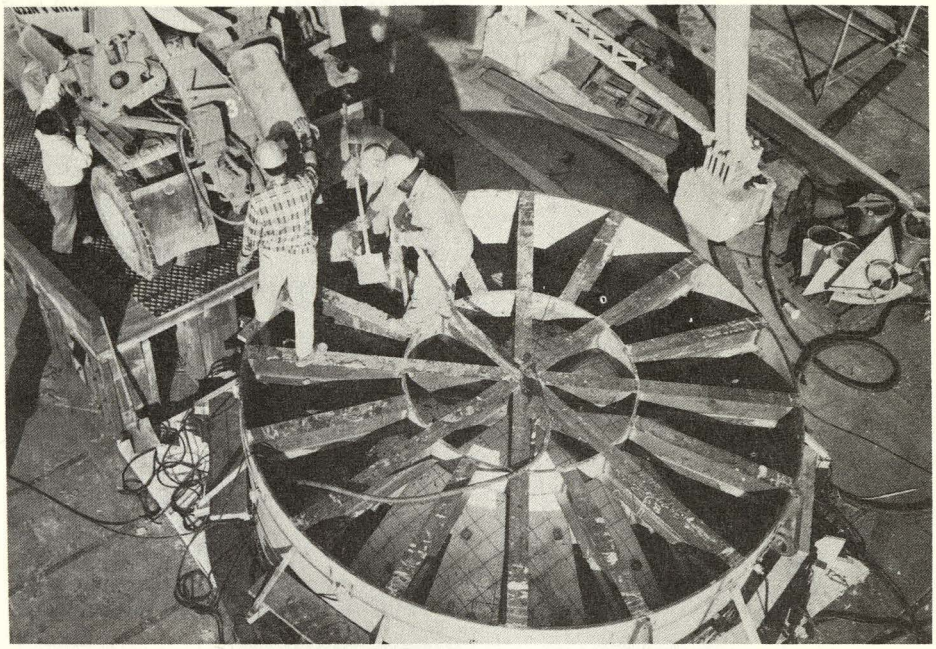


Fig. 35. I-beam structure forming bottom of die, concrete being poured

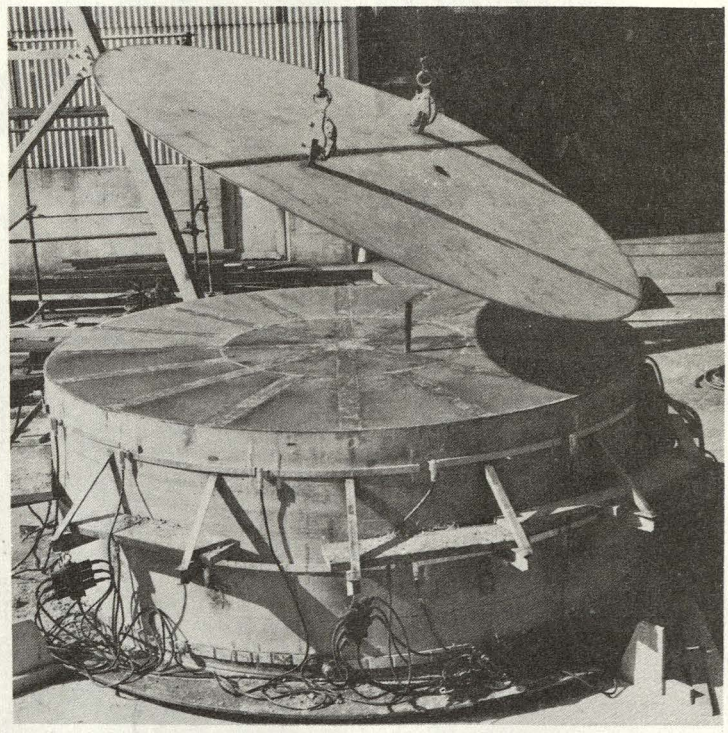


Fig. 36. Concrete is screeded and bottom of die is capped airtight with steel plate

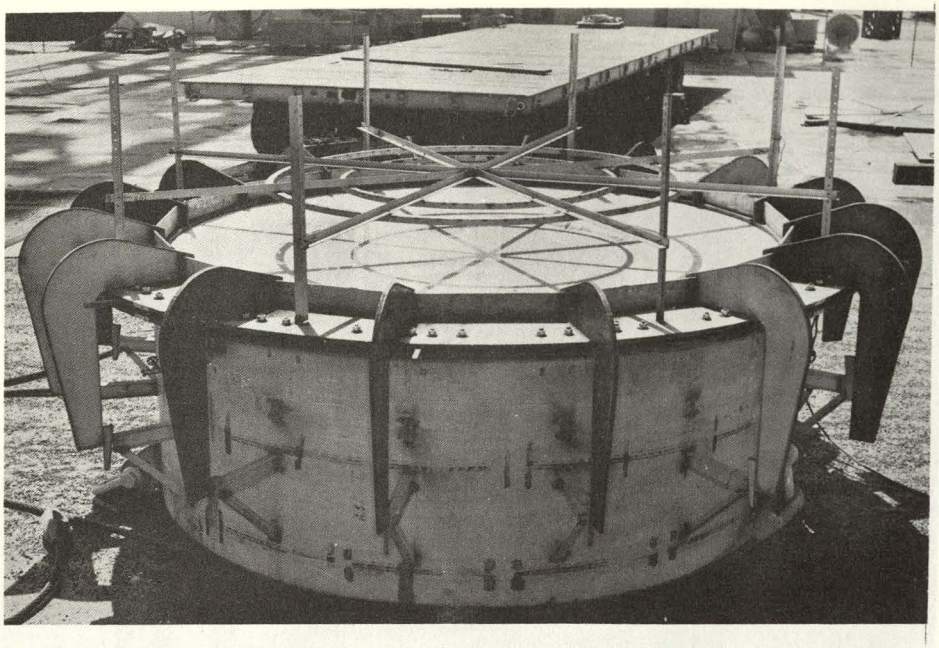


Fig. 37. Steel blank is clamped in place on top of die with dogged hold-down ring

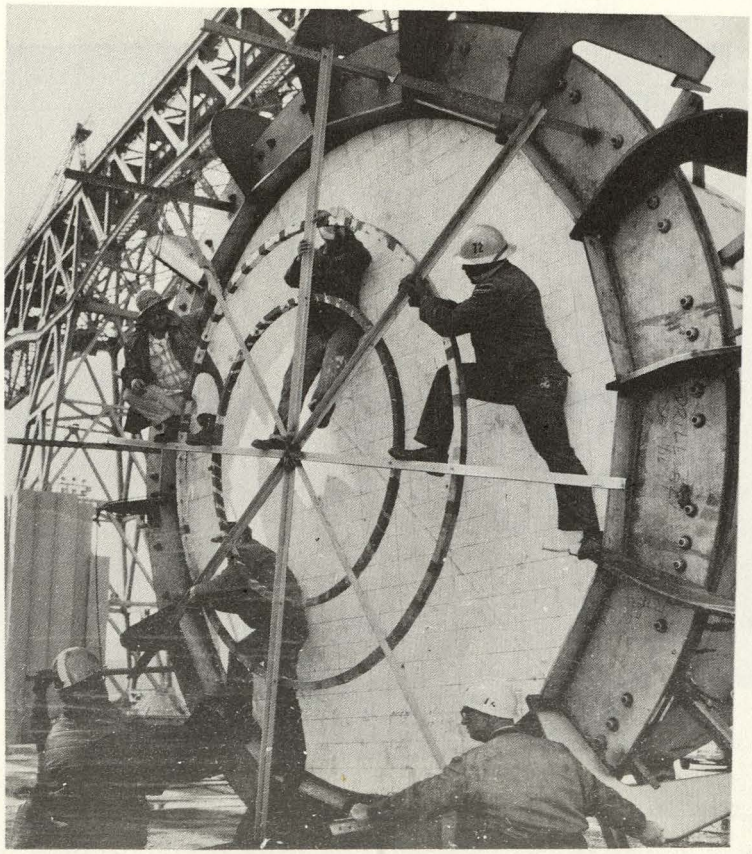


Fig. 38. Ring-shaped explosive charges being mounted on die assembly

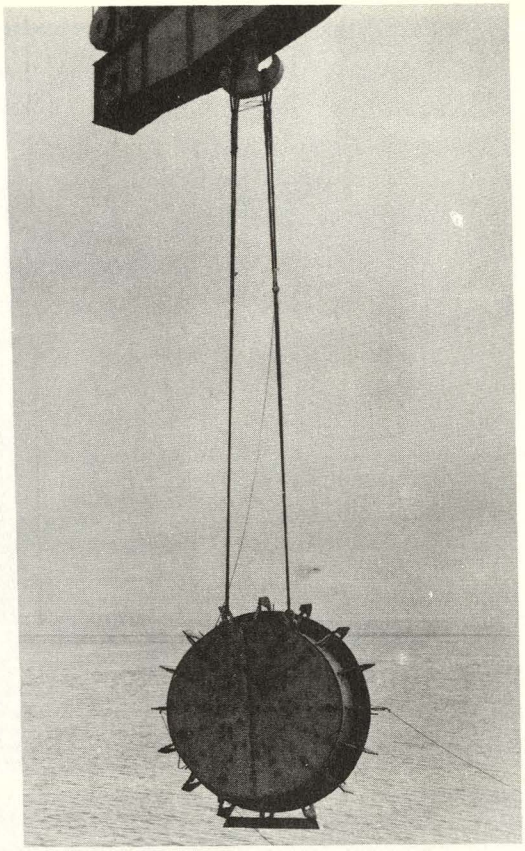


Fig. 39. Sixty-ton die assembly is lowered into San Francisco Bay to 30-ft depth

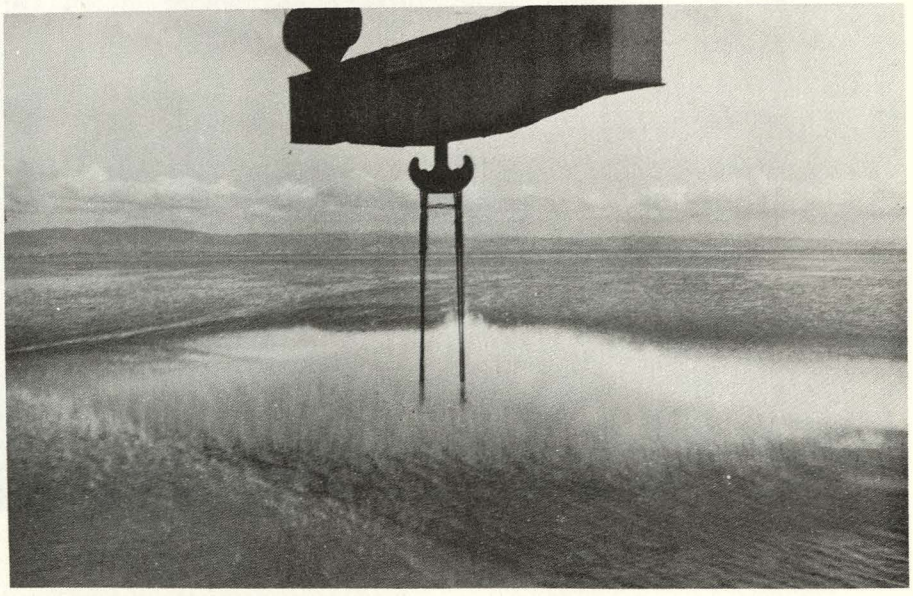


Fig. 40. Spray dome at instant of detonation

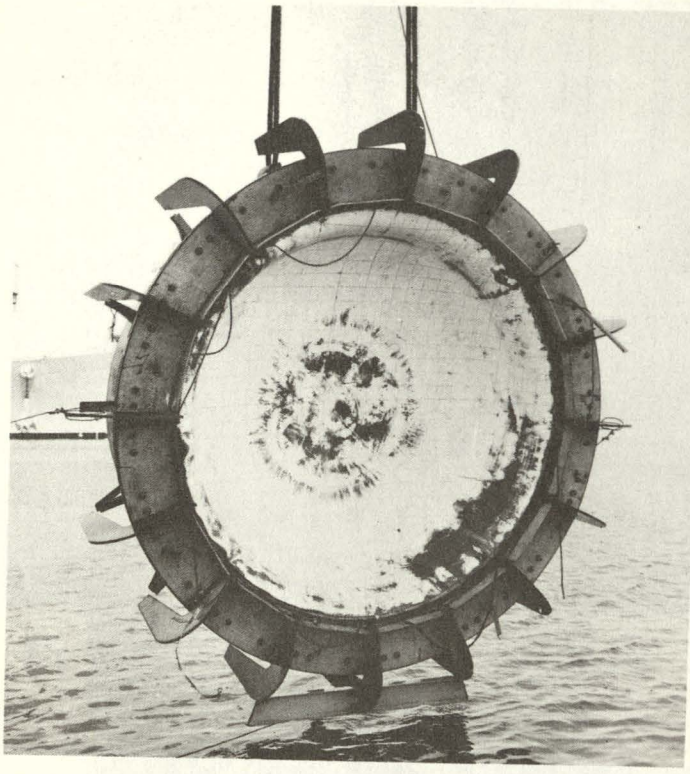


Fig. 41. Formed blank immediately after lift up

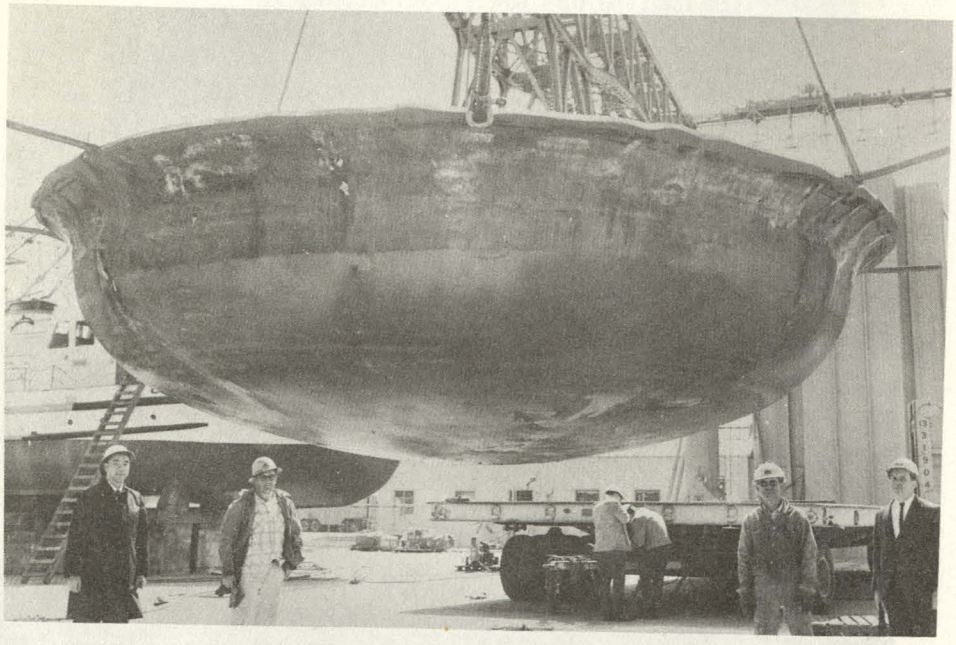


Fig. 42. Formed blank immediately after being removed from die



Fig. 43. Waste fringe of piece is trimmed before stress relieving

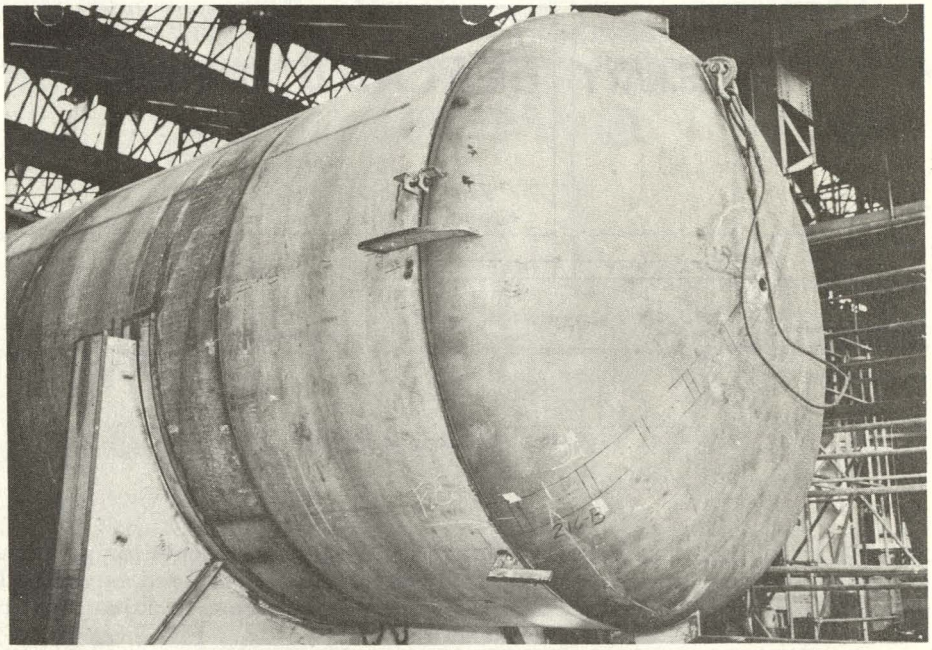


Fig. 44. Dished head is welded in place

SEALAB II CHARACTERISTICS

Hull Exterior

Sealab II is essentially a nonpropelled submarine built to withstand an internal working pressure of 125 psi (Fig. 45). It is a cylinder of one inch thick mild steel, 12 ft in diameter and 57-1/2 ft long. The cylinder is surmounted by a conning tower 8 ft in diameter and 7-1/2 ft high. The conning tower provides dry access when surfaced as well as reserve buoyancy during the pressurizing operation, but is designed to withstand a Δp of only 15 psi.

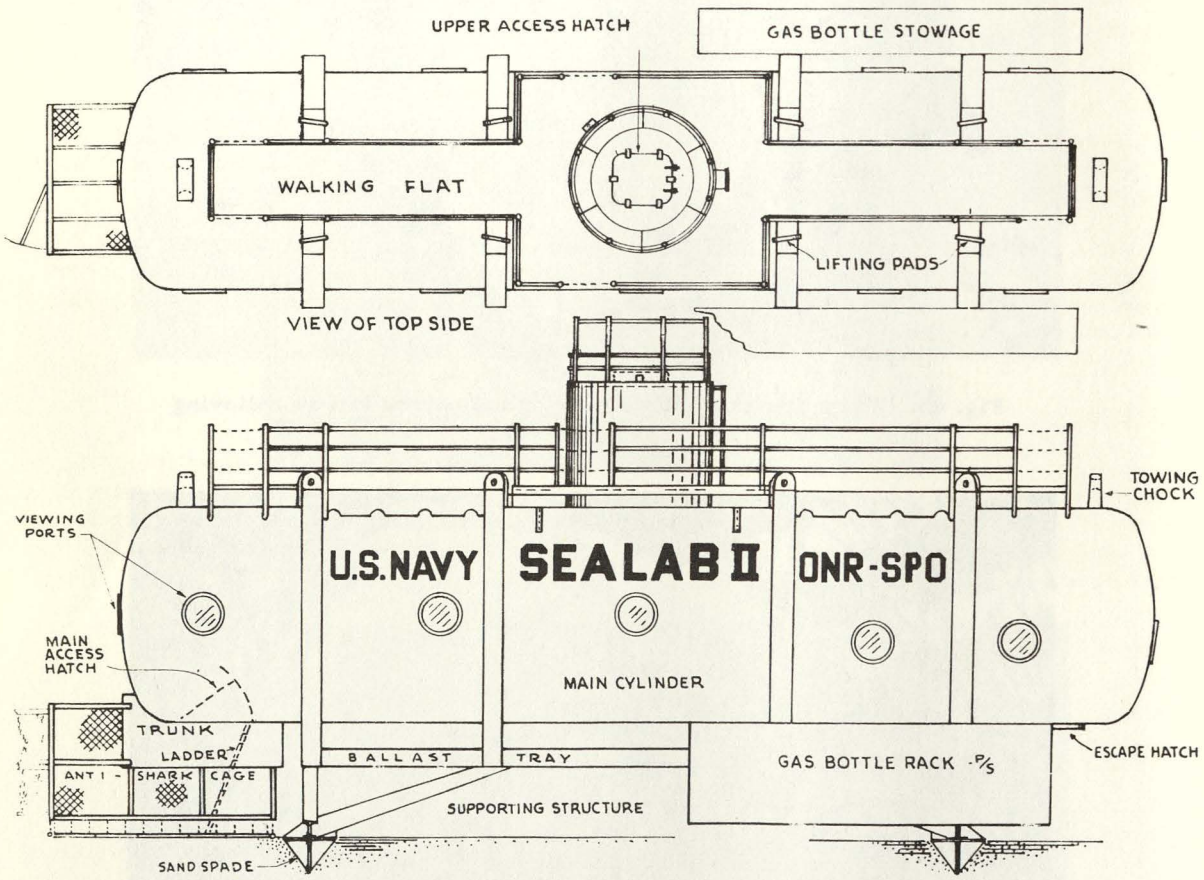


Fig. 45. Sealab II exterior

The cylinder is set in a cradle-like structure with trays underneath for permanent lead ballast stowage. A walking flat is provided around the conning tower and extending fore and aft. Variable lead ballast is stowed under this flat for ready access to adjust final trim if necessary.

Access while on the bottom is through a 48-in. diameter hatch aft. Entry is from the sea, into a protective anti-shark cage, up a sloping ladder, though the water-atmosphere interface in an 8-ft-square access trunk, and into the main cylinder. The water level in the access trunk is maintained by regulating the internal Sealab pressure. The trunk is designed to allow sufficient volume to accommodate the severest expected tidal change.

Emergency exit is forward through a 30-in. hatch. Access on the surface is through the upper conning tower hatch, a 30 psi surface ship weather deck hatch, and the lower hatch, a 30-in. hatch. The 48-in. main access hatch was specially fabricated, while the two 30-in. hatches are standard submarine escape trunk side hatches.

Lifting pads are provided for both the dry maximum weight lift and the negative buoyancy lowering. Special slings are designed for each operation. Towing chocks are provided fore and aft.

When on the bottom Sealab II is 13 tons negative and the bearing surfaces, two pads extending athwartships fore and aft, are designed for 300 psf, the bearing strength of the bottom at the site. Corner spades 15 in. in depth allow a firm implacement and increase resistance to sliding. No provision is made to level the pads, such leveling is the task of the occupants if possible by a washing process using compressed air and water.

Stowage racks for 24 - 1300 cu ft gas bottles are provided port and starboard forward. The bottles contain make-up helium (10), make-up oxygen (11) and a helium-nitrogen-oxygen mixture for emergency breathing (3).

There are 11 viewing ports each 24 in. in diameter. These ports are designed to withstand 15 psig internal pressure and are protected at full internal pressure by hinged steel covers. An equalizing line allows maintenance of a $\Delta p = 0$ across the glass while submerging. This line is capped at depth and the steel covers opened.

Hull Interior

The variable water ballast tanks are three feet deep and located in the overhead (Fig. 46). These tanks are "soft" tanks, i.e., the bottom boundary cannot withstand a Δp of greater than 15 psi. These tanks provide, with the conning tower, the negative buoyancy necessary for initial submergence and lowering, and the negative buoyancy necessary for firm seating on the bottom.

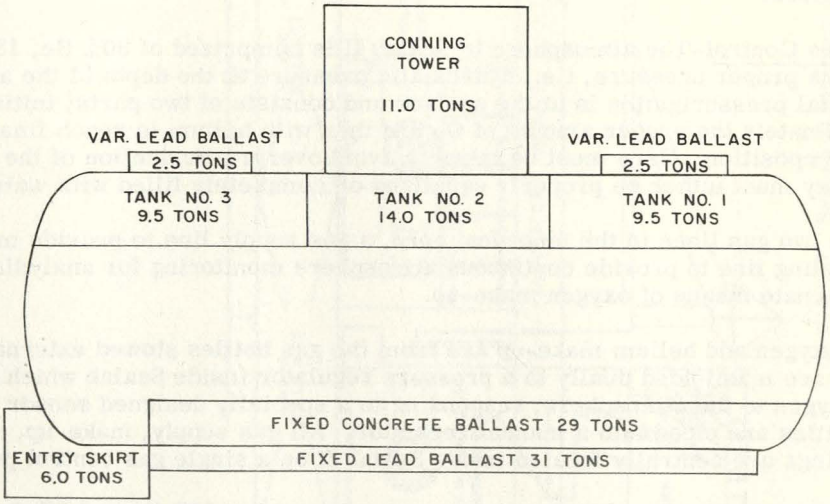


Fig. 46. Sealab II fixed and variable ballast

The deck is made of poured concrete two feet in depth and comprises a portion of the permanent ballast. The deck and overhead ballast tanks reduce the usuable internal volume and consequently the amount of helium needed to fill the atmosphere, an important economic consideration (Fig. 47).

This usable internal volume, 7 ft in height, is divided into four separate areas (Fig. 48). The aftermost area is the entry and contains two tub-showers to aid in regaining body heat after a sortie in 50°F water, as well as stowage for wet-suits and breathing apparatus.

The next area forward is the laboratory, separated from the entry by a 3-1/2-ft watertight dutch door which gives an extra margin of safety if the water level should rise in the entry trunk into Sealab itself. The laboratory contains counter and stowage space, a sink, a cable trunk, instrumentation racks, the communications center, and the fan room, heart of the ventilation system.

Next forward is the galley area, containing stowage and counter space, an electric range, a refrigerator-freezer, wash basin and water closet, and the main power transformer enclosure and distribution panels.

Finally, forward most is the berthing area with ten bunks, a dropleaf table, locker and stowage space. Access to the emergency exit hatch is through a removable cover in the deck.

Mechanical/Electrical

Ventilation System-The system consists of a central fan room with a 250 cfm capacity, recirculating centrifugal fan, discharging through ducting to the berthing, galley, laboratory, and entry areas. Return atmosphere is drawn into the fan room as follows:

60 cfm directly through a LiOH CO_2 scrubber, with the remaining 190 cfm by-passing the scrubber through a duct in the water closet bulkhead. The combined 250 cfm is passed through an activated charcoal filter, where noxious hydrocarbons are removed, and thence to the fan inlet. Bracket fans are utilized to aid circulation. The pitch on the fan blades and the impeller configuration are modified to allow for the increased density of the atmosphere as well as its increased pressure.

Atmosphere Control-The atmosphere in Sealab II is comprised of 80% He, 15% N_2 and 5% O_2 by volume at the proper pressure, i.e., hydrostatic pressure at the depth of the air-atmosphere interface. Initial pressurization is at the surface and consists of two parts, initially with air to give approximately the proper amount of O_2 and then with helium to reach final pressure and mixture composition. Care must be taken to avoid overpressurization of the internal ballast tanks. They must either be properly equalized or completely filled with water.

There are two gas lines in the umbilical cord, a gas supply line to provide make-up helium and a gas sampling line to provide continuous atmosphere monitoring for analysis and also to provide an alternate means of oxygen make-up.

Primary oxygen and helium make-up are from the gas bottles stowed externally. The oxygen bottles are manifolded dually to a pressure regulator inside Sealab which automatically replenishes oxygen to the atmosphere, responding to a specially designed sensor (Krasberg). The helium bottles are piped into a manual regulator. All gas supply, make-up, and sampling valves and fittings are centrally located inside Sealab II on a single gas control panel.

Three external bottles are filled with a premixed supply of 95% He and 5% O_2 piped into a regulator on the gas control panel which supplies eight, four outlet manifolds to which standard Scuba regulator-mouthpiece units can be plugged. This comprises the emergency breathing system, (Bibb System), and is used in case of severe atmosphere contamination.

In the overhead of the entry area four supply compressors and four vacuum pumps are installed. Their function is to supply Sealab atmosphere through an external hose to the breathing gear of a swimmer on sortie and return exhaled gases back to Sealab. This is called an

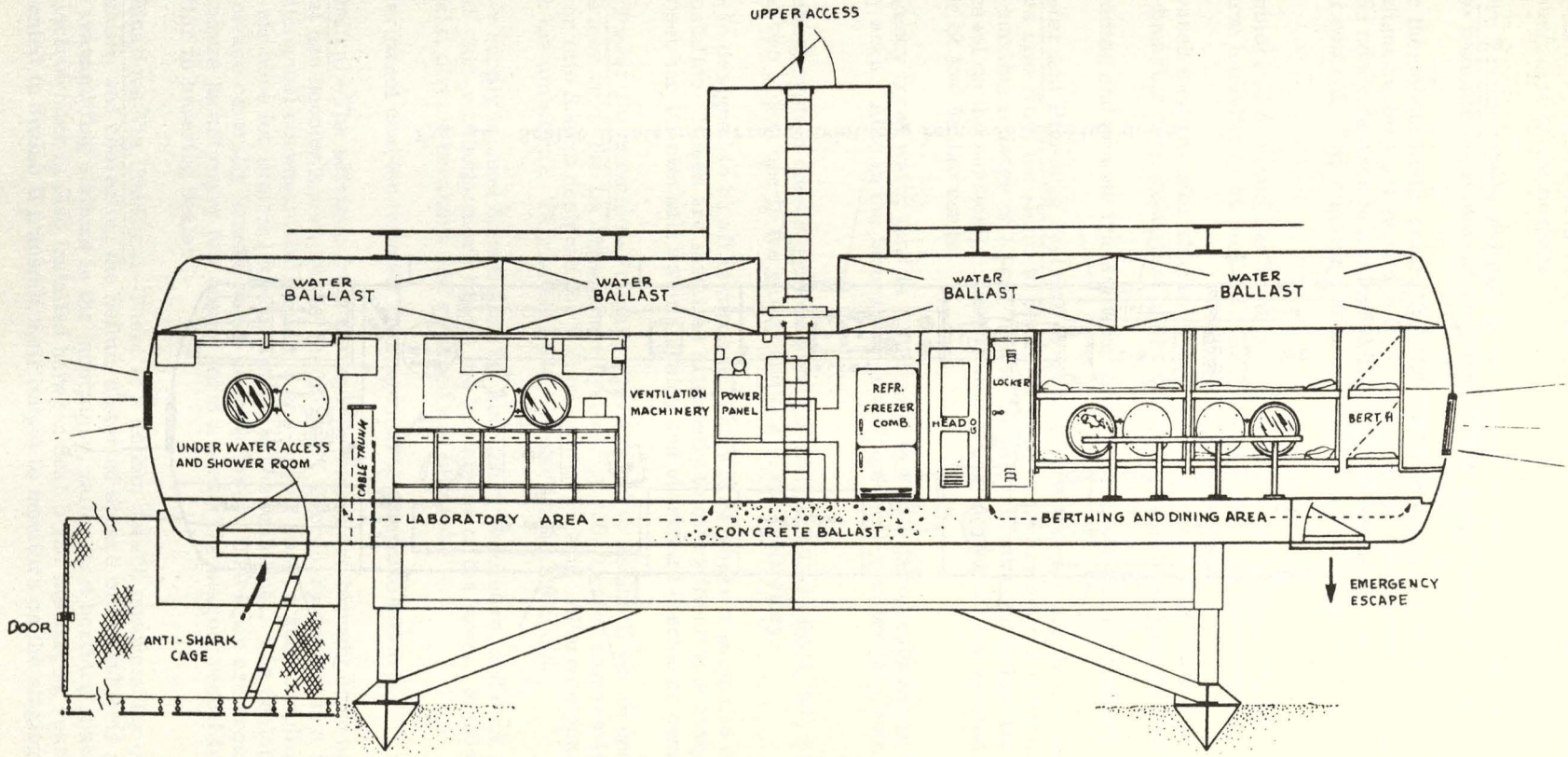


Fig. 47. Sealab II interior arrangement, centerline section looking to port

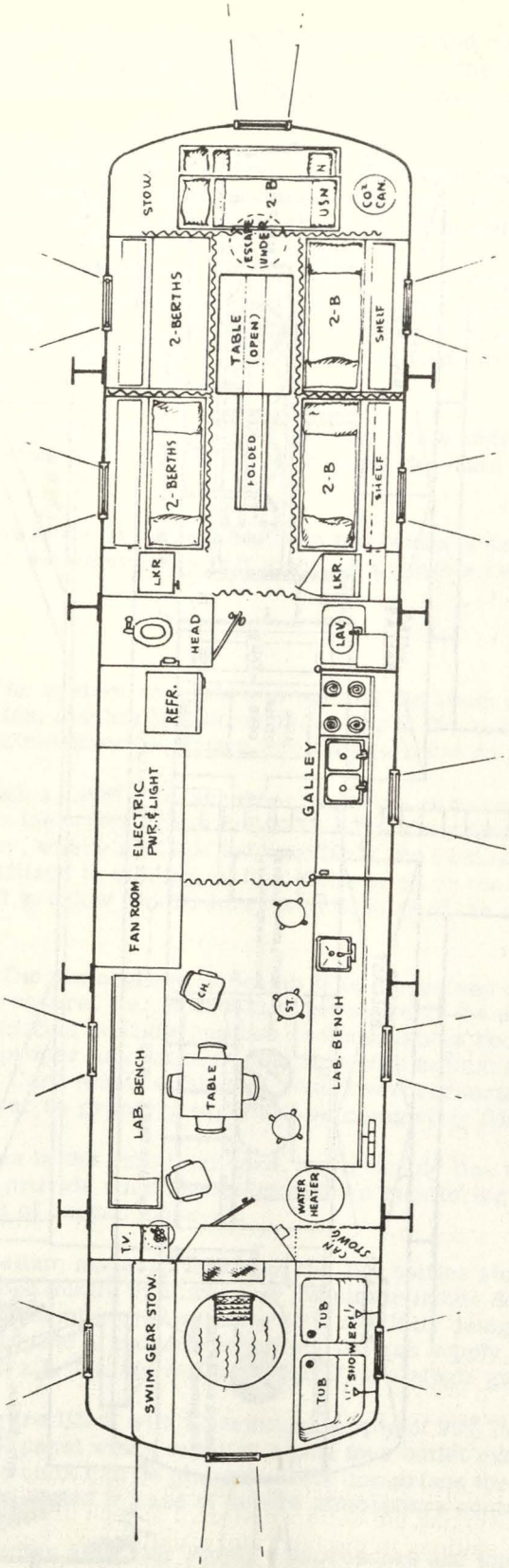


Fig. 48. Sealab II interior arrangement, top removed, looking down

Arawak or "hookah" system and is very desirable for short sorties in that it frees the swimmer from cumbersome scuba devices.

Atmosphere Treatment—In addition to the control of CO_2 and hydrocarbon content, means are provided to regulate the temperature and humidity of the Sealab atmosphere.

There are thermostatically controlled baseboard convection heaters in each area except the entry. Radiant heaters are provided in the entry area, nonthermostatically controlled. Imbedded in the concrete deck is a mineral insulated (MI) electric cable, with its own independent thermostat control. The maximum total heating load is 25 KW. Normal design temperature is 88°F.

Eight commercial dehumidifier units are installed, each with a capacity of 47 pints/day to keep the relative humidity at 60 percent. Each is controlled by a humidistat.

The increased heat transfer characteristics of the helium atmosphere require two inches of standard submarine cork insulation on the hull and one inch on the overhead.

Direct reading and remote transmitting temperature and humidity sensors are installed.

Fresh Water and Plumbing Systems—A boosted fresh water supply consisting of two one-inch PVC pipes laid from the shore to Sealab II is the primary source of fresh water. Demand is based on a maximum usage of 10 gal/min at 50 psig. In addition, a line from Sealab II to the staging vessel on the surface provides a means for topping off the staging vessel tanks during periods of low Sealab usage.

An emergency fresh water tank is installed with a 150-gallon capacity in the overhead of the laboratory area. Also in the laboratory is a 50-gallon hot water tank with a short recovery time.

The plumbing system consists of one small boat-type water closet, two tub showers, a washbasin and two sinks, one in the galley and one in the laboratory.

Drainage is designed to be aft towards the entry area where a sump and overboard connection are installed. Hoses are installed externally to carry the drains away from Sealab. The water closet has its own salt water flushing and overboard discharge connections.

Electric Power Distribution—Primary power is led to Sealab II via an underwater 2300-440 v transformer from the La Jolla power system. A 300-ft cable carries 440 v, three-phase 60-cycle power into Sealab designed for a maximum of 75 kva. Alternate power is available via a cable in the umbilical. This is also 440 v, three phase, 60 cycle.

The 440-v supply is used directly for the hot water, baseboard, and deck heaters. 400-120-v and 440 -208-v transformers handle the remainder of the loads. Standard protective distribution panels, circuit breakers and switches are utilized.

A transfer panel enables transfer from normal to alternate power.

The Umbilical—The services from the staging vessel are brought down hoses and cables nested in what has become known as the "umbilical." Secondary power via a three-conductor cable, a multichannel communication cable, a gas-supply hose, a gas-sampling hose, and a compressed-air hose for external tool use make up the umbilical. The Sealab terminations for these lines are centrally located at the conning tower. The lines are brought together and lashed in a canvas jacket every few feet to form a nest. The staging vessel terminations are hooked up prior to lowering Sealab.

Communications Via Umbilical—There is a helium speech unscrambler on the staging vessel modulating and converting the helium distorted speech of the subjects and is fed via one channel with transmitting stations in the laboratory, galley, and berthing spaces in Sealab II. A two-way electrowriter is also installed between Sealab and the staging vessel. Four TV cameras mounted in Sealab II transmit their output to monitors on the staging vessel. In

addition a TV receiver for entertainment as well as closed circuit monitoring is provided in Sealab. A two-way intercom system is available in the laboratory to the staging vessel. There it may be patched into the helium unscrambler. Another two-way intercom channel is alloted but this passes through Sealab for further transmission to shore. An FM entertainment receiver, a wedge spirometer output (measuring subject respiration remotely), and O_2 partial pressure sensing comprise the remainder of the channels in the communications link in the Umbilical.

Communications Via the Benthic Laboratory—Scripps Institute has developed an underwater multichannel data transmission station, called the "benthic laboratory" which is situated on the bottom close to Sealab II. A trunk is provided in Sealab aft on the portside of the laboratory which can be opened and through which cables can be passed. These cables then can run to and from benthic to provide the link with a shore based benthic control station. The link is audio, visual (TV), and digital and analog data transmission.

Buoyancy and Stability

The following tables should illustrate the various conditions of buoyancy and displacement.

Refer to Fig. 43.

Structure weight (less ballast, including outfit)	119 tons
Fixed Concrete Ballast	29 tons
Fixed Lead Ballast	31 tons
Variable	5 tons
Surface Displacement = Total Weight	184 tons
Submerged Displacement (defined as volume of conning tower, main cylinder, entrance skirt, and appendages):	209 tons
Ballast Tank 1	9.5 tons
Ballast Tank 2	14.0 tons
Ballast Tank 3	9.5 tons
Conning Tower	11.0 tons
Total Water Ballast	44.0 tons
Entrance Skirt	6.0 tons

The net buoyancy of Sealab II under various ballasting operations is as follows:

		Weight	Net Buoyancy Tons
Condition I	Surface displacement 1' 8" freeboard	184 tons	+25 tons
	Flood tanks 1 and 3	+19 tons	
Condition II	Sealab II floating at mid-height of conning tower	203 tons	+6 tons

		Weight	Net Buoyancy Tons
Condition II	Sealab II pressurized with helium (tank 2 and main cylinder)		
	Flood conning tower	+11 tons	
Condition III	Sealab during lowering operation	214 tons	-5 tons
	Set Sealab on ocean floor		
	Flood tank 2	+14 tons	
Condition IV	Sealab on ocean floor, tank 2 flooded	228 tons	19 tons
	Blow entry trunk	-6 tons	
Condition V	Sealab ready for entry and occupancy	222 tons	-13 tons

Stability at each Condition:

Condition	
I	GM = 2.29 ft
II	GM = 1.87 ft
III	BG = 2.21 ft

BG at Condition III included the effect of the lowering whip as buoyant force. Conditions IV and V are on the bottom and bottom reaction would increase stability. Curves of forms, though academic, were prepared.

CONCLUSIONS AND RECOMMENDATIONS

It becomes very apparent in retrospect that a remarkable experiment, Sealab II, was successfully conducted in spite of several salient facts. Severe time and schedule limitations coupled with a very close budget precluded orderly progression and thorough investigation of many important engineering areas germane to underwater habitat design. Nonetheless, though lacking perfection of design in several areas, Sealab II functioned well as a habitat for three 10-man teams for 45 days at 205 ft. It supported life safely and relatively comfortably.

Experience gained in the progress of the design, construction, and outfitting of Sealab II as well as in its operation and overall project organization, will aid immeasurably in further man-in-the-sea operations. This has been just a whistle stop on our excursion down the continental shelves.

For the record, several conclusions can be drawn and recommendations made from the vantage point of the author. These reflect his opinions and analysis and may or may not be included in the official summary report of the project.

1. A Naval Shipyard can be expected to respond to and undertake a project of this nature and deliver hardware on time and at a competitive cost. The Navy does have an in-house capability for underwater habitat design and construction.

2. A significant contribution to the technology of metal forming was made in the development and perfection of the technique of underwater explosive forming of large steel sections.

3. Engineering studies in the following areas must be undertaken at once:

a. Atmosphere treatment to insure comfort and safety. Phychrometric charts for an $He-O_2$ atmosphere must be developed, and adequate dehumidification devices must be designed.

b. An integrated gas supply and ballast control system to allow controlled descent and pressurization from within, much as a submarine statically dives. Once perfected, this would preclude heavy pressure structures.

4. The interior arrangment of future habitats must be developed from the standpoint of human engineering, wherein careful functional analyses are made. In particular, attention must be given to the entry and diving-station area.

5. A means for leveling the habitat is a necessity, since it became obvious a level site is very difficult to find.

6. Communications and monitoring equipment must be improved.

7. For succeeding man-in-the-sea operations, realistic schedules must be developed. Expedience must never be a substitute for quality.

In conclusion, appreciation must be given to the fine people connected with the Sealab II project, and in particular the men and women of the Hunters Point Division of the San Francisco Bay Naval Shipyard. All of them made Sealab II and this paper possible.

Chapter 12

MODIFICATIONS AND OUTFITTING OF THE SEALAB II HABITAT

W. B. Culpepper
U. S. Navy Mine Defense Laboratory
Panama City, Florida

and

E. P. Carpenter
Naval Ordnance Laboratory
Pasadena, California

Originally, the Sealab II habitat was to have only final outfitting and trim tests performed while at Long Beach Naval Shipyard. However, due to schedule changes, design reevaluations, and the requirements of the Certification Board, a number of modifications were necessary (see Fig. 49 for valve locations).

These modifications, with the reasons for their accomplishment, are listed below.

I. Exterior Modifications

	Item	Reason
1.	Install guards at forward end of bottle-storage racks.	Protect high-pressure piping and valves.
2.	Shorten external portion of water closet overboard drain line.	Less vulnerable.
3.	Add expanded metal bin on starboard side.	Additional exterior storage.
4.	Install valve from vent valve B-3 to top of skirt.	Blowing skirt; pressure equalization during tidal changes.
5.	Remove protective cover from valve B-3.	Better access to valve handle.
6.	Install padeyes on top of shark cage.	Attachment of dumbwaiter line.
7.	Add miscellaneous hooks inside skirt.	For handing equipment.
8.	Add vent valve A-10.	Permit venting tank No. 4 while maintaining pressure equalization between other tanks and interior.

II. Umbilical cord Modifications

1.	Replace air hose, gas-supply hose, and gas-sampling hose.	Original hoses kinked and unusable.

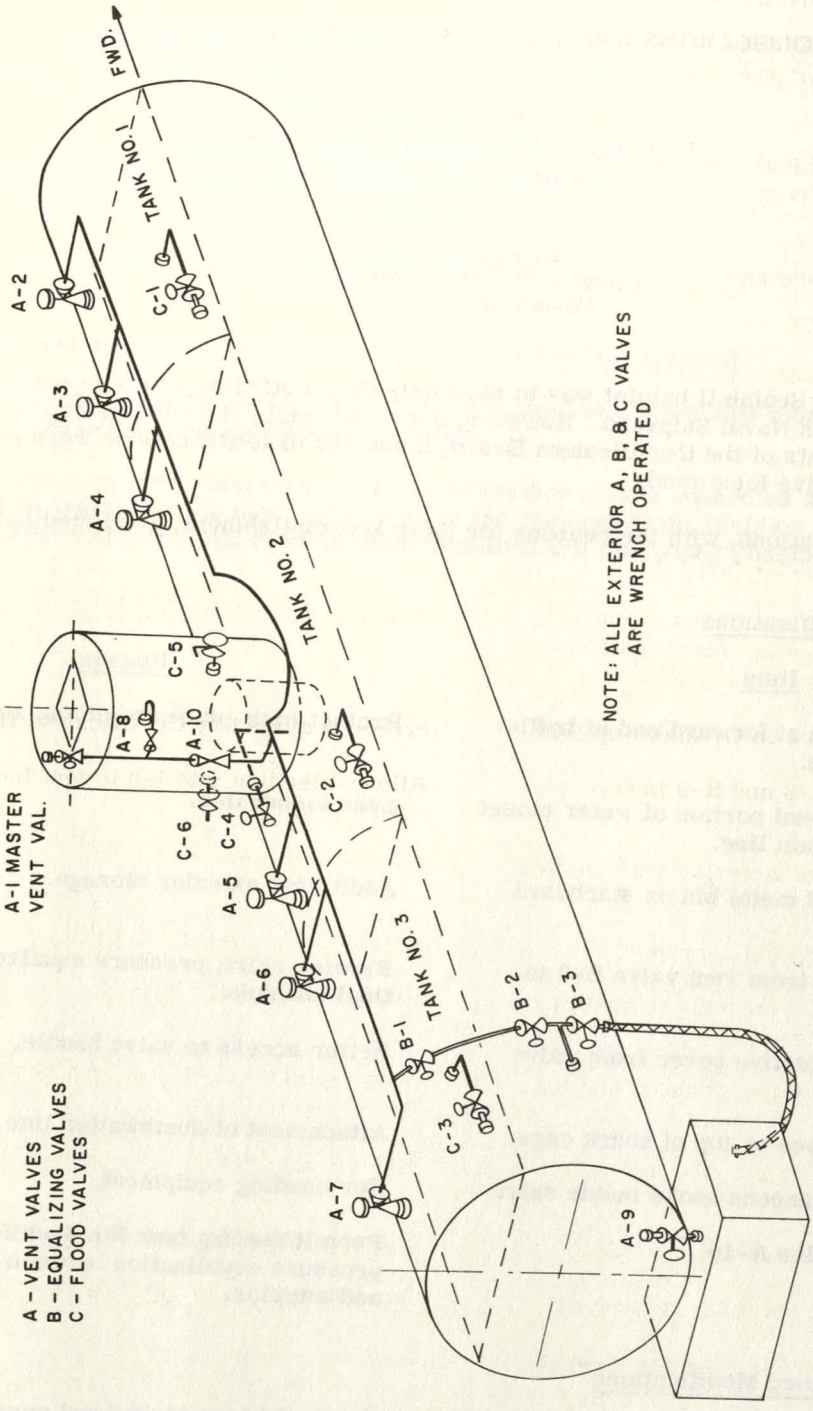


Fig. 49. Sealab II flood, vent and equalizing systems

Item	Reason
2. Add three cables.	Two for external lights, one for camera control
3. Marry umbilical components at 8 ft intervals with 9-thread manila.	Ease of handling.

III. Interior Modifications

1. Remove chain stanchions and deck sockets at entryway.	Ease of entry.
2. Shorten vent duct and move radiant heater in entryway.	Provide space to install hookah compressors.
3. Add sound-absorbing curtains between entry and laboratory space.	Improve communications while operating hookah.
4. Remove electrical convenience outlets in entryway.	Damp entryway could cause shorting.
5. Install copper tubing from waterheater relief valve to deck drain.	Safety-required by Certification Board.
6. Install pressure-relief valves on O_2 and Bibb system with overboard discharge through benthic trunk.	Safety-required by Certification Board.
7. Install flow meter in O_2 make-up line.	Safety-required by Certification Board.
8. Install valves H-8 and H-9 in O_2 make-up system.	Allows bleeding into lab if vent blower becomes inoperative.
9. Add U-tube monometer on suction side of vent blower.	Determines when filter needs charging.
10. Install screen on CO_2 scrubber.	Protects CO_2 scrubber filter.
11. Install additional shelving in berthing and galley spaces.	Additional storage space.
12. Relocate helium speech unscrambler plug receptacle in galley.	Avoid interference with circuit breaker door.
13. Modify doors and screws on electrical distribution panels.	Permit complete closing of doors.
14. Move washbasin away from hull.	Provide adequate head room.
15. Install two 220-cu ft O_2 cylinders.	Provide supply for manual O_2 make-up.
16. Remove thresholds between berthing and galley spaces.	

During the same period in which the above modifications were being accomplished, final outfitting was completed. Major items accomplished during this outfitting period are listed below:

I. Exterior

1. Secure gas bottles in racks with wooden wedges.
2. Install freshwater manifold and pressure regulator in Sealab/Staging Vessel freshwater system.
3. Attach human-engineering test platform to after end of shark cage.
4. Install BT winch mount on shark cage.
5. Install racks for ten 38-cu-ft emergency scuba bottles.

II. Interior

1. Install shower curtain rod.
2. Install hookah compressors.
3. Install self-coiling hoses on all Bibb system outlets.
4. Install carpet on deck.
5. Install heated-suit power pack in laboratory space.
6. Install event recorder in laboratory space.
7. Install Krasberg PO_2 sensing and monitoring unit on vent-system compartment.
8. Install electric timers for human-engineering tests beneath patch panel.
9. Install hanging rod behind refrigerator-freezer for stowage of charcoal filters.
10. Install light banks, filter, and plant-box racks in water-closet space.
11. Install FM speakers overhead in berthing space.
12. Clean and pressure test all gas systems.
13. Install TV camera mount aft of main access.
14. Install electrowriter transceiver.
15. Install wedge spirometer.

When it was determined that all modifications were complete, a complete systems check was performed. Sealab II was sealed and pressurized to 5 psi above atmospheric pressure. All electrical and gas systems were checked for proper operation. Sealab II was then placed in the water for trim tests and cycling of the flood and vent system.

With all preparations complete, the habitat was towed to the site near La Jolla.

Chapter 13

SEALAB II EXTERIOR LIGHTING

R. A. Barth and P. A. Wells
U. S. Navy Mine Defense Laboratory
Panama City, Florida

INTRODUCTION

The exterior lighting provided for Sealab II was Standard Navy diving lights, Symbol 313, as shown in BuShips Drawing 9000, S6405-74445, mounted on the exterior of the hull. As constructed by San Francisco Naval Shipyard, the power cables and plugs were to be led in through a section of the instrumentation trunk, connected to an interlocking switch and receptacle directly above the instrumentation trunk. A switch and receptacle was provided for each light. During the outfitting by Naval Ordnance Test Station at Long Beach, a decision was made to alter this arrangement by using Electro-Oceanic underwater connectors. The underwater connectors as well as the locations of the lights were numbered 1 through 6 for identification. Consideration was given to the use of the Burns-Sawyer Underwater Lights; however, the reports from Sealab I indicated that more problems were experienced with these lights than with the Navy diving lights. An oversight in selecting the Navy diving lights was in their short life, 50 hours nominal. The experience of Sealab II, however, indicates that the life is much longer.

After failure of the Navy diving lights on Sealab II, other types, such as quartz iodine and mercury vapor were used with varying degrees of success. From all reports, it seems that the primary failure of the quartz iodine light was due to the housing. Quartz lamps are very rugged to thermal shock and are small in size and produce about 21 to 22 lumens per watt. They can be operated on standard voltages and require no auxiliary equipment. The mercury vapor lamp, like any discharge lamp, requires that some sort of current-limiting device be used. Ballasts are used to limit the current and act as transformers to provide sufficient voltage for starting and operating. This voltage may be as high as 460 volts. The efficiency of the mercury vapor lamp is very high; the lumen-per-watt output ranges from 23 for the 100 watt size to 54 for the 1000 watt size. The mercury lamp produces a bluish-white light which is not suitable for photography.

It would appear there is a need for improved underwater lighting. The writer suggests that the following factors be considered in the development of improved underwater lighting.

1. Diver safety, i.e., low operating voltage or good insulation
2. Long life
3. Efficiency
4. Simple lamp replacement
5. Light and portable
6. Suitability for photography

EVALUATION OF DIVING LIGHTS, TEAM I

1. There were six diving lights on the Sealab II habitat - one on each end and two on each side. The lights were 1000-watt incandescent bulb type. The plugs were Electro-Oceanics types which were plugged in underwater. These plugs gave no trouble.

2. The amount of light from each bulb was sufficient; also the number of bulbs. The lights were necessary during the day due to the darkness of the water at Sealab II depth. The maximum range observed was 80 to 90 ft.

3. The first diving light failure was noted on day 5. The time required to fix this light, splicing in a new bulb, was about one hour. By day 15, all of the lights except one had failed.

4. Conclusions: The bulbs provided sufficient light but were of short duration. Too much time is consumed in changing the bulbs. A better way of changing the bulbs is definitely needed, with screw-in or bayonet type preferred. A longer life bulb is desirable.

EVALUATION OF DIVING LIGHTS, TEAM II

1. Three types of lights were used during Team 2's stay on the bottom:

a. The standard Navy diving lights that were mounted at various locations outside.

b. The Burns-Sawyer type light. This was a portable light utilized mainly around the shark cage area.

c. The mercury-vapor light that was manufactured by "Oceanics."

2. During Sealab I the standard Navy diving light and the Burns-Sawyer light were both used and, of the two, the Navy diving light proved to be more trustworthy, although it required bulb replacement quite frequently, a task always long and seemingly not worth the effort. The Burns-Sawyer types gave very limited service and were eventually abandoned because of their constant failure.

3. During Team 2's stay in Sealab II, both these lights were used, and with about the same results as that of Sealab I. The Burns-Sawyer lights were more or less abandoned for the same reason as in Sealab I. The standard Navy diving light required very frequent bulb changing; this was generally a half-day job which usually involved two or more lights. Very seldom were all these lights in operation. Two divers could have kept themselves busy for the complete 15-day stay just going through the sequence of bulb replacement.

4. The mercury-vapor light was introduced to Team 2 during our stay. Although a power pack was required to operate this light, it proved to be very superior to anything that most of us had ever witnessed. The brilliancy of this light was outstanding. Compared to the other two types, it was many times brighter and gave us practically "sunshine brightness" when mounted above the shark cage and used to illuminate the inside of same. To my recollection, very little maintenance was required, and even then only a short time was involved.

5. A very limited amount of experience was actually obtained by Team 2 on the mercury-vapor light, since only one was available. What little experience that was had with this light proved its high potential. Its brilliancy is what is necessary for this type of work in the waters where it will be used.

EVALUATION OF DIVING LIGHTS, TEAM III

1. First day: Upon arrival of team, two lights were burning. One was mercury-vapor type which requires a separate power pack inside the lab in addition to the 110-v ac source. This bulb may be replaced in the water. The second light burning was the standard USN 1000-watt diving light, which burned out on the second day. With no replacement bulbs, no further work

with the USN diving lights occurred until the 14th day when all lights were made up and stowed in the cage on the starboard side.

2. a. An underwater harness had been made up for disconnecting the USN lights outside the habitat, but no record had been kept so no one knew which light was connected to which underwater connection. We had to turn off all lights when removing or replacing or repairing bulbs.

b. The USN 1000-watt light lasted on the average of 36 hours. It is known that turning on and off both types of lights shortens the life of the bulb considerably.

3. Team 3 used three mercury lights during its stay, burning out three bulbs each and one power pack. These lights were very good, but usually they burned out when they were turned off and then on, even in the water.

4. The power pack which burned out in the lab was disconnected when the odor of something burning was detected. A short was subsequently discovered in the underwater connection plug.

5. The Burns and Sawyer photo lights were connected with the switch topside, but this was a poor arrangement, since two separate divers received electrical shocks when recovering them to be sent topside for repair after burn-out. There was a slight crack in the lens of each one. These lights were the quartz type.

6. General Comments.

a. USN Diving Lights:

(1) The mix-up in the lights occurred as a result of making them up prior to lowering and not tagging in several places. Recommend: Sealab divers install and connect own lights and keep a log of same.

(2) Get a longer-life bulb.

(3) Recommend: An easy underwater bulb-replacement procedure.

(4) Recommend: Mercury-vapor type lights.

b. Mercury-vapor type:

(1) Need an easier underwater connector. The one used required two men to disconnect and had two-prong poles, one just a little smaller than the other. This required bringing inside the lab to connect up.

c. Burns and Sawyer Diving Lights:

(1) Install switch inside the lab.

(2) Eliminate the electrical hazard of cracked lens.

Chapter 14

ARAWAK SYSTEM ON SEALAB II

B. Deleman, B. Cannon, W. T. Jenkins, and P. A. Wells
U. S. Navy Mine Defense Laboratory
Panama City, Florida

INTRODUCTION

The Arawak system for divers was purchased on contract from Westinghouse Electric Corporation of Baltimore, Maryland. Equipment delivered consisted of four motors, four pumps, and two sets of breathing-gas hoses (100 ft each), with vests and demand regulators.

At Long Beach Naval Shipyard, the equipment was dismantled and installed on a common base above the entry hatch. Minor modifications were made prior to installation. Gate values were procured and installed in the supply and return systems to cross-connect all units, so that one set of hoses would always be ready for use.

After completion of installation all units were checked out and tested. Results were satisfactory, but the units were very noisy. The time element prevented elimination of some of the noise problems common to these pumps and compressors. Space limitations also restricted the installation design.

ARAWAK EVALUATION, TEAM 1

General

No specific record of Arawak time was kept while Team 1 was in Sealab, except in the ship's log. Therefore, only an estimate of the time used can be made at this time. Of the total period spent outside the habitat, divers employed the Arawak system about 50 percent of the time. Since the major portion of Team 1's initial tasks concerned the habitat or immediate vicinity, the Arawak was used considerably the first nine days. It is ideally suited to this situation.

Advantages and Disadvantages

The major advantages of the Arawak are (a) lack of predive preparation, and (b) unlimited gas duration. The units were very reliable, with the only malfunction being a stuck vane on No. 2 vacuum pump. This pump was repaired on the bottom satisfactorily.

The hoses were a nuisance, getting tangled and twisted every couple of days. The vest design needs improvement, especially in the way the hoses attach. There is a tendency due to the weight of the hoses to pull the vest open. The regulator is too close under the chin and must be disconnected to get out of the vest. The range was about 80 ft horizontal and 30 ft up or down. At times kinks developed, causing extremely hard inhalation or exhalation.

Operation

The Arawaks were used extensively for pot handling, PTC work, and removal of the outer port covers. They were easy to breathe in, and, since the two vacuum and two pressure pumps

were paralleled, supplied plenty of gas. The vests were awkward to get into, and a tender was definitely needed.

Recommendations

Smaller, neutrally buoyant (or slightly negative) hoses would be helpful, and the vest needs some redesign. The regulator should not be so close under the chin, since ditching the rig would be virtually impossible. The pumps were very noisy and need some sort of acoustical shielding inside the Sealab.

ARAWAK EVALUATION, TEAM 2

General

During the 13 diving days that the members of Team 2 were in Sealab II, the two Arawaks were used a total of 36 hours, or slightly more than 1/3 of the total diving time of some 98 hours 50 minutes. Individual use of the rigs varied widely from man to man, with ranges of 5 to 70 percent of total diving time being Arawak. Every aquanaut used these rigs from a low of 18 minutes total to 10 hours 14 minutes total, with an average use of 3 hours 36 minutes per man.

Initially the Arawaks were used as a secondary or "back-up" system to the Mark VI, but more and more emphasis was placed on them each day. Most Arawak dives were very local, being used for pot transfer and general maintenance work on or in immediate vicinity of the habitat. No Arawak dives were made to distances greater than 50 ft. from the habitat due to hose limitation.

Advantages and Disadvantages

Advantages of the Arawak included the ease and rapidity with which it could be made ready for use. The unlimited gas supply and the safety of being tethered to the habitat gave the aquanauts an additional feeling of security which was not felt using the Mark VI. The time and effort necessary for setting up a Mark VI for a dive was an additional strain on the aquanauts; the Arawak was a welcome relief from this.

Disadvantages were incurred using the two Arawaks, the most prominent of which was the noise inside the diving-staging area while the pumps were running. This noise, plus the distorted voices, made conversation nearly impossible in this area. In addition, the buoyant hose had a tendency to pull the aquanaut up and back as he swam out from the habitat. This hose tended to kink and also tended to snag on the transfer pots, which made it unsafe to use during pot transfer. The limited range in which a diver using the Arawak could operate was the most important factor governing their use.

Recommendations

Improvements should include a baffle system so the pumps could be run and not interfere with conversation. Hoses should be neutrally buoyant so they won't kink; and a safe, quick-release system should be incorporated into the harness. The quick release is necessary due to the chance that a diver, in an emergency, would have his hose snag while swimming back to the habitat.

ARAWAK EVALUATION, TEAM 3

General

Use of the Arawak varied from at least one dive for all members to 12 dives for one member. Team average was three dives. The Arawak was used a total of 84 hours.

The method of operation was to run both pumps connected together via a 1-in. I. D. manifold. No one performed work with a single vacuum and pressure pump running; therefore, all comments refer to the system with both pumps running.

Condition of the equipment at the start of the Team 3's dive: pressure pump gauges read 20 psi vs 24 psi; vacuum-pump gauges read 14.5 psi; one vest was completely beyond use, i.e., no zipper, and regulator would not exhaust.

General Comments by Team Members

Advantages

1. Liked the weight arrangements in the vest.

2. Three team members liked the positively buoyant hoses.

3. Some heating was obtained from the warm gas pumped from the habitat, i.e., when using the Arawak, divers felt warm.

4. Could not overwork the rigs with both pumps running.

5. No pump maintenance was required by Team 3.

Disadvantages

1. Did not like the position of the regulators. The position could not be adjusted for the varying heights of the users.

2. Hard to exhaust.

3. The pumps were too noisy. Voice communication was impossible when the pumps were running.

4. Seven members thought the hoses would have been less easily tangled if they had been slightly negatively buoyant.

5. All felt that they could not get out of the rig quickly in an emergency.

Summary

All members realized the importance of the Arawak for future deeper dives in Sealab-type operations and therefore were very interested in it, even though all preferred free diving. If safe diving techniques were employed, all members felt the Arawak was a safe rig as designed.

Chapter 15

HANDLING CHARACTERISTICS OF SEALAB II

T. N. Blockwick
Boston Naval Shipyard
Boston, Massachusetts

and

E. P. Carpenter
Naval Ordnance Test Station
Pasadena, California

INTRODUCTION

During construction of Sealab II, eight lifting padeyes were provided. Four of these eight were used whenever Sealab was moved by lifting. Cranes capable of lifting the 200-ton habitat completely out of the water were available in San Francisco and Long Beach. For towing, a closed chock was provided on both the bow and stern.

The primary restriction imposed on all handling operations was that at no time could the habitat be allowed to come in contact with any dock or floating vessel. This restriction was imposed bacause of the vulnerability of its many exposed fittings, valves, and external gas-storage bottles.

HANDLING OPERATIONS

Sealab II was transported from the construction site, Hunter's Point Division, San Francisco Bay Naval Shipyard, to Long Beach Naval Shipyard by barge towed by USNS Gear. At Long Beach, the habitat was placed in the water and towed to the site near La Jolla by USNS Gear. This tow was an event with many unknowns, because the hull of Sealab was not designed for towing. Only the conning tower and 1 ft 8 in. of the main cylinder were above the surface. Most of Sealab was under water. Most of the stores and equipment were loaded at Long Beach. It was planned that only last-minute items would be loaded at the site.

The most important procedures for preparing Sealab for surface towing was putting on internal and external port covers, placing internal strongbacks on the main access hatch, and the emergency escape hatch. All hatches were closed, and Sealab was pressurized to 20 psi gage. A light alarm was rigged to indicate loss of pressure. If the pressure dropped to 16 psi, the light would be actuated.

The tow was rigged from one of the forward lifting pads through the bow bull-nose chock. Starting from the lifting pad, the tow was arranged, as follows: pelican hook, 1-1/2-in. chain through bull nose, about 150 ft of 1-5/8-in. wire that was attached to the main 2-in. towing wire of the GEAR (ARS-34).

The distance from Long Beach to the Sealab II site at La Jolla was 80 naut mi, and 36 hours was allowed for transit. This time would give an average speed of slightly more than two knots. However, Sealab towed better than anticipated, and it arrived at the site early. The scope of wire used by the Gear (ARS-34) was only from 100 to 300 ft. The normal minimum of 1200 ft could not be used, since the weight of the 2-in. tow wire could probably cause the Sealab to plunge. After arrival of Sealab at the site, it was moored to the No. 2 mooring spud until it was ready for lowering.

Preparations for submergence included a complete systems checkout (see Sealab II Lowering Plan, this chapter), the final loading of supplies and equipment for the aquanauts, and the flooding of ballast tanks 1 and 3. When tanks 1 and 3 were flooded, the waterline was on the conning tower at a point which indicated that, when the conning tower was flooded, Sealab would be approximately 10,000 pounds negatively buoyant.

The Sealab was then placed in a four-point moor between the Gear and the stern of the surface support craft (Fig. 50). Prior to this, the Gear was placed in a three-point moor parallel to the stern of the surface support craft about 100 yd away, so it could assist in the lowering of Sealab.

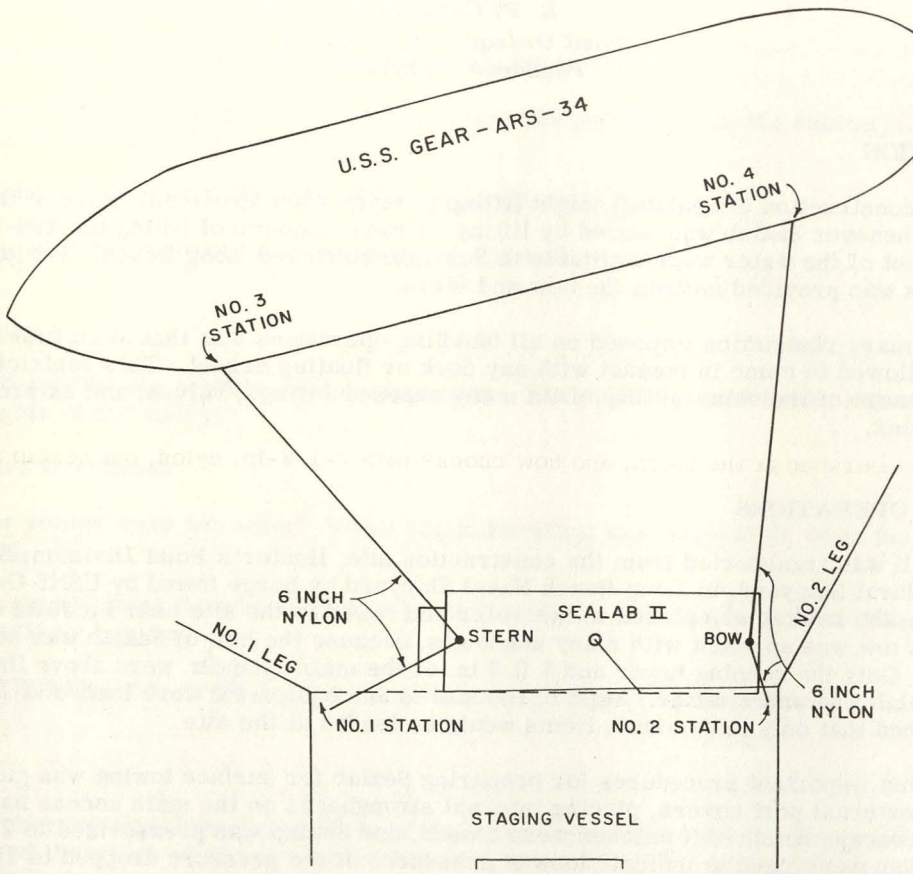


Fig. 50. Sealab attitude from surface to 30 feet depth (also see Fig. 66)

The actual lowering was done from a boom that extended only ten feet from the surface-support craft. Thus, the Sealab habitat had to remain about 30 ft clear until it was well submerged.

The lowering wire was 1-1/8-in. nonrotating and was connected to a winch. To absorb the dynamic loads of Sealab due to wave and swell action of four to six feet, the lowering wire had a counterweight of 13,000-lb, which was controlled by the second winch on the surface craft.

When all was ready, the flooding of the conning tower was started, and a mixture of helium and oxygen gas was maintained at 30 to 40 lb over ambient water pressure inside the Sealab. When Sealab became slightly negative, it submerged gently and rotated down to a depth of about

60 ft. At this point, a short stop was made to disconnect excess lines and to inspect it for leaks. Some of the ports developed gas leaks. To minimize gas loss, the Sealab was lowered to the bottom as soon as possible.

When Sealab landed, instrumentation indicated that it had a 10-degree trim by the stern and a list to port of three degrees. It was then lifted about ten feet off the bottom and rotated to another position. It ended up with a list to port of six degrees and a trim by the stern of also six degrees. No. 2 tank was then flooded, and Sealab was hard on the bottom.

The counterweight system on the lowering tackle performed extremely well, and readily absorbed shock loads imposed by the swells and the movement of the Berkone. The Dynaline Tensiometer, which measured the tension in the lowering wire at all times, showed maximum loads of about 25 percent over the negative weight of Sealab II, which was 9500 lb.

Sealab was then ready for occupancy. The following day, on Aug. 28, the first ten aquanauts entered Sealab to begin their existence in 205 ft of water.

Shortly after Aquanaut Team 3 surfaced on Oct. 10, preparations were begun to raise Sealab to the surface. The items shown in Phase I of the raising plan were accomplished by Team 3 prior to their surfacing. The same day, most of the preparations to be made by surface divers were carried out, with the exception of blowing ballast tank 2.

On Oct. 11, the Gear was placed in a four-point moor in a position to control Sealab as it started to surface. Refer to the Sealab II Raising Plan, Phase II.

Then tank 2 was blown, and a strain was taken on the lifting wire and the counterweight system, to pull the spades of Sealab out of the soil. From the original six-degree port list and six-degree trim by the stern, both of these values reduced to about three degrees. However, despite 20,000 to 25,000 lb pull, Sealab II would not raise. Additional pulls were also taken by the Gear and Berkone at the stern, and bow chocks with 3-1/2-in. nylon, but Sealab apparently was too heavy.

It was decided to add a 3000-lb anchor to the 13,500-lb counterweight to reduce chafing of the wire under heavy strain. A dive was made to blow tank 2 clean and to blow tank 1 for three minutes and tank 3 for two minutes. This procedure reduced the load somewhat, to about 17,000 lb. Three of the porthole plugs were also capped to minimize gas loss. Later, another dive was made to blow tank 2 clean and tank 3 for three minutes. This raised the bow and reduced the tension in the cable to about 15,000 lb. Sealab was raised to 65 ft, and six-inch lines were run, as shown in the Raising Plan. At 1500, Oct. 11, Sealab was brought to the surface, after the conning tower was blown. She remained in this position overnight, with 33.5 psi absolute being maintained. On Oct. 12, the pressure was reduced via the umbilical and opening of valve B-3. To expedite this, the conning tower was pressurized to open the hatch leading from the conning tower to the Sealab. However, when this was done and Sealab opened to the atmosphere, it began to take in water, apparently through the ballast-tank equalizing system. The Sealab was then quickly repressurized to 25 psi. It was decided to take her back to Long Beach as it was, without opening Sealab on the surface. The primary reason for opening up Sealab was to install the interior strongback over the large access hatch. After the water was blown out of it, Sealab was repressurized to 25 psi. The low-pressure light indicator was set to 10 psi. In addition, a pressure gage was provided on Sealab. Facilities were provided so that air could be supplied by the Gear while under tow. Four Sealab II divers rode the Gear to assist in the event of an emergency. Sealab was taken in tow at about 1800, Oct. 12, 1965, and arrived at Long Beach at about 1400, Oct. 13, 1965. It was lifted out of the water shortly after arrival.

The sea and weather conditions during both tows were good and essentially State 1.

SEALAB II LOWERING PLAN

Conditions: Sealab II outfitting is completed, and it is sitting out of the water at Long Beach Naval Shipyard. All stores and dry (nonfrozen) provisions are stowed aboard. See Figure 49 for location and function of valves.

1. Secure the internal pressure-proof covers onto the viewing ports and bolt down hard, using a diagonal bolting sequence.

2. Remove the equalizing plugs on each viewing port from the outside.

3. Open the equalizing plug and valve in the transformer enclosure and in the base of the water closet.

4. Install the external protective covers on the viewing ports.

5. Fill the 150-gallon emergency fresh-water tank.

6. Open the faucet on the water heater and all other faucets on the fresh water system. DO NOT fill the water heater.

7. Block the water-heater switch on the main power panel in the off position.

8. Open the gas supply and gas-sampling valves D1, D2, D3(2), E2, E3, and E5.

9. Close the 48-in.-diameter hatch and bolt down tightly.

10. Check the emergency escape hatch to be sure that it is properly secured.

11. Install and bolt down tightly the strongbacks on the main and emergency access hatches.

12. Secure all systems and switch off power.

13. Vacate Sealab via the conning tower, close and secure the lower conning tower hatch.

14. Close the upper conning-tower hatch and bolt down securely.

15. Stow the normal power pigtail on top of the conning tower.

16. Attach the atmosphere-gas-loss alarm to the end of the gas-sampling line of the umbilical cord.

17. Remove the caps from all flood and vent valves.

18. Open equalizing valves B1 and B2 and vent valves A2, A4, and A6 to equalize the pressure between ballast tanks 1, 2, and 3 and the living compartment.

19. Conduct a 15-psi pressure test and a 10-psi vacuum test on Sealab as outlined in NAVSHIPYD SFRAN Test Memo Mo. SLII-126T-147.

20. During the pressure test, check that the atmosphere-gas alarm is working properly. Leave the alarm energized.

21. Attach the German Crane lifting slings to Sealab.

22. With the German Crane, lift and place Sealab in the water. Sealab should float with 1 ft 8 in. of freeboard. Access can be gained through the conning-tower hatches.

23. Conduct the necessary trim and buoyancy checks.

24. Remove the lifting slings.

25. Make the necessary towing connections. Towing will be done with the forward inboard pad.

26. Install the lowering bridle to the lifting pads.

27. Recheck to insure that items 1 through 18 are still in force.

28. Charge Sealab with air to 20 psig through the gas-supply line of the umbilical.

29. Close valves D1, D2, A2, A4, A6, B1, and B2. The conning tower is not pressurized. (DO NOT tighten the nuts on the securing brackets of the main access hatch after charging.)

30. Energize the towing lights.

31. Tow to the site with Gear, following coastal shallow water. A Sealab II Officer will be on the Gear and will ascertain the correct towing speed.

32. Upon arrival at the site, Gear will pass Sealab to an LCM and then place herself in a moor directly aft of the staging vessel.

33. Kickers pass positioning lines from Sealab to the staging vessel and to the Gear (two lines to each)

34. Connect the lowering line (slack) to the Sealab lowering bridle, rig the counterweight and connect the Dynaline Tensiometer.

35. Open vent valves A2, A3, A4, A5, A6, A7, A10, and equalizing valves B1 and B2.

36. THEN open master vent valve A1 to bleed out pressure inside of Sealab.

37. Open upper and lower conning-tower hatches and enter.

38. Close valves A2, A3, A4, A5, A6, A7, A10, B1, and B2.

39. Close gas valves D3(2), E2, E3, and E5.

40. Check the operation of positioning lights on the bottom.

41. Remove all but two bolts from the external protective covers on the viewing ports, using surface divers. (Recheck to insure that the viewing port equalizing valves are open.)

42. Flake out the umbilical onto the sea and attach intermediate floats. Connect the umbilicla to the staging vessel.

43. Connect the normal power pigtail to the shore power line.

44. Switch on the alternate electrical power to Sealab from the staging vessel.

45. Move the alternate power switch on the main power panel in Sealab to the on position. Switch on all circuits, except the water heater (it is empty) and spare circuits, in the main power panel.

46. Switch on all circuits in the three power panels located adjacent to the main power panel in the galley area.

47. Turn on all lights, heaters, dehumidifiers, ventilation, and the refrigerator.

48. Check all systems to insure that they are working properly on alternate power.

49. Switch on the normal power supply from shore.

50. Move all switches on the main power panel to off.

51. Move the normal power supply switch to on.

52. Move the remaining switches, one at a time to on. (Except the switches for the water heater, stove and radiant heaters in the entry.)

53. Check all systems to insure that they are working properly on normal power.

54. Using the same procedure, switch back to alternate power. Alternate power will be used during lowering.

55. Lower the TV camera tripod to the bottom and check it out for proper operation.

56. Complete the final loading of equipment into Sealab.

57. Place the automatic oxygen system in a "service for use on the bottom" condition by opening the following valves in sequence: H9, H3, H2(2). Then energize the Krasberg oxygen sensor.

58. Prepare to charge Sealab by opening internal valves D3(2), E3, and E4 or E5.

59. Remove the strongback from the main access hatch. Stow it in Sealab.

60. With all necessary systems operating on alternate power, vacate Sealab and secure the conning-tower access hatches.

61. Take Sealab draft readings.

62. Open vent valves A2, A3, A6, and A7 of ballast tanks 1 and 3.

63. Open flood valves C1 and C3 of ballast tanks 1 and 3. Then open vent valve A10 and master vent valve A1. Sealab, if properly ballasted, will submerge to approximately the 9000-lb mark, near the mid-height of the conning tower.

64. Close flood valves C1 and C3 and vent valve A1 and A10 when tanks 1 and 3 are completely flooded.

65. Take Sealab draft readings.

66. Open the equalizing valves B1 and B2 and vent valves A4 and A5 of ballast tank 2.

67. Open external valves D1, D2, and E2 and charge Sealab through the gas-supply line of the umbilical cord to Sealab depth plus 5 psi. A pressure gage will be attached to the gas-sampling hose in the atmosphere control van to read out the pressure. The charging will be done as follows: (1) Charge to approximately 28 psi* with air. (2) Complete the charge with helium.

68. Check for pressure in the conning tower by opening and closing C4.

69. Take marks on the lowering wire.

70. Inspect the complete counterweight system to insure that it will function properly.

71. Flood the conning tower by opening its vent valve A8 and its flood valve C4. Sealab will now completely submerge and will impose a tension load of approximately 9000 lb on the lowering line. Leave valves A1, A8, and C4 open to prevent any damage to the conning tower during lowering.

72. Prepare to plumb Sealab on short stay as it becomes negative.

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*The exact pressure will be decided by the exact Sealab test depth.

73. When Sealab is in the plumb position, make all possible checks of lowering equipment. Take dynaline readings and make certain that the reading remains constant before starting the lowering.

74. Lower Sealab to within approximately 20 ft of the bottom (within sight of the positioning lights). Make sure that the umbilical follows it down smoothly.

75. Take another dynaline reading. It should agree with the reading taken in item 73.

76. Position Sealab with the tag lines from Gear. The bow of Sealab should point at approximately 345°T. The shark-cage end is the stern.

77. When Sealab is correctly positioned, lower it to the bottom. When it is on the bottom, check to insure that it is reasonably level.

78. Flood ballast tank 2 by closing equalizing valves B1 and B2, then opening flood valve C2, then opening vent valve A10.

79. Leave the bridle (slack) in place until everything is completely checked out. (This checkout will take at least 24 hours.)

SEALAB RAISING PLAN

Phase 1

Conditions: The necessity for raising Sealab may arise at any time after Sealab is placed on the bottom. For this reason, it is not possible to state the exact condition of the many systems aboard. For the purpose of this bill it is assumed that Sealab has been on the bottom and occupied for a sufficient length of time that all systems are checked out and in operation on normal power. Also, ballast tanks 1, 2, 3 and the conning tower are flooded and the entry skirt is blown out.

1. Lift up way-stations, water-clarity meter, acoustic ranges, and other equipment as necessary.

2. Remove caps on the inside end of the equalizing plugs in the eleven viewing ports.

3. Remove preventer anchor cable, attach to messenger, and send topside. Attach tag lines to prevent Sealab rotation.

4. Secure the internal pressure-proof covers on the viewing ports and bolt down hard, using a diagonal bolting sequence. Use a torque wrench adjusted to not more than 100 ft-lb.

5. Remove the equalizing plugs on the outside of the viewing ports.

6. Remove all outside TV cameras (and mounting brackets).

7. Install the external protective covers on the viewing ports if time permits.

8. Connect an air salvage hose from the staging vessel to vent valve A1. The air salvage hose should have a check valve at the staging-vessel end, with a valve capable of venting pressure on Sealab as required.

9. Block the water-heater switch on the main power panel in the off position.

10. Disconnect the diving light cables and lash in place.

11. Notify shore control to turn off Benthic power. When power-off confirmation is received from topside, proceed with item 12.

12. Remove all cables and pipes from the wiring trunk and stow them in their respective places.

13. Ascertain that all cables are clear of Sealab. This is a continuing project.

14. Install the cover on the wiring trunk and bolt down tightly (100 ft-lb).

15. Remove the hoses from the outside plumbing drains, close the valves, and cap. Stow hoses in outside cage.

16. Close the fresh water valves, disconnect the two fresh-water hoses from Sealab. Inform shore control when this is completed.

17. Close the salt-water supply valve to the water closet and cap.

18. Open the equalizing plug and valve in the transformer enclosure and in the base of the water closet.

19. Move all switches on the main power panel to off position.

20. Apply power to the umbilical power cord from the staging vessel.

21. Move the alternate power supply switch to on.

22. Notify shore control to secure shore power on the pier to the power beehive.

23. Move the remaining switches, one at a time, to on. (except the water heater switch.)

24. Install the inclinometer: plug into the FM Music and Electrowriter receptacles noting the color code.

25. Loosten the covers on all hand lanterns.

26. Insure that the emergency escape hatch is secured and install the strongback. The strongback is topside - must be called for.

27. Stow and lash down all equipment as necessary.

28. Vent the emergency fresh water tank and the water heater at high points as necessary.

29. Secure all electrical circuits except those requested by NOTS to remain on during raising. (Lights, open microphones, inclinometer)

30. Ascertain that the inclinometer is working.

31. Close all valves on the external gas cylinders. Leave D2 and E2 open.

32. Close internal gas valves G, H, J, and J1. Test with topside that air can be provided to Sealab via umbilical while raising and that pressure inside Sealab can be measured.

Note: When valves are aligend as indicated in items 31 and 32, topside must be capable of reading pressure inside Sealab at all times and must be able to provide air pressure to Sealab. In general, all bottom self-supporting systems shall be secured while topside control systems shall be operable.

33. Swim around Sealab to check for loose lines, etc. During this check be sure that all protective valve caps are removed.

34. Secure all hookah/Arawak valves and dispose of the hose.

35. Vacate Sealab, close the main access hatch and bolt down with one dog.

36. Pressurize Sealab to 10 psi over bottom pressure with air, or about 100 psi gage.

Comment: This ends the activities which will be accomplished by the Sealab inhabitants. All other activities will be accomplished by surface divers after the Sealab inhabitants have been transferred via PTC to the DDC and decompression has started.

Phase 2

Sealab II has been vacated with main access hatch dogged down with one dog, and pressurized to 15 psi over bottom, which is about 100 psi gage, depending on tide conditions. Important: Bottom is defined as the lower portion of the pressure hull. The reason for this selection of a depth reference point is that the main access hatch is very near this point. This main access hatch as well as the two other hatches on Sealab must always have positive internal pressure to ensure that they are sealed. This is particularly true of the main access hatch which is large and does not have an internal strongback to resist negative pressure.

The pneumofathometer hose will be attached to the top rail of the walking flat, which is 16 ft above the bottom to the pressure hull of Sealab. Thus, 16 ft must be added to the pneumogage to get the depth at the bottom of the pressure hull, the depth reference point.

Pressure inside Sealab will be measured via the sampling line in the umbilical. Similarly, air pressure may also be supplied to the Sealab via the umbilical.

Sealab is on bottom with 6 degree port list and trim by stern of 6 degrees, with spades completely dug into the bottom.

Phase 2 Operations

1. Move staging vessel over Sealab. This will be about a 55 ft move.

2. Modify counterweight to handle a 12,000 lb load since it is believed that a minimum of 2000 lb of water will be left in C-2 after blowing.

3. Make all dogs tight on main access hatch.

4. Ensure that Valve B-3 is closed.

5. Open skirt vent valve A9 to flood skirt.

6. Pressurize Sealab to 15 psi over bottom if not previously possible since one dog may not have been sufficient to hold pressure.

7. Place Gear in moor (2nd day).

8. Attach pneumofathometer gage hose to top life rail of walking flat. This point is 16 ft above bottom of pressure cylinder. Therefore 16 ft at depth must be added to get depth at bottom of pressure cylinder.

9. Attach lifting wire to the lifting bridle of Sealab and put on small counterweight to take slack out of lifting wire.

10. Close flood valves C1, C2, C3 and vent valve A-8. Leave C4 open so that any air expansion in conning tower can be equalized as Sealab is raised.

11. Check that vent valves A2, A3, A4, A5, A6 and A7 are open.

12. Check that all valves on topside air salvage system are closed. Open valves B1 and B2. This will equalize pressure between the living compartment and tanks 1, 2, and 3. Open valves A-10 and then A-1 to test air system. Then close A-10 and A-1.

13. Inspect 3-1/2-in. nylon at bull nose attached to buoy. If line is good, remove buoy and bend additional line and pass to Gear.

14. Attach 3-1/2-in. nylon to stern bull nose of Sealab and lead to No. 2 Station aboard staging vessel.

15. Disconnect and remove counterweight and dumb waiter system.

16. Open valve A-10 and then A-1.

17. Open valve C2 to blow tank 2. While tank 2 is blowing, maintain pressure in Sealab and blowing system via the air salvage hose, and then the umbilical as an alternate means for pressurization to 15 psi over bottom. Caution: Do not exceed 125 psig.

18. The normal lift off weight of Sealab should be about 12,000 lb. However, due to the 6 degree list and trim, tank C-2 cannot be blown clean of water until Sealab is reasonably level. The water remaining in C-2 after it is blown at the present 6 degree list and trim is estimated at 2,000 lb. It may be necessary to take a pull at the stern bull nose with 3-1/2-in. nylon at about 5000 lbs. to help level Sealab before it leaves bottom in addition to the 12,000-lb pull on the lifting wire.

19. As C-2 is being blown, take a moderate strain of about 12,000 lb and observe inclinometer. Assist in leveling Sealab with 3-1/2-in. nylon at stern bullnose staging vessel station No. 1.

20. When C2 starts to bubble when Sealab is level, close valve C-2. Then close A-10 and then A-1. C-2 may not be left open since pressure inside Sealab would drop to at least less than bottom pressure at the main access hatch. A-1 and A-10 are closed to isolate the system in the event of failure in the air salvage system while raising.

21. Take a strain of at least 12,000 lb to lift Sealab off bottom. This may require a continuing pull of 30 minutes or more to break out the Sealab spades. The nylon lines at bow and stern may be used to assist. Note attitude of Sealab via inclinometer. Note any change in internal pressure of Sealab and look for leaks.

22. After Sealab is off bottom hoist slowly to 60 ft, noting any pressure changes in Sealab. Maintain not less than 15 psi in Sealab over bottom at all times in the event of air leaks by adding air thru umbilical.

Note: Tanks and Sealab are isolated from the salvage air system by having valves A-1, A-10 and A-8 closed. Keep moderate strain on nylon lines to keep Sealab from rotating.

Phase 3

Sealab at 60 ft to bottom of pressure cylinder and basically perpendicular to stern of Berkone pneumofathometer gage reading should be 44 ft (60-16). Pressure inside Sealab, if there are no leaks, should be essentially the same as it was on the bottom or about 100 psig.

At the 60 ft stop do following:

a. Inspect for leaks

b. Remove excess lines

c. Attach 2 6-in. nylon lines from fore and aft bull nose to stations 1 and 2 of Berkone. Similarily pass 2 6-in. nylons to station 3 and 4 of the Gear. See sketch.

d. Rotate Sealab clockwise about 90 degrees so that it is roughly parallel to the stern of Berkone.

e. Vent interior of Sealab to 15 psi over bottom (bottom of pressure cylinder), thru the air salvage hose by opening valves A-1 and A-10 and venting thru topside manifold. This will relieve excessive pressure inside Sealab. Pressure inside Sealab should be (.445 × 60) plus 15 = 42 psi gage.

f. If necessary blow tank No. 2 by opening valve C-2.

g. Close valve A-10

Raise Sealab slowly to 30 ft, always maintaining 15 psi over bottom in Sealab thru umbilical air supply.

Phase 4

Sealab at 30 ft (to bottom of pressure cylinder) Pneumofathometer reading should be 14 ft (30-16). Internal pressure of Sealab should remain as at 60 ft stop, (42 psi gage) assuming no leaks. No further changes will be made in Sealab pressure or in tanks 1, 2, 3 pressure until Sealab is surfaced.

Note: At this depth the point of interest will shift from Sealab and ballast tanks 1, 2, and 3 to the conning tower. Pressure in Sealab will be kept to at least 15 psi over bottom. At 30-ft depth the top of conning tower hatch will be 11 ft below the surface. The conning tower top hatch has been tested to 15 psi. Therefore 15 psi can be applied to blow out the water and should the top hatch break surface in a swell, the hatch should hold this pressure differential.

At the 30-ft stop accomplish the following:

a. Check that bolts on top conning tower hatch are tight.

b. Have Gear take light strain on No. 3 and 4 lines to keep Sealab clear of staging vessel.

c. Make overall inspection of Sealab.

d. Check that bolts on main access hatch are tight.

e. Adjust air in salvage hose to 15 psi.

f. Ensure valve C-4 is open.

g. Open valve A-8 slowly.

Maintain not more than 15 psi gage on salvage hose and gradually blow water out of conning tower. As Sealab gets lighter gradually pay out raising wire and raise counterweight to allow Gear to pull Sealab from the staging vessel by gradually increasing pull on lines 3 and 4.

When conning tower is blown clear keep Sealab about 40 ft from staging vessel.

Close valve A-8 first and then C-4. Sealab should now float at midpoint of conning tower.

Phase 5 - Sealab on Surface

Sealab on surface with conning tower blown. It should have a buoyancy of 6 tons or about 13,000 lb. It should float at midpoint of conning tower.

Maintaining 15 psi over bottom (bottom of pressure vessel) ensure that valves A2, A3, A4, A5, A6, A7, B-1 and B-2 are open. Open valve A-10.

Open first valve C1 and then C3 to blow water out. Caution: Maintain 15 psi over bottom at all times. The compressed air atmosphere must not be reduced at this time by using only the compressed air in Sealab, as this may produce negative pressure on the large access hatch.

Caution: Great care must be exercised so that the tanks 1 and 3 are blown symmetrically. It may be desirable to blow the bow (tank 1) slightly ahead of the stern; the stern may then be corrected (lifted) by blowing air into the skirt or by control of valves C1 and C3.

Caution: Valves A-2, A-3, A-6 or A-7 may not be used to control trim as this may produce a dangerous pressure differential in the tanks.

When tanks 1 and 3 are blown clear, Sealab will float at the normal waterline of about 1 ft-8 ins. Close valves C-1 and C-3.

Check that valve A-8 is closed. Vent conning tower by opening valve C-4.

Gradually vent Sealab via the salvage hose ensuring that large access hatch is holding.

Warning: Sealab may not be entered at this time until it has been ventilated with air sufficiently to support life.

a. Open conning tower top hatch

b. Ensure conning tower air can support life.

c. Bail lower conning tower hatch well.

d. Open lower conning tower hatch.

Caution: Do Not enter Sealab.

Ventilate interior of Sealab with air from the rough umbilical and other means until O_2 content is sufficient to support life and that toxic gases are not present.

Enter Sealab, with safety line tended by man in open air.

When atmosphere in Sealab is safe, perform tasks as required. The first should be placing strongback on large access hatch and secure.

Prepare Sealab for tow. Refer to towing bill.

Gear Take Sealab in tow to Long Beach. Speed not to exceed 4 knots.

RIG FOR SURFACE TOW OF SEALAB II AFTER RAISING

1. Install strongback on main access hatch and bolt securely.
2. Install towing lights.
3. Check internal pressure port bolts for tightness.
4. Check that equalizing plugs on each viewing port are open from the outside.
5. Install external protective covers on the viewing ports.
6. Make provisions to supply air from the towing ship Gear in event of emergency.
7. Secure all systems and switch off power.
8. Vacate Sealab and shut the lower conning tower hatch securely.
9. Shut upper conning tower hatch and bolt down securely.
10. Install and test the atmosphere gas loss alarm.

11. Assuming that all vent, flood, and equalizing valves are shut, open one vent valve on each of the main ballast tanks.

12. Open the equalizing valves B1 and B2. This will equalize pressure between the ballast tanks and the living compartment.

13. Charge Sealab with air to 20 psi gauge through the gas supply line of the umbilical. This will keep all hatches and battle covers tightly secured.

14. Flake umbilical around conning tower.

15. Close all valves except A9 and any valves necessary to supply air to Sealab via umbilical while under tow.

16. Attach towing rig.

17. Energize towing lights. Sealab is now ready for tow.

18. Take Sealab in tow with speed not to exceed 4 knots, following shallow water coastal route. Have two men from the Sealab program aboard that know Sealab and its systems well.

19. If alarm shows air loss, resupply air via the umbilical. In the event Sealab starts to sink, head for the nearest shallow water and beach it.

Chapter 16

SEALAB II ATMOSPHERE CONTROL

W. F. Mazzone
Submarine Medical Center
New London, Connecticut

INTRODUCTION

Sealab II was initially charged with a mixture of compressed air and helium, producing an atmosphere which contained 4.5 percent oxygen, 17.4 percent nitrogen, and the balance (78.1 percent) helium. With relatively small changes, this basic atmosphere was maintained throughout the entire operation.

Pressure within the habitat, as read out on the gage in the atmosphere control van, averaged 100.7 pounds per square inch absolute (psia), equivalent to a gage depth of 193 ft. Variations with the tide were from 191 to 196 ft gage.

ATMOSPHERE ANALYSIS

During the entire period in which Sealab II was occupied by personnel, frequent monitoring of the habitat atmosphere was carried out in the atmosphere-control van of the support vessel, Berkone. A sampling line incorporated in the umbilical to the habitat permitted direct sampling of the Sealab atmosphere at any time. The analysis was performed by gas-absorption chromatography, using a modified Fisher-Hamilton gas partitioner. This method gave good results for oxygen, nitrogen, and carbon dioxide, but would not measure helium directly, since helium was used as the carrier gas. Helium concentration was estimated by subtracting the total of the three measured gases from 100 percent. Commercially prepared standards of oxygen, nitrogen, and carbon dioxide in helium (all in approximately the concentrations being measured in the Sealab atmosphere) were used to calibrate the partitioner.

Analysis for trace quantities of hydrocarbons in the habitat atmosphere were carried out by Doctor Merle Umstead of the Naval Research Laboratory, using a gas-liquid chromatographic method. Samples for these analyses were obtained by opening evacuated steel bottles in Sealab II, then resealing them and sending them to the surface. This method prevented hydrocarbon contamination of the samples, which would have resulted from passing them through the rubber sampling hose. Many chromatographic peaks were found, indicating the presence of minute quantities of many different organic compounds. Full identification of these compounds is as yet incomplete.

Some of these steel flasks were returned to Doctor Ray Saunders at the Naval Research Laboratory for further analysis. Precise carbon monoxide measurements have been requested on these samples.

Semiquantitative analyses were made for carbon monoxide both topside and in Sealab, using portable tube-type detectors (Draeger, MSA, and Kitagawa). These analyses yielded no positive results, except in the case of carbon monoxide. On several occasions, carbon monoxide levels in the range of 20 to 30 parts per million were indicated by the tubes. These techniques are rather inaccurate at low concentrations. One sample was analyzed by the Linde Corporation, with results on two determinations of 20 and 20.5 parts per million. It is hoped that other accurate carbon monoxide measurements can be made on some of the samples returned to NRL.

Carbon monoxide was implicated as a possible factor in the headaches which troubled a number of the aquanauts. This points up the importance of providing future Sealab operations with a sensitive, accurate method of measuring carbon monoxide in the habitat atmosphere, in the scuba bottles, and in the compressed air used in charging the personnel-transfer capsule and the deck decompression chamber complex. No such apparatus was present for Sealab II.

Relative-humidity measurements were made in the habitat, using wet-bulb and dry-bulb thermometers. Special correction factors had to be introduced because of the increased thermal conductivity of the Sealab atmosphere. Relative-humidity values ranged from 60 to 92 percent, staying mostly between 65 to 85 percent.

Temperature of the habitat atmosphere ranged generally from 80° to 90°F.

ATMOSPHERE CONTROL

The principal controlling mechanism used was the Krasberg oxygen sensor and controller, which automatically regulated oxygen levels in the habitat. The Krasberg controller was set for 4.25 percent oxygen (PO 221 mm Hg) during most of the run, with limits of 4.0 percent (208 mm Hg) and 4.5 percent (234 mm Hg). It functioned well and in general maintained atmospheric oxygen within prescribed limits. Near the end of the stay of Team 2, oxygen was reduced to approximately 3.5 percent for two days to test the effects of this change on personnel. The lowest level actually recorded was 3.28 percent.

In the first few days of the run, it was found that the water level in the trunk tended to rise rather rapidly, and had to be blown down with additional gas every few days. After the stopping of some small gas leaks from the habitat, blowdowns were much less frequently required. The blowing was accomplished with either compressed air or helium, depending upon the oxygen level in the habitat at the time. During these early days it was not necessary to bleed any oxygen into the habitat to maintain the desired oxygen tension. This was attributed initially to the compressed air used in blowing down. Later in the stay of Team 1, however, it was discovered that compressed air was leaking into the habitat through the pneumatic air hose to the pneumonfathometer. This apparently accounted for the rise in nitrogen during the second week, when it reached a peak of 25.2 percent.

Carbon dioxide was controlled by means of a specially designed manifold which held twelve standard canisters (6.2 lb) of lithium hydroxide. This scrubber maintained very low levels of carbon dioxide (undetectable to 0.02 percent) for periods of 24 hours or longer. Carbon dioxide would then increase rather rapidly, usually reaching 0.25 percent within about 36 hours after the canisters were changed. At this level (1.7 percent effective at sea level), the aquanauts often were aware of some increase in their rate of breathing and mild discomfort. Canisters were usually changed before carbon dioxide reached 0.3 percent, but on one occasion it rose to 0.42 percent (2.9 percent effective). After canister changes, carbon dioxide concentration fell precipitously, often falling below 0.01 percent in but a few hours. Efficiency of carbon dioxide scrubbing was somewhat diminished late in the run, when some of the lithium hydroxide canisters were replaced with Hopcalite and some with silical gel for humidity control. The principal effects were shortening of canister life by a few hours and raising of minimum carbon dioxide levels from below 0.01 percent up to 0.02-0.04 percent.

Carbon monoxide removal was not included in the planning for Sealab II, as it was not expected that carbon monoxide would occur in significant concentrations. When carbon monoxide levels of 20 parts per million or more were detected, two lithium hydroxide canisters were replaced with Hopcalite and silica gel for catalytic oxidation of carbon monoxide. This measure appeared to lower the carbon monoxide to 10 to 15 parts per million (according to the rough measurements available), and no further headaches were reported.

Hydrocarbons and odors were controlled by the insertion of large filters of activated charcoal into the atmosphere recirculating system. Samples of this charcoal bed have been sent to NRL for further analysis.

Chapter 17

THE DECOMPRESSION COMPLEX

D. C. Pauli and G. P. Clapper
Office of Naval Research
Washington, D.C.

and

W. P. Frost
U.S. Navy Mine Defense Laboratory
Panama City, Florida

INTRODUCTION

The at-sea decompression of ten divers saturated at a depth of approximately 200 ft presented new problems for the U.S. Navy. First, the men would have to be lifted from the ocean floor in a personnel transfer capsule (PTC), maintaining the ocean-floor pressure, to the surface-support vessel; second, they must be transferred to a larger, more comfortable deck decompression chamber (DDC); and then they finally must undergo the lengthy decompression — approximately 30 hours — at the prescribed 6 ft per hour linear decompression schedule.

Alternate modes of decompression were possible, but in view of accompanying problems and the general need of the Navy to have experience in use of mating PTC/DDC decompression complex systems, these alternate solutions were not considered. Alternate solutions available were:

1. Use of the habitat as the decompression complex — This solution would require lifting the habitat for each crew change or decompression of crews at depth, with later free ascent, which would considerably complicate the design of the habitat.

2. Use of the PTC as not only a transfer capsule, but also as the main decompression chamber — This was done on Sealab I, where a smaller crew (four men) was involved. Reasonably comfortable space for ten men for the duration of the decompression would require a much larger PTC and associated difficult at-sea handling problems. Further, the PTC, if thus occupied, could not serve as a refuge or for lift of the following team should an emergency arise.

The concept of shuttling aquanauts from surface to the habitat, where they become saturated, and then back to the surface for decompression placed certain back-up safety requirements on the system. The possibility of contamination of the atmosphere within the habitat required that a refuge be available to the aquanauts that had the necessary self-contained life-support systems. The possibility of the surface-support vessel losing one or more legs of its moor implied that the support-vessel winches might not be readily available in an emergency to lift the PTC to the surface; thus, the PTC should be equipped with a self-contained raising subsystem.

PTC-DDC SYSTEM

PTC Functional Requirements

The following are the functional and design requirements to which the PTC was designed. The PTC was to be:

1. Sufficiently large to transport ten aquanauts.

2. Designed to ASME unfired boiler-code specifications to withstand an internal pressure of 200 psig.

3. Provided with a life-support system which could be operable internally and which could maintain the ten personnel for a minimum of 12 hours.

4. Provided with an internally controlled raising system which would allow personnel under pressure to raise themselves to the ocean surface.

5. Equipped with systems for communicating with surface personnel.

6. Provided with necessary appurtenances for being lifted and handled by the surface-support vessel.

7. Provided with a system for mating the PTC with the DDC.

DDC Functional Requirements

The following are the functional and basic design requirements of the DDC:

1. Sufficiently large to decompress, in relative comfort, ten aquanauts.

2. Designed to ASME unfired boiler-code specifications to withstand an internal pressure of 200 psig.

3. Provided with a life-support system to be operated externally for decompression.

4. Provided with a medical lock and an outer lock.

5. Provided with an overhead flange and hatch for mating with the PTC.

PERSONNEL TRANSFER CAPSULE

A simplified cross-section view of the PTC is shown in Fig. 51, and its mated position on the DDC is shown in Fig. 52. The PTC being lifted from the water, transferred, and mated to the DDC is shown in Figs. 53, 54, 55, 56, and 57. The basic controlling dimensions of the PTC were: diameter, 6 ft; height, 11 ft; entrance hatch diameter, 27 in. The cylindrical portion of the unit was 8 ft long. Four pipe-type flared legs provided the necessary PTC mounted guides for mating. These legs, extending below the mating flange, also provided necessary protection to the mating surface during the handling of the PTC without its stand. The stand for the PTC provided adequate room (5 ft) below the PTC to gain entrance through the hatch. Ballast to provide negative buoyancy for the PTC was contained in two lower ballast trays at the base of the stand. The upper tray was permanently affixed to the stand; the lower tray was clamped to the upper tray during normal recovery operations by the crane of the surface-support vessel. The emergency self-contained raising system for the PTC was, basically, a pneumatically controlled, "Green-Giant" sized clock escapement mechanism as shown in Fig. 58. The ratchet gear is fixed to the cable spool shaft. One end of the cable is fixed to the upper ballast tray. The other end of the cable is fixed to the lower ballast tray. When the lower tray is released from the upper tray, the resulting 2000 lb of net buoyancy of the PTC, its stand, and upper ballast tray provides the necessary lifting force. Were it not for the pawls and the pneumatically controlled escapement arm, the PTC then would freely ascend to the surface on its cable, and the lower tray would serve as an anchor. The positions of the pawls and the escapement arm are controlled by the pneumatically controlled piston actuator. Each side of the actuator piston can be connected by means of a three-position control valve to either PTC internal atmosphere or to the low-pressure side of the He gas regulator. Thus, if both sides are connected to the internal atmosphere, the piston will float and the escapement mechanism will run free, the cable pay-out speed and hence the ascent rate being only a function of the buoyancy, dynamic

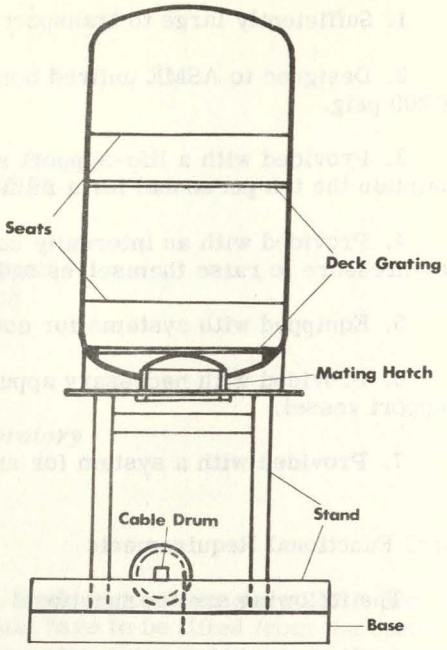


Fig. 51. Personnel transfer capsule, cross section

drag, and the mass-arm length relationships of the escapement mechanism. An ascent rate of about two to four feet per second will result from this free-running condition. The other two positions of the controller result in the actuation moving the escapement arm upward or downward, respectively, and thus permitting the ratchet gear to move one tooth (7 in.). Actuation up and down of the control, thus, permits the PTC to be raised slowly and positively to the surface. Three ports were incorporated into the structure to permit observations of the occupants. Internal pressure gages were so placed as to permit their observation from outside as well as inside.

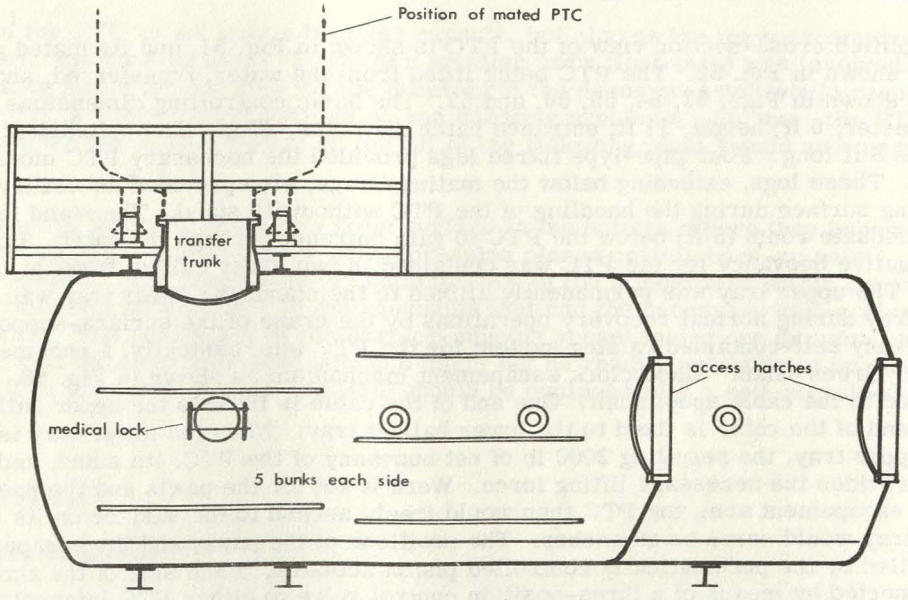


Fig. 52. Deck decompression chamber, cross section



Fig. 53. Personnel transfer capsule being lifted out of the water

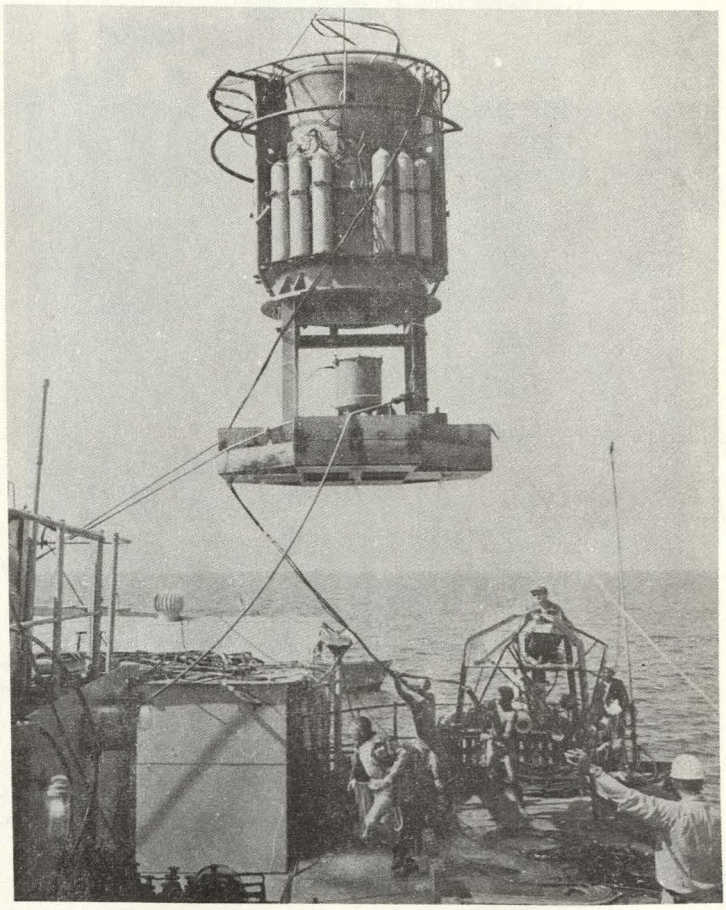


Fig. 54. Personnel transfer capsule being transferred from the ocean to the surface-support vessel

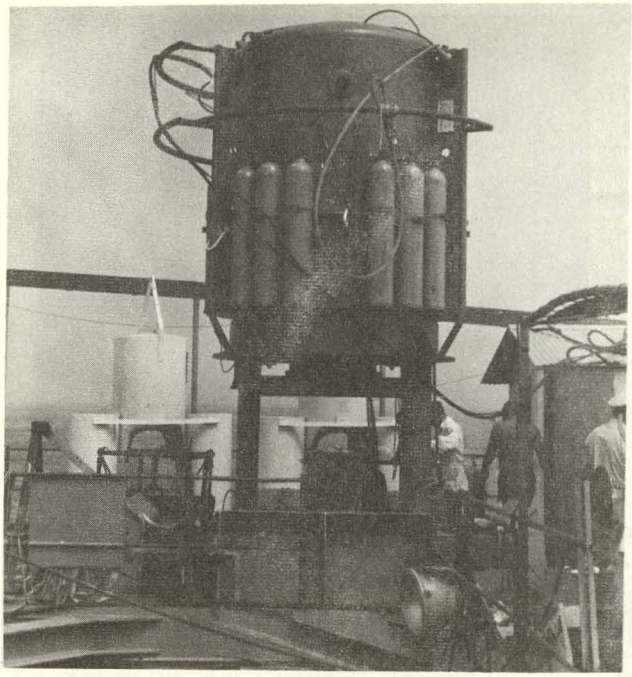


Fig. 55. Personnel transfer capsule sitting on its stand on the deck of the surface-support vessel

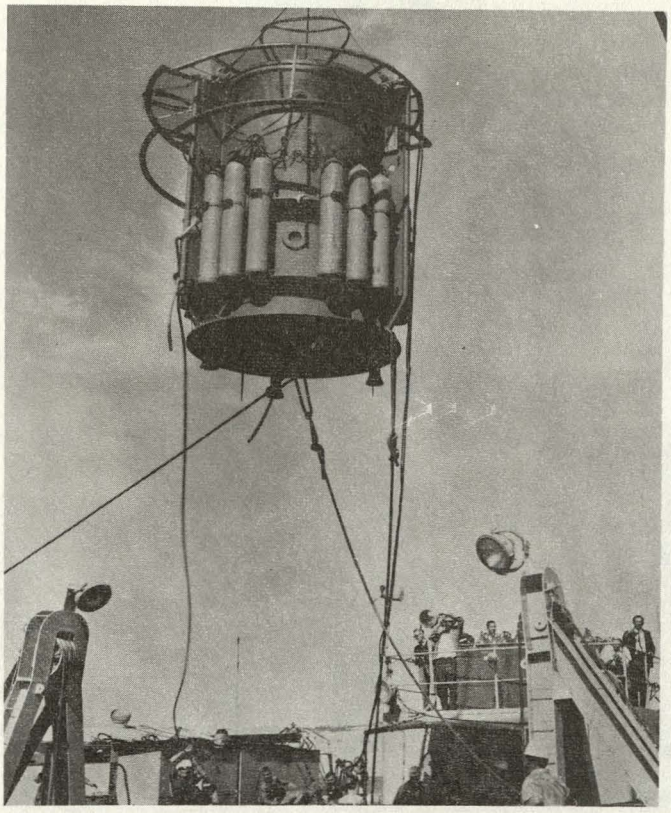


Fig. 56. Personnel transfer capsule being transferred, with stand removed, to the deck decompression chamber

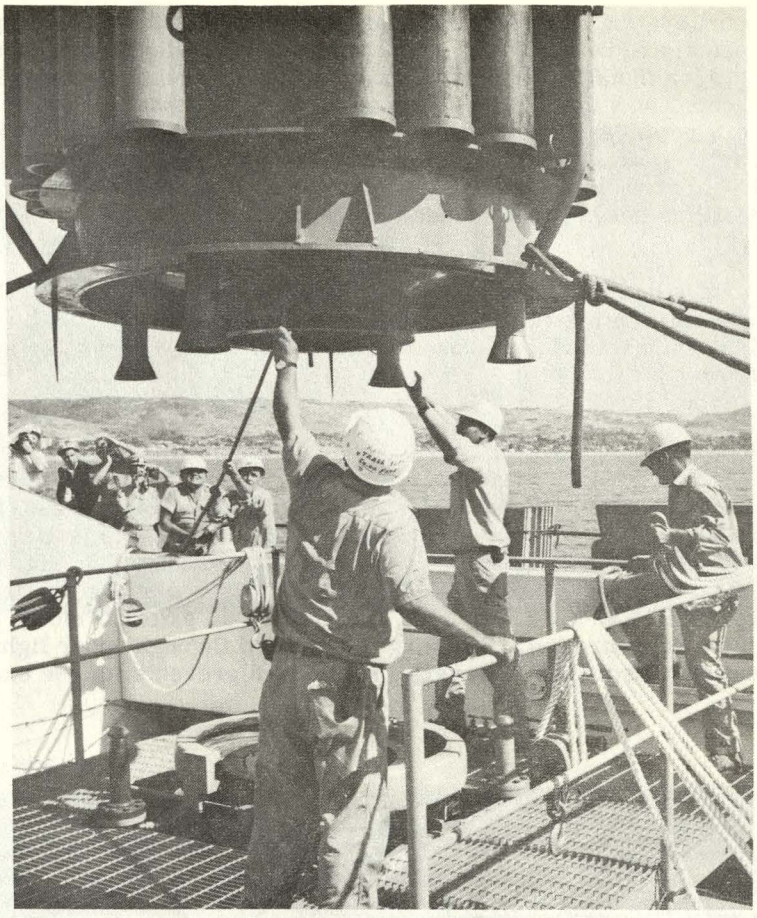


Fig. 57. Personnel transfer capsule just before mating to the deck decompression chamber

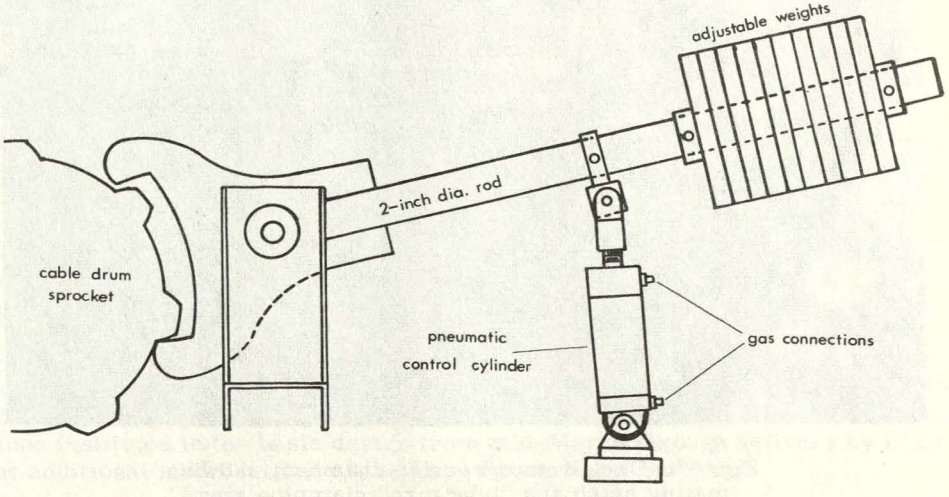


Fig. 58. Personnel transfer chamber escapement mechanism

The life-support system consisted of 200 cu ft O_2 and He bottles strapped to the exterior with pertinent connections, penetrations, and control valves. Regulators, control valves, and an O_2 flow meter were installed internally for aquanaut control. A standard portable five-canister CO_2 scrubber was installed with an externally mounted pressure-compensated lead-acid storage battery power supply. A solid-state converter thus permitted operation by the external battery, to provide 12 hours of effective CO_2 removal. An umbilical provided power from the support ship for normal scrubber operation, as well as for internal lighting. Gas-sampling and gas-filling hoses were included in the umbilical for normal surface control of the PTC atmosphere.

Communications with the PTC were provided by sonic and wire links. The wire link, connecting with the control-van intercom, was combined in the PTC umbilical. The sonic link consisted of an Aquasonic transducer mounted externally and an Aquasonic surface type control panel mounted internally.

DECK DECOMPRESSION CHAMBER

The DDC is shown in Figs. 59 and 60. It contains berthing for ten men, an entrance lock, a medical lock, a CO_2 scrubber, a gas-supply manifold, exhaust manifold with constant-flow regulators, and a mating hatch for the PTC. It is 23 ft long and 10 ft in diameter. The DDC is designated to be operated without any internal electric power to minimize fire hazard under high O_2 decompression. The CO_2 scrubber is driven by an external motor with a rotating-shaft seal through the pressure hull. Lighting is provided through upper light ports. An electrical appliance outlet is provided; however, a key switch prevents its use except by the medical officer.

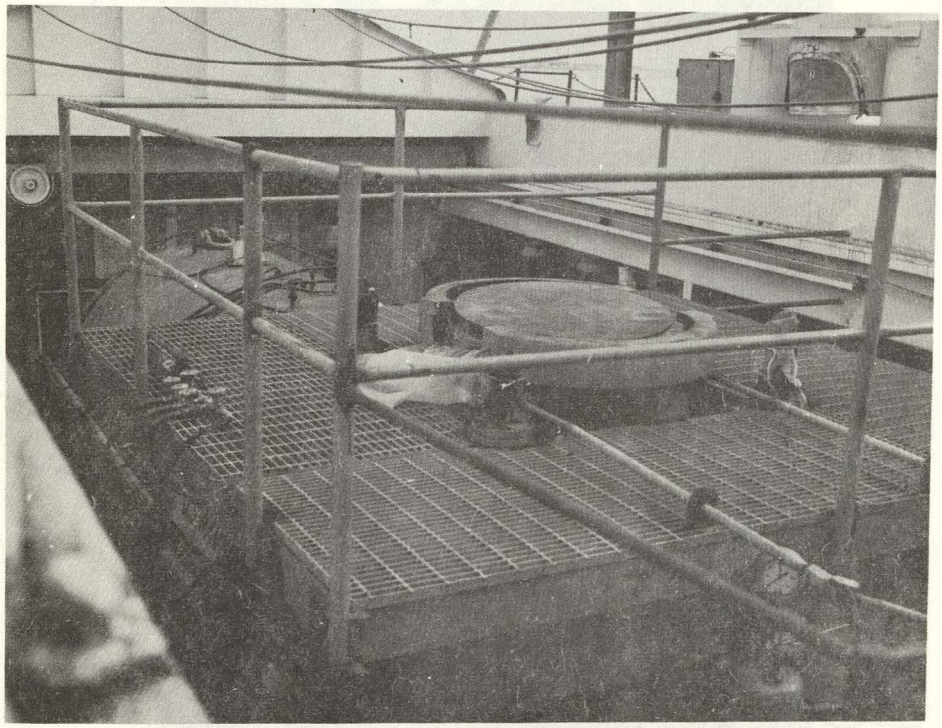


Fig. 59. Deck decompression chamber, showing mating hatch and "tube turn" clamping ring

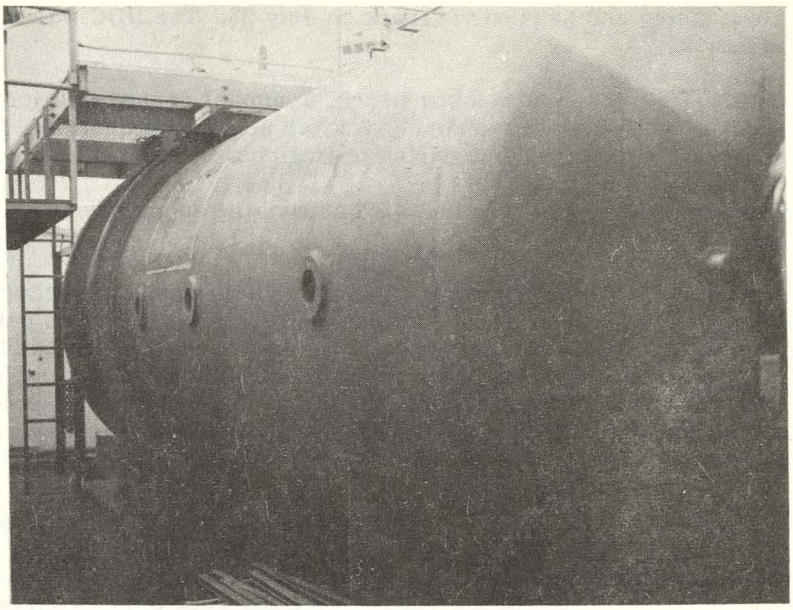


Fig. 60. Deck decompression chamber

PTC-DDC OPERATIONS

In normal operations, with the PTC on the sea bottom, the saturated divers enter and close the hatch in the bottom of the capsule, thereby sealing themselves at bottom pressure. The PTC is then hoisted aboard the support vessel and set on deck. The chamber is removed from the stand and base (Fig. 55) and placed on the mating hatch of the DDC (Figs. 56 and 57). The PTC is sealed to the DDC by means of a "tube turn" clamping ring (Fig. 59). The pressures in the PTC and DDC are equalized, and the hatches of the PTC and DDC are then opened. The divers then enter the DDC from the PTC, close the DDC hatch, and undergo decompression. The PTC is then returned to the ocean floor as the emergency capsule for the next team.

CHRONOLOGY

Functional specifications for development of the PTC and DDC were given to bidders on Feb. 10, 1965. Dixie Manufacturing Company of Baltimore, Maryland, was selected by a review board on Mar. 1 to be awarded the design and fabrication contract. After notification of contract award on Mar. 10, Dixie immediately initiated detailed design engineering and procurement of steel and major components for fabrication.

The steel industries of the United States were threatened with a strike shortly after the acceptance of Dixie's proposal. This threat resulted in delay in delivery of the steel for both the DDC and PTC. Steel was finally delivered during the last week of May.

Several other components caused delay to the completion of the chambers. These were: oxygen reducing valve for inside the PTC, the medical lock for the DDC, the forged door rings for the DDC, and the counterbalance springs for the overhead hatch in the DDC. A number of modifications instituted in the basic design from mid-March through delivery by Dixie were followed by additional modifications at the Long Beach Naval Shipyard.

A certification board, headed by Captain L. B. Melson of the Office of Naval Research, was appointed by the Chief of Naval Research to review the design and make recommendations to insure that the design met safety requirements. This board inspected the PTC and DDC at Dixie on July 15. Recommendations of the Board were received on July 23.

The PTC was completed and shipped via truck on July 23. The DDC was completed and shipped via rail on July 29.

Upon arrival of the PTC and DDC at Long Beach, a number of modifications were made. The emergency release mechanism was tested and, after slight modifications, found satisfactory. No need was found for its actual use during operations.

The decompression complex was then installed aboard the support vessel and final checkout tests performed.

During decompression of the three teams, the only unusual operation occurred during the decompression of Team 3. At a depth of 23 ft Master Diver Sheets reported pain in one leg. Subsequently, Captain Bond entered the chamber via the outer lock, inspected Sheets, and returned. Hospital Corpsman Manning thereupon entered the DDC, to stay with Sheets during his decompression. The other nine aquanauts were moved into the 6-ft outer lock to continue decompression to the surface at 6 ft/hour. Sheets was "sent back down" to 60 ft, given O_2 treatment, and decompressed at a linear rate of 4 ft/hour.

Chapter 18

THE SUPPORT VESSEL

E. P. Carpenter
Naval Ordnance Test Station
Pasadena, California

and

T. N. Blackwick
Boston Naval Shipyard
Boston, Massachusetts

INTRODUCTION

The support vessel was originally built for the Polaris pop-up tests conducted by the Naval Ordnance Test Station at the San Clemente Island Test Range. The craft consisted of two 110 34 ft YC barges, spaced 22 ft apart and connected at one end by a covered structure. This arrangement provided a rigid platform with overall dimensions of 110 × 90 ft with an open well at one end with dimensions of 65 × 22 ft (Figs. 61, 62).

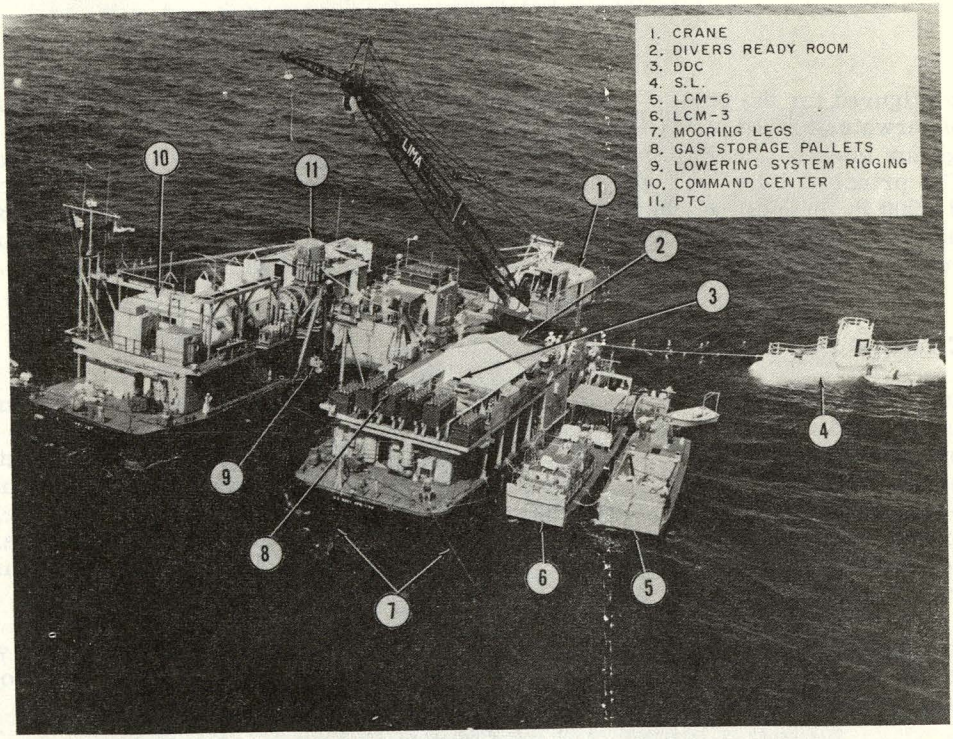


Fig. 61. Surface support vessel with Sealab II moored nearby

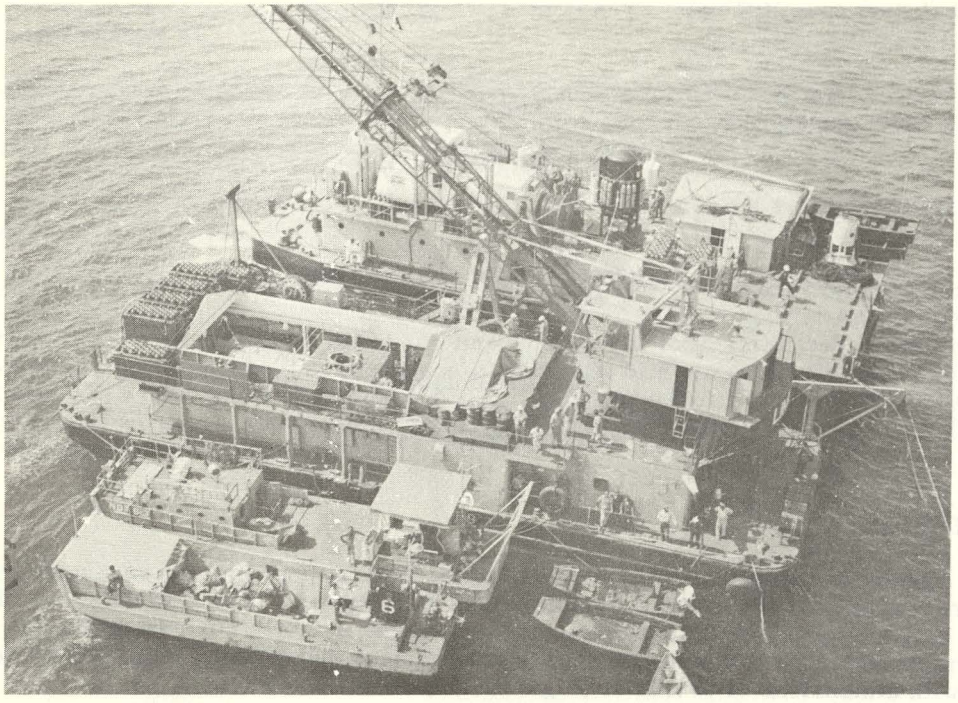


Fig. 62. Sealab II surface support vessel

As configured for the pop-up tests, the support vessel consisted basically of an open well with an underwater hinged platform for launcher loading operations, an open missile bay on the port barge for missile handling, storage spaces and machinery, equipment, dining and galley areas. The principal items of machinery were three ac generators with a total capacity of 460 kw, two 15,000 lb line pull winches, one high-pressure air compressor, one low-pressure air compressor, and a 100-ton Lima crane, restricted to a 50-ton working load as mounted on the staging vessel. The machinery was used for Sealab operations without modification.

MODIFICATIONS

To adapt the vessel for Sealab support, several modifications were made. The underwater hinged platform was removed. A portion of the missile bay was roofed over, and the enclosed space used as a divers' ready room with head facilities, showers, and racks for breathing equipment and wet-suit drying. The remainder of the missile bay was used for the installation of the 10-man Deck Decompression Chamber (DDC) and was fitted with a canvas cover which could be removed during Personnel Transfer Capsule - Deck Decompression Chamber mating. The space immediately aft of the ready room was fitted out with benches, plumbing, and power as required to overhaul and charge the Mk-VI semi-closed breathing equipment.

On the starboard barge, 01 level, two vans (Fig. 63) with a connecting enclosure were installed as the Sealab control center. Included in the vans were communications, atmosphere control, and medical equipment.

Other installations required on the support vessel for operations included the counterweighted lowering system for lowering and raising the Sealab and the Personnel Transfer Capsule (PTC), the dumbwaiter system for transporting both dry and wet items between the support vessel and Sealab (Figs. 64, 65), and the breathing-gas storage and distribution system.

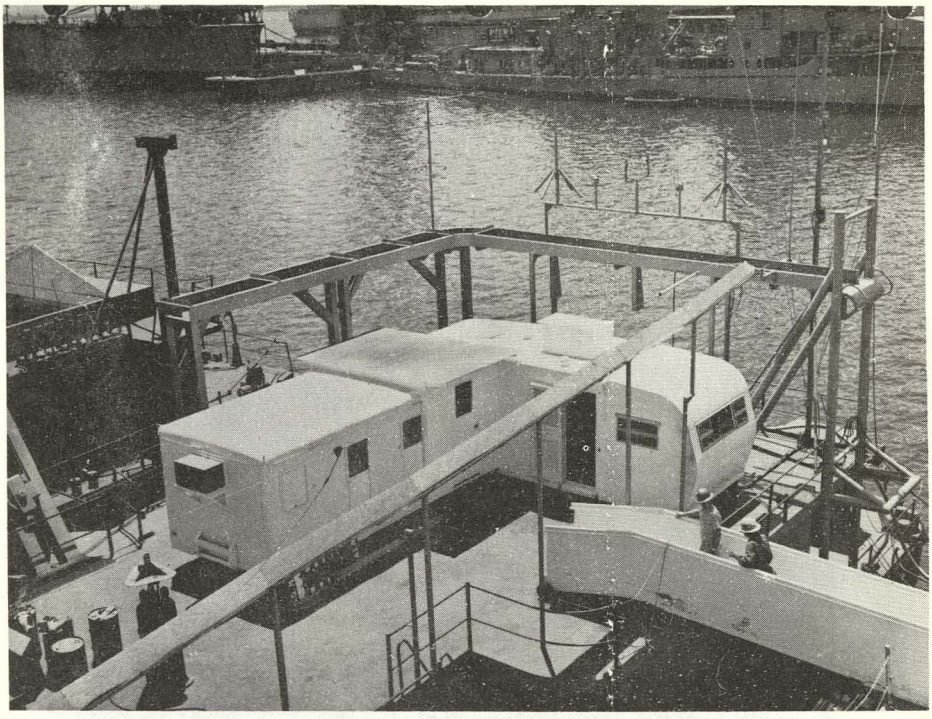


Fig. 63. Support vessel medical and communications vans

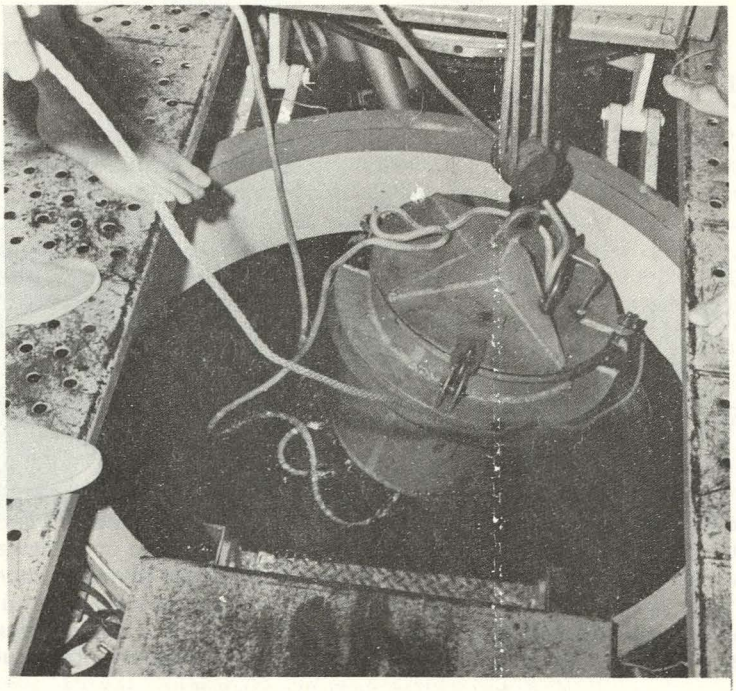


Fig. 64. Pressure pot for transferring dry items is lifted into Sealab II entry trunk

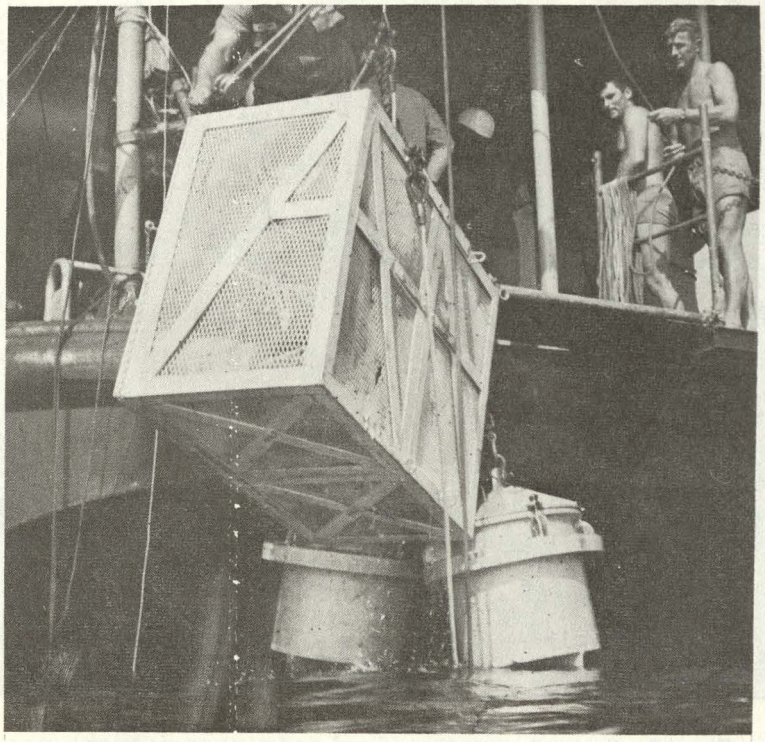


Fig. 65. Pressure pot for transferring dry items and cage for transferring wet items are lifted aboard the surface support vessel

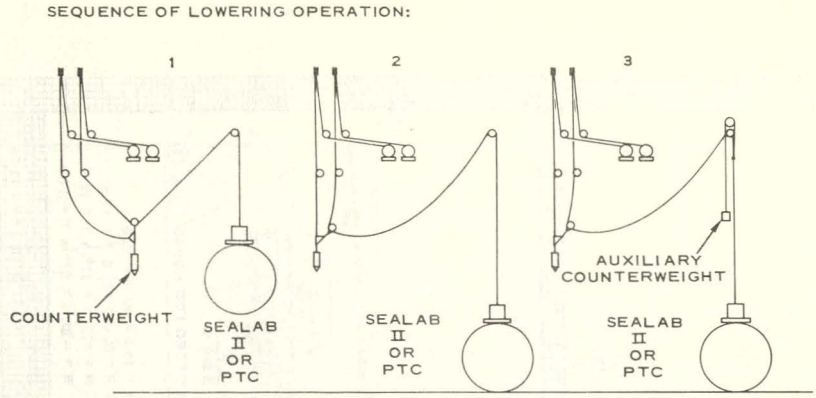
LOWERING COUNTERWEIGHT SYSTEM

In order to safely lower and raise the Sealab between the staging vessel and the bottom, it was necessary to make some provision for allowing for the relative motion between it and the vessel. It was anticipated that a maximum relative motion due to wave action, of about 10 ft, would be possible during a wave half-period of about 5 sec. Accordingly, a counterweighted system, as shown in Fig. 66, was used for lowering and raising both the Sealab and the PTC. This system had the effect of maintaining a nearly constant tension on the lowering line during the lowering and raising operations. Had this system not been used, the tension in the line would fluctuate between zero (free fall of the object through the water) to a value so high as would likely part the line or cause other failure of the weakest element.

Characteristics of the counterweight system as used for the Sealab II Project are shown in Fig. 67.

When operated properly, the system had the very desirable characteristics of smoothly and automatically loading and unloading itself when the bottom or surface is reached. The system could handle a wide range of loads without changing the size of the counterweight. There are theoretically no points of discontinuity, or conditions that would produce shock loads on the line, between the load range of zero to infinity. This was not strictly true in actuality, of course, since at low loads, fluctuating between 0 and 500 lb at the staging vessel's natural pitch period, the counterweight's response would not match the vessel's motion due to its own inertia.

Operation in this load range (0 to 500 lb) was required on occasions to keep a slight tension on the line when the PTC was sitting on the bottom prior to liftoff. This condition was met by placing a small auxiliary counterweight directly on the lowering line (allowing it to hang in the



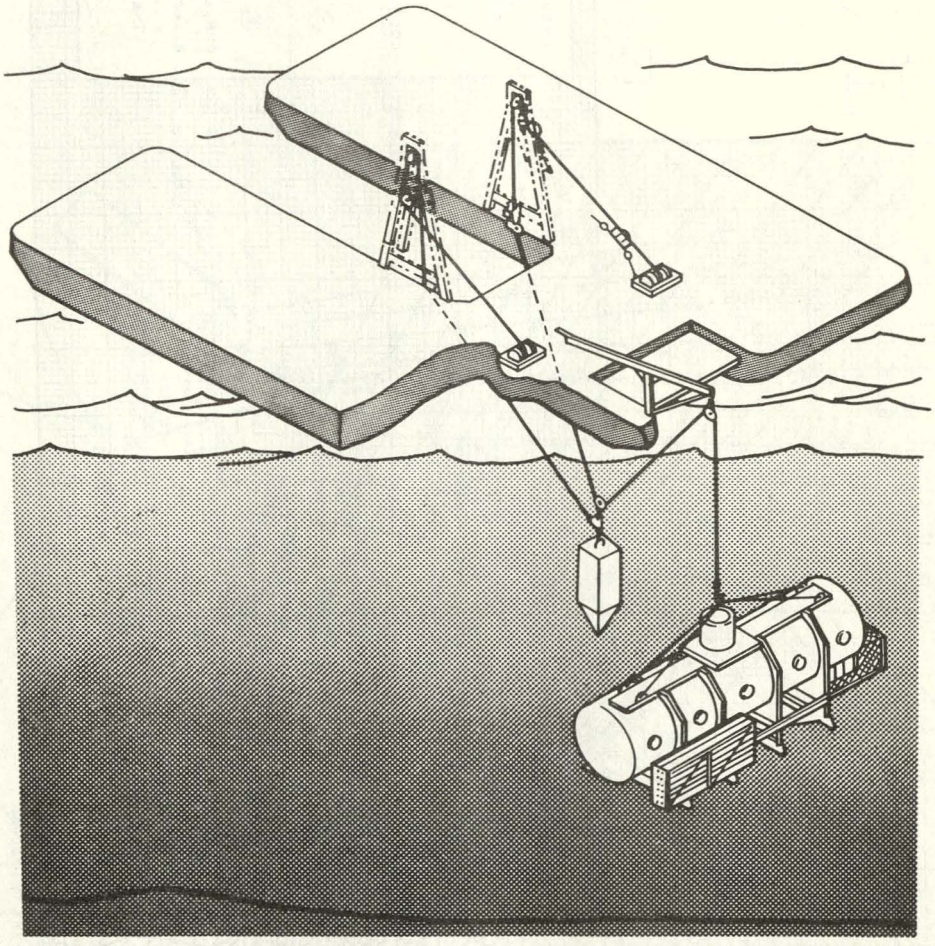


Fig. 66. Sealab II counterweight lowering system

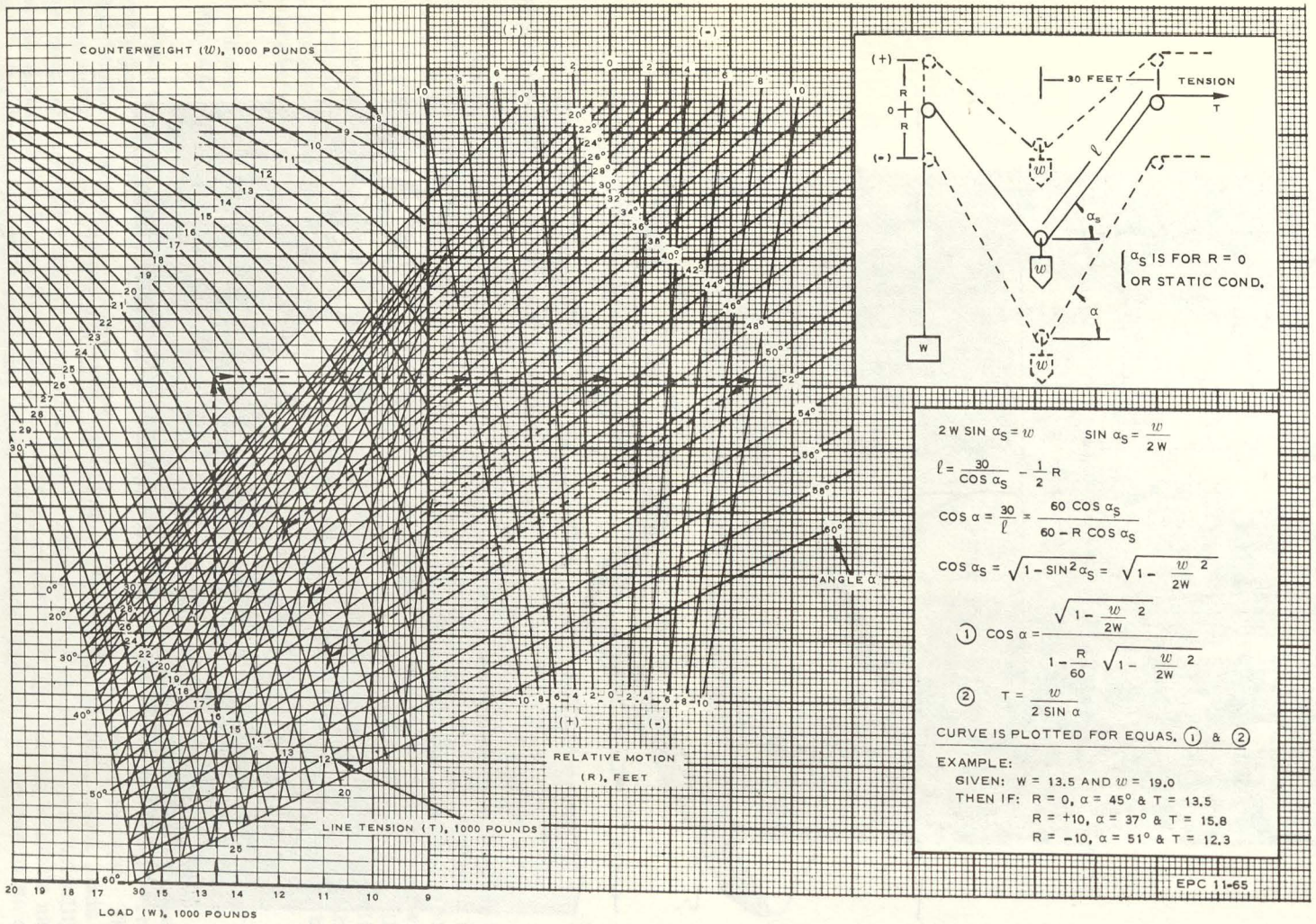


Fig. 67. Static characteristics of counterweight lowering system; dashed lines refer to example at the lower right.

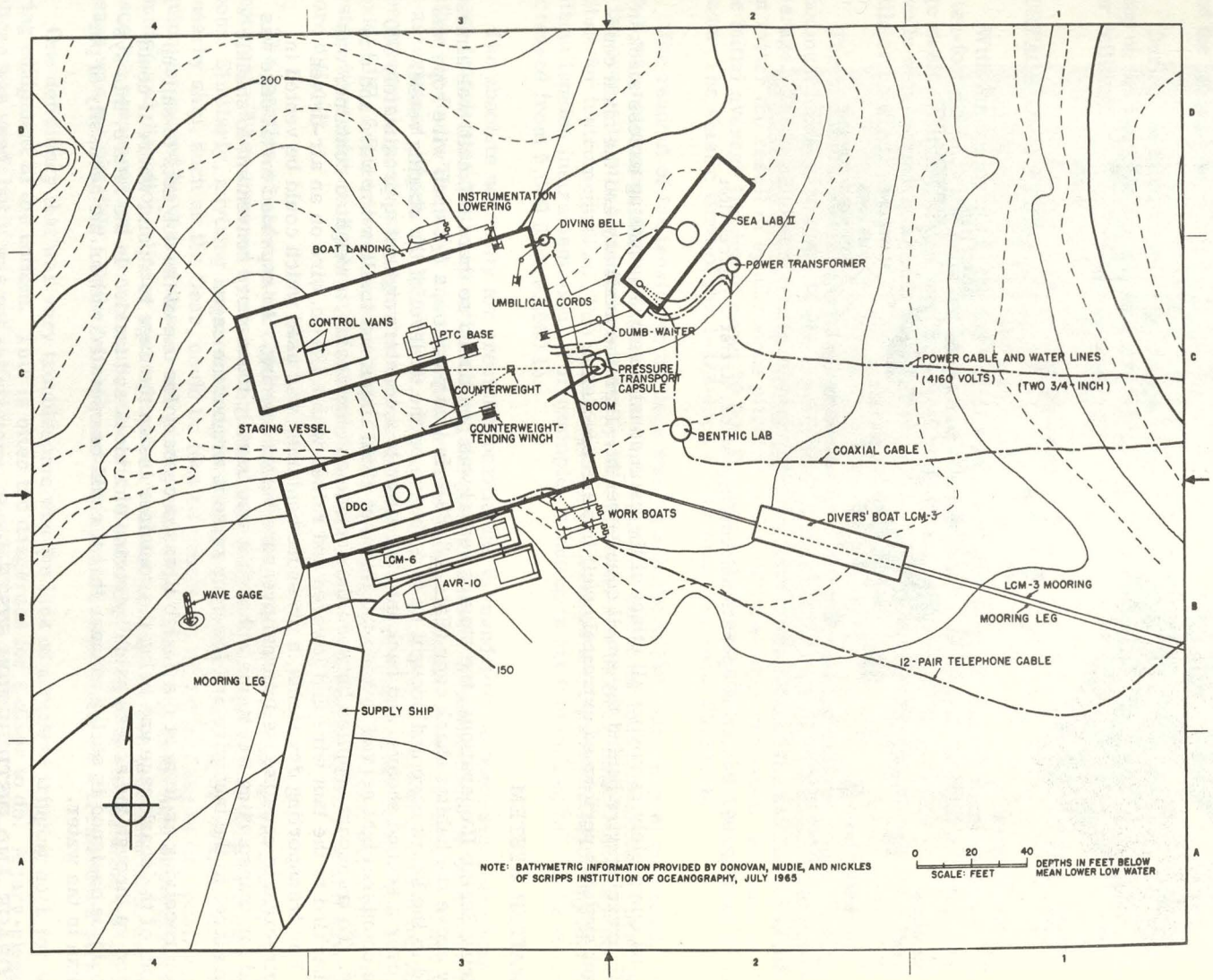


Fig. 68. Sealab II operational configuration

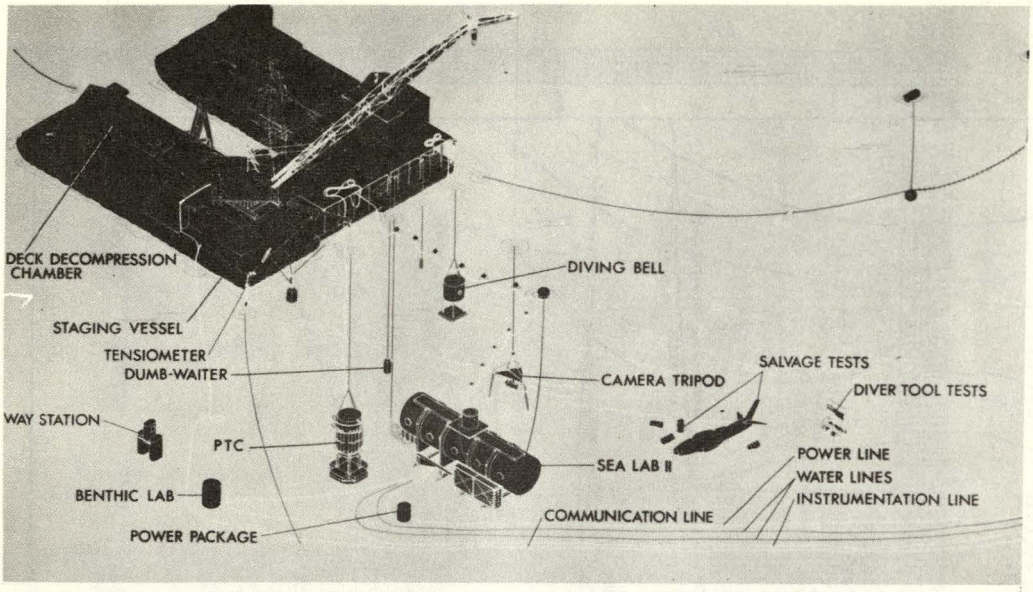


Fig. 69. Sealab II operational configuration, artist's conception

water) and completely removing all effect of the main counterweight by putting excess slack in the main lowering wire behind the small counterweight. Both the auxiliary and the main counterweight systems performed extremely well in all respects.

DUMBWAITER SYSTEM

During Sealab II operations, the staging vessel was positioned so that its fantail was almost directly above the habitat shark cage (Figs. 68, 69). In this position, a 1/2-inch wire rope was attached to the shark cage and brought up to a sheave on the 01 level of the staging vessel, passed over a second sheave, and back into the water to a counterweight of approximately 500 lb. The counterweight served to keep the line taut at all times and to allow for wave and tide motions. To transport supplies between the surface and the Sealab, a weighted container was loose shackled to the taut wire and lowered and raised with a 1/4-in. wire on an air-driven winch. For transporting dry items, a pressure container was used which could be vented in either direction to equalize its internal pressure before opening. An expanded metal cage was provided for transporting wet items although it was usually found more convenient to shackle the item direct to the taut wire and lower or raise it without the cage.

Upon receiving an item at the Sealab it was necessary for one of the subjects to suit-up and go out of the shark cage and bring the container inside the cage to a point where it could be hoisted up through the access hatch by means of a block and tackle. In the future, this system should be designed in such a manner that it could be operated without the necessity of putting a man in the water.

GAS STORAGE AND DISTRIBUTION SYSTEM

A total of approximately 300,000 cu ft of gas was used for Sealab II operations, the major part of this gas consisted of helium, oxygen, and helium-oxygen mix. Approximately half of this gas was purchased in bulk and delivered from the vendor's tube trailer directly to Sealab receivers consisting of the Sealab interior, the DDC, and, the 24 1300-cu-ft bottles mounted on the Sealab. The remainder of the gas consisting mostly of helium-oxygen mixture was delivered in "towner" pallets. Each of these pallets consisted of 30 200-cu-ft bottles manifolded

together. Nine pallets were stored onboard the staging vessel at all times, making a total capacity of 54,000 cu ft of gas available. Empty pallets were continually replaced with full ones as the gas was used. A high-pressure piping system was provided to deliver the gas from the pallets to the points of use as needed. These points included the DDC, PTC, Mk VI filling area, and the Sealab.

During the third team's stay on the bottom, a hose was run to the Sealab from the Mk VI shop on the Berkone for use in charging the Mk VI bottles in Sealab instead of bringing them up for refilling.

SURFACE OPERATIONS

With the aquanauts in the habitat, it was necessary that the staging vessel remain in about a ten-foot circle. The seaward legs were tensioned to about 10,000 lb. This was for an average swell condition, which was three to five feet, and winds of 10 to 15 miles per hour. The swells were normally at their worst from about 0200 to 0900. However, at this time there was little or no wind.

The maximum swells experienced were 7 to 8 ft; these were measured with a swell gage. Maximum loads of 50,000 lb were experienced in the weather legs. This was about three times the average. These maximum loadings were not a function of the size of the swells at the moment, but rather the result of synchronous pitching of the surface-support vessel. Because of this, the initial average tension of about 10,000 lb could not be exceeded without producing dangerous loads. The elastic limit of the 1-1/4-inch 6 × 19 wire was about 65,000 lb.

The readout of the tension in the legs was on a Sanborn 150 four-channel recorded. Leg No. 2 was not connected; thus, readouts were available under various conditions. These point to the necessity of a tension-recording system for open-sea moors. Experience is a poor substitute for instrumentation. The safe balancing of forces in the legs is virtually impossible without tension instrumentation. For example, in taking in six feet on Leg No. 4, the tension increased from 5,000 lb to 30,000 lb.

The absolute necessity for precision positioning is mandatory in open-sea operations. The shore transit stations were satisfactory, and positions of the Berkone could be determined within one foot. The mast and the antenna were used as targets. Thus the heading could also be ascertained, which was 255° True. The chart for plotting had a scale of one inch for 20 ft. The electronic positioning system was satisfactory, but sometimes broke down. The latter was Model GDR-T Recorder, made by T. H. Gifft and Associates, of El Segundo, California. If this system were more reliable, it would have been satisfactory, although plotting would have been more difficult.

The location of underwater objects around the surface-support ship was likewise extremely important. When lowered by crane, this location could be determined by taking bearings on the boom. Similarly, anything lowered straight down from the surface-support vessel Berkone or a nearby ship, such as the Gear, could be located precisely. However, any of the locations of equipment moved by divers was an educated guess, since they knew only their approximate position and direction. Under water pingers could not be used to locate objects from the surface. Since the aquanauts had no communication with topside during their dives, location by such means was not possible. Even reliable one-way comunication would be a tremendous stride.

One deficiency that was very troublesome was the lack of a remote tripping hook for lowering equipment to the bottom. This is often too dangerous for a diver to do. A jury-rigged pelican was used, but it was not satisfactory. Related to this is the necessity of marking lowering wires so that the depth of the hook below the surface can be determined.

The importance of accurate hydrographic surveys must not be minimized. It is considered that the chart used in this operation was one of the best available. Yet, important anomalies were discovered.

The water/air interface is troublesome at best, and particularly so in open-sea conditions. The use of a crane to lift the PTC and mate it to the DDC leaves much to be desired. A capture system with rigid constraints would seem a far better solution, although such a system would be costly.

One of the most useful movement indicators on the Berkone was the counterweight on the dumb waiter leading to the shark cage. The overall range of movement provided an excellent indication of sea conditions and synchronous pitching, which produced high loading on the mooring legs and made handling of equipment with the Berkone crane hazardous.

Chapter 19

SITE SELECTION

D. C. Pauli and G. P. Clapper
Office of Naval Research
Washington, D.C.

and

T. N. Blockwick
Boston Naval Shipyard
Boston, Massachusetts

INTRODUCTION

The purpose of the Man-in-the-Sea program is not only to place man at a depth equal to any depth encountered on the continental shelf, but also to give him the ability to perform useful work at these depths regardless of the severity of the environment.

Sealab I proved that man could survive under 200 ft of water. It remained for Sealab II to indicate what useful work could be performed at this depth in an environment typical of the continental shelf.

Therefore, one of the initial concepts of Sealab II was that the operation would be conducted at a depth of approximately 200 ft with bottom conditions of some severity, i.e., temperature 45° to 55°F and visibility 50 ft or less.

With these guidelines in mind, site selection began.

SELECTION OF GENERAL AREA

The off-shore site at the Scripps Institution of Oceanography near La Jolla, California (Fig. 70) was chosen for several reasons.

1. The site provided conditions of lower water temperature (48° to 52°F) and lessened visibility (0 to 50 ft), as more typical of the conditions under which routine fleet operations would be conducted.

2. The proximity of the excellent research facilities of the Scripps Institution of Oceanography and the Naval activities of the Southern California area enhanced the opportunities of obtaining the maximum results from the experiment.

3. The proximity of Scripps Submarine Canyon gave an ideal area for excursion diving to deeper depths, while precluding the necessity of swimming long horizontal distances. At several points the depth increases from 190 to 300 ft in a horizontal distance of only 100 ft.

4. The ocean floor from the beach at Scripps Institution of Oceanography out to Scripps Submarine Canyon was as well charted as any comparable section of ocean floor in the world (Fig. 71). The ecology of the area was also very well known as a result of numerous investigations by Scripps scientists. This knowledge would give the Physical Oceanographers and Marine Biologists in the Sealab teams an excellent basis for further investigations during the experiment (Chapters 39,40,41).

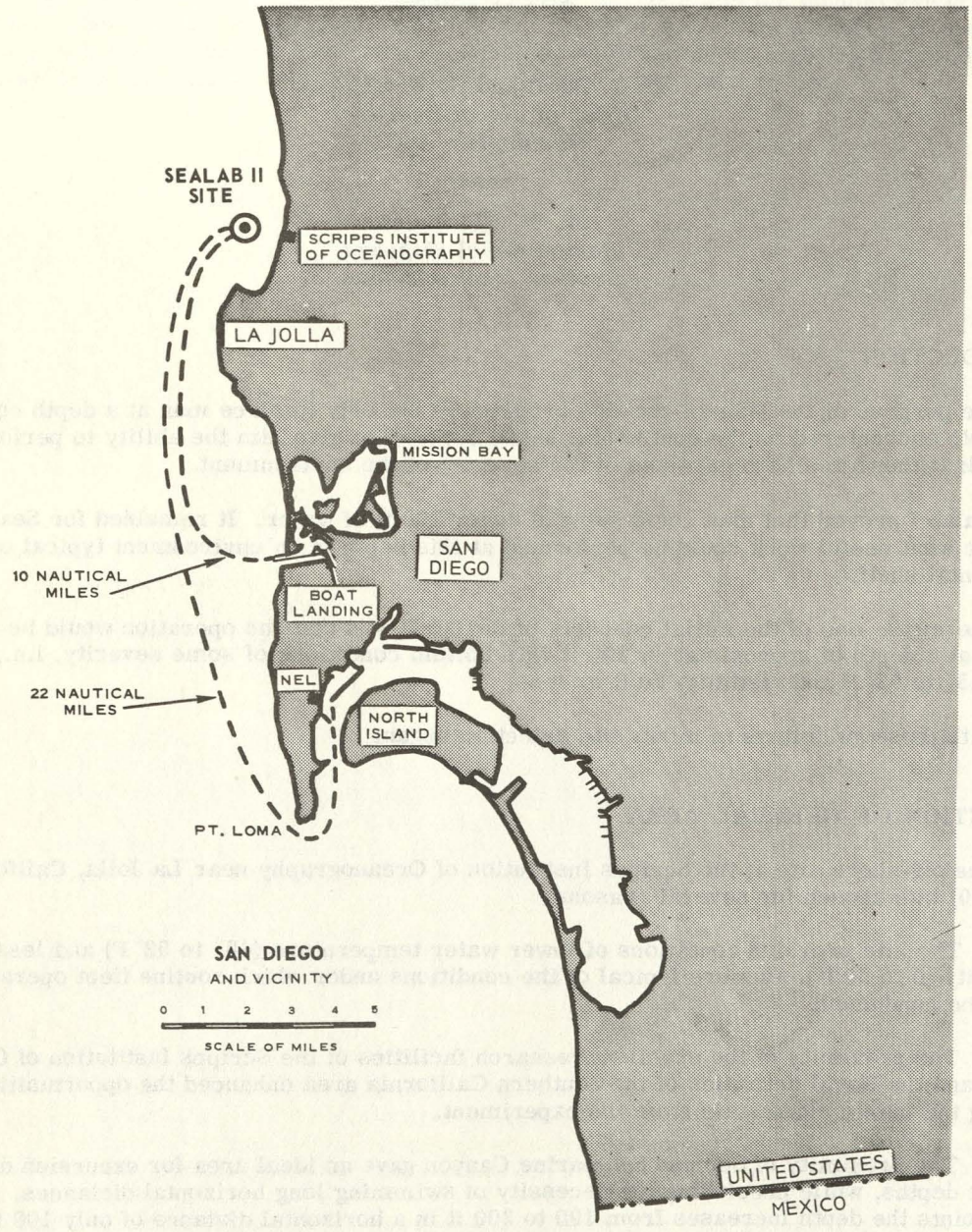


Fig. 70. Sealab II site vicinity

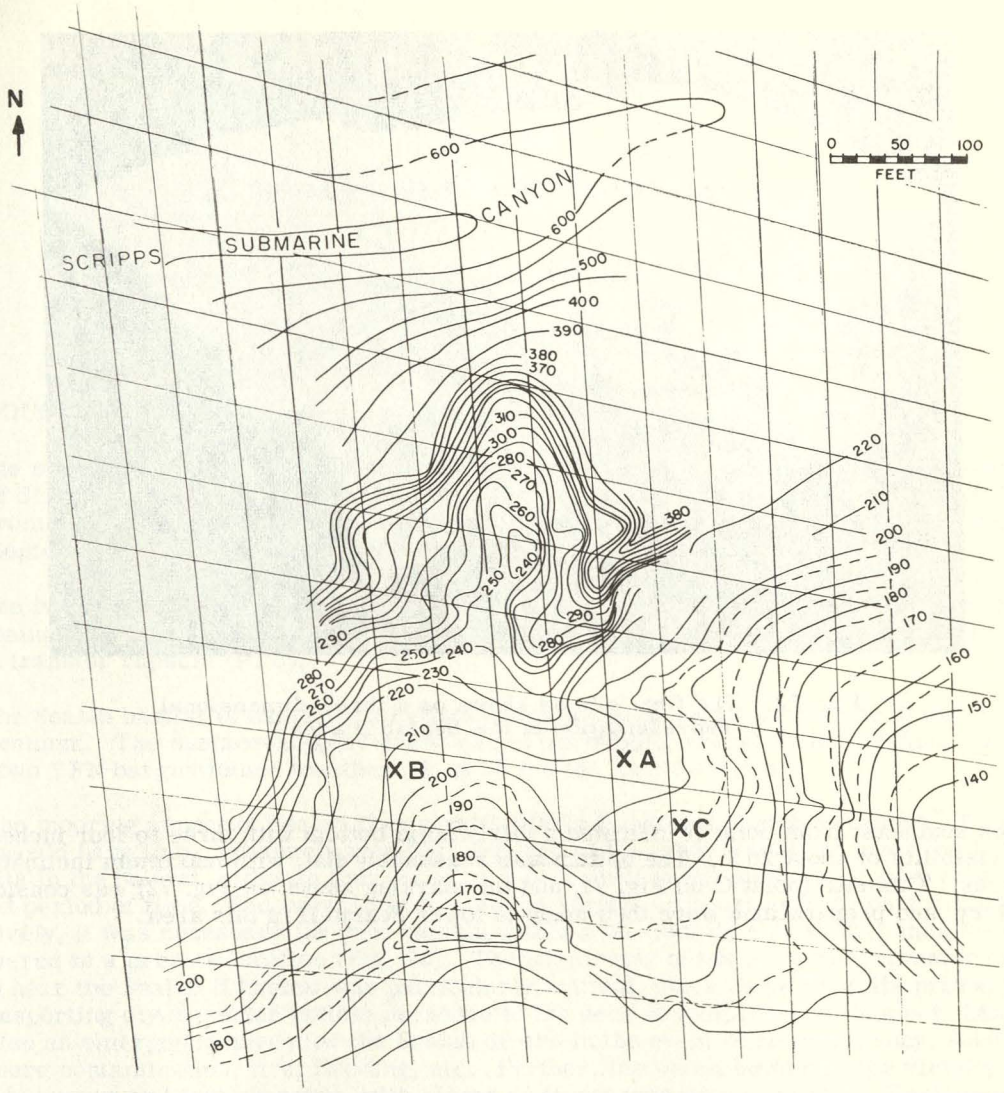


Fig. 71. The three sites considered for Sealab II. Point A - first site picked, later deemed unsatisfactory due to great amount of silt. Point B - investigated as possible site, but slopes up to 45° made it unsatisfactory. Point C - final site selected. The site was covered with three to four inches of silt, and the slope was no more than 10°.

The specific area for emplacement of the Sealab was selected on the basis of detailed bottom soundings made by the Marine Physical Laboratory of Scripps Institution of Oceanography. Figure 71 is a bottom contour chart based on these soundings. The valley area (point A on Fig. 71) or its immediate surrounding area was deemed to be satisfactory from oceanographic and excursion-diving considerations. Preliminary dives on the site were made in April 1965, and the general area was accepted as satisfactory by the steering committee. Dives at point A, however, indicated that the valley contained a great amount of deposited silt, and to avoid the difficulties of settlement, swimming, etc., the final site would have to be either on the side of a hill or further up the valley.

The surface-support vessel was positioned over point B, Fig. 71, on Aug. 18, and exploratory dives were begun. However, the dives showed that the terrain was more precipitous than the charts indicated, with inclinations up to 45 degrees. The visibility was quite poor, only 10 to 20 ft. The site was considered unacceptable and would, if utilized, require considerable wash-out leveling operations and thus jeopardize the project.

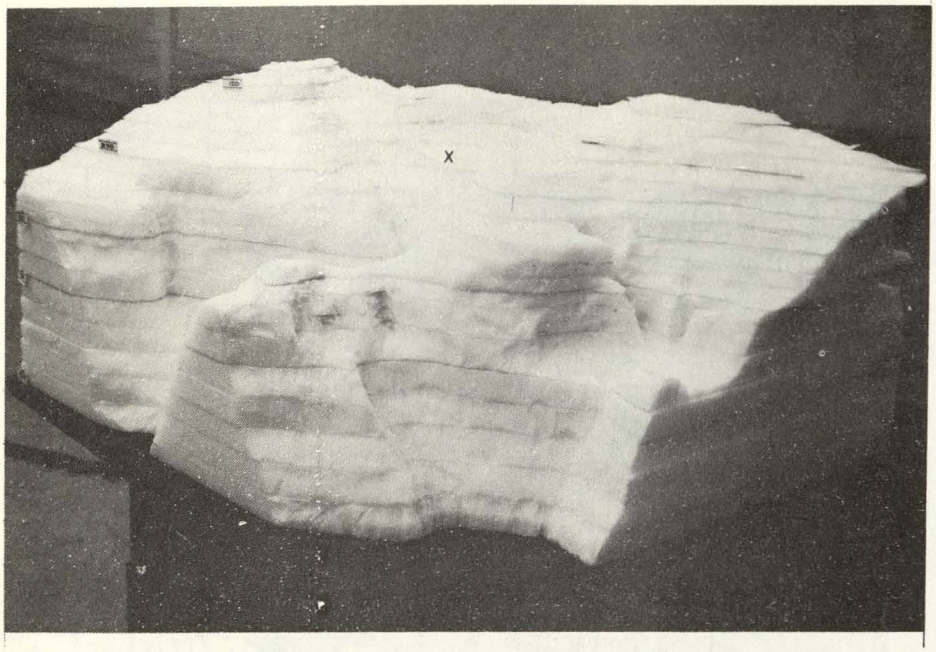


Fig. 72. The final site as shown on a three-dimensional representation of the Sealab II area

Dives southeast from point A indicated a fairly solid bottom with three to four inches of silt and visibility of about 20 ft. The bottom was reasonably flat, with maximum inclinations of ten degrees. This site (point C on Fig. 71, and the marking shown on Fig. 72) was considered satisfactory, and preparations were then made to lower Sealab II in this area.

Chapter 20

STAGING VESSEL MOORING COMPLEX

T. N. Blockwick
Boston Naval Shipyard
Boston, Massachusetts

INTRODUCTION

The site of Sealab II was about 4000 ft offshore at La Jolla, California, and almost directly west of Scripps Pier. This location made all surface sea operations vulnerable to weather and seas from the prevailing western direction. Although bad weather was not expected during August, September, and October, the possibility could not be discounted.

The two most important open-sea operations of Sealab II were the precision mooring and positioning of the surface-support craft and the handling of the Sealab II habitat and the personnel transfer capsule (PTC).

The Sealab habitat is basically a cylindrical unpowered small submarine of about 200 tons displacement. The surface-support craft, called the staging vessel or the Berkone, is essentially two YFN barges joined together. It is 90 ft wide and 110 ft long.

The mooring aspect of Sealab II was particularly important, for two reasons. First, the moor would have to be extremely reliable. Failure of the moor would endanger the lives of the subjects in the habitat, although they could be independent of the surface-support craft for a limited period of time. Secondly, in order for the surface-support craft to perform its function effectively, it was necessary for it to remain within a ten-foot circle, so that equipment could be lowered in a precise location (Fig. 73). The positioning of the personnel transfer capsule (PTC) near the Sealab II habitat was particularly critical, since aside from its primary function of transporting divers under bottom pressure to the deck decompression chamber (DDC), it was also an emergency haven for the Sealab divers in the event of an emergency, such as atmosphere contamination, fire, flooding, etc. Further, the ocean bottom in the vicinity was extremely uneven and fast changing, with slopes of 45 degrees not uncommon. Equipment could not be landed in such terrain, and suitable flat areas had to be pinpointed. The site was near the Scripps Canyon, which drops precipitously to a depth of 700 ft.

To provide for safety in bad weather and precise mobility, a five-leg moor (Fig. 74) was designed. Three of the legs were located in the sector of maximum expected weather which was from the west. Two of the legs (Nos. 1 and 5) were unique, in that they had to span the Scripps Canyon (Fig. 75).

Each leg was designed to resist a 50-knot wind on the surface-support vessel. This would require that each leg be capable of resisting a 50,000-lb pull. To determine the holding power of the soil in the area, several anchor tests were made under controlled conditions and a two-to-one scope. The holding-power-to-weight ratio was found to be at least seven to one and was considered satisfactory.

The basic leg consisted of the following:

1. A 13,000-lb Navy Stockless Anchor with a 1-1/4-in. crown wire of length equal to the water depth plus 30 ft connected to a 59-in. spherical buoy of 3000-lb buoyancy.

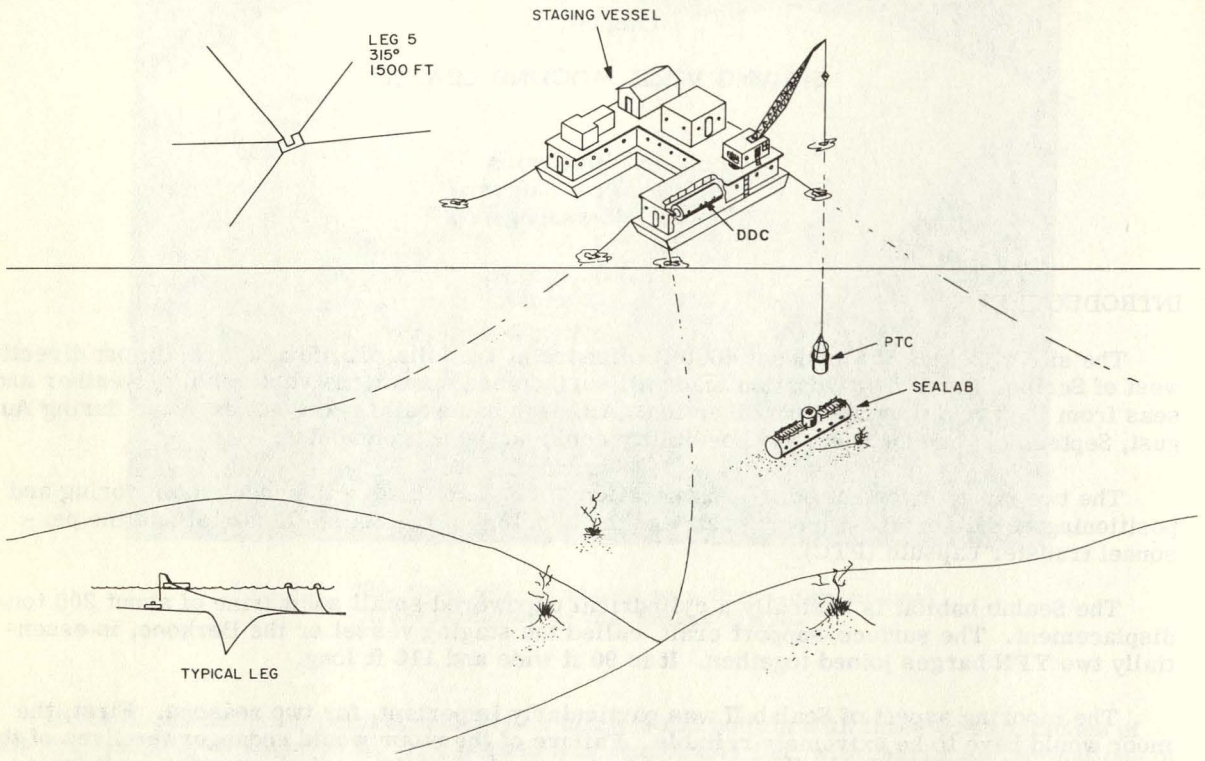


Fig. 73. Sealab II operational configuration, showing relationships of Sealab, staging vessel, PTC, mooring legs, and canyon

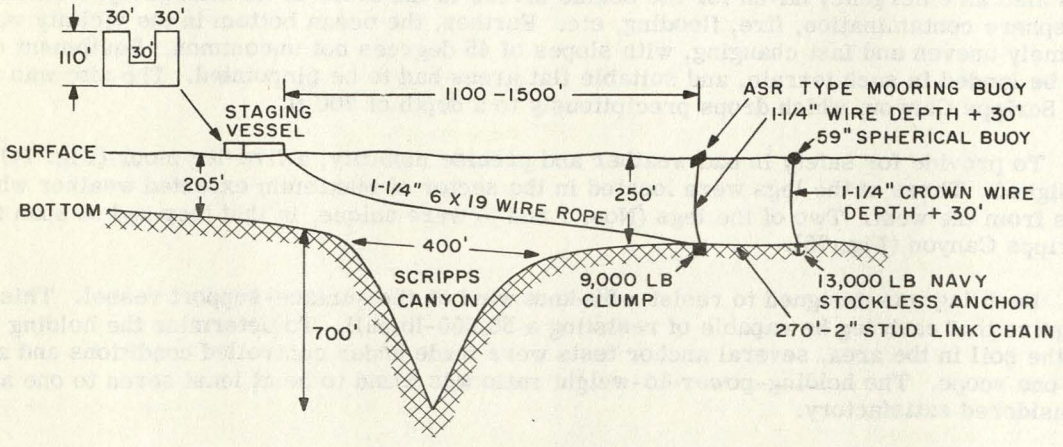


Fig. 74. A typical mooring leg

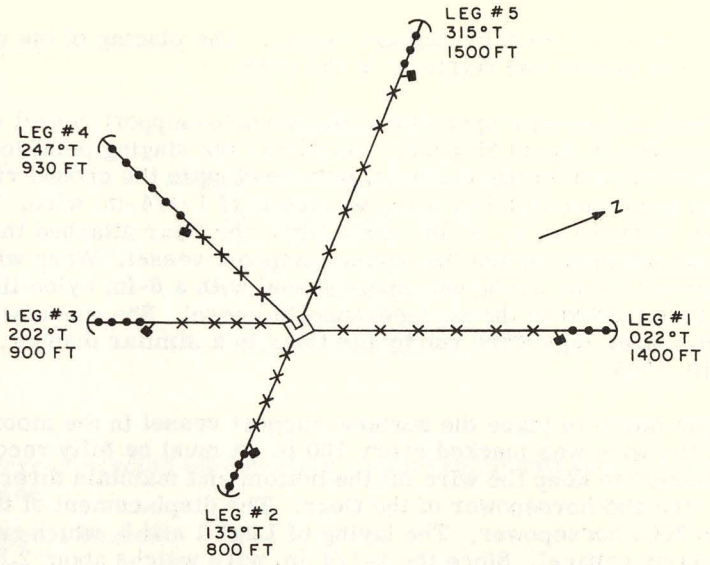


Fig. 75. The staging vessel moor

2. Three shots of 2-in. stud link chain (270 ft) leading from the anchor to the ground ring, where a 9000-lb clump was attached.

3. One ASR type mooring buoy connected by 1-1/4-in. wire of length equal to depth plus 30 ft to the ground ring. No pull would be transmitted through the buoy. The chief purpose of the ASR buoy was to permit laying of all but the final connecting wire portion of the moor as an entity and to use it for mooring ships and craft during Sealab operations.

4. Leading from the ground ring with a Miller swivel, 1-1/4-in. 6x19 wire rope was connected to the surface-support vessel. Although 6x37 wire was specified, 6x19 arrived because of an error. This substitute was acceptable, although it was more difficult to handle.

Two 1-1/4-in. Carpenter Stoppers and Bridles were used to hold the wire at the attachment points of the surface-support vessel. After the desired position of the support vessel was reached, a short 1-1/2-in. chain was attached to the tension link. The chain was inserted in the system to eliminate chafing of the wire, especially during swells. The tension link was connected to a Sanborn 150 four-channel recorder.

For basic mooring leg, refer to Yards and Docks Drawing No. 1,039,768.

INSTALLATION OF MOORING LEGS

All legs, except for the final connecting wires, were laid several weeks (July 12-16, 1965) before the surface-support vessel was towed to the site. The legs were lowered in position from the bow and then stretched. The USNS Gear (ARS-34) was used to lay the legs. They were laid within 25 ft of their planned locations. Two shore transit stations were used to ascertain the position of the ship laying the legs.

The prior laying of these legs facilitated the mooring of the staging vessel when it arrived at the site.

MOORING OF STAGING VESSEL

In preparation for placing the surface-support vessel in the moor, all the 1-1/4-in. wire, except for Leg 5, was placed on the main towing drum of the Gear. The wire for Leg 5 was

placed in stopped bights on the surface-support vessel. The placing of the wire on the towing drum would permit easy payout and retrieval of the wire.

When all was ready for on-site operations, the surface-support vessel was taken in tow to the site from the Long Beach Naval Shipyard, which was the staging point for Sealab II. The surface-support vessel picked up the 1-1/4-in. wire leading to the ground ring, which was secured to the mooring spud, and attached it to the 1200 ft of 1-1/4-in. wire. With the aid of two YTBs, it drifted back toward Leg 2. At the same time, the Gear attached the wire on the towing drum to Leg 2 and steamed toward the surface-support vessel. When within about 100 yd, the Gear attached herself to the surface-support vessel with a 6-in. nylon line. The end of the 1-1/4-in. wire was then passed to the surface-support vessel. She was now in a two-point moor. The remaining three legs were run by the Gear in a similar manner. The mooring was completed on Aug. 18, 1965.

It took about eight hours to place the surface-support vessel in the moor. To facilitate precise positioning, the wire was marked every 100 ft. It must be fully recognized that to maintain adequate tension to keep the wire off the bottom and maintain direction, it is necessary to use a ship of the size and horsepower of the Gear. The displacement of the Gear is about 2000 tons, and it has 3000 horsepower. The laying of Legs 1 and 5, which spanned the Scripps Canyon, was particularly critical. Since the 1-1/4-in. wire weighs about 2.5 lb per foot in water, the placing of the wire on the main towing drum for safe handling was almost mandatory.

Chapter 21

ASPECTS OF COMMUNICATIONS IN SEALAB II PROJECT

G. P. Clapper, editor*
Office of Naval Research
Washington, D. C.

INTRODUCTION

Six locations were connected together for routine communications. The communications links established were:

1. Habitat - support vessel
2. Habitat - shore
3. Habitat - swimmer
4. Swimmer - swimmer
5. Support vessel - shore
6. Personnel Transfer Capsule - support vessel

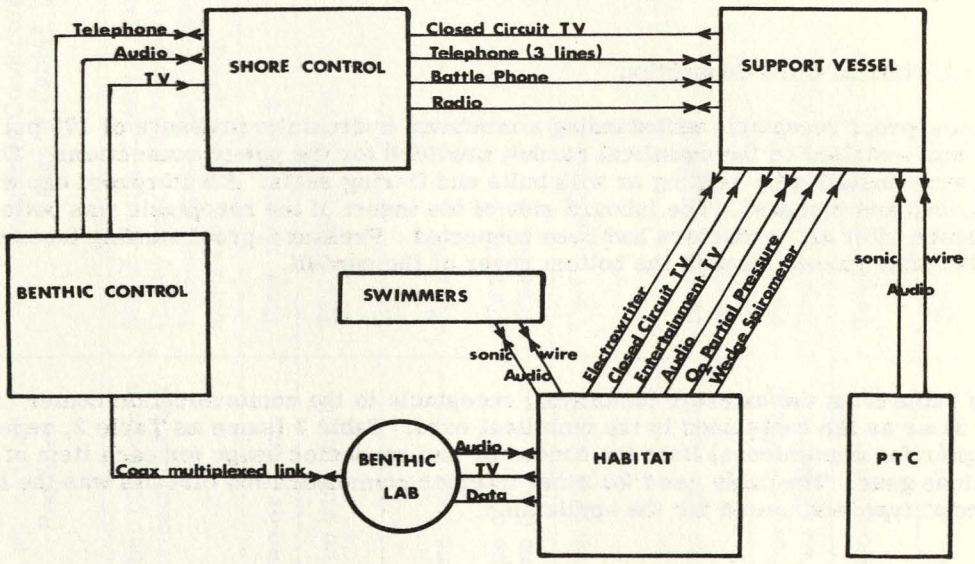


Fig. 76. Sealab II communications block diagram

*The material for this chapter was contributed by E. P. Carpenter, Naval Ordnance Test Station, V. C. Anderson, Marine Physical Laboratory, M. Mackinnon III, San Francisco Bay Naval Shipyard, W. B. Culpepper, and B. L. Cannon, U. S. Navy Mine Defense Laboratory.

Commercial telephone lines were used, in addition, for special calls made between Jacques Cousteau's submerged Conshelf III oceanauts and the submerged Sealab II aquanauts, and between President Johnson in Texas and CDR Scott Carpenter during decompression aboard the support vessel. Special radio and land lines were provided by NASA for providing a communication link between CDR Scott Carpenter in Sealab and astronaut Gordon Cooper passing overhead in Gemini V.

HABITAT - SUPPORT VESSEL

The primary communication link between the habitat and the support vessel was the umbilical cord. Certain engineering, environmental, and physiological information was also transmitted through the umbilical cord. The following modes of communication were provided:

1. Helium speech unscrambler
2. Electrowriter
3. Television
   a. Closed circuit monitors
   b. Entertainment
4. Audio

In addition to the above, wedge spirometer output and O_2 partial pressure were transmitted via the communication cable in the umbilical. All equipment was installed at Long Beach Naval Shipyard by the Naval Ordnance Test Station according to Mine Defense Laboratory Specifications.

Exterior Umbilical Cord Connection

A waterproof receptacle withstanding a minimum hydrostatic pressure of 175 psi without leakage was installed on the umbilical conduit provided for the power connections. The connectors were installed by welding or with bolts and O-ring seals. A waterproof cap with chain was provided and installed. The inboard side of the insert of the receptacle was potted to seal out moisture after all conductors had been connected. Pressure-proof stuffing tubes were used where the cable passed through the bottom cover of the conduit.

Cable

The cable from the exterior (umbilical) receptacle to the communication center in Sealab was the same as the cable used in the umbilical cord. Table 3 (same as Table 2, repeated in this chapter for convenience) lists the conductor and connector usage for each item of communications gear. The cable used for other interior communication circuits was the Navy or commercial type best suited for the application.

Sealab Communications Center

A section of the laboratory bench adjacent to the fan cabinet was used for the Sealab communication center. A patch panel was designed and installed at this location to facilitate connecting the various pieces of equipment at the test site. The panel had multipin receptacles for all the TV circuits, and switches for the audio link from Sealab to the support vessel. Table 3 lists the particular receptacles required to mate with an existing plug on the equipment. A panel was also built and furnished to NOTS and was installed in the communications van on the support vessel. The panel was identical to the panel in Sealab, except that (a) switches for the audio link were not required, and (b) an Amphenol receptacle replaced the two separate receptacles for the audio link to Sealab and shore.

Table 3

SEALAB II COMMUNICATION SYSTEM CONDUCTOR AND CONNECTOR REQUIREMENTS

Item	No. of Cond. Required	Suggested Conductor Usage W Cable*	Patch Panel Connectors		No. Pins Req'd in Umbilical Plug
			Sealab	Support Vessel	
Helium speech unscrambler	Four conductors for each headset	Sealab Comm. Center - Quad 1 Galley space - 2 from perimeter Berthing space - 2 from perimeter and 2 from center group	Information not available	Info. not available	4 4† 4
FM speakers	Two or four	Time share Quad 1	Amphenol series	91 or equal	None
Electrowriter	Two with shield	Two from perimeter	Amphenol series 91 or equal	Same	2†
Television (1) Closed circuit monitor (2) Entertainment (3) Spare	 One coax One coax One coax	 Coax No. 1 Coax No. 2 Coax No. 3	Amphenol series 83 or 31 or equal	Same	 2† 2 2
Audio, CCC to Sealab	Two with shield	Two from Quad 3	Amphenol series 91 or equal	Amphenol No. 67-02E 14-5S	2†
Audio CCC to shore via Sealab	Two with shield	Two from Quad 3 shield common	Amphenol series 91 or equal		2†
Wedge spirometer	Four with shield Two singles	Four from Quad 2 Two from center group	Amphenol 67-02E14-9P, Do not substitute	Same	4† 2†
O_2 partial pressure	Two singles	Two from center group	Cinch-Jones S-202-CCT or equal	Same	2
Trunk water level	Two singles	Two from center group	Cinch-Jones S-202-CCT or equal	Same	2

*Conductor usage is based on BIW Cable No. TV-33N. Quads and Coax conductors have been arbitrarily numbered for identification in this table only.

†All shields except coax shields shall be connected to pin 34 of the umbilical connectors.

Helium Speech Unscrambler

The helium speech unscrambler was provided by the Naval Applied Science Laboratory in cooperation with BuShips. Three headsets were provided and were located in the Sealab communication center, galley, and berthing area. Conductors and connectors are listed in Table 3. Unscramblers were located on the support vessel and on shore. The shore unit did not improve the helium-speech distortion. The support-vessel unit was used intermittently and was considered by some to be marginal. During the visit of Mr. Copel of the Applied Science Laboratory, the adjustment of the unit improved the voice materially. Such improvement was not generally experienced.

Electrowriter

The electrowriter, consisting of a transmitting and receiving unit, was provided by the Mine Defense Laboratory and installed by the Naval Ordnance Test Station. Conductors and connectors are listed in Table 3.

Television

The TV units for monitoring and entertainment were furnished by Scripps Institution of Oceanography. Conductors and connectors are listed in Table 3.

Audio

The audio link for two-way communications from the support vessel to Sealab was a Bogen commercial intercom system. A two-station master was provided for the communication van on the support vessel with a remote unit in Sealab. A headset which was compatible with the master station was provided for the Sealab communication center. A two-position selector switch was provided on the patch panel to permit the selection of the speaker or headset. A momentary contact switch was provided as press-to-talk switch to permit the speaker to be used as a microphone only when using the headset.

Wedge Spirometer

The wedge spirometer was furnished by the Submarine Medical Center and installed by the Naval Ordance Test Station. An extension cable with appropriate plugs on each end was installed from the communications van to the atmosphere control van.

O_2 Partial Pressure

The Krasberg unit for determining the O_2 partial pressure in Sealab was furnished by Westinghouse. Provisions were made to monitor and record the O_2 partial pressure remotely.

Equipment Mounting Strips

To facilitate the installation of communication and monitoring equipment during the fitting-out period, two slotted metal angle strips were installed on the overhead on the surface of the cork insulation in the lab, galley, and berthing spaces. The strips were approximately 2 ft 2 in. on either side of the center line and ran the entire length of each space, except where interference existed.

In addition to the systems discussed in the foregoing, which were incorporated in the umbilical cord, two acoustic voice communication systems were provided between the support-vessel diving platform and the habitat. The two systems were (a) a Navy submarine voice communication system, AN/BQC and (b) an Aqua-Sonics voice communication system. Because of

the high noise level at the diving platform, the results obtained with these systems were not completely satisfactory.

HABITAT - SHORE

Benthic laboratory, a multichannel data transmission station was placed on the bottom close to Sealab. The following habitat-to-shore links were provided through this station.

Benthic link 2 - Two-way, push-to-talk microphone loudspeaker. This station was monitored in benthic control center 24 hours a day. The benthic control watchstander processed any call immediately and patched through for two-way communications to the public telephone lines or to any control station on the Scripps campus.

Benthic link 3 - Telephone type handset located at the port watch station. No speaker. Has the same capability as benthic link 2.

Benthic Link 4 - Two-way telephone handset near trunk. This station was not monitored in benthic control. Calls had to be organized via links 2 or 3. The other capability is the same, but it is intended primarily for a telephone patch.

Benthic links 5, 6, 7 - Open microphones located in berthing, galley, and laboratory areas of Sealab. These microphone outputs were telemetered to shore and could be patched through to PIO, the psychological station, or shore control. Most of the time these links were patched to the shore control closed-circuit TV monitors.

Benthic link 8 - Electrowriter receivers but no transmitters were located in benthic shore control and at the physiological station. They were not used.

HABITAT TO SWIMMER

To enable the swimmer to communicate with the habitat while on a sortie, two means of communication were planned. One was a sonic type with a maximum range of 1000 ft, and the other was a wire-type intercom with a 300-ft range.

AQUASONIC UNDERWATER COMMUNICATOR

Frequency Range: 42 kc
Modulation: AM
Battery Life: 80 hr
Range: 1000 ft
Depth: 300 ft

SWIMMER INTERCOM

Frequency Response: 300 cps - 3 kc
Battery Life: 40 hr
Range: 300 ft
Depth: 300 ft

The Aquasonic had been used during acoustic tests at the U.S. Navy Mine Defense Laboratory with the Mark VI scuba. Four diver units were placed in Sealab II for swimmer use. A surface unit was also installed to communicate with the swimmer and/or support vessel. Communication tests, intelligibility in particular, were planned using the swimmer units. Due to a crowded diving schedule, the first Aquasonic was connected to a Mark VI scuba and tested on day 6. An aquanaut tested the rig and attempted to communicate with the habitat. Because of the normal back pressure of the Mark VI, the Bioengionics mask lost gas around the edges. This loss caused some difficulty in breathing. The receiver section of the swimmer unit worked fine, but

according to the listeners in the habitat, all transmission from the swimmer was garbled and unintelligible. On day 10 a different swimmer unit was tried with another aquanaut, but again, the mask gas loss occurred and the transmission was completely garbled. After this, no further attempts were made with the Aquasonic.

The wire intercoms were tested during Team 1's dive. The transmission was completely garbled and unintelligible. The same type intercom had been tested at 10 ft at the U.S. Navy Mine Defense Laboratory, with very good results.

SWIMMER TO SWIMMER

The only type of swimmer to swimmer communication used with any degree of success was the standard hand signals which have been used by Navy divers for many years. Development of the sonic system discussed in the previous paragraph will add immeasurably to the ability of divers to coordinate their underwater work.

SUPPORT VESSEL TO SHORE

Several communication links were available through the benthic laboratory. These included:

Benthic link 1 - Two-way equipment and capability identical to that described in benthic link 2.

Benthic links 9, 10 - Two additional telephone handsets and amplifiers for two-way communications to benthic control from the support vessel.

None of the above three links were ever connected or used at the staging vessel end, because of an underwater telephone cable which was laid furnishing four telephone lines to the staging vessel prior to the installation of the benthic laboratory. Three of these lines were commercial telephones connected directly to the Pacific Telephone system, while the fourth was a magneto type two-terminal circuit ("battle" phone) connected directly from shore control to the support vessel.

One HF, three UHF, and five VHF channels of communications installed aboard the support vessel provided radio communications for the administrative and logistic functions of the operations. With these channels, communications were provided for the various support craft, Scripps Institution of Oceanography, Mission Bay Aquatic Control Center, and various portable and mobile units in the area. Through an unattended relay station on San Clemente Island, the range of the radio communications was extended to include Long Beach and Pasadena.

MISCELLANEOUS COMMUNICATIONS SYSTEMS

PTC voice communications - The PTC used two systems of communication. The primary system was an open microphone in the PTC to an intercom amplifier on the support vessel. An Aquasonic system was used as a backup, but proved unsatisfactory.

Support vessel interior voice communications - A 12-channel interior communication system was installed on the support vessel connecting all primary and normally manned operating stations. In addition, an intercom voice communication system from the outside DDC control area to the interior of the DDC chamber was used with adequate results. Inasmuch as it was vital that the atmosphere van personnel be cognizant of the physical condition of the subjects during decompression, a slave station of the DDC intercom was set up in the Atmosphere Control Center.

Benthic and Sealab Television - The TV system for benthic and Sealab used standard 525-line interlace scan frequencies. Video transmission was accomplished using five amplitude-modulated carriers on frequencies of 51, 60, 69, 78, and 87 MHz.

The four cameras furnished Sealab were duplicates of the ones designed for use in Benthic, with the exception that the Sealab cameras were not equipped with remotely operated pan/tilt mechanism, as were the two cameras used in benthic.

Three of the four video coaxial connections to benthic, along with telemetered signals for focus and sensitivity adjustments, were lost during the initial benthic-to-Sealab hookup as a result of the cable-connector damage.

Both cameras installed inside Sealab functioned normally and transmitted acceptable pictured ashore via benthic, when either was connected through the one existing good video channel. Focus and sensitivity adjustments were made using a jury-rig substitute in Sealab for the lost control functions.

The two underwater cameras outside of Sealab were never lifted out of the mud for testing, presumably because there were no additional video channels available for their use, and because the limited visibility in the surrounding water discouraged their use.

Both inside cameras remained operable throughout the 42 days of operation, but they became less and less usable as a result of many holes burned in the vidicon targets by the frequent flashing of flash bulbs by photographers in Sealab. It is believed that the vidicons were vulnerable because of the low heat-absorption characteristics of the Lucite lens. A piece of heat-absorbent glass was taped over the front of the lens of the one camera in use during the closing days of the operation, and no additional burns appeared.

On shore at benthic control, TV carriers were boosted and distributed to various offices in the headquarters building and to Sumner auditorium, where they were viewed by officials of the project, the press, and the public on standard commercial home entertainment-type TV receivers.

During the operation, additional TV video signals from cameras supplied by Oceanographic Engineering Company were brought ashore via separate coaxial cables laid to the Berkone. These cameras did not perform satisfactorily in the Helium atmosphere, probably due to helium leaking into the case, causing overheating and detuning. The same type of cameras, placed in the water outside the habitat looking through the ports into the habitat, performed well, and were used as the primary monitoring cameras during the last half of the program.

Support Vessel Television - Two industrial TV tuners were located in the command van. Coaxial cable was run from these to various locations throughout the vessel and to monitors which could be switched to either tuner.

CONCLUSIONS

Before pressurizing Sealab, the Aquasonic units aboard were opened to ambient pressure to ensure that the batteries could be changed at 200 ft. It is felt that pressure on the components had some effect on the intelligibility. Transmissions between support vessel and Sealab via Aquasonic were somewhat garbled, but this may have been partly due to the thermocline.

The Bioengionics mask that was used had straps connecting it to a hood. It was impossible to get a tight seal sufficient to prevent gas loss around the edges. The back pressure of the Mark VI scuba makes a tight seal imperative.

The wire-type intercom used a bone-conduction microphone. It was felt that pressure on this unit deformed the sides such that the frequency response was severely limited. To verify this, a test recording was made in a chamber at 200 ft using the bone phone. The recording showed that the increased pressure did limit the frequency response, but not enough to account for the distortion noted in Sealab II.

The present Navy helium speech unscrambler did not provide continuously reliable and improved intelligibility, due to either equipment malfunction or maladjustment.

RECOMMENDATIONS

Communications from swimmer to habitat are necessary on some sorties. This need was amply demonstrated on Sealab II. The sonic type has an obvious advantage over the wire type, particularly on long-range sorties. Since the Aquasonic is the only long-range communicator readily available at this time, testing is needed to determine what causes the garbled transmission from the swimmer at the 200-ft depth. A better strap design is needed to ensure that the Bioengionics mask seals gas tight to the swimmer's face. A redesigned mask might be necessary to alleviate this problem.

In the future, a sonic communicator compatible with helium speech should be developed. This communicator should be much smaller than the Aquasonic and more reliable.

The swimmer intercom should be investigated to determine the source of distortion. A smaller unit with two-way capabilities is desirable and well within the present state of the art. A different type of microphone might be necessary

Improvement in helium speech unscrambling techniques is needed.

Chapter 22

UTILITIES

V. C. Anderson
Marine Physical Laboratory
San Diego, California

WATER SUPPLY

The Sealab water supply was taken from the water main near the pier on the Scripps Institution of Oceanography campus.

Water was piped at main pressure to the outer end of the pier via 1000 feet of 1-1/2-in. polyethylene pipe. At the pier end, two 3/4-horsepower helical rotor pumps were provided and mainfold connected into the two 3/4-in. schedule-80-vinyl pipes used for transmission of water to Sealab. Each pump was capable of providing an output pressure 70 psi over the source pressure at 5 gpm flow. After a few days of operations it was determined that main pressure, which averaged 75 psi, was sufficient for supplying Sealab. At this time the pumps were bypassed and secured.

The two water lines were laid with and attached to the Sealab power cable (see Power Supply for laying procedures). The lines were terminated at the transformer dome in a pair of Hansen B6K31 self-sealing couplers. There couplers were secured to the transformer dome near its base for easy access by the divers. Check-valve assemblies were coupled at the time of installation to permit the line to be flushed with fresh water. Divers removed the check-valve assemblies and coupled flexible water hoses for the connection to the Sealab fresh-water system.

POWER SUPPLY

The power supply for Sealab was taken from a main power distribution pad on the Scripps Institution of Oceanography campus. A length of armored four-conductor submarine cable, identical to that used on the ocean floor to the Sealab site, was laid along the pier. The pier end of the cable was terminated in a high-voltage disconnect switch, while the campus end was wired to disconnect when the demand exceeded 100 kva. Transmission voltage was 4160 volts 3 phase.

The underwater submarine cable lay was terminated at a point near the Sealab site in an underwater transformer housing containing three 37-1/2-kva transformers providing a 3-phase 440-volt output. The shore end of the cable was connected to the high-voltage disconnect switch on the pier.

INSTALLATION

The initial installation was made on Aug. 20 using an oil-filled concrete dome 6 ft in diameter and 6 ft high as a housing for the undersea transformers. The laying procedure consisted of transferring the dome with cables and water lines attached to the staging vessel, using the staging-vessel crane. The power cable - water pipe bundle was then taken aboard the staging vessel and stopped off with a length of nylon line. The cable layer (NEL's YFU-45) then proceeded to lay the cable in a direct line to the pier. As the cable payed out from the cable well, the water lines fed from their individual ten-foot-diameter spools, and were banded to the

power cable just prior to passing over the forward bow sheave. The cable layer tied off to a buoy upon reaching the pier and passed the cable and water lines across to a crew on the pier end.

While the power cable was being laid, the staging-vessel crew attempted to place the concrete transformer housing on the bottom. The attempt was unsuccessful; the transformer dome was severely damaged by shearing off of the support legs and undercarriage and carrying off of the cable gland fitting. The rigging crew and divers on board the staging vessel were able to salvage the concrete dome and managed to replace it on board the YFU-45 for return to NEL.

A new steel transformer dome was fabricated over the weekend from a surplus air-pressure tank previously removed from FLIP. On Aug. 31 the new dome was transported to the Sealab site on board the Oconostota, where it was transferred to the staging vessel. The shore cable splice was made, and the dome emplanted on the bottom. The shore power and water supply were available continuously during the 45 days of the Sealab operation.

Chapter 23

OPERATIONAL AND EMERGENCY BILLS

SEALAB II STEERING COMMITTEE

INTRODUCTION

Any operation of the type of Sealab II must be prepared for an emergency. While it is next to impossible to provide detailed procedures to cover every emergency that might develop, it is possible to provide a set of general instructions which can be applied to nearly all situations.

The following operational and emergency bills are included in this section:

OPERATIONAL BILLS

1. Staging vessel swimmer safety
2. Sealab swimmer safety
3. MK-VI maintenance
4. Personnel Transfer Capsule maintenance
5. Personnel Transfer Capsule operation
6. Fresh water and fuel oil
7. Staging vessel general safety precautions
8. Duties of Staging Vessel Personnel

EMERGENCY BILLS (SEALAB)*

1. General casualty instructions
2. Accident or illness
3. Loss of pressure or flooding
4. Fire
5. Outside loss or accident
6. Atmosphere contamination
7. Electrical power loss

EMERGENCY BILLS (SUPPORT VESSEL)

1. Foul weather
2. Moor slipping

SWIMMER SAFETY BILL, STAGING VESSEL

General

In order to insure the most possible safety for support swimmers and divers, certain coverage from topside personnel must be readily available. Constant vigilance must be kept for any emergency confronting support divers.

*SEALAB raising and lowering procedures are included in Chapter 15.

Diving Operations

Unless an actual emergency exists, support diving will in all cases be governed by existing regulations. All current publications as to weather and state of sea conditions must be adhered to. The diving officer on board the staging vessel will in all cases have the final say as to whether or not diving operations will be allowed.

Safety Swimmers

Two men will be assigned to act as safety swimmers during diving operations. The duties of these men will include keeping a vigil for any emergency. They will have at their disposal a complete set of diving gear and a safety boat. Both the diving gear and the boat will have been checked out prior to diving operations and be maintained in the standby conditions.

Equipment

Two Mk VI rigs - charged with 68% He/32% O_2
Two aqualungs fully charged
Two sets of fins
Two face masks
Two life jackets
Two weight belts
Two diving knives
Two depth gauges
Two compasses
Two diving watches
Two day and night flares
Wet suits - complete
Buddy line
Safety boat - motor, oars, gas, resuscitator, first aid kit
Complete set of decompression tables

In Case of Emergency

All further diving operations will cease. The standby swimmers will immediately render assistance as needed. Medical aid will be summoned and the recompression chamber readied for use. A Minute Man Resuscitator will be available at all times.

General Surface Dive Procedures for Operation Sealab II

Normal diving needs during Operation Sealab will require four divers per day. An emergency standby team comprised of two divers will be assigned for each 24-hour period, commencing at 0700. Rotation of divers will be such as to allow one day out of three without deep diving exposure whenever possible.

Surface dives to be made on the project will involve diving to depths beyond maximum working limits outlined in the Diving Manual; therefore, strict adherence to the following safety procedures must be observed:

1. All bottles used will be gaged and pressures logged on the dive sheet immediately prior to the dive.

2. The following equipment must be worn on all surface dives made:

Life jacket
Knife
Depth gauge

Diving watch
Weight belt (if wet suit is used). Weight belts must be secured in such a manner as to be shed easily.

3. The buddy system will be used on all dives, with the divers remaining close enough together to allow return to the diving bell using the buddy breathing system in the event of equipment failure.

4. All exposure and decompression times will be maintained by stop watch and recorded by the timekeeper in the diving log book.

5. Divers will be briefed prior to dives on maximum exposure times. Whenever possible divers shall leave the bottom two minutes prior to maximum time set for the dive. This rule may be exceeded in emergencies.

6. A 60 ft per minute rate of ascent will be maintained on all dives, with all divers briefed on action to be taken in the event of variation from this ascent rate.

7. Pneumofathometer readings will be used to record diving bell decompression depths. Where maximum depth of dive is concerned, and divers do not exit from the Submarine Rescue Bell, 5 ft shall be added to pneumofathometer readings to determine depth of dive.

8. When oxygen is used as a breathing media during decompression, divers shall keep their physical activity to a minimum.

9. It shall be the responsibility of the master diver or senior diver present to see that safe diving practices are observed. No divers shall enter the water without permission from the senior diver present.

SWIMMER SAFETY BILL, SEALAB

Predive Safety

1. All dives will be planned and discussed with all members of the diving team before suiting up.

2. All dives will be under supervision of an assigned diving supervisor.

3. Pertinent data including estimated time, location, divers' names, etc., will be logged with watch stander.

4. After suiting up, divers will check diving partner's equipment.

Diving Safety

1. Log time of entry into water at the trunk with watch keeper.

2. Recheck partner's equipment upon submergence.

3. Abort on any life-support-equipment failure.

4. All diving will be with an assigned partner.

5. Because of possibility of zero visibility, no breath-holding dives will be allowed outside of shark cage.

6. Length of dive will be limited to 2/3 of gas-supply duration except in emergency.

7. Swimmers will not venture outside established perimeter except in cases of emergency, and then with permission from top side.

8. Communications will be maintained.

9. An accurate depth gauge will be worn, and no ascents above 33 ft from the Sealab entrance water level will be permitted. Routine descents greater than 33 ft are also prohibited.

10. Swim groups will carry a pinger receiver to home on the habitat. In zero visibility a life line will be carried from the habitat.

11. All divers will be negative when breathing bags are extended.

12. SPU operations will be under supervision of Officer in Charge.

13. Buddy-line communicators or buddy lines will be worn by swim pairs unless permission granted otherwise by Officer in Charge.

14. Bounce dives of greater than 33 ft will be conducted only upon control and discretion of the surface command center.

MK-VI MAINTENANCE BILL

Each subject in Sealab will be assigned a Mk VI breathing apparatus for excursions outside the dwelling. Daily maintenance of the Mk VI will be the responsibility of each individual. After each use perform the following maintenance procedures on the breathing apparatus.

1. Thoroughly rinse the Mk VI with clean, fresh water until all foreign matter is removed.

2. Inspect inlet filters of regulator, assembly, regulator aneroid chamber, diaphragm (once each week), control block assembly, safety rupture disk, exhaust valve assembly, and "buddy-breathing" assembly for foreign matter and contamination.

3. Inspect all rubber components for deterioration, cuts and nicks, and replace parts as necessary.

4. Check for smooth operation and return of bypass valve by pulling bypass lever.

5. Inspect all cloth material components for breaks and excessive wear.

6. Separate cylinders and manifold valve assembly from breathing bag and vest assembly. Send cylinders and manifold valve assembly topside for recharging.

7. Dump CO_2 absorbent from canister and wipe clean. If canister has been flooded, wash thoroughly with fresh water and dry.

8. Remove exhaust valve from bag assembly. Hang bag assembly and mouth piece "T" tube assembly and let dry.

Preparation of Mk VI for excursion:

1. Check gas pressure and O_2 percentage in cylinders, making sure they have been properly refilled.

2. Secure yoke assembly, regulator assembly, control block assembly and properly filled canister assembly to the apparatus.

3. Check regulator assembly and control block assembly for proper pressure setting and flow requirements.

4. Completely assemble apparatus for diving.

5. Check all connections as hanson fittings, hose fittings, mouthpiece "T" tube assembly, exhaust valve and "buddy-breathing" apparatus.

6. Check the breathing apparatus for leakage by submerging in water.

Refer to NAVSHIPS 393-0653 Service Manual for "Mark VI Underwater Breathing Apparatus" for Complete Maintenance Instructions.

PERSONNEL TRANSFER CAPSULE MAINTENANCE BILL

The Personnel Transfer Capsule is the means of transport for Sealab subjects between Sealab and the Deck Decompression Chamber. It is the subject's transfer vehicle, which takes him down at the start of his tour and returns him at the end. Further, during the subject's stay in Sealab, the personnel transfer chamber will remain in position near Sealab. It is imperative that it be maintained in constant readiness. Daily checks should therefore be performed by the subjects.

The following checks are to be made daily:

1. Water level

2. Gas sample

3. Gas bottle pressure

4. Scrubber operation.

Water level in the chamber will rise and fall with changes in tide. Water-level checks should be made each day half way between high and low tide. Water level should not be above the grating at half tide. Any helium added to adjust water level should be logged.

Gas sample will be taken daily through gas-sample hose to the gas control van via the Sealab gas-control panel.

Gas bottle pressures for He and O_2 should be recorded in the log daily.

Scrubber shall be turned on momentarily each day to check operation.

PERSONNEL TRANSFER CAPSULE OPERATIONAL BILL

Gas Manifold

The gas supply system for the Personnel Transfer Capsule (PTC) is simple, and very flexible. Although designed for operation by the occupants of the capsule, atmosphere control can easily be taken over by topside personnel, once the PTC is on deck, and requirements for external control exist. This is considered to be a remote possibility, occasioned only by extensive delays in the mating procedure or by the necessity of using the PTC for decompression purposes. In normal use, the occupants of the PTC will exercise control of the atmosphere, adhering to the following protocol.

Normal Use of PTC

Before entering the PTC, either topside or on the bottom, two aquanauts will check the external O_2 and He manifold, and open bottle valves to assure that one bottle of each gas is on the line to the internal piping system. In the event of anticipated rise to the surface, without surface support, all bottles must be opened to the manifold.

Next, these two aquanauts will enter the PTC (hatch open at all times), and check together both the routine mode of gas delivery, via the regulator (outboard) controlled pipeline, and next the emergency (inboard) direct-flow system, assuring that all valves operate satisfactorily without stick or leak. During this procedure, caution must be exercised to flow only a small amount of the gas in each manifold, in order to preserve normal gas balance in the PTC. Once satisfactory flow has been demonstrated in both channels on each gas system, and the O_2 Flow-Rator Tested to 20 cfm for a period not to exceed ten seconds, all internal valves will be secured. The PTC is now ready for occupation.

After all occupants are on board, check O_2 level before securing entrance hatch. Prior to descent from surface, this should not exceed 25 percent if leaving from the deck, at sea-level pressure. If departing from Sealab II depth, O_2 level may not exceed 10 percent. In any case, overoxygenation can be corrected by inflow of helium, at a slow rate, and with the entrance hatch open. Once these requirements are met, the entrance hatch will be shut, and the transfer in either vertical direction can be accomplished.

During transit in either ascent or descent, both O_2 and CO_2 levels will be checked every three minutes. Oxygen levels will not be allowed to exceed 1.5 atmospheres (Strasberg), and CO_2 levels must not exceed 0.5 percent (Dwyer). Should these values be exceeded, notify topside, and appropriate orders or measures will be taken. In event of a stay in excess of 3 to 5 minutes in the PTC, CO_2 scrubber operations and O_2 bleeding will become mandatory. Since CO_2 buildup will be a controlling factor, the scrubber should be in operation prior to entrance-hatch closure. Oxygen should be bled in, after five minutes, at a rate to maintain a constant partial pressure of O_2 of not less than 160 mm Hg = 0.2 atmosphere, and not more than 1.0 atmosphere. In the event of Krasberg unit failure, a safe rule of thumb will be the admission of 10 cu ft of O_2 every 30 minutes. In event of power failure, the foot-operated CO_2 scrubber should be operated continuously. Should this latter equipment fail, spread the absorbent in the lower flats of the PTC, and expend as little energy as possible.

Abnormal Use of PTC

It is conceivable that through loss of mating capability, or necessity of use as a deck decompression facility, the PTC might require external control and monitoring of internal environment. Provisions have been made for this unlikely situation. Three access penetrations are provided in the design of the PTC to permit complete atmospheric control by topside personnel. One of these penetrations will be available for gas sampling, while the remaining apertures will be available for decompression exhaust and oxygen replenishment. An external CO_2 scrubber will be available for use. Thus, even without active participation of the aquanauts, decompression can be accomplished within the PTC mounted topside, and without use of the Deck Decompression Chamber (DDC). The necessary steps to establish this capability are as follows.

1. In event of delay in the mating of PTC to DDC in excess of ten minutes after return to the staging vessel, caps will be removed from inlet and exhaust penetration lines to the PTC, and appropriate topside connections made. The inlet line will provide only compressed air. The outlet line will exhaust for decompression. No attempt will be made to provide an He/O_2 mix. Decompression calculations will simply be changed to allow for the different gas mix.

2. Varying percentages of oxygen will be supplied to the PTC, as dictated by the physical condition of the occupants, and the decompression profile. These determinations will be the sole responsibility of the Principal Investigator.

3. Hookup of the CO_2 scrubber system (external) will be dictated by operational circumstances. Should a delay of more than one hour be anticipated, action will be instituted to assure incorporation of this life support item.

4. Communication with the occupants of the PTC will be maintained throughout, and recorded.

FRESH WATER AND FUEL OIL BILL

Fresh water and diesel fuel service connections are located portside aft on the surface-support vessel, the diesel-oil connection being directly above the fresh-water connection. Both lines are made of 2-in. galvanized pipe. The diesel-oil connection is reduced to 1-1/4 in., and the fresh-water connection is reduced to 1-1/2 in.

When taking aboard fresh water, the tank cover located in the machinery room will be opened to lower the chance of flooding the machinery spaces. Located on the after starboard side is a 2-in. gate valve used for filling the small tank. When the small tank is within one foot of the top, open the second 2-in. gate valve located against the after starboard bulkhead. This is the filling line for the large tank. Close the 2-in. valve for the small tank and close the cover. It is unnecessary to open the large tank cover, as this tank vents overboard. Secure taking on water when the large tank overflows.

When taking on diesel oil, open the 2-in. gate valve located on the stern, starboard side. Soundings will be taken frequently, and when the tank is 95 percent full, secure taking on fuel.

The duty machinist will take fresh-water and diesel-oil soundings each morning and keep a log of the amount of water and oil that is on hand. He will turn into the range supervisor a correct finding as to the total gallons of fuel and water remaining on board.

STAGING VESSEL GENERAL SAFETY PRECAUTIONS

General Safety Precautions

1. All barrels of the U.S. Standard (55 gallon) size will be stowed in racks provided on the stern of the staging vessel. Spare barrels will be lashed securely to the life lines. Small gas cans used in work boats will be placed in the rack provided for them on the stern, starboard side. The five-gallon safety fuel cans will be stowed on the stern, portside.

2. All oxygen, acetylene, and oxygen-helium cylinders will be readily available for emergency use in racks provided for them on the 01 deck.

3. All civilian contractor personnel will be required to wear safety hats, shoes, and glasses. Safety glasses are to be worn when grinding, chipping, and wire brushing, or when in an area where any of these activities are going on.

4. When civilian personnel are riding aboard a military-controlled boat or vessel, the boat coxswain, under the senior line officer aboard, is in complete charge. Civilian personnel will at no time interfere with or dispute the orders of the coxswain.

5. At no time when the ten-man Deck Decompression Chamber is in use will there be any welding, burning, grinding, or smoking in the area.

Starting, Operating, and Maintenance Procedures for Staging Vessel Major Equipment

Ingersoll-Rand L P Air Compressor

1. Check crankcase oil level with bayonet gage before starting.

2. Open the unloaders to lessen the load pressure and drain off accumulated condensation.

3. Turn automatic switch to "on" position, starting compressor. When the compressor has attained normal speed, close unloaders. When air pressure has built up to normal pressure, the compressor will automatically stop and start as air is needed.

4. When the compressor has been operated for 500 hours, change the oil and strainers. Use straight naphthnic base oil.

5. The operator will maintain a continuous watch when the compressor is in operation. He will also keep the compressor and surrounding area clean at all times.

Ingersoll-Rand H P Air Compressor

1. Open outside natural air-supply vent and cut in electric supply air blowers.

2. Check crankcase for correct oil level.

3. Open unloaders to lessen load pressure and to drain off accumulated condensation.

4. Push down the green "start" button and hold until the oil pressure builds up to at least 35 lb.

5. Open main valve to accumulator and close unloaders.

6. When the compressor has been operated for 100 hours, change oil and clean or replace filters as required. If operating in a dirty or dusty area, change oil and filters more often as considered necessary.

7. When the compressor is operating, the two exhaust blowers at the after end of the compressor must be running to pull cooling air across the receivers. If the blowers are not running, secure the compressor until the blowers can be started.

8. The operator will maintain a continuous watch when the compressor is in operation. He will also keep the compressor and surrounding area clean at all times.

60-kw Generator

1. Cut in supply and exhaust blower

2. Check starting batteries for proper charge.

3. Cut in diesel fuel.

4. Check oil level in crankcase.

5. Check cooling water.

6. Turn the starting switch to the right and hold until the engine starts.

7. Adjust engine speed to maintain 40 lb of oil pressure.

8. Cut in control panel and adjust as required.

9. When the generator has been operated for 30 hours, change the oil (9250) and replace the filter.

10. The operator will maintain a continuous watch when the generator is in operation. Oil leaks and drippings will be cleaned up and waste disposed of in a flashproof container.

200-kw Generators

1. Cut in supply and exhaust blowers.

2. Check starting batteries for proper charge.

3. Cut in diesel fuel.

4. Check oil level in the crankcase.

5. Check cooling water in the sight glass.

6. Turn on the starting switch.

7. Pull the starting throttle to the stop until the engine starts, then retard the throttle to the center notch.

8. Adjust the govenor to give the required generator speed and cut in the control panel.

9. When the generator has been operated for 30 hours, change the oil (9250) and replace the filter.

10. The operator will maintain a continuous watch when the generator is in operation. Oil leaks and drippings will be cleaned up and waste disposed of in a flashproof container.

DUTIES OF STAGING VESSEL PERSONNEL

Electricians

Primary Duties—The primary duties of the electricians are to maintain electrical power at all times, to make electrical repairs on switchboards, controllers, and motor-generator sets, to install light bulbs and fuses, and to repair or replace faulty wiring and cable.

Collateral Duties—The electrician will turn on outside standing lights and anchor lights one half hour before sunset and secure them one half hour after sunrise. During slack time he will chip, wire brush, paint, and assist in keeping the vessel clean.

Shipfitters

Primary Duties—The primary duties of the shipfitters are to repair all piping, inspect and repair washbasins and sanitary equipment, inspect voids and compartments for damage and flooding, weigh fire extinguishers, and maintain firefighting and safety equipment in top repair condition.

Collateral Duties—The collateral duties of the shipfitters will be to assist the experimental group as requested, to chip, wire brush, and paint where required, and to assist, in general, in keeping the vessel clean and in safe operating condition.

Mechanics

Primary Duties—The primary duties of the mechanics will consist of repair and maintenance of machinery and equipment. This will include the repair of outboard motors, diesel engines, air compressors, gasoline starting engines, salt- and fresh-water pumps and the taking aboard of fresh water and fuel.

Collateral Duties—The collateral duties of the mechanics will be to assist the experimental group as requested, to chip, wire brush, and paint where required, and to assist, in general, in keeping the vessel clean and in safe operating condition.

Machinists

Primary Duties—The primary duties of the machinists will consist of servicing and operating the 200-kw and 60-kw generators, HP and LP air compressors, port and starboard fire and bilge pumps, fresh-water pumps, salt-water cooling pumps, and the diesel-oil transfer pump.

Collateral Duties—The collateral duties of the machinists will be to assist the machanics in any repair work. The machinists will also assist the experimental group as requested, and will chip, wire brush, and paint where required, and will assist, in general, in keeping the vessel clean and in safe operating condition.

Riggers

Primary Duties—The primary duties of the riggers are to give standard signals to the crane operator, make hookups of all loads that are hooked to a crane or hoist, be familiar with the safe work-load tables, be responsible for the safety of all hitches, and be responsible for the safe moving of any load. The riggers will also splice wire, nylon, and manila ropes as necessary.

Collateral Duties—The collateral duties of the riggers will be to assist the experimental group as required, to chip, wire brush, and paint where required, and to assist, in general, in keeping the vessel clean and in a safe operating condition.

Crane Operators

Primary Duties—The primary duties of the crane operators are to familiarize themselves with the crane mechanism and its proper care, and with all operating safety rules. At the beginning of each shift the operators shall examine their crane for any defective parts or any other condition which would make the crane unsafe. Upon finding such a condition, the operator will immediately notify his supervisor. When operating the crane, the operator will accept only standard crane signals given by a qualified rigger.

Collateral Duties—The collateral duties of a crane operator will be to assist the experimental group as requested, to chip, wire brush, and paint where required, and to assist, in general, in keeping the vessel clean and in a safe operating condition.

General Safety Rules for Rigging and Crane Operation

Safety Rules for Riggers

1. Safety shall always be given first consideration in material-handling operations. The rigger shall constantly bear in mind that the safety of others, the equipment, and himself depends upon the safe movement of materials.

2. Only a designated rigger shall give signals to a crane operator. The signals shall be standard crane signals.

3. The rigger shall be responsible for the safety of all hitches and for the save moving of any load that is hooked to a crane or hoist.

4. All rigging equipment shall be checked for defects before being used. When in doubt about the safety of any equipment, the rigger will consult his supervisor.

5. Hitching equipment shall be properly applied so that the load can be lifted in a secure and stable position without danger of dropping, shifting, or turning.

6. A rigger shall not permit any load to be moved if its weight exceeds the posted capacity of the crane or the permissible safe load for the slings being used.

7. Wire rope and fiber slings shall be protected by the use of softeners at the sharp edges of a load.

8. No one shall work under a suspended load unless the load has been adequately supported from the deck. All conditions of this type must be approved by the supervisor.

9. The rigger shall not permit anyone to pass under any suspended load that is being moved.

10. Before the crane is moved, the rigger shall determine that the load is high enough to clear all obstructions. All loose material shall be removed from the load before it is moved.

11. No one shall be permitted to ride the hook, sling, or load,

Safety Rules for Crane Operators

1. Safety shall always be given first consideration in the operation of cranes. Operators shall constantly bear in mind that the safety of personnel on deck, as well as their own safety, depends upon the careful operation of the crane. Therefore, operators should be permitted to operate cranes only when they are physically fit. Any illness will be reported to the supervisor immediately.

2. If any doubt exists concerning the safety of any situation or condition, the operator shall not move the crane or proceed with the lift until the unsafe condition is corrected and the supervisor has decided that the situation is safe.

3. Operators shall familiarize themselves with the crane mechanism and its proper care, and with all operating safety rules.

4. Both hands shall be used whenever ascending or descending the vertical crane ladder.

5. Operators shall keep crane cabs clean at all times.

6. Operators shall examine their crane daily for defective brakes, loose parts, or any condition which could make the crane unsafe.

7. Whenever adjustments or repairs are necessary, the condition shall be reported to the supervisor immediately.

8. At the beginning of each shift, operators shall test each limit switch by slowly raising the block until the limit switch opens the circuit.

9. At least two full wraps of hoist cable shall be kept on the hoist drum.

10. When leaving the crane, operators shall:

a. Spot the crane at approved access.

b. Raise all hooks to the upper limit switch.

c. Move all controls to the "off" position.

d. Lock the crane disconnect switch in the "off" position.

Safe Lifting and Transportation of Heavy Loads

1. The safe transportation by cranes of heavy loads depends upon the following three basic elements:

a. The capacity and safe operating condition of the mechanical lifting equipment.

b. The capacity and condition of the hitching devices and accessories used.

c. The capabilities of the persons that operate, use, inspect, and repair the lifting equipment and hitching devices.

2. The capacity of all hoisting equipment is posted and shall not be exceeded.

3. A safety factor is required for all lifting equipment. For example, the safety factor of wire rope is five, and the safe working load for any such equipment is one-fifth of the ultimate strength of the equipment when new.

4. The crane shall be placed directly over the load being lifted to avoid sliding of the load and overstressing of the hoisting equipment.

5. The load or hook shall at all times be raised high enough to clear all objects that are in the path of travel.

6. Loads shall never be left suspended in the air while waiting or when the crane is left unattended.

7. When lowering a load, the operator shall proceed carefully and make sure that the load is under control at all times.

General Rules

1. Cranes shall be operated only by an authorized crane operator.

2. Only lifting materials and equipment which meet required specifications shall be used for the movement of any load.

3. Crane operators and riggers shall operate as a team. Any disagreements concerning the safe handling of a load shall be referred to the rigger supervisor for a decision before proceeding with the lift.

4. Only qualified personnel (riggers) shall be permitted to hook loads to a crane.

5. Before any load is moved, it shall be the joint responsibility of both the rigger and the crane operator to be certain that all hitches have been safely made.

6. Cranes and hitching equipment shall not be loaded beyond their rated capacity.

7. Standard crane signals shall be accepted by the crane operator only from the rigger who is responsible for the lift. Only one rigger will give signals to the crane operator on each lift. In the event of an emergency, however, stop signals shall be accepted from anyone.

8. It shall be the responsibility of the riggers and crane operators to keep personnel clear of all loads.

9. No one shall be permitted to ride on the load, a hook, or a sling.

10. Thorough housekeeping shall be maintained at all times on decks, in the crane cab, and on the catwalks.

11. All personal injuries, no matter how slight, will be reported to the supervisor. In addition, any accidents that cause damage to equipment or materials, or any irregularities observed in the operation of equipment, will be reported immediately.

GENERAL CASUALTY INSTRUCTIONS

1. In the event of a casualty resulting in an unbalance of atmospheric gases, all Sealab personnel will remain on the emergency air breathing system until the atmosphere is brought back into balance.

2. In the event of any casualty, the bottom commander must insure that an adequate flow of information be provided topside. The topside commanders must be aware of current status and corrective procedures being instituted.

3. In general, the topside commanders will confer with the bottom commander whenever feasible; however, all orders issued by topside commanders will be considered mandatory.

4. When in the opinion of the bottom commander that the Sealab structure must be evacuated, he will order all personnel to the Personnel Transfer Capsule and so notify the topside commanders. The topside commanders will render the final decision as to decompress or hold, pending further evaluation of the situation.

ACCIDENT OR ILLNESS EMERGENCY PROCEDURES

1. In the event that the Senior Medical Monitor determines that the treatment of an accident or illness is beyond the capabilities of the hospital corpsman, the subject can be brought to the surface in the Personnel Transfer Capsule.

2. The Senior Medical Monitor may elect to send qualified personnel into the Sealab habitation for treatment of any casualty or call for the evacuation of the subject to the surface.

3. In the event it becomes necessary to bring a subject to the surface in the Personnel Transfer Capsule, a surface-support diver shall be provided to serve as a tender.

4. Subject and tender shall be transferred to the Deck Decompression Chamber for decompression and treatment, as determined by the Senior Medical Monitor. The Senior Medical Monitor may elect to return the subject to the Sealab habitat, in which case decompression would not proceed.

LOSS OF PRESSURE OR FLOODING EMERGENCY PROCEDURES

1. In the event of a pressure loss with flooding, it will be necessary to utilize damage-control materials and procedures. Immediately upon sounding the alarm, the bottom commander will designate one man to monitor communication system topside, with a continual flow of information, minimizing the need for topside to ask current status.

2. Should efforts to correct the loss of pressure or to stem the flooding meet with failure, all subjects will proceed to the Personnel Transfer Capsule and be brought topside for transfer to the Deck Decompression Capsule.

3. The Senior Medical Monitor and On-Site Commander will make the decision to decompress or hold pressure, pending an evaluation of the habitability of the dwelling.

4. An evacuation order issued by topside will be considered mandatory.

FIRE

1. With the concentration of oxygen levels established for Sealab II, it is unlikely that fire of significant proportions can occur. Severe electrical short circuit, however, could burn insulation and produce atmospheric contaminants.

2. In the event a fire is detected, the oxygen supply system must be secured.

3. If a fire alarm is sounded, the bottom commander will designate one subject to man the communication system to provide a flow of information topside.

4. Those individuals designated by the bottom commander to fight fires will don the emergency air-breathing masks, and proceed to take corrective measures. All other subjects will evacuate to the Personnel Transfer Capsule to await further instructions.

5. Orders to evacuate issued by topside will be considered mandatory.

LOSS OR ACCIDENT OUTSIDE THE SEALAB STRUCTURE

1. In the event of a casualty outside the Sealab structure, the bottom commander shall sound the general recall alarm. All personnel outside the structure shall return immediately except the swim partner of the injured person or person lost from view.

2. The bottom commander will then institute corrective measures which in his judgment appear to be most feasible and practicable.

3. One man will monitor communications to provide a flow of information to the topside commander.

SEALAB II ATMOSPHERIC CONTAMINATIONS

Precautions

The purpose of this instruction is to alert all personnel associated with Sealab type structures to the importance of controlling atmospheric contamination, particularly those items which possess a toxicity hazard, toxicity hazard being the probability that injury may be caused by the manner in which a particular substance is used.

In Sealab, inhalation of contaminated air is by far the most probable means by which toxic substances will gain entry into the body. This is of increasingly more importance when one considers that at normal atmospheric pressures, an individual under conditions of moderate exertion will breathe about 10 cubic meters (10,000 liters) of air in eight hours, thus somewhat in the area of 30,000 liters per day.

Although general ground rules have not been necessary for early manned undersea dwellings, relative to various items which may be introduced into the structure, this philosophy can no longer be considered valid. With increasing periods of prolonged submergence at greater sea pressures, and the increasing number of personnel and personnel logistic requirements, it is essential that careful consideration be given to minimizing toxicity hazards within any manned undersea dwelling or vehicles used in conjunction therewith.

The capacity for removal of air contaminants which can be built into manned undersea dwellings and small vehicles is extremely limited. In Sealab II, contamination control is limited to (a) carbon dioxide removal with lithium hydroxide and (b) activated charcoal for removal of some contaminants. In this regard, it must be remembered that charcoal will not remove all possible contaminants, and that, furthermore, it is capable of selective absorption. Selective absorption simply means that it may release one substance previously absorbed in exchange for another; therefore, it is possible that a toxic substance absorbed early in a bottomed dwelling may reappear later as this exchange process takes place.

In manned undersea dwellings, paints and adhesives may be one of the largest offenders. It is suggested that principles which have been set down for nuclear submarines be adopted for future dwellings and vehicles.

1. All major painting should be accomplished at least 30 days prior to manning, and any touch-up painting with oil-based paints be accomplished no less than 15 days prior.

2. If it is necessary to paint interiors with less than 30 days remaining, water-base paints shall be used in lieu of chlorinated rubber-base paints.

3. No painting shall be done within 72 hours of manning.

Contaminants possessing a toxicity hazard may be introduced in many unsuspected ways, such as glues, hobby paints, some aerosol bombs, and cleaning solvents.

In an effort to minimize the possibility of toxic substances being introduced into the atmosphere of Sealab II, the following control procedure will be instituted.

1. All items of equipment, both professional and personal, shall be reviewed and approved for stowage and use aboard Sealab II.

2. A careful log of all items intended for use within Sealab II shall be maintained by the Atmosphere Control Officer.

3. Only the Senior Medical Monitor or the Atmosphere Control Officer may grant approval of items, and all items shall be logged.

4. The log of items shall also list an approximate weight and storage location within the structure. This is necessary for accurate analysis of ballasting required for both towing and placement on the bottom at the chosen site.

Captain Walter F. Mazzone, MSC, USN will maintain supervision of this program; therefore all approvals granted by the Senior Medical Monitor, Captain George F. Bond, MC, USN, will by necessity have to be transmitted for logging the required data.

Specific Conditions

Sealab II is emplaced on the sea floor. The atmosphere can suffer contamination in many ways. One source is from electrical fires, which may generate smoke, ozone, and other objectionable gases and odors. A second source could be spilled chemicals.

Procedures

In the event of atmospheric contamination, all subjects designated by the bottom commander will don the emergency air-breathing masks. All other subjects will proceed to the Personnel Transfer Capsule to await further instructions.

Depending on the type of contamination, immediate measures will be taken to remove the source of contaminant. If the source is electrical, secure the main power. If the source is chemical, cover the source or wash down any spillage with a hose.

Sealab's atmosphere can be purged with fresh helium and oxygen from the spare bottles carried aboard. The racks carry ten bottles of helium, eleven bottles of oxygen and three bottles of premixed helium-oxygen gas. Fresh helium is introduced into the vent plenum. Fresh oxygen is introduced into the fan discharge duct. The fan should always be running when oxygen is introduced, to effect proper dilution of the gas, and to avoid a fire hazard.

If all efforts to clear the atmosphere should fail, all subjects will proceed to the Personnel Transfer Capsule to be brought to the surface for transfer to the Deck Decompression Chamber, either to be decompressed or held at pressure pending an evaluation of the situation. The decision to decompress will be given by the Senior Medical Monitor and the Project Director.

SEALAB II; ELECTRICAL POWER LOSS BILL

In case of total power failure, take the following steps.

1. Move all switches on main power panel to OFF.

2. Notify support vessel to restore power.

3. When either indicator lamp on panel glows, move corresponding power-supply switch to ON. (Mechanical interlock will prevent both NORMAL and ALTERNATE power supply switches from being on at same time).

4. Move remaining switches, one at a time, to ON. (These are the load switches, No. 1-4P-A to 1-4P-F).

5. Notify support vessel that power has been restored.

To transfer power from alternate to normal supply (when indicator lamp on power panel shows normal power available).

1. Move all switches on main power panel to OFF.

2. Move normal power supply switch to ON.

3. Move remaining switches, one at a time, to ON. (These are the load switches, No. 1-4P-A to 1-4P-F.)

4. Notify support vessel to switch off alternate power. Note: Normal power supply is from shore. Alternate power supply is from support vessel.

STAGING VESSEL FOUL-WEATHER BILL

1. Take hourly tensiometer readings on each leg and record. Note change. Tension should not exceed 50,000 lb.

2. Request ComServRon One ATF to stand by. Alert Gear. If ATF not available, request Gear to stand by.

3. Notify Commander, Naval Base, San Diego, of situation and alert for possible assistance.

4. Secure all loose gear.

5. Send all boats except one LCM to Quivira Basin, Mission Bay.

6. Set up special 24-hour watch.

7. Check position of "dumb waiter" line extending from Staging Vessel to Sealab II.

8. Check position of Sealab II acoustically every hour or oftener.

9. Check mooring legs for signs of dragging.

10. If situation deteriorates, have ATF or Gear attach tow line, preferably nylon, and relieve strain or leg with the highest tension.

11. In the event an anchor drags, shift pull of ATF to compensate.

12. Maintain constant communication with all concerned.

STAGING VESSEL MOOR SLIPPING BILL

When weather and wave-prediction information indicate a hazardous condition is imminent, it will be necessary to move the staging vessel into the San Diego Harbor. These warnings should be received at least 24 hours in advance. The following procedure shall be followed for slipping the mooring:

1. Request a ComServRon One ATF at site with at least one YTM or YTB tug. If ATF not available, request Gear.

2. When tow line is attached to staging vessel, remove legs generally in inverse order of mooring. Buoy wire off with 59-in. spherical buoys or equivalent. Great care must be exercised so that nothing is dropped on Sealab II and that all connections to Sealab II are broken.

3. Take Staging Vessel into San Diego escorted by YTM or YTB tug.

4. Send all boats to Quivira Basin, Mission Bay, LaJolla.

Section II
AQUANAUTS

Chapter 24

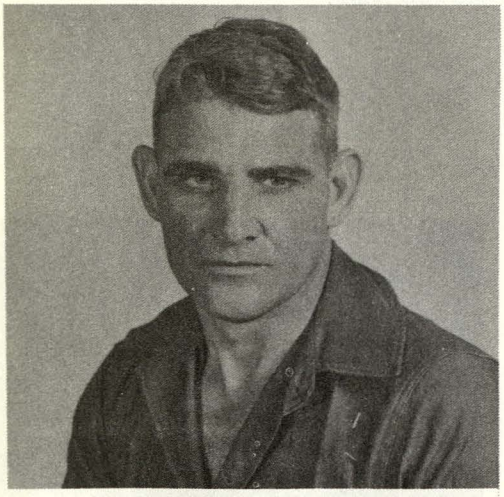
AQUANAUT BIOGRAPHIES

G. P. Clapper
Office of Naval Research
Washington, D. C.



Robert A Barth, Chief Quartermaster (DV), USN
Team 2

Chief Barth, 35, participated in Project GENESIS and as an aquanaut in Sealab I. He is presently assigned to the U.S. Navy Mine Defense Laboratory, Panama City, Florida. He is married to the former Joyce Williams of Tampa, Florida and has two sons.



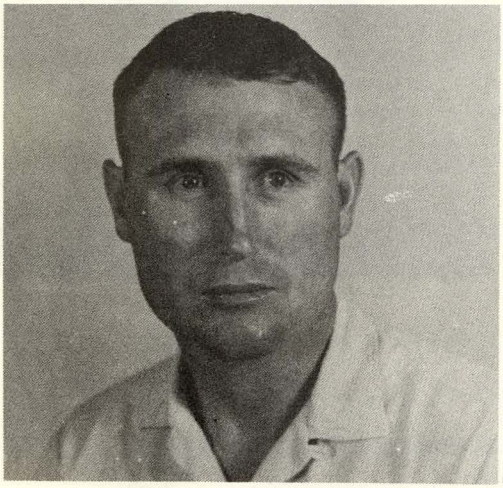
Howard L. Buckner, Chief Steelworker (DV), USN,
Team 2

Chief Buckner, 36, served in Sealab I as a surface support diver. He is presently assigned to the Experimental Diving Unit, Washington, D.C. He is married to the former June Morris of Falls Church, Virginia, and has three daughters.



William J. Bunton, Team 3

Mr. Bunton, 32, is an army veteran. He is presently an Experimental Test Mechanic at the Scripps Institution of Oceanography, La Jolla, California. He is married to the former Betty LeClaire, of Detroit, Michigan, and has three daughters and two sons.



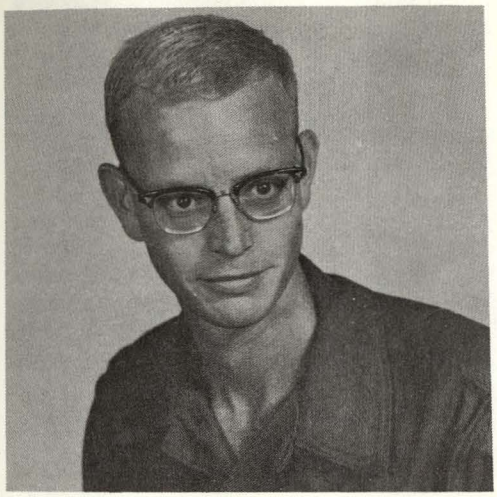
Berry L. Cannon, Team 1

Mr. Cannon, 30, is a Navy veteran. He is presently an Electronics Engineer at the U.S. Navy Mine Defense Laboratory, Panama City, Florida. He is married to the former Mary Louise Rutkowski of Chula Vista, California, and has two sons.



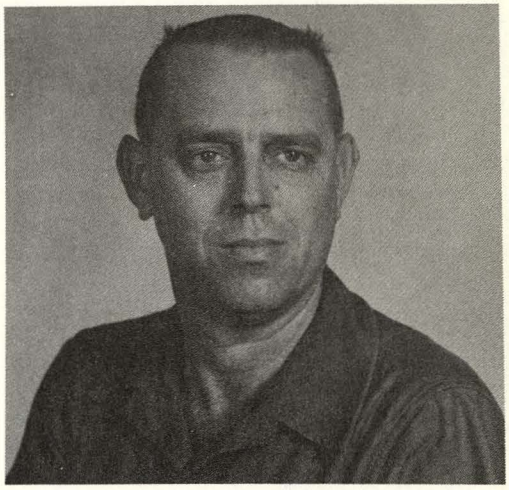
CDR. M. Scott Carpenter, USN, Team Leader, Teams 1 and 2

CDR. Carpenter, 40, has been assigned to the National Aeronautics and Space Administration since April 1959. He piloted the three-orbit Mercury-Atlas 7 (AURORA 7) flight in May 1962. He participated in Sealab I as a topside assistant. He is married to the former Rene Louise Price and has two sons and two daughters.



Thomas A. Clarke, Team 3

Mr. Clarke, 25, is the youngest Sealab II aquanaut. He is a graduate student in Marine Biology at the Scripps Institution of Oceanography, La Jolla, California. He is not married.



Billie L. Coffman, Torpedoman First class (SS) (DV), USN, Team 1

Coffman, 36, has served with the Experimental Diving Unit as an instructor. He is presently assigned to the Submarine Medical Center, New London, Conn. He is married and has one daughter.



Charles M. Coggeshall, Chief Gunner's Mate (DV), USN, Team 3

Chief Coggeshall, 35, is presently assigned to the U.S. Navy Mine Defense Laboratory, Panama City, Florida. He is married to the former Hazel Smith of South Norfolk Virginia and has two sons.



Kenneth J. Conda, Torpedoman First Class (SS) (DV), USN, Team 2

Conda, 33, is presently assigned to the U.S. Navy Submarine Medical Center, New London, Conn. He is married to the former Elsbeth Chace, of Somerset, Massachusetts, and has three daughters.



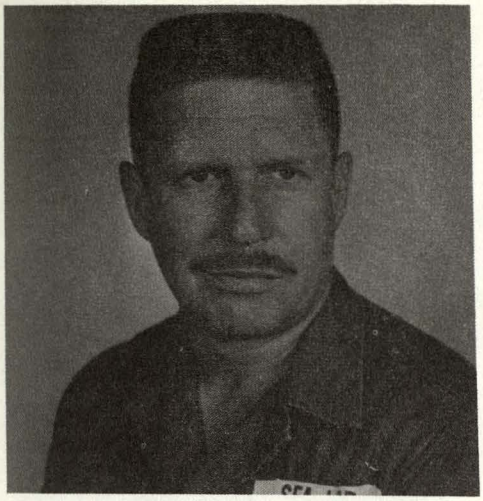
George B. Dowling, Team 3

Mr. Dowling, 39, is a Navy veteran. He is presently employed at the U.S. Navy Mine Defense Laboratory, Panama City, Florida, as a Research Physicist. He is married to the former Janet Davis of Brondidge, Alabama, and has three daughters and one son.



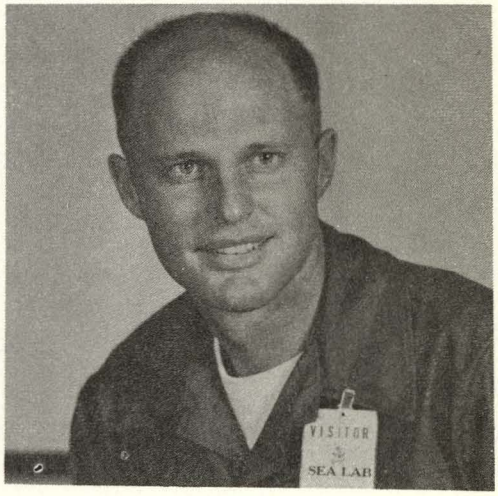
Wilbur H. Eaton, Gunner's Mate First Class (DV), USN Team 1

Eaton, 39, participated in Sealab I as a surface support diver. He is presently assigned to the U.S. Navy Mine Defense Laboratory, Panama City, Florida. He is married to the former Annice Lee White of Plattsmouth, Nebraska, and has four daughters and two sons.



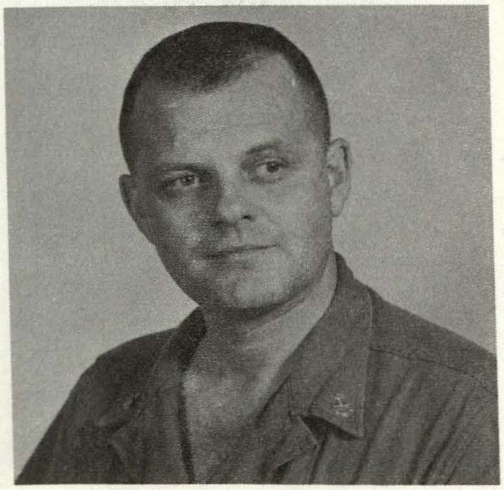
Arthur O. Flechsig, Team 2

Mr. Flechsig, 41, is chairman of the Scripps Diving Control Board. He is presently a Specialist Oceanographer at the Scripps Institution of Oceanography, La Jolla, California. He is married to the former Phyllis Grant of Alamo, California, and has two sons and two daughters.



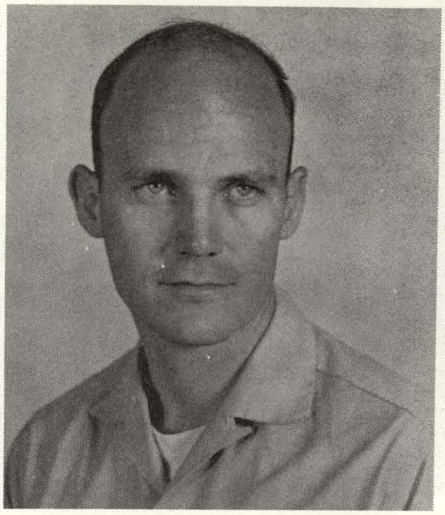
Richard Grigg, Team 3

Mr. Grigg, 28, is presently a graduate student in Marine Biology at the Scripps Institution of Oceanography, La Jolla, California. He is married to the former Sandra Song and has one daughter.



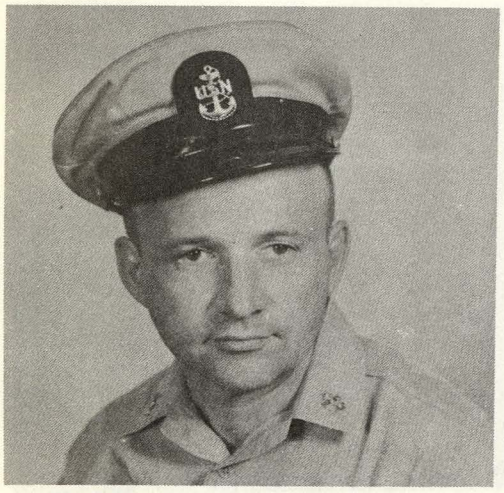
Glen L. Iley, Chief Hospital Corpsman (DV), USN, Team 2

Chief Iley, 36, participated in Sealab I as a surface support diver. He is presently assigned to the U.S. Naval Submarine Base, New London, Conn. He is married to the former Edna P. McKay of Selma, Alabama and has two daughters.



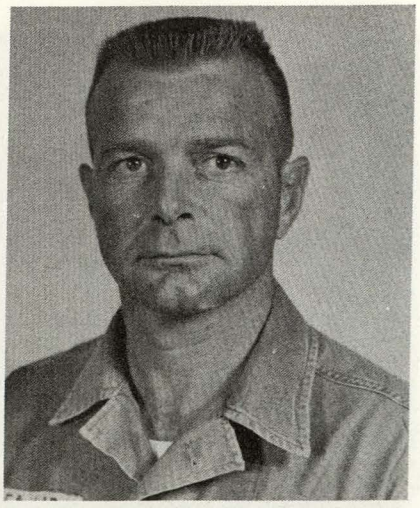
Wallace T. Jenkins, Team 2

Mr. Jenkins, 30, is a Navy veteran. He is presently an Equipment Specialist at the U.S. Navy Mine Defense Laboratory, Panama City, Florida. He is married to the former Sandra K. Sackman of Sedro Wooley, Washington, and has one son.



Frederick J. Johler, Chief Engineman (DV), USN, Team 1

Chief Johler, 40, participated in Sealab I as a surface support diver. He is presently assigned to the U.S. Naval Submarine Base, New London, Conn. He is married to the former Genevieve Blake of Buffalo, New York, and has two daughters.



John J. Lyons, Engineman First Class (DV), USN, Team 3

Lyons, 35, is presently assigned to the U.S. Navy Mine Defense Laboratory, Panama City, Florida. He is married to the former Shirley Miller of Chicago, Ill., and has two sons and one daughter.



William D. Meeks, Boatswains Mate First Class (DV), USN, Team 3

Meaks, 34, is presently assigned to the Experimental Diving Unit, Washington, D. C. He is married to the former Doreen A. Conner of Wilmington, Delaware.



Lavern R. Meiskey, Chief Shipfitter (DV), USN, Team 3

Chief Meiskey, 38, is presently assigned to the U. S. Navy Mine Defense Laboratory, Panama City, Florida. He is married to the former Dorothy Spiess of Spring Valley, Minnesota, and has one daughter.



Earl "A" Murray, Team 1

Mr. Murray, 38, is a Navy veteran. He is presently employed as a laboratory Assistant at the Scripps Institution of Oceanography, La Jolla, California. He has two daughters.



John F. Reaves, Photographer First Class (DV), USN
Team 2

Reaves, 36, is presently assigned to the Pacific Mobile Photo Unit, NAS North Island, San Diego, California. He is married to the former Hilda Gray Dubberly of Jacksonville, Florida, and has two sons.



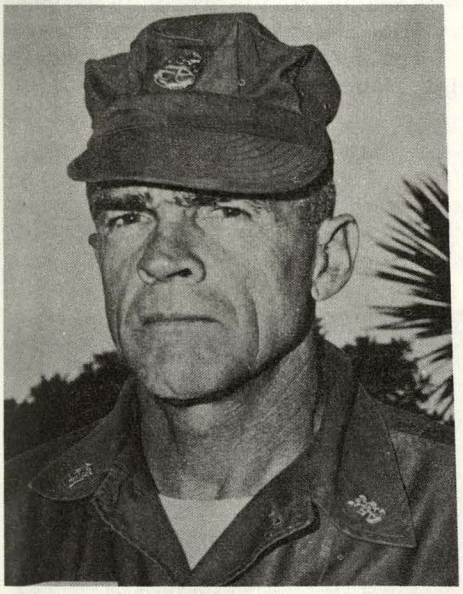
Jay D. Skidmore, Chief Photographer (DV), USN, Team 1

Chief Skidmore, 37, has participated in Project Nekton with the Bathyscaph Trieste. He is presently assigned to the Pacific Mobile Photo Unit, NAS North Island, San Diego, California. He is married to the former Lois Irene Wedeberg of Tacoma, Washington, and has one son and one daughter.



Lt Robert E. Sonnenburg, MC, USNR, Teams 1 and 3

Lt Sonnenburg, 28, received his MD degree in 1962. He is presently assigned to the U.S. Navy Mine Defense Laboratory, Panama City, Florida. He is married to the former Patricia Ann Molin, San Diego, California, and has two daughters and one son.



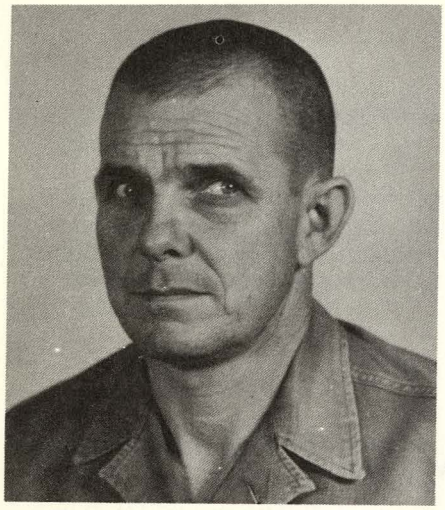
Robert C. Sheats, Master Chief Torpedoman (DV), USN, Team Leader, Team 3

Chief Sheats, 50, participated in Sealab I as the Master Diver for surface support. He is presently assigned to the U.S. Naval Torpedo Station, Keyport, Washington. He is married to the former Alberta M. Bellerue of Poulsbo, Washington and has two sons.



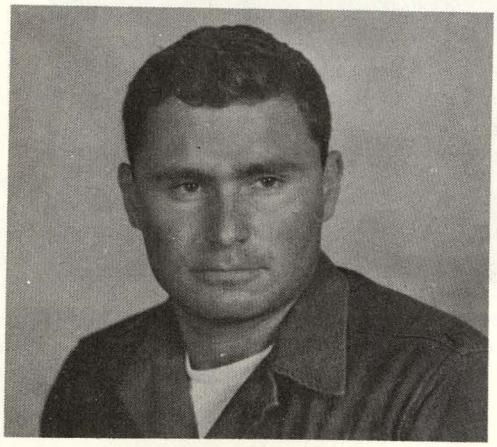
William H. Tolbert, Team 2

Mr. Tolbert, 39, is presently employed as an Oceanographer at the U.S. Navy Mine Defense Laboratory, Panama City, Florida. He is married to the former Betty Hammett of Vicksburg, Mississippi, and has two sons.



Cyril J. Tuckfield, Chief Engineman (DV), USN, Team 1

Chief Tuckfield, 44, participated in a submarine escape from 302 ft in 1959. He was a surface-support diver with Sealab I and is presently assigned to the U.S. Navy Mine Defense Laboratory, Panama City, Florida. He is married to the former Natalie Kryg, of Norwich, Connecticut.



John M. Wells, Team 3

Mr. Wells, 25, is presently employed as a Research Assistant at the Scripps Institution of Oceanography, La Jolla, California. He is not married.



Paul A. Wells, Chief Mineman (DV), USN, Team 3

Chief Wells, 38, is presently assigned to the U.S. Navy Mine Defense Laboratory, Panama City, Florida. He is not married.

Chapter 25

AQUANAUT TRAINING

M. S. Carpenter
National Aeronautics and Space Administration
Houston, Texas

Training activities for crew members began April 1, 1965, in Panama City, Florida, nearly six months prior to the scheduled beginning of the underwater experiment. Classroom work included diving physiology and physics, detailed study of the Mk-VI semiclosed-circuit breathing apparatus which was used throughout the operation, underwater photography techniques and equipment, and familiarization with the hookah breathing apparatus, or "Arawak." In addition, many hours were spent becoming familiar with the Mk-1 SPU, or Swimmer Propulsion Unit, and other auxiliary equipment such as test kits and gas charging pumps for the Mk-VI tanks.

Underwater audio communication equipment and hand-held active and passive sonars were studied and operated, and many hours were spent in the diving locker designing and building equipment to support our operation, mix our gas, and store and ship our gear. Divers, by necessity, are jacks-of-all-trades.

Classroom familiarization with the Mk-VI breathing apparatus took one week. This time may seem excessive, but the Mk-VI is not the simple open-circuit scuba gear that most people associate with diving. Figure 77 shows the gas bottles and CO_2 absorbent canister worn on the back. The control block, or pressure and flow regulator, is shown above the center canister. Figure 78 shows the Mk-VI vest, which is made up of an inhalation bag on the diver's right side and an exhalation bag on his left. Hoses and a mouthpiece connect the two, and on the upper part of the exhalation bag is an exhaust valve which can be adjusted in the water by the diver. Adjustment of this valve regulates the amount of each exhalation that is exhausted, usually about one-third; that function is what qualifies the Mk-VI as a semiclosed-circuit breathing apparatus. The valve, used in conjunction with a bypass valve on the control block, also controls the degree of inflation of the breathing bags. This valve gives the diver some control of his buoyancy, which is very useful when he works at varying depths.

Actual use of the equipment began in the swimming pool. After two one-hour sessions, we took to deep water, where we conducted the rest of the diving training. One day was spend diving in 30-ft water, four days in 60-ft water, five days in 100-ft water, all on N_2O_2 mix, and another five days in 200-ft water on HeO_2 mix.

A good portion of our time was spent in becoming familiar with the physiological and psychological testing equipment and procedures. This orientation was necessary in its own right, of course, but it also provided good base-line performance data on each man. In addition, a day was spent at the Pensacola Naval Hospital with EEG, ECG, cardiopulmonary function, long-bone X-rays, and other physiological base-line studies.

Unfortunately, the entire Sealab team was not available for training at the same time, which necessitated conducting all of the training at least twice. This difficulty, plus the lack of fast surface transportation to deep water, which was quite a way out, made for a not-too-efficient use of our time during this phase of our training.

Throughout the three-month training period at Panama City, there was little opportunity to learn much about Sealab II herself, or the two decompression chambers we would be using. When the crew moved to Long Beach in July, we saw for the first time the nearly completed

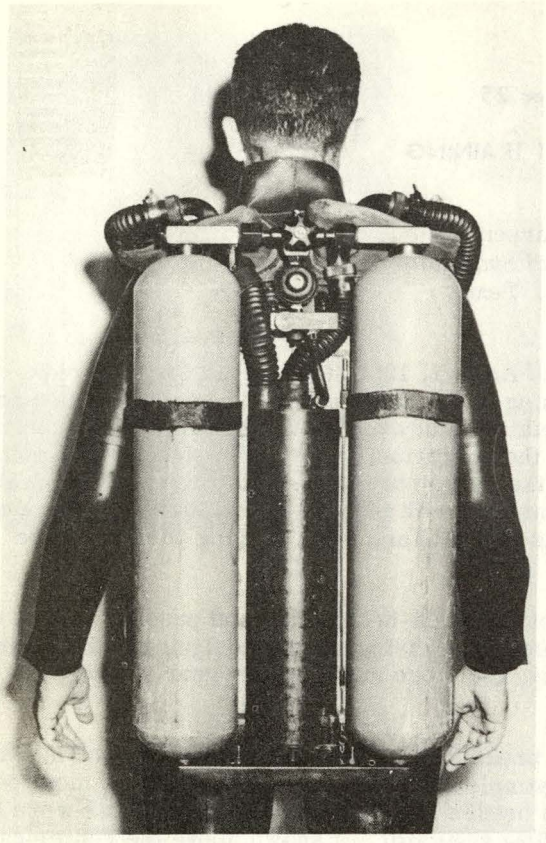


Fig. 77. Diver wearing Mk-VI semiclosed breathing apparatus showing gas bottles and CO_2 absorbent canister



Fig. 78. Diver wearing Mk-VI semiclosed breathing apparatus showing inhalation and exhalation bags

Sealab, and became busily engaged in learning her functions — valving procedures, mechanisms, etc. — and idiosyncrasies. Under the critical eyes of this crew, and those of Captain Walt Mazzone of the Submarine Medical Center and Joe Berkich of the Naval Ordnance Test Station (NOTS), many design changes were proposed and incorporated. Serious deficiencies in the design and fabrication of both decompression chambers, which could have caused the loss of the entire crew of ten men, were uncovered and corrected. Testing procedures had to be devised, and operating instructions had to be drawn up, all by trial and error, before training in the proper use of the PTC and DDC could be conducted. Throughout this period, much time was spent doing the labor required to get our home ready for the sea floor. The time might have been spent better in study of procedures, blueprints, system operation, and continued on-site deep-water exposure with the Mk-VI. This, however, would have required more men, more time, and, of course, more money than we were allotted.

Throughout this four-month training period, each day was started with 30 to 40 minutes of compulsory physical training in the form of running and calisthenics.

The training schedule and a breakdown of the Mk-VI portion of the schedule are shown in Tables 4 and 5, respectively.

Table 4
TRAINING SCHEDULE FOR SEALAB II SUBJECTS

Subjects	April				May					June				July			
	5	12	19	26	3	10	17	24	31	7	14	21	28	5	9	19	26
Mk VI																	
Classroom																	
Human Factors																	
PQS Mk 16																	
SPU and Human Factor																	
Hookah																	
Leave																	
System Check West Coast						Group Alpha Group Bravo											

Table 5
MK-VI DAILY TRAINING SCHEDULE

First Week			Second Week		
Day	Time	Subject	Day	Time	Subject
Mon	0700-0705	Muster	Mon	0700-0705	Muster
	0705-0800	Physical Training		0705-0800	Physical Training
	0800-1100	Diving Medicine		0800-0900	Set up Units
	1230-1430	Diving Medicine		0900	Underway DV Boat
	1430-1530	Resuscitation and First Aid		1000	Two 30-minute dives at 30 ft
				1400-1530	Charge 60%. Secure Gear
Tue	0700-0705	Muster	Tue	0700-0705	Muster
	0705-0800	Physical Training		0705-0800	Physical Training
	0800-0900	Theory of Semiclosed Scuba		0800-0900	Set up Units
	0900-1000	CO_2 Absorbents		0900	Underway DV Boat
	1000-1100	Introduction to Mk-VI nomenclature		1000	Two 45-minute dives
	1230-1430	Assembly of the Mk-VI		1400-1530	Charge 60%. Secure Gear
	1430-1530	Principle of Operation of the Mk-VI			
Wed	0700-0705	Muster	Wed	0700-0705	Muster
	0705-0800	Physical Training		0705-0800	Physical Training
	0800-1000	Predive Preparation		0800-0900	Set up Units
	1000-1100	Mk-VI Maintenance		0900	Underway DV Boat
	1230-1430	Splitting and mixing formulas		1000	Two 45-minute dives
	1430-1530	Handling Procedures		1400-1530	Charge 60%. Secure
Thur	0700-0705	Muster	Thur	0700-0705	Muster
	0705-0800	Physical Training		0705-0800	Physical Training
	0800-1100	Mixed Gas Formulas		0800-0900	Set up Units
	1230-1300	Beckman Analyzers		0900	Underway DV Boat
	1300-1330	Oxygen Transfer Pump		1000	Two 30-minute dives
	1330-1345	Gas Rack and Gas Stowage		1300	One 1000-yard swim
	1345-1500	Changing the Mk-VI Cascade and Transfer Pump		1400-1530	Charge 60%. Secure Gear
Fri	0700-0705	Muster	Fri	0700-0705	Muster
	0705-0800	Physical Training		0705-0800	Physical Training
	0800-1100	Mk-VI Introduction		0800-0900	Set up Units
	1230-1530	Charge 60%. Secure Gear		0900	Underway DV Boat
				1000	Two 30-minute dives
				1300	One 1000-yard swim
				1400-1530	Charge 60%. Secure Gear

Table 5 (Continued)

Third Week			Fourth Week		
Day	Time	Subject	Day	Time	Subject
Mon	0700-0705 0705-0800 0800-0900 0900 1000 1300 1400-1530	Muster Physical Training Set up Units Underway DV Boat Two 30-minute dives One 1000-yard swim Charge 60%. Secure Gear	Mon	0700-0705 0705-0800 0800 1600	Muster Physical Training Underway in MSO. Upon arrival at Op area commence deep diving operations. Secure diving operations Charge 32-1/2%
Tue	0700-0705 0705-0800 0800-0900 0900 1000 1300 1400-1530	Muster Physical Training Set up Units Underway DV Boat Two 30-minute dives One 1000-yard swim Charge 40%. Secure Gear	Tue	0745 0800 1600	Muster Commence deep diving operations* Secure diving operations Charge to 32-1/2%
Wed	0700-0705 0705-0800 0800 1000 1400-1530	Muster Physical Training Underway DV Boat Two 100 ft dives Charge 40%. Secure Gear	Wed	0745 0800 1600	Muster Commence deep diving operations* Secure diving operations Charge 32-1/2%
Thu	0700-0705 0705-0800 0800 1000 1400-1530	Muster Physical Training Underway DV Boat Two 100 ft dives Charge 40%. Secure Gear	Thu	0745 0800 1600	Muster Commence deep diving operations* Secure diving operations
Fri	0700-0705 0705-0800 0800 1000 1400-1530	Muster Physical Training Underway DV Boat Two 100 ft dives Charge 32-1/2%. Secure Gear	Fri		Make up dives

*Approximately 180 ft.

Chapter 26

AQUANAUT DAILY ROUTINES

M. S. Carpenter
National Aeronautics and Space Administration
Houston, Texas

After the lowering operation was completed and the condition of the lab had been monitored for approximately 36 hours, the occupancy by the first crew was commenced. The first team of two divers opened and inspected the Sealab; the second team of two divers opened and inspected the personnel transfer capsule, which rested on the bottom within 20 ft of the Sealab entrance hatch. When the satisfactory condition of both had been reported topside, the remaining three two-man teams swam down to the lab, accomplishing as much of the necessary work outside the lab as time would allow. The rest of the first day was spent unstowing and rearranging the equipment inside the lab and doing the essential work outside the lab. This work consisted mainly of connecting the fresh-water lines, which was done with relatively little trouble except for some valve-management problems on the lab, and connecting the drain hoses. This operation presented some unforeseen problems, because the lines were buoyant and had to be weighted in order to prevent gas leakage from the lab.

The first tasks on the bottom involved unsecuring the rest of the equipment that had been lashed down for the tow from Long Beach, and restowing it so that there was room enough for ten men. The safety anchor line, sewage lines, diving-light leads, benthic lab lines, Arawak hoses, and guide lines had to be connected. All drain plugs, external and internal port covers, and lowering lines had to be removed and stowed.

Once the lab was reasonably habitable, all of the spare time in the water was devoted to the scientific programs and equipment evaluations. These activities included the erection of the strength-test platform and associated torque wrenches, the two-hand coordinator, the current meter, underwater weather station and sound range, visual acuity range, stationary target array, water clarity meter, pneumofathometer, fish cages, homing beacons, compass rose, external TV cameras, bioluminescence meter, foam and salvage project equipment, bottom current trailers, underwater studgun equipment, photo and diving lights, bathythermograph, wave gage, and antitorque underwater tool test equipment.

Before and after each dive, strength and manual dexterity tests were performed in the water with the aid of equipment designed specifically for this purpose. Another task that required quite a bit of in-the-water time was that of straightening the outside Arawak hoses, which continually fouled and kinked. This job had to be accomplished almost daily. Resupply through the system of pots and baskets also consumed altogether too much of divers' time.

During the third team's tenure on the bottom, the storm of activity centered around resupply abated somewhat because of the installation of a high-pressure helium-mix line in the lab. This line, supplied by pumps on the surface ship, permitted recharging of the Mk-VI bottles in the lab instead of sending them topside for refilling. It not only reduced the workload on the men, but also was kinder to the equipment.

A watch schedule had been set up prior to the first dive, and it went into effect immediately after the lab was occupied. The schedule which appears in Table 6 provided two men on watch at all times during the working hours, and one-man watch sections during the sleeping hours. The responsibilities of the working-hours watch section included keeping the log, handling communications with topside, preparing and cleaning up after the meals, and staging the divers. It was more a rule than an exception that these tasks had to be performed concurrently; and

frequently the duty section found it necessary to stage divers, keep the log, cook, communicate, and clean up all at the same time. Needless to say, without the cooperation of the entire crew through the entire working day, the mission of the lab just could not have been carried out.

Table 6
SEALAB II WATCH SCHEDULE

Time	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed
0600 to 1100	1	3	5	2	4	1	3	5	2	4
1100 to 1600	2	4	1	3	5	2	4	1	3	5
1600 to 2100	3	5	2	4	1	3	5	2	4	1
2100 to 2400	4A	1A	3A	5A	2A	4B	1B	3B	5B	2B
0000 to 0300	4B	1B	3B	5B	2B	4A	1A	3A	5A	2A
0300 to 0600	5A	2A	4A	1A	3A	5B	2B	4B	1B	3B
Super-numer-ary	5B	2B	4B	1B	3B	5A	2A	4A	1A	3A

Buddy Team and Individual Number Assignments

Carpenter 1A, Eaton 1B — Team 1
Tuckfield 2A, Cannon 2B — Team 2
Sonnenburg 3A, Coffman 3B — Team 3
Murray 4A, Skidmore 4B — Team 4
Johler 5A, Clarke 5B — Team 5

The sleeping-hours watch section, although composed of only one man, was not nearly so hectic. There was time to engage in a little idle chatter with the surface, make the daily report of our activities to topside, finish off the log, and set up four or six Mk-VI breathing rigs for the next day's sorties.

The daily schedules changed each day, as did the "Plans-of-the-Day" (P.O.D.), until a smooth operation evolved out of the first trial-and-error week of activity on the bottom. The accompanying list shows the Plan of the Day in the form which was adopted after a week or ten days of evolution. The Sunday P.O.D. continued with the same watch schedule, but there was no scheduled breakfast; each man fixed his own brunch, and diving was at the discretion of the individual teams. The evening meal was prepared by the duty section as usual.

Activities not specifically covered by the Plan of the Day went as follows:

SEALAB II

Monday P.O.D. 24 20 Sept. 1965

Duty		Diving Teams
06-11	Barth - Buckner	1. Jenkins - Tolbert*
11-16	Reaves - Jenkins	2. Dowling* - Carpenter
16-21	Conda - Dowling	3. Barth* - Buckner
21-24	Flechsig	4. Buckner - Conda*
00-03	Tolbert	5. Reaves* out with each team at his discretion for photos
03-06	Iley	
Super	Carpenter	* Standby Diver

DIVING JOBS

1. Bioluminescence Meter Installation
2. Compass Rose Orientation
3. Retrieve Bathythermograph
4. Check Current Meter
5. Release Bottom Current Trailers
6. Bring in Two-Hand Coordinator
7. PQS-1 Evaluation
8. Locate Way Station
9. Excursion to 266 ft — ten minutes
10. Measure Lab Heading
11. Logistics
12. Lengthen Pneumofathometer
13. Logistics
14. Measure Sealab Settling
15. Hook up PTC Steady Light
16. Rig Diving Lights
17. Sound Range Test at 1430

TEAM ASSIGNMENTS

Team 1. (A) 1, 2, 3, 4, 17, Prepost Strength and Touch Sensitivity Tests

Team 2. (E) 5, 6, Clean up Team 1, Prepost Touch Sensitivity and Δ No. 2 (Carpenter) No. 5 (Dowling)

Team 3. (M) 9, 10, 11, Prepost Strength Test

Team 4. (E) 15, 16, 17, 14, 13, Prepost Δ No. 1 (Buckner) No. 4 (Conda)

A = Arawak M = Mk-VI E = Either

NOTES

1. BIB and BOB modifications
2. Change pulley and camera mount stowage
3. Condensate records
4. LiOH cans
5. Camera fitting
6. Parts to Δ's
7. Sound test
8. Barth - Envelopes
9. Gov. Brown Talk

The two-man 0600-1100 watch section was awakened at 0545, and the preparation of breakfast was begun. Reveille was held at 0700. Breakfast was over, and the cleaning up was usually completed, by 0800, when morning quarters was held. Prior to breakfast, each man recorded his weight on a chart provided for that purpose. Other physiological studies were done at this time, i.e., blood and urine sampling.

During quarters, the P.O.D. was discussed, and often changed because of conflicting activities on the surface, and occasionally because of headaches or other temporary indispositions of the crew members. As far as I know, no man dived if he did not feel up to the job.

An effort was made to have each man dive at least once with each of the other men in his crew during his two-week stay on the bottom, although this was not always possible because of the nature of some of the scientific work that was done.

The close quarters that comprised our diving station made it very difficult to get more than one team of divers in the water at one time. It often required ten hours to get five two-men teams in the water during the day, even though the average duration of our dives was in the neighborhood of 45 minutes. In addition, divers were always called back to the lab during the lowering of equipment or supplies from the surface and also during the noon meal hour.

The afternoon work period was similar to the morning work period, and was usually completed by 1800, with the exception of resupply activities which often required the services of a suited Arawak diver until much later in the evening.

Daily repair activities usually took place after the evening meal, as did continued physiological and psychological testing. The diving lights burned out much too frequently and had to be brought in, repaired, and reinstalled. An Arawak pump required disassembly on two separate occasions; dehumidifiers needed modification to allow proper drainage, as did the central conning tower area, the scupper drains, and the sink and shower drains. This work was necessitated by the list and pitch of the lab, which was just outside the limits of the slope of all our drain lines.

Commercial TV was available to the crew each night, but usually everyone was too busy to pay much attention to it. A phone line to the shore was also available; but, with few exceptions, it was not utilized very much for outgoing calls.

Drying the Mk-VI hoses and vests was a daily activity that usually did not start until the evening hours, but continued throughout the night. A commercially available ladies hair dryer was taped to the Arawak pump support framework and ducted with rubber hoses in such a fashion that three Mk-VI vests could be dried at the same time. The system worked very well, but was difficult to set up, and it needs some refinement before the next experiment. A greater air-flow rate is one requirement.

In general, activities associated with preparing for each dive, repair of equipment, and logistics required too much of the Sealab divers' time. Although we spent an unprecedented amount of time in the water, the support activity presented a work load far out of proportion to the useful work done. The long hours and hard work were cheerfully accepted by these crews, but when this type of duty becomes more prolonged and more commonplace and the motivation provided by the experimental situation is no longer present, crew efficiency and morale will flag. Better human engineering of all the equipment will be a most effective means for reducing the amount of time spent in diver support.

The days on the bottom in Sealab II often consisted of 20 hours of steady work. There is, however, no reason not to believe that with the refinement of procedures and equipment, and a crew of the same calibre, we will be able in the future to accomplish much more useful work in much less time, and have a little left over for recreation and a more nearly normal way of life underwater.

Chapter 27

FUTURE SELECTION OF AQUANAUTS

R. Radloff
Naval Medical Research Institute
Bethesda, Maryland

PURPOSE

The purpose of this chapter is to describe and explain some of the measures which may be used in selecting men for future operations similar to Sealab. The information used in this analysis is based on correlations between background information and measures of performance and adjustment on men who participated in Sealab II. It should be emphasized that this presentation represents the barest beginning of a process of developing a uniform set of procedures and instruments to be used in selecting future aquanauts. Not only were materials and methods of measurement used in Sealab II limited, but also the analysis and interpretation of even those limited materials is incomplete at this time. However, it has been said that a journey of a thousand miles begins with a single step. This discussion represents, hopefully, at least a few solid strides toward a soundly based system of crew selection.

DEVELOPING A SELECTION METHOD

The basic aim of this section is to predict performance and adaptation in Sealab. Both predictors and criteria are multiple. Ten criteria have been derived. Four are intended to be indices of work. Examples are diving time and number of sorties. Four of the criteria can be loosely called measures of adjustment. Examples are satisfaction with meals and quality of sleep. Men in each crew were given quantitative ratings by their crew leaders. Finally, each man was asked to name the men he would most like to have as crew mates in future Sealabs. These postchoices have been used as a criterion variable.

Only a few of the many possible predictor variables have been chosen for this presentation. They are of two types. First are a set of demographic variables, such as age, diving experience, and education. Second, the Allport-Vernon-Lindzey Study of Values has been selected for analysis. The scale of values is probably the easiest to understand and interpret of the standard measuring instruments administered to the aquanauts.

Only a few predictors have been used, for a variety of reasons. First, the ones chosen were judged to be among the best in terms of their ease of interpretation and understanding. Second, it will require some time, even for a computer, to reproduce all the intercorrelations. Third, even if the thousands of intercorrelations of predictors and criteria were available, too much time and space would be required to analyze and interpret them meaningfully for this report. In fact, more predictor variables have been correlated with the criteria than those presented in this report. Those not included either did not correlate significantly with the criteria, or the associations were difficult to interpret and explain.

This report, therefore, is not the full story on crew selection. Even when all the data available on Sealab aquanauts have been analyzed, however, only a small beginning will have been made. What is meant here can best be illustrated by citing the philosophy and experience of the Peace Corps in its outstanding program of selecting overseas personnel. Peace Corps Director Sargent Shriver, in discussing selection, said, "...a selection process must depend on a conglomeration of considerations. No one test, nor any one procedure can be counted upon." Dr. Abraham Carp, Peace Corps Selection Director, further stated, "The selection of

people is a young science. No one selection tool even begins to approach perfection. That is why Peace Corps selection is deliberately structured to bring to bear many different selection tools." "...no one element of this process is determinative but each makes a definite and distinctive contribution to the process." Thus the tests or predictors used on this one group of aquanauts cannot be used, by themselves alone, to select future crews of undersea dwellers. The results of this study will have to be crossvalidated in similar situations. However, a beginning has been made. Because information was collected on the crews of Sealab II, predictors and criteria are available. More important, information is available on this group so that comparisons with other groups are possible.

CRITERION VARIABLES

General Comments

No single criterion could describe adequately the behavior of the men in Sealab. Ten criterion variables will be used in this report. More are available for later reports. They have not been included here, since many of them require involved and complex treatments of data. It is recognized that any criterion which is used is biased in the sense that it tends to favor the performance or behavior of some men over that of others. However, it should be pointed out that the purpose of this report is not to rate the men as such but to rate characteristics of men, with the purpose of producing a profile of characteristics which might predict favorable adjustment and performance in a Sealab-type environment.

Each of the criteria will be defined and their shortcomings and advantages or biases indicated. Most of these criteria have been corrected for within-team differences. That is, each man's performance is rated only against members of his own ten-man team for purposes of determining his score on each variable. This is done because conditions varied considerably from team to team. For example, Teams 2 and 3 had the advantage of experience over Team 1. Also, Team 3 had the advantage of a charging hose for the Mk-VI bottles, which allowed them to spend considerably more time in the water than either Teams 1 or 2. Finally, there appear, from the diving log, to have been differences among teams in recording various aspects of work. Using within-team comparisons does not, however, preclude the comparison of men between teams. This is because once standard scores within teams are assigned, these scores can then be used to compare a man from one team with a man from another.

Types of Criterion Variables

Three types of criterion variables have been used here. One type is called the "work" criterion variable. There are four of these. A second is called the "general adjustment" criterion variable. There are also four of these. Two variables do not fit into either category; these are leader ratings and peer choices.

Definitions of Criterion Variables

Diving Time—A Work Criterion — Diving time was checked against the diving log kept in Sealab. While there were a few missing times in this document, it was remarkably complete and accurate considering the hectic pace and the multiple duties of men in Sealab and the fact that the log was kept by 28 separate individuals. It should be pointed out that diving time tends to favor members of Team 3; however, as previously noted, a correction is made for this bias by rating men within teams. A bias which cannot be corrected is the discrimination against men with special tasks which required them to work inside Sealab rather than out in the water. However, there are other variables on which these men are probably favored, and an overall criterion will probably give an accurate picture.

Number of Sorties—A Work Criterion — The number of sorties was also checked against the diving log. There appears to have been some change in the definition of a sortie from team to team. Also, some excursions into the water for minor tasks, such as taking out the garbage or bringing in pots from the surface, were not given numbers and defined as sorties. Since

there appeared to be very little consistency on this matter in counting sorties, each definable departure of a man from the capsule was counted as a sortie regardless of whether it had been given a number in the official log. On many, perhaps the majority of sorties, men returned to Sealab for brief periods. If the same partners went out after returning to Sealab and if they did not stay in longer than 10 minutes, or if the sortie was recorded as only one sortie in the diving log, men were not given credit for a second sortie after returning to Sealab. However, if a man went out with a new partner after returning to Sealab, or if his original departure had not been counted as a sortie and the time in Sealab was greater than 10 minutes, he was credited with an additional sortie when he left a second or more than a second time. Sorties were not counted as a number but rather as a ratio of the number of sorties to the number of days dived; for example, if a man dived on 12 days and was out on 18 separate sorties, he would have a ratio of 1.50. If another man dived on only 10 days and was out on 15 separate sorties, he would also have a ratio of 1.50. This system was used because many of the men, for a variety of reasons, did not dive every day. In many cases, this was due to scorpion stings, headaches, skin rashes, and the like. Since lesser diving time due to such incidents is recorded in diving time as a variable, it was felt that the number of sorties as a variable would be quite redundant if no correction were made for such incidents. Therefore, the denominator for the ratio of number of sorties was the total number of days a man entered the water. As with diving time, number of sorties was also computed within teams.

Increase or Decrease in Diving Time—A Work Criterion — This variable compares the time a man spent in the water during the second week with the time spent in the water during the first week. It is somewhat different from diving time and number of sorties. Regardless of how long a man was in the water, it would have been possible for him to increase or decrease his time from week one to week two. Such an increase or decrease can probably best be considered as a measure of stamina, motivation, or both. In computing this variable, an average dive time per day was used. Diving times from Monday through Saturday only were used, since Sunday was an unusual day in Sealab. As in figuring the sortie ratio, only the number of days on which a man dived was used as a denominator in this variable. For example, if a man dived on only four days during the six-day week and was inactive the other two days because of ill health, the number 4 was used in the denominator for calculating his average dive time for the week. For nearly all men, the amount of time spent in the water increased in week two compared to week one. Scores were computed within teams.

Number of Human Performance Tasks Completed—A Work Criterion — This variable is a ratio of the number of tasks completed on the human performance program per sortie. For most dives, most men were asked, if time was available, to perform one or more tasks in the human-performance program. In many cases, other things took precedence over these tasks. From debrief interviews, however, many of the men were completely candid and said that they were just too cold, too tired, or didn't feel like doing a particular task before they came back into the capsule. Therefore, performance of these tasks appeared to be somewhat dependent on motivation.

Outside Telephone Calls—An Adjustment Criterion — The number of outside telephone calls made by a man is considered a measure of overall adjustment. The notion behind such consideration is that if a man were completely satisfied with his lot in Sealab he would have very little need to have contact with the outside world. Therefore, he should make very few telephone calls. This variable was also adjusted for between-team differences, since the capability of making outside calls was not available for approximately half the stay of Team 1. Teams 2 and 3 were able to make outside calls during their entire stays. However, there is another reason for correction within teams. Only one telephone was available; if one man were occupying the phone, it would be impossible for another man to make a call at that time.

Meal Satisfaction—An Adjustment Criterion — Each day each aquanaut completed a daily-activities checklist. On this form he indicated whether or not he had eaten each of the meals during the day and, on a quantified scale, how much he liked the meal. These meal ratings were summed across each man for all meals eaten, and the mean reported satisfaction is the score used for this variable. These scores were computed within teams also, since there were differences in the types and methods of preparation of meals between teams. It should be noted that this is a self-report variable. With all such variables, there is always the possibility

that some men may report what they feel is the desired reaction or the appropriate reaction rather than their true reaction.

Quality of Sleep--An Adjustment Criterion -- Also on the daily-activities checklist each man was asked to indicate how well he had slept the night before. These reactions were given on a five-point scale. Scores were computed within teams, since there were apparently some differences in the atmosphere in the capsule between teams which may have affected quality of sleep. It should be noted that this is another self-report variable.

Times Up During the Night--An Adjustment Criterion -- A fourth indicator of overall adjustment, closely correlated with quality of sleep, was the number of times a man got up during the night. This variable was corrected for between-team differences for the same reason as the quality-of-sleep variable. It is, of course, a self-report variable.

Leader Rating -- The team leaders were asked to rate the performance of each man in their teams at the end of the Sealab experiment. These ratings were given on two 4-point scales. On one scale, the leaders were asked to rate the men on overall performance as divers. On the second scale, they were asked to rate the willingness of the man to perform his share or more of common work. The results of these two scales were summated to produce one leader-rating score. For purposes of analysis, the two leaders themselves were given the top ratings available on this variable. No corrections were made for between-team differences on leader ratings. One man who was rated by both leaders was given a score which was the average of the two leader-rating scores.

Teammate Choices -- At the end of his 15 days in Sealab, each man was asked to name the five men he would most like to have with him on a future hypothetical Sealab submersion. Instructions were that men could be chosen from among the 28 Sealab aquanauts. For this variable, each man was given a score determined in the following way; if he was chosen first by a teammate, he was given 5 points; if chosen second, 4 points; if chosen third, 3 points; if chosen fourth, 2 points; and if chosen fifth, 1 point. If he was not chosen, of course he was given no points. The weighted choices were then added for each man, and this score was used in determining the favorability of teammates toward each man. It should be noted that within-team choices increased from a pre- to postmeasure for all three teams. However, the choices within teams were by no means unanimous, and there were still a large number of choices across teams.

PREDICTOR VARIABLES

As indicated above, only a limited number of predictor variables have been used for this preliminary analysis. Only two types of predictor variables will be reported here. They are demographic characteristics and basic values as measured by the Allport-Vernon-Lindzey Study of Values

Demographic Characteristics

Six variables of this type were used. They are age, diving experience, education, birth order, family mobility, and size of home town. At first glance this may seem to be an odd mix of variables; however, they were not chosen capriciously, and an explanation of their choice may be in order.

First of all, demographic characteristics have one appealing advantage over such variables as interests, attitudes, personality, and the like for the purpose of developing criteria. The advantage is that they are objective and therefore highly reliable. A problem with measures of interests and attitudes is that they are frequently of low reliability. This is particularly true if a man knows that such measures will be used as selection criteria. In such circumstances he may say to himself, "How will it affect my chances of being selected if I answer this question 'yes' vs 'no' or 'strongly agree' vs 'moderately agree'," and answer accordingly. Even without such conscious or unconscious biasing influences there is the problem that some men are just more candid about themselves than others, or that they know their own thoughts and

feelings better. Distortions of answers are possible but far less likely to questions concerning objective demographic characteristics than they are for variables of the interest-and-attitude variety.

A second advantage of demographic characteristics is that they are easy to obtain and analyze. A few simple and unobjectionable questions can frequently supply as much information as a long battery of less objective questions, or possibly more. Once their utility as selection predictors has been established, demographic characteristics can be used without a complex scoring or analysis process.

Finally, demographic characteristics have useful predictors in other situations where men have been exposed to stressful environments. A brief discussion of some of the possible relations among the demographic variables and performance will indicate why these particular variables were chosen. Probably no discussion of age and experience are necessary in this regard. It is quite reasonable to expect that an older and more experienced man will cope better with a stressful situation than will a younger and less experienced man. On the other hand, there is no reason to expect that education per se would have an appreciable relation to performance in Sealab. However, there was a considerable range in years of education among the aquanauts, and the civilian and military subgroups were quite different in education, and in the functions they performed as well. This fact would tend to wash out any correlation between education and performance in the group as a whole. However, if amount of education is related to how well a man does his job or to his ability to adjust to others in the group, there could be a correlation between education and criteria within either the military or civilian subgroup.

Birth order, size of home town, and family mobility are variables which are similar to each other, in that each one can be significantly related to the type of person one has become. It has long been known in psychology that whether a person was an only child or first born, or whether he had older siblings, had profound effects on his personality and behavior. However, the nature of these effects has been confused and muddled for an equally long period. In recent years, studies have accumulated which indicate that first and only borns are more reactive to other people and may be more dependent upon them, particularly in stressful situations. The findings regarding birth order are not at all clear at this time, but the variable has been found to be of great significance in a variety of situations involving social behavior and stress. Perhaps the finding of most relevance for present purposes is the fact that later-born men were significantly better fighter pilots during the Korean War as measured by the number of enemy planes they destroyed. Similar data are not available for size of home town and family mobility. These variables were included because of the reasonable presumption that men who had been raised in a small town or whose families had not moved while they were growing up would be different from men who were raised in the city or whose families moved frequently. It would be an unnecessary digression to present the speculations concerning the possible relationship between these variables and performance and adjustment in Sealab.

The other type of measure used in this analysis is the "Study of Values." This series of scales measures the basic value orientation of a person. It is perhaps the most widely used measuring instrument of its type. There are six basic value orientations measured by this form; they are theoretical or scientific, economic, aesthetic, social, political, and religious. By answering a series of questions, a person indicates the relative importance of each of these value orientations for himself. For example, a person scoring high on the theoretical scale is interested in studying the world around him, of acquiring knowledge for its own sake. A person scoring high on the political scale is interested in activities in which he is in control of or directing other persons. In contrast to the specific objective information represented by the demographic variables, the study of values provides data which is general and subjective. Thus, in a sense, considering types of information available about a man, this analysis employs data from two ends of a continuum ranging from specific and objective on one end to general and subjective on the other.

Intercorrelations of Demographic and Criterion Variables

Correlations between demographic and criterion variables are presented in Table 7. The symbols in the table indicate the degree of association. No symbol means, of course, that the correlation is not significant.

Table 7
INTERCORRELATIONS OF DEMOGRAPHIC AND CRITERION VARIABLES

Criterion	Age	Diving Experience	Education	Birth Order	Family Mobility	Size of Home Town
Number of Sorties	0.32†	0.43‡	-0.19	0.50§	-0.15	-0.33†
Diving Time	0.02	0.12	-0.05	0.47§	-0.28	-0.49
Human Performance Tasks	0.09	0.15	-0.15	0.20	-0.17	-0.18
Change in Diving Time	-0.14	0.12	-0.26	-0.10	-0.11	0.14
Outside Telephone Calls*	0.31	0.06	-0.14	0.42‡	-0.15	-0.39
Meal Satisfaction	0.30	0.13	-0.08	0.04	-0.15	-0.21
Quality of Sleep	0.02	0.04	0.05	0.09	-0.15	-0.12
Up During the Night*	-0.12	-0.01	0.13	-0.05	-0.06	-0.33†
Teammate Choice	0.61§	0.52§	-0.29	0.18	0.42‡	-0.16
Leader Rating	0.38‡	0.23	-0.16	0.27	0.09	-0.34†

*Fewer considered better.
†p 0.10, slightly correlated.
‡p 0.05, moderately correlated.
§p 0.01, highly correlated.

The predictors most frequently and highly correlated with the criteria are age, diving experience, birth order, and size of home town. Family mobility is correlated with only one of the criteria, and education is correlated with none. Among the criteria, number of sorties, diving time, outside telephone calls, teammate choice, and leader rating each have two or more significant correlations with predictors. It is interesting to note that of the three self-report criteria (meal satisfaction, quality of sleep, and times up during the night) only one is correlated, and that one only slightly, with only one of the predictors. Number of human-performance tasks completed and changes in diving time are not correlated with any of the predictors. There are three facts of interest in Table 7 which lend particular weight to the results. First is the fact that the better or harder criteria are the ones correlated with the predictors. Second is the large number of significant correlations. Third is the internal consistency of the results. Each of these points warrants a brief elaboration.

By better or harder criteria is meant those which are based on more data rather than less, objective data rather than subjective, and direct rather than indirect measures. Thus, number of outside telephone calls is a harder measure of adjustment than are meal satisfaction, quality of sleep, and times up during the night, because it is an objective and factual record rather than a subjective self-report. The difference here is in rating a man by what he does rather than by what he says. Number of human-performance tasks completed is a poorer measure of work performance than number of sorties, simply because there were so many fewer human-performance tasks performed than there were sorties. Change in diving time is a complex and derived measure compared to the straight record of diving time. The variable of teammate choice involves a tremendous amount of data, since in reality each man was rated 27 separate times, since he either was or was not chosen by his fellow aquanauts. The leader ratings can

be considered semiobjective, since they were made by hard-headed, experienced men using quantitative scales.

Using, then, the five harder or better criterion variables and the five predictor variables — eliminating education, since the civilian-Navy differences would tend to restrict correlations — we have a 5×5 matrix. Within this 5×5 matrix there are 10 out of a possible 25 significant correlations, with three more of borderline significance. By chance, we would expect only one significant correlation from this matrix. The demographic and criterion variables have an extremely high number of correlations.

Finally, there is the fact of internal consistency. Looking down the columns of Table 7 it can be seen that the signs of all significant correlations within each column are the same. That is, age is always positively correlated with the criteria when the correlations are significant, and size of home town is always negatively correlated, and so on.

We can conclude from Table 7 that the more successful aquanaut in Sealab II was older, had more diving experience, was more likely to have been later born, and was raised in a smaller-sized town than was the less successful aquanaut. By success is meant that he went on a greater number of sorties, spent more time in the water, was chosen as a teammate more often by his peers, his performance was rated higher by his leader, and he appears to have been more satisfied with life in Sealab, as indicated by the fact that he made fewer outside telephone calls. A word of caution is in order in considering these results. These correlations are group tendencies only. They cannot be applied to individual aquanauts, excluding other considerations. There may well have been first-born, young men, with relatively little diving experience, not raised in small towns, who were among the best divers in Sealab. If this is true, then what do these results mean? Just how these predictors should enter into a selection process will be discussed after additional results are presented.

Correlations Between Allport-Vernon-Lindzey Values and Criteria

The Allport-Vernon-Lindzey Study of Values has six value scales. Ten criterion variables were used. In the 6×10 matrix of values by criteria there was only one significant correlation. Since the appearance of one significant correlation could be a chance occurrence, this correlation probably does not merit further consideration.

The lack of significant correlations for the group as a whole does not, however, mean that values have no relation to performance in Sealab. There were several types of men in Sealab. Two well-defined subgroups are the Navy and civilian divers. It is reasonable to assume that the men in these two subgroups entered Sealab with somewhat different goals. These differences in goals may in turn have been reflected in basic values, as measured by the "Study of Values." Thus, while one value may have correlated with performance positively for say the civilian subgroup, the correlation on the same value may have shown a negative correlation for the Navy subgroup. This was in fact the case. Before presenting the results illustrating this point, it is necessary to discuss first the criterion factor scores on which the analysis was based.

Criterion Factor Scores

In attempting to evaluate performance and adjustment in a complex situation such as Sealab, it is necessary to use multiple criteria. Ten have been used in the present analysis, and more are available for future analyses. The use of multiple criteria has both advantages and drawbacks. The principal advantage is that multiple criteria provide a more complete picture of behavior than would a single criterion. The principal disadvantage is that the picture is fractionated and diffuse, since some criteria correlate with some predictors but not with others. Factor analysis provides at least a partial answer to the choice between a simplistic few or a confusing multitude of variables.

Three factor scores were derived from an analysis of the ten criterion variables. One of the factor scores is an unrotated or general factor. For the general factor, each of the ten

criterion variables is weighted according to its importance in the factor. Importance is determined by the amount of variance accounted for by each of the criteria. Thus the better criteria, those which account for more of the variance, are weighted more heavily than are the poorer criteria. The weighting or loading of each of the ten criterion variables are given in order of importance for the general factor in Table 8.

Table 8
LOADINGS OF CRITERION VARIABLES ON THE GENERAL FACTOR

Criterion	Loading	Criterion	Loading
Number of Sorties	0.75	Human Performance Tasks	0.55
Leader Rating	0.68	Meal Satisfaction	0.52
Diving Time	0.68	Up During the Night*	0.47
Teammate Choice	0.62	Quality of Sleep	0.38
Outside Telephone Calls*	0.58	Change in Diving Time	0.17

*Fewer considered better.

Examining the factor loadings in Table 8 and the correlations between criteria and demographic characteristics in Table 7, it is heartening to note that the five most important criteria according to their loadings are also the five criteria which correlated with the demographic variables. Thus, those things which are important are predictable.

The unrotated or general factor, loadings for which are presented in Table 8, weights each criterion against every other criterion and thus provides information regarding the relative importance of each criterion. In the definitions of criteria, however, different types of criteria were identified. Whether or not such types of criteria "hang together" mathematically can be determined by rotating the factor matrix. Rotating the matrix is a technique which maximizes loadings on one group of variables while minimizing loadings on another.

Two factors emerged from the rotated matrix. The first we will call a work factor, and the second an evaluation-adjustment factor. Loadings for the criteria are presented in order of importance for these two factors in Table 9.

Note that the heaviest loadings on these two factors are considerably higher than are the heaviest loadings on the general factor. Similarly, the lightest loadings are much lower, many of them nonexistent. Note also that those two factors are relatively independent. That is, those variables loading heavily on one factor load lightly on the other factor.

An examination of the loadings justifies the names of these two factors. For the work factor, the two strongest work variables, diving time and number of sorties, have near maximum loadings. Number of human-performance tasks completed and change in diving time, the other two work variables, are among the top five variables. Only two nonwork criteria, outside telephone calls and leader rating, have even modest loadings. The other factor, evaluation-adjustment, shows the opposite pattern. Teammate choice and leader ratings, evaluations by others, are the top two variables. The only other loadings of any consequence are on two adjustment criteria, outside telephone calls and meal satisfaction. None of the work criteria have appreciable loadings on this factor.

Correlations Between Factor Scores and Values

Correlations between the three factor scores and the six Allport-Vernon-Lindzey values are presented in Table 10. Correlations for the group as a whole are at the top of the table, followed by the civilian and Navy subgroups.

Table 9
LOADINGS OF CRITERION VARIABLES ON WORK AND EVALUATION-ADJUSTMENT FACTOR

Work Factor		Evaluation-Adjustment Factor	
Variable	Loading	Variable	Loading
Diving Time	0.91	Teammate Choice	0.81
Number of Sorties	0.88	Leader Rating	0.76
Outside Telephone Calls	0.50	Meal Satisfaction	0.52
Change in Diving Time	0.39	Outside Telephone Calls	0.45
Human Performance Tasks	0.38	Number of Sorties	0.20
Leader Rating	0.38	Human Performance Tasks	0.18
Up During Night	0.14	Diving Time	0.02
Teammate Choice	0.07	Quality of Sleep	0.00
Meal Satisfaction	0.00	Up During Night	-0.03
Quality of Sleep	-0.05	Change in Diving Time	-0.39

Table 10
CORRELATIONS BETWEEN FACTOR SCORES AND ALLPORT-VERNON-LINDZEY VALUES — ALL AQUANAUTS

Sealab Personnel	Factors	Values					
		Theoretical	Economic	Aesthetic	Social	Political	Religious
All	General	0.03	-0.06	-0.01	0.02	0.03	-0.10
	Work	0.04	0.21	-0.14	-0.06	0.20	-0.17
	Evaluation-Adjustment	-0.11	-0.09	0.10	-0.07	0.06	-0.10
Civilian $\underline{N} = 10$	General	0.09	0.35	0.07	-0.47	0.03	-0.02
	Work	0.04	0.26	0.26	-0.52	0.25	-0.15
	Evaluation-Adjustment	0.15	0.75†	-0.71†	-0.47	0.25	0.09
Navy $\underline{N} = 18$	General	0.31	-0.12	0.06	0.17	-0.01	-0.32
	Work	-0.03	0.21	-0.31	0.20	0.19	-0.16
	Evaluation-Adjustment	0.45†	-0.39*	0.42*	-0.04	-0.03	-0.38

*Slightly correlated $\underline{p} < 0.10$.
†Moderately correlated $\underline{p} < 0.05$.

For the group as a whole there are no significant correlations between factor scores and basic values. This was the case for individual criteria as well. There are, however, several correlations between factor scores and values for the civilian and Navy subgroups, and the correlations present an interesting pattern.

On two of the values, economic and aesthetic, there were significant correlations with the same factor score, the evaluation-adjustment factor, for the two groups, Moreover, these correlations were in the opposite direction for the two subgroups. Scores on the theoretical scale were correlated positively on the evaluation-adjustment criteria for the Navy divers. At a minimum the pattern of these correlations supports the view that Navy and civilian divers entered Sealab with different goals. It is possible to speculate further on how these different goals might have affected performance and adjustment in Sealab.

The correlations in Table 10 imply that the closer a man in one subgroup was to the mean value of men in the other subgroup, the better his performance or adjustment in Sealab was likely to be. For example, the Navy subgroup had a higher mean value on the economic scale than did the civilian group, and civilian divers seemed to fare better if they were more similar to the Navy divers on economic values. The same is true of aesthetic values, with the signs reversed. That is, high aesthetic values predicted favorable adjustment for Navy divers, while the opposite was true for civilian divers.

The correlation between scores on the theoretical value scale and the evaluation-adjustment factor for Navy divers is also of interest, even though there were no similar correlations for the civilian divers. It is not surprising that scores on this value were extremely high for the civilian divers, since they were scientists, and the scale is intended to measure theoretical or scientific value orientations. Even though the mean value for the Navy divers as a group was significantly lower than that of the civilians on the theoretical scale, this value was still the highest of all six values for the Navy divers. In other words, the Navy divers were very high on scientific values for a group of nonscientists. Furthermore, those with the highest scientific value scores rated higher on the evaluation-adjustment factor.

Information from the debrief interviews illustrates the way in which a high theoretical orientation may have operated to produce intragroup harmony. Marine life around Sealab was a constant source of amusement and diversion. Many of the men spent hours observing fish through the portholes. Some of the scientists were engaged in taking a marine-life census and observing fish behavior. In the debrief interviews, one of the marine biologists spoke enthusiastically of the ability of one of the Navy divers to see and identify fish, saying, "I trained him on observing fish and he got so he could spot them before I could." This same Navy diver also commented spontaneously and favorably on his work as an amateur marine biologist. Thus, this shared interest appeared to have provided a bond between these two men which acted favorably on their performance and adjustment.

Can these men be characterized in more meaningful terms than correlations and mean values? While it is in a sense simplistic and misleading to do so, an attempt to identify the value patterns associated with better adjustment for civilian and Navy aquanauts may serve to illustrate how the Study of Values can be used. It would appear in general that the Navy divers fared better in Sealab if they had high scientific interests enabling them to appreciate and understand the goals of their scientific colleagues; if their aesthetic orientation enabled them to enjoy fully the wonder and beauty of the unique aesthetic experience provided by Sealab; and if economic values did not loom too large in their outlook on life. Conversely, it seems that the civilian scientists fared better if they were more down to earth, since better adjustment for civilians was correlated with lower aesthetic values and higher economic values. This analysis may represent a very complex way of saying that people get along better if they understand the other fellow's point of view. However, it is important to know the areas in which shared values, as measured by these scales, produce this understanding. The results of this study hopefully represent a step toward such knowledge.

Factor Scores and Demographic Variables

In Table 11 correlations between factor scores and demographic variables are presented. Table 11 also includes a nondemographic variable, Teammate Choice - Pre, which is the

Table 11
CORRELATIONS BETWEEN FACTOR SCORES AND DEMOGRAPHIC VARIABLES—ALL AQUANAUTS

Sealab Personnel	Factors	Demographic Variables						
		Age	Diving Experience	Education	Birth Order	Family Mobility	Town Size	Teammate Choice-Pre
All	General	0.26	0.18	-0.20	0.47†	-0.17	-0.48‡	0.44†
	Work	0.00	0.10	-0.17	0.51‡	-0.31	-0.38†	0.07
	Evaluation-Adjustment	0.55‡	0.23	-0.16	0.27	0.22	-0.27	0.64‡
Civilian N = 10	General	-0.13	-0.02	-0.14	0.46	-0.51	-0.42	0.27
	Work	-0.08	0.07	0.01	0.45	-0.52	-0.05	0.05
	Evaluation-Adjustment	0.28	-0.28	-0.66†	0.60*	0.42	-0.46	0.83‡
Navy N = 18	General	0.37	0.16	-0.16	0.50†	-0.11	-0.53†	0.44*
	Work	0.09	0.14	-0.45	0.45*	-0.19	-0.57†	0.10
	Evaluation-Adjustment	0.61‡	0.26	0.10	0.17	0.07	0.21	0.59‡

*Slightly correlated $p < 0.10$.
†Moderately correlated $p < 0.05$.
‡Highly correlated $p < 0.01$.

number of times each man was named as a preferred teammate by the other 27 aquanauts before entering Sealab.

A comparison of Tables 10 and 11 indicates that basic values and demographic variables predicted different aspects of behavior in Sealab. In general, the Allport-Vernon-Lindzey values tended to correlate with the evaluation-adjustment factor, but not with the work and general factors. On the other hand, the demographic variables correlate with the general and work factors, but not with the evaluation-adjustment factor. Results on Table 11 also reveal that there are no reversals of correlations between demographic variables and criterion factors for civilian and Navy subgroups. There were reversals in the case of basic values. This means that demographic variables tended to predict similarly regardless of subgroup. The low occurrence of significant correlations in the civilian subgroup for demographic variables is probably due to the small number of cases, since most of the demographic variables which are correlated for the whole group and for the Navy subgroup also have sizable, though non-significant, correlations for the civilian group.

Navy and Civilian Difference

Since the analyses in Tables 10 and 11 are broken down by Navy and civilian subgroups, it may be of interest to examine some of the differences between the two groups. On the criterion-factor scores, there were no differences; that is, the Navy and civilian groups performed and adapted equally well, according to the three criterion-factor scores. There were small differences on two of the separate criteria, teammate choice and meal satisfaction. The Navy divers

reported slightly greater satisfaction with the meals and were chosen more frequently as teammates. Choice as teammates is probably due to the fact that Navy divers tended to choose their colleagues rather than civilians, although this was by no means unanimous. There were numerous choices across groups. Navy divers being chosen somewhat more frequently could also have been due to the fact that, as a group, they were older and more experienced as divers. In any case, the differences were slight. There were no differences on any of the work criteria, and for practical purposes the groups can be considered equal.

SUMMARY OF SEALAB II STUDIES

Since the foregoing discussion is somewhat lengthy and involved, it may be best to review the results before discussing how the information obtained in this study might be used in a selection program for future aquanauts.

Ten criterion variables measuring performance and adjustment were used. Four of these, the work variables, were number of sorties, diving time, number of human performance tasks done, and change in diving time from week one to week two. Four of the criteria are called measures of adjustment. They are satisfaction with meals, quality of sleep, number of times up during the night, and number of outside telephone calls. The first three of these variables are based on self-reports, while the last is an objective record. Two other variables were ratings by the team leader and choice as a teammate. A factor analysis of the ten variables resulted in three criterion factors which were labeled the general factor, the work factor, and the adjustment-evaluation factor. All ten criteria contributed in varying amounts to a score on the general factor. On the work factor, the four work variables and outside telephone calls made large or moderate contributions. For the evaluation-adjustment factor, leader rating, teammate choice, meal satisfaction, and outside telephone calls were the significant components.

The ten criterion variables and the three factor scores were correlated with six demographic variables and six values from the Allport-Vernon-Lindzey Study of Values. The demographic variables were age, diving experience, education, birth order, family mobility, and size of home town. In addition, a pre-experiment measure of teammate choice was correlated with the factor scores.

Results of the correlation matrices indicate that men who performed better in or adapted better to the Sealab environment tended to be older and more experienced divers. They were more likely to have been later born rather than first, and to have been raised in a small town and moved less often during childhood. Among the Navy divers, a man tended to fare better if he had relatively high theoretical interests, relatively lower economic values, and higher aesthetic values as measured by the Allport-Vernon-Lindzey Study of Values. Among the civilian divers, better performance and adaptation was associated with relatively higher economic values, lower aesthetic falues, and less education.

A SELECTION PROGRAM FOR AQUANAUTS

It would be extremely naive to suggest that the results of the research reported here be the sole basis of selecting future aquanauts. By using these predictors alone, one could doubtless select an excellent team of aquanauts. However, there are at least three good reasons why these predictors should not be used by themselves. First, it might be difficult to find men who met all or even most of the qualifications specified. Second, many well-qualified and potentially successful men would doubtless be eliminated from consideration. And, third, better predictors may be available. The value of these predictors is that they are based on experience. Because of their basis in real life they are invaluable and unique. The information gained from this study could not be duplicated anywhere, and characteristics of men who performed best in Sealab can contribute greatly to future selection. The question is, how can they and should they be used?

The selection criteria developed here may best be used in a seven-point program of selection. (Seven points are used merely to assist in presenting an outline of a selection program.

Experience may show that either more or fewer steps are necessary.) The steps recommended in the order of their application are:

1. A call for volunteers
2. An assessment of the training and experience of each volunteer
3. Standardized ratings of the man by instructors and supervisors
4. Similar ratings by his peers
5. Use of the present criteria
6. A physical examination
7. Selection during training

It should be pointed out that all factors in selection outlined above, except the present criteria, and peer ratings, were probably used, albeit informally, in selecting the team for Sealab II. By this it is meant that, since the candidates were selected on the basis of personal knowledge of leaders of the program, it is assumed that reputation and past record played the major role in selection. For future operations involving potentially large numbers of men, personal acquaintance may not suffice. Therefore an attempt to standardize, formalize, and evaluate selection procedures should be the aim of a future selection program. Let us examine each of the above steps.

Call for Volunteers

It may be self-evident that men taking part in a hazardous or specialized program will be volunteers. Nevertheless, the fact that they are volunteers can play an important role in selection. Careful attention should be given to a complete and realistic portrayal of the opportunities and dangers involved to insure the recruitment of informed and properly motivated candidates.

Assessment Based on Training and Experience

Presumably men applying as aquanauts will have had some training as divers, although it is possible that this may not always be the case. Assuming that the applicant has attended diving school, the level of his training and his grades should be considered as factors in selection. Conduct and proficiency ratings should be considered, particularly when they comment on a man's work as a diver. However, the validity of this information should be examined carefully for two reasons. First, proficiency ratings may be based largely on work having little to do with diving. Second, the most successful aquanauts may not necessarily be men who have the best conduct reports. This mildly heretical suggestion is supported by the lack of correlation between measures of both juvenile and adult misconduct and performance in Sealab II. It is quite possible that excellent aquanauts may be found among the ranks of those who occasionally "kick over the traces." Some men volunteering for a program like Sealab may crave excitement and adventure and thus may have some minor blemishes on their conduct records. The lack of correlation between measures of misconduct and performance in Sealab does not mean that men should be selected who have been in trouble occasionally; rather, it means that information concerning misconduct may be of no use as a selection factor.

Ratings by Instructors and Supervisors

In addition to assessing a man's past performance, specific ratings of his work as a diver by those who have supervised him in this work should be useful in selection. Letters of recommendation are notoriously biased toward favorable comments. In its highly successful selection program, the Peace Corps has developed an apparently useful correction for such biases.

Letters of recommendation are requested of three persons for all Peace Corps volunteers. The recommenders are informed in detail of the type of qualifications necessary and of the importance to himself and others of the applicant's possessing these qualifications. In addition, the persons making recommendations are informed that no single negative or lukewarm endorsement will be definitive in assessing an applicant's fitness. This provision lets the rater know that he alone cannot disqualify an applicant. Similarly it protects the applicant from the biased viewpoint of a single person rating him. Peace Corps selection officials feel that this assurance has resulted in unusually candid appraisals of volunteers. Some variant of this technique might increase the validity of ratings for man-in-the-sea volunteers.

Ratings by Peers

For a diver, confidence in his buddy is of great importance. It would seem that the most valid source of information bearing on his qualifications as a diving partner would be a man's diving buddies. Care will be required to develop a useful measure of buddies' reactions, but the information provided by such a measure is of sufficient potential to warrant an expenditure of time and effort in its development.

Sealab II Criteria

The above types of information can be combined with the predictive data available from research on Sealab II, and hopefully from similar ventures. All applicants should be asked to complete a battery of background information similar to that collected on Sealab II aquanauts. This background data can then be compared and combined with the other information available on a man. Details of the method of combining this information are beyond the scope of the present discussion, but it can be stated with confidence that an overall assessment of candidates will be possible. Ideally each man would be assigned a score placing him somewhere along a continuum of acceptability. According to the number of men needed, a cutting point is selected on the continuum, and those with scores above the cutting point are chosen as candidates. A physical examination can be the final step in this phase of the process.

Selection During Training

If the selection criteria are valid and the group of applicants is large enough so that marginal candidates do not have to be accepted, it is possible that no further selection will be necessary. However, no selection system will guarantee that every applicant will be completely successful. Thus selection should continue through the training period. For economic reasons, and to spare volunteers embarrassment and disappointment, elimination during training should be used infrequently. A good pretraining selection program is the best method of insuring low rejection rates during training.

In summary, valuable selection criteria have been developed from this study of the Sealab II aquanauts. An attempt has been made to identify other selection criteria which may have been used to select the Sealab team from the available manpower pool and to indicate how the use of this information can be formalized and standardized so that future selection will not have to depend on personal acquaintance. Whatever selection criteria are used should be checked against experience by methods similar to those used in the Sealab II study. The goal should be to predict future behavior, performance, and adaptation in undersea dwellings, from past behavior.

The process of selection should be conceived of as being open ended. That is, it is a process in which new information, based on research and experience, is combined with previously acquired knowledge in a developing program. The program should be open ended for at least two reasons. First, the science of selection is so young there is always room for improvement. Second, requirements may change in any of a number of ways. If man is to invade and inhabit the continental shelf for increasingly diverse reasons and in increasing numbers, different skills will be required of team members. As he learns more of the economic, scientific, and military potential of undersea habitation, new ways of organizing teams may prove necessary or desirable. Continued observation and study of men and teams will help to make operations safer and more rewarding personally, and will increase economic efficiency.

Section III
MAN-IN-THE-SEA PROGRAMS

Chapter 28

PHYSIOLOGICAL STUDIES IN SEALAB II

G. F. Bond
U. S. Navy Special Projects Office
Washington, D. C.

Although Sealab II was not designed to yield a large amount of physiological data, it was nevertheless considered prudent to pursue a course of selective monitoring of personnel of each of the three teams for overall safety of the operation. Previous meticulous physiological studies, conducted through the Genesis series,* and subsequently in Sealab I, had indicated that the great majority of physiological parameters examined would show no significant change under conditions of high pressure and exotic gas mixtures. It was therefore considered adequate to monitor only those vital functions of our human subjects which might assist topside control in medical management of the experiment.

In consequence, the number of physiological tests performed in Sealab II was severely curtailed, and the selection of monitored subjects was likewise limited. A program was established to provide for intensive physiological sampling from two or three aquanauts of the first two teams on a daily, alternate daily, then each-third-day basis. Sampling included extraction of about 20 cubic cemtimeters of blood daily for topside analysis, with appropriate quantities of urine and saliva for additional inspection. In addition, the majority of aquanaut personnel participated in daily studies of pulmonary function, electrocardiographic recordings, body-temperature control, exercise tolerance, and a number of routine physical tests.

By and large, the results of tests on selected subjects in the three teams of Sealab II were essentially negative. All of the classical blood chemistries which were performed fell easily within the normal ranges during the experiment. These tests included blood sugars, blood urea nitrogen determinations, creatinines, all serum electrolytes, and calcium and phosphorus values and ratios. Blood morphological values were likewise followed on a regular basis, with no evident deviation from the normal pattern. Urine specimens remained generally within acceptable limits, considering the problems of accurate collection and analysis.

Nevertheless, the following chapters will show, there were suggestive trends in certain areas which will warrant further intensive investigation under controlled laboratory conditions, and with considerable refinement of techniques. For example, the red-blood-cell count of the subject (MSC) who was exposed for 30 days of continuous stay to partial pressures in excess of 200 mm Hg of oxygen, showed a linear decrease in red-cell count, although no evidence of cell destruction could be demonstrated. Likewise, most of the "Stress" enzymes and other indicators of stress were clearly elevated during the first three to five days of hyperbaric exposure-indicative of some initial problems which require further investigation.

During Sealab II, attention was particularly directed to examination of the "stress enzymes," since these indicators, together with the corticosteroid determinations, had demonstrated greatest liability during past human exposures. As will be seen in the following chapters, these data give provocative evidence of an increased stress effect on the aquanaut subjects during the first three-to-five-day period of undersea exposure, with a slow return to normal values. Of the

*Extreme pressure-chamber studies by Capt George Bond at the Submarine Medical Center New London, Connecticut which demonstrated that men could live in an artificial helium-oxygen atmosphere at a simulated depth of 200 ft for prolonged periods and not realize any harmful effects.

eight blood stress factors examined, LDH (lactic dehydrogenase) provoked greatest interest, since values for this enzyme are generally considered to be proportional to a degree of tissue damage. Unfortunately, advanced stratifying techniques could not be utilized with the limited facilities of Sealab II; hence, the particular organ responsible for the observed LDH overproduction could not be pinpointed. It would appear that stress indicators are probably the most sensitive physiological warning signals available to topside monitors, and this fact will be suitably exploited in future undersea experiments.

In summary, it would appear that two important physiological observations are evident. First, almost all physiological functions demonstrate a sharp deviation from baseline values during the first three to five days of exposure in all Sealab experiments. Secondly, the accepted indicators of physiological/psychological stress are generally elevated during the first few days of exposure. These two provocative observations indicate an urgent need for additional research in this area.

Chapter 29

THE TELEMETERING OF HUMAN SUBJECTS AND ANIMALS UNDER WATER

Samuel Bellet, Allan Slater, and David Kilpatrick
Philadelphia General Hospital
Philadelphia, Pennsylvania

INTRODUCTION

To obtain information relative to the interaction of cardiac response to under water working tasks and swimming, acoustic underwater telemetering of EKG* signals from the swimmer to the habitat and hard wire transmission to the staging vessel was experimentally performed in Sealab II operations. Success was achieved in obtaining a limited number of electrocardiograms. A number of technical difficulties were revealed, as well as possible solutions thereto.

Ultrasonic telemetry was selected as the method for transmitting information from the swimmer to the habitat. After studying a number of techniques of modulating an ultrasonic carrier, frequency modulation was chosen as the best method to transmit the data in the transmission medium (sea water). The factors considered were bandwidth, medium inhomogeneity effects, multipath propagation, and battery energy utilization.

The design of a sonic telemetry system is a relatively simple problem. The signal bandwidth of a few hundred cycles per second for cardiac electrical activity, for example, is so small that frequency modulation is compatible with the medium. The primary limitation of water as a communication medium is carrier bandwidth. This is due to the rapid increase of propagation attenuation with increasing frequency. A typical submarine voice communication system must heterodyne the voice signal to a higher but still audio frequency, and "transmit" single sideband in order to limit the carrier bandwidth to the same value as the signal, or about 3,000 cps. It is practical to utilize frequency modulation with a total deviation of less than 3,000 cps for a cardiac signal of 100 cps bandwidth. Frequency modulation has many advantages for the accurate transmission of information in a noisy medium.

BASIC SYSTEM

The complete data link can be broken down into four subsystems (Fig. 79). Electrodes pick up electrical signals induced by the heart in the chest wall. These signals are relayed to the transmitter, where they are converted to a frequency-modulated acoustical wave. This wave is propagated from the diver through the sea to the receiver and is processed to recover electrocardiographic information. Output from the receiver is recorded with a Sanborn recorder located in the Berkone staging vessel.

Electrode Details

Two types of electrodes have been used. All tests prior to delivery of the equipment to Sealab II used Beckman electrodes, while tests at Sealab II used both silver-silver chloride (Beckman) and tin (Sem-Jacobsen) electrodes. Electrode construction is shown in Fig. 80.

* Electrocardiogram.

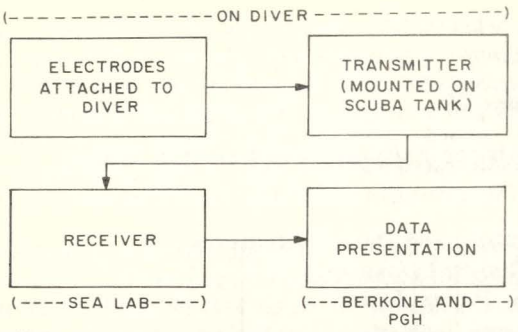


Fig. 79. Basic telemetry systems

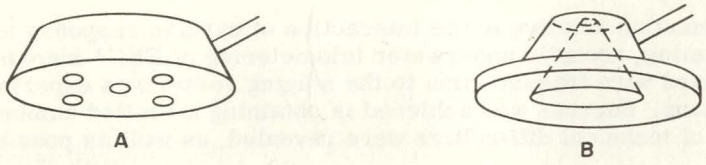


Fig. 80. Basic electrode construction; A - silver-silver chloride (Beckman) electrode, B - tin (Sem-Jacobsen) electrode

Both types of electrodes were attached to the chest with waterproof tape; the silver-silver chloride also employed double-backed tape washers and "Stomaseal Disks" to achieve water tightness. The tin leads (developed by Dr. Sem-Jacobsen) were simply taped to the chest or were glued on prior to going down into the Sealab habitat. Electrodes were placed as shown in Fig. 81.

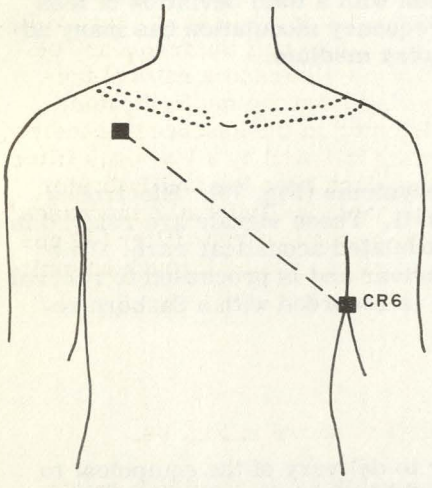


Fig. 81. Placement of electrodes on subject

Transmitter Details (Electrical)

The basic block diagram of the transmitter is shown in Fig. 82. Electrocardiographic signals from the electrodes drive the input preamplifier, which provides differential amplification of the signals from the two chest leads. Variations in signal levels induced by changing impedance of the skin at the electrode contacts is minimized by the 3.3-megohm input impedance. In addition, the preamplifier has a high value of common mode rejection and a large common mode voltage-handling capability to minimize requirements for good contact of the ground electrode.

Output from the preamplifier is capacitively coupled to a single-ended amplifier with a gain of 50. The amplifier output, in turn, is capacitively coupled to the base junctions of a multivibrator. Variations of the base voltages shift the frequency of oscillation of the multivibrator from its natural frequency of 25.0 kc/sec. Frequency shifts of approximately 250 cps per millivolt of EKG voltage at the electrodes are obtained. Output from the multivibrator drives a push-pull amplifier which drives the transducer. The resultant ultrasonic energy containing electrocardiographic information propagates through the water to the receiver.

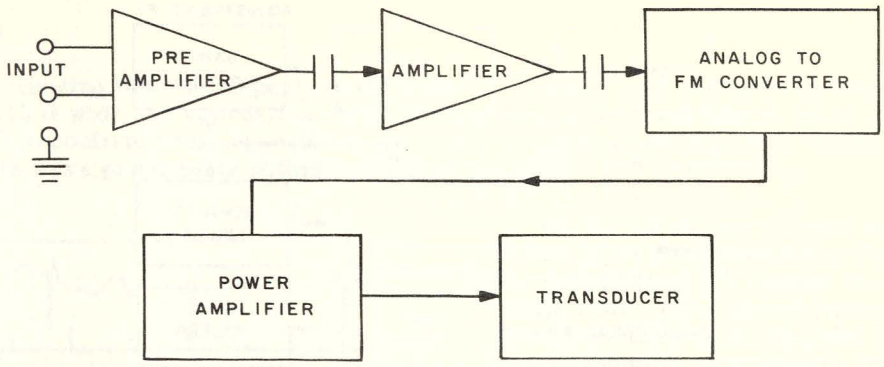


Fig. 82. Block diagram, basic transmitter

Transmitter Details (Mechanical)

The transmitter is housed in a 2-in.-diameter pipe with an overall length of 14 in. A single five-pin connector serves as the input for the three electrocardiographic leads and as the power switch. The transmitter turns on automatically whenever the electrocardiographic leads are plugged into the connector. About four hours of operation can be obtained from each battery set. Batteries can be reached by removing the instrument casing.

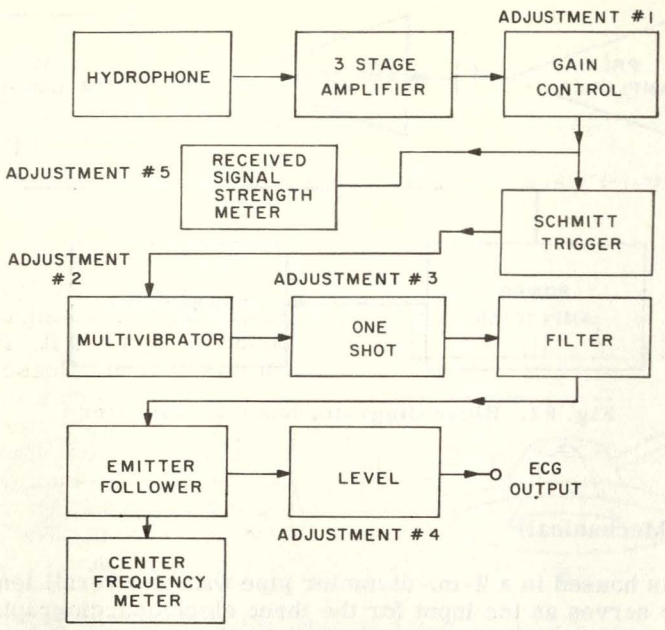
Receiver

A block diagram of the telemetry receiver is shown in Fig. 83. Acoustical energy from the water is converted into electrical energy by the receiving transducer. Signals from the transducer are amplified by a three-stage tuned amplifier with a center frequency of 25 kc/sec. Output from the tuned amplifier drives a variable-gain stage. Normally, the gain is set to maximum. However, when the diver is very close to the receiver, clearer signals can be obtained by reducing the gain setting. The sinusoidal signal from the variable-gain amplifier is converted to square-wave form by a Schmitt trigger, whose triggering level is set to zero volts. Output from the Schmitt trigger synchronizes a multivibrator to exactly half the frequency of the received signal. In the absence of a signal, the multivibrator oscillates at a natural frequency of 12.5 kc/sec. Therefore, there is always a signal coming from the multivibrator, which prevents excessive excursions of the output of the FM detector in the absence of received signal. FM detection is achieved with a monostable multivibrator followed by a low-pass filter. The monostable multivibrator generates a 40-microsecond pulse each time the multivibrator output swings positive. The average output level from the monostable multivibrator increases with received signal frequency. This average value is extracted by the low-pass filter (80 cps cutoff frequency) and is taken as the electrocardiographic output after passing through an emitter follower and gain control.

SEALAB INTERFACE

The system layout for the equipment as installed at Sealab II is shown in Fig. 84.

The hydrophone and receiver were placed within the Sealab habitat. As the diver swims in the water, the received electrocardiographic signals are relayed topside for immediate observation. Cables between Sealab and the Berkone were shared with a wedge spirometer. The signals were recorded in the medical van on a Sanborn recorder. Preparations for relay to Philadelphia via Bell Dataphone were also made.



ADJUSTMENT CHART

ADJ NO.	ADJUSTMENT PROCEDURE	LOCATION
1	ADJUST FOR CLEAR ECG	FRONT PANEL
2	ADJUST FOR TRIGGERING AT ZERO CROSSINGS OF MULTIVIBRATOR OUTPUT	REAR PANEL
3	ADJUST FOR ZERO ON FREQUENCY METER WHEN INPUT SIGNAL IS 25 KILOCYCLES	REAR PANEL
4	ADJUST FOR SUFFICIENT OUTPUT TO DRIVE DISPLAY DEVICE	REAR PANEL
5	ADJUST FOR PROPER INDICATION OF SIGNAL LEVEL	REAR PANEL

Fig. 83. Block diagram, receiver

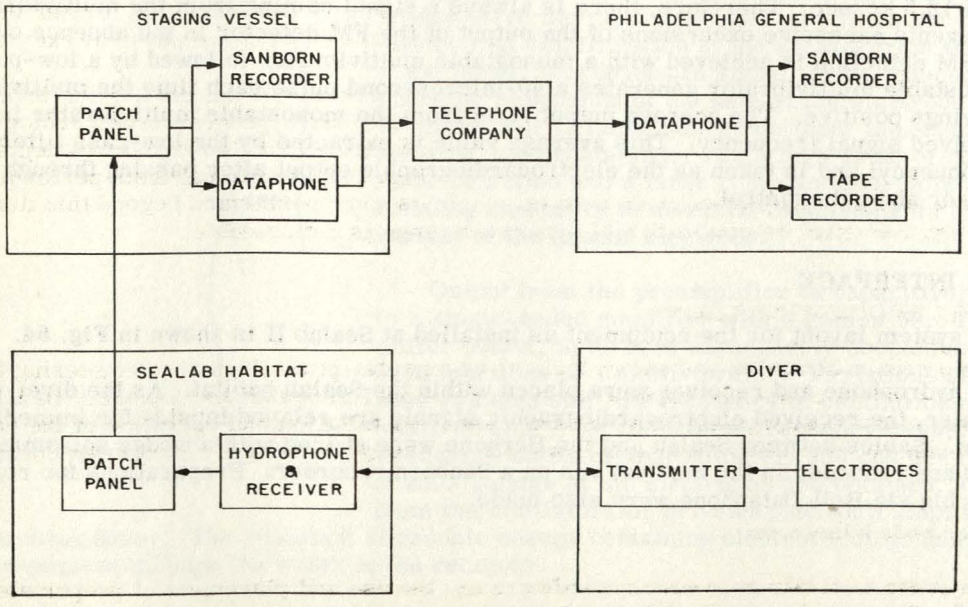


Fig. 84. Block diagram, complete telemetering system

RESULTS

The following tests were performed at the therapeutic pool at the Philadelphia General Hospital (13 ft wide and approximately 25 ft long) and at the local YMCA (pool is approximately 40 × 70 ft) to confirm basic operations capability of the system (Fig. 85). Tests indicated that all circuits were performing within specifications.

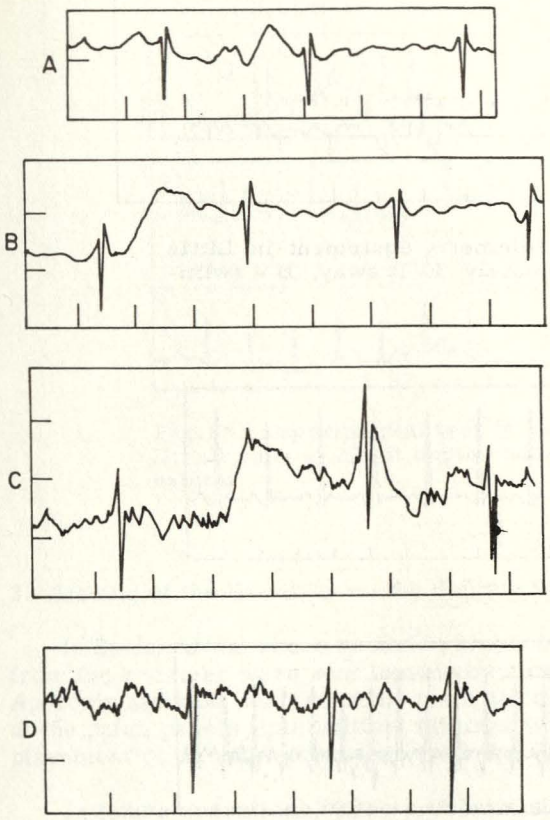


Fig. 85. Experimental tests of sonic telemetry equipment
A and B - in 15 × 25 ft pool
C and D - in 40 × 70 ft pool

A second series of tests were performed in the Little Magathey River (Maryland) to test the operation of the system in a large salt-water body. Good signals were obtained at distances up to 50 ft. Beyond that, range dropout was severe. Reasonable interpretation of range from this data is not possible due to the fact that the water conditions were not as expected; i.e., actual depth of the water was 3.0 ft, with much swamp grass which absorbed the signal. Figure 86 shows data obtained at a distance of 30 ft. The data at this time showed significant amounts of muscle tremor due to the fact that excessive exertion was needed to move through the vegetation. When the subject relaxed, significant improvement in the quality of the received signal was observed.

Data are also shown (Fig. 86) when the diver was at a distance of 60 ft from the recording appartus. Although the data showed significant amounts of dropout, heart-rate data were still available.

Final study of the equipment before delivery to Sealab was performed at the Aquarama in Philadelphia at a depth of 10 ft and a distance of 50 ft from the recording apparatus. Before entry to the water, a baseline air test was performed using the equipment. The results are shown in Fig. 87. Figure 87 shows data obtained at a distance of 20 ft after the diver had undertaken extreme physical exertion.

Tests with the first diving team have yielded high-quality electrocardiograms at distances up to 100 ft and at a depth of 220 ft (Fig. 88). Additional tests performed under similar conditions yielded similar results. No tests were performed beyond this distance; consequently, the exact determination of maximum range is not possible.

FUTURE RECOMMENDATIONS

Experience at Sealab has shown that the underwater physiological telemetering equipment requires too much time and experience from personnel in Sealab and topside. To alleviate this problem, a new design policy emphasizing ease of installation and operation of the equipment will be adhered to. The following factors will be studied to simplify equipment operation.

1. Electrode Placement

In order to obtain good electrocardiograms, the use and placement of proper electrodes is crucial. Personnel in the Sealab found that the Beckman electrodes required too much time to

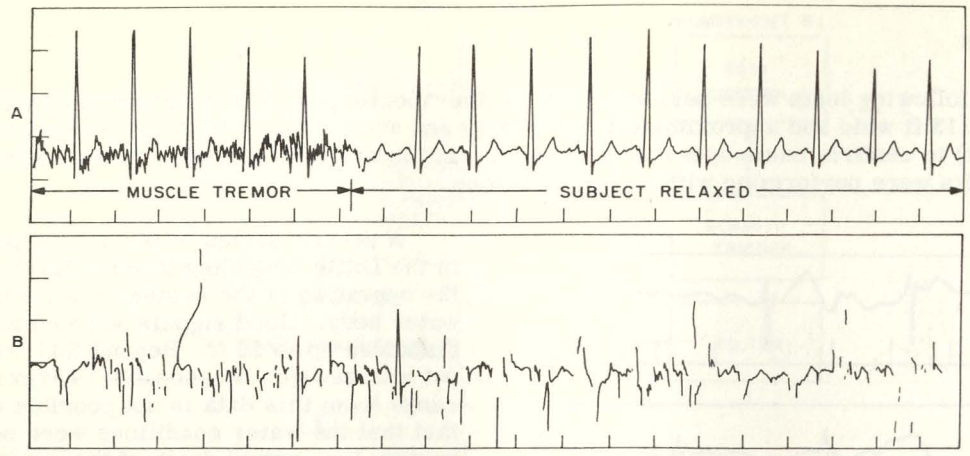


Fig. 86. Experimental test of sonic telemetry equipment in Little Magathy River, A - swimmer approximately 30 ft away, B - swimmer approximately 60 ft away

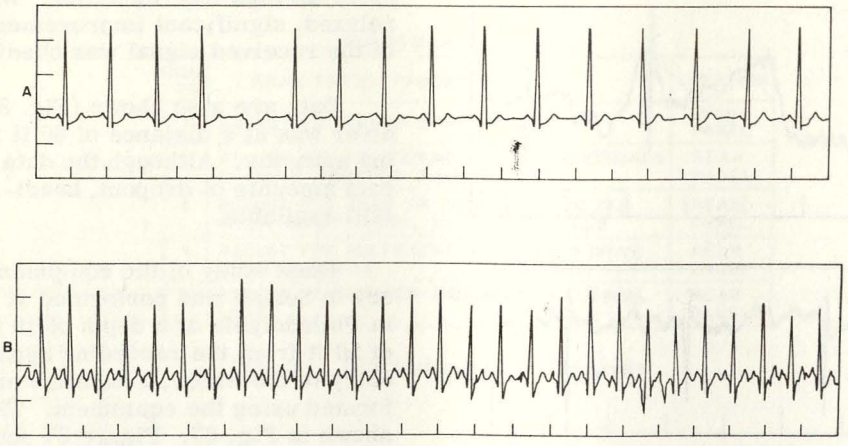


Fig. 87. Experimental test of sonic telemetry equipment at Philadelphia Aquarama, A - in air, B - in water at a range of 20 ft, after extreme physical exertion

put on; in addition, the procedure was too complicated. Consequently, the electrodes were often put on improperly, and signals with considerable extraneous noise were therefore obtained. Studies are being conducted to obtain a special electrode design optimized for use under a wet suit. For example, a thinner electrode that can be held in place by the pressure of the wet suit will be considered.

Recent studies at the Philadelphia General Hospital indicate that it will be possible to eliminate the third or ground lead entirely. If further analysis of the two-lead system proves successful, the time required to put leads on will be reduced by one-third by this factor alone. The goal will be to design effective electrodes that can be put on easily in a few minutes.

2. Simpler and Quicker Mounting to the Scuba-Tanks

In the equipment delivered to Sealab II, the transmitter was attached to the scuba tanks by two steel bands which were tightened in place by use of a screwdriver (Figures 89 and 90). It is an easy matter to redesign the mounting in the form of a snap-on type device that will allow attachment and removal of the transmitter in a few seconds without tools.

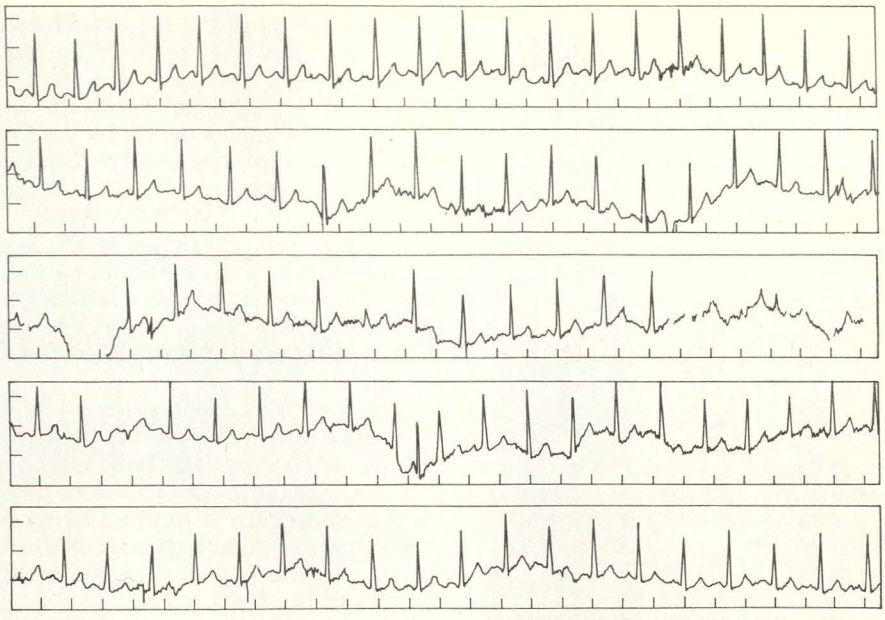


Fig. 88. Experimental test of sonic telemetry equipment during Sealab II; all runs at 220 ft depth and approximately 100 ft from the Sealab II habitat

3. Placing of the Receiver on the Staging Vessel

In Sealab II the receiver and hydrophone were placed in the Sealab habitat. The signals from the receiver were sent topside by a cable system which caused considerable difficulties. Approximately 50 percent of the tests attempted were aborted because of improper connections at the patch panels, intermittent failures in the connectors to these panels, and loss or misplacement of the cables between the receiver and the patch panels.

In future operations, these problems should be bypassed by placing the receiver on board the staging vessel. This procedure will eliminate the need for the entire patch-panel cable system (except as a backup) and will also save space in the Sealab habitat. This procedure will also eliminate the work required by the aquanauts of turning the receiver on and checking its operation, etc. (A second hydrophone placed on board Sealab and connected to the staging vessel by the patch panel will allow reception of signals for testing the gear prior to entry into the water.) This hydrophone will also serve as a backup in case difficulty is experienced with the other hydrophone.

4. Automatic Receiver and Recorder Operation

It is a simple matter to design a squelch circuit into the receiver that will automatically activate the recorder whenever signals are being received from the transmitter. In this mode of operation, the receiver can be left on all the time. When it is necessary to record data, the diver will merely have to enter the water. As soon as the receiver detects the incoming signal it will automatically activate the system and record the information, and it will also automatically turn off when the diver leaves the water. Provision for bypassing this mode of operation will be provided in the event that it does not function properly.

5. Future Telemetry Systems

The following parameters are candidates for the additional channels.

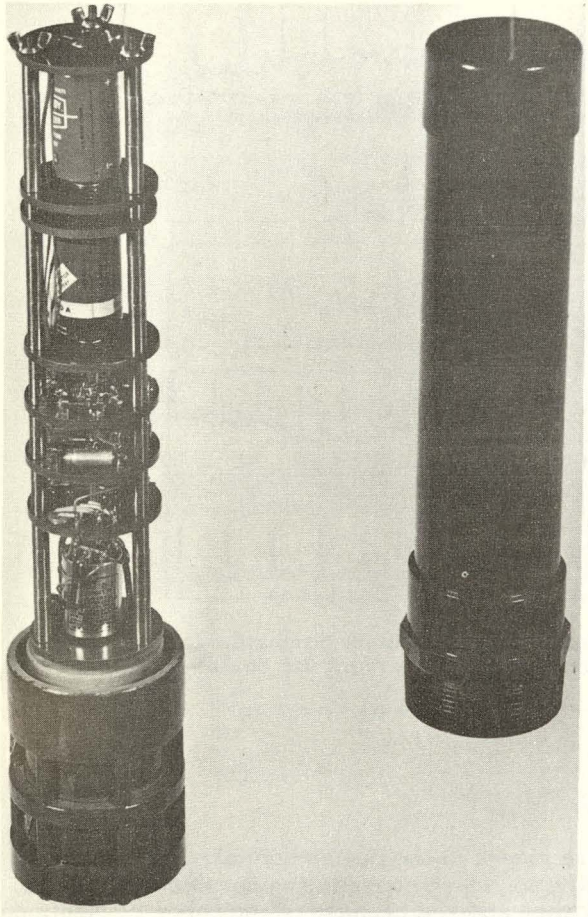


Fig. 89. Sonic transmitter with case removed

Body Temperature—Body-temperature data are of prime importance, since one of the limiting factors to man's performance in the sea is his ability to endure loss of body heat to the water. Telemetering of body-temperature data should greatly help in the evaluation of the various experimental heated wet suits.

Additional EKG Leads—It is well known in medical practice that more than one electrocardiogram is necessary to get a maximum amount of data from the heart. Additional leads will provide the necessary data.

Electroencephalograms—Telemetering of the EKG may be implemented in the telemetering system, since the bandwidth requirements for the EKG are actually less than the electrocardiogram. It would merely be necessary to provide a higher gain amplifier in the transmitter to compensate for the smaller signal levels of the EKG.

A Voice Channel—Addition of a voice channel will be very helpful in correlating the data received for the type of physical activity. In addition, the voice channel would also serve as an excellent means of communication between divers and personnel on Sealab. The bandwidth requirements for a voice channel are considerably greater than those of the EKG channel; consequently, the design of the voice channel might not be practical in view of our transmitter configuration. However, the great usefulness of the voice channel will make it worthwhile to investigate.

6. Extension of Transmitting Range and Improvement of Signal

In tests at Sealab to date, high-quality signals have been received at the maximum distance tested (100 ft through the water). Therefore, the range of the system in its present form is greater than 100 ft. However, significant improvements can be made in the efficiency of the final amplifier of the transmitter. In addition, low-noise transistors can be used in the front end of the receiver and the EKG preamplifier of the transmitter. Both of these changes should result in significant increases in range and reductions in the amount of noise in the received electrocardiogram.

7. Packaging

The design philosophy for packaging future equipment should be to allow for maximum flexibility of the equipment. For instance, all telemetry channels will be constructed as plug-ins to the basic transmitter. Several plug-ins will be constructed. The plug-in will be chosen to telemeter the data for a given mission. As an example of plug-in types, there will be a single-lead EKG plug-in which will give the same performance as the equipment used on Sealab II. The second type of plug-in will consist of four temperature channels. Another example would be a plug-in designed for one EKG and one EEG channel. The advantage of the plug-in system is that if one particular data type is unsuccessful, other plug-ins can be used so that the system will not be rendered useless.

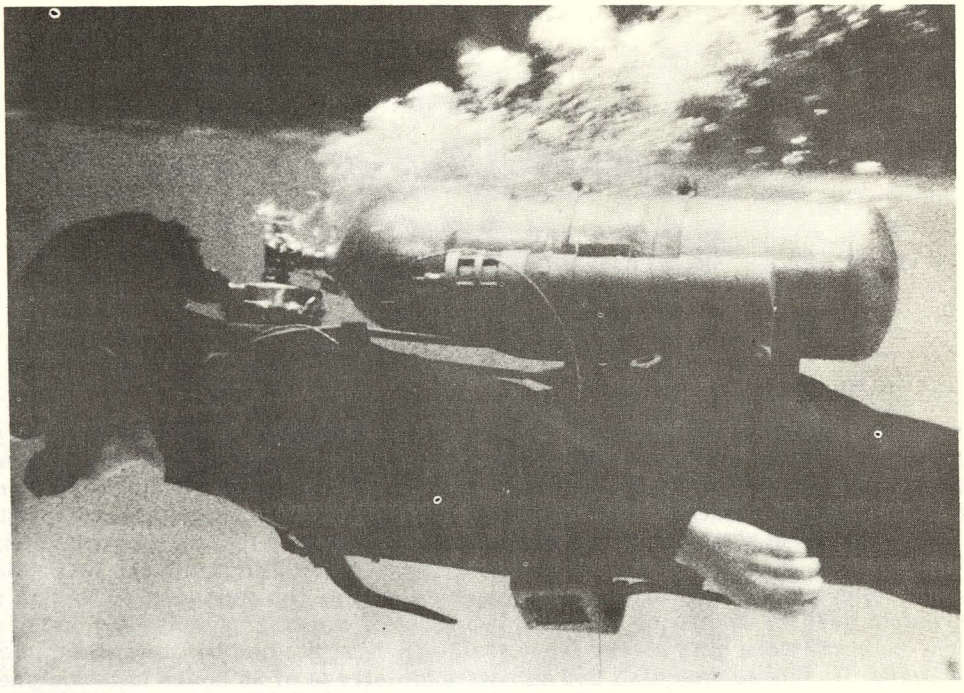


Fig. 90. Sonic transmitter in place on a swimmers scuba tanks

8. Backup Equipment

Accidental breakage of the telemetry transmitter and occasional loss of cables reduced the number of tests performed. In the future, several extra pairs of EKG leads, cables, and other support equipment should be provided.

Chapter 30

ADAPTATION TO ENVIRONMENTAL STRESS IN SEALAB II

Steven M. Horvath and Fred W. Kasch
Instiute of Environmental Stress
University of California
Santa Barbara, California

Responses of man to various natural environmental stresses can be evaluated by preliminary studies in simulated environments. Although the environment of Sealab II may not be considered as naturally occurring yet it is obvious that it soon may well be one in which men will have to live for extended periods. The combined stresses of cold water, high temperature and humidity, and work present a complex of environmental stresses that may best be studied at the site, but considerable insight into the effects of such a stressful situation can be obtained by appropriate studies conducted prior to and immediately after the exposure. The data being presented represent such an evaluation based on two tests of working capacity and one of cold exposure. The subjects were nine divers from Sealab II, first studied before and again after their 15 days in Sealab II. These men also had an additional stress of 36 hours of decompression.

Table 12
PHYSICAL CHARACTERISTICS OF SEALAB II SUBJECTS

Subject	Age (yr)	Height (cm)	Weight (kg)		Surface Area (M^2) (PRE)	Predicted Basal Metabolism (ml/min)
			Pre	Post		
MM	38	171	72.6	71.6	1.85	244
JL	35	165	70.3	70.4	1.76	232
RB	35	178	81.6	80.8	1.97	265
FJ	39	170	66.0	68.5	1.76	232
JR	36	181	81.6	78.8	2.03	268
WM	32	189	91.1	85.7	2.19	293
RS	28	194	109.8	106.3	2.40	327
WC	36	183	96.9	92.7	2.19	289
GI	37	176	97.1	99.9	2.13	280
Mean	35	179	85.2	83.8	2.03	270

These data are preliminary in nature, but they do suggest certain alterations in capacity to perform and indicate the need for additional studies of men exposed to environments such as present in Sealab II. Table 12 presents certain of the physical characteristics of the nine men studied. The first test was a modified maximal work-capacity test whose primary purpose was to determine the maximal oxygen uptake of these divers. The data presented in Table 13 indicated that these men have a level of maximum work capacity which was within the average range (for their age) of the values obtained by Astrand and Robinson. Two of the men were slightly (10 to 20 percent) below the average. No appreciable shift in maximum oxygen uptake was noted as a consequence of their exposure to Sealab II, although the absolute time the men could work was decreased in six subjects. A decrease in one subject was due to stoppage of his own volition, and a second subject was stopped because of some questions regarding his electrocardiogram. There are other evidences that these men during their post-test time had some decrease in their effective responses to a maximum work load (Table 14). The oxygen debt was greater and the level of blood lactates higher in the second test. Subjective evaluation

Table 13
RESPONSE TO MAXIMAL EXERCISE TEST OF SEALAB II SUBJECTS

Subject	Test Wt. Loss (kg)	Rectal Temp. Rise (°C)	Ex. Test Duration (min)	Maximal V_{O_2}		Max. Vent. (L/min)	Maximal H.R./min	R.Q. @ max.	160 Heart Rate Values			Recovery V_{O_2} m1/min/kg		Recovery H.R. (Beats/min)		Net O_2 Debt L/30'	Net O_2 Debt m1/kg/30'	Post Lactate (mg %)
				L/min	m1/min/kg				V_{O_2} (m1/min/kg)	Minutes	Vent. (L/min)	@ 1 min	@ 30 min	5 min	10 min			
Pre test																		
MM	0.430	–	21	3.308	45.4	99.34	205	1.12	24.8	11	37.00	–	6.2	140	130	14.295	160	50.0
JL	0.342	0.5	21	3.128	44.2	87.63	210	1.15	22.0	10	32.16	35.6	6.0	123	120	10.923	154	74.6
RR	0.298	0.5	19	3.426	43.1	85.01	189	0.93	36.5	13	46.76	–	5.5	118	104	10.647	134	94.0
FJ	0.315	0.1	19	2.933	43.9	60.35	182	0.87	32.5	13	45.76	–	–	134	128	13.129	196	74.3
JR	0.566	1.6	22	3.568	43.0	77.74	200	1.05	27.3	13	42.35	–	3.6	120	115	11.071	134	81.1
WM	0.285	2.1	20	3.998	44.0	83.13	195	1.01	28.8	14	60.20	–	5.9	131	120	10.062	111	72.6
RS	0.970	2.7	23	5.114	46.4	125.34	204	1.07	28.4	11	49.49	30.4	5.5	140	130	17.168	156	71.4
WC	0.493	4.0	19	3.804	40.4	92.10	213	0.95	27.0	9	41.45	–	5.4	171	150	11.426	122	75.3
GI	0.350	0.2	15	3.058	32.0	83.55	169	1.06	27.1	13	68.00	–	3.7	129	120	9.055	95	47.1
Post test																		
MM	0.225	1.9	20	3.548	47.4	95.13	200	–	17.8	9	30.69	36.1	6.7	149	136	12.338‡	172‡	119.0
JL	0.050	0.7	20	3.151	45.0	81.85	202	–	26.8	10	31.41	30.9	5.9	132	125	9.497	136	98.3
RR	0.267	–	21	3.790	46.6	106.76	192	–	29.5	14	50.26	26.3	–	116	116	9.883	122	79.4
FJ	–	–	19.75	3.000	44.3	81.10	190	–	30.3	12	44.62	23.6	–	137	122	15.461	228	121.9
JR	0.399	2.0	19.5	3.576	44.8	81.83	190	–	36.1	13	54.46	26.6	5.1	123	108	13.244	166	69.8
WM	0.315	0.6	17.2	3.660	42.6	92.21	201	–	25.2	9	49.79	27.1	6.3	142	126	11.049	129	104.1
RS	0.520	1.4	20	4.146*	38.5	101.61	182	–	31.7	14	73.53	26.8	4.4	102*	99*	10.325*	96*	48.6
WC	0.321	–	18	3.538†	38.4	87.80	205	–	21.8	9	38.17	23.9	5.2	163	142	12.474	135	89.0
GI	0.360	1.8	16.5	3.327	33.8	105.27	175	–	22.4	10	49.69	23.0	4.7	125	123	12.479	127	103.9

*Arbitrarily stopped at 20 minutes.
†Test terminated early by M.D. (ECG abnormality).
‡All oxygen values are STPD.

Table 14
BLOOD COMPONENTS BEFORE AND AFTER* EXERCISE TEST FOR MAXIMUM OXYGEN UPTAKE MEAN VALUES FROM 9 SUBJECTS†

Blood Fraction	Test I			Test II			Difference Control I & II
	Control	Post Exercise	Difference	Control	Post Exercise	Difference	
Hemoglobin (gm percent)	16.0	16.5	0.5	16.6	17.4	0.8	0.6
Hematocrit (percent)	47.8	49.7	1.9	50.4	52.6	2.2	2.6
Plasma Protein (gm percent)	7.57	8.26	0.7	7.64	8.00	0.4	0.07
Blood Glucose (mg percent)	103	137	34	112	127	15	9.0
Blood Lactate (mg percent)	17.3	71.2	53.9	16.5	98.2‡	81.7	-0.8
Blood Pyruvate (mg percent)	0.9	2.6	1.7	0.9	2.3	1.4	0.0
Plasma Sodium (mEg/L)	131.6	135.8	4.2	135.3	137.8	2.5	3.7
Plasma Potassium (mEg/L)	3.9	3.9	0.0	4.1	4.0	-0.1	0.2
Plasma Chloride (mEg/L)	103.5	104.8	1.3	105.6	106.9	1.3	2.1
Serum SGOT (units)	9	10	1	10	11	1	1

*All bloods obtained four minutes following cessation of test.
†The first test was made prior to entering Sealab II, while the second test was performed two days after 15 days in Sealab and 36 hours of decompression.
‡Eight subjects - one eliminated due to failure to complete test.

of the subjects by observers indicated that these test subjects had greater evidence of fatigue than was noted on their first test. Again it should be noted that full evaluation of this data has not been made and that these statements are preliminary.

The study made on steady-state work (Table 15) also reflects the general statements made above. This impression is verified by the greater number of men (4) who could not complete the test the second time. Again, final decision will be made after analysis of the data is completed.

The cold-exposure test consisted of a two-hour exposure to an ambient temperature of 7°C. The subjects wore shorts and were lying on a nylon mesh cot during the test. Temperature and metabolism measurements offered opportunity for a rather complex analysis of thermal stress. Figures 91, 92 and 93 present a preliminary analysis of this data. The data found in Fig. 93 suggested an alteration in their responses to cold stress. The men were able to increase their metabolic levels, with a consequent diminution in loss of body-heat content. The reasons for this alteration can not be determined until the data analysis is completed. One problem, not clearly identifiable, was the major loss (mean 2 kg) of body weight by the subjects between their two visits to this laboratory.

In brief, there was a suggestion based on the data obtained that some alteration in physiological function occurred in men living under the conditions present in Sealab II. Definitive statements on these patterns will not be available until these and other data have been subjected to final analysis.

Table 15
STEADY-STATE TEST OF SEALAB II SUBJECTS

Subject	Resting Heart Rate	Light work load (600 kg)				Moderate work load (900 kg)					Heavy work load (1200 kg)				Test Wt. Loss (kg)	Rectal Temp. (°F)	
		Duration (min)	V_{O_2} * (L/min)	Vent. (L/min)	Heart Rate	Duration (min)	V_{O_2} * (L/min)	Vent. (L/min)	Heart Rate	Collection Time	V_{O_2} * (L/min)	Vent. (L/min)	Heart Rate	Collection Time		Pre	Post
Pre test																	
MM	105	30	1.934	35.6	148	30	1.958	39.0	179	15	1.799	49.0	187	25	0.289	100.9	102.9
JL	68	30	1.564	33.8	127	8	‡	‡	160	8†	–	–	–	–	0.450	98.8	100.6
RB	82	30	1.779	37.3	132	23	1.805	42.2	168	15	1.966	46.0	165	21	0.550	99.5	100.4
FJ	86	30	1.351	28.0	115	30	2.003	41.3	145	12	1.878	46.4	159	25	0.690	100.8	101.7
JR	85	30	1.716	34.2	135	30	2.433	49.3	177	15	2.381	52.7	185	25	0.575	98.9	101.6
WM	74	30	1.475	33.0	129	30	2.212	50.1	150	15	2.002	52.2	170	27.5	0.670	98.4	100.2
RS	85	30	0.856	16.7	123	30	1.569	30.3	143	15	1.850	36.0	150	30	1.480	98.4	102.4
WC	108	30	1.408	32.8	144	22	1.820	47.1	180	15	–	39.2	186	20	0.670	99.5	–
GI	62	30	1.637	29.3	98	30	2.452	50.5	135	17	2.328	50.2	144	23	0.450	98.4	101.6
Post test																	
MM	107	30	1.413	23.6	147	30	2.079	43.7	170	15	2.271	43.9	173	25	0.528	99.7	101.2
JL	85	30	1.472	29.0	152	5	2.321	43.3	162	5†	–	–	–	–	–	99.0	99.4
RB	90	30	1.171	24.4	144	15	1.765	39.8	168	14	–	–	–	–	–	99.2	100.9
FJ	88	30	1.160	25.9	115	30	1.313	30.3	137	15	1.672	35.2	148	25	0.375	100.2	102.0
JR	94	30	1.415	31.2	128	30	1.960	43.7	160	15	2.104	48.2	160	25	0.655	99.4	102.0
WM	101	30	2.358	52.8	160	25	2.432	66.6	186	15	2.416	70.8	195	25	0.496	98.1	101.0
RS	66	30	1.494	33.2	102	30	2.173	45.5	123	15	2.257	47.7	138	25	0.364	97.8	99.6
WC	123	30	1.470	29.2	134	30	2.109	47.5	175	15	2.109	49.5	184	25	0.361	99.2	100.6
GI	89	30	–	–	112	30	–	–	139	15	–	–	149	25	0.818	99.6	100.4

*All oxygen values are STPD.
†Work load of 1200 kg.
‡Stopped due to leg cramps.

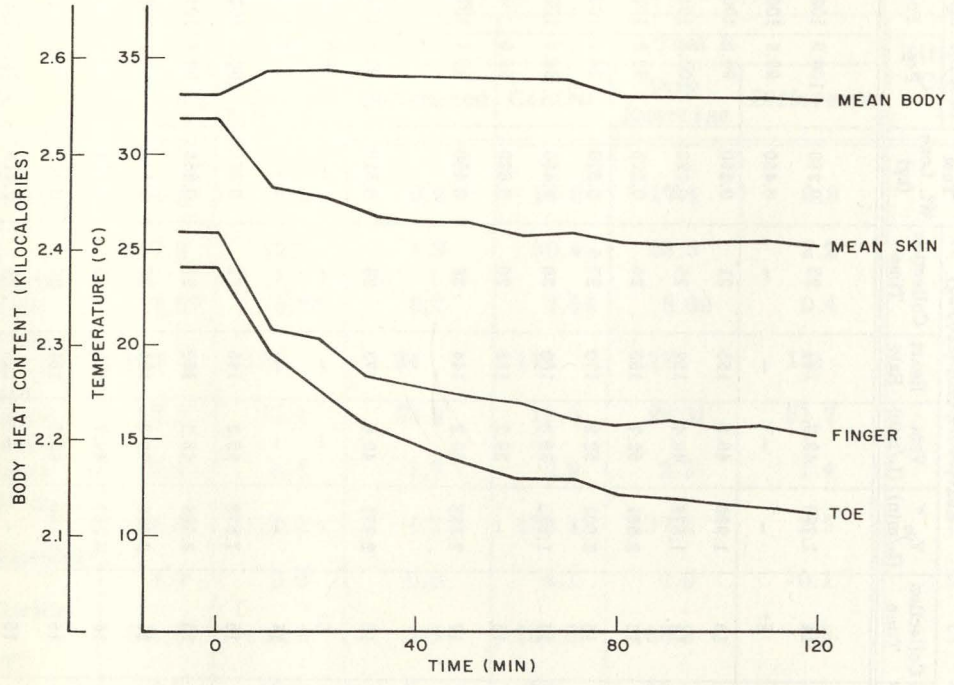


Fig. 91. Predive cold exposure tests, cold response

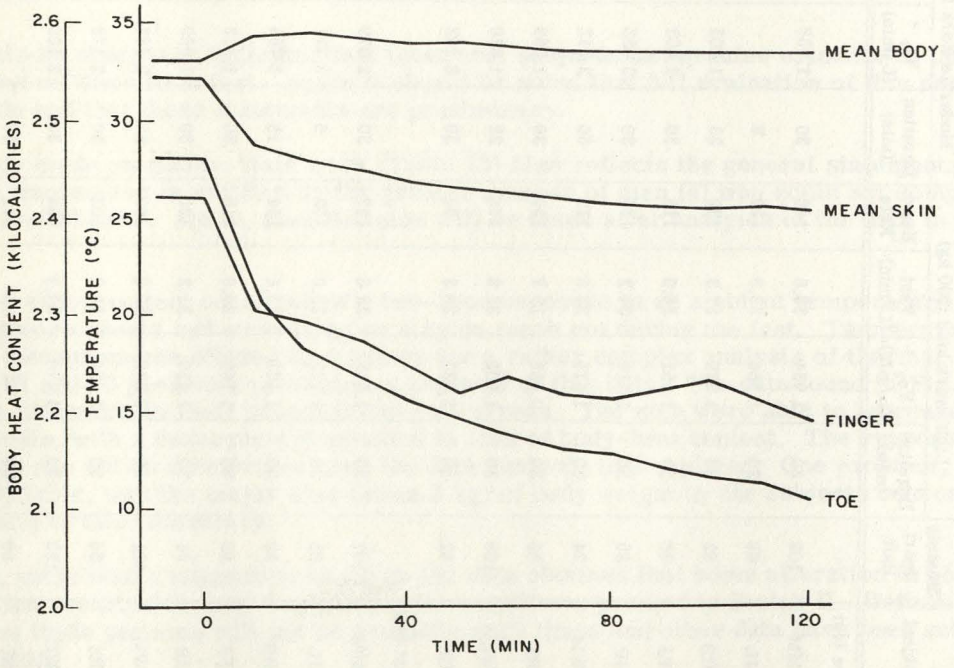


Fig. 92. Postdive cold exposure tests, cold response

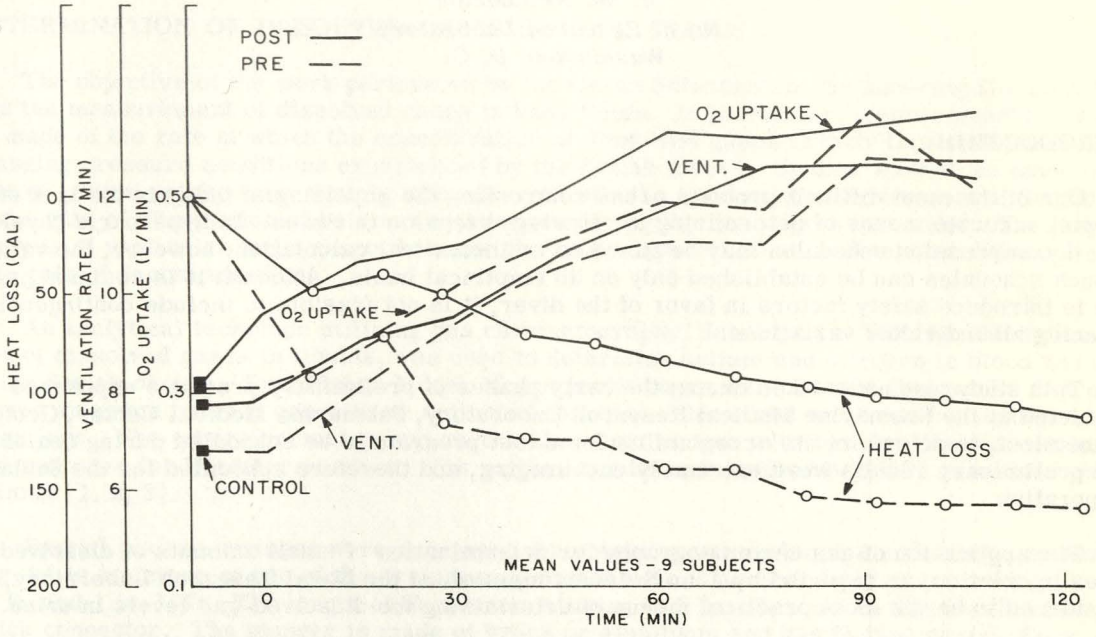


Fig. 93. Predive and postdive cold exposure tests, metabolic reponse

Chapter 31

DETERMINATION OF DISSOLVED GASES IN BODY FLUIDS

W. F. Mazzone
Submarine Medical Center
New London, Connecticut

G. F. Bond
Special Projects Office
Washington, D. C.

J. W. Swinnerton
Naval Research Laboratory
Washington, D. C.

INTRODUCTION

One of the most difficult problem areas confronting the physiologist today is the lack of a simple, accurate means of determining the inert-gas tension in tissue. In hyperbaric physiology, decompression schedules may be based on mathematical calculation; however, the validity of such schedules can be established only on an empirical basis. Although it is common practice to introduce safety factors in favor of the diver, it is not feasible to include contingencies covering all individual variations.

This study was undertaken during the early phases of preliminary pressure exposures conducted at the Submarine Medical Research Laboratory, Submarine Medical Center, Groton, Connecticut, to determine its acceptability for a test program to be scheduled during Sealab II. The preliminary results were extremely encouraging, and therefore scheduled for the Sealab II operation.

The application of gas chromatography for determination of small amounts of dissolved gases in solution, as reported by John Swinnerton, et al. of the Naval Research Laboratory, was considered to be the most practical means of determining the dissolved-gas levels in urine.

The equipment consists of all-glass sample chamber in which the dissolved gases are stripped from solution by inert carrier, a four-way bypass valve, a commercially available gas partitioner, and a 1-mv recorder. Calibration for routine work is accomplished by carrying out the determination on a sample of water saturated with pure gas at a known temperature and pressure.

The partitioner may be fitted with two columns, each containing a separate packing material. Generally in the evaluation of respirable gases, column one contains a material called diethyl hexyl sebacate, which removes or retards the carbon dioxide. Column two contains molecular sieve 13x, where oxygen and nitrogen are separated.

With argon gas as the inert carrier, it is possible to analyze for helium concentrations in urine. With argon, the sensitivity for oxygen-nitrogen separation is considerably diminished.

Note: The introductory remarks are authored by Captains Bond and Mazzone, while the report itself is by Dr. Swinnerton.

With helium at the inert carrier, it is possible to analyze carbon dioxide, oxygen, and nitrogen.

During the early phases of Sealab II, it was planned to conduct chromatographic analysis of urine in an effort to obtain preliminary data on gas uptake. Due to logistic difficulties, this procedure was not considered feasible.

During the decompression cycle, it was possible to conduct a program of urine monitoring each hour.

The graphic presentation of each hourly analysis, presented in the following pages, indicates that a high correlation exists between the amount of dissolved gas in the urine and the ambient atmospheric concentration. Application of this observation to decompression schedules is under serious consideration.

The detailed report of this work follows.

DETERMINATION OF DISSOLVED GASES IN BODY FLUIDS

The objective of the work performed by the Ocean Sciences and Engineering Division, NRL, was the measurement of dissolved gases in body fluids. In particular, measurements were to be made of the rate at which the concentration of dissolved gases in body fluids responds to changing pressure conditions experienced by the Sealab divers. Studies were to be made of the rate of helium uptake immediately after descent into the atmospheric enviroment of Sealab and of the rate of elimination of helium and nitrogen during the decompression stage. The latter study is of particular importance, because the rate of gas elimination determined the optimum safe rate of decompression.

An analytical technique utilizing gas chromatography, developed at NRL for the determination of dissolved gases in liquids, was used to determine helium and nitrogen in blood and urine of the Sealab divers. Two Fisher Model 25 gas partitioners were used in this work. One employed an argon carrier gas with an activated charcoal column and was used for helium determinations. The other chromatograph used helium carrier gas with a molecular sieve column and was used for N_2 determination. The method has been described in detail in various publications [1, 2, 3].

Special plastic syringes were developed for obtaining urine samples under high pressure. Fig. 94 is a picture of one of the syringes used in Sealab. The main body of the syringe is 2 in. O. D. and 1 in. I. D. The length of the plastic housing is 5 in. One end is fitted with a Swagelok quick connector. The plunger is made of brass or aluminum and has O-ring seals. Four screws pass through the back flange of the syringe; these screws with nuts are used to prevent the plunger from backing out when the external pressure is reduced. When filling the syringe with urine, the plunger is removed and the barrel is carefully filled. The plunger is then fitted into the barrel. All bubbles are expelled through the quick connector, and the plunger is pushed in until the four screws protrude through the back flange. The nuts are then tightented with a small wrench. The above procedures all take place in Sealab, or the deck decompression chamber (DDC). The syringe was then sent topside for analysis. The syringe quick connector was then fastened to its couterpart quick connector, which was attached to the sampling-valve inlet of the stripping chamber. The urine was then forced into the sampling loop of the valve and immediately injected into the stripping chamber. While this method works very well for sea water or any liquid at one atmosphere, some shortcomings were evident when injecting samples under pressure. This problem will be discussed later.

A modified Hamilton glass syringe was used for blood analysis. A Hamilton luer lock two-way valve was used on the front end of the syringe. The plunger has a Chaney adaptor modified with an aluminum stop to retain the plunger in position under pressure when the syringe was sent topside. The plunger was also fitted with an O-ring to insure a leak-tight fit. The blood was heparinized to prevent clotting. Blood samples were injected through a serum cap directly into the stripping chamber. A sampling program for obtaining blood and urine from the Sealab subjects was arranged by Captain Walter Mazzone, MSC, USN (Physiological Measurement Officer), for both the helium uptake and elimination studies.

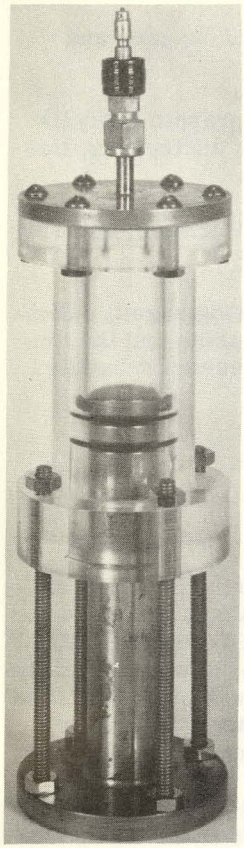


Fig. 94. Special plastic syringe developed for taking urine samples under high pressure during Sealab II

The uptake studies were to be run on the subjects as they entered Sealab, and were to be followed for 24 hours or until helium saturation was reached. Samples of blood and urine were also to be taken in Sealab daily on arising. Three subjects would each given one urine and one blood sample. These samples would be analyzed for helium and nitrogen to establish a base line of helium saturation and also to serve as a starting point for the decompression studies. The elimination studies were to be run during the decompression, which would take place on the staging vessel in a deck decompression chamber. In Table 16 are listed the various studies run on all teams and the number of samples obtained in each.

Table 16
SEALAB II ELIMINATION STUDIES

Team	Study	Type and Number of Samples		
		Urine (He)	Urine (N_2)	Blood (He)
1	Uptake	None	None	None
	Base Line (In Sealab)	38	None	18
	Decompression	24	None	None
2	Uptake	5	None	1
	Base Line (In Sealab)	5	1	None
	Decompression	31	20	2
3	Uptake	None	None	None
	Base Line (In Sealab)	8	5	6
	Decompression	50	46	None

OUTLINE OF HELIUM UPTAKE STUDIES

No uptake studies on Team 1 were planned, since their time during the first 24 hours was spent in setting up and checking out various pieces of equipment. This activity included the sample-pot transfer system, which was not in operation until the second day.

Three men from Team 2 were to enter Sealab about five hours before Team 1 was to enter the personnel transfer capsule (PTC) for their transfer to the DDC. The PTC was a pressurized underwater "elevator" which was used to transfer the Sealab divers from the habitat to the DDC. These men would participate in various physiological tests, one being the helium uptake studies. Samples of urine were to be taken every two hours for about 24 hours and blood every three to four hours. A similar schedule was planned for Team 3.

BASE-LINE RESULTS

The results of the base-line studies are listed in Table 17 and are averages of all the subjects who gave samples over the 15-day period in Sealab.

HELIUM AND NITROGEN ELIMINATION STUDIES

These studies were performed on Teams 1, 2, and 3 during their respective decompressions, which required about 30 hours each. Four subjects were to provide urine and blood samples. Two subjects would give two urine samples each and alternate with the remaining two. Both helium and nitrogen gas would be followed each hour during the decompression. One blood sample, to be taken every three hours would be used for helium studies.

Table 17
SEALAB II BASELINE STUDIES

Team	Dissolved Gases, ml/l (Avg.)		
	Urine (He)	Urine (N_2)	Blood (He)
1	45.0	-	44.3
2	48.0	15.0	-
3	49.0	20.0	47.0

RESULTS OF DECOMPRESSION STUDIES

The most reliable and complete data were obtained during the decompression studies of Teams 2 and 3. Decompression studies on Team 1 were not started until approximately halfway through their decompression, since at the same time efforts were concentrated on Team 2 uptake studies. When it became evident that no worthwhile uptake data were going to be obtained on Team 2, it was decided to switch to Team 1 decompression. The helium and nitrogen decompression data obtained on Teams 2 and 3 agreed very well with the partial pressure of helium and nitrogen recorded at the various stages of decompression.

Decompression of Team 2

Fig. 95 relates to the decompression studies on Team 2. The upper part of Fig. 95 is a plot of the absolute partial pressure of inert gases in the atmosphere versus the decompression time in hours. The total pressure in Sealab was approximately 6.8 atmospheres, and the composition of the major gases was O_2 - 7.9 percent, N_2 - 14.2 percent, and He - 77.9 percent. In all habitats, i.e., Sealab, PTC, and DDC, the percentages of O_2, N_2, and CO_2 were measured directly by gas chromatography, and helium was determined in all cases by difference.*

A urine sample was taken just before the divers left Sealab. No samples were taken while the divers were in the PTC, which was approximately one hour. The total absolute gas pressure in PTC was decreased from 6.9 atmospheres in Sealab to 6.6 atmospheres, at which time the men transferred to the DDC. Deck decompression was started at this time. The first urine samples from the DDC were obtained about two hours after entry. Decompression continued at a steady rate for ten hours (see point A, Fig. 95). At this time it was determined that the O_2 level was higher than desired. It was decided to purge the DDC with helium in order to reduce the O_2 level. This also resulted in a reduction of the N_2 level. The helium level of course increased during this time. After a total of 30 minutes for helium purging, decompression was resumed. After approximately 23 hours (point B, Fig. 95) another hold was instigated for the purposes of sending in a medical team via the outer lock of the DDC. This step resulted in an immediate loss of helium and similarly an increase in the N_2 level, as the outer lock was compressed to 2.3 atmospheres with air. Decompression was resumed, and after 32 hours the DDC was flushed with air.

In the lower half of Fig. 95 is plotted the concentration of inert gases in ml/liter for urine versus the decompression time in hours. Comparison of the changes in partial pressure

*The gas mixture percentages and total pressures used to compute the absolute partial pressures seen in Figs. 95 and 96 were supplied by the personnel of the New London Medical Research Laboratory, U.S. Naval Submarine Base, New London, Connecticut.

with the corresponding changes in gas concentration in urine shows that the loss in inert gases by the body closely follows the reduction in partial pressure of the inert gases in the chamber.

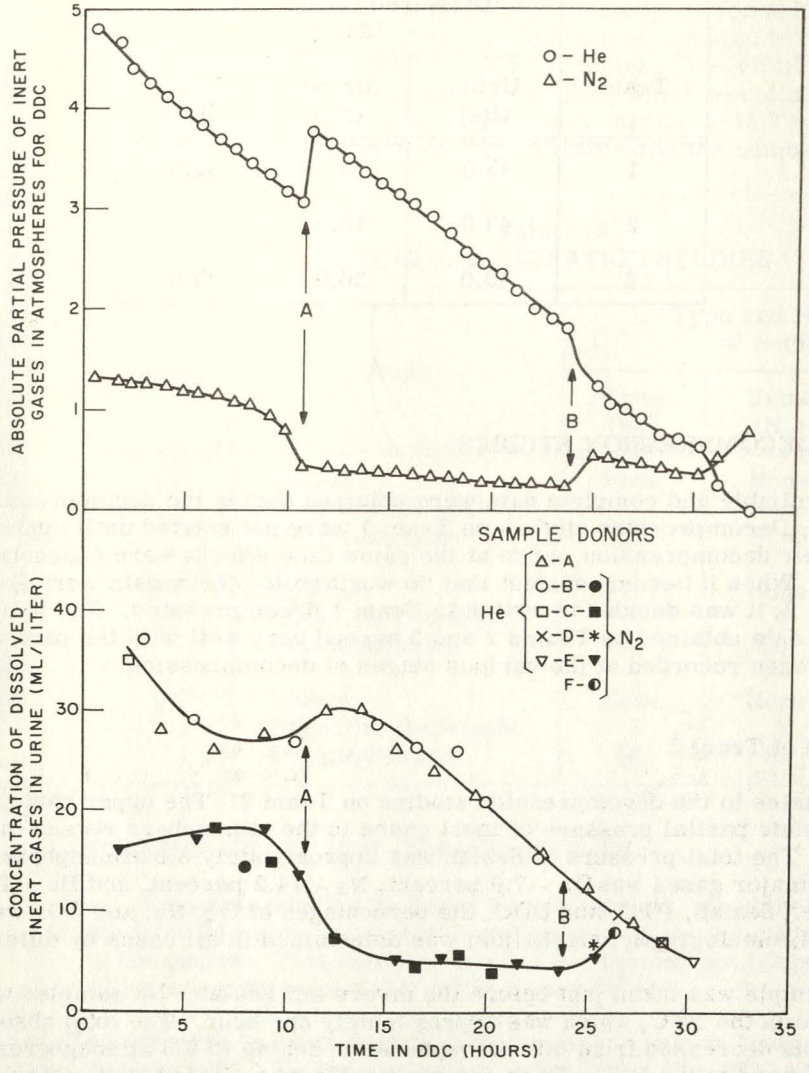


Fig. 95. Sealab II, Team 2 inert-gas elimination during decompression; A - helium purge reducing nitrogen concentration and increasing helium concentration, B - outer lock pressurized with air, increasing nitrogen concentration and decreasing helium concentration

Decompression of Team 3

Fig. 96 presents results of the decompression studies on Team 3. These results are less dramatic than those of Team 2, since a steady continuous decompression was followed for 26 hours. The first urine sample after Team 3 entered the DDC was taken about two and one-half hours after entry. In comparing the upper halves of Figs. 91 and 92 it should be noted that the partial pressure of N_2 in the DDC was initially higher for Team 3 than for Team 2. In fact, at all stages of decompression for Team 3 the N_2 level was greater than that of Team 2, and similarly the helium partial pressure was less. The lower half of Fig. 96 is a plot of the concen-

tration of dissolved inert gases in ml/liter for urine versus the decompression time in hours. Again, the inert gases in urine decrease with time and follow very closely the corresponding decrease in partial pressure of inert gases in the DDC. Urine sampling was terminated 26 hours after start of decompression, since one of the divers was experiencing slight pain and in fact had developed a case of decompression sickness. The remaining nine divers were transferred to the outer lock of the DDC and were brought to surface pressure separately. No separate medical lock was available in the outer lock for transferring urine samples, so no further analyses were possible.

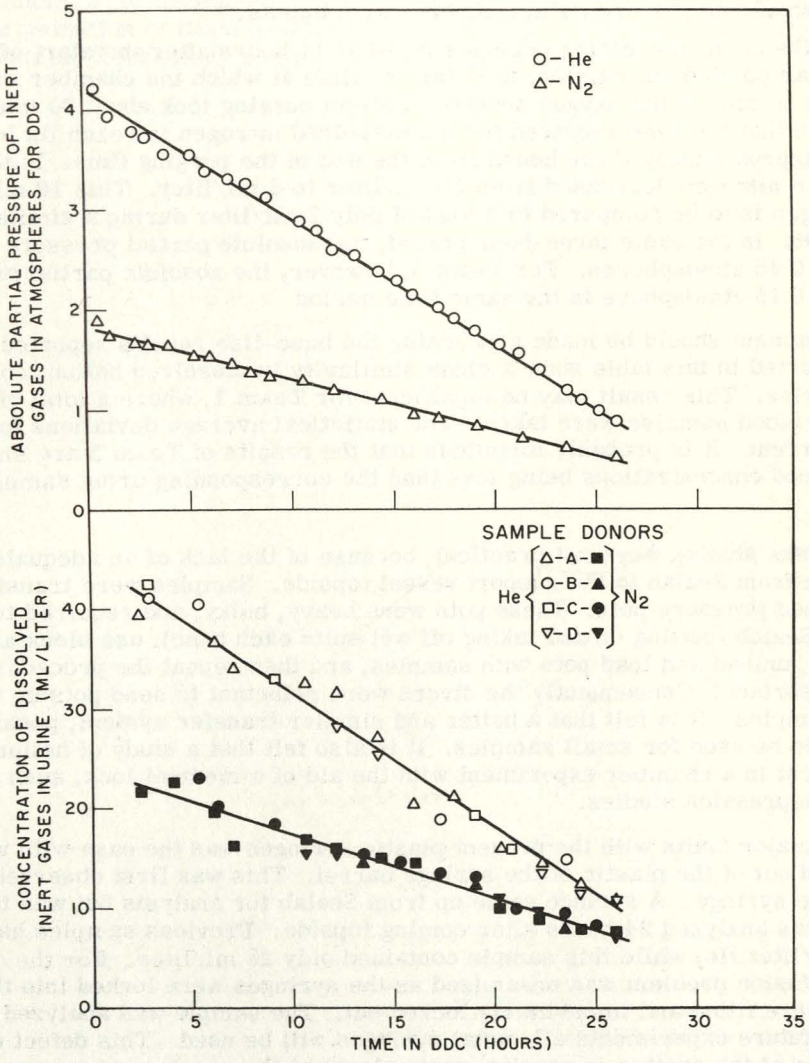


Fig. 96. Sealab II, Team 3 inert-gas elimination during decompression

DISCUSSION

As mentioned previously, the most reliable data were obtained during the decompression studies on Teams 2 and 3. The primary reason for this was that the divers were under closer supervision of the support personnel while in the DDC. Another factor was the ease with which samples could be transferred from the DDC to the support people via the medical lock.

From a physiological point of view, Fig. 95 is the most significant. Both Figs. 95 and 96 show a continuous decrease of inert gas concentration in urine with a corresponding partial pressure decrease. Referring to Fig. 96, it is obvious that the rate of inert-gas loss from the body paralleled decreasing partial pressure of inert gas with time. This in itself is significant, in that it is the first time such measurements have been made. The question to be asked is: could the rate of inert-gas losses from the body have paralleled the decreasing chamber gas pressures if the rate of decompressions were greater than 0.18 atmosphere per hour, which was maintained in this experiment? In order to ascertain if a higher rate of decompression could be used, one would not want to use human subjects, but instead animals should be used. These studies should be performed in chamber experiments.

In Fig. 95 the most interesting point occurred at 11 hours after the start of decompression (see point A). As pointed out earlier, this was the time at which the chamber was flushed with helium in order to reduce the oxygen content. Helium purging took about 30 minutes. It is interesting to note that the time required for the dissolved nitrogen to reach its lower level (at 15 hours) was approximately three hours from the end of the purging time. In this time interval the dissolved nitrogen decreased from 15 ml/liter to 5 ml/liter. This 10 ml/liter loss of dissolved nitrogen is to be compared to a loss of only 2 ml/liter during a similar three-hour period in Fig. 96. In the same three-hour period, the absolute partial pressure of N_2 for Team 2 decreased by 0.45 atmospheres. For Team 3, however, the absolute partial pressure of N_2 decreased only 0.15 atmosphere in the same time period.

A short comment should be made concerning the base-line results reported in Table 17. The values reported in this table show a close similarity in dissolved helium concentration in the blood and urine. This result may be significant for Team 1, where a total of 38 urine samples and 18 blood samples were taken. The statistical average deviations for these samples are ±10 percent. It is probably fortuitous that the results of Team 3 are similar to Team 1 (that is, with blood concentrations being less than the corresponding urine samples for each team).

Helium-uptake studies were not practical, because of the lack of an adequate sample-transfer system from Sealab to the support vessel topside. Samples were transferred with specially designed pressure pots. These pots were heavy, bulky, and required two subjects to swim out from Sealab (putting on and taking off wet suits each time), use block and tackle to lift pots into Sealab, unload and load pots with samples, and then repeat the procedure to return samples to the surface. Consequently the divers were reluctant to send pots up with only one or two small samples. It is felt that a better and simpler transfer system, possibly a pneumatic tube, could be used for small samples. It is also felt that a study of helium uptake could be performed best in a chamber experiment with the aid of a medical lock, such as the one used during the decompression studies.

One of the major faults with the present plastic syringes was the ease with which helium diffused into and out of the plastic of the syringe barrel. This was first observed after a few days of using the syringe. A syringe came up from Sealab for analysis but was temporarily misplaced. It was analyzed 24 hours after coming topside. Previous samples had been averaging about 45 ml/liter He, while this sample contained only 28 ml/liter. For the decompression studies, this diffusion problem was minimized as the syringes were locked into the DDC until needed. They were filled and immediately locked out. The sample was analyzed usually within 20 minutes. In future experiments all-metal syringes will be used. This defect certainly accounted for some of the scatter in results, particularly at the greater pressures. Another major factor contributing of the scatter was poor sampling technique on the part of the divers. Many syringes came up with large gas bubbles in them. It is felt that much more reliable data could have been obtained in this study if the subjects had been better indoctrinated and made cognizant of the importance of their participation in this specific area.

The introduction of urine samples into the valving system of the chromatograph also will require modification. When the syringe quick connect was attached to the valve quick connect, the pressure was immediately reduced inside the syringe. Small bubbles formed due to the pressure reduction; however, the sample was immediately injected into the loop, so it is felt that any gas loss was at a minimum. Some refinements should be made, particularly in view of the fact that future experiments will be at greater depths and consequently at higher pressures. Modifications are presently being made which will allow the introduction of the sample into the loop at the pressure at which it was taken. No bubble formation can occur under these conditions.

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Chapter 32

SERUM ENZYME STUDY AND HEMATOLOGICAL DATA

W. F. Mazzone
Submarine Medical Center
New London, Connecticut

and

G. F. Bond
Special Projects Office
Washington, D. C.

SERUM ENZYME STUDY

The development of pathophysiological responses of the body to hyperbaric environments has not as yet been subject to extensive study. Over the past few years, increasing interest has been generated in the use of oxygen under hyperbaric conditions. In the study of physiological responses to increased oxygenation, it appears that biochemical responses of cellular activity must be given further consideration. The opportunity to study enzymatic response under high ambient pressure in an artificial gas environment can be provided only in prolonged exposures such as are available in Sealab operations. Thus, in an effort to increase the background data of physiological responses to other than normal atmospheres, it was decided to include a preliminary study of the serum enzymes associated with those organ systems of the body which would most likely be effected.

Enzymes

A. Lactic dehydrogenase (LDH)

B. Serum Glutamic Oxalacetic Transaminase (SGOT)

C. Serum Glutamic Pyruvic Transaminase (SGPT)

Method

Physiological sampling under conditions of open-water tests are extremely difficult. On the basis of past experiences, it was deemed advisable and more logical to conduct a selected test program of blood sampling. Thus, in addition to the continuous monitoring of vital signs (Fig. 97) it was decided that blood studies would be conducted on three individuals of Team I, and two individuals from Team 2. Since Team 3 was to be concerned with salvage projects, physiological testing in this case was to be minimal.

Enzymes may be determined specifically, and when studied simultaneously, may provide valuable information relative to the organ system of the body which may be involved.

Limits

A hyperbaric experiment conducted in open water is obviously subjected to many variables which affect end results. It is recognized that certain factors which may affect enzyme response have not been identified or evaluated in this limited study.

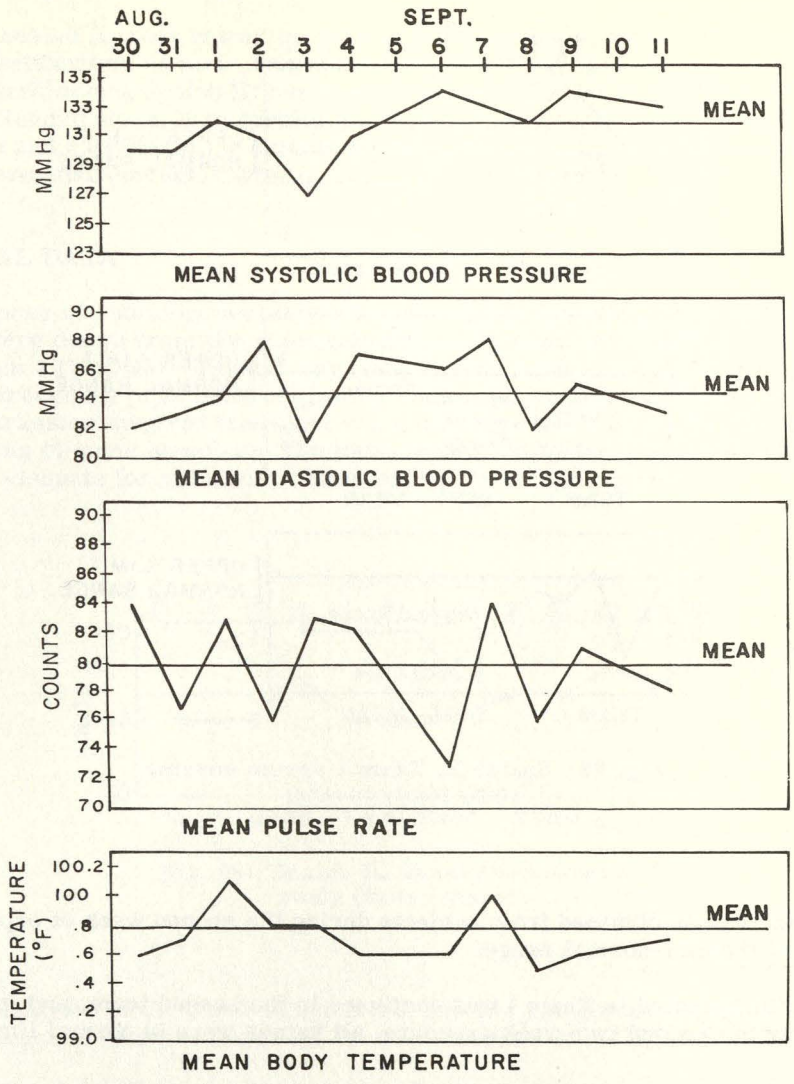

Fig. 97. Sealab II, Team 1 vital signs

Findings

The normal values accepted for this study have been taken from a publication by the Bureau of Medicine and Surgery, which indicates standards for the U.S. Naval Medical School Clinical Laboratory.

Lactic Dehydrogenase (LDH) (Fig. 98)

Normal range: 200 to 700 units

The three subjects from Team 1 show a definite increase above the upper limits of normal value at about days three to four, returning gradually to within normal ranges by the end of the first week.

The two individuals from Team 2 remained within normal limits.

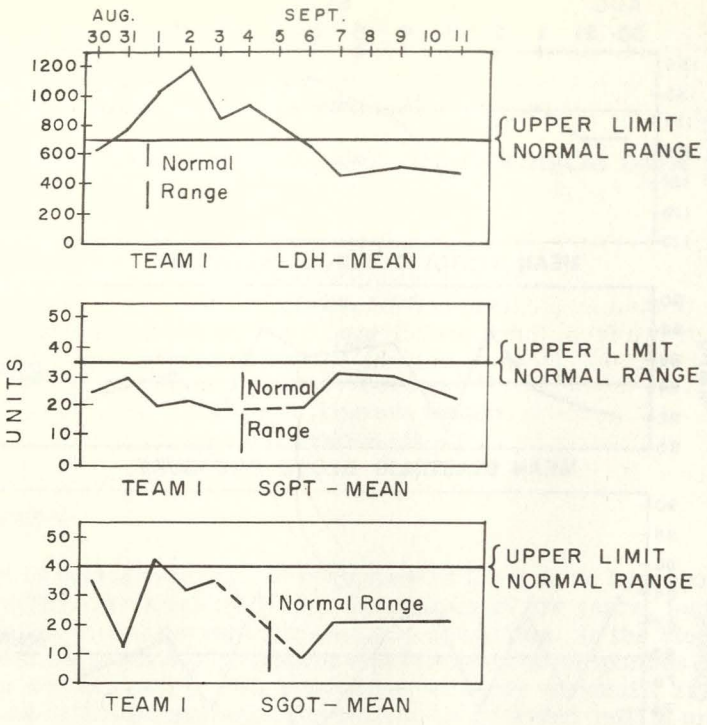

Fig. 98. Sealab II, Team 1 serum enzyme study (daily means)

In general, the values obtained from subjects during the second week of exposure remained on the high side of the mid-normal range.

One subject (SC) studied in Team 1 was continued in the second team, and it is of interest to note that during the second two-week exposure, all values were in normal limits.

Serum Glutamic Pyruvic Transaminase (SGPT)

Except for a very brief statement relative to a single above-normal finding for one subject on day two, no other individual exceeded the upper limit. The SGPT values do appear to be in the high normal range, and oddly enough, seem to bear an inverse relationship to LDH levels. Low LDH levels, which appear around day nine, are paralleled by high SGPT levels.

One member of Team 2 demonstrated an elevated SGPT which persisted for approximately three days. On day four, this individual's SGPT fell to within normal ranges, and for the balance of the run approximated the trends shown in a plot of Team 1's enzyme levels.

Serum Glutamic Oxalacetic Transaminase (SGOT)

Except for one subject from Team 1 who started with an elevated SGOT level which persisted for five days, all values were within normal limits. The low SGPT level was noted on day eight, one day preceding the high SGPT and low LDH levels.

DISCUSSION

The role of selected enzyme assay in the evaluation of physiological responses to environmental stress is far from clear at this time. In addition, the intercorrelation of the enzymes

selected for the Sealab II study cannot be evaluated at this time. Currently available techniques which permit stratification of some enzymes—hence offering a clue to the organ system involved—could not be utilized during Sealab II; hence our enzyme data are incomplete and permit little interpretation. Nevertheless, it is certain that careful enzyme studies, together with the more classical steroid and catecholamine determinations, should yield vital information in this important field of severe environmental stress.

HEMATOLOGICAL DATA

For the purpose of obtaining necessary hematological data during the operation, venous blood samples were drawn from three preselected team members of Team 1, and from two team members of Team 2 (Fig. 99). Team 3 was not utilized for these particular studies. Samples were taken at a frequency of at least every other day, and immediately transferred topside for analysis. This transfer involved transport via a large pressure pot, with attendant difficulties and inevitable loss of some samples. The total number of samples received intact, however, was considered adequate for valid interpretation.

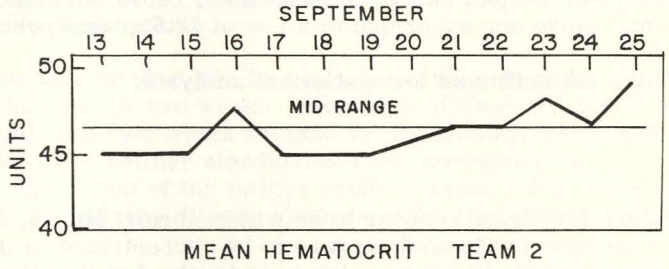

Fig. 99. Sealab II, Team 2 hematocrit study (daily means)

Basically, analysis of the blood samples fell into two categories: blood chemistry determinations and conventional examination of the formed elements of the blood.

The blood-chemistry determinations included non-protein-nitrogen and urea nitrogen values; blood sugar; all serum electrolytes; calcium; phosphorus, and creatinine determinations; and, in the case of team three, extensive carboxyhemoglobin and added carbon monoxide studies.

The data obtained from the conventional examination of the formed elements of the blood are discussed below.

Red Blood Cells

The red-blood-cell study for Teams 1 and 2 show very little of significance. The blood-cell count remained within the normal range of 4 to 6 million cells per cubic millimeter, with an average count of approximately 4.5 million. Team I seemed to peak at approximately nine days, where Team 2 remained at about 4.5 million cells until day eight, when all values began to increase toward five million.

White Blood Cells

The white-blood-cell study for Teams 1 and 2 fell well within normal limits, though falling between mid and upper normal range limits. Except for one excursion above the upper normal limit by one individual over a three-day period, all values for Team 2 samples fell within mid to upper normal limits.

Normal limits have been taken as five to ten thousand cells per cubic millimeter.

Sedimentation Rate

Two subjects in Team 1 remained within normal sedimentation limits throughout the bottom stay for Team 1, while one subject went above the upper normal limits on two occasions, once at about six bottom days and once on day 15, possibly as an aftermath of a sculpin sting received on the previous day.

Except for one elevated sedimentation rate on day ten for one subject, all rates for those sampled in Team 2 remained within normal limits. The normal sedimentation rate has been established as 0 to 9 millimeters per hour (Wintrobe).

Hemoglobin

Hemoglobin ranged from 13 to 15 grams percent for Team 1 and from 12.5 to 15 grams percent for Team 2. If hemoglobin content is considered to be normal at 14 to 18 grams percent, then in Team 1, only one subject remained essentially below normal throughout the run, and one subject in Team 2 made one excursion to a low of 12.5 grams percent.

The data obtained are not sufficient for statistical analysis.

Hematocrit

The hematocrit values for Team 1 appear to be within normal limits, generally around midrange. The hematocrit picture for Team 2 appears to be concentrated in the second week. The significance of high normal ranges is not completely understood at this time.

Platelets

The platelets for both teams appear to be well within normal limits, though once again, Team 2 is on the high normal side of midrange.

Chapter 33

PHYSICAL FITNESS TESTS

R. E. Sonnenburg
U.S. Navy Mine Defense Laboratory
Panama City, Florida

INTRODUCTION

The Sealab living quarters permitted unrestricted physical motion. Comfortable bunks were provided for sleeping. Food was available in wide variety and ample quantity. Daily activities consisted of donning rubberized suits, swimming, performing light to moderate underwater tasks at various depths above and below 205 ft, and doffing the swimming gear. The water temperature was 50° to 55°F. and caused shivering and cold discomfort which was relieved by a hot shower in the Sealab cabin.

The Sealab crew was divided into three teams of 10 men each. Each team stayed in the Sealab II undersea habitat for two weeks. Members of Teams 1 and 2 reported subjective sensations of fatigue and lassitude which seemed to impair their work performance capacity. Since the work tasks were neither standardized nor measured and the physiological responses were not recorded, the extent of the fatigue problem could not be ascertained. Thus it was decided to study the daily physical fitness changes of Team 3 during its duty period in Sealab.

METHOD

Physical fitness was monitored by a test in which the heartbeat rate and pulmonary ventilatory rate was measured before and immediately after a barbell lifting exercise. Prior to the test program, the individual stood erect while his nose to deck distance was measured. The exercise procedure consisted of raising and lowering a special 37-lb barbell from the deck to nose level and return at the rate of 30 cycles per minute for a period of one minute. The cadence of the exercise was controlled by an observer who used a watch sweep second hand to pace the rate of the exercise. The exercise was performed in a steady, rhythmic manner and the observer coached him to go "faster" or "slower" as his rate of exercise declined below or exceeded one cycle per two seconds.

The exercise test was performed each evening, excepting one instance (ME), between 2000 and 2100 hours. This test time was placed at the end of daily work activities in order to detect fatiguing effects of the tasks or the environment, if such occurred.

Heartbeat rate was counted for 30 seconds while the subject stood quietly before the exercise and again immediately after the exercise. The observer used a stethoscope placed over the apex of the heart and a watch sweep-second hand to count the heartbeat rate. The 30-second count was multiplied by 2 and the frequency per minute thus calculated was recorded.

The pulmonary ventilation rate was counted and timed by a second observer who placed the back of his hand about an inch below the subject's nostrils in order to detect the incidence of respiratory flow. A 30-second count was multiplied by 2 to obtain the frequency per minute of the ventilatory rate. The ventilatory rate was recorded before and immediately after the exercise.

RESULTS

The data from the seven subjects are presented in Table 18. The pre-exercise heartbeat rates and ventilatory rates either declined (SH,SO,ME) or remained fairly constant (CO, BU, LY, WE) during the 9 days of the tests in Sealab. The response to the test exercise was unchanged in all subjects except two (SH, CO) who showed some reduction in post-exercise heartbeat rate when the first two and last two test scores are compared.

DISCUSSION

From these data it may be concluded that exercise tolerance did not deteriorate during 9 days in the Sealab II environment. If fatigue was present it was either not of the type, or not of sufficient magnitude to affect physical work performance.

Table 18
EXERCISE TOLERANCE STUDIES—SEALAB II—TEAM 3

Name	Time	Sep 29		Sep 30		Oct 3		Oct 4		Oct 5		Oct 6		Oct 7	
		Exercise		Exercise		Exercise		Exercise		Exercise		Exercise		Exercise	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Sheats															
Pulse rate	2000-2100	84	136	84	128	72	128			78	120			60	
Respiratory rate		12	19	12	16	13	16			4	14			10	13
Sonnenburg															
Pulse rate	2000-2100	84	156	88	108	64	124	86	144	68	132			59	103
Respiratory rate		16	24	12	20	10	19	12	26	10	17			10	26
Coggeshall															
Pulse rate	2000-2100	88	148	92	144			100	148	96	152	84	124	80	129
Respiratory rate		20	30	28	33			32	48	28	36	28	32	28	36
Bunton															
Pulse rate	2000-2100					66	120	82	128	72	108			68	96
Respiratory rate						17	20	20	21	24	23			18	24
Lyons															
Pulse rate	2000-2100			80	132	84	124	84	132	76					
Respiratory rate				12	18	16	22	17	20	14					

(Table Continues)

Table 18
EXERCISE TOLERANCE STUDIES—SEALAB II—TEAM 3—Continued

Name	Time	Sep 29		Sep 30		Oct 3		Oct 4		Oct 5		Oct 6		Oct 7	
		Exercise		Exercise		Exercise		Exercise		Exercise		Exercise		Exercise	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Wells Pulse rate	2000-2100					56	132	80	140	56	140			60	112
Respiratory rate						15	23	16	20	16	20			14	21
Meisky Pulse rate	2000-2100					80	140	84	132	78	132			76	113
Respiratory rate						16	20	14	16	12	14			12	15
														@ 1200 on 10/8	

Chapter 34

EEG AND EKG OBSERVATIONS IN SEALAB II

C. W. Sem-Jacobsen
Gaustad Sykehns
Oslo, Norway

INTRODUCTION

High-pressure-oxygen toxicity, anoxia, and nitrogen narcosis produce marked changes in behavior and in the electroencephralographic record. Minor changes in the EEG are seen as early warnings.

The purpose of the present study was to determine if prolonged submergence (15 days) in an artificial atmosphere of He, O_2, N_2, 205 ft below the surface of the sea would cause permanent or transient physiological or pathological changes in the brain, and study an correlation between such changes and fluctuation in the environment including the gas mixtures.

The experience with biological recordings from free-swimming divers in the ocean or in a habitat at 200 ft depths is very limited, and a number of expected and unexpected artifacts were encountered in Sealab II. If proper precaution was not taken, gross artifacts due to air bubbles from the respiration or movement in the salt water were encountered. In the same way salt water would through internal shorting to the body, short out the electrodes more or less completely. Artifacts due to the movement in the ocean as an infinite body moving in the earth's magnetic field were also encountered. The electrical signals generated by the waves against the beach were of an order of 10 millivolts. Electrical potentials generated by magnetic storms over Indonesia propagated through the ocean, and arrived at the location of Sealab II between 1700 and 1800 in the early evening.

These latter potentials would in the EEG recordings give slow-wave artifacts similar to those generated by some brain tumors or unconsciousness. Muscle artifacts were only a minor problem in the recording.

RESULTS

A number of good recordings were obtained from free-swimming divers in the ocean and the aquanauts inside Sealab II during the operation. The number of records obtained during the operation were limited, and the results are therefore given with some reservations.

Recordings from aquanaut R show a marked increase of the alpha-frequency after he had been in the habitat four to six hours (Fig. 100). On the staging vessel on Sept 12, when the electrodes were attached the frequency of the alpha activity was 10-11 cps. In the habitat that first evening about 2000 the activity was up to 14-15 cps. The next evening, Sept. 13, it was down to 13 cps, and two days after he went down, on Sept. 14, his alpha was back to 11 cps.

During the same period there were some marked changes in the gas mixture at the time of recording as reported by Dr. Larson.

Date	CO_2 (Percent)	O_2 (Percent)	N_2 (Percent)	PSI absolute pressure
Sept. 12	0.056	5.51	21.6	100.8
Sept. 13	0.02	4.60	22.0	100.0
Sept. 14	0.05	4.20	21.9	100.8

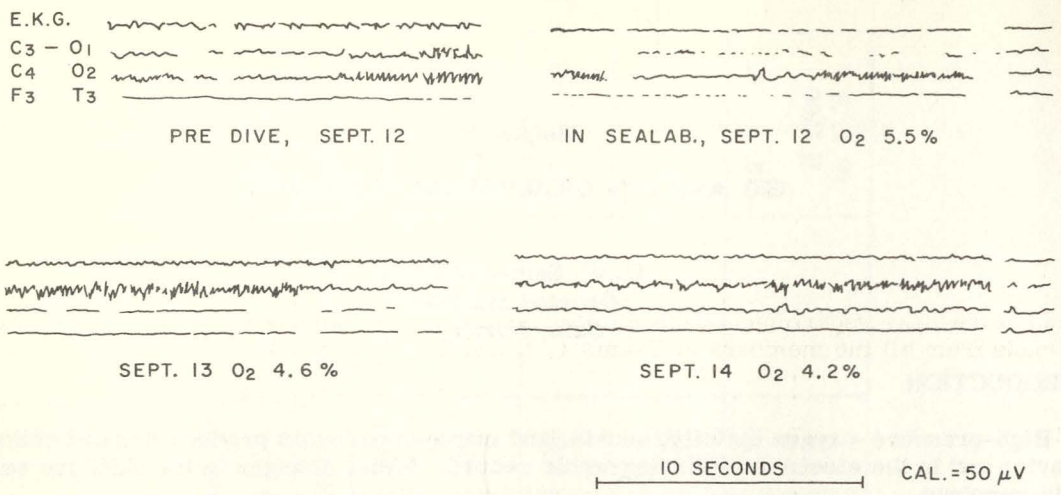

Fig. 100. Increase in Alpha frequency of EEG during Sealab II dive period

The changes in the alpha frequency may be due to acclimatization. They coincided with subjective difficulty with the problem-solving tasks and mental confusion reported by some participants.

The changes in the EEG coincided also with fluctuation in the gas mixture in the atmosphere in Sealab. The role of O_2 in this respect is not clear, but will be studied further.

In parallel with changes in the alpha frequency, there appeared during the initial dive period, expecially the first 24 hours, a marked increase in paroxysmal activity in the EEG which diminished and disappeared by the 14th of September. This observation needs further volidation due to insufficient artifact control. The changes are, however, in conformity with the change one would expect from recordings during O_2 or CO_2 toxicity and recordings during influence of N_2 anesthesia.

Even with a low N_2 content in the atmosphere, the body's normal excretion of N_2 through the lungs may be transient impaired, resulting in a transient N_2 or narcotic effect.

The result of the findings indicates that it will be possible to use the EEG to verify physiological compatible atmosphere in the habitat at the bottom of the ocean, as well as in free-swimming divers. The problems of the most compatible atmosphere for free-swimming divers are still of major concern.

INSTRUMENTATION

The Vesla biological recorder was used for recording EEG and EKG. In cooperation with Scripps Institution of Oceanography (Dr. Snodgrass and Mr. Hill) the instrumentation was modified, and a special high-pressure container was built for the equipment. The housing tolerated seven atmospheres of pressure in salt water, as well as in a helium atmosphere. The Vesla equipment was in the sealed container kept under one atmosphere pressure, thus avoiding any complication from "the bends" in the ink system.

A standard type S-J airborne EEG electrode was used for pre-descent recordings of selected members from Teams 1 and 2, as well as for the recordings from the same subjects inside Sealab II during the initial dive period. The same electrodes were also used for the preliminary EEG recording in the decompression chamber and in Sealab II.

To obtain good records from free-swimming divers in the ocean, and in Dr. Scholander's salt-water tanks, the electrodes and the surrounding skin surface were isolated by a special

technique. For the ascent in the decompression chamber specially developed snap-on electrodes were used.

Compatibility with telemetery system for EKG used in Sealab II was studied, and will be incorporated in the recording system.

PROGRESS AND MATERIAL

Neurophysiological investigations were carried out in close cooperation with Dr. Laverne Johnson of the EEG Department of the Balboa Naval Hospital, where preliminary EEG tracings were made from all the members of Teams 1, 2, and 3.

Dr. Scholander at Scripps Institution of Oceanography made his tanks available to one team for preliminary technical testing and for calibration of the instrumentation. Additional recordings were made from free-swimming scuba divers in the ocean.

A total of 18 records was made from free-swimming scuba divers in the salt-water tanks and the ocean.

Subjects for these recordings were members from the Sealab teams, and volunteers from the Scripps Institution of Oceanography - all competent divers who also gave valuable information about their experiences during the tests.

The records were made in the decompression chamber, and two records were made inside Sealab II with all electrical systems and equipment turned on. This was done before the actual operation started, to make sure that no artifact would be encountered from the environment. Members of Dr. Sem-Jacobsen's team were subjects for these later recordings.

Finally ten records were made in the laboratory to test out the quick recording technique used for the recording of EEG in the decompression chamber during the ascent of Team 1.

On the day of the descent into Sealab II four members of Team 1 and five members of Team 2 had EEG and EKG electrodes attached to their heads and chests. Using the Vesla miniaturized unit, a preliminary EEG and EKG record was made on the staging vessel before submergence. To obtain the maximum number of recordings from Sealab, the Vesla unit was shuttled back and forth between Sealab and the staging vessel as frequently as possible during the first initial four days of the dive period for both Teams 1 and 2.

Nine preliminary recordings were made from the members of Teams 1 and 2 on the staging vessel, and 18 recordings were obtained from inside Sealab II during the initial dive period.

RECOMMENDATIONS FOR FUTURE STUDIES

1. In addition to pre and post dive recording, EEG should be recorded on permanent equipment inside Sealab.

2. Biomedical monitoring should include EEG recordings from free-swimming divers. This may easily be operational on the basis of experience from Sealab II, and with some further homework in Norway during this winter. The Norwegian Navy has given free use of their facilities for this work.

Chapter 35

NEUROLOGICAL, EEG, AND PSYCHOPHYSIOLOGICAL FINDINGS BEFORE AND AFTER SEALAB II

Laverne C. Johnson and Michael T. Long
U. S. Navy Medical Neuropsychiatric Research Unit
San Diego, California

INTRODUCTION

Neurological, EEG, and psychophysiological examinations were obtained before and after Sealab II to determine possible changes resulting from prolonged exposure to a hyperbaric environment. The psychophysiological variables included heart rate, respiration rate, skin resistance, and finger plethysmogram. The postdive examinations were completed 12 to 36 hours after decompression. No significant predive or postdive neurological or EEG changes were found. While marked individual differences were found in the psychophysiological variables, the only significant difference was a drop in arousal level from predive to postdrive.

While the laboratory findings of Genesis E (Workman, Bond & Mazzone [1], Lord, Bond, & Schaefer [2], Bond 1964 [3] and the data from Sealab I indicated that man could exist and perform useful tasks in a hyperbaric environment, Sealab II was the most stringent test to date of man's ability to live in the sea. The potential hazards of this unusual environment are many, but of primary concern for this report are the neurological hazards of diving and the neurological and psychophysiological effects of prolonged exposure to unusual concentrations and pressures of gases.

The neurological problems posed by decompression, air embolisms, inert-gas narcosis, and oxygen toxicity have been summarized by Gillen [4, 5]. The effect of high partial pressures of inert gases on EEG and measures of performance have been reported by Bennett & Glass [6] and Bennett [7]. Under hyperbaric conditions they found subjects were less efficient on problem-solving tasks and that alpha blocking to stimuli was absent.

The effect of varying ambient pressures and varying gas mixtures on psychophysiological variables has not been extensively studied. The only known report is that of Weybrew, Greenwood and Parker [8] who studied three subjects during a 12-day exposure to an atmosphere of helium, oxygen, and nitrogen. Outside of a general indication of arousal in two of the subjects, no definitive conclusions could be drawn from this small sample.

As part of the pre and postdive examinations of the divers participating in Sealab II, neurological, EEG, and psychophysiological data were recorded. During Sealab II, three teams of ten men spent 15 days 205 ft below the ocean's surface. One of the participants spent 30 continuous days in the habitat, and a second participant spent 30 days in two 15-day periods, interrupted by a period of 15 days. The Sealab environment consisted of the following atmosphere: temperature 82 to 88°F, humidity 60 to 80 percent, pressure 6.8 atmospheres, and the average composition of the major gases was oxygen 4 to 5 percent, nitrogen 21 to 22 percent, and helium 73 to 75 percent. As the postdive examination could not be performed before 12 to 36 hours after the decompression, it was not expected that transitory changes, if present at all, would still persist. Our examinations were oriented toward determining if there were any changes that might be chronic. Recordings of EEG activity during the dive for Teams 1 and 2 were done by Dr. Carl W. Sem-Jacobsen (Chapter 34).

PROCEDURE

All but four of the 28 subjects were evaluated at the research unit at some time between 9 and 59 days before diving. The postdive examinations were done from 12 to 36 hours after completion of approximately 30 hours of decompression. In addition to the neurological examination, EEG and autonomic variables (heart rate, HR, respiration rate, RR, finger pulse response, FPR, galvanic skin response, GSR, and basal skin resistance) were obtained. The autonomic variables were scored for basal levels, spontaneous fluctuations in basal activity, and response to stimuli. The methods of recording and scoring these variables have been previously reported (Johnson (9, 10).

The pre and postdive neurological examinations included assessment of the cranial nerves, motor system, sensory system, cerebellar function, gait, and station, and they also included a screening test for aphasic signs. The subjects were also asked to subtract 7 serially from 100, repeat numbers both as read and in reverse, name the five most recent presidents and vice-presidents, and interpret two proverbs.

During the EEG, each subject was stimulated by means of a Grass Model PS-2C photic stimulator from 5 to 20 cps and asked to breathe deeply and rapidly (hyperventilate) for three minutes. The EEGs were interpreted by the neurologist as being either normal or abnormal. A normal EEG record was defined as having:

1. Rhythmic and arrhythmic activity at 8 to 13 cps with asymmetry up to one-half the voltage side

2. Rhythmic beta activity regardless of the amplitude excepting focal beta

3. Fronto-temporal theta of less than maximal alpha amplitude, occupying less than 2 percent of recording time, but no focal theta or asymmetry of more than one-half the alpha amplitude

4. Variable low amplitude fast activity

5. Any amount of drowsiness or sleep.

RESULTS

Electroencephalogram

All predive EEGs during resting, waking, activation, and periods of sleep were interpreted as being within the criteria for normal as defined above. The postdive records were distinguished by more rapid onset of sleep and the appearance of large amounts of spindle stage and slow-wave sleep. One subject's postdive record, because of a marked buildup of slow waves during hyperventilation, was read as abnormal. As this subject has not eaten in the six to seven hours preceding the recording of his EEG, he was brought back to the laboratory after fasting for some 15 hours to determine if the responses were due to hypoglycemia. The same response to hyperventilation was observed. He was then given 25 grams of sugar in orange juice. Hyperventilation 15 minutes after the ingestion of the glucose failed to produce the slow-wave activity. It was therefore concluded that the response to overbreathing seen on his postdive record was a result of fasting and not to his stay in Sealab II.

Neurological

Minor neurological abnormalities were found in seven individuals on initial examination. In five men one of the following was found: (a) alternating exotropia and difficulty interpreting proverbs; (b) hyperactive left knee jerk (residual of a previous decompression left hemiparesis); (c) unilateral optic atrophy with an abnormal visual field in that eye; (d) cerebellar ataxia of a mild degree with finger to nose intention tremor and ataxic handwriting; or (e) extremely slow mental responses with apparent confusion. Unilateral neurosensory hearing loss

was present in two men. The individual with the mental slowness and mild confusion was seen at the laboratory a few minutes after completing a two to three hour dive to 200 ft. A repeat evaluation when the diver was rested and had not been diving for a few days was completely normal. This diver's EEG showed an irregular pattern with dominant 4 to 7 cps activity on the first examination which was not present on the repeat examination.

Neurological changes were found in the postdive examinations in only one man; marked improvement was noted in the man who exhibited the cerebellar findings on predive examination.

The men were questioned in order to ascertain whether neurological symptoms were present while they were in the habitat. Sixteen men reported suboccipital, retro-orbital, or generalized headaches. For most the headaches were mild, but for three divers, the headache was so severe they were obliged to go to bed. The headaches were most severe on awakening and abated with activity. Three individuals reported that their thought processes were slowed, and two subjects experienced euphoria for the first few days. Sleep problems, getting to sleep as well as staying saleep, were reported by some divers.

Psychophysiological

Basal level values were obtained during the initial 15 minutes of both pre and postdive examinations. During this period, the subject was told to relax, but stay awake, and to keep his eyes closed. The basal levels were the average values for each of the variables during this period. Skin resistance values were converted to microohms and will be reported as conductance. Heart rate and respiratory rate variabilities were the average of the variations in rate from beat to beat for one minute. For skin resistance the measure of variability was number of GSRs occurring without any known external stimuli. A similar measure of spontaneous activity was used for FPR, i.e., the number of vasoconstrictions during this 15-minute period which were not a response to external stimuli.

Autonomic responsiveness was evaluated by measuring the response to the flickering light. The response to the first flicker as well as the average response to the 21 flicker presentations was scored. The flicker was presented at each frequency from 5 to 20 for 30 seconds, after a 30-second off period between frequencies. Spontaneous GSRs and FPRs were not counted while the flicker was on. More complete scoring procedures are presented in the reports by Johnson.

The pre-post basal values are listed in Table 19. Since there were no statistical differences among the three teams on any of the predive or postdive measures, they were combined into one sample. As four men from Team 1 were not available for predive examination, the pre-post comparisons are based on 24 subject examinations.

Table 19
PREDIVE-POSTDIVE AUTONOMIC BASAL LEVEL VALUES

Parameter	Predive	Postdive	Significance
Heart Rate			
Mean	76	75	ns
SD	13.9	14.2	
Respiratory Rate			
Mean	15	14	ns
SD	3.9	3.4	
Skin Conductance			
Mean	11	8	.01
SD	3.7	3.3	
Spontaneous GSR			
Mean	10	10	ns
SD	6.7	13.3	
Spontaneous FPR			
Mean	4.9	6.0	ns
SD	2.8	3.3	

While there was marked variability about the mean on both predive and postdive records, all basal mean values were within normal limits. The predive range for heart rate was from 48 to 107 beats per minute, while the postdive range was from 45 to 110. The same two men provided the minimum-maximum pre-postdive scores. This stability in pre-post heart measures is reflected in the 0.69 ($p < .01$) correlation between pre-post heart rate values. For respiration rate the predive range was from 8 to 21 breaths per minute, and the postdive range was from 9 to 20. The correlation between pre-postdive respiratory rates was 0.65 ($p < .01$).

Similar wide ranges were found for skin conductance and the measures of spontaneous fluctuation in basal values. In contrast to the significant pre-postdive correlations for heart rate and respiratory rate, the pre-postdive correlations for skin conductance and spontaneous activity were not significant, indicating marked and inconsistent individual fluctuations in these measures of basal variability.

The only significant difference between the predive and postdive basal means was for skin conductance. The predive conductance mean was significantly higher, reflecting the higher degree of arousal before the dive. These data are consistent with the EEG findings of more drowsy records and quicker onset of sleep during the postdive examinations.

Though there was a larger response in all variables to the flicker on the predive than on the postdive record, only the number of spontaneous GSRs during flicker was significantly higher. These findings, especially the GSR data, are in keeping with the difference in arousal level between the two examinations.

CONCLUSIONS

Prolonged exposure to the hyperbaric atmosphere present during Sealab II appears to have had no prolonged deleterious effect on man's central or autonomic nervous systems. Any changes precipitated by exposure to this atmosphere of helium, oxygen, and nitorgen under 6.8 atmospheres were transient and no longer evident by our recording techniques 12 to 36 hours after decompression.

The postdive interview data, however, suggested that some transient effects were present, especially during the initial period of the dive. Headaches were evidently not uncommon, some slowing of mental processes were reported, sleep patterns appear to have been disrupted, and changes in affect, i.e. euphoria, were reported. Dr. Sem-Jacobsen, while experiencing many technical problems in this first attempt to record EEG changes from men during the dive, did obtain data suggesting that EEG changes may be present and correlated with variations in gas pressures.

These clinical reports and the suggestive EEG findings indicate that some detailed and reliable EEG and psychophysiological recordings during the dive would be of value, especially during the initial periods. When compared with predive baseline data, these data could determine the initial effects of the environment on each man. Changes in the EEG or psychophysiological variables during the dive could also be used to indicate the effect of prolonged exposure and possible changes in performance level.

The wide range of predive basal values and the negative postdive findings indicate that the ability to adjust to atmospheres and gas mixtures such as those in Sealab II is not restricted to a narrow band of physiological values. It would be of interest to determine whether the predive data could be used as predictors of initial or prolonged response to hyperbaric environments. As the dives proceed to greater depths and for longer periods, the predive data may be of greater significance.

The negative postdive data can be viewed as a confirmation of the results from the Genesis experiments and Sealab I. Sealab II further demonstrated man's ability to expand his sphere of aquatic activities. The lower level of arousal on the postdive examination was probably due to the fatigue and sleep loss resulting from the decompression schedule and demands upon the men for reports and interviews post decompression. The sleep difficulty experienced during the dive also added to the sleep debt of some of the divers.

As future Sealab projects try for greater depths, postdive examinations of these men will be of value equal to those of Sealab II. In addition to the predive-postdive comparisons for each man, a comparison of changes from each Sealab project as the depths vary should be of interest.

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Chapter 36

THE SEALAB II HUMAN BEHAVIOR PROGRAM

James W. Miller
Office of Naval Research
Washington, D.C.

Rowland Radloff
Naval Medical Research Institute
Bethesda, Maryland

Hugh M. Bowen
Dunlap and Associates
Darien, Connecticut

Robert L. Helmreich
Yale University
New Haven, Connecticut

PURPOSE AND SCOPE

The purpose of the Sealab Human Behavior Program was to make an overall assessment of man's behavior while living in the sea. The program was designed to study broader aspects of adaptation to life and work in the hostile environment and, more specifically, to determine how well man can perform specific tasks of a scientific or operational nature. Such information should be invaluable from the standpoint of planning future undersea operations, as well as in selecting and training individuals for such operations.

The collection of data began in the early stages of the training period, continued throughout the divers' stay on the bottom, and concluded with postdive interviews, questionnaires, and tests, as well as continual observation of each diver's performance and interaction with the other members of the team by closed-circuit television. In addition, the divers' performance in the other scientific and salvage programs was monitored, where possible, in order to increase the validity of the overall assessment of performance.

The members of the Human Behavior Team also assumed the responsibility for organizing, coding, and punching on cards, the data from many of the other programs, including salvage, medical, physiological, and oceanographic. As a result, the data from one program can readily be correlated with those of another. Because of the early deadline for this report, however, the results of many of the interactions will not be included. The report which follows is preliminary in nature.

As with all field investigations, particularly those carried on in the ocean, the conditions under which the data were collected were less than ideal, and compromises had to be made. In addition to the restrictions imposed by the physical environment, equipment failures, etc., the Human Behavior Program was carried on under additional constraints. These included limited experimental time and the absence of an on-the-bottom experimenter (resulting in decreased planning flexibility). These comments seem to emphasize the fact that such studies cannot be carried out with all the checks and balances possible in the laboratory, in spite of careful planning.

GENERAL METHODOLOGY

The Human Behavior Program was planned to search for relationships between social, personality, and performance areas of study. As a result, the program had basically three components:

1. Specific tests of visual, auditory, and psychomotor skills

2. Observation of the performance aspects of the scientific and salvage tasks undertaken

3. A careful study of how a diver carries on his work, lives in the habitat, and gets along with his fellow divers, utilizing the closed-circuit television and audio systems available.

As the project developed, it became increasingly evident that it was important to establish the relationships between various reports, including reports made by or about the divers and their level of work accomplished. Achievement of this objective will permit social, personality, and motivational variables to be correlated with work performance.

Standard data-gathering techniques were used in this program, including: (a) quantitative recording of physical measurements; (b) self-report, including standardized checkoff lists, interviews, diaries; and (c) evaluative observations, using closed-circuit television.

DATA-COLLECTION PROGRAM

Predive Baseline Data

Demographic and Attitudinal Measures — These data consisted of background and baseline information on the aquanauts, supplied by them. The aquanauts filled out a series of paper-and-pencil forms, some especially designed for Sealab, some adapted from research on Antarctic groups, and some standard psychometric instruments. These forms included:

1. Personal history booklet — largely demographic data
2. Attitude inventory
3. Adjective checklist — characteristics desired in a friend
4. FIRO-B — standard test measuring attitudes toward interpersonal relations
5. Scale of values — standard test measuring broad life goals
6. Strong vocational interest blank — standard test of vocational and avocational interests
7. Mood checklist — adjectives describing characteristic moods
8. Sociometric questions — choice of most preferred leaders and teammates.

Psychomotor Tests — About one-half of the group of 28 subjects were introduced to the Human Behavior Program during May and June 1965, at the U.S. Navy Mine Defense Laboratory, Panama City, Florida. Some dry-land baseline data were collected on the individual assembly test, two-hand coordinator, group assembly, and arithmetic tests. Baseline data were also collected for the first three of these tests performed in shallow water (fresh water, 70°F, at a depth of 20 ft, under exceptionally good visibility conditions).

During the first two weeks of August, further dry-land baseline data were collected on the strength test, individual assembly, two-hand coordinator, group assembly, and arithmetic tests. Time and diver availability restrictions were such that the baseline data were some 70 percent complete prior to the beginning of the Sealab II submersion.

Report forms and procedures were developed with the help of the divers. The tests chosen were selected in order to probe specific features of psychomotor behavior. They are adaptations of tests used in other situations. The adaptation was necessary because of the conditions in the water and the absence of the experimenter. It will be noted that the tests range from measurement of simple short-term performance to complex prolonged performance. The psychomotor tests required the application of maximum force, manipulative dexterity, eye-hand coordination, and cooperative assembly of components as outlined in the following paragraphs.

Strength Tests — The purpose of this test was to determine whether there would be a change in exertable strength between dry-land, shallow-water, and deep-water conditions.

The test utilized two calibrated torque wrenches, one with a scale from 0 to 800 lb, the other with a scale from 0 to 1200 lb. Two strength tests were used; the lift test, and the pull test. The lift test consisted of bracing the feet on a platform and lifting upwards on a handle positioned about 30 in. above the platform. The pull test was carried out by grasping the handle with the left hand at about shoulder height, while simultaneously grasping a grip with the right hand (Fig. 101). By adjusting the right-hand grip, each man could achieve a full arm-stretch position. In both tests, the subjects were told to exert maximum force. The torque achieved was recorded by a deflexion arm which moved a recording marker along a scale.



Fig. 101. Diver performing strength test in shallow water

These tests were chosen because they are representative of the actions required when divers are used as primary power sources, and because they provide data that are directly applicable to the design of hand tools. In addition, it was expected that the forces recorded in the lift test would be two to three times those recorded in the pull test, thus giving an appreciable range in terms of muscle activity.

Individual Assembly Test – This test measured manual dexterity and the ability to form spatial relationships. The test required the diver to assemble three one-foot lengths of steel plates into a triangle by joining the corners of the plates together with nuts, washers, and bolts. The divers were required to assemble each corner by placing a washer on each side of two lengths, pushing a bolt through the four pieces, and securing the whole assembly by screwing on a nut. Two bolt sizes were used: 5/32 and 5/8 in. The holes at the ends of the plates were placed either symmetrically (same corners), so that any end would fit to any other end, or asymmetrically (different corners), so that the end of one length would fit only to one end of one of the other two lengths. The combination of the bolt size and symmetry variables resulted in four forms of the test. While it was possible to assemble the symmetrical plates in any combination, only one manner of assembly resulted in the exact superimposition of two lengths at each corner. Thus, the four versions of the test varied the challenge to the subject in terms of the degree of fingertip dexterity required, as well as his ability to form spatial relationships. Performance in the water was expected to deteriorate as compared to dry-land conditions, due to the cold, the wearing of gloves, etc. In addition, one might expect performance to decrease as a result of poor visibility and general problems associated with maintaining body orientation with respect to work components. The test was selected as being representative of tasks requiring the assembly, adjustment, and general handling of small items of equipment.

Two-Hand Coordination Test — The purpose of this test was to measure eye-hand coordination. The test utilized a specially designed gear box, mounted on a stand four feet high (Fig. 102). On two sides of this box were knobs, 2 in. in diameter. These knobs were attached to worm gears which produced movements in a peg protruding through the top of the box. Turning the right-hand knob caused the peg to move forward and backwards; turning the left-hand knob caused the peg to move left and right. One of nine templates could be placed on the top of the box. In each template a track was cut. At the start of each test, the peg was positioned at the end of the track. The task of the diver was to move the peg along the track from one end to the other and return in as short a time as possible (Fig. 102). The elapsed time was recorded. The tracks varied in difficulty; i.e., some had straight lines with right angles, others had straight sloping lines, while still others had curved lines, such as an S. The test was selected as being representative of tasks which require continuous control or adjustment of equipment, dynamic systems, or vehicles.

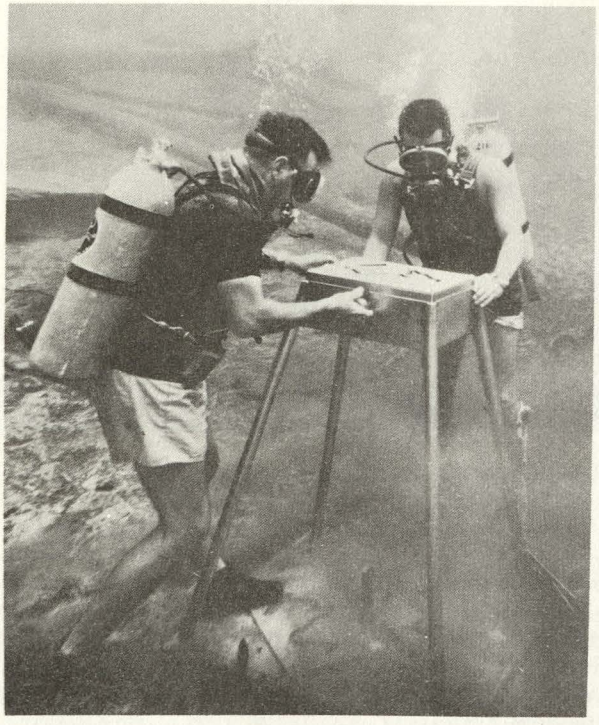

Fig. 102. Diver performing two-hand coordination test in shallow water

Group Assembly Test — The purpose of this task was to observe the manner in which a group of four men planned and carried out a task requiring the perception of complex spatial relationships and the cooperative assembly of components. The task required four divers to cooperate in the assembly of a three-dimensional structure utilizing short lengths of 1/2-in. pipe and appropriate connectors. A drawing showing the final assembly was provided to the divers. The divers were asked to work out a plan of attack, prior to beginning assembly. The time taken to execute the assembly was recorded.

Sensory Tests — The sensory tests were chosen to gain knowledge of visual and auditory functions and to determine specific answers of interest to the operational Navy. For a variety of reasons (to be discussed later), several of the planned experiments were not carried out. Those tests which were conducted are mentioned below.

Audiometric Tests — Pre-exposure and postexposure hearing tests were administered to all divers. Hearing levels (re American Standards Association, 1951) at 500, 1000, 2000, 3000, 4000, and 6000 cycles per second (cps) were obtained using a Rudmose ARJ-4 Bekesy-Type Audiometer with Otocups. The technique and equipment for all tests were identical, and the equipment was calibrated before and after each series of tests. Hearing levels were derived from the Bekesy-Tape tracings in the usual manner of accepting midpoints of the tracings and recording thresholds in 5-decibel (db) increments.

Visual Tests — Although several visual tests were planned related to color, form, and light visibility, it was not possible to collect baseline data before submersion on these tests. During a predive briefing, however, the divers were shown the types of targets to be used, and the procedures to be followed. In addition, brightness measurements were made so as to establish the optical characteristics of the targets.

Mental Ability Test — A test of mental arithmetic was given to estimate the gross level of mental functioning of the divers. This test consisted of multiplying a two-digit number by a one-digit number; zero's, fives, and multiples of eleven were excluded. The task was to complete as many items as possible in a two-minute period. Laboratory and chamber studies have shown that mental arithmetic is affected by narcosis. It was desirable, therefore, to ascertain differences between dry-land data and data collected during submersion.

Data Collected Inside Habitat During Submersion

1. Mood checklist — A self-report of moods filled out every other day.

2. Daily activities checklist — A self-report of eating, sleeping, and recreational activities filled out each day.

3. Sortie reports — Specially designed report forms were provided to the divers on a daily basis to enable them to report in detail on their activities during each sortie into the water. These forms were filled out in the habitat following each dive or during the evening. The forms had three main parts. Part I required the subject to state the plan of his dive and, when he did not complete the plan, the reasons preventing completion. Clothing, equipment, and tools used also were noted. Insofar as feasible, this reporting was done by means of a checklist. Other insertions in this portion of the form included the name of the "buddy," exit and reentry times, diving depth, and conditions encountered in terms of visibility, temperature, and bottom state.

Part II provided space for reporting the objective results of the various tests the diver performed. Part III required the diver to estimate the difficulty or ease of any task he undertook during the sorties; his personal state in terms of a strong or weak continuum; and whether the task required him to be active or passive. In addition to these scales, the divers were encouraged to comment in writing on their diving experience.

4. Arithmetical tests — The arithmetical tests described in the preceding section were administered three times during the period of submersion; at the beginning, near the middle, and at the end.

5. Helium speech data — Although a helium atmosphere has long been known to have a marked effect on speech, little systematic data have been collected. With the advent of underwater living, it is imperative that we study this problem from the standpoint of gaining a better understanding of the underlying mechanism, and to provide information for the design of communication systems. With this in mind, periodic samples of conversational speech were recorded in the surface monitoring station, utilizing the open mikes strategically placed inside Sealab. In many instances, the signal-to-noise ratio was extremely low, due to ambient Sealab noise, and/or noise generated by the communication system itself. Therefore, specified sentences and word lists were read directly into a tape recorder inside the habitat during the periods of relative quiet. It is planned subsequently to analyze the speech content of these tapes. In addition, subjective data were obtained during interviews and with questionnaires as to speech intelligibility in the habitat.

Data Collected in Water During Submersion

To fully understand the data on the performance measures in the water, it is important to keep in mind that the Sealab II Project was not undertaken solely for the purpose of testing human performance capabilities.

The plan for diver participation during each team's 15-day submergence period called for each diver to do each psychomotor test at least once, and for a pair of divers to do one of the tests every other day. It also was planned that when a test measuring strength or manipulative ability was used, it be carried out at the beginning and at the end of a sortie. It quickly became apparent that this plan, or any plan, calling for a systematic accomplishment of the test, could not be implemented. The pressure of events, unforeseen circumstances, malfunctioning of equipment, and the necessity for putting the safety of the divers before every other consideration, rendered the following of any fixed schedule impossible. Under these conditions, it was decided to gather some data on all of the tests, even though the observations from any one test would be small in number, and unsystematic with respect to who did the test, and when.

While the amount of material collected overall was considerable, it is much broader than deep. We may thus expect to see the emergence of a pattern of effects, rather than the precise testing of individual cause-and-effect relationships.

In addition to the tests on which data were collected, plans and preparations were made to conduct additional tests. These tests and the reasons for their lack of success will be described later in this report.

Psychomotor Tests — The following four psychomotor tests are those on which data were successfully collected. In each test the apparatus and general experimental procedures were those described in the Predive Baseline Data section of this chapter. Any modifications of the procedures will be noted.

Strength Test — The two torque wrenches were mounted on the habitat at the end of the shark cage. While performing the test the diver stood on a platform approximately two feet above the bottom. The data were recorded by the divers and later transferred to the Sortie Report Form described earlier. This test usually was done at the beginning or the end of a sortie.

Individual Assembly Test — This test was performed using a platform, mounted on the end of the habitat shark cage, designed to be at working height while standing on the bottom. Due to the arrangement of lights, however, the test sometimes was done on top of the shark cage. This latter situation, coupled with the fact that the habitat had a six-degree list in two directions, made the task more difficult than anticipated. In spite of these obstacles, the divers were able to perform the task successfully.

Two-Hand Coordination Test — The gear box described earlier, with its supporting stand, was located on the bottom about 15 ft from the shark cage. The procedure was followed as planned. Due to technical difficulties with the automatic timer, the divers' watches frequently were used for timing the performance.

Group Assembly Test — This test, due to scheduling difficulties, was only performed once. The plan of attack was worked out inside the habitat. The actual assembly took place in the water using the platform attached to the shark cage.

Visual Tests of Form and Color — The purpose of the Form/Color Test was to measure detection and discrimination of form and color underwater. Many operational situations require a swimmer to distinguish form and color. In addition, future underwater communication systems may require the use of shape and color. For these and other reasons, it was thought desirable to take advantage of the Sealab II program and collect data at depths greater than any worked at previously. Because of variations in ambient light, and the absorption and filtering characteristics of sea water, one cannot be sure as to whether data collected near the surface, say on color discrimination, can be extrapolated to greater depths.

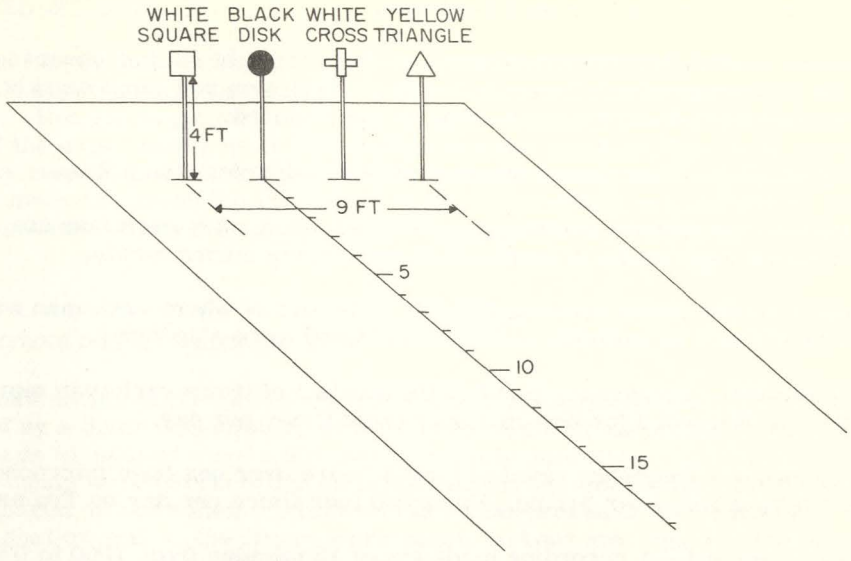

Fig. 103. Arrangement of Sealab II form/color visibility range

Four targets were used; a white square, a black circle, a white cross, and a yellow triangle. The size, area, and experimental arrangement of the targets is shown in Fig. 103. Each target was mounted on the end of a piece of black channel iron. A specially marked surveyor's tape was layed on the bottom, so that the zero end of the tape was directly in front of the line of targets. The test was conducted as follows. Two divers swam to the 48-ft mark on the surveyor's tape, faced the line of targets, and proceeded to swim slowly toward them. The task of the divers was to note independently at what distance they could detect the targets, and at what distance they could positively identify the form. Extreme care was taken not to kick up the mud on the bottom. The tests were taken far enough from the habitat that only ambient light fell on the targets. The observations were made at various times of the day, ranging from 10:00 in the morning, until 6:00 in the evening. Most of the observations were taken around noon. Six different observers were used in this experiment. A total of 20 observations on each target was obtained.

Visibility Studies — The Sealab II program provided one of the few opportunities to collect data on the optical characteristics of sea water simultaneously with human visual data. Each diver was required to estimate the distance at which he could see the lights of the habitat, as well as individual diving lights.

An Inshore Water Clarity Meter, developed by the Scripps Institution of Oceanography, was used during the submergence of Teams 2 and 3. This is an instrument for measuring scalar irradiance and the attenuation coefficient at sea. The instrument can produce profiles of scalar irradiance at depths to 500 ft. During Sealab II it was lowered by cable to a depth of 180 ft. The data, which include a measure of incident light falling on the surface of the sea, is automatically recorded. Whenever possible, readings were taken during the same time intervals that visibility and form/color discrimination tasks were performed. This test is of great importance, as it is the first time that perceptual measurements have been made concurrently with optical measurements underwater. The results of such tests should enable us to predict more accurately visibility ranges for operational purposes from measurements made using a Water Clarity Meter alone.

Topside Audiovisual Monitoring During Submersion

This program consisted mainly of recording behavior in the habitat observed on TV or sounds heard over the open microphones in Sealab. Television and audio signals were monitored 24 hours a day for the entire study. These data included:

1. Order of arising — Observation of when and in what order men got up.

2. Meal recording — Record of who prepared each meal, when each man ate, and who cleaned up. Attempts were made to judge mood and activity during meals.

3. Location record — Taken every half hour. A record of where each man was and what he appeared to be doing if on camera. Activity and mood were also rated.

4. Activity record — A frequency count of the number of times each man moved on and off one of the cameras. Recorded for one-half hour eight times per day.

5. Laugh record — A frequency count of laughs heard over one open microphone set at a standard level during a half-hour period. Recorded four times per day on Teams 2 and 3.

6. Night watch record — A recording made every 15 minutes from 2000 to 0700 hours indicating who was up and what they were doing. Other measures were suspended during this time.

7. Log book — A running account of "significant" occurrences observed over TV or audio signals, or learned of in other ways.

8. Telephone calls — A count of the number of calls made by each man each day.

Postdive Data

Following each 15-day submersion, the divers underwent approximately 30 hours of decompression. This was followed by about a six-hour rest period and a press conference of 1-1/2 to 2 hours. The debriefing period began at 1300 on the second day, about 50 hours after leaving Sealab. Three men were debriefed the first afternoon, three more the following morning, and the remaining three or four men the second afternoon. The debriefing consisted of an audiometric examination, medical examinations, the completion of questionnaires, and a personal interview.

The members of the Human Behavior Program had the responsibility for the following:

1. A debrief interview of each diver.

2. A debrief questionnaire filled out by each diver.

3. Sociometric questions — Choices of most preferred leaders and teammates.

4. Audiometric tests — Examinations were given to each diver at times ranging from 12 hours to 36 hours after they emerged from the decompression chamber. These tests were administered by the same individual, using the same equipment as for the predive test. Although it is recognized that there may possibly have been temporary threshold shifts immediately after coming out of the water, circumstances did not permit earlier examination.

In addition to this program, data have been gathered from numerous log books of both an official and personal nature. Much of this data has not been analyzed at the writing of this report. A detailed analysis of such information should greatly increase our understanding of life and work in Sealab.

UNCOMPLETED STUDIES

The scientific program of Sealab II was intentionally ambitious. It was anticipated, however, that some of the work planned might not be successfully carried out due to constraints imposed by the situation in general and by the physical environment in particular. Furthermore, most of the experiments were being attempted for the first time in an operational situation. For this reason, the following accounts of experiments, which were not completed, are presented. In many instances the reason for lack of completion was primarily one of scheduling. It is hoped that such information may provide guidelines for future efforts of a similar type.

Auditory Threshold and Localization Study

The purpose of this study was to determine the distance at which various types of sounds could be heard by a diver underwater, as well as to measure his ability to localize the direction. The sounds to be used were a 500 and 5000 cycle pure tone, a series of clicks, and FM chirps. The sounds were prerecorded on tape, calibrated, and fed into three piezoelectric hydrophones placed on the bottom. Although the sound-pressure levels had been calibrated previously in shallow water, the divers were unable to hear any signal at the observer's station. A microphone, placed at the observer's station, would not pick up the stimulus signals, but was able to pick up verbal instructions recorded on the tape, indicating that the system was working. Apparently, the 50 watts of power utilized was not sufficient. This is undoubtedly due partly to the high ambient noise levels caused by large generators operating on the surface, noises originating in the habitat, masking of sound by the diver's rubber hood, and bubbles.

Stationary Target Array

Plans were made to set up ten rectangular visual targets to be viewed by the divers from inside the habitat. These targets were to be arranged so that target 1 was five feet from the port window, target 2, 15 ft, target 3, 25 ft, etc. The first four targets contained four colors: black, white, yellow, and orange. The remainder were half white and half black. The purpose was to gather daily data on visibility and to assist divers in planning activities where visibility was a factor.

The Measurement of Visual Acuity

Specially mounted eye charts were devised to measure visual acuity. Although it was not anticipated that acuity would change, it was felt that when taken with the other visibility measurements, these observations would increase our understanding of visual capability underwater.

Observation of Minute Organisms

A special collimated light source was obtained from the Scripps Institution of Oceanography for the purpose of observing the natural motions of plankton and other minute organisms in the water. It was intended that this unit be placed on the bottom in such a way that the light would point into one of the ports of the habitat. Because the light rays would be parallel, all plankton and other small organisms would be seen clearly silhouetted to anyone looking into the light from the habitat. Not only would this permit the density of the plankton to be estimated, but the characteristics of their motions could be studied as well.

Television vs Human Visibility

In cooperation with divers of the U.S. Navy Mine Defense Laboratory, it was intended to compare the detection and recognition capabilities of a diver with those of underwater television cameras. The plan called for the diver to swim toward a series of targets with his buddy carrying the camera. The detection and recognition ranges of the diver would be compared

with those seen on the TV monitor. The successful completion of this experiment would have had considerable implications, both from a standpoint of research, as well as military applications. The lack of a suitable underwater TV camera prevented this study from being carried out.

In addition to the specific problems of in-water experimentation, there were several of a more general nature which affected the data gathering in the topside audiovisual monitoring station. Some of these are described briefly below.

1. Unavailability of subjects — The entire Sealab crew was seldom, if ever, available together at any one place at the same time during training. This fact, coupled with inadequate lead time, made data collection less complete than it might have been otherwise.

2. Communications — The marginal intelligibility of helium speech, particularly in a high-ambient-noise environment, caused serious difficulties with regard to monitoring communications and conversation. Furthermore, the failure of the electrowriter, provided for the purpose of recording written communications to topside, meant that these data likewise were not available for analysis as had been planned.

3. Problems in TV monitoring — The data gathered around the clock by observing TV was compromised by frequent poor picture quality, plus the fact that the entrance area of the capsule was not covered by a TV camera at any time. This was the area in which nearly all preparations for dives were carried out. Extensive plans had been made to gather data on dive preparation, and the availability of such information would have increased greatly the knowledge of social interaction and problems associated with such activities.

RESULTS

This section, to be meaningful, should be interpreted with a clear understanding of the nature of the Sealab environment. For this reason the following comments are included prior to presentation of the results.

Environmental Stresses of Sealab

There can be little doubt that the Sealab environment was stressful. This, however, does not imply that deterioration in behavior as a result of the existing stresses was necessarily predicted. Rather, to speak of Sealab as stressful is to attempt to define the context in which behavior was assessed in this study.

The following description of the Sealab II environment is intended to give to the reader a clear picture of conditions as they existed during this experiment. It should be understood, however, that the aquanauts were more accustomed to working under such circumstances. While these adversities may seem almost insurmountable to the average reader, they are viewed more as a challenge and inconvenience by the Sealab divers.

A principal cause of stress in Sealab was the sea itself. The ocean at 200 ft is an unforgiving adversary. The water was cold (46° to 50° F) and visibility was poor, ranging from zero to 30 ft at best. For safety reasons, slight negative buoyancy was desirable for a swimmer. Negative buoyancy, however, kept a man on the ocean floor, where swimming action would stir up fine silt, thus complicating the visibility problem. Further, by being close to the bottom, he was exposed to the painful stings of bottom-lying scorpion fish. Additional complications in the water were presented by the fact that the terrain was unfamiliar. Landmarks had to be learned gradually, and it always was necessary to follow lines attached to Sealab; otherwise it would have been quite easy to get lost. Once lost, a man away from Sealab would be at the mercy of his limited air supply, since there was no possibility of heading for the surface, the normal reaction of a diver in trouble. To surface would mean instant and certain death from the bends, as each man was saturated with gas at approximately seven atmospheres pressure. A single 40-in.-diameter hole, the entrance hatch in his habitat, was the only safe haven for a Sealab aquanaut.

Danger was inherent in the equipment which supplied breathing gas in the water. Both the Arawak and Mark VI presented problems. The Arawak enabled a man to breathe the Sealab atmosphere through hoses from inside the habitat. There was the constant danger of the hoses fouling or kinking, cutting off a man's gas supply and trapping and holding him in the water. The Mark VI self-contained breathing apparatus is a delicate piece of equipment. It was subject to a variety of malfunctions, some of which could occur without warning, such as CO_2 buildup or malfunctions in regulator valves. The divers' wet suits also were far from perfect. Some fitted too losely, thereby allowing cold water to flow inside and chill the man; others fitted too tightly and restricted mobility. Finally, aside from the discomforts and dangers, there were numerous frustrations associated with work in the water. Frequently a man would go out to work on something he couldn't find or for which he didn't have the proper tools.

Working inside Sealab was no picnic either. Crowded conditions in the entrance area presented probably the most vexatious problems. The entrance area was a bottleneck in a very literal sense. Men crowded around in bulky and uncomfortable gear waiting to get into the water. There was almost no place to stow gear out of the way. The habitat sat unevenly on the bottom, with a list of six degrees in two directions. As a result, drawers would slide open or shut, objects would fall off counters, and men would walk up or down hill while leaning sideways. Long hours of careful preparation were required to put a man in the water, and the work schedule was constantly interrupted, delayed, and revised by emergencies or necessities. Work time far exceeded an eight-hour day. Communications with topside and within the capsule were difficult at best, due to the problems of understanding helium speech, and aggravated by constant background noise which rose to a level rendering verbal communication nearly impossible when the Arawak pumps were running. Work involving writing was made difficult by lack of privacy and the fact that writing surfaces were not level and extremely limited in space.

Added to the inconveniences of working were the problems of living in the capsule. The fact that the atmosphere was 80 percent helium gave speech a "Donald Duck" quality. Helium also may have disrupted the human thermostat, so that men were sweating at the same time they felt chilled. Humidity was extremely high in the capsule. It was difficult to provide adequate air circulation, particularly in the bunk areas. This may have caused a buildup of CO_2 and CO, causing frequent headaches. Ear infections and skin rashes provided additional irritations. Although culinary triumphs were achieved by Sealab chefs, the diet was restricted because of a prohibition on frying. It was impossible to smoke in Sealab, and many of the divers were smokers. There were no relaxing drinks or family to come home to at the end of a hard day's work. Sleep was severely disrupted for most men by the long hours of work, high humidity, poor air circulation, and nagging physical complaints. In addition, the necessity of maintaining night watches further disrupted the normal diurnal cycle, and the crowded conditions interfered with all aspects of the daily routine.

Sealab divers also endured the inconveniences and uncertainties associated with their roles as experimental subjects. They were poked, probed, stuck, and asked to fill out repetitious questionnaires. A multipurpose program dictated heterogeneous crews, so that men with wide variations in background and interests were in constant contact with one another. Added to all the uncertainties of a first-of-type operation were such real dangers as the possibility of an object being lowered from the surface caving in one of the portholes, causing instant flooding of the capsule. At the end of their stay, before emerging into the normal atmosphere topside, the dangerous and boring processes of transfer and decompression remained to be endured. Despite the most careful precautions being taken, the transfer from the bottom to the decompression chamber on the support vessel posed the ominous threat of instant loss of pressure, and each man was aware of the possibility. Decompression involved a 30-hour sojourn in quarters even more cramped than those of Sealab.

This then was the stressful environment; crowded, inconvenient, and potentially dangerous. The remainder of this report will be concerned with a description of the men who lived and worked in that environment and how they interacted with it and with each other. Analyses of the data are preliminary and sketchy, but they do permit tentative conclusions and indicate what further analyses may reveal.

Demographic Data

Only a few demographic variables will be listed in this report. There is still a large array of interest and attitude measures to be analyzed. Tables and brief comments below are given for the variables of age, years of diving experience, education, marital status, size of home town, civilian/military status, and career commitment. Breakdowns are given for the entire group and for each team. There were ten men on each team, but only 28 in the total group, since two men were in two crews.

Age — Data on age are presented in Table 20. The numbers in the table represent the numbers of men in each age category. Mean age and age range is given below.

Table 20
SEALAB II AQUANAUTS — AGE

Age	All Teams	Team 1	Team 2	Team 3
20-24	1	1	0	0
25-29	4	1	1	3
30-34	5	1	2	2
35-39	13	4	5	4
40-44	5	3	2	0
45-49	1	0	0	1
Total	28	10	10	10
Mean	35.1	35.2	35.9	34
Range	26	20	12	25

It is perhaps not surprising that the mean age of the group is over 35 and that nearly half the men are in the 35-to-39 age range, since experience was one of the primary considerations in choosing team members. It is no doubt for the same reason, experience as a criterion in selection, that this group is similar to two other adventurous populations, namely, NASA astronauts and the American Mt. Everest climbing team. Both these groups have mean ages in the mid-30 range.

Although mean ages of the three teams are quite similar, there are differences in the range, with Team 2 having markedly less variation in age range than Teams 1 and 3. Since Team 3 had among its members the oldest man in the group, by six years, the mean age does not fully reflect how much younger this group was than were Teams 1 and 2.

Experience — As a group, the aquanauts averaged nearly eleven years of diving experience (Table 21). It is interesting to note that, while Team 3 was the youngest group, its members had the most diving experience. This is true despite the fact that for all team members there was a correlation of about 0.70 between age and diving experience.

Table 21
SEALAB II AQUANAUTS — YEARS OF DIVING EXPERIENCE

Years of Experience	All Teams	Team 1	Team 2	Team 3
0-4	4	4	2	1
5-9	7	0	4	2
10-14	8	3	2	3
15-19	8	3	2	3
20-29	1	0	0	1
Total	28	10	10	10
Mean	11	9.4	9.2	12.5

Education – Sealab aquanauts were quite diverse in educational background, with training ranging from less than a high school education to advanced degrees (Table 22). Members of Team 2 had, on the average, completed more years of school than members of Teams 1 and 2, although differences were not marked.

Table 22
SEALAB II AQUANAUTS – EDUCATION

Level of Education	All Teams	Team 1	Team 2	Team 3
Less than High School Grad.	3	1	0	2
High School Grad.	12	4	4	4
Some College	3	1	1	1
College Grad.	5	3	2	1
Advanced Degree	5	1	3	2
Total	28	10	10	10

Marital Status – As can be seen from Table 23, the men in Sealab were family men, i.e., married men with children. It is interesting to note that the same is true of the two previously mentioned adventurous groups; astronauts and Mt. Everest climbers. Thus it appears that rather than being unencumbered by family responsibilities, the opposite is true of men volunteering for assignments in adventures of this type.

Table 23
SEALAB II AQUANAUTS – MARITAL STATUS (AUGUST 1966)

Marital Status	All Teams	Team 1	Team 2	Team 3
Single	1	1	0	0
Divorced	3	1	0	2
Married/No Children	2	1	0	1
Married with Children	22	7	10	7
Total	28	10	10	10

Hometown Size – Most of the aquanauts grew up in small towns and small cities (Table 24). Whether small-town lads seek adventure in disproportionate numbers is an interesting question worthy of study in its own right.

Table 24
SEALAB II AQUANAUTS – SIZE OF HOMETOWN

Size of Community	All Teams	Team 1	Team 2	Team 3
Farm or Village	8	2	2	4
Small City of 5000-50,000	10	3	5	3
City of 50,000-500,000	6	4	1	2
Large City over 500,000	3	1	1	1
Total	27	10	9	10

Civilian/Navy Status – Civilian scientists and technicians and Navy divers participated in Project Sealab. Table 25 gives the numbers of men so categorized by team and for the whole group. Among the Navy men, two were commissioned officers, 10 were chief petty officers,

and six were first class petty officers. Whether Navy or civilian, officer or enlisted man, every one of the aquanauts in Sealab was fully committed to his career. In response to the question, "In general, how do you feel about your present occupation?" all men chose the response, "I am strongly dedicated to a career in my present field." The unanimous answer to this question probably sums up as well as any battery of questions could why these men were in Sealab. For comparative purposes, it can be noted that the answer to this question is far from unanimous for men participating in Project Deep Freeze. Men of Deep Freeze include Navy and civilian specialists who winter over in the Antarctic.

Table 25
SEALAB II AQUANAUTS – CIVILIAN/NAVY STATUS

Status	All Teams	Team 1	Team 2	Team 3
Navy	18	7	6	7
Civilian	10	3	4	3
Total	28	10	10	10

Psychomotor Tests

Strength Test – The data comparing performance on land with that during submersion are shown in Table 26.

Table 26
COMPARISON OF STRENGTH-TEST DATA ON LAND AND SEALAB SUBMERSION (RECORDED IN FT-LB)

Type of Test	Dry Land	Sealab	Difference of Group Means	Mean Difference Scores*	Number of Observations to Compute Mean Difference Scores
Pull					
Group Mean	236 ft-lb	200 ft-lb	36 (15%)	38	12
Number of Observations	15	58			
Lift					
Group Mean	626 ft-lb	606 ft-lb	24 (4%)	25	13
Number of Observations	15	60			

*Difference scores are computed by comparing each individual's performance on dry land and in Sealab when the same individual performed the test under both conditions. Twelve men performed the pull test both on dry land and in Sealab. Thirteen men performed the lift test in both locations.

It is evident that exertable force decreased under Sealab II conditions, particularly for the pull test. This may reflect, in part, the difficulty of performing the test when the feet cannot be anchored as firmly as on dry land and, in part, the relatively greater attrition that smaller muscle groups may suffer due to cold as compared to larger muscle groups. In discussing

this test with the divers following submersion, it was revealed that some of the men found it annoying to be required to perform the test. This was particularly true at the end of a sortie when they were cold and tired. As a result they occasionally vented their frustrations and annoyance on the test by pulling for all they were worth. This large expenditure of energy (for whatever reason) may have had the effect of counteracting what might, under normal conditions, be a larger loss of overall strength. The fact remains, however, that the energy resources were available when called upon.

It is interesting to note further that a significant positive correlation was found to exist between the amount of strength exerted and (a) the expressed dislike for meals, and (b) complaints about not having enough free time. These relationships lend support to the notion that certain men felt frustration and annoyance and that they found suitable expression both by reporting their dislikes and by extreme application of themselves on the strength test.

Individual Assembly Test — The individual assembly (triangle) test was performed on dry land, in shallow water, and during Sealab. Table 27 presents the group means (M) and the number of times the test was performed (N). The (N) does not necessarily indicate the number of divers who performed the test, inasmuch as some divers performed the same test more than once.

Table 27
GROUP MEANS (M) AND NUMBER OF TRIALS (N)
FOR INDIVIDUAL ASSEMBLY TEST
(Data Given in Seconds)

Test Configuration	Dry Land		Shallow Water		Sealab	
	M*	N†	M†	N†	M†	N†
Triangle 1 (Lg. Bolts Same Corners)	58.7	12	78.5	13	105.2	9
Triangle 2 (Sm. Bolts Same Corners)	83.1	21	97.3	13	110.7	8
Triangle 3 (Lg. Bolts Diff. Corners)	77.6	12	87.1	13	108.2	10
Triangle 4 (Sm. Bolts Diff. Corners)	85.9	21	103.3	13	159.0	7

*Mean value.
†Number of tests.

Figure 104 illustrates more clearly the overall trend of the data. The data show a 37-percent increase in performance time between dry-land and Sealab conditions. It also shows that performance time increases as a function of smaller size components and greater restriction on the number of available ways to assemble the triangle properly. It should be noted that success in the individual assembly task is significantly correlated with the amount of diving experience and significantly negatively correlated with the number of aborted missions. That is, the shorter the assembly time, the fewer number of aborted missions. An interpretation of these findings will have to await further analysis.

Two-Hand Coordination Test — The amount of data taken on this test was less complete than for all other psychomotor tests due to equipment malfunctions and allows a comparison to be made of the three conditions of performance only for plate 5. The track on this plate was essentially a straight line S with a "bump." Table 28 presents a summary of the data.

The data indicate a 17-percent increase in performance time between dry land and Sealab conditions. Plate 5 might be considered to be a medium difficulty. It should be of interest in the future to determine the relationship between level of difficulty and performance decrement, using some of the more difficult plates not used sufficiently in this study for valid conclusions to be drawn.

Group Assembly Test — Only one group assembly test was undertaken outside the habitat. The time taken was 12 min, 20 sec. However, the team had practiced assembling the components and discussed their strategy immediately prior to going out to do the test. Hence, the time taken may be compared to the best time recorded by a team operating on dry land who had inspected the test, discussed it, and practiced it. The best dry-land assembly time was six minutes. There is thus prima facie indication that this type of work may take twice as long to do under Sealab conditions as compared to dry-land conditions.

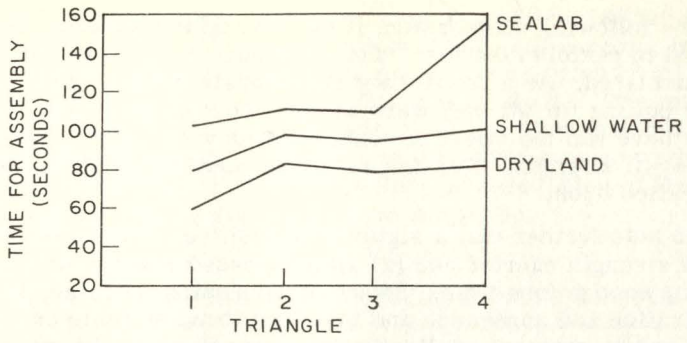

Fig. 104. Mean time (in seconds) of all subjects and all trials for individual assembly test (triangle 1 - large bolts, same corners, triangle 2 - small bolts, same corners, triangle 3 - large bolts, different corners, triangle 4 - small bolts, different corners)

Table 28
TWO-HAND COORDINATION TEST DATA FOR PLATE 5 UNDER THREE CONDITIONS
(Data Given in Seconds)

Test Environment	No. of Tests	Time to Accomplish Test (Mean)	Difference in Means	Mean of the Difference Scores	No. of Divers Performing Both Tests
Dry Land	45	125.1	19.2	21.8	14
Shallow Water	14	144.3	Insufficient Data		
Sealab	6	150.8			

Mental Arithmetic Test -- As described earlier, this task consisted of multiplying a two-digit number by a one-digit number. The divers were instructed to complete as many problems as possible in a two-minute period. Table 29 compares the predive results with the results obtained in the habitat during submersion.

Table 29
COMPARISON OF MENTAL ARITHMETIC TEST DATA OBTAINED ON DRY LAND AND INSIDE SEALAB

Performance	Dry Land N* = 55	Sealab N = 66
Mean Number of Problems Attempted	26.49	30.10
Mean Number of Problems Correct	24.31	27.78

*N is number of tests.

The results indicate that not only was there no decrement in performance, but rather that performance actually improved in Sealab. This suggests that there was a practice effect (although not statistically significant) between the two conditions. These data do not demonstrate

that there was no mental deterioration during Sealab, but only that, if there was any, it was not gross enough to be detected by this test.

Visual Studies

Form/Color Test -- It will be recalled that the purpose of this test was to measure detection and discrimination of form and color underwater. Six divers were used to obtain a total of 20 observations on each of the four targets. Table 30 shows the mean detection and recognition distances.

Table 30
DETECTION AND RECOGNITION DISTANCES
FOR THE FORM/COLOR STUDY
(N = 20)

Measured Parameter	Targets (ft from subject)			
	Black Circle	White Square	Yellow Triangle	White Cross
Detection	24.4	18.3	16.7	16.5
Recognition	20.0	14.2	13.5	13.4

It is readily apparent that the black circle is both detected and identified at greater distances than either the white or yellow targets. This is particularly interesting when considering that it is the smallest of the four targets in area (black disc = 707 sq cm, white targets = 900 sq cm). The differences between the means of the black circle and the white square were tested using the standard t-test and found to be significant at better than the 0.01 level of confidence. The mean detection and recognition distances of the white cross and yellow triangle are even less than the white square.

When one considers that visibility is a function of contrast between target and background, it becomes clear that the contrast of the black circle was greater under the conditions surrounding Sealab.

General Visibility Observations -- A major factor in underwater operations is visibility. The selection of the Sealab site was, in fact, almost changed at the last minute because of poor visibility. Although the experiments on underwater light visibility were not carried out as planned, some data were obtained during the debriefing interviews. Each diver was asked to estimate the maximum distance he could see a 1000-watt underwater quartz light. For Team 1 the mean answer of nine responses was 48 ft, with a range of 30 to 60 ft. For Team 2 the mean answer was 60 ft, with a range of 50 to 70 ft. Team 3 had a mean of 95 ft and a range of 40 to 170 ft. It is apparent that the general visibility was improving during the 45-day submersion period.

Data were collected with the water-clarity meter during Teams 2 and 3 dives, which hopefully can be related to the daily reports of visibility recorded on the sortie report form.

All 28 divers stated that the white habitat was far more visible than the reddish-orange personnel transfer capsule (PTC) sitting on the bottom 15 ft away. In many cases the habitat was said to be visible at two or three times the distance of the PTC.

Further studies need to be performed on underwater visibility of light and color. It must be kept in mind that studies in fresh water and even at shallow depths in the ocean cannot necessarily be extrapolated to greater depths. This is particularly true when selecting paint and coding colors.

Tentative Findings on Overall Adjustment and Adaptation

Introduction — In this section we will present a few tentative findings on adjustment and adaptation to the Sealab experience by team and by men. It is important to emphasize the fact that the data presented and discussed here are in a most preliminary and rudimentary stage of analysis.

Three facts stand out. First, there is the general observation that, as a group, the aquanauts performed at a high level and adapted very well to their environment. Second, there were individual differences in performance and adaptation. The existence of individual differences in performance does not, however, imply that some men succeeded and others failed in Sealab. It means simply that some men performed better than others in a situation in which the level of performance of all of the men was at a high level.

Third, it seems apparent that individual differences in performance and adaptation can be predicted on the basis of demographic and personality characteristics of the men. Since there are some 12 to 15 criterion variables and 20 or more predictor variables, the analysis is extremely complex. However, such an analysis should produce a profile of characteristics which predict performance and adaptation in a Sealab-like environment, as well as in other unusual and hazardous environments. Thus the results of this study should produce valuable information for selecting future personnel to participate in programs of these types.

Team Performance and Adaptation — As mentioned previously, the best general descriptive statement regarding performance and adaptation is that all three teams performed at a remarkably high level and adapted to their environment and to each other very well. Possibly the best specific indication of this generalization is the fact that there was an increase in average daily time in the water for each succeeding team. Even more indicative of adjustment by each team is the fact that there was an increase in average daily time in the water in the second week compared to the first week for each of the three teams. A second specific indication of favorable adjustment is that team cohesiveness, as measured by sociometric choice, increased for each of the three teams from pre to post choices.

In Table 31 data are presented bearing on cohesiveness. The numbers in Table 31 were derived as follows. Each aquanaut was asked to name in order the five men he would most like to have as teammates in Sealab. Each man's choices were given a weight of 5 for first, 4 for second, etc., to 1 for fifth. For use in Table 31, these weighted choices were called in-group or out-group, according to whether or not the man chosen was on the same team as the chooser. Thus the in-group choices could range from 0 to 150 (10 men $\times$ 15 points per man; i.e., $5 + 4 + 3 + 2 + 1) \times 10 = 150$) and the out-group choices would be the reciprocal. A total of zero in-group choices would mean that no one on a team chose another team member, while a total of 150 in-group choices would mean that all men on the team chose fellow teammates for all five choices. Thus, the higher the number, the more cohesive was the team. Data in Table 31 include some slight correction for missing cases, since data were not obtained from two divers on the postexperiment measure.

Table 31
SOCIOMETRIC CHOICES OF SEALAB AQUANAUTS OF OWN-TEAM MEMBERS BEFORE AND AFTER TEST

Time of Choice	Total All Teams	Team 1	Team 2	Team 3
Pre	147	47	27	73
Post	250	102	47	101
Change Pre to Post	+103	+55	+20	+28

The numbers in Table 31 contain a wealth of interesting data for both speculation and specific inference. First and most important is the fact that in-group choices increased for all three teams, indicating a favorable within-group atmosphere. There was no particular reason to anticipate this result, as the change could easily have gone in the opposite direction. A second interesting fact is that team composition appears to have been virtually random according to sociometric choice before the experiment. What is meant by this statement is that only 147 of a possible 450, almost exactly 1/3, of the choices for teammates were made from within the teams as assigned. Thus, it appears that there was as much identification with the entire group of 28 aquanauts as there was for a ten-man team before the dive. A third point of interest is the difference in cohesiveness scores among teams. Team 1 apparently had a much greater increase in cohesiveness than did the other two teams. The greater increase in cohesiveness in Team 1 could have been due to their being the first team, that is, due to the greater stresses associated with initiating the system, and to the fact that there seemed to be greater similarity in the types of tasks performed by members of Team 1 than there was on Teams 2 and 3.

In addition to the quantitative data regarding time in the water and team cohesiveness, there were other less precise indications of successful performance and adaptation. Chief among these indicators were comments by a number of men to the effect that work got easier as time went along; that there was better planning and scheduling; that they adapted to the cold water; the nearly universal eagerness to take part in future Sealab type studies; and the complete absence of any serious interpersonal disagreements on any of the three teams.

Despite the overall favorable reactions indicated above, there were some ripples in this sea of tranquility which should be mentioned.

Most of the aquanauts expressed dissatisfaction or disappointment with the amount of work they were able to accomplish. Their dissatisfaction is no doubt in part an indication that this was a highly motivated, task-oriented group of men. A major factor limiting work output was the design of the capsule, particularly the entrance area.

Another factor was fatigue. For a variety of reasons many men had a great deal of difficulty in getting adequate sleep in Sealab. A number of men commented that while they would like to have stayed longer, they were ready to leave at the end of 15 days because of fatigue.

Another work-inhibiting factor was the amount of time which had to be spent on housekeeping and maintenance chores. One change which might be considered would be either supplying meals from topside or including a crew member whose sole duty would be to prepare meals. To adopt one of these alternatives would, however, make future Sealabs more dependent on surface support than was the case with Sealab II. Finally, there was the factor of crew heterogeneity. A number of men felt that others on their team either did not cooperate fully in helping them to perform their functions or that others had insufficient work to do while they were overloaded. Comments to this effect were made by the majority of divers on Teams 2 and 3.

Association Among Predive, Dive, and Postdive Measures — Data presented in this section represent more a preview of things to come than they do a systematic presentation of results.

Each diver was assigned a score representing the number of times he was chosen as a desirable leader or teammate. *These scores were correlated with a variety of diver characteristics and behavioral variables. There are missing data which may alter slightly some of the correlations presented here.

Each man was asked to name, before and after, the five men he would most like to have as a leader and the five men he would most like to have as teammates in Sealab II or in future

*NOTE: A comment about the significance of correlations is appropriate for understanding the results presented. Human behavior is so complex that nearly all interrelations involving measures of men and their performance are inexact and probabilistic. Therefore, rules involving the laws of probability are used to determine when a relationship exists. To say that a correlation is significant means that the relationship involved is of such a magnitude that it does exist and is not due to chance factors. All correlations reported here are significant by this definition, except where stated otherwise.

Sealabs. Correlations between before-and-after choices were very high, but there were changes. The correlation between men chosen as leaders on the predive and postdive measures was +0.94, while the same correlation for teammates was +0.79. It is not surprising that these correlations were so high in view of the previously mentioned good intra-team relations. Climbers on the American Mt. Everest team evidenced the same stability in predive and postdive sociometric choices. The higher correlation for leader than for teammates is probably due to the fact that fewer men were seen as potential leaders.

Although the correlations between before-and-after choices were high, there were changes in men chosen. First, there is an indication that different characteristics were used in naming leaders and teammates, since the correlations between predive leader and predive teammate choices was +0.42 and that between post leader and post teammate choices was +0.49. While these correlations are quite high, they do not approach the level of predive-postdive correlations on either the leader or teammate choices.

Age was a significant variable in the choice of leader and teammate. Older men also tended to be preferred for leaders and teammates on before-and-after measures. As could be expected, the correlation between age and choice for leader is higher than that between age and choice as a teammate. At first glance it is somewhat surprising to see that choice as leader and years of diving experience are not significantly correlated. This lack of relationship, however, is probably artificially determined by one man who was highly chosen as leader even though he had relatively little diving experience. Of considerably greater interest is the fact that there is a high correlation between years of diving experience and choice as teammate on the predive measure ($r = +0.55$), but that this correlation drops to +0.27 (not significant) on the postdive measure. This means that while diving experience played a large part in choosing teammates in the predive measure, other factors assumed greater importance as a result of exposure in Sealab.

A brief look at some other variables provides clues as to what might have made the difference in pre and post choices. There was a tendency not to choose men who complained about conditions in Sealab or who made frequent telephone calls from the capsule. Measures of complaints are taken from answers to the postexperiment questionnaire. The number of telephone calls is a straight frequency count of personal calls initiated by divers from Sealab. While extreme caution is necessary in attributing causative relations to such correlations, it does appear that men who were most satisfied and content with their lot in Sealab were the ones who were chosen as desirable future teammates. This interpretation is supported by the fact that the amount of time a man spent in the water was correlated with postdive sociometric choices. Finally, sociometric choices were correlated with a number of predive measures of mood and attitudes. Although these measures are too obscure in meaning to warrant discussion at the present stage of analysis, the existence of such relations does indicate that it will be possible to specify the characteristics of divers which are deemed desirable by their teammates.

Audiometric Test* — An examination of the pre-exposure data provided a basis for several general observations. Only four of the 28 subjects had normal hearing, conventionally defined as no more than 15-db loss at any of the test frequencies in either ear. Four other subjects had normal hearing for one ear, with below-normal hearing levels for the contralateral ear only at test frequencies above the speech range (3000, 4000, and 6000 cps). Five of the subjects had hearing loss (greater than 15 db) at one or more of the test frequencies in the speech range (below 3000 cps), in addition to high-frequency hearing loss. The remaining subjects (about half) all had high-frequency loss, with some extreme instances (up to 70 db). The average hearing levels for all ears (subjects combined) were within the normal range, except at 4000 cps and 6000 cps, but these averages are inherently deceptive, as they tend to conceal the wide range of individual differences. As the main interest and concern are with individuals rather than group data, statistical analysis of the data is not appropriate.

*This test was conducted and the results analyzed by Dr. George Harbold, Life Sciences Division, Naval Missile Center, Point Mugu, California.

Comparisons between the predive and postdive data were made to determine any possible trends from the effects of prolonged pressure exposure on hearing levels. Again, a wide range of individual differences was demonstrated. The differences between predive and postdive thresholds were aggregated for all subjects and ears by test frequencies. Less than one-fifth of the changes were in the direction of better hearing levels. Slightly less than one-fourth of the threshold differences, when viewed in the same manner, showed no change between predive and postdive levels. In contrast, more than half of the hearing-level changes were in the direction of hearing loss. Thus a trend toward acquired hearing loss is indicated. It should also be pointed out that although changes were relatively small when postdive levels showed better hearing (usually 5 to 10 db), the postdive hearing loss changes were more prevalent and greater (up to 25 db).

The conclusions from a pilot effort such as this should be viewed as tentative, but certain implications are fairly obvious:

1. Hearing levels of divers tend to reflect a pattern of acoustic trauma quite similar to that of personnel exposed to high-intensity noise levels. Hearing ability of divers is also subject to additional deleterious effects from more than the usual amount and degree of ear pathologies. Therefore, the need for a program of hearing conservation for these personnel is indicated.

2. The single episode of exposure to the environmental conditions of Sealab II resulted in very little change in hearing levels for frequencies in the speech range (below 3000 cps), but a trend was indicated for hearing loss at the higher test frequencies (3000 cps and above). Therefore, any future projects of this nature should include a more comprehensive and carefully planned study of auditory functions.

GENERAL DISCUSSION

Psychomotor Tests

The data at hand indicate that a general decrement in human performance occurs between dry-land and shallow-water conditions, and increases under Sealab conditions. The trends of the data indicate that short-term, simple performance, requiring little thinking and not dependent on the use of the senses to any extent (e.g., strength test) is least affected, and that complex, prolonged performance, calling on many human faculties (e.g., group assembly), is most affected. This differential decrement effect can be seen most clearly in the data from the individual assembly test, where the task difficulty increases in terms of dexterity requirements and the need to attend to spatial relations.

There are indications in the data, as analyzed thus far, that some part of the performance decrement is associated with personality variables. As previously mentioned, relative lack of frustration tolerance, evidenced by expressed dislikes and complaints, is echoed in high strength-test scores. It also appears that persons enjoying above-average choice as fellow team members do well on the individual assembly test. This may reflect a desire to be with persons who are careful and methodical in their work, virtues which would tend to be shown in high scores on the individual assembly test. As examination of the data continues, other relationships of this type are expected to emerge.

While these individual differences in underwater performance are important for the purposes of team selection, task allocation, etc., the major issue is the observation of the average performance decrement, particularly the sizeable decrements associated with the more complex tasks.

Helium Speech

The problem of verbal communication in a helium atmosphere is well known. The difference in the density of the medium causes everyone to sound like Donald Duck. Upon entering Sealab, many divers, especially those to whom the experience was novel, found the situation

utterly hilarious. In addition to the humorous aspects, however, the voice distortion posed a considerable communication problem.

This problem, to a certain extent, annoyed the divers during the entire 45 days. It often was difficult to communicate a complex idea or set of instructions. For regular conversation regarding food and equipment, however, there was a remarkable amount of adaptation. Although postdive questionnaires and interviews revealed that 23 of the 28 divers had initial difficulty in communicating, when asked, "How soon were you able to understand all nine other aquanauts quite well?" the responses showed that 16 divers felt they could in one to two days, eight more by the end of four days, two more by the eleventh day, and one never.

Each diver stated that the voices tended to get lower in pitch and that the rate of speaking slowed down. Most divers said they learned to recognize voices in two to three days. There always was extreme difficulty in localizing sounds due, it is supposed, to the inherent difficulty of locating high-pitched sounds plus the reverberation characteristics of a closed chamber. Several commented also that their voices did not seem to carry over two to three feet. Whether this was due to high ambient noise level produced by equipment or to the helium atmosphere was not determined. A striking example of the extent to which adaptation took place was brought out when three members of Team 2 entered the habitat prior to Team 1 leaving. Team 1 members had so adapted to each other, over the 15-day period, that they were hardly able to understand the three newcomers for several hours. The newcomers were laughed at because of their "high squeaky voices."

Although once again man's tremendous powers of adaptation were shown, there is much work to be done in this area. Inasmuch as men in a helium environment will always have to communicate with "outsiders," techniques of making the speech understandable will have to be developed. Likewise, future diving operations will require swimmer-to-swimmer communication systems. For these reasons the selected word lists and phrases recorded during Sealab will be carefully analyzed.

Personal Equipment

The men spent much time in selecting and preparing their personal equipment. In some cases, they had little choice in the matter, while in others they had complete freedom. Two types of wet suits were available, in three different thicknesses: 3/16 in., 1/4 in., and 3/8 in. Generally, the men preferred the 3/16 or 1/4 in. suits because of greater mobility. In some cases the top of one suit and the bottom of another would be worn. There was no unanimous choice of one particular suit. The experimental heated suit used by a few divers was found to be comfortable and warm, but because of poor fits (resulting in cold water leaking in), was of limited usefulness in Sealab II. The battery packs were felt to be too large and interfered with various activities. This was a prototype suit, and such difficulties are to be expected. The suit is a big step in the right direction.

Three different kinds of gloves were worn. Mittens were found to be warm, but totally unsatisfactory for doing work. Both the three-finger and five-finger gloves were used satisfactorily. Preference for these gloves was about equally divided. Four or five divers never wore gloves because they felt they couldn't work with them. On the other hand, some of the individual triangle assembly tasks were satisfactorily done while wearing both three-finger and five-finger gloves.

The conventional hand tools (wrenches, rope, etc) were found to be satisfactory. All moving parts had to be carefully washed and coated with permalube daily to prevent corrosion. Carrying tools around sometimes presented problems. Whereas one tool could be tucked inside the wet suit, a diver carrying several had either to tie them on his wrist or use a bag. The development of multipurpose hand tools would help to alleviate some of these problems. Some type of coding to make it easier to find dropped tools would also be of great value. A dive may, at times, have to be aborted because a dropped tool cannot be found. With the advent of underwater living, more sophisticated jobs will be undertaken calling for more sophisticated tools. Collaboration between designers, divers, and human engineers should result in greatly improved tools and/or equipment.

Divers' Comments on the Habitat

Whenever long periods of time are spent in a confined area, factors related to comforts and conveniences, workspace layout, noise levels, lighting, etc., which, for short stays, are hardly noticed, become annoying and, at times, intolerable. The Sealab habitat is no exception.

The debriefing interviews and questionnaires revealed that there are many improvements which can be made. Each diver was asked to indicate the relative importance of a detailed list of improvements. No attempt will be made here to discuss each of these lists. There were, however, several problems of sufficient importance to affect the performance of the overall operation.

The single most important problem with respect to work interference was the size of the entrance hatch and diving area. This area was always congested with men and equipment and severely hampered operations. For example, it took an average of 45 minutes to prepare for a dive with the Mark VI scuba rig. It took another 30 to 40 minutes to clean up after a dive. This amount of preparation and cleanup time for a 30 to 40 minute dive sometimes discouraged divers from going into the water at all. The overall result was less time in the water than otherwise might have been the case.

Other serious problems were related to humidity control, air circulation, storage space, and noise levels (primarily due to the air compressors for the diving hose). In addition, there were problems concerning outside lighting, hoist and cargo-handling facilities, layout of bunkroom, and poor communication equipment.

Cold Water and Visibility

As discussed in the introductory paragraphs of the Results section in this chapter, there are many hostile features present when living in the ocean. Cold water and poor visibility were constant companions during Sealab II. When asked on the questionnaire, "Did you feel you became better acclimated to the outside water temperature as time went on?" of the 26 divers responding, ten said, "Yes, quite well;" 12 said, "Yes, somewhat;" three said, "Yes, only slightly;" and one said, "No, not at all." During the debriefing interviews some stated that they felt they adapted in two to three days, while others felt they were still adapting to the cold even at the end of the 15-day period. Interestingly, a few said the water felt warmer at night, even though the thermometers did not bear them out. Many reported that their efficiency increased as adaptation took place, and that at the end they were coming back to the habitat more because of becoming tired than being cold. The degree of physical activity, of course, had a marked effect on the feeling of being cold. All in all, the problem of cold can be overcome by initial selection of divers, by careful planning of activities in the water, and by the continued development of improved heated suits.

Poor visibility is a problem over which we have less control. The general poor visibility during Sealab II was of continual concern. Many of the men reported that they were constantly preoccupied with their own and their buddies' personal safety, especially during the first few days. In addition to concern over equipment, there was the ever-present danger of becoming lost. Tether lines or guide lines were used at all times, even though the men became familiar with the topography as time went on. As shown earlier, a diver's light could be seen from 15 to 90 ft, depending upon the water clarity; the glow of the combined lights of Sealab could be seen even further, especially at night. Communication and signaling systems must be developed which will increase the confidence of divers to work a greater distance over wider areas under conditions of poor visibility.

Comments on General Stress

Many reports have suggested that the divers had short memory losses, that silly mistakes were made, poor planning was commonplace, and that generally there was much more confusion than would be expected.

It certainly is true that there was much confusion due to logistic difficulties, schedule changes, etc. Perhaps some of the confusion, mistakes, and memory loss was due to the stressful situation. It must be kept in mind, however, that prior to each dive, detailed preparations had to be made. Each diver had to remember many things, maintain a constant vigil over his air supply, his location, the location and state of his buddy, etc. Furthermore, the lack of swimmer-to-swimmer communication means that a pair of divers have to return to the habitat simply to exchange a few words or plan at great length what appears to be an extremely simple task.

In other words, in addition to the multitude of safety precautions there were numerous details to contend with in an extremely hostile environment. With so much on their minds, it is not surprising that some things were forgotten and that in retrospect, silly things were done and details overlooked. An additional factor is that, in most instances, it was not possible to practice each operation in detail or to conduct simulation training on land. As a result, procedures were not routine to the extent that performance was automatic. It might be mentioned that general observation of performance indicates that the more complex a task the greater the likelihood was that something would go wrong. The human-performance tasks also suggest a relationship between complexity and poorer performance; i.e., the decrement in performance was least for the simpler tasks. One, therefore, must carefully temper judgment regarding the effects of stress with the potentially overwhelming problem of human information processing.

Another factor to be considered is the relationship of the symptoms mentioned above and fatigue due partially to lack of sleep. The behavioral symptoms of sleep loss (forgetfulness, short-term memory loss, difficulty in planning and executing plans, etc.) are extremely similar to those described above. During the debriefing interviews, it was found that almost all of the men had difficulty in sleeping. Some stated they never slept longer than 1-1/2 hours at one time. Previous research has shown clearly that the symptoms described above are associated with sleep deprivation, even in the absence of other stressful factors. It is difficult to pinpoint the reasons for lack of sleep at this point. Some of the most probable contributing factors were high humidity, constant headaches, poor air circulation in the bunkroom, high noise levels, and perhaps being overly tired. Subsequent analysis should permit a more thorough understanding.

General Comments on Motivation and Morale

The preceding sections of this report, describing the environment and working conditions, paint a dismal picture of Sealab II. In spite of all these adverse conditions, the motivation and morale of the divers was extremely high. The comments of the divers upon emerging at the end of each 15-day period indicated that they "were amazed that men of such diverse backgrounds and experience could get along so well under such conditions."

It may be premature to attempt to answer at this stage of data analysis how or why the men of Sealab were able to perform and interact so well. Indeed, this question can probably never be answered definitely. The primary value in attempting to assess reasons for successful performance in Sealab is that it may stimulate thought and discussion and may afford a basis for comparison with similar situations.

Probably chief among the reasons for the performance of men in Sealab II was motivation. The knowledge that they were part of a project with unlimited potential and great significance doubtless had an impact on most if not all of the men. The sentiment behind this high motivation was probably best expressed by one of the divers on Team 1 who, upon being congratulated, responded, "Hell, I'm no hero, 10,000 other Navy divers would have given their right arm to have been in Sealab." Similar thoughts were expressed by many other divers during debriefing interviews. Comments such as, "It was the greatest experience of my life," were made by many. Closely related to the feeling of being involved in a significant project was a real feeling of accomplishment. Despite disappointment in the accomplishment of personal objectives, there was the knowledge that useful work was done and invaluable information obtained in the face of very trying circumstances. Possibly as important as the feeling of individual accomplishment was the sharing of this feeling. In talking to the individual divers there was apparent a sense of shared affect, of vicarious satisfaction in what the whole group had achieved.

All the divers were volunteers, a fact which probably produced a predisposition to endure whatever hardships came along with the feeling that, "I got myself into this and now it's up to me to prove that I can do the job."

Furthermore, each diver expressed a desire to participate in future Sealab operations. Most of them felt, however, that they would prefer to stay down longer in the future, but that a crew size of six to eight would be better in the Sealab II habitat. When asked, "How many days do you think you could live and work in the Sealab II habitat?" the average answer was 31 days. One of the chief reasons given for lengthening the bottom time was that the first week was spent getting organized and becoming familiar with the equipment and topography. Once these goals were accomplished, more time and mental activity could be devoted to accomplishing the job at hand.

While many felt that it would be desirable in the future to have some of the specific housekeeping chores assigned permanently, 22 out of 28 felt that the workday schedule was about right. Along similar lines, some of the Navy members of Team 2 felt they had no jobs to call their own and were primarily supporting the scientific personnel. In the future, it might be advisable either to assign specific operational tasks or to train Navy divers to work closely with a scientist.

Some of the Naval personnel felt it would be much more challenging and that they would be motivated to spend more time in the water if the salvage projects in future Sealabs were genuine. Even though the tasks during Sealab were of an operational nature, it was not the same to them as actually performing a "real job."

The men were asked to compare working from Sealab with doing a similar job from the surface. The response of one of the men expresses the general feeling that, "There is the tremendous advantage of being able to start a job and then finish it. Whereas, say a guy could drop down from the surface and maybe have 20 minutes on the bottom, he could be just two or three minutes away from completing the job and his bottom time would be up and he'd have to quit and they'd bring him up and put somebody else down." It was stated further that if operating from the bottom, "You'd maybe take a couple of tools and go out and start on the job and see just what it was with the idea that, if you needed some more tools, you could pop back in a couple of minutes and maybe change your tools, or get a different wrench and get some more information and then go back out."

Another question asked on the postdive questionnaire was, "Based on your experience, which of the following characteristics do you think most important for a man to live and work in a Sealab environment?" The possible answers are shown in the following list in the rank order in which they were rated by the divers. A desire to "get the job done" and general sociability seem to be the personality characteristics most valued.

A question frequently asked of men living in an unusual environment concerns the matter of isolation feelings. When asked on the postdive questionnaire, "How isolated from the world topside did you feel?" of the 24 responding, ten said, "Not at all," nine said, "A little," four said, "Quite a bit," and one said, "Very much." One interesting comment during debriefing was, "I kept waiting for this sense of isolation, you know — where you hate everybody topside. I never did."

Summary of Rank Ordering by 28 Divers When Asked for the "Characteristics You Think Most Important for a Man to Live and Work in a Sealab Type Environment

1. Diving experience
2. Willingness to do his share of general work
3. Competence in work specialty
4. Physical condition
5. Sense of humor
6. Has imagination
7. Takes orders well
8. Tries to keep everyone's morale high

9. Is tactful
10. Keeps his mind always on the job
11. Doesn't waste time or energy
12. Ability to mind own business
13. Previous experience working with the team
14. Is the kind of person you could tell your troubles to if you felt like it
15. Doesn't get too personal
16. Age
17. Has led the same general kind of life you have

Although all indications are that high levels of motivation and morale are maintained, it must be kept in mind that the novelty of the situation may have played an important role. The next few man-in-the-sea projects may likewise have no morale problems. If, however, large numbers of men are to be chosen in the future for undersea operations, it is important to gather data on which selection criteria can be based.

In summary, it can be stated that the team effort was a success, interest and morale was high, useful work was accomplished, and that much was learned that will benefit both the scientific community and the Operational Navy.

CONCLUSIONS

Much of the data analysis has not been completed at the time of writing this report. There are, however, some conclusions which can be made at this time.

Psychomotor Tests

1. The results of a lift and pull strength test showed a decrease in exertable strength between dry land and Sealab.

2. The individual triangle assembly (manual dexterity) tests reveal a 37-percent decrease in performance between dry land and Sealab.

3. The two-hand coordination test shows a 17-percent decrement in performance in Sealab.

4. The three-dimensional group assembly task took twice as long in Sealab as on dry land.

Visual Tests

1. It was found that a black target was seen at significantly greater distances than either a white or yellow target at a depth of 205 ft in ambient light.

2. It was observed that the white habitat was far more visible than the orange/red personnel transfer capsule.

Mental Arithmetic Tests

No decrement was found between predive and Sealab tests.

Audiometric Test

Little change between pre- and postdive exposure tests were found in hearing levels for frequencies in the speech range (below 3000 cps), but a trend was indicated for hearing loss at the higher test frequencies (3000 to 6000 cps).

Helium Speech

Most divers understood and recognized voices after two to three days, but had continual difficulty in localizing sounds inside the habitat. Speech became lower in pitch and slower with adaptation.

Adaptation to Cold Water

Although some divers said they adapted to the cold water within the first two to three days, many said they were still adapting at the end of the 15-day period. As expected, there were large individual differences in cold tolerance.

The divers stated overwhelmingly that, if the Sealab II habitat is used again, the team size should be six to eight. Many felt also that specific tasks should be laid out for each man before going down.

Motivation and Morale

The motivation and morale of the men was extremely high in spite of the stressful aspects of the situation. It is concluded that mixed teams of Navy and civilian divers can successfully perform useful work. It is cautioned, however, that when the novelty of being "first" wears off, more attention must be paid to the selection of team members.

Overall Adjustment and Adaptation

The amount of time spent diving increased from team to team, and within all three teams from the first to the second week. Group cohesiveness, as measured by the divers' choices of own team members, increased for each of the three teams from pre- to postexperiment measures. That is, more men were chosen from within a man's own team post as compared to preexperiment.

There were differences between teams in original levels of cohesiveness as well as differences in increase in cohesiveness between the teams.

There was no evidence of any serious interpersonal difficulties on any of the three teams.

Despite a general feeling of accomplishment, many men were dissatisfied with the amount of work they personally achieved.

Correlations between pre- and postchoices of both leaders and teammates were very high, indicating that in general the same men were chosen as most desirable leaders and teammates after the experiment as before.

There were, however, some interesting changes between pre- and postchoices, chief of which is the fact that number of years of diving experience was not associated with postchoices, whereas it was with prechoice.

Different criteria were used for choosing leaders and teammates. Men who complained about conditions in the Sealab habitat tended not to be chosen as a teammate on the postdive questionnaire.

In conclusion, it should be made clear that in spite of all the obstacles and dangers present during Sealab II, an unprecedented amount of useful work was accomplished. While some of this work possibly could have been performed from the surface, a diver, with his inherent flexibility for on-the-spot decision making and planning, was the essential element in the program. The aquanauts' performance of scientific and operational tasks demonstrates clearly that man can live in harmony with the hostile undersea environment. Having again demonstrated the tremendous ability of man to adapt, the future of undersea habitation and exploration should be limited only by our technology and imagination.

Chapter 37

ELECTRICALLY HEATED PRESSURE-COMPENSATED WET SUITS FOR SEALAB II

E. L. Beckman
Naval Medical Research Institute
Bethesda, Maryland
and
H. R. Frey
United States Rubber Company
Wayne, New Jersey

INTRODUCTION

Studies on the physiological mechanisms which relate to thermal conservation of the immersed diver have been in progress at the Naval Medical Research Institute for several years. At the time of the inception of Sealab II, this laboratory had a contract with the Marine Corps to develop an insulative and supplemental heating garment for thermal protection of Marine reconnaissance swimmers. A prototype garment had been designed and produced on contract and was in the process of being evaluated at the Naval Medical Research Institute. This R&D program served as a basis for the development of the electrically heated, constant-volume, insulated garment which was ultimately procured for use by the Sealab II aquanauts. As part of this development for the Marine Corps, considerable work had been done to evaluate different types of insulative materials as to their effectiveness as thermal insulators.

A project was therefore established at the Naval Medical Research Institute by Special Projects May 3, 1965, for the design, development, and procurement of electrically heated, insulative underwater swimmers wetsuits for Sealab II aquanauts. Although this time period was very short for a developmental program, it was considered to be sufficient for the development of a prototype garment for use and evaluation by Sealab II aquanauts, because most of the preliminary work had already been done, and the basic concepts of such a garment had already been developed. A contract was let with the U.S. Rubber Company to design and fabricate eight electrically heated, insulative, underwater swimmers wetsuits to be powered by either a battery pack or through a cable from a power supply from within the Sealab. The preliminary description of the suit requirements defined the duration of the underwater exposure as four hours and the temperature of the water as between 45° and 50°F. These two parameters then defined the amount of thermal insulation required of the suit as well as the number of kilocalories (kcal) of heat to be supplied by the suit to the wearer. With these design limitations, the U.S. Rubber Company's inflatable insulative electrically heated wetsuit was designed and fabricated to fit eight of the personnel who were expected to become the aquanauts of Sealab II (Subsequently it was found that one of the wetsuits fitted two aquanauts).

Four aquanauts of Team 1 were fitted with the U.S. Rubber Company's electrically heated underwater swimsuit (Figs. 105, 106). Unfortunately, time had not been available to indoctrinate and train the aquanauts adequately in the use of these garments. Therefore, in several instances when the suits were worn by the members of this team, the gas-purging valves were

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Note: The Introduction to this chapter was written by CAPT Beckman; the balance of the chapter written by Mr. Frey, was originally published as the final report for Contract No. N600(168)63855.

left open during swimming, so that the suits were flooded with seawater.* Although the aquanauts reported that they provided adequate supplemental heating, they were not operating satisfactorily because of the flooding of the air cavity within the suit.

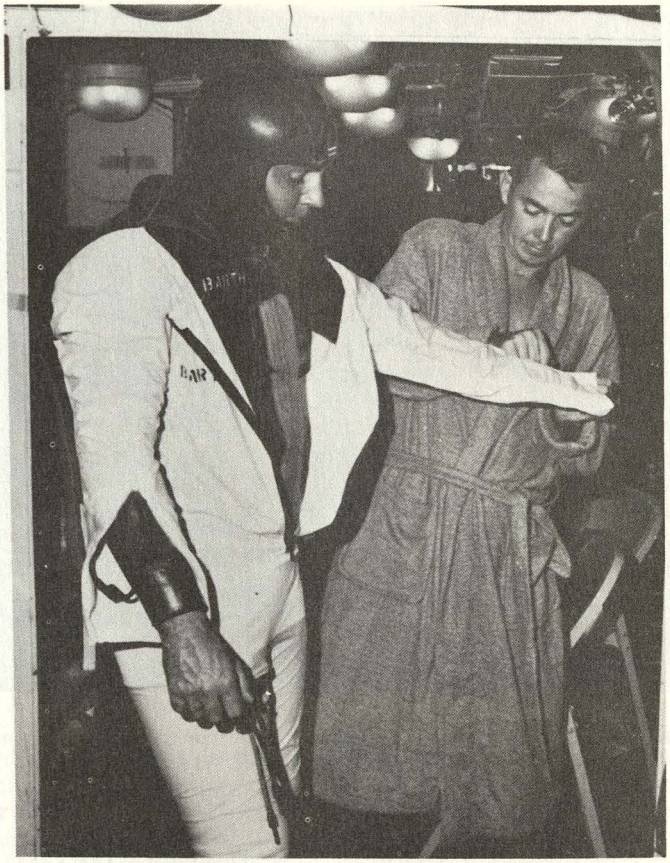

Fig. 105. Aquanaut Dowling assists Aquanaut Barth in donning the snag suit over the electrically heated wet suit.

Four members of Team 2 were also fitted and provided with electrically heated underwater swimmer wetsuits. Three of these aquanauts had had an opportunity to be indoctrinated in the use of the suit and to practice using the suit in a salt-water pool, so that familiarity and confidence in the suit were obtained before the suit was used on the sea bottom. These three aquanauts found the suit to be most helpful in increasing the duration of their dives. One of these aquanauts used the electrically heated suit with a battery pack for a swim of 2 hr and 53 min. Inasmuch as the heated suit with battery power was designed to provide thermal protection in 50° F water for a duration of 3 hr, the operational use of the heated suit for a 2 hr and 53 min

*Editors note—Weighting of the heated suit was accomplished by the use of inner pockets, into which small bags of lead pellets were placed. In the course of Team 2's submergence, one of the Team 2 divers became buoyant upon leaving the habitat. Only by vigorous swimming and aid from his diving buddy was he able to return to the habitat. The cause of the incident was attributed to misjudgment on the part of the aquanaut. Nevertheless, the incident emphasizes the need for extreme care in the design and use of gas-purging valves and the check out of weight requirements by the aquanauts.

period infers optimization of design. These aquanauts found the suit to be comfortable and to increase their time in the water significantly. No physical measurements were obtained as to skin or body-core temperature or oxygen utilization during these periods.

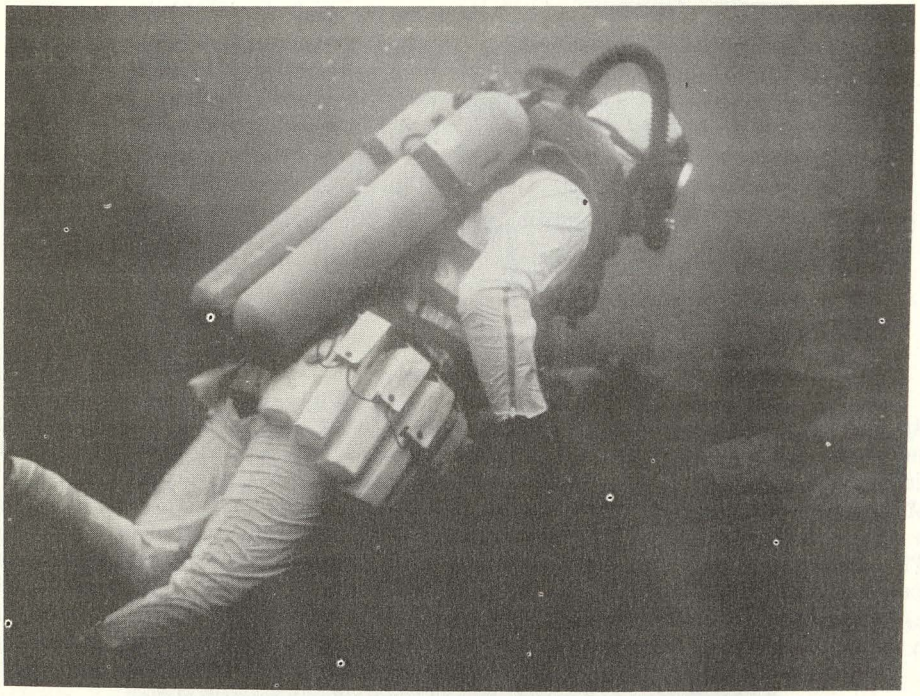

Fig. 106. Aquanaut Jenkins wearing the electrically heated wet suit near Sealab II

It was the consensus of opinion of the nine aquanauts who used the electrically heated underwater swimmer wetsuits that this type of garment was definitely useful and should be further developed by improvements in compactness and ease of donning. In addition, the basic conception of supplying supplemental heating as a method of increasing diving time in cold water was definitely established.

BACKGROUND

Recent developments in mixed-gas saturation diving have permitted man to remain submerged at depth for longer periods than ever before. The reasons for extending man's diving capabilities to greater depths and longer intervals are legion. The general goal is to take advantage of the vast continental shelf areas for commercial exploitation and for military defense. Among the ultimate specific goals are submarine rescue, deep salvage, in situ physical and biological oceanographic research, oil and gas mining, mineral mining, submarine farming, and many more. Many of the tasks required to accomplish the military, scientific, and commercial goals will require the remarkably complex intelligence and dexterity of man rather than machines and instruments. To perform these tasks with maximum efficiency, man needs to be provided with modern diving equipment.

The developments in diving equipment have not kept pace with the relatively recent developments in diving medicine and physiology that have led to projects such as Sealab II. Saturation-diving techniques enable man to remain submerged for periods of weeks rather than minutes or hours as before, but he must face the severe demands of the underwater environment with

equipment that hardly satisfies the modern requirements. Emphasis has only recently been put on the need for research, design, and development of equipment that will enable man to operate effectively in the depths along the continental shelves.

One of the most severe problems facing the modern diver is maintaining the thermal balance of his body is an environment which is essentially a cold and infinite heat sink. A comparison of the heat capacity and thermal conductivity of water versus air indicates that the subsurface environment is indeed a tough adversary. Body-heat loss is a relatively rapid process in cold water unless ample thermal protection is afforded the diver. The problem is by no means a new one. It has been with us since the early days of diving. Only the operational requirements have changed as diving activities became more diversified. Today, the problem is acute mainly because exposure times have been increased by orders of magnitude.

HISTORY

The need to insulate the human body to reduce heat loss to the water is obvious and has been appreciated for many years. But the supply of heat to supplement the body's heat production has received very little attention. Electrically heated underwear for surface-supplied helium-oxygen diving was developed during the late 1930's. Technological problems left much to be desired, and the heated underwear was barely acceptable. Until recently, no attempt was made to provide a heated, insulated garment for other forms of diving and underwater swimming.

A study of prolonged immersion in cold water has indicated that supplemental heating is essential for thermal balance. Insulation alone will not suffice. The physiological problems, analyses, and recommendations for solutions can be found in reports by Beckman, et. al. [1, 2, 3].

Evidence to support the concept of supplemental heat in an insulated garment is also given in these reports. The development of heated suits for Sealab II was based partly on the arguments set forth in CAPT Beckman's study.

The development of protective garments for divers and swimmers was not a new one for the U.S. Rubber Company. The history of such work within the company dates back long before the beginning of World War II. The Clothing Department, part of the Consumer Products Division, has pioneered the development of various types of diver's and swimmer's dress and has had substantial experience in fabricating such products. Developments were sporadic, however, because interest and funding existed only to solve immediate problems with dispatch. There has been very little long-term research and development by any organization in this field. Prior to the work reported here, the most recent development by the Clothing Plant was a pressure-compensated wet suit for the 432-ft saturation dive made by Stenuit and Lindbergh in 1964. The concept of such a suit was established to be worthwhile, even though there were technological problems, of the type that always seem to be associated with an accelerated schedule.

The Research Center of the U.S. Rubber Company began to examine the problem of cold-water immersion during 1963. New concepts in protective garments were sought. Novel methods for insulating and heating divers were studied. It became apparent that thermal protection for long exposures would require new approaches and modern technology. A team of specialists was formed, drawing on personnel from various departments within the U.S. Rubber Company corporate structure.

The work reported here is the result of a negotiated contract issued on the basis of "Technical Proposal to Perform Research, Development, and Testing of Electrically Heated Hydronaut's Suits for Sealab II." The government's request for this proposal followed from a more general and extensive unsolicited U.S. Rubber Company proposal. Much of the groundwork for the heated-suit development was performed in-house prior to the contract.

OBJECTIVES

The principal technical objective was to evaluate the concept of an electrically heated pressure-compensated wet suit under actual operating conditions. The concept of supplemental electrical heating in a non-pressure-compensated suit had already been established in the laboratory by the Naval Medical Research Institute. Another important objective was to provide thermal protection for Sealab II aquanauts, with the view of increasing their useful work time in the water. One of the earliest objectives was to survey the various means of providing supplemental heating and pressure-compensated insulating material and to make selections based mainly on the most expeditious design and hardware procurement. The overall objective of the program was to accomplish a first step in the development of an electrically heated pressure-compensated wet suit.

STATEMENT OF THE PROBLEM

The problem, as stated in the negotiated contract, was to: "Provide the necessary research, development, and engineering tests, as required, to supply electrically heated garments for use in maintaining thermal comfort of underwater swimmers operating in water of down to 40°F. and at a depth of 320 ft for periods of up to four hours. This procurement shall include both the insulative garment with electrical heating system incorporated and battery power supply so as to provide approximately one (thermal) kilowatt hour as required by the swimmer. The rate shall not be more than 350 watts. The garment shall likewise be designed to have power supplied through a 100-ft power cable so as to permit heating the suit from a power source within the Sealab II compartment or other source. Four cables and four sets of batteries are to be supplied."

Eight experimental suits were to be delivered on or before Aug. 31, 1965, allowing only eleven weeks for the contract program. The main problem was in the time frame of the program rather than in some technological aspect of the work. A request was made to accelerate the schedule even more and to deliver the suits on Aug. 7. This was done.

PLAN OF THE REPORT

The technical discussion in this report features mainly the highlights of the program. Detailed technical information is given for some aspects of the work. Both negative and positive results of materials evaluation are discussed, with the hope that such discussion will be beneficial in reducing the amount of repetitive effort by other investigators. Suit prototype fabrication details are not given extensively, because much of that information is proprietary. The technical discussion includes research, design, development, prototype fabrication, training and field engineering, evaluations, malfunction analysis, and recommendations for further work.

RESEARCH

Review of Physiological and Physical Concepts

The approach to thermal protection taken during the program reported here was based in part on the findings of Beckman, et al. [1, 2, 3].

Regional heat losses from the fingers, hands, and arms have been shown to result in an increased reaction time, a decrease in tracking proficiency, a decrease in manual dexterity, with a loss of tactile discrimination and kinesthetic sensation, as well as a decrease in muscle strength (4). Severe body-heat loss can result in degrees of hypothermia, with various symptoms such as amnesia, loss of contact with one's surroundings, pain, loss of voluntary motion, and cardiac irregularities (5, 6). Factors which can be used to limit the loss of body heat during cold water immersion are (1):

1. Controlling the duration of the period of immersion

2. Utilizing the body's own thermal protective mechanisms to maximum advantage

3. Use of adequate external body insulation to limit heat loss

4. Use of supplementary body heating to replace the heat loss.

Control of the exposure duration imposes a serious limitation on the useful work time of both military and commercial divers. This approach is impractical and, in some cases, impossible. The second factor, utilizing the body's own thermal protective mechanisms to maximum advantage, can contribute relatively little to the thermal-balance problem. Cold-water tolerance by training and/or conditioning has only limited value.

External insulation and supplemental heating are the only two body-heat-loss factors considered [1]. Insulation alone cannot satisfy the thermal requirements, because of the adverse geometries of the hands and feet. It is necessary to replace body heat to provide thermal stability for immersed subjects. On the other hand, supplemental heating alone is not the answer, because of the severe power requirements it would impose on a portable power pack. A combination of effective insulation and supplemental heating of critical areas is a logical engineering approach to cold-water thermal protection.

For the interest of the reader, the reports by Beckman, et al. [1, 2, 3] include detailed information about the physiological processes and problems, references to thermal protection for Arctic troops and for aviators, a summary of power-source and heat release methods and hardware, and a list of 21 references.

Delimitation of Technological Research

The accelerated-program schedule dictated that applied research be limited to short-term work. Studies carried out inhouse prior to the contract award made it possible to select research tasks on the basis of maximum probability of near-future results. Of the numerous approaches to thermal protection, the electrically heated pressure-compensated wet suit was selected as the best candidate for rapid development. This approach was specified in the contract. Power efficiency of the self-contained power source was a major criterion in determining the heating system. Another major criterion was the need to perform only minor development to off-the-shelf hardware for the integration of components. Power efficiency and hardware availability indicated the use of silver-zinc batteries, resistance wires for heating, commercially available gas and underwater electrical fittings, and an insulating sandwich material which had already been developed to an advanced degree by U.S. Rubber Company.

INSULATING MATERIAL

The need to provide constant buoyancy and thermal insulation regardless of the depth indicated the use of an insulating material which would either be incompressible or capable of being pressure-compensated. Both approaches were investigated. Foremost among the requirements for the insulating material was low stretch modulus, to provide adequate diver mobility in a form-fitting wet suit.

Pressure-Compensated Insulation—Open-cell foamed elastomers were reviewed as candidates for a pressure-compensated insulating material. Natural rubber latex foam was chosen above all others for its low modulus of elongation, high rebound, low compression set, small and uniform pore size, behavior at near-freezing sea-water temperatures, and relative ease of fabrication into a laminate. Relatively thin elastometric skins on both sides of the foam layer were required to serve as water-impermeable membranes.

The skin material research included natural rubber, neoprene, and butyl latices. Despite the severity of ozone-cracking, natural rubber latex was chosen for the same reasons (except pore size, of course) as given above for the selection of natural rubber latex foam. The skin material was formed by latex-dipping methods and was applied to the latex foam.

It was important to avoid using any substances in the insulating material which would cause toxicological effects. Such effects could be quite hazardous, as the diver's body is nearly completely covered by the material. The compounds used were screened for toxicological effects by a company toxicologist prior to being used in the garments.

Natural rubber is particularly susceptible to surface cracking due to ozone in the atmosphere. Such cracking originates when the rubber surface is strained either statically or dynamically. Static ozone-cracking is more severe and will usually continue, allowing the initial small cracks to grow deeper and longer. In a relatively thin (15 mils) skin, such severe cracking would result in gas and water leakage and render the insulating structure virtually useless. Chemical additives are often used to minimize ozone-cracking but these are usually aromatic amines which possess toxic characteristics. All known anti-ozonants are toxic to some degree. However, it is possible to prolong the life of rubber by providing a nontoxic wax coating on the surface which prevents ozone from attacking the rubber. Initial protection was provided by brush-coating the rubber parts with wax. In addition, wax was included in the liquid latex compound. Long-term protection is provided when the wax in the compound blooms to the surface.

Finally, with regard to ozone cracking, the problem is made severe by forming curved surfaces from flat laminate materials. The outer surface is always under static tension, while the inner surface is under static compression. The high-curvature folds on the outer surface of a garment so constructed are particularly susceptible to ozone attack.

A layer of stretch nylon was added to the inner side of the insulating laminate to enhance the ease of donning and doffing the suit. This procedure has become rather standard in wet-suit construction, and it eliminates the need for talcing. The nylon lining must be fabricated into the laminate so that it will not cause abrasion of the diver's skin.

To summarize the insulating-material structure, starting with the inner side, against the diver's skin, we have a layer of stretch nylon, a thin rubber skin, a one-quarter-inch-thick layer of latex foam, and an outer thin rubber skin.

The insulating material is subject to volume changes upon changing sea-water pressure, if the garment is sealed to confine the gas in the foam. A decrease in ambient pressure would cause expansion of the gas, with a resulting stress on the laminate material. Continued expansion of the material can result in stresses of sufficient magnitude to cause delamination, a condition which would seriously alter a diver's buoyancy. The mechanics of delamination depend upon geometry and constraints as well as the tensile strength of the latex foam and the interlaminar strengths between layers. Finished suit parts were tested for delamination pressure, which turned out to be nominally 3 psig differential. The limiting factor was the strength of the latex foam, rather than the bond between layers of material.

Increased ambient pressure causes a decrease in volume of the insulating material. Figure 107 shows the decrease of the open-cell latex insulating material with percent increase of absolute external pressure. Buoyancy and thermal insulation experience changes with varying volume.

Relief of overpressure can be realized through use of appropriate valving in a diver's suit constructed of such material. Such valving was anticipated early in the program but was abandoned at the suggestion of the government. The point of view was that it would not be necessary so long as the Sealab II aquanauts remained within the change in pressure limits which were physiologically safe for saturation-diving excursions.

Insulating Gases—The thermal conductivity of an open-cell laminate depends upon the filling gas within the cell pores as well as the volume fractions of material and cell spaces. Various filling gases were considered for use during Sealab II, but the final choice, made in the field, was to use the habitat atmosphere having a high helium content. The criteria for selecting a gas to maintain the equilibrium volume of the insulating material and to enhance its thermal characteristics are size and weight of the stored compressed gas, its thermal properties, and, in the event the suit is worn in a submersible chamber, the physiological effects of the gas in an elevated pressure environment. Table 32 lists the thermal-conductivity values of various gases.

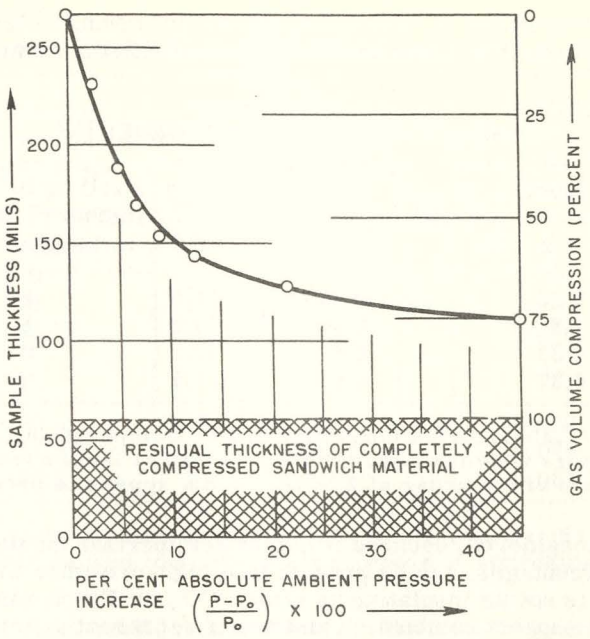

Fig. 107. Insulation thickness of open-cell Laytex vs external pressure

Table 32
THERMAL CONDUCTIVITY k OF GASES
[cal / (sec-cm^2) (°C/cm)]
(Approximate Values at Ordinary Temperatures and 1 ATMA)

Gas	$k \times 10^5$	(k_{gas}/k_{air})
Air (0°C)	5.68	1.
Carbon Dioxide (0°C)	3.07	0.540
Helium (0°C)	33.9	5.97
Hydrogen (0°C)	32.7	5.76
Nitrogen (7°-8°C)	5.24	0.922
Oxygen (7°-8°C)	5.63	0.990

Carbon dioxide is a likely candidate from the point of view of bulk and weight since, under adequate pressure, it can be stored in the liquid phase. The thermal conductivity of CO_2 is approximately one-tenth that of helium. Small amounts of CO_2 are readily scrubbed from the atmosphere by chemical absorbents, permitting use of the gas in a life-support enclosure. (CO_2 was selected as the insulating gas prior to the Sealab II evaluations, and a filling manifold was provided for filling two suits simultaneously. But the cramped space in the Sealab II diving locker would not permit use of the CO_2 filling manifold. The Sealab II habitat atmosphere was used rather than CO_2.)

Another interesting candidate for an insulating gas is the family of fluoromethane refrigerants (DuPont's Freons), some of which are nontoxic in small concentrations. Although these gases are good insulators, they cannot be scrubbed from a closed high-pressure breathing environment and would accumulate as the gas diffused from the garments. The properties of the Freon gases suitable for the heated-suit application are shown in Table 33. Freon-13B1 is the best choice, comparing all of its properties with the other Freons. Its thermal conductivity is only 64 percent that of carbon dioxide. Aside from their thermal characteristics, Freons are

low in toxicity, are not flammable or explosive, and do not conduct electricity. The Freons listed in Table 33 cause less than 1 percent elongation of natural rubber due to swelling.

Table 33
PROPERTIES OF FREON GASES [8]

Product	Thermal Conductivity, k [Btu/ (hr. ft^2) (°F/ft)] at 32°F k × 10	k_{gas}/k_{air}	Boiling Point (°F.)	Swelling of Natural Rubber (% Increase in Length at R.T.)	Underwriters' Laboratories Classification
Freon-13	6.33	0.445	-114.6	1	6*
Freon-13B1	4.9	0.345	-72.0	1	6
Freon-115	6.33	0.445	-37.7	0	6
Freon-C318	6.27	0.442	21.5	0	6

*Group 6, Underwriters' Laboratories Classification of Comparative Life Hazard of Gases and Vapors: "Gases or vapors which in concentrations up to at least about 20 percent by volume for durations of exposure of the order of 2 hours do not appear to produce injury."

Nitrogen was also considered, because it has better thermal insulating properties than helium and, in small percentages, can be present in a high-pressure breathing gas with no deleterious effects. But it is not as insulative as either CO_2 or Freon gas. Compressed air was ruled out because it will support combustion and would represent a fire hazard in an electrically heated suit.

Purging the helium-oxygen mixture from the suits with insulating gases was ruled out in the Sealab II habitat. This procedure was considered unacceptable because of the need for stringent atmosphere control.

Thermal conductivity is not the only aspect to consider for selection of an insulating gas. Heat transfer by convection is also a participant in the total heat transfer across the insulating sandwich. Radiation will be small because of the relatively low absolute temperature differential. No attempt was made to calculate the effect of convective cooling or to measure the total heat transfer coefficient of the insulating sandwich. Such study would not fit into the time frame of the research program.

The effect of convective cooling in cellular materials is currently a topic of study at the U.S. Army Research Institute of Environmental Medicine at Natick, Massachusetts.

Low Compressibility Insulation—Materials other than open-cell foams were evaluated for the insulating laminate. The use of microballoons was rigorously examined but was found to be impractical. The writer suggested incorporating microballoons into a diving-suit insulating material during 1963. Subsequent in-house research was conducted by U.S. Rubber Company to study the thermal and mechanical characteristics of microballoons encapsulated in a polymeric matrix. The matrix material was chosen to be a polyvinyl chloride plastisol for convenience. Its specific heat is very nearly the same as other rubber-like organic materials.

The results of the thermal-conductivity measurements were not very promising, and the material was deemed too rigid for use in diver's suits. But, while there are not written reports offering data, there was a claim by an overseas investigator that such materials exhibit a fraction of the thermal conductivity of closed-cell neoprene at depth. The details of the foreign measurements were not made known, but much interest was generated in the United States.

To settle the question, a second set of measurements was made by U.S. Rubber independent of the first ones. The results were not vastly different, although the sample preparations and measurements were performed by different investigators in independent studies. The results are given in Table 34. The difference between the two control samples amounts to 9.5 percent. This difference is probably due to different degrees of cure, degassing of the material, and measuring procedures.

Table 34
MICROBALLOON/PVC PLASTISOL THERMAL CHARACTERISTICS

Sample	Percent Microballoons by Volume	Percent Voids	Microballoon Wall Material	Thermal Conductivity [Btu/ (hr. ft^2) (°F/ft.)]	Percent Difference of Conductivity
First Set					
1 (control)	0	0	-	0.084	0
2	39	35	Borosilicate	0.084	0
3	55.7*	50	Silica	0.090	+7.1
					9.5
Second Set					
4 (control)	0	0		0.092	0
5	57.3*	34	Epoxy	0.079	-14
6	39.1	34	Silica	0.081	-12

*The volume of closely packed uniform spheres in space is 53 percent. The volume of closely packed microballoons in space is approximately 69 percent.

Microballoons were first considered because, in the loosely packed condition and without a binder material, the thermal conductivity is close to that of cellular neoprene used for standard wet suits (Tables 35 and 36). This information is given in the manufacturer's specifications and thermal-conductivity measurements were not made during this program to verify the manufacturer's data.

Table 35
MICROBALLOON PROPERTIES [9]

Parameter	Silica	Boro-silicate Glass	Epoxy
Particle Diameter	30-125 microns	30-300 microns	0.13-0.18 in.
Wall Thickness	~ 2 microns	~ 2 microns	0.01 in.
Bulk Density (lb/ft^3)	11	14	15.6
Average True Particle Density (gm/cm^3)	0.28	0.42	0.45
Thermal Conductivity of Loosely Packed Material (Btu/hr/ ft^2/°F/ft)	0.03	0.04	—

An analysis of the heat transfer across such a composite material indicates that thermal short-circuiting occurs across the elastomeric material used as the binder and across the glass microballoon walls. The microballoon wall materials exhibit about eight times the thermal conductivity of PVC, which tends to offset insulation due to the voids within the microballoons. See table 36 for comparisons of the thermal conductivities of materials.

To make matters worse, the composite microballoon/elastomer material is very stiff compared to the same thickness of the elastomer alone. The high bending and elongation stiffness of the material makes it a poor choice for a flexible diver's suit. There is also a decrease in tensile and elongation strength (Table 37).

Table 36
THERMAL CONDUCTIVITY OF VARIOUS MATERIALS [10]
(Range of Typical Values Near Room Temperature)

Material	Thermal Conductivity k(Btu/hr/ft^2/°F/ft)	
	Low	High
Pure water (12)	0.348*	
Neoprene (unicellular)	0.021	0.029
Natural Rubber Foam	—	0.025
Neoprene Rubber	—	0.11
Natural Rubber	—	0.08
Butyl Rubber	—	0.05
Polyvinyl Chloride	0.07	0.10
Epoxies (cast)	0.1	0.8
Silica Glass	—	0.8
Borosilicate Glass	—	0.7

*Somewhat lower for sea water depending on pressure, temperature, and salinity.

Table 37
BREAK CHARACTERISTICS OF MICROBALLOON/ PVC PLASTISOL SAMPLES

Sample No.	Tensile Stress at Break (psi)	Elongation at Break (percent)
1 (control)	350	330
2	180	245
3	91	265

Self-Contained Power Source

The choice of heat-release materials (resistance wires, carbon yarn, liquids, etc.) would have to be made after selection of the portable power pack for use by the free-swimming aquanaut. Overall power efficiency was the principal criterion, because of the rather high heat level required and the long exposure period (three hours).

Radio-isotopes, thermochemical reactions, fuel cells, and thermoelectric heating were ruled out on the basis of nonavailability of off-the-shelf components which could be integrated into a suit system. Secondary cells were considered because of their availability and the need for only minor modifications to adapt them for the application.

A simple formula was derived to determine the size and apparent weight in water of secondary batteries providing one kilowatt-hour of stored energy. The apparent weight is:

$$W_A = (W_b - V_b \rho_w)$$

where

W_b is the dry weight of the battery, lb

V_b is the volume of the battery, in.^{3}

ρ_w is the weight density of sea water, 0.037 lb/in.^{3} [11]

W_b and V_b are determined from:

$$W_b = K/\alpha_w \text{ and } V_b = K/\alpha_v$$

where

K is the stored energy, watt-hours

α_w is the watt-hours stored per pound of battery

α_v is the watt-hours stored per cubic inch of battery

Finally, the apparent weight is:

$$W_a = K\left[\frac{1}{\alpha_w} - \frac{\rho_w}{\alpha_v}\right]$$

Table 38 shows the calculated weight and bulk of various battery candidates. The figures for weight and bulk are conservative (on the low side) and are based on nominal characteristics. The calculations are for the batteries alone and do not include the weight and volume of other components of the power pack.

Table 38
CALCULATED WEIGHT AND BULK OF ONE KILOWATT-HOUR BATTERIES*

Type of Battery	$\frac{\alpha_w}{\text{watt-hr}/\text{lb}}$	$\frac{\alpha_v}{\text{watt-hr}/\text{in.}^3}$	W_b (lb)	V_b (in.^{3})	W_a‡ (lb)
Silver Zinc (secondary)	55	3.5	18.0	286	7.4
Silver Cadmium	35	2.8	28.6	358	15.4
Lead Acid	20	2.1	50.0	476	32.4
Nickel Cadmium	13	0.9	77.0	1110	35.9
Silver Chloride/Magnesium†	30	2.5	33.3	400	18.5

*α_w and α_v from Reference [12].
†Primary (not rechargeable) sea-water activated.
‡W_a = weight in water (apparent).

Lead acid, nickel cadmium, Leclanche, and sea-water batteries were ruled out because of the bulk and weight required for storage of one kilowatt-hour of energy. Silver cadmium cells were just a little too large and heavy for the purpose.

Silver-zinc, the most efficient of the secondary cells for energy storage per unit weight and per unit volume, were selected for the application. Thus, the portable power pack would provide chemically stored energy which would be released as electrical power. This suggested that the most efficient means of using the stored power would be direct conversion to heat through use of resistance wires.

In a sense, selecting immersible silver-zinc cells opened Pandora's box because of the need for rather demanding maintenance and charging procedures. Off-the-shelf silver-zinc cells cannot be immersed in seawater without design adaptations for pressure equalization and waterproofing to prevent electrical shorting.

Pressure-compensation of the individual cells can be provided by filling the cells almost completely with electrolyte (potassium hydroxide, 40 percent aqueous solution) and installing a deformable rubber bladder. Total filling is not possible for three reasons; gases are occluded in the plates, hydrogen is generated in the cells, and it is difficult to purge the gas bubble entrapped at the top of the cell without spilling the caustic electrolyte. An alternative to pressure compensation would be to insert the cells into a single pressure housing, but this would increase the weight of the battery pack, and the weight of the cells alone is almost to the acceptable

limit. The sealed battery also presents an explosion hazard should a hot short occur within the cell. However, hot shorts can be predicted through proper maintenance procedures. The pressure-housing approach was ruled out mainly because the apparent weight concentrated on the swimmer's back could render him hydrostatically unstable. Also ruled out was the approach of filling the upper part of the individual cells with insulating oil, because the oil would find its way between the plates whenever the diver inverted himself.

The design of the silver-zinc cells will be discussed in the section of this chapter titled "Battery Pack and Power Control."

Heat-Release Material

Heat-release material research was oriented toward those materials which derive power electrically. The principal candidates were metallic resistance wires, carbon yarn and cloth, and electrically conducting rubber. Despite some disadvantages, resistance wires were selected as the near-future solution. All heat-release materials investigated will be discussed.

The main factors to consider in selection of heat-release materials for a diver's suit are as follows: flexibility of the material configuration to maintain mobility of the diver, prevention of hot-spotting and shock hazards, compatibility with the insulating materials, appropriate power distribution at relatively low voltage, adequate fatigue resistance, minimal fabrication effort, availability of materials, constancy of heat release with static pressure, and ease of attaching feed wires and underwater electrical connectors.

Heat Power Requirements—The maximum power level required of the heating system is about 350 watts. This level is based on experimental data obtained on NMRI subjects sitting motionless in a wet pot while wearing 1/4-in.-thick unicellular neoprene wet suits in 40°F water. The distribution of the total power is given in Table 39 [13].

Table 39
HEAT POWER DISTRIBUTION

Body Region	Power Distributed (watts)	Total Power (watts)
Head	25	25
Arms	15 each	30
Chest	30	30
Upper Back	30	30
Abdomen	30	30
Lower Back	25	25
Legs	20 each	40
Hands	30 each	60
Feet	40 each	80
		350

The data in Table 39 are based on subjects breathing compressed air; there were no data available on subjects breathing helium-oxygen mixtures.

An average man with a skin surface area of 1.8 square meters was considered for the calculations of heat release per unit area. The body-region areas [14] were corrected to allow for the hood opening of the suit and for heating the hands and feet from the dorsal sides only. Beckman found that dorsal heating to the hands and feet is adequate and that subjects could not tell whether their extremities were heated from one side only or from all sides. The results are given in Table 40. The resistance required for each body area is also given based on a 12-volt supply, with the various body-region heaters connected in parallel.

Electrically Conducting Rubber—Electrically conducting rubber was studied as a possible heat-release material. Resistivity of electrically conducting rubbers is a function of carbon

black concentration, temperature, extension, compression, and the rheological history of the material. Flexing of such material can damage the interfacial bonding of the carbon black particles, resulting in irreversible resistivity changes. Decreases in resistivity with static compressional loading would cause hot regions. The negative temperature effect on resistivity would result in less power release whenever the rubber is allowed to cool. All of the aforementioned effects could very easily cause power-release variations in excess of the 10-percent maximum power variation requirement.

Table 40
HEAT-RELEASE-SYSTEM REQUIREMENTS

Body Region	Resistance (ohms)	Power (watts)	Area ($in.^2$)	Power/Area ($watts/in.^2$) 10^2
Head	5.75	25	282	8.87
Arms (each)	9.60	15	140	10.71
Chest	4.80	30	264	11.36
Upper Back	4.80	30	357	8.40
Abdomen	4.80	30	186	16.13
Lower Back	5.75	25	279	8.96
Legs (each)	7.20	20	411	4.87
Hand (each)	4.80	30	54	55.6
Foot (each)	3.60	40	93	43.0
All circuits	0.412	350		

Electrically conducting rubber was eliminated as a candidate heat-release material because the resistivity cannot be controlled to the degree required in this application.

Carbon and Graphite Yarns and Fabrics—The relatively new development of carbon and graphite yarns and fabrics presents interesting possibilities for diver's suit heat-release material. These materials are flexible and strong, have good dimensional stability, and allow more uniform heat release compared to resistance wires. The use of such materials had to be ruled out during the present program because of technological problems associated with providing high stretch, constant resistivity, and ease of fabrication into the insulating material.

Carbon filaments comprising carbon yarns possess a high modulus of elasticity (about 6×10^6 psi) along with a low elongation at break (about 3.5 percent) and a high tensile strength (about 1.8×10^5 psi). Carbon yarns are available in a range of filaments per ply, plies per yarn, and twists. The yarns can be woven or knitted in various configurations with or without other materials such as glass. Yarn and plain woven fabrics are very flexible in bending but very stiff in elongation.

Knitted fabrics display some stretch, however isotropic, but suffer from filament fatigue due to interfilament abrasion.

Resistance Wires—Metal alloy resistance wires remained the only candidate for immediate application. Despite their susceptibility to fatigue, copper alloys can be soft-soldered with relative ease. The criteria for selection of the alloy, wire gauge, physical configuration, and electrical circuitry are described in the section of this chapter titled "Resistance Wire Circuitry."

DESIGN

Wet Suit and Snag Suit

The rubber wet suit design consists of a jacket with an attached hood, trousers, mitts, and boots. Figures 108 and 109 show a suit on aquanaut W. Tolbert, USNMDL. General design features include a jacket opening from the breastbone downward, gussets on the wrists, ankles,

mitts, and boots, and the exclusive use of Velcro rather than zippers. The inner surfaces are lined with nylon for ease of donning and doffing. The trousers are provided with a high-rise back to minimize cold-water flooding in that region. The boots are fitted with high-modulus rubber soles to protect them against puncture and scuffing and to minimize the possibility of the diver slipping while walking on a wet deck.



Fig. 108. Aquanaut Tolbert wearing the electrically heated wet suit (a) With snagsuit partially donned (b) Complete with battery pack

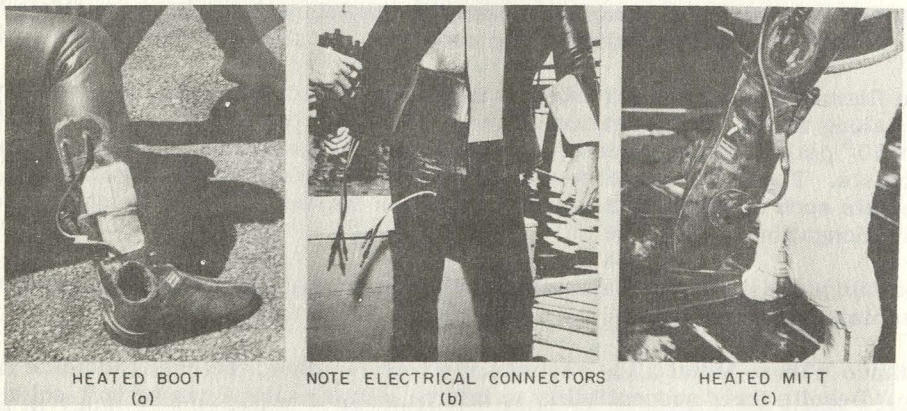

Fig. 109. Several views of the electrically heated wet suit (a) The heated boot (b) The electrical connectors (c) The heated mitt

The buoyancy and thermal insulation of the gas-inflated wet suit would suffer serious consequences if the outer rubber skin were punctured or torn. An outer suit, a snag suit, was designed to guard against tear, puncture, scuff, and abrasion. The snag-suit design includes using both a nonstretch and a stretch material in a zippered coverall with separate boots and mitts. The nonstretch material is polyurethane-coated nylon fabric chosen for strength and good resistance to mechanical damage. The stretch material is used to permit mobility in a

fairly snugly fitting outer garment. Figure 104 shows aquanaut Bill Tolbert with the snag suit partially on and with it completely on. A single front zipper and double back zippers allow the diver to insert his arms into the snag suit with ease. Lemon yellow coated nylon and white stretch fabric were chosen to enhance underwater visibility.

The mitts are removable under water to permit maximum finger dexterity for fine work. They are replaced before the hand becomes painfully cold. At about 52°F, aquanauts found that they could remove their mitts for about a half minute, replace them for one quarter minute and repeat the cycle. Figure 110 shows QMC R. Barth practicing the procedure in a training tank.



Fig. 110. Aquanaut Barth adjusts the cabel-powered ac control on the electrically heated wet suit during a swimming-pool test

Resistance-Wire Circuitry

The following factors were considered in the design of the resistance-wire circuitry:

1. Maximum allowable separation to prevent hot-spots
2. Flexibility of the wire configuration for maximum mobility
3. Power distribution required of different body areas
4. Wire diameter and specific resistivity of the wire material.

The best available information about hot-spotting indicated a maximum allowable wire separation of about 3/8 in. The requirement for flexibility suggested that a sinusoidal or modified sawtooth pattern would be appropriate. The power distribution to the various body areas was shown in Table 39. Wire diameters in the range of B&S gauges 30 to 33 (0.010 to 0.007 in.)

were considered within a reasonable range to obtain good configuration flexibility, adequate strength, and minimal bulkiness when incorporated into the laminated insulating material.

The resistance required for a body-region circuit is determined by the supply voltage, the wire length, and the power required for heating the area. The resistances for body-region circuits were given in Table 40. The resistance-wire circuit design includes parallel heating wires in each area and the area circuits connected together in parallel. Single resistance wires for some body areas would require, within a reasonable range of wire gages, a lower resistivity than found in any commercially available alloy.

A general approach was taken for the design of all body-region circuits, with the exception of the hands and feet, which were treated specially. The generalized configuration was designed as follows.

1. Assume a configuration which is periodic, will permit stretch, and has a wire separation, x. Let λ be the wavelength of the periodicity. Then:

$$L/\lambda = C_1 x \text{ and } A/\lambda = C_2 x^2$$

where C_1 and C_2 are constants depending on the configuration, L is the wire length, and A is the area to be heated. We then have that:

$$L/A = C_1 x/C_2 x^2 = C/x \text{ where } C = C_1/C_2.$$

Rewriting, we have $L = CA/x$, which is the wire length to cover the area in the chosen configuration.

2. The supply voltage is applied across parallel heating circuits. The resistance for each body area circuit is: $R = E^2/P$, where E is the supply voltage and P is the power.

3. The resistivity of the wire is given by $(R/L)_1 = R/L$ if the circuit consists of only one heater wire. For parallel wires of the same material emitting equal heat power, we have that:

$$(R/L)_i = n^2(R/L)_1$$

arising from

$$1/R_1 = \sum_{i=1}^{n}(1/R_i) = n/R_i \text{ and } L = nL_i$$

where the subscript, i, denotes an individual heater wire.

4. Writing the expression for resistivity, we have:

$$(R/L)_j = \rho_j$$

where j denotes specific diameter and material.

5. Introducing a requirement for an allowable power deviation, $R \pm \epsilon = E^2/P \pm \epsilon$, which can also be written as:

$$[n^2(R/L)_1 - \rho_j]/[n^2(R/L)_1] \leq \epsilon .$$

6. Compute the values of the expression given in step 5 for n = 1 to 20 (number of parallel heaters).

7. Choose the value of n which satisfies the permissible deviation, E.

8. If no value of n satisfies the permissible deviation, alter the configuration and/or spacing by using the value of n corresponding to the minimum ϵ. The new spacing constant is given as

$$x' = C_j A/n^2 R.$$

9. Compute a new L for each x'.

10. Print-out n, ϵ, x', L'.

This procedure was programmed on a Burroughs E101 computer to reduce the computation time from several days to about a half hour. Preliminary computations indicated that alloys having higher specific resistivities than copper would have to be employed. Stranded wire in small diameters and special alloys is not commercially available. Therefore, it became practical to attempt to use only one type of wire throughout the suit. The selection was "Advance" wire which, in B&S gage 33 (7 strands of B&S gate 42), has a resistivity of 0.486 ohm per inch. "Advance" wire alloy consists of 43 percent nickel and 57 percent copper. It has a nominal specific resistance of 294 ohms per circular mil-foot at 68°F and a specific heat very close to that of copper. "Advance" was chosen over the nickel-chromium-iron alloys because it can be soft-soldered with as much ease as copper.

Table 41 shows the print-out design information corresponding to the general configurations shown in Fig. 111. Departures from the configuration were made near seams and gussets.

Table 41
RESISTANCE WIRE CIRCUITRY
(ρ = 0.486 ohms/inch, x' = 0.375 in.)

Body Region	No. of Parallel Heater Wires n	Power Deviation (%)	Wire Length (per element) L' (in.)
Head	8	6.0	94.81
Arm	4	4.7	79.01
Chest	8	1.3	79.01
Upper Back	9	5.5	88.89
Lower Back	8	7.0	94.81
Abdomen	7	2.8	69.14
Hand, Foot } Special cases			

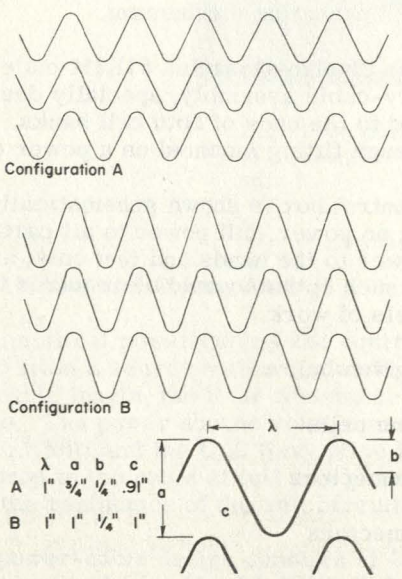

Fig. 111. Electrically heated wet suit—general resistance wire configuration

Boot and mitt circuitry were handled as specific cases. The wire configurations differ from those shown in Fig. 111. The mitt circuit design provides heat to the dorsal side of the thumb and hand and to the ventral side of the fingers. The boot circuit provides heat to the entire foot area.

The need to interconnect the various suit parts required the use of safe underwater electrical connectors. Aside from watertight integrity, the requirements of the connectors are to take the current to have low contact resistance, and to be as small as possible. The current requirements are 3.5 amperes for the mitts and boots connectors and 15 amperes for the jacket and trouser connections. The mitt and boot circuits were designed to be supplied independently of the remainder of the suit. Electro-Oceanics connectors were employed, principally because of their small size and flatness. The connectors were fastened to the suit parts through neoprene oral inflation tube fittings.

Feeder wires to supply the resistance wires were chosen to be B&S gage 22 or 24 copper, depending on the length of the feed wire. It is important that the resistivity of the feed wire be very small compared to the resistivity of the heater wires, to prevent large voltage drops across the heating circuit. Such voltage drops result in uneven heat release.

Battery Pack and Power Control

The battery-pack design includes eight silver-zinc cells in fabric pouches, interconnecting cell cables, a battery cable assembly attached to a power-control box, and a 2-in. nylon belt with a fixed buckle, rather than a quick-release type.

The silver-zinc cells are Yardney LR 85 cells modified for this application. The 12-volt supply consists of two banks of cells, four cells per bank, in series. The cell banks are parallel switched to provide one-quarter heat power to the suit. The cells were designed so that they could be immersed without using an external pressure housing. They are inserted into fabric pouches made of heavy-gear diver's dress material.

The modification of the LR 85's consists of use of watertight electrical connectors and total filling with electrolyte. Electro-Oceanics 51E1F female connectors were attached to the cell terminals and potted in place with an epoxy compound. Figure 112 shows one of the cells. Compressibility of the cell is minimized by nearly total fillings of the cell with the potassium hydroxide electrolyte. Volume changes due to gases remaining in the cell after filling, and gases generated by the cell during discharge, are compensated for through use of a deformable rubber finger. Figure 113 shows the pressure-compensating mechanism.

The interconnecting cell cables consist of two Electro-Oceanics 51E1M male connectors molded onto 11 in. of B&S gage 16 wire. A battery-cable assembly, specially designed and constructed for the purpose, is electrically connected to the ends of both cell banks. The cable terminates in an Electro-Oceanics 4104 feed-through fitting mounted on a power control box.

The electrical circuit for the battery-pack control box is shown schematically in Fig. 114. The switching arrangement provides five options; no power, full power to all parts of the suit, one-quarter power to all parts of the suit, full power to the hands and feet only, and one-quarter power to the hands and feet only. It was felt that such options would be required to cover the range of body-heat production during various levels of work.

The list of components shown in Fig. 114 is given below.

B_1-B_8 Yardney LR-85 modified silver-zinc cells

C_1-C_{16} Electro-Oceanics 51E1F female connectors

C_{17}-C_{32} Electro-Oceanics 51E1M male connectors

C_{33} Electro-Oceanics 4104 feed-through fitting

C_{34}-C_{37}	Electro-Oceanics 59F2F female bulkhead connectors with 51F2M male connectors
C_{38}-C_{41}	Electro-Oceanics 51F2F female connectors mated to Electro-Oceanics 51F2M male connectors
S_1	DPDT neutral center off toggle switch
S_2	SPST toggle switch
F_1	20 amp fuse
F_2	15 amp fuse

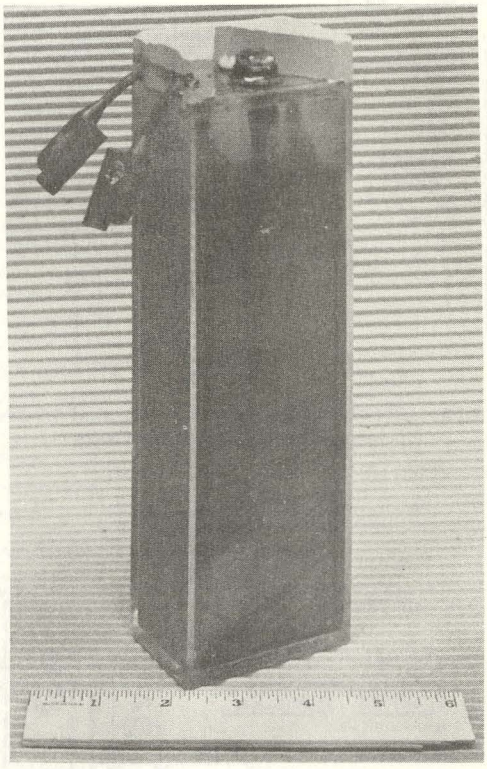

Fig. 112. Silver-zinc cell used to power electrically heated wet suit

AC Umbilical Cable and Power Control

The ac umbilical power cables and control boxes were designed to permit heating power to be derived from a source within Sealab II. The design of the cable included consideration of the desired cable length, the total resistance of the heating circuitry, and the voltage of the power source. The power source voltage was chosen as 24 volts by the contractor through consultation with NMRI and the U.S. Navy Mine Defense Laboratory. This choice determined that the voltage drop in the cable at full suit power would be 12 volts and that the cable resistance would equal the resistance of the suit circuit. The selection of cable wire gage followed.

The ac power-cable design consists of 100 ft of two-conductor No. 12 AWG cable spliced to 18.5 ft of two-conductor No. 14 AWG cable. The inboard connector selected was a Cannon

straight plug with a strain relief. The wet end of the cable was terminated in an Electro-Oceanics 51E4F connector, with pins 1 and 2 paralleled and pins 3 and 4 paralleled. The total resistance of the cable assembly was chosen to be 0.412 ohm to coincide with that of the suit.

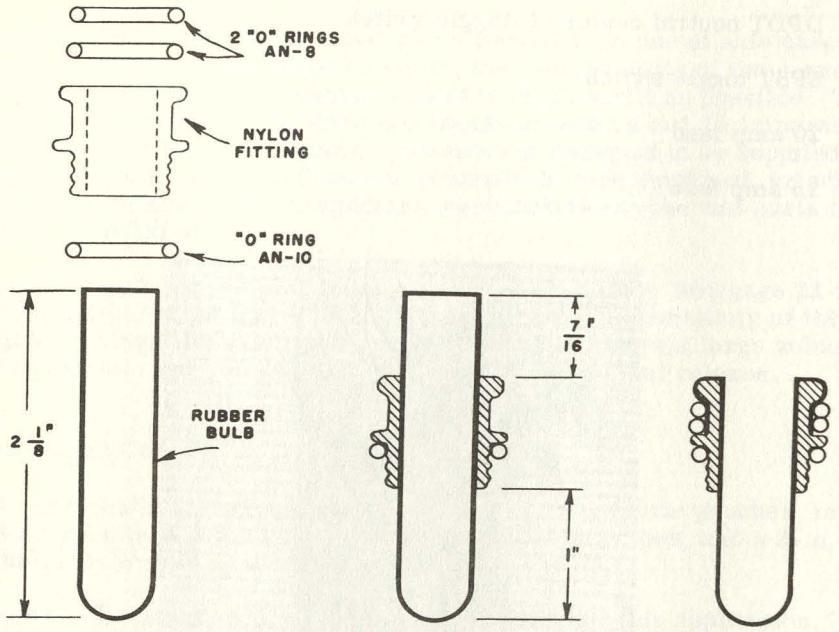

Fig. 113. Electrically heated wet suit pressure-compensating mechanism

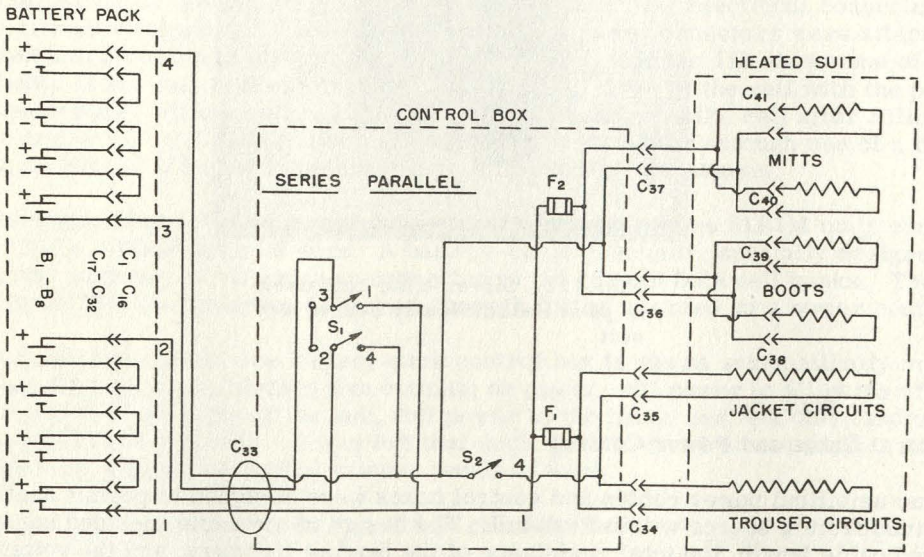

Fig. 114. Schematic diagram of electrically heated wet suit battery pack control circuit

The ac power-control box is identical in design to the battery-pack control box, with the exception of the power-input connector. The power cable plugs into an Electro-Oceanics 51E4M bulkhead connector. Figure 115 shows the circuit schematic of the ac power-control box. The power options with the ac control are different from those in the battery-pack control. This difference arises from series-parallel switching the suit-circuit resistances rather than the supply voltage. The cable resistance is an integral part of the circuit. The method of switching suit-circuit resistances is shown in the schematic in Fig. 115.

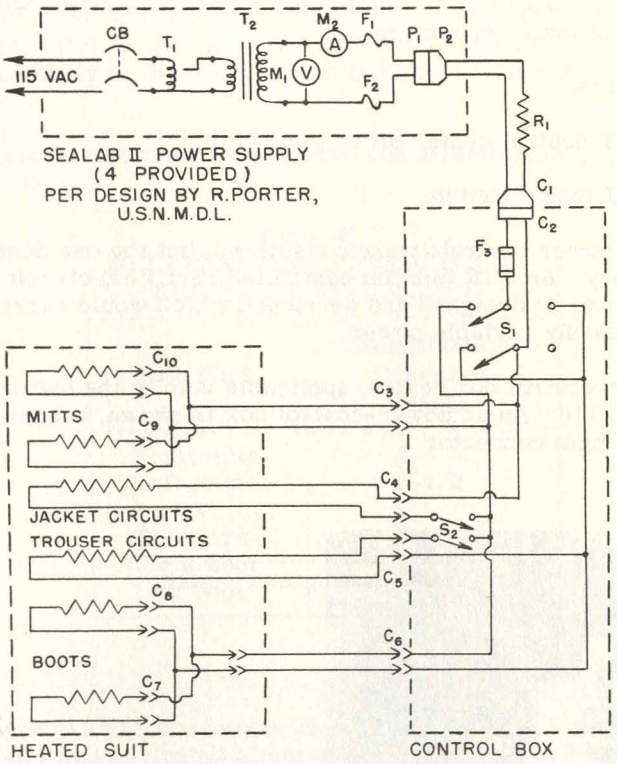

Fig. 115. Schematic diagram of electrically heated wet suit ac power control circuit

The list of components shown in Fig. 115 is given below.

CB	Circuit breaker
T_1	0-125 vac variac
T_2	115V/24 v transformer, 50 amps
M_1	0-50 VAC voltmeter
M_2	0-50 AMP ammeter
F_1, F_2	30 a, 32 v fuses
P_1	Cannon MS3102R-16-11S receptacle
P_2	Cannon Ms3106R-16-11P plug/CA45161 strain relief

R_1	Umbilical cable, 100 ft 2-wire No. 12 AWG plus 18.5 ft 2-wire No. 14 AWG
C_1	Electro-Oceanics 51E4F connector, female
C_2	Electro-Oceanics 51E4M bulkhead connector, male
C_3-C_6	Electro-Oceanics 59F2F bulkhead connector, mated with Electro-Oceanics 51F2M male connectors
C_7-C_{10}	Electro-Oceanics 51F2F female connectors mated with Electro-Oceanics 51F2M male connectors.
F_3	30A fuse
S_1	DPDT neutral center off toggle switch
S_2	DPST toggle switch

Other designs for power controls were considered, but the one described above was chosen primarily for expediency. An SCR (silicon controlled rectifier) circuit was considered, but time did not permit a circuit to be designed and developed which would carry 30 amperes at 12 volts while providing continuously variable power.

The general power-control box design, applicable both to the battery and ac power-control boxes, is shown in Fig. 116. An ac power-control box is shown, but the dc box is identical except for the electrical input connector.

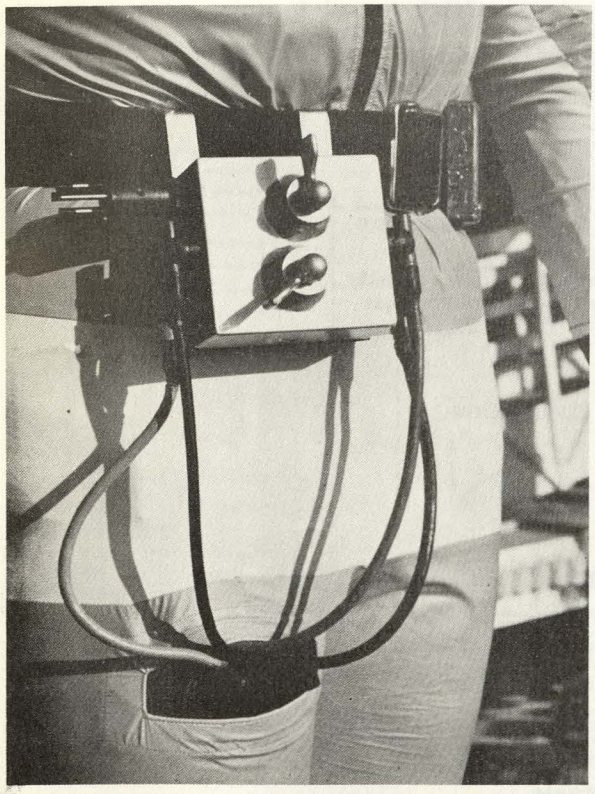

Fig. 116. Electrically heated suit power control box, ac power. The upper switch controls power level; the lower switch selects heat to hands and feet or to the full suit.

DEVELOPMENT AND FABRICATION

First Wet-Suit Model

An unheated pressure-compensated wet suit was constructed initially to check the suit design and fit. This suit was tailor-made to fit CAPT E. L. Beckman and was tested at NMRI. Some design changes were indicated. Most of the changes were minor and do not deserve discussion. The most important change was to add the nylon inner lining for ease of donning and doffing.

The evaluation of the first suit model was generally favorable. The insulating material was said to feel considerably softer to the skin than unicellular neoprene. The suit enabled CAPT Beckman to have good mobility in the water. Mobility was not as good in air as it was in the water.

The first wet-suit model was tested to observe the delamination pressure. The results were as shown in Table 42.

Table 42
DELAMINATION PRESSURES OF
FIRST WET-SUIT MODEL

Suit Part	Delamination Pressure (psig)
Right mitt	5
Left mitt	2-1/2
Jacket	7
Trousers	4
Right boot	3-1/2
Left boot	3-1/2

Mark I, Mod. 0 Suit

The second prototype evaluated was electrically heated as well as pressure compensated. The first snag-suit model was evaluated along with this wet suit at NMRI. Pattern alterations were required because of a tighter fit than the first suit around the arms and legs. This tightness was due to the increased modulus of elongation caused by the resistance wires, which were not present in the first suit. Other fit and styling alterations were minor. The heat distribution in the mitt had to be redesigned because the original design provided too much heat in the thumb. Originally, 7-1/2 watts were applied to the thumb. This was changed to 3-3/4 watts. It was decided to color-code the electrical leads from the suit to the switch box. The revised version of the second wet-suit model became the Mark I, Mod. I suit.

Time did not permit further suit development. Most important, it did not permit extensive laboratory and field tests. Likewise, there was virtually no development time for the battery pack or the power controls. The prototypes had to be constructed from the first design without extensive test and evaluation.

The Mark I, Mod. 0 electrically heated suit was tested to destruction for delamination pressure at Washington, Indiana. The suit was worn by a subject and inflated with air, part by part, until each suit part delaminated. The results were as shown in Table 43.

Carbon Tape Heater Attempt

Although the decision to use resistance wires had been made, an attempt to fabricate at least a few mitts heated with carbon tape was made. This development was abandoned because of technological difficulties. A carbon-glass tape especially woven and supplied through the

good offices of Union Carbide was laminated into the insulating sandwich material and evaluated electrically.

Table 43
DELAMINATION PRESSURES OF ELECTRICALLY HEATED PROTOTYPE

Suit Part	Delamination Pressure (psig)	Description of Delamination
Right mitt	3-1/2	Balloon on dorsal side of finger area
Left mitt	3-1/2	Same
Jacket	3-1/4	Balloon on left sleeve just below shoulder
Trousers	2-3/4	Balloon on front of left knee area
Right boot	3-1/2	Balloon on inside of ankle
Left boot	3-3/4	Balloon on inside lower ankle area

The resistance of an 8-in. length of the 2-3/4-in.-wide tape was 3.97 ohms prior to lamination and 9.49 ohms afterward. The change in resistance can be explained by the poor electrical contact between the carbon yarn and the copper tinsel used as the feed wires. Liquid latex decreases the conductivity of these junctures in an uncontrolled fashion. The change of resistivity with static loading was about 14 percent and 21 percent for the unlaminated tape and the laminated tape, respectively. The change was a decreasing resistance which would result in overheating in a garment. The static load was about 1.5 psi.

It had to be concluded that such an approach would have to be delayed until some of the engineering problems associated with carbon heaters are solved.

Mark I, Mod. I Prototypes

The electrical resistance of the Mark I, Mod. I wet-suit parts was measured using a Wheatstone bridge. The values are given in Table 44. Variations in the resistances are due principally to variations in the contact resistances of the Electro-Oceanics connectors.

Table 44
MEASURED RESISTANCES IN OHMS OF THE SEALAB II SUIT PARTS

Suit No.	Jacket	Trousers	L. Boot	R. Boot	L. Mitt	R. Mitt
Design	1.25	1.52	3.60	3.60	4.80	4.80
1	1.535	1.725	3.885	3.915	4.965	4.915
2	1.485	1.625	3.845	3.895	4.955	4.905
3	1.455	1.665	3.835	3.865	4.905	4.995
4	1.395	1.625	3.935	3.895	4.975	4.935
5	1.515	1.585	3.875	3.925	4.945	4.855
6	1.405	1.615	3.895	3.885	4.885	4.985
7	1.485	1.665	3.955	3.895	4.925	4.945
8	1.525	1.705	4.045	3.995	4.985	5.255
2A	(Spare parts)				4.905	4.945
8A	(Spare parts)		4.265	3.815	5.085	4.975
8B	(Spare parts)			3.825		4.955

The suit parts were tested for air-tightness as well as electrical resistance.

The power-control boxes were pressure tested to 650 ft of sea water. The silver-zinc cells were pressure tested to 150 psig.

Eight suits were fabricated for Sealab II evaluations, based on measurements supplied by the government for the following personnel:

Suit No.	Name	Rank
1	M. S. Carpenter	Commander (NASA)
2	R. E. Sonnenburg	Lieutenant (MC, USN)
3	W. H. Eaton	Gunner's Mate 1st Class
4	R. A. Barth	Chief Quartermaster
5	W. D. Meeks	Boatswain's Mate 1st Class
6	F. J. Johler	Chief Engineman
7	L. E. Anderson	Gunner's Mate 1st Class
8	E. L. Beckman	Captain (MC, USN)

The following is the list of equipment supplied by the U.S. Rubber Company in fulfillment of and in excess of requirements:

Quantity	Item
8	Electrically heated pressure-compensated wet suits
5	Extra mitts
3	Extra boots
8	Snag-suits
8	2-in. nylon belts with web buckles
4	12-volt silver-zinc batteries (32 cells), watertight electrical connectors, pressure-compensated
32	Cell pouches for silver-zinc cells
4	Extra cell pouches
4	12 volt dc power-control boxes with battery cable assemblies and cell jumpers
4	Extra cell jumpers
4	AC power control boxes
4	Power cables, 118-1/2 ft long, Cannon and Electro-Oceanics fittings
25	Manuals, aquanaut Suit (Mark I, Mod. I)
8	Zippered bags for suit storage
8	Talc bags for dusting rubber parts
1	Two-suit purging manifold
1	Rubber repair kit
1	Battery maintenance kit
1	Fabric repair kit
1	Power-control maintenance kit

Silver-Zinc Cells

The pressure-compensation fitting at the top of each silver-zinc cell had originally been made of stainless steel. Salt-water immersion tests indicated a leakage current of 0.4 ampere across eight cells (about 12 volts). Coating the steel with silicone grease or petroleum jelly was attempted but did not solve the problem adequately. The fittings were remade using nylon.

The O-Ring seal around the rubber bladder was introduced after Ty-wraps failed to provide a good seal. This seal was important, as the electrolyte (potassium hydroxide) is a strong caustic and is therefore hazardous.

The cells were fabricated by the Yardney Electric Company for the U. S. Rubber Company.

Power Controls

Time did not permit development of the power-control boxes. They were designed and fabricated at the Research Center. Water leaks were experienced due to hairline cracks in the heliarc weldments of the aluminum parts. These were repaired by filling them with epoxy

resin under vacuum. The boxes were plated with chemically deposited nickel and coated with epoxy paint. They were individually pressure tested to 650 ft of sea water.

TRAINING AND FIELD ENGINEERING

The need for training personnel in the use of the suits and ancillary equipment was considered vital because of the novelty of the hardware. Field engineering was also considered important, because of the experimental nature of the newly developed suits, batteries, and power controls. The writer carried out this work at the Sealab II site from Aug. 24, 1965, to October 3, 1965, with the cooperation of CAPT E. L. Beckman (MC) USN.

Training

Elaborate plans for rather thorough training were shattered by the nonavailability of the Team 1 subjects for whom suits had been provided. LT R. E. Sonnenburg was the only Team 1 subject who received any training at all, and that was limited to less than half a day. The others in Team 1 who wore the suits were CMDR M. S. Carpenter, Chief Engineman F. J. Johler, and GM1 W. H. Eaton. These personnel were available only to try on the suits to check fit just prior to their descent.

All personnel in Team 2 who wore the electrically heated suits were familiarized with the equipment and trained in its use fairly thoroughly. The measurements of all Sealab II aquanauts were studied to determine whether or not the suits could be used by personnel other than those for whom they were made. Substitute subjects on Team 2 were found and displayed eagerness to assist in the suit evaluations. They were:

Suit No.	Name	Position
5	W. T. Jenkins	Equipment Specialist/Diver
7	W. H. Tolbert, Jr.	Oceanographer/Diver
8	G. B. Dowling	Research Physicist/Diver

These personnel are civilian researchers attached to the U.S. Navy Mine Defense Laboratory at Panama City, Florida. The fourth member of Team 2 to wear the suit was Chief Quartermaster R. A. Barth of the same Navy organization as the civilian divers.

The Team 2 personnel were trained at the Scripps Institution of Oceanography in large outdoor tanks filled with ocean water. Training varied from subject to subject, but all generally received the same instructions and had equal opportunity to become completely familiar with the suits and equipment. All subjects (including LT Sonnenburg of Team 1) were specifically asked if they would be able to reach the bypass and pop-off valve of the Mark VI while wearing the electrically heated suit. The amount of lead weight required to achieve negative buoyancy was evaluated individually by each of the subjects. The complete battery pack weighs 35 lb in air and 16 lb in sea water. Both the battery pack and the umbilical cable were employed during training sessions. For training purposes, the umbilical power cable was supplied by two 12-volt lead-acid storage batteries in series. In addition to the training session at Scripps, W. H. Tolbert, Jr. made a dive off one of the Naval Electronics Laboratory docks using compressed-air scuba and the umbilical cable.

Three members of Team 3 were also trained at Scripps. Two of them were fitted with suits fabricated for others. They were:

Suit No.	Name	Position
3	J. J. Lyons	Engineman 1st Class
6	R. Grigg	Graduate Student - Scripps Institution of Oceanography

The third subject was BM1 W. D. Meeks. The Team 3 subject training was incomplete because their suits had malfunctioned to various degrees during the Team 1 and Team 2 evaluations. The suits were not worn during the Team 3-stay in Sealab II.

Field Engineering

The field-engineering work was concerned mainly with charging and maintaining the silver-zinc batteries, maintaining the suits, familiarizing the surface staff members with the heated suit program, conducting liaison with the subjects on the bottom to instruct and assist them, and perhaps most important of all, to take care of the legion of seemingly small problems invariably associated with accelerated research and development programs.

The first problem encountered in the field was poor fit of the chin area in both the wet suits and the snag suits. This was nearly universal and occurred in all but two suits. The chin areas of the suits were too tight, causing both upward forces and forces directed toward the back of the head. The chin area is critical, both for comfort and safety. The suit parts were returned to the Clothing Plant, altered, and returned by air express. The value of field engineering was demonstrated to be essential in this instance. The program might very well have ended here without it.

Most of the subjects found it difficult to put their swim fins over the boots. The boots are slightly bulkier than standard 1/4-in. neoprene boots because of the added hard sole. Dr. Sonnenburg found it impossible to wear his super-extra-large Duck Feet over the heated boots, and extremely difficult to wear them over any other boot. To solve this problem, the writer provided a pair of altered super-extra-large Duck Feet with 2-in. nylon webbing and buckles rather than the fixed rubber strap. It would be well if the fin manufacturers provided swim fins for size 13 and 14 feet which are covered with 1/4-in. boots. But they do not.

Battery charging and maintenance accounted for a significant fraction of engineering time. Silver-zinc cells require careful attention during the charge cycle, unless automatic scanning chargers are employed. None were available. The cells are generally charged at constant current until the end-of-charge voltage is attained. They can be ruined if current is maintained after the end-of-charge voltage has been reached.

An attempt to charge the cells was made aboard the Sealab II staging vessel, but it was unsuccessful and had to be abandoned. Power-line surges due to heavy electrical equipment in the circuit together with an inadequate patch-board for connecting the cells were the principal obstacles. An arrangement was made to have the cells charged at the Battery Maintenance Shop at the Naval Electronics Laboratory at Point Loma. The cells were charged at 6 amps until the normal end-of-charge voltage (2.05 volts) was achieved. But these cells did not provide power to a suit the very next morning. The voltages measured at that time were between 1.52 volts and 1.83 volts. Most readings were about 1.58 volts. The open-ciruict readings should have been 1.86 volts.

The problem turned out to be the resistance of the underwater electrical fittings, which was greater than the resistance of the cells. This difference in resistances resulted in voltage drops across the connectors had spurious voltage readings. The cells were then charged at 3 amperes to the end-of-charge voltage. This procedure, however time consuming, was a solution. The batteries did not deliver full capacity during the first discharge, even though they were partially developed by Yardney prior to shipment. They had been put through one charge-discharge cycle. Development of a silver-zinc cell consists of several charge-discharge cycles until full capacity is achieved. The high resistance of the electrical connectors caused erroneous voltage readings during the development cycles, and the cells were not fully developed.

The pressure-compensating fittings had to be removed and washed after each use. Potassium hydroxide forms a salty deposit which can be removed by vigorous washing in fresh water.

Three of the suits worn by Team 1 members were flooded because valves were left open. This was attributed to the nonavailability of the subjects for indoctrination and training. The sea water was removed by applying a vacuum to the suit parts. Flooding of these suits vitiates,

at least partially, the evaluations. Even after applying a vacuum until no further water was removed, the latex foam was found to be damp several weeks later when the suits were examined for malfunction analyses. The vacuum pump and a technician were supplied through the good offices of Professor H. Bradner, University of California.

EVALUATIONS

CAPT E. L. Beckman and the writer interviewed the suit evaluators to obtain their subjective impressions. No significant numerical data were collected, e.g., skin and rectal temperatures, heat-power cycles, oxygen consumption, etc., during the dives. The evaluations were recorded on a portable tape recorder and subsequently transcribed.

The general consensus of opinion among the subjects who evaluated the suits was that such suits, with appropriate improvements, would indeed be valuable in operational diving. Most of the complaints were ones that the suit-project personnel could forecast prior to the Sealab II evaluations. These were associated mainly with inadequate time for thorough design, development, and testing prior to the construction of the final prototypes.

The suits were evaluated both by divers using both the Mark VI (semiclosed circuit breathing apparatus - 85 percent helium, 15 percent oxygen) and the Arawak hose-supplied apparatus (Sealab II habitat gases).

Suit Design and Fit

The design of the rubber suit was acceptable with minor reservations. The hood attached to the jacket succeeded in preventing free flooding in the neck region. The jacket opening from the breastbone downward eliminated pressure points on the trachea - a condition usually associated with neck-level front zippers and separate hoods. The Velcro closure material was judged to be superior to zippers in reliability. The trouser design was good in that the Velcro gussets at the waist and ankles made donning fairly easy. Removal of the trousers and jacket was difficult because the Velcro wrist and ankle gussets tended to lock together when the garments were peeled off. The mitts were somewhat bulky and suffered from moderate flooding. The boots also suffered from flooding and were quite difficult to fit into swim fins.

The electrical connectors on the boots were difficult to make and break because they were on the outside of the ankles. The inside of the ankle is much more accessible when a subject is sitting down. He merely crosses his leg. The Electro-Oceanics electrical connectors were very compact but required some effort to make and break.

The snag suit was objectionable for some subjects in that it was time consuming to don and doff. Others had no problems. But this was mainly a problem of fitting. Nylon zippers used on the mitts, boots, and sleeves experienced a high mortality rate.

Rubber-suit fit ranged from very good to poor. Most of the subjects found the chin area to be too tight. This almost universal problem required immediate alterations. It is difficult to evaluate suit fit, because suits were not always worn by personnel for whom they were made. CDR Carpenter experienced some tightness in the sleeves.

Most subjects enjoyed the softer feel of the suit material compared to neoprene wet suits. Several aquanauts wore their heated suits for short dives without using the heat power because the suits were quite comfortable. One judged his suit to be superior in insulating qualities compared to neoprene suits.

Heat Power

Evaluations of the heat-power distribution were sometimes made by subjects who were busy doing other chores. Therefore, their evaluations represent recollection of comfort with some uncertainty. Skin-surface temperature measurements would have removed some of this

uncertainty. However, several aquanauts had the opportunity of concentrating on their thermal comfort and gave detailed evaluations.

The heat-power distribution was evidently close to ideal. No subject complained of significant unequal heating. Most subjects agreed that the power distribution was adequate.

There was some hot-spotting in the boots and mitts, and only one man reported a hot spot at the lower rear part of his neck. Hot-spotting in the boots occurred in the sole area and was aggravated whenever the diver's weight caused pressure on his soles. This problem can be corrected by heating only the upper parts of the foot. Hot-spotting in the mitts occurred on the knuckles, where the contact pressure with the mitt is maximized by flexing the fingers. Lowering of local wire temperatures by incorporating more wire may solve this problem.

Snug-fitting heated wet suits will require careful fitting to prevent hot areas due to the pressure of the suit against the skin.

Power Source and Control

There were no serious problems with the ac power source in Sealab II. The negatively buoyant electrical umbilical cable had to be pulled along the bottom whereas the positively buoyant Arawak hoses floated overhead. The two should have been mated together. But the electric cable was fed out of the Sealab II hatch, while the Arawak hose passed through a bulkhead. A systems approach in future programs should eliminate nuisance problems of this type. One subject reported that his cable became disconnected from his power-control box. A safety lock will prevent this from happening in the future.

The silver-zinc battery pack was too bulky. A question exists as to whether or not it is safe when worn with the Mark VI. Some subjects feel that it is safe; some do not. The battery could have been one-third the size for Sealab II. A one-kilowatt-hour battery to provide three hours of heat at full power was specified in the contract. However, the gas duration of the Mark VI was only about 50 minutes.

The power-control boxes maintained watertight integrity and operated well electrically. The uppermost switch control (power range) was easily knocked out of position. A more positive switching arrangement will have to be designed.

Miscellaneous

Only one subject reported skin irritation. All others reported none. The afflicted diver stated that his skin was discolored prior to donning the suit and that he wore the suit for more than 12 hours. His skin may have been abraded by the wet nylon suit lining.

All subjects found it difficult to don their fins over the heated boots. It will be necessary to wear a larger fin over the heated boots unless the boot is made thinner. However, this would reduce its insulating property and require more electrical heating. Additional heating will mean less battery time, or larger batteries.

On the positive side, at least three subjects wore the suits without using the supplemental heat power. They claimed that the suits did not suffer from the pressure effect as did their sponge neoprene suits. The suits achieved normal dimensions immediately after opening the gas valves in Sealab II. Neoprene suits, on the other hand, were severely distorted for the first few days, until the habitat atmosphere gases permeated the closed cells. Upon ascent to the surface, the neoprene suits were severely distended for several days. The pressure-compensated suits were decompressed instantly by opening the gas valves.

MALFUNCTION ANALYSIS

The principal reason for malfunction of the suits was resistance-wire fatigue and consequent failure. Ozone cracking of the natural rubber skin material was evident to a moderate degree.

Water leakage into the insulating foam was experienced due to pin holes, tears, and human error. Although there was some criticism of the battery pack, umbilical cable, and power-control boxes, these components did not malfunction at all. The rubber suits stood up quite well to the rigors of repeated donning, diving, and doffing. The snag suits, although objectionable, experienced only zipper failures and some seam splitting.

The resistance wires failed in the various suits from minor to major degrees. Suit parts were dissected and examined for wire failure as well as ozone cracking, pin holes, tears, and moisture in the foam.

Nearly all of the boots and mitts malfunctioned electrically. More wire breaks occurred in the "uppers" of the boots than in the soles. Wire failure in the mitts seemed less systematic. The boot and mitt wire design simply did not allow enough stretch, and the wires were severely strained. Of seven boots examined for wire breakage, there was a total of ten breaks in the soles and about 31 in the uppers. Five mitts were examined. Eighteen breaks occurred in the palm side, while 12 occurred on the dorsal side.

Two jackets and two trousers were also examined. Wire breaks occurred mainly in or near areas of high suit material extension: hood, sleeve, upper back, and leg (especially the knee area).

Breakage of the resistance wires was evidently followed by electrical arcing and metal corrosion. Arcing resulted in scorching of the foam rubber, while corrosion contributed to further wire failure.

Fourteen out of 16 suit parts had moist or wet latex foam due to pin holes or tears in the outer skin or because gas valves were left open during sea-water immersion. Tears occurred in suit parts not protected by snag suits. Valves were left open only by Team 1 subjects who were not made available for thorough training.

Thirteen out of 18 suit parts displayed ozone cracking to various degrees. All mitts, three out of eight boots, and all jackets and trousers suffered ozone cracking.

No delamination of the insulating sandwich material was evident in any suit part examined. The copper "feed" wires were all intact, as were the soldered connections to the underwater electrical connectors. All potted solder joints were in good condition.

The rubber suit seams were in excellent condition. None of the Velcro closure material suffered from any apparent wear or damage. There was only minor separation of the stretch nylon liner material from the inner latex skin.

Ozone cracking can be minimized by applying a layer of neoprene latex to the skin material prior to suit fabrication. Some snag and abrasion resistance without a separate snag suit can be realized through the addition of an outermost layer of stretch nylon. This will result in a stiffer suit, but it is the price one must pay for durability and speed of donning and doffing.

The resistance-wire problem requires a complete redesign of the wire configuration as well as more durable wires. The stranded wires (7/42 Advance) do not have adequate flex-fatigue characteristics. Many more finer filaments of higher modulus alloy should be employed. They should be coated with an insulating material which will not bind them all together.

RECOMMENDATIONS FOR FUTURE WORK

The principle of supplemental heating in a pressure-compensated wet suit has been demonstrated conclusively to be worthwhile for saturation diving. With the inclusion of a constant-volume feature, these suits also will be extremely useful for deep diving from the surface. It would seem appropriate to continue the development of such suits until they are operationally acceptable.

Specific recommendations for a second-generation suit are outlined below. Following this outline, suggestions are offered for the research, design, and development of other approaches to thermally protective underwater garments.

Electrically-Heated Constant-Volume Wet Suit

Based on the evaluations of Sealab II subjects and Navy and U.S. Rubber project personnel, the following design alterations and additions should be incorporated into an improved suit.

Jacket—Alter the face profile, use a soft-rubber face seal, remove bunching in the chest area, prevent Velcro from attaching to itself while donning and doffing.

Trousers—Lower the hip openings, make ankle area softer to minimize chafing, prevent Velcro from attaching to itself while donning and doffing.

Mitts—Extend length by about one inch.

Boots—Use stocking seal, increase height by one inch, position gussets and connectors on inside ankle areas, try to make it easier to don swim fins.

Snag Resistance—Apply stretch nylon to outer surfaces of all suit parts, supply separate chafing gear kit to be used as required only for severe conditions, avoid snag-suit design used previously.

Resistance Wires—Redesign wire layout configuration, design new insulated wire for maximum resistance to failure in flexing and kinking.

Power Control—Provide positive switch positioning for both ac and dc operation, design special continuous power control silicon-controlled rectifier circuit for ac umbilical cable use.

Voltage—Employ 24 volts to reduce current through connectors and switches and to make system compatible with swimmer propulsion units.

Battery Pack—Provide capacity compatible with scuba gas-supply duration (about one hour), design pressure-resistant single battery housing to be suspended from scuba bottle(s), avoid the maintenance and charging problems encountered previously.

AC Umbilical Cable—Provide safety lock to prevent inadvertent disconnection from power-control box, "marry" to Arawak hose, use bulkhead connection to Sealab III.

Constant Volume—Add low-pressure differential pop-off valves to rubber suit, provide insulating gas (Freon 13B-1, CO_2, or N_2) bottle to be attached to scuba or to "come-home" bottle of Arawak, provide pressure regulator and manual flow control.

Connectors—Design special gas/electric connectors for suit parts for minimal size and quick operation.

Tailoring—Obtain accurate measurements, draft patterns, and provide fitting and alteration service.

Testing—Perform thorough testing prior to use at Sealab III, incorporate modifications where necessary and if possible prior to Sealab III.

Training—Conduct thorough training sessions in a tank and in open water. Subjects should become completely indoctrinated prior to use during saturation dives.

Field Engineering—Provide services in the field to maximize successful usage of the suits.

Electrically Heated Undergarment

Preliminary work has been done to develop electrically heated undergarments. U.S. Rubber has begun to develop techniques by which such garments can be made waterproof and stretchable. A thin, high-stretch immersible garment could be worn under almost any type diver's suit; wet suit, dry suit, lightweight dress, standard dress, etc. Such a garment would be versatile while moderately priced.

Water-Heated Suit

Plastic tubing incorporated into a stretch fabric holds great promise for heated diver's suits. U.S. Rubber has developed a knitting technique for producing this structure. Figure 117 shows a stretch fabric-plastic tube sample. Hot water pumped through the tubing would serve as the heat-release material. The advantage of this method of heat release is that it is directly compatible with thermochemical and isotope power sources, whereas resistance wires are not. Hot water also could be pumped into the suit via an insulated hose to the surface or to an underwater habitat.

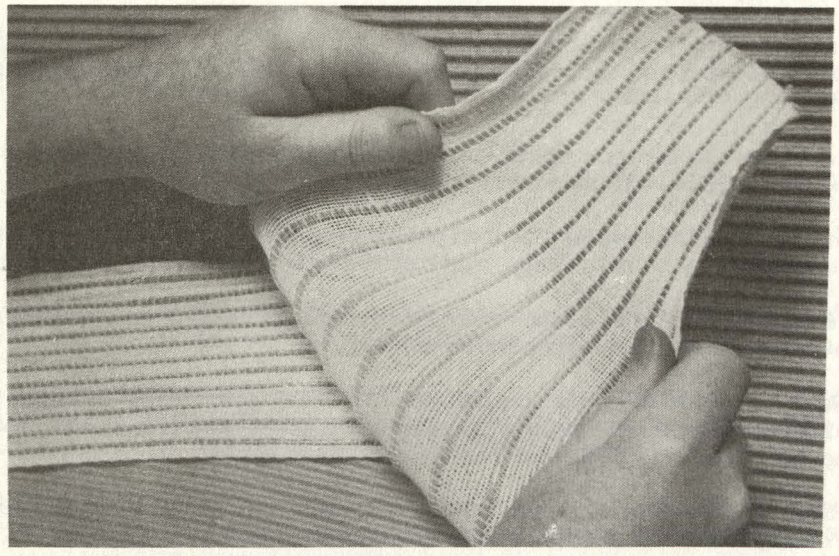

Fig. 117. Stretch fabric, plastic tube material

Other

New developments in carbon-yarn technology should be monitored, since the material has many merits. Materials research is necessary to provide superior insulation along with durability, maintainability, and mobility. The development of power sources would seem important. Power sources more efficient than silver-zinc secondary batteries in terms of weight and volume would be desirable. Lastly, the problem of thermal protection for swimmers and divers should be considered vital enough to warrant a concentrated effort until good working solutions are found.

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Chapter 38

ENGINEERING EVALUATION OF SEALAB II

W. B. Culpepper, R. B. Porter, W. P. Frost, and B. Deleman
U.S. Navy Mine Defense Laboratory
Panama City, Florida

INTRODUCTION

Project Sealab II was the second in the U.S. Navy series of tests of man's ability to live and work underwater at ambient pressure for extended periods of time. The underwater test phase began Aug. 28, 1965, and was successfully completed Oct. 10, 1965. The test site was approximately 3,000 ft off the Pacific coast at Scripps Institute of Oceanography at La Jolla, California, in 205 ft of water near Scripps Canyon. Twenty-eight men, divided into three teams, lived and worked for 15 days each in a synthetic atmosphere of 4 percent oxygen, 85 percent helium, and 11 percent nitrogen at an ambient pressure of approximately 102 pounds per square inch absolute (psia).

The Sealab II craft, which served as the undersea quarters for the aquanauts, was 57-1/2 ft long and 12 ft in diameter, with a semielliptic head on either end. It was equipped with the necessary life-support equipment, such as breathing-gas systems, ventilating system, heating system, electric and communication systems, food-stowage and preparation facilities, sanitary facilities, and berthing and work space.

This report presents a brief description of Sealab II and associated systems and facilities and their evaluation from an engineering standpoint. The evaluation is based on observation, interviews with the aquanauts, and recorded data.

HULL

General

The hull of Sealab II was designed as an internal pressure vessel 12 ft in diameter and 57-1/2 ft in overall length, in accordance with the 1962 ASME Boiler and Pressure Vessel Code, Section VIII, unfired pressure vessels. The design working pressure of 125 pounds per square inch gauge (psig) was selected so that the vessel could be fully pressurized on the surface and then lowered to the required working depth of 250 ft. Because of handling problems encountered with Sealab I, complete surface pressurization was used to minimize the time required for lowering of Sealab II. The hull-plate material utilized was mild steel one inch thick, since the strength-to-weight ratio was not critical (additional ballast was required for submergence). Some decided advantages in the use of this material for a vessel of this size are ease of fabrication and the avoidance of postwelding heat treatment. The hull ends were ASME semielliptic heads, which were explosively formed because of the long lead time involved in procuring commercially formed heads. For arrangements and locations of items described in the following sections, refer to Figs. 118 through 122.

Ports

Eleven circular viewing ports were installed in the hull. To avoid the restricted field of view through the 12-in. ports in Sealab I, these ports were made 24 in. in diameter. Each port was fitted with an internal pressure-tight steel cover to protect the plastic port lights during

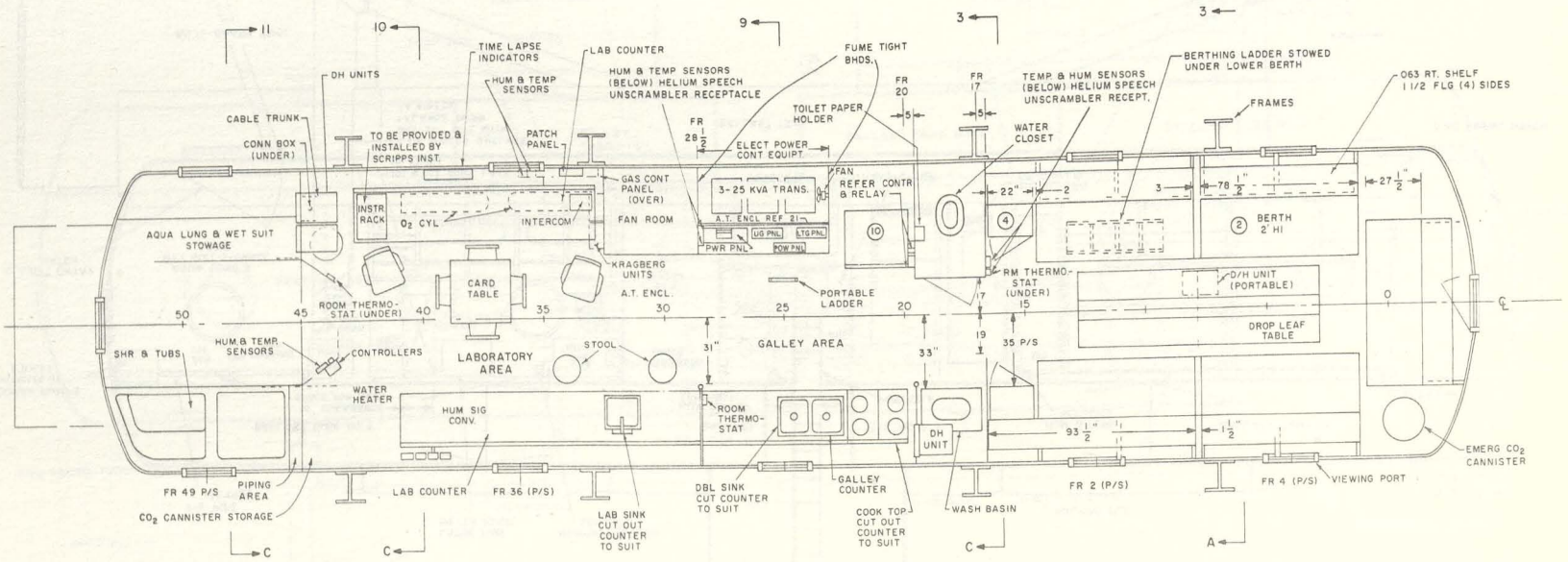

Fig. 118. Sealab II deck plan

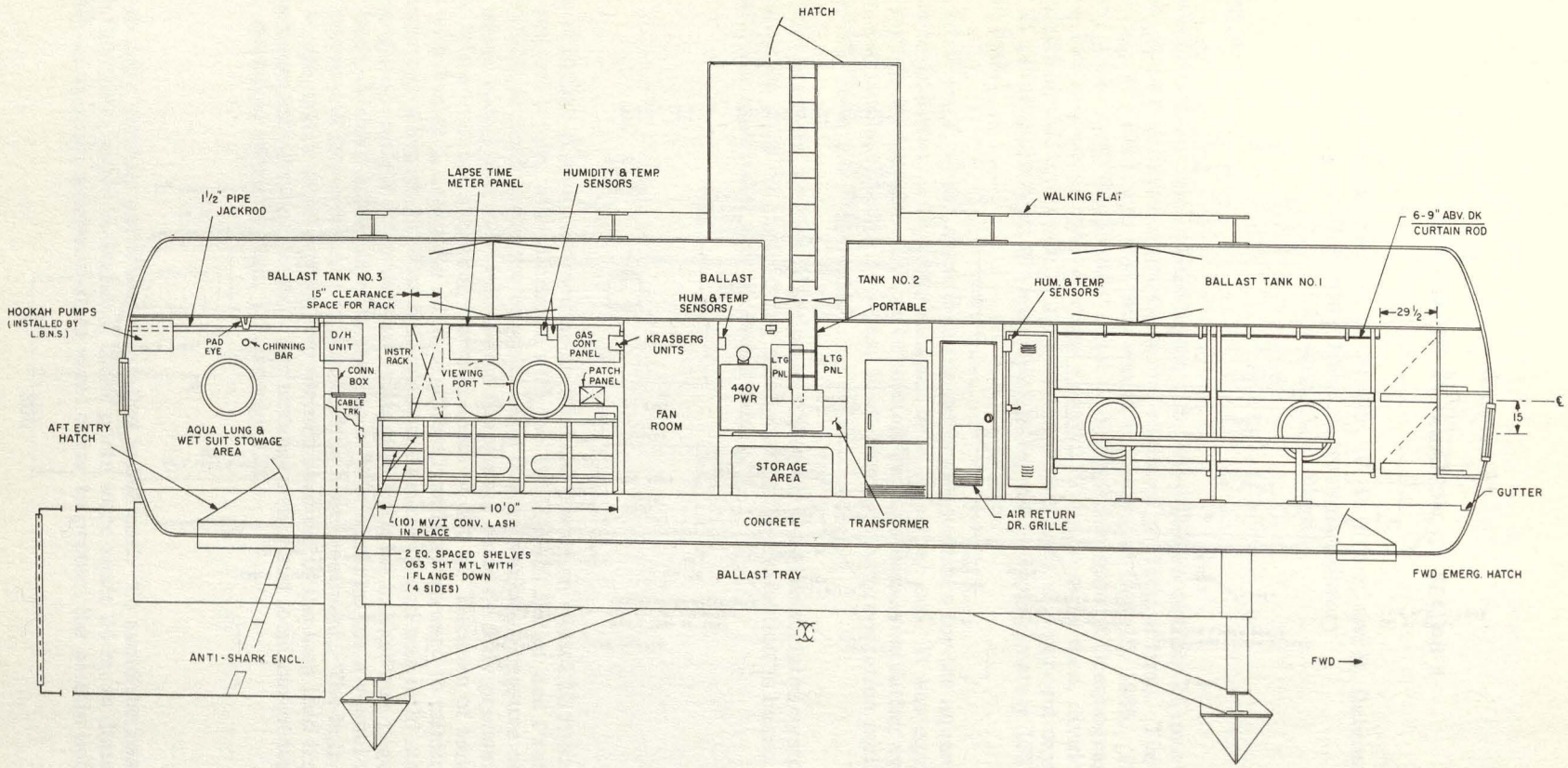

Fig. 119. Sealab II interior view looking to port

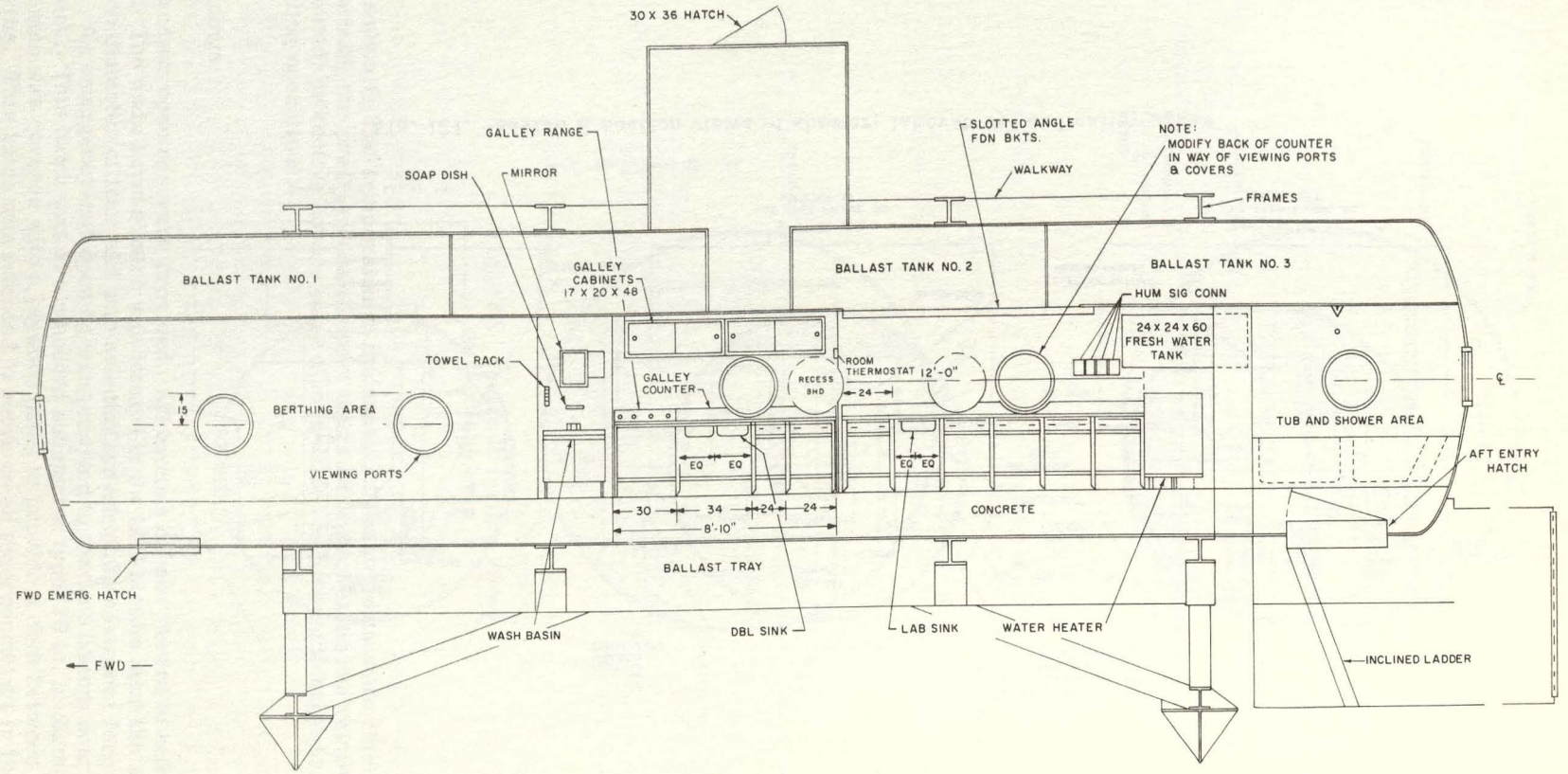

Fig. 120. Sealab II interior view looking to starboard

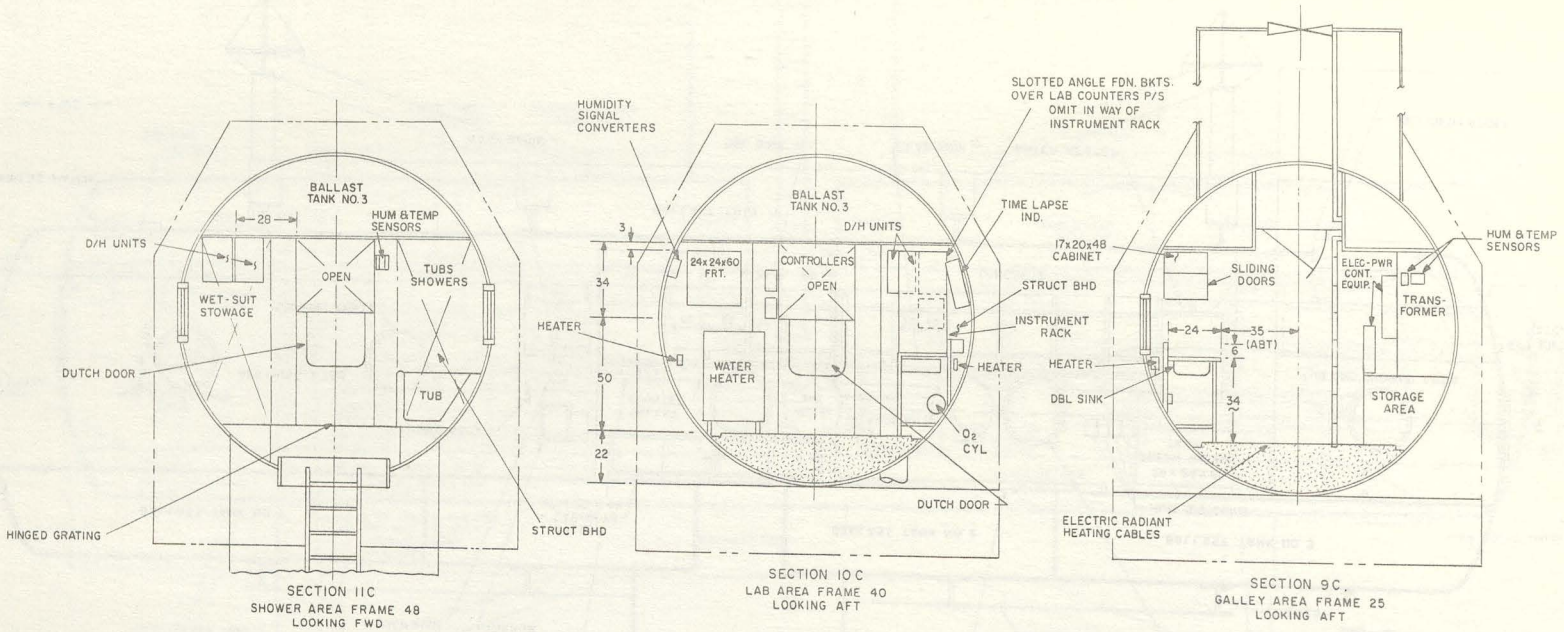

Fig. 121. Sealab II section views of shower, laboratory, and galley areas

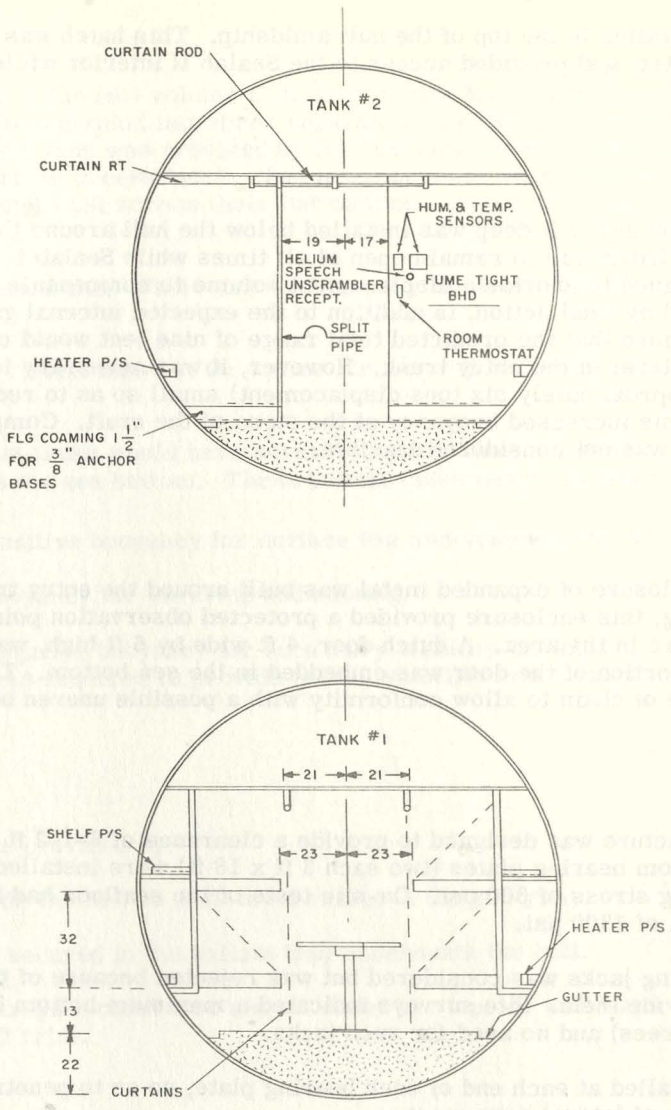

Fig. 122. Sealab II section views of berthing area

surface pressurizing and submersion of the vessel. These covers were fitted with vents to facilitate equalizing the pressures on the port lights during lowering and raising operations. External (vented) protective covers were also provided to prevent damage to the port lights during handling operations.

Access Openings

Three access openings were provided. All hatches opened inward to reduce bolting requirements. The main access hatch was located in the hull bottom near the stern in the entryway. A hatch diameter of four feet was selected for adequate clearance for swimmers with scuba gear. An emergency exit opening was provided in the hull bottom near the bow, in the berthing space. This hatch was of a standard submarine type, 30 in. in diameter. The emergency exit hatch was covered with a plywood panel to provide a deck between the tables and the forward berths. This hatch was intended to serve as an emergency exit in the event of any equipment casualty which might introduce toxic fumes into the Sealab II atmosphere. A surface

access hatch was installed in the top of the hull amidship. This hatch was also of a submarine type, 30 in. in diameter, and provided access to the Sealab II interior while in the water but still on the surface.

Entry Trunk

A trunk 8 x 8 ft by 2-1/2 ft deep was installed below the hull around the main entry hatch. Since the main entry hatch was to remain open at all times while Sealab II was inhabited, the entry trunk was designed to provide a displacement volume to compensate for seawater pressure variation caused by tidal action, in addition to the expected internal gas pressure fluctuations. It was determined that the predicted tidal range of nine feet would cause a 2-1/2-ft excursion of the water level in the entry trunk. However, it was necessary to keep the gas volume of the entry trunk (approximately six tons displacement) small so as to reduce the tipping moment created by this increased buoyancy at the stern of the craft. Compensation by ballasting from the surface was not considered feasible.

Shark Cage

A protective enclosure of expanded metal was built around the entry trunk. Approximately 8 ft wide by 12 ft long, this enclosure provided a protected observation point or retreat in the event that sharks were in the area. A dutch door, 4 ft wide by 6 ft high, was provided to permit access if the lower portion of the door was embedded in the sea bottom. The lower foot of the shark cage was made of chain to allow conformity with a possible uneven bottom.

Support Structure

The support structure was designed to provide a clearance of 6-1/2 ft between the hull and the sea bottom. Bottom bearing plates (two each 3 ft x 18 ft) were installed to provide a maximum seafloor bearing stress of 300 psi. On-site tests of the seafloor had indicated a minimum soil-bearing strength of 1300 psi.

The use of leveling jacks was considered but was rejected because of their cost and the time required to provide them. Site surveys indicated a maximum bottom slope of 5 percent (approximately 3 degrees) and no need for such jacks.

Spades were installed at each end of each bearing plate, so as to penetrate the bottom and reduce the possibility of lateral movement.

Hull Penetrations

All hull penetrations for gas lines, water line, sanitary drains, and cables, were located as near deck level as possible to minimize loss of atmosphere and flooding of Sealab II in the event of external line damage. These penetrations were sealed by double stuffing tubes, or the pipes were welded to the hull. Hull penetrations were optimally located to minimize the lengths of high-pressure lines inside Sealab II. A 10-in. pipe was installed through the bottom near the after end of the lab space to accommodate power leads for the outside diving lights and signal leads for the benthic lab, an underwater data multiplexing and telemetering system developed by the Marine Physical Laboratory of the University of California. This pipe extended from the horizontal centerline of the hull to a point 2-1/2 ft below the hull, so that the required cables could be installed upon removal of a pressure-tight bolted flange after habitation of Sealab II. A 3-in. pipe was installed inside the 10-in. pipe to provide shielding between the diving light power leads and the benthic lab signal leads. Bilge drains with manually operated valves were provided to allow draining the bilges overboard while Sealab II was on bottom.

Variable Ballast

The upper portion of the hull volume (3 ft deep by full hull length) was utilized for water ballast. This volume was divided into three separate tanks (No. 1, forward; No. 2, amidships, and No. 3, aft). A fourth tank was provided by the "conning tower," which also served as a breakwater for the surface access hatch. The internal tanks were designed to withstand a pressure differential of 15 psi across their flat bottoms. Internal ballast tanks were utilized for several reasons:

1. To reduce internal gas volume and consequently the total volume of helium required for charging.

2. To reduce the virtual mass of the entire structure in water by eliminating external ballast tanks.

3. External ballast tanks would have severely limited the field of view from the Sealab II viewing ports towards the sea bottom. These ballast tanks were utilized to provide

   a. Adequate positive buoyancy for surface tow and systems checkout.

   b. Negative buoyancy for lowering and raising.

   c. Adequate negative buoyancy for necessary stability on bottom. A maximum negative buoyancy of 13 tons was required to provide bottom stability in a maximum athwartship current of 2 knots.

Fixed Ballast

Fixed ballast was provided by:

1. Concrete inside the hull to deck level except in the entryway.

2. Lead weights secured in the ballast tray underneath the hull.

Lead pigs in ballast trays located fore and aft under the topside walkways were utilized to provide final fore and aft trim.

Hull Insulation

The insulation used in Sealab II was Navy "standard stock" submarine corkboard in one-inch-thick boards. The coefficient of thermal conductivity (k) for this material at standard atmosphere is 0.025 Btu/hr-ft-°F. The overhead was insulated with one inch and the hull sides with two inches of this corkboard. No insulating material was utilized on the concrete deck except carpet, since radiant heating cables were installed in the concrete. The thermal conductivity (k) of helium is 0.090 Btu/hr-ft-°F, six times that of air. Since the insulating material was to be permeated by the helium at the ambient pressure of approximately 102 psia, the theoretical coefficient of thermal conductivity (k) for the cork insulation under ambient conditions was calculated to be 0.100 Btu/hr-ft-°F. This value of k was then utilized to calculate the expected heat losses in Sealab II, as shown in Appendix B.

UMBILICAL CORD

An umbilical cord provided the necessary utilities from the support vessel to Sealab II. The original umbilical cord consisted of five components, providing:

1. Alternate electrical power

2. Communication circuits

3. Atmosphere gas supply

4. Atmosphere gas sampling

5. Compressed air for pneumatic tools (external use only).

The umbilical cord was permanently attached to Sealab II near the top of the "conning tower." The power and communication cables penetrated the hull through pressure-proof stuffing tubes. The hose components of the umbilical cord were connected to piping installed on the exterior of the hull with two-way shut-off, quick-disconnect type connectors. The piping for the atmospheric gas supply and atmospheric gas-sampling systems penetrated the hull through welded hull fittings. The compressed air piping terminated in four valved hose connections located on exterior corners of the hull. These connections provided for the operation of pneumatic tools in the sea.

The alternate power cable was of Navy type THOF-42 (three conductor 42MCM). The communication cable was a neoprene-jacketed 33-conductor TV cable, Boston Insulated Wire Company No. TV-33N. The short lead time allowed did not permit the design of a special communications cable.

During checkout at Long Beach, California, it was found that the hose components had been kinked, causing the hose liners to separate from their jackets when subjected to test pressure. The rubber fabric hose originally in the umbilical cord was replaced by high-pressure hose with a seamless nylon core, a flexible braided nylon reinforcement, and a polyurethane jacket. The gas supply and compressed-air hoses were 3/4 in. I.D. and the gas-sampling hose 1/4 in. I.D.

In the course of replacement of the hose components, two additional power cables for underwater photographic lights and a cable for remote camera control were added to the umbilical cord. In lieu of the original canvas jacket on the umbilical cord, the components on the modified cord were married together at 8-ft intervals. The umbilical cord was stowed on the platform on top of Sealab II when it was towed or transported on a barge. A circular protective enclosure on top of the "conning tower" was provided for stowing the umbilical cord; however, it was not adequate for stowing the enlarged cord.

The upper end of the umbilical cord terminated at a central point on the stern of the support vessel and connected to the various supplies of gas, air, and power, and to the communication circuits.

SYSTEMS

Ballast System

The ballast system was designed with sufficient compartmented liquid ballast to permit adjustment of weight and of center of gravity for several conditions. First, sufficient positive buoyancy and stability were required for towing Sealab II to its site. Second, positive buoyancy, stability, and freeboard were required when the vessel was moored on the surface at the site with the upper hatch open. During lowering of the vessel, a negative buoyancy was required, but such as not to cause undue strain on the lowering gear. In place on the bottom, the vessel requires sufficient negative buoyancy to overcome that added by blowing water from the entry skirt, and enough negative buoyancy with its center of gravity well between the legs to be stable on the bottom in the prevailing current. The above conditions were to be satisfied with inside ballast tanks, with soft boundaries between the tank space and the pressurized habitation space, together with limited external ballast. This habitation space was to be pressurized before lowering, so provision had to be made to prevent damage to the tank boundaries. These conditions were satisfied with an internal ballast tank in the upper portion of the main cylinder, extending its entire length and subdivided into three compartments, and a conning tower of sufficient size to double as tank and provide on-surface entry.

Provision was made to flood each tank space at its bottom, and all tanks were vented through individual valves to a common manifold which led to a master vent valve. The manifold was further connected to the main cylinder through a valve to provide pressure equalization between any tank and the habitation space. The manifold was also connected to the entry skirt to provide for blowing the skirt and equalizing the skirt with the habitation space.

The weights and centers of gravity were calculated for all operational conditions, and a surface waterline was established. After all gear was aboard in its proper location, Sealab II was put into the water dockside, and the pig ballast under the topside walkway was adjusted to attain the pre-established water line.

With all ballast tanks dry and the entry skirt flooded and hatches sealed, Sealab II was in condition to go to sea with buoyancy and stability as required for towing. On site, the conning-tower hatches could be opened to allow final checkout of equipment. The conning tower provided the necessary freeboard to prevent flooding of the habitation space by wave action. Before the habitation space was pressurized with its atmosphere, the end tanks overhead could be flooded. In this condition, buoyancy with hatches sealed was adequate to keep Sealab II afloat while it was pressurized. With the end tanks full, all flood valves were to be closed and internal tanks were to be opened to the vent manifold, with the manifold open to the habitation space. In this way, during atmosphere pressurization, no pressure differential would exist on the boundary between the habitation space and the internal tanks. After pressurizing of the hull to slightly below the final pressure, the conning tower could be flooded to give the system negative buoyancy for lowering. Once on the bottom, the center overhead tank was flooded to stabilize Sealab II on the bottom and allow blowing of the entry trunk. While the center tank was flooding, its vent could be opened via the manifold to the interior; the vented gas then gave the habitation space its final desired pressure.

For return to surface after all hatches were sealed, provision was made for blowing the center overhead tank and hoisting to surface.

Electrical System

Supply Voltage — The electrical distribution system used in Sealab II was 450 volts three-phase and 208/120 volts three-phase with ungrounded neutral. The system had a total capacity of 75 kva. Normal power was supplied from shore at 4160 volts three-phase by an underwater cable. The 4160-volt power terminated in an underwater transformer bank and was stepped down and supplied to Sealab at 450 volts three-phase. Alternate power for use in case of normal power failure was supplied from the support vessel at 450 volts three-phase through a cable in the umbilical cord. Both cables entered the hull through pressure-proof stuffing tubes near the bottom of the hull. Both supplies were connected to the main power-distribution panel through 100-ampere three-pole circuit breakers. A mechanical interlock assembly was provided so that both supplies could not be used at the same time. Indicator lights on the main panel indicated from which source power was available.

Utilization Voltages — The electrical loads in Sealab II utilized the following voltages:

1. 440 volts, three-phase
2. 208 volts, three-phase
3. 208 volts, single-phase
4. 120 volts, single-phase.

A transformer bank consisting of three 25-kva single-phase transformers connected delta-wye supplied the 208/120-volt power. The transformer bank was installed in a gas-tight compartment to prevent atmospheric contamination in case of transformer overheating. The hull formed one side of the compartment and was left uninsulated to aid in cooling the compartment. A fan was installed in the compartment to improve air circulation and provide additional cooling. A remote-reading thermometer was also installed so that the interior temperature of the enclosure could be monitored. The transformer bank and all equipment operating on 440 volts were supplied from the main distribution panel. Three low-voltage power panels were supplied from the load side of the transformer bank. Two of the panels supplied all of the 120-volt

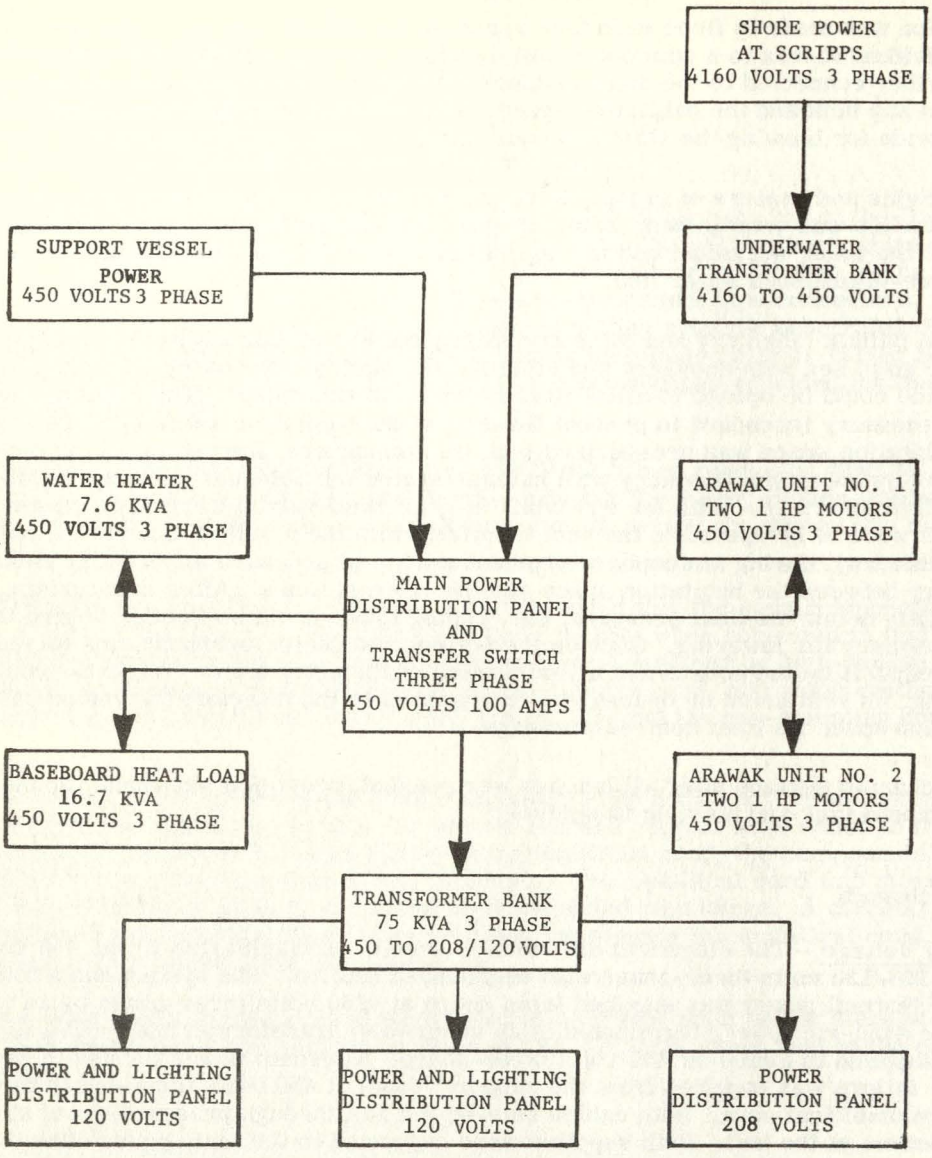

Fig. 123. Sealab II electrical system block diagram

circuits, while the third panel supplied the 208-volt circuit. Figure 123 is a block diagram of the electrical power distribution system.

Branch Circuits and Loads — All electrical circuits were controlled and protected by circuit breakers located in the distribution panels. Wiring was installed in accordance with General Specifications for Ships of the U.S. Navy, with the use of standard Navy shipboard cable and equipment. The electrical circuits were ungrounded to eliminate shock hazards. Figures 124 and 125 show the power and lighting systems. Table 45 shows the total connected load of the electrical power-consuming equipment installed in Sealab II.

Interior Lighting — The interior lighting fixtures were marine type fixtures using commercial 40-, 50-, 75-, or 100-watt lamps (A-19 bulb size). These lamp sizes were all tested to ascertain their ability to withstand pressures twice that equivalent to the water depths of 200 ft (approximately 178 psi). All fixtures were controlled by conveniently located toggle switches. A red standing light was installed in the berthing area for low-level lighting. Individually controlled berth lights were installed for each berth.

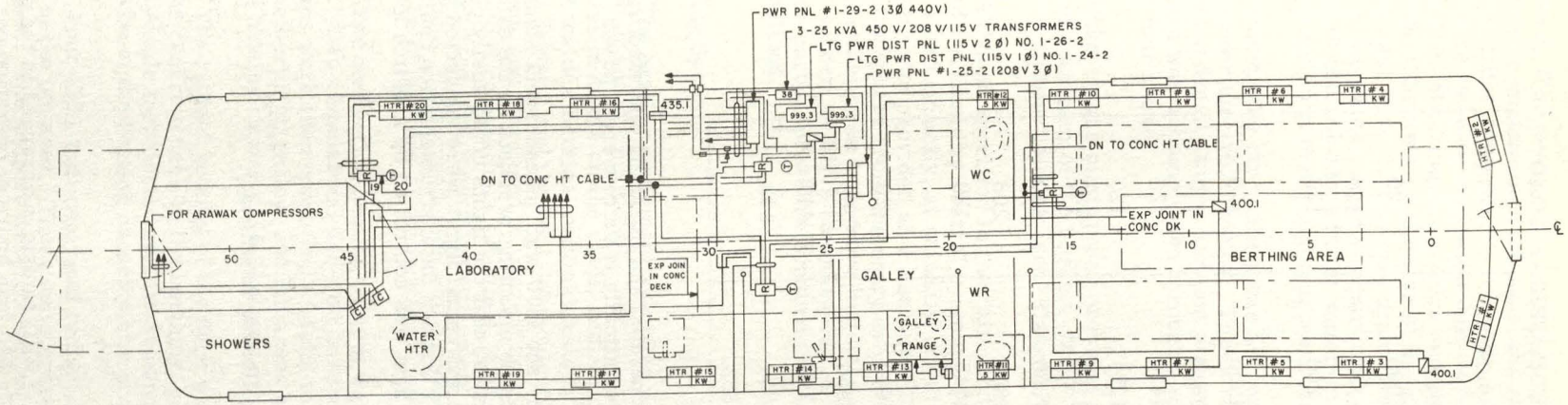

Fig. 124. Sealab II power system deck plan

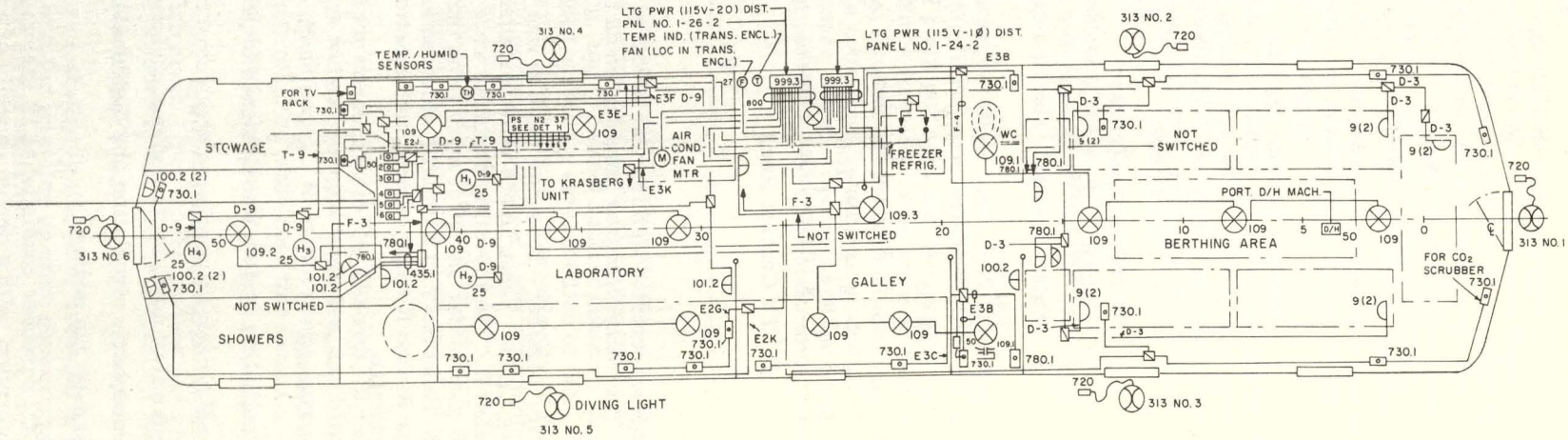

Fig. 125. Sealab II lighting system deck plan

Table 45
SEALAB II — TOTAL CONNECTED ELECTRICAL LOAD

Load	Volt-Amperes	Voltage
Interior Lighting	2450	120
Exterior Lighting	6000	120
Electric Blankets	1800	120
Berth Lights	250	120
General Purpose Outlets:		
1. Berthing	1500	120
2. Galley	2640	120
3. Laboratory	4426	120
Refrigerator-Freezer	1224	120
Arawak Units	3168	440
Water Heater	7600	440
Range	4800	208
Ventilation	1345	120
Heat		
1. Radiant Heating	5000	120
2. Floor Heating	4950	208
3. Convection Heating	16,700	440
TV Control Rack	1800	120
Total	65,653	

Emergency interior lighting was provided by relay-operated and manually operated hand lanterns. The relay-operated lanterns would turn on automatically if there were a power failure.

Exterior Lighting — Exterior lighting was provided by six 1000-watt incandescent standard Navy diving lights. These lights were installed on adjustable mounting brackets on the exterior hull of Sealab II. The mounting brackets were constructed so that the lights could easily be removed and used as far as 150 ft away from the hull. The individual lights were connected by underwater connectors to a pigtail, which entered the hull through the instrumentation cable trunk, after Sealab II emplacement on the bottom. Each light was controlled by a switch located inside the Sealab.

Ventilation System

The ventilation system was designed to provide the following functions:

1. Removal of carbon dioxide (CO_2)
2. Removal of odor, hydrocarbons, and aerosols
3. Atmospheric circulation and distribution
4. Make-up gas mixing.

The CO_2 scrubber consisted of 12 lithium hydroxide (LiOH) canisters arranged in the parallel configuration, with a design capacity of approximately 540 man hours of operation per 12

canisters. The design flow capacity of the CO_2 scrubber was approximately 60 cfm. At this flow rate, complete circulation of the atmosphere (4000 cu ft) would require 66 minutes. The charcoal filter consisted of two units containing approximately 1400 cu in. of charcoal each. The filters were rechargeable and were sized to operate for approximately ten days before replacement. Six filter units were supplied. The design flow capacity of the charcoal filter was 250 cfm. Complete circulation of the atmosphere through this filter would require 16 minutes. Of this total flow, 60 cfm was drawn through the CO_2 filter. The remaining 190 cfm was drawn through the water-closet compartment and generally from the galley area. This arrangement served to control odors in the water-closet compartment (where the sanitary drains were vented) and to remove any hydrocarbons produced in cooking.

Atmosphere circulation was accomplished with a centrifugal blower powered by a 1/2-horsepower electrical motor. The normal power input to the fan was doubled because of the increased density of the ambient atmosphere, approximately twice that of standard air. Distribution was accomplished through a single fore-and-aft duct, with one overhead grill in each of the four areas.

Make-up gas mixing was provided for by introducing make-up helium or air into the vent plenum upstream of the blower. Make-up oxygen was introduced into the discharge duct at the point of highest velocity (see "Oxygen System," later in this chapter).

Although specified in the "air conditioning package," time and budget did not allow integration of the humidity control system. Three dehumidifiers were installed in Sealab II, each having a rated capacity, at standard conditions, of 47 pints per day, and one portable unit of like capacity was provided as a back-up. Two of the three installed units were located for intake of wet atmosphere from the entry area and discharge into the lab area. The third unit was located in the galley area to remove moisture produced in cooking and washing. A design control level of 70 percent relative humidity was selected to insure reliable operation of the "Krasberg" oxygen partial-pressure sensors for the total test period, based on manufacturer's recommendations.

Heating System

The heating equipment specified as a part of the air-conditioning system was omitted because of space limitations. The living space was heated by means of electrical convection heaters mounted on the shell, radiant deck heating, and overhead radiant heaters. A total of 26.65 kw of electrical heating capacity was provided, based on extrapolation of data obtained from Sealab I and the heat-loss calculations shown in Appendix B. The capacity of the heating system was increased to provide approximately 50 percent more heat input than indicated by the heat-loss calculations. Further, it was anticipated that as much as 20 kw of sensible heat might be realized from operating equipment in Sealab such as lights, electronics, motors, pumps, and fans. This overdesign was considered to be extremely desirable in the event of possible failure of portions of the heating system.

The convection heating system was designed for connection to the 450-volt, three-phase line. Two commercial 240-volt baseboard heaters were connected in series, and three such groups were then connected in delta to the three-phase power. Separate banks were installed in the berthing, galley, and lab areas and were controlled by individual thermostats. Of the total heating capacity, 16.7 kw was provided by the convection heaters.

The radiant heating of the deck was provided by embedding mineral insulated heating cable in the concrete deck in the berthing, galley, and lab areas. The entire system was controlled by a single thermostat with its sensing element embedded in the concrete deck. A total of 4.95 kw of the heating capacity was provided by this system.

Four 1250-watt overhead radiant heaters were installed in the entry area and in the after end of the lab area. These units provided quick heat for warming up after showers and outside sorties. The heaters were controlled by individual off-on switches.

Breathing-Gas Systems

General — The primary breathing (atmosphere) gases for Sealab II were stored externally in 24 standard 1300-cubic-foot bottles at a nominal pressure of 2400 psig. All high-pressure lines were designed for 3000-psi service, and all low-pressure lines for 400 psi. A gas-control panel was installed above the communication center on the port side of the lab area to provide centralized control and monitoring of all gas systems, with the exception of the emergency breathing (Bibb) system. The Bibb system controls were located in the galley area for utmost convenience in the available space. All pressure regulators were of the standard welding type, which were easy to obtain and which permitted easy adjustment at ambient pressure. Three identical regulators were used. They were interchangeable and required a minimum stock of spare parts.

Oxygen System — An on-board oxygen supply of 14,300 cu ft was provided as the primary breathing supply. The oxygen system was installed essentially as shown in Fig. 126. The primary oxygen system was automatic in operation and was controlled by the Krasberg oxygen partial-pressure sensor. This unit monitored oxygen partial pressure and in turn controlled an electrically operated solenoid valve to admit oxygen as needed. Remote readouts were provided on the surface vessel for topside monitoring. Two separate, manually selected supplies of oxygen were available.

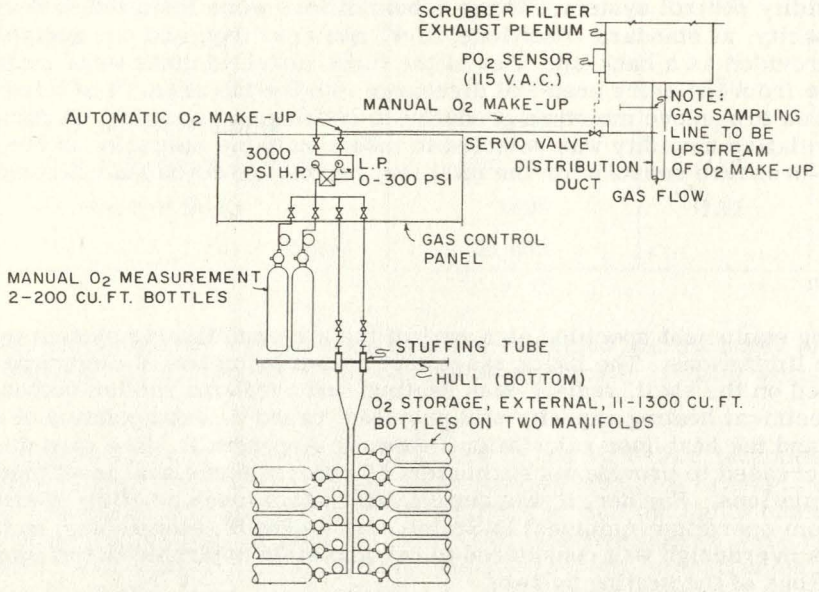

Fig. 126. Sealab II oxygen system

A secondary, manually operated system was included as a backup in the event of failure of the automatic system.

The primary input of oxygen was directed into the discharge of the ventilation system to provide thorough mixing. This point of introduction also prevented high oxygen concentrations in the immediate vicinity of the blower motor. An input directly into the atmosphere was provided for use in the event of failure of the blower system.

A third oxygen-supply system was tied into the manual oxygen system so that emergency oxygen could be supplied from the surface. This supply would utilize the gas-sampling system via the umbilical cord.

A pressure-relief valve (400 psig) was installed in the low-pressure portion of the oxygen system (immediately downstream of the pressure reducer). The pressure relief valve was discharged overboard through the benthic wiring trunk. A flow meter was installed in the oxygen input line to provide a visual indication of flow rates.

Helium System – A total of 13,000 cu ft of helium was provided in the on-board supply. This helium was intended for use in make-up of any losses due to leakage and absorption and also to adjust the water level in the entry trunk. The helium system was installed essentially as shown in Fig. 127. The helium was introduced into the blower intake of the ventilation system to insure adequate mixing with the atmosphere.

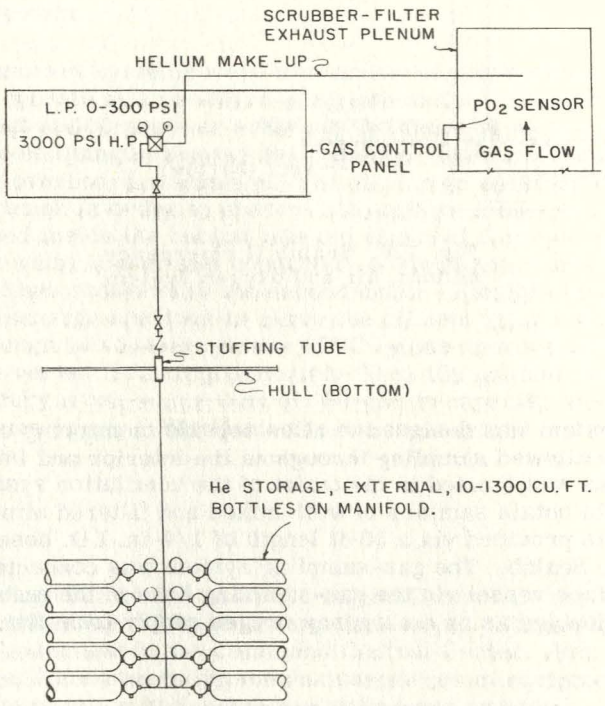

Fig. 127. Sealab II helium system

An additional helium system for initial charging and emergency make-up was installed as shown in Fig. 128. This system was supplied from the staging vessel through the umbilical cord.

Emergency Breathing System – An emergency breathing (Bibb) system was installed to provide emergency premixed breathing gases in the event that the habitat atmosphere became contaminated (Fig. 129). The system would provide approximately 43 minutes' breathing time for ten aquanauts. Three standard 1300-cu-ft cylinders of premixed gas were valved into a regulator located in the galley area and supplied eight manifolds containing four quick-connective outlets. Twelve Calypso model 1050 single hose scuba rigs, modified by removal of the first-stage pressure regulator and the addition of a quick-connective fitting, were provided for use with the Bibb system.

In addition to the Bibb system, twelve 38-cu-ft scuba bottles with first-stage regulators (removed from Calypso rigs) and quick-connective fittings identical to those on the Bibb manifolds were provided near the entry trunk. These bottles were to be utilized by the aquanauts to swim to the Personnel Transfer Capsule (PTC) in the event of emergency evacuation of the habitat.

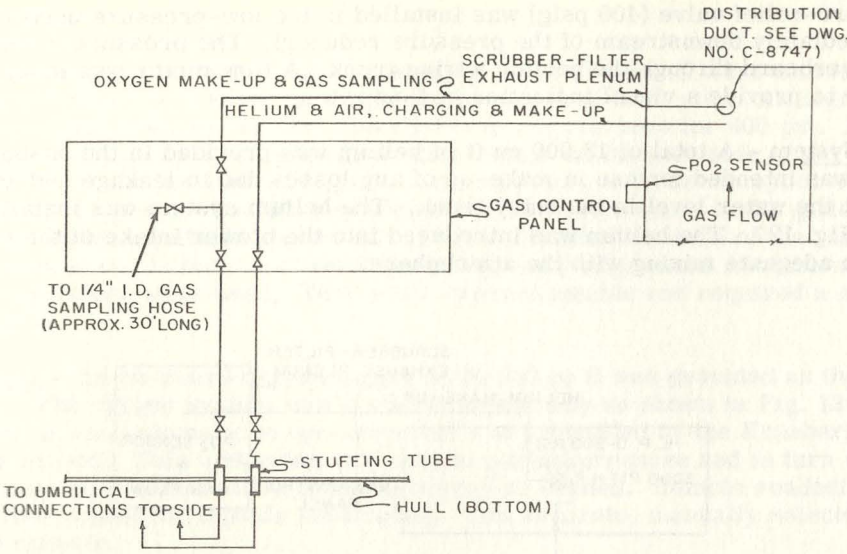

Fig. 128. Sealab II emergency helium, air and oxygen system

Gas-Sampling System

A gas-sampling system was designed to allow topside monitoring of the atmosphere of Sealab II. This system allowed sampling throughout the interior and in the ventilation plenum. The gas-sampling intake was located in the outlet of the ventilation system, upstream of the oxygen input, in order to obtain samples of well-mixed and filtered atmosphere. An additional gas-sampling intake was provided via a 30-ft length of 1/4-in. I.D. hose for sampling at any desired point inside the Sealab. The gas-sampling system was connected to the Atmosphere Control Van on the surface vessel via the gas-sampling hose in the umbilical cord. The gas-sampling system also doubled as an emergency oxygen supply from the surface.

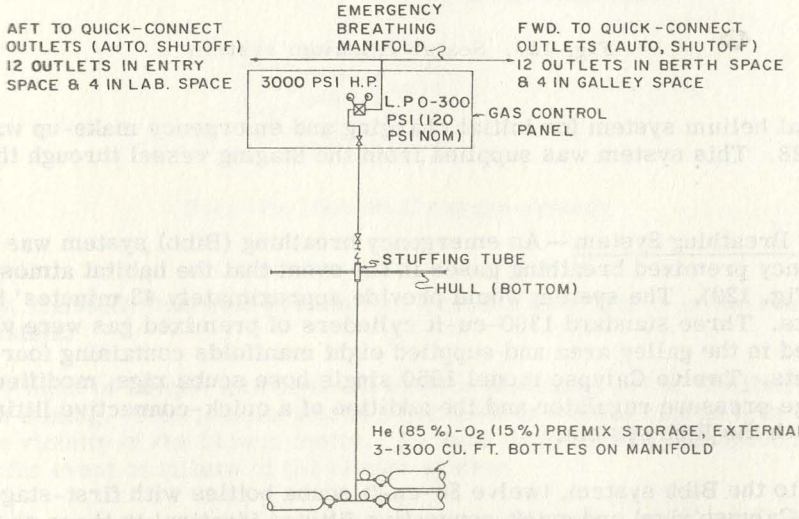

Fig. 129. Sealab II Bibb system

Arawak System

The Arawak system was utilized to pump the Sealab atmosphere to a swimmer through a hose. As the swimmer exhales, the gas is returned through a second hose to the Sealab II atmosphere for reprocessing. The equipment installed in the Sealab consisted of two positive-displacement, carbon-vane pumps driven by separate one-horsepower electric motors. One pump, operating at approximately 23 psig, supplied breathing gas to one swimmer while the other pump, operating at a negative pressure of approximately 15 in. Hg, returned the exhaled gases to the Sealab. This equipment was mounted overhead in the entry area. Two complete systems were installed, with cross connections to provide continuing operation in the event of failure of either system.

Plumbing and Sanitary System

The plumbing and sanitary systems were essentially of conventional design. The plumbing system was designed to operate at a pressure of approximately 40 psi over ambient, with pressure-relief valves set at 100 psi over ambient. All fixtures were conventional; the water closet was a marine type utilizing sea water for flushing. The sanitary system was a gravity-flow system, with direct overboard discharge. The discharge openings were kept below the water level in the entry trunk in order to prevent atmosphere loss. All fixtures were trapped. Sanitary lines were vented inside the habitat into the charcoal filter of the ventilation system to eliminate odors. The water closet was connected to one sanitary drain and all other fixtures (lavatory, two sinks, and two showers) to the second drain. Flexible hoses 50 ft long were attached to the sanitary discharge openings to carry the effluent away from Sealab II. Water was supplied from shore through two 3/4-in. plastic (PVC) pipes approximately 3,500 ft long. Shore water pressure could be varied from approximately 70 to 100 psi and was metered to determine usage rates. An emergency fresh-water tank of 150-gallon capacity was provided in the event of interruption of the shore supply. This tank was not pressurized and was not connected to the normal water system.

Communication System

Communication between Sealab II and the Command Control Center on the support vessel was provided by a communication cable in the umbilical cord. The cable terminated in patch panels in the habitation space and in the Command Control Center. Receptacles were utilized in the patch panels to facilitate connecting the various pieces of equipment at the test site. The following modes of communication and instrumentation were provided:

1. Helium Speech Unscrambler - three circuits
2. Electrowriter, two-way
3. Television - closed circuit monitoring
4. Television - aquanauts' entertainment
5. Audio - intercom, two-way
6. Audio - carrier-transmitted two-way voice communication between support vessel and shore (via Sealab and benthic lab)
7. FM music - aquanauts' entertainment
8. Wedge spirometer output
9. Oxygen partial pressure
10. Open microphones.

The patch panel in Sealab II was located in an area on the port side of the laboratory designated the communication and watch center. All communication with surface control originated at this point, except two helium speech unscrambler circuits, which were installed in the galley and berthing area. The primary purpose of the two additional helium speech unscrambler

outlets was to permit unscrambled speech communication between aquanauts. FM music and commercial television signals were provided for entertainment. FM speakers were located in the berthing area and the laboratory area and were provided with individual volume controls. The entertainment TV was located in the laboratory area and had the video tube enclosed in a specially designed, pressure-proof container.

Three open microphones were installed in the laboratory, living quarters, and galley for continuous monitoring of conversations of the aquanauts. A commercial two-way intercom was used to pass information from the surface and for limited two-way conversations. The system consisted of a master unit in the topside Command Control Center and a slave unit below.

The oxygen partial pressure output from the Krasberg oxygen control unit was transmitted to the Atmosphere Control Center through the Command Control Center. The output of the wedge spirometer transducer, a device for measuring the flow and volume of the lungs, was also transmitted to Atmosphere Control Center. Data from other experiments and tests were transmitted to the surface on the wedge spirometer conductors on a time-sharing basis.

The signals from three closed-circuit TV cameras were transmitted to the Command Control Center via a single coaxial cable at three different frequencies.

Data-Recording System

To obtain data which would aid in future Sealab designs, provisions were made in Sealab II to record certain engineering and environmental data. It was originally planned to transmit some of this data to shore through the facilities of the benthic lab, but technical difficulties prevented its use. The following data were recorded by hand on preprinted forms by the personnel on watch:

1. Power consumption
2. Equipment running time
3. Temperature, interior
4. Temperature, equipment
5. Humidity, interior.

Power-consumption figures were obtained from a commercial three-phase kilowatt-hour meter installed on the load side of the main transfer switches.

Equipment running time was recorded for the following equipment:

1. Water heater
2. Dehumidifiers (4)
3. Baseboard heating banks (3)
4. Deck heating
5. Overhead radiant heaters (4)
6. Refrigerator
7. Freezer.

Elapsed-time meters for the above equipment were installed in a convenient panel near the watch center to facilitate recording of data by the man on watch.

Temperature sensors were installed in the entry area, lab area, galley, and berthing area, and in the refrigerator and freezer compartments. The sensors were connected to millivolt-to-current converters. The outputs of the converters were shunted by a resistor to obtain a 0 to -6 volt dc output. The output from the resistor of each converter was connected to a high-input-resistance voltmeter through a selector switch. This readout meter was located

adjacent to the time-lapse panel, and the voltage analog of the temperature was recorded on the preprinted data forms.

Humidity sensors were installed in the entry, lab, galley, and berthing areas. The humidity system was similar to the temperature system described above, except for the sensors and a signal converter connected between the sensors and the millivolt-to-current converters. The voltage analog of the humidity was obtained from the meter used in the temperature system. The humidity sensor in the entry area failed to operate after Sealab II was placed on the bottom, and no data were obtained from this sensor.

It would not have been necessary to change the output of the MV/I converters to a voltage, but this was done to permit the output information to be telemetered to shore via the benthic lab.

EQUIPMENT

General

All equipment installed in Sealab II was checked and certified for use in the operational environment. Particular emphasis was placed on the elimination of materials which might introduce toxic fumes into the closed atmosphere. All equipment cavities and enclosures were either vented for pressure equalization or were proven to be capable of withstanding 1-1/2 times the ambient pressure of the Sealab II atmosphere. Performance characteristics were checked in artificial Sealab environments to ensure required operational performance. All equipment used in Sealab II was essentially "off-the-shelf" hardware.

Refrigerator-Freezer

The refrigerator-freezer was a Navy "standard stock" item with refrigerator and freezer capacity of five cubic feet each. The two refrigeration systems were of conventional mechanical (Freon) type and were powered by 1/6-hp electrical motors. Insulation consisted of four inches of spun fiber glass. In order to reduce heat losses in the helium-rich atmosphere, two inches of cork insulation was added to the outer surfaces of the cabinet. The standard aneroid temperature-sensing elements, which would not operate properly at hyperbaric pressures, were replaced with mercury sensors. These were well protected to reduce the possibility of rupture and spillage of mercury.

Cooking Equipment

The cook top for the galley consisted of four heating units installed in the counter top. Each unit had a heat-control switch. The units were rated at 1250 watts at 220 volts; however, the supply voltage was only 208 volts and the maximum output approximately 1180 watts each. A commercial 1500-watt rotisserie and four-slice standard Navy toaster were also included in the galley equipment.

Water Heater

The water heater was a Navy "standard stock" type with a storage capacity of 50 gallons and a recovery rate of 50 gph. Maximum power consumption was rated at 7.6 kw. A temperature-and-pressure-sensitive pressure-relief valve was installed and set for a relief pressure of 100 psig. No special insulation was added to the water heater.

DISCUSSION AND TEST RESULTS

Hull

General — The hull appeared to be leak free and structurally adequate, and generally performed its function well. There was little evidence of corrosion or marine fouling.

Ports — The viewing ports in the laboratory and galley were utilized extensively to observe swimmers in the water (visibility permitting), to monitor the interior with externally mounted TV cameras (helium permeation of the TV monitors necessitated removal from the interior), and to provide a diversion in the form of fish watching. The viewing ports presented several problems, as follows:

1. The flat gaskets installed on the internal pressure-tight covers leaked (four out of eleven ports), preventing full pressurization of the hull on the surface as intended.

2. Opening and securing of the internal covers was a time-consuming task because of the number of bolts and the torque required to pull down the gaskets.

3. The swing of the internal covers consumed excessive space inside the hull.

4. Removal and replacement of the external port covers was a difficult and hazardous operation because of their size and weight.

5. The cold inside surface of the port light caused moisture condensation, resulting in wet areas around the ports.

Access Openings — The main access hatch performed its intended purpose well, with no evidence of leakage. Some of the aquanauts had difficulty in entry and exit through this hatch. However, it seems that these difficulties stemmed primarily from lack of space in the entry area and the necessity of climbing the entry ladder in full swimmer dress.

The surface access hatch was useful for the final systems checkout on surface and for the last-minute stowage of gear. Minor problems associated with this hatch were the lack of counterbalance, making hatch operation difficult, and moisture condensation on the cold surface of the uninsulated hatch, which dripped on the walkway. As a remedy, a plastic sheet was stretched underneath the hatch to shed the water to one side of the walkway.

The emergency access hatch was fortunately not required. This hatch is considered too inaccessible to serve its intended purpose.

Entry Trunk — The entry trunk provided ample displacement volume for internal pressure changes and water-pressure variations due to tidal action. The six-foot tidal range experienced was somewhat less than the predicted nine-foot range. The maximum recorded water-level excursion was less than two feet.

Shark Cage — The shark cage, provided for swimmer protection, served little useful purpose in this test, since sharks were not a problem.

Support Structure — The support structure served its intended purpose with little evidence of sinking into the sea bottom. However, because of a late change in site location, the Sealab was placed on an uneven bottom, causing the craft to assume a final attitude having a 6-degree port list and a 6-degree bow-up angle.

Hull Penetrations — No significant problems were encountered with hull penetrations.

Variable Ballast — The ballast tanks, generally, functioned as intended. However, difficulties with the associated piping and valving were encountered, as discussed under "Ballast System," later in this chapter.

Hull Insulation — The cork insulation used in Sealab II functioned well. The average heat input (60,000 Btu) required to maintain the design temperature (88°F) agreed very closely with the theoretical calculations of heat loss (54,300 Btu). Some additional heat losses not considered in the design calculations were the heat of warm water drained overboard, Arawak gas heat, and electrical transformer heat losses to sea. Minor damage to the insulation was caused when the Sealab partially flooded during the final raising operation.

Umbilical Cord

No problems were reported with the umbilical cord as assembled at Long Beach Naval Shipyard. Since supporting floats were married to the umbilical cord as it was streamed, handling at the test site was cumbersome and time consuming.

Systems

Ballast System — In actual operation, certain problems developed in using the system as designed. First, when the end overhead tanks were flooded on surface, trim was difficult to control. These tanks flood independently, and one tends to fill faster than the other. As it does so, that end trims down, increasing the head on the flood valve, accelerating the out-of-trim conditions. Ultimately, the flood valve on the high end broaches and the tank will not fill further. When this happened the tank on the high end was filled by hand from buckets. In the future, provision should be made for better control of flooding of longitudinally flooded tanks.

A further difficulty was encountered in blowing the center overhead tank prior to surfacing. Sealab was in an inclined position on the bottom, and there was no valve opening on the low edge of the tank. It was therefore impossible to blow all the water out. Some water then had to be blown from the end tanks to remove enough weight to surface. As there was no way of determining the volume of water in any of these tanks when partially full, it was impossible to control trim, and when Sealab II surfaced, it was at about a 30-degree angle. An improved system of blowing tanks is necessary to assure complete removal of water from tanks when desired.

Electrical System — The electrical system as a whole functioned satisfactorily and introduced few problems. The power capacity provided appears adequate on the basis of power consumption during the underwater test phase (see Tables A1, A2, A3, and A4, in Appendix A). The maximum average power requirement was 38.8 kw. There are long intervals between readings during this period, and it appears that some error entered the readings of the watt-hour meter. Since a recording wattmeter was not used, the instantaneous peak-power requirement is not known and could have been much greater than the maximum average peak load. The average daily power requirement for the 42-3/4-day period was 21 kw. In any case, a maximum of 75 kva at unity power factor certainly appears ample.

The only major problem experienced with the electrical system was with the external lighting. The short life of the 1000-watt incandescent bulbs (rated 50 hours) necessitated frequent bulb changing, which proved to be a time-consuming job. The lighting level was not sufficient for photography; however, this was not the original intention of the external lighting. Some trouble was experienced by the aquanauts in identifying the proper underwater pigtail connector to be utilized for connecting each exterior light.

The main complaint concerning the interior electrical system was the location and insufficient number of convenience outlets in the lab area. Also, the level of the interior lighting was not sufficient for photography. Here again, the interior lighting was not designed for this purpose.

There were no apparent problems with the thermal-magnetic circuit breakers. The high thermal conductivity of helium affects the thermal characteristics of this type of breaker and probably does not provide the proper overload protection for the electrical circuits. The high conductivity of the helium atmosphere also works in favor of electrical equipment, in that they can operate at higher currents without danger of overheating.

Ventilation System — The ventilation system of Sealab II provided for satisfactory mixing of make-up oxygen, helium, and air. The four dehumidifiers, with a total rated capacity of 23.5 gallons of water per day, actually condensed an average of only about three to four gallons per day. The fan motors of the dehumidifiers were replaced by 1/4-hp motors to provide additional load capacity required by the increased density of the Sealab atmosphere. The poor performance of the dehumidifiers caused difficulty in controlling the humidity during periods of peak moisture input. Table A4 indicates an average relative humidity of 72.1 percent, but with relatively wide excursions as shown in Fig. A7.

The poor performance of the dehumidifiers was not anticipated, but is attributed largely to inadequate cooling capacity. The specific heat of the Sealab II mixture of oxygen, helium, and nitrogen at approximately seven atmospheres pressure is about 32 times that of air at sea level (Appendix C). Hence, a much larger amount of heat must be removed from the Sealab II mixture than from air at the same temperature to effect the same dehumidification. The fact that the Sealab atmosphere was approximately six times as conductive as air tended to offset this difficulty but could not remedy it altogether. Other factors such as film coefficients and the dew point of the Sealab II atmosphere also tended to offset the specific-heat effect, but the extent is not known.

The relative humidity was reduced considerably by the use of an automatic coffee urn for heating water for beverages rather than open pots. The radiant heaters in the entry area were turned off at night to reduce evaporation of sea water.

The atmospheric circulation and distribution system was not adequate and contributed to the dehumidification problem. A higher flow rate and improved distribution of the atmosphere would have lessened the buildup of humidity in the berthing and galley areas and would have improved the evaporation of perspiration. Better moisture distribution should have permitted more uniform and efficient operation of the dehumidifiers.

The performance of the carbon dioxide filter was acceptable but was somewhat less than satisfactory. Each set of lithium hydroxide canisters provided for only about 400 man-hours of operation rather than the design figure of 540 man-hours (75 percent saturation). This limitation aggravated an already severe handling and storage problem aboard Sealab II. A total of 291 canisters of LiOH (1700 pounds) were used for 427.5 man-days of operations. One pound of LiOH should absorb one pound of CO_2. The average rate of production of CO_2 is approximately 0.10 pound per man hour, or 2.4 pounds per man day. Hence, the efficiency of absorption in the canisters was only

$$100 \times \frac{428 \text{ man-days} \times 2.4 \text{ lb } CO_2/\text{day}}{1700 \text{ lb } CO_2/1700 \text{ lb LiOH}} = 60 \text{ percent.}$$

The charcoal filters seem to have operated satisfactorily, since objectionable odors were not evident. These filters were well overdesigned by normal standards in order to provide for such anticipated but unknown quantities as high humidity, LiOH dust, internally vented sanitary systems, and contaminants from cooking at the high ambient pressures.

Heating System — The heating system performed exceptionally well. As can be seen from Table A4, the baseboard heaters and radiant heaters 1 and 2 could have been omitted without affecting the comfort of the Sealab. The radiant deck heating proved ideal for Sealab and provided a comfortable atmosphere. Radiant heaters 3 and 4, installed in the entry area, were used primarily for quick warmup after outside excursions. It should be noted that the total average heat requirement for Sealab II, approximately 60,000 Btu, was somewhat higher than indicated by heater operation, since essentially all electrical power except exterior lights (17 kw average) was realized as sensible heat inside Sealab.

Breathing-Gas Systems — The automatic oxygen system performed well, except that the solenoid valve chattered when the oxygen level fell just below the mean control level. This difficulty occurred during the first team's stay and was remedied by deenergizing the system until the oxygen level neared the lower control limit. At this point the system would be reenergized and allowed to replenish the atmosphere with oxygen to the upper control limit. Since the cycle time for this procedure was from one to two hours, it was not considered a major problem. The malfunction seemed to be caused by a faulty relay in the control system.

During the third team's stay the pressure reducer failed, causing oxygen to be dumped overboard through the pressure-relief valve. Since the spare regulator furnished did not have the proper connections, the automatic system was secured. Subsequent oxygen input was controlled using the manual system. In addition, the emergency system was utilized to replace the lost oxygen from the surface.

The helium system performed satisfactorily. Approximately 20 percent of the onboard helium supply was used to replace losses through the sanitary drain discharge and by absorption into the sea water.

The emergency breathing system was not required. However, during on-bottom test procedures, the pressure reducer did not provide adequate flow for all ten aquanauts simultaneously unless the pressure was increased above the level compatible with the Calypso breathing apparatus. At the end of the test period, excessive corrosion was observed on all quick-connective fittings installed on the Bibb manifolds. The system could have been used in an emergency, but it was considered to be marginal.

Gas-Sampling System — The gas-sampling system performed satisfactorily and caused no difficulty.

Arawak System — Evaluation of the Arawak systems by aquanauts of each team indicated that the type of work to be done determined what breathing system was to be used. Team 1 utilized the Arawak system approximately 50 percent of the time. The majority of the work required of the subjects was in the close proximity of Sealab. Minor repairs to the vacuum pump were accomplished by team members.

Team 2 relied on the Arawak approximately 35 percent of the time. The subjects of this team ventured further away from Sealab. In general, no sorties of over 50 ft were conducted by aquanauts using the Arawak. Most Arawak sorties were local, being used for dumbwaiter transfers and general maintenance work on or in the vicinity of the Sealab.

Team 3 utilized the Arawak system approximately 30 percent of the time. The majority of work assigned to this team was beyond the 100-ft length of the Arawak's hose. No maintenance was performed by subjects of Team 3.

The primary problem encountered with the Arawak system inside Sealab was that of noise. The noise produced was that of intake and exhaust of the pumps making communications in the entry area most difficult when the Arawak was in operation.

Plumbing and Sanitary System — Some minor difficulties were experienced with the sanitary drains. The discharge hoses attached to the drains were lighter in weight than those specified and required weights to hold them down and prevent the loss of atmosphere from the water-closet drain. This overboard discharge was shortened during fitting-out to reduce line restriction. This modification raised the hose-connection point above the entry-trunk water level, but below deck level. Some atmosphere loss was reported through the salt-water supply line for the water closet. Apparently the check valve malfunctioned. The manual pumping effort required for flushing the water closet was reported to be excessive. This effort was apparently greater than that required in Sealab I and was due to the smaller flushing capacity of the Sealab II water closet. Also the shower tubs would not drain, since the overboard discharge (starboard side) was trapped by the six-degree port list of Sealab. Drain holes were drilled through the port side of the tubs, allowing the water to drain overboard through the entryway.

Water-usage rates were determined for the first team as shown in Fig. A2. Overall usage rates could not be determined, since the meters were not read regularly, and a leak which occurred in the line from Sealab to the surface vessel on Sept. 24 prevented the use of the final meter readings.

Communication System — Considerable crosstalk was experienced between circuits in the communication system, even though shielded conductors were used in the communication cable of the umbilical cord. The exact cause of the crosstalk was not ascertained. It was found that the shielding of the conductors in the communication cable had not been carried through the patch panels. This failure may have been the problem. Some crosstalk may have been caused by improper shielding and shield grounding of conductors in the Command Control Center.

The TV cameras became inoperative when high-pressure helium apparently leaked into the interior of the cameras and placed the components under pressure. Although the camera seals were capable of withstanding pressures much greater than ambient, the helium apparently

permeated the rubber O-ring seals and the glass lens. Replacement TV cameras were secured and placed outside the hull, looking through the ports on either side of the lab area. No further problems were experienced.

The slave unit of the intercom became inoperative during the second week of the operation and was replaced by a master unit wired as a slave. This master unit became inoperative after two days of operation. The cause of the failures was not determined. A second master wired as a slave was installed and operated satisfactorily the remainder of the test. The original slave unit is nothing more than a permanent-magnet speaker and should not be affected by pressure. The master unit has a transistorized power supply and amplifier and provides amplification for the slave unit.

Although the electrowriter performed satisfactorily, some ink splattering occurred when the Command Control Center initiated messages. This condition may have been caused by the high ambient pressure.

No problems were experienced with the entertainment TV and FM music equipment.

Data-Recording System — The equipment of the data-recording system performed its intended function, with the exception of the humidity sensor in the entry area. The major problem with the system was the necessity of recording the data by hand. As can be seen from examination of Tables A1, A2, and A3, data were recorded irregularly and in some cases not at all. The most complete data were obtained by the first team and is considered to be representative of the operation.

Equipment

Refrigerator-Freezer — The refrigerator was marginal in operation and definitely too small in storage capacity. As can be seen in Tables A1, A2, and A3, the refrigerator was capable of lowering the temperature inside the compartment to the desired level of 42°F during long periods when the compartment door remained closed. However, it did not maintain this temperature level during periods of frequent opening or normal turnover of stored items. One contributing factor was the upright design, which allowed the cold atmosphere inside to "fall out" each time the compartment door was opened. The circulating fan inside the storage compartment would aggravate this effect whenever the door was opened during the "on" cycle. The major factors, however, were the high thermal conductivity and specific heat of the atmosphere.

The freezer was not capable of producing the desired temperature of 5°F. As shown in Table A1, the lowest temperature reached was 16.9°F after three days of continuous undisturbed operation. On Sept. 2, the freezer thermostat was readjusted to 38°F to provide additional refrigerator volume. Freezer operation was affected by the same factors as the refrigerator.

Cooking Equipment — The aquanauts did very little food preparation, since most food was canned or precooked and required only reheating. The cook top and the rotisserie operated satisfactorily. The toaster would not toast bread in the helium atmosphere.

Water Heater — The water heater performed satisfactorily, failing to meet the demand on only a few occasions. When the hot-water supply was exhausted, recovery was effected within a relatively short time, approximately 20 minutes.

CONCLUSIONS AND RECOMMENDATIONS

Hull

General — Although the Sealab II was not designed for full surface pressurization for depths greater than 280 ft, it can and should be utilized for deeper runs. With the installation of a suitable automatic or semiautomatic pressure-control system, the Sealab II hull could be utilized to the continental-shelf depth of 600 ft or more.

Ports — Since viewing ports in the berthing area and in the entry area were not utilized, these ports should be eliminated. The internal pressure-tight covers for the remaining ports should be redesigned for use of a radial squeeze O-ring seal. This change should eliminate the leakage problems and will allow the use of fewer bolts with less torque.

Another desirable alteration is the design of viewing ports to withstand the required pressure differential. This end could be attained by using heavier, high-strength glass or by reducing the port diameter, or both. This alteration would eliminate the need for internal covers and for pressure equalization of the volume between the internal cover and the port glass. External covers would still be required for protection during Sealab handling operations. The external protective covers should be hinged to the port frame to reduce handling difficulty and improve diver safety.

Access Openings — The emergency exit hatch should be made more accessible, possibly to the extent that it may be used as a secondary access hatch for resupply. This provision would relieve the congestion and traffic at the main access hatch. Improved bilge drainage in this area should be provided.

The surface access should be provided with a counterbalance system for improved ease of opening and closing and a latch for securing when open. This hatch should also be insulated to reduce heat loss and to prevent moisture condensation.

The main access hatch appears to be adequate without modification. One item to be considered is a means of draining the bilge around the hatch thimble.

Entry Trunk — As a means of providing much-needed additional space, the entry trunk should be enlarged and enclosed (nonpressure) for use as a diving station. This area should be used for:

1. Entry and exit.
2. Storage of diving gear.
3. Donning and doffing of gear.

Large viewing windows should be installed in the entry trunk to permit observation of the outside area and divers in the vicinity. These observation windows will eliminate the need for the shark cage. This modification, however, will depend on the following additional design considerations:

1. Additional life-support requirements, including heat and atmosphere control and circulation.

2. Increased buoyancy at the stern of the craft.

3. A water-trapped entry arrangement of adequate displacement volume, which can be negotiated by the divers in full diving dress with a minimum of climbing.

4. Downward extension of all open-ended hull penetrations to the lowered water level in the entry.

A similar room at the emergency access hatch would serve for use as a resupply and observation station. This arrangement would offset the increased buoyancy at the stern.

Support Structure — In order to provide increased versatility in adapting the Sealab to varying bottom conditions, the supporting structure should incorporate a means of self-leveling when placed on the bottom. The operation of this leveling system should be completely automatic or require little diver support. One method of accomplishing this objective would be the use of four cross-connected hydraulic rams. When placed on the bottom, hydraulic pressure equalization between pairs of rams would allow the Sealab to trim itself. Stabilization of the system (hull and support or hold-down structure) would require closing only one valve in each of the two cross-connecting lines. These valves could be operated remotely from inside Sealab.

In addition, a hydraulic pump could be installed to provide final trim, if necessary. This type of system would be relatively fail-safe; loss of hydraulic fluid would only cause loss of trim, since the rams at full extension or collapse still provide a safe mechanical connection. The support or hold-down structure should be designed such that the height of the Sealab hull above bottom is minimized if visual observation of the bottom from inside Sealab is to be a consideration.

Variable Ballast — In view of the problems encountered with the internal ballasting arrangement, and in order to provide additional usable internal volume, an external variable ballast system should be considered. The internal volume of the present ballast tanks could then be utilized as additional equipment and stowage space.

Hull Insulation — Since the cork insulation used in Sealab II functioned quite successfully, it would seem to be the logical choice for use in Sealab III. Other insulating materials are available, such as urethane foams, which offer increased thermal efficiencies (2 to 1) over cork at standard conditions. However, in the Sealab environment the theoretical efficiency of the foam is only 13 percent better than cork. In addition, one must carefully consider the disadvantages of the foam, such as increased cost and possible toxicity.

The Sealab hull could be insulated externally to eliminate the reduced thermal efficiency caused by the Sealab atmosphere. However, some new problems would be encountered; the material used must be relatively impermeable to water, must have the necessary compressive strength to withstand the ambient water pressure, and must be relatively rugged to withstand normal handling of the Sealab.

The only insulation system which would seem to eliminate the effects of both the Sealab atmosphere and the outside water would be a double-shell arrangement similar to the "vacuum-bottle" principle. This system is considered not feasible from the standpoint of economic considerations.

Umbilical Cord

The umbilical cord should be designed as a composite unit. The design should provide for a smaller size, reduced weight, increased ruggedness, and self-buoyancy. A small reel should be provided for storage and improved handling of the umbilical, and Sealab hull connections should be provided to permit replacement of the entire umbilical when needed. A thorough review of conductor requirements should be made so that an adequate number may be provided. A generous number of spare conductors should also be provided for backup and nonessential use.

Systems

Electrical System — As has been pointed out, the electrical system as a whole was very satisfactory. It is recommended that the basic system be retained and that the following changes be made.

1. Replace the present thermal-magnetic circuit breakers with hydraulic-magnetic type. These circuit breakers are commercially available but would require pressure testing and possible modification of the hydraulic tube. This type breaker is not temperature sensitive.

2. Install multiple plug strips along the top of all lab benches. Connect the plug strips to existing circuits with portable cable and twist-lock plugs and receptacles.

3. Redesign the interior lighting system to provide two levels of lighting, one for photography and one for normal use. Quartz-iodine lamps should be considered, since they are capable of withstanding the ambient pressures expected. They can also be dimmed with commercially available dimmers; however, tests will be required to determine the effect of the helium-rich atmosphere on the bulb temperature. The iodine cycle of the quartz-iodine lamp will not function below a certain temperature. To prevent burning the vidicon tubes of the TV

monitors, the fixtures for the interior lighting should be recessed overhead or constructed so that no light is emitted from the sides.

4. Redesign the exterior lighting system to provide two levels of lighting, one for photography and one for normal use. Quartz-iodine type lamps should be used. The fixtures should be mounted with universal swivel mounts on short booms extending from the hull. Power outlets which can be connected wet should be installed at each light location and each outlet controlled by a dimmer switch located inside Sealab. Fixtures with wet-bulb changing capabilities would be desirable. The use of mercury vapor lamps is not recommended, since they require auxiliary equipment and operate at voltages up to 400 volts.

Ventilation and Heating System — It seems desirable to retain the radiant-deck heating system and some overhead radiant heating, which contributed much to the level of comfort in Sealab II. Otherwise the ventilation system should be completely redesigned as an integrated atmosphere-control or conditioning system. Ideally, this system should perform all atmospheric-control functions including ventilation, distribution, filtering, dehumidification, atmospheric replenishment, and temperature control (heating and cooling). This system must include adequate sensing and control equipment and should be specifically designed for use in the Sealab environment. The dehumidifiers must be capable of maintaining the required physiological comfort levels in the Sealab environment. Means should be provided for more efficient removal of carbon dioxide than in Sealab II. Means should also be provided for the removal of carbon monoxide and other trace contaminants which were not absorbed by charcoal or LiOH in Sealab II.

Breathing-Gas System — As indicated above, the atmosphere-replenishment functions should be incorporated into the atmosphere-control system. The gas systems need improvements of control equipment, such as more reliable valves, more reliable regulators with higher flow rates and bypass circuitry, improved sensing and control equipment, and leak-free piping and storage systems.

Since the emergency breathing (Bibb) system installed in Sealab II was considered marginal, it is recommended that the basic design be improved to provide adequate flow rates at the required pressure and that adequate corrosion-resistant quick-connect fittings be provided. Although the Bibb system was not required in Sealab II, it is felt that it provides a required safety feature which should definitely be included in all future Sealab designs.

Gas-Sampling System — The gas-sampling system performed its intended function and certainly should be included in any future designs. However, every effort should be made to obtain equipment for atmosphere analysis inside Sealab. It would also seem desirable to provide the capability of detecting and monitoring the long-term buildup of trace contaminants which may create a safety hazard as test runs become longer in duration.

Arawak System — It is recommended that sufficient lead time be allowed for satisfactory development of future Arawak systems. More efficient compressors and vacuum pumps are essential, but reduced noise levels are equally important. Hoses, vests, and regulators should be evaluated and tested to assure compatibility with diver's requirements. The installation of Arawak systems in Sealabs should also be designed to eliminate or reduce the noise level.

Plumbing and Sanitary System — The discharge lines for the sanitary drains must be nonbuoyant when filled with air or gas to prevent "trapping." The salt-water intake for the water closet should be extended downward to a point below the water level in the entrance trunk, to prevent atmosphere loss. A water closet with a larger flushing pump should be installed.

Since the shower tubs were not utilized, they should be removed, and one shower should be eliminated to provide additional space in the entry.

Provisions are necessary for increased water-supply capacity. The 50-gallon-per-man-day supply used for Sealab II was adequate but probably should be doubled for colder runs, where hot water may be used to restore or maintain the body heat of the divers.

Communication System — Inasmuch as adequate and reliable communications between Sealab occupants and surface-control personnel are of critical importance, the communication system deserves special attention. It is recommended that a complete study be made of the communication problems involved in a Sealab-type operation and that the special equipment required be developed. It is recommended that a helium-speech modifier be developed that would operate as an intercom set. Headphones could also be provided for secure communication.

The electrowriter should be retained, since it has performed satisfactorily in the past and provides a good communication link. In view of the ink-splattering problem experienced in Sealab II, it is recommended that this problem be investigated and corrected.

It is recommended that the entertainment TV and FM facilities be retained. It would be desirable to have individual speakers at each berth in the sleeping quarters in place of the one central speaker.

Data Recording System — It is recommended that in future Sealab operations, required data be recorded remotely on the support vessel or on shore. This provision would ensure more complete data records and would relieve the subjects of the task of recording data or servicing recorders. Remote recording would also permit the use of standard off-the-shelf equipment. A separate cable should be provided in the umbilical cord for data-recording circuits. The following is a recommended list of data that should be recorded for engineering evaluation of the next Sealab operation.

1. Electrical power (watts)
2. Voltage
3. Current
4. Equipment power consumption
5. Interior hull temperature
6. Exterior hull temperature
7. External water temperature
8. Interior atmospheric temperature
9. Interior atmospheric humidity
10. Equipment operation time
11. Equipment temperature
12. Simultaneous audible and unscrambled helium speech
13. Oxygen makeup
14. Flow in various air ducts
15. Water usage
16. Remote readout of all sensing and control devices

Equipment

Refrigerator-Freezer — Refrigerator-freezer facilities must be designed and developed specifically for use in the Sealab environment. Commercially available equipments do not have the required refrigeration capacity, insulation systems, or control systems. Consideration must be given to the fact that the thermal efficiency of ordinary insulations will be reduced by an average factor of four. The atmosphere in Sealab is six times as conductive as air and has a much higher specific heat. The frequency of door openings is considerably greater than in normal use. The storage capacity must be increased by a factor of at least three in order to provide adequate storage. A chest type should be considered as a means of reducing heat losses when the doors are opened, and circulating fans which tend to blow out the cold atmosphere should be eliminated.

Since the major use of the refrigerator in Sealab II was for cooling fruit and vegetable juices, it seems that a juice-can vending machine similar in operation to commercial machines might be advantageous.

Cooking Equipment – Although the cooking equipment installed in Sealab II generally performed its intended functions, it is not considered to be the ideal arrangement. Certain safety hazards are presented in cooking in a closed atmosphere which are not normally considered in conventional situations. Also, since the pressure in the Sealab environment may be as high as 18 atmospheres (600 ft), cooking times are considerably less than normal and boiling points are much higher. The boiling point of water in Sealab II was approximately 330°F and at 20 atmospheres, 281 psia, water boils at 411°F. Considerable care must be exercised to minimize the introduction of hydrocarbons and other toxic vapors produced in uncontrolled cooking.

In view of the above considerations, it is believed that the best methods for cooking in the Sealab environment are a microwave oven or an infra-red oven with a filtering system capable of removing all atmospheric contaminants produced. Water should be heated only in a closed container with precise temperature control to reduce evaporation and the possibility of severe burns. If a bread toaster is considered desirable, it must be designed to provide the required heating-element temperature (possibly by increased voltage) in the Sealab atmosphere. The toaster also should be adequately "filtered" to control atmospheric contaminants.

Water Heater – Since the water heater in Sealab II seemed to be no more than adequate, an increased hot-water capacity will be required for deeper and colder runs. The required hot-water capacity for use inside Sealab could probably be provided with the existing heat input by increasing the storage capacity to 100 gallons and installing additional insulation. However, if hot water is utilized for heating or warming divers outside Sealab, additional water-heating capacity will be required.

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Appendix A

ENGINEERING AND ENVIRONMENTAL DATA—SEALAB II

One of the important elements of the Sealab II operation was the recording of engineering and environmental data. Even though the data-recording system used in Sealab II was simple and possessed some shortcomings, much useful data was obtained.

The objective of this appendix is to present the reduced data in tabular and graphic form and discuss briefly how the raw data was obtained and reduced.

The data were manually recorded by the Sealab personnel on preprinted forms and, in the case of water usage, by shore personnel. The major shortcoming was the failure of the Sealab personnel to record the data at regular intervals. The data recorded while the Sealab was manned by Team 1 was more complete than the recorded data of the second and third teams. Since the data recorded each day covered periods of time ranging from eight to 24 hours, all equipment running time was reduced to a common base for better comparison by reducing the running time for the recording period to percent of time operating. The graphs were prepared from the data recorded by Team 1 and are considered to be representative of the other two teams.

During the period manned by Team 3 the power usage was recorded only four times. The peak-power requirement occurred during this period. However, in view of limited data it appears that an error could have been made in reading the watthour meter, and that a peak-power requirement of this magnitude did not occur. The equipment-running-time meters do not indicate any unusually heavy electrical loads during this period.

Table A1
SEALAB II ENGINEERING AND ENVIRONMENTAL DATA (TEAM 1)

Item	Units	Day of Measurement														
		28 Aug	29 Aug	30 Aug	31 Aug	1 Sept	2 Sept	3 Sept	4 Sept	5 Sept	6 Sept	7 Sept	8 Sept	9 Sept	10 Sept	11 Sept
Hours in Averaging Period		8	25	24	24	24	22	26	22.5	19.5	26	28	23.75	20.25	26	26
Average Electrical Power	KW	19.6	14.24	19.75	21.5	20.2	20.68	22.1	24.1	18.5	23.5	23.4	21.7	20.25	21.8	20.77
Average Temp. Trans. Comp.	°F	74.3	74.3	76	76.4	76	76.3	75.1	74.4	74.6	76	76	75.7	75	75.6	75.4
Baseboard Heating, Fwd.		15.0	9.6	0.4	5.4	10.8	-	-	7.1	12.3	8.8	1.4	0	3	2.7	0
Baseboard Heating, Amid		6.3	7.2	15	0	0	0	0	0	0	21.5	27.9	35.8	47.4	46.9	55.4
Baseboard Heating, Aft		26.3	0.4	0	0	0	0	1.2	0	0	0	0	0	0	0	0
Water Heater	Operation Percent of Time	27.5	12	18.3	22.9	21.7	25.9	25.8	30.2	20	40.4	32.5	32.0	35.6	27.7	24.6
Deck Heating		80	67.6	99.2	97.9	93.3	90.9	98.9	100	99	100	99.6	99.8	100	99.2	100
D/H Machine, Fwd.		82	98.8	100	100	98.8	93.6	99.2	100	99	100	100	93.9	100	99.2	100
D/H Machine, Aft, Port		67.5	100	100	100	97.1	97.7	98.9	100	99	100	100	99.4	100	99.6	100
D/H Machine, Aft, Stbd.		67.5	97.2	100	100	97.1	97.7	98.9	100	99	100	100	96.0	100	99.2	100
Refrigerator		61.3	42	60.4	66.3	64.6	65.9	66.5	61.8	65.1	55.0	40	37.5	44	26.2	68.9
Freezer		98.8	100	100	100	97.1	94.1	74.2	82.7	87.7	56.1	69.3	74.5	77.5	58.5	67.7
Radiant Heater No. 1		42.5	0	0	2.1	15.8	35.0	0	0	11.3	0	0	12.6	0	0.4	5
Radiant Heater No. 2		0	0	0	0	1.7	0	0	0	11.3	0	0	12.6	0	0.4	0
Radiant Heater No. 3		85	75.6	100	95.8	75.0	84.5	87.7	74.2	51.8	16.5	69.3	98.9	76.5	73.1	33.8
Radiant Heater No. 4		66.3	76	99.2	96.3	74.6	85.0	87.7	73.8	0	16.5	44.6	0	0	73.1	33.5
D/H Machine, Portable		0	0	0	0	0	49.5	98.9	100	96.9	-	-	-	100	-	-
Average Temp., Berthing	°F	85.8	85.4	85.9	86.3	84.4	85.9	85.4	86.3	85.8	87.5	87.6	86.8	87	89.0	88.3
Average Temp., Galley	°F	87.4	87.3	88.1	89.9	86.4	85.6	84.5	84.6	84.7	86.6	87.0	86.2	86.9	86.8	87.7
Average Temp., Lab	°F	88.9	88.0	89.9	90.9	88.9	90.7	90.0	89.8	87.6	89.2	90.7	89.7	89.3	88.6	89.9
Average Temp., Entry	°F	94.4	92.7	98.2	98.5	92.6	96.4	95.5	94.6	89.9	89.9	93.5	95.4	91.8	89.7	93.9
Average Temp., Refrigerator	°F	48.5	46.4	46.4	44.0	44.9	45.2	44.7	44.5	41.0	42.5	54.9	54.2	55.5	53.1	53.5
Average Temp., Freezer	°F	16.9	17.9	17.9	18.3	20.1	34.5	38.9	39.3	35.8	40.6	44.0	43.2	41.8	46.2	46.4
Average Humidity, Berthing	% RH	69.6	74.9	75.5	79.4	81.2	77.9	74.9	70.8	71.9	68.2	73.4	77.5	73.3	73.1	72.6
Average Humidity, Galley	% RH	71.3	72.9	73.8	75.0	81.5	82.3	81.7	76.7	79.9	75.1	80.9	82.3	78.3	79.9	78.3
Average Humidity, Lab	% RH	68.2	70.1	70.2	70.0	78.8	72.7	71.2	69.9	74.8	72.7	75.7	75.4	73.9	76.0	72.1
Average Humidity, Entry	% RH							Sensor Inoperative								
Average Temp., Habitat	°F	87.4	86.9	89.1	89.0	86.6	87.4	86.6	86.9	86.0	87.2	88.4	87.6	87.7	88.1	88.6
Average Humidity, Habitat	% RH	69.7	72.6	73.2	74.8	80.5	77.6	75.9	72.5	75.5	72.0	76.7	78.4	75.2	76.3	74.3

Dash indicates reading not available.

Table A2
SEALAB II ENGINEERING AND ENVIRONMENTAL DATA (TEAM 2)

Item	Units	Day of Measurement														
		12 Sept	13 Sept	14 Sept	15 Sept	16 Sept	17 Sept	18 Sept	19 Sept	20 Sept	21 Sept	22 Sept	23 Sept	24 Sept	25 Sept	26 Sept
Hours in Averaging Period		23.5	18.5	29.5	22.75	18	30.5	21.75		47	*10.5/ 20	*39/ 29.5	22.5	*49.8/ 27.3	21.8	24
Average Electrical Power	KW	16	18.35	18.78	20.18	26.7	18.0	26.98		22.7	20.95	18.82	-	21.1	21.24	-
Average Temp. Trans. Comp.	°F	74.5	74	73	74.3	75	75	75		75	-	73.5	-	74	74.5	-
Baseboard Heating, Fwd.	Operation Percent of Time	8.1	5.4	1.7	4	8.9	4.6	2.3		1.5	2.0	0.7	6.2	1.1	2.3	11.3
Baseboard Heating, Amid		4.7	4.3	0	0	0	2.3	0		2.3	0	0.2	12.9	0	74.9	6.3
Baseboard Heating, Aft		8.9	0	2.0	25.5	7.8	0	9.7		6.8	0.05	0.7	0.9	3.7	5.1	-
Water Heater		14.0	21.1	33.6	32.5	3.0	44.6	29.9		24.3	29.0	38.0	35.6	37.8	28.0	12.1
Deck Heating		91.9	100	100	100	100	99.7	100		100	98.5	100	100	99.5	95.6	93.8
D/H Machine, Fwd.		91.9	100	100	100	100	99.7	100		100	98.0	100	100	84.8	89.7	94.6
D/H Machine, Aft, Port		91.9	100	100	100	100	99.7	100		100	98.5	100	100	100	82.8	100
D/H Machine, Aft, Stbd.		91.9	100	100	100	100	99.7	100		100	98.0	100	100	99.5	83.2	94.6
Refrigerator		37.9	46.5	41	53.2	48.9	62.0	63.9		56.4	57.0	57.3	12.4	48.8	56.6	17.9
Freezer		50.2	66.5	48.8	60.2	52.2	73.8	41.8		54.0	55.0	64.1	54.7	47.3	57.5	48.3
Radiant Heater No. 1		38.3	0	0	2.2	20.0	0	0		0	0	0	12.4	0	0	100
Radiant Heater No. 2		0	0	0	1.8	0	0	0.5		0	0	2.0	4.9	0	0	100
Radiant Heater No. 3		9.4	38.9	52.5	0	44.4	23.0	46.9		43.8	41.5	42.7	4.4	49.9	13.3	66.3
Radiant Heater No. 4		9.4	39.5	52.5	0	44.4	12.1	30.3		40	40.0	24.4	2.7	40.4	13.8	64.2
D/H Machine, Portable		-	100	-	-	-	99.7	99.3		100	-	100	-	-	-	-
Average Temp., Berthing	°F	86.1	85.0	84.6	87.1	87.6	86.6	88.3		85.4	84.5	86.7	87.8	89.0	88.4	87.9
Average Temp., Galley	°F	84.0	84.2	86.0	86.3	85.6	85.6	87.4		85.6	84.8	83.8	85.1	83.9	84.9	86.5
Average Temp., Lab	°F	86.5	85.9	87.3	92.4	92.4	87.8	92.0		90.1	90.1	88.4	89.7	89.0	88.1	87.4
Average Temp., Entry	°F	85.9	87.2	90.2	89.4	91.2	90.3	90.4		89.3	92.0	91.8	89.4	89.7	87.0	87.7
Average Temp., Refrigerator	°F	53.3	54.4	53.5	50.3	45.8	44.0	43.9		40.6	42.1	45.9	45.2	43.7	43.6	39.3
Average Temp., Freezer	°F	46.4	46.0	46.0	47.1	45.6	44.2	45.2		41.9	41.4	39.8	38.3	41.0	46.6	29.2
Average Humidity, Berthing	% RH	74.2	73.2	73.4	72.6	73.7	70.7	74.5		71.0	75.3	74.2	75.7	73.5	76.9	67.3
Average Humidity, Galley	% RH	80.3	75.9	76.6	79.5	81.4	80.4	78.5		75.3	83.5	76.4	82.4	84.2	84.4	75.3
Average Humidity, Lab	% RH	73.4	75.1	75.1	68.4	72.1	75.8	69.2		65.9	74.6	72.8	71.4	71.4	79.1	71.0
Average Humidity, Entry	% RH							Sensor Inoperative								
Average Temp., Habitat	°F	85.6	85.0	86.0	88.6	88.5	86.7	89.2		87.0	86.5	86.3	87.5	87.3	87.1	87.3
Average Humidity, Habitat	% RH	75.9	74.7	75.0	73.5	75.7	75.6	74.0		70.7	77.8	74.5	76.5	76.4	80.1	71.2

No Data Recorded Accumulated Totals Averaged under Sept 20 Column

*Power period.
Dash indicates reading not available.

Table A3
SEALAB II ENGINEERING AND ENVIRONMENTAL DATA (TEAM 3)

Item	Units	Day of Measurement														
		27 Sept	28 Sept	29 Sept	30 Sept	1 Oct	2 Oct	3 Oct	4 Oct	5 Oct	6 Oct	7 Oct	8 Oct	9 Oct	10 Oct	
Hours in Averaging Period		50.8	9.5	49.2	*69.2/ 20	12	37	24	*84/ 23	25.3	36	36	10.8	*120/ 37.3		
Average Electrical Power	KW	38.8	-	-	19.6	-	-	-	31.13	-	-	-	-	18.1		
Average Temp. Trans. Comp.	°F	74	-	-	75	74.5	-	-	75	-	-	74	74	74		
Baseboard Heating, Fwd.	Operation Percent of Time	3.7	-	2.6	0	3.3	1.6	0.4	0	-	1.1	1.9	0	0.3		
Baseboard Heating, Amid		1.5	-	33.9	54.5	2.5	38.4	55.8	83.9	-	8.9	0	7.4	21.2		
Baseboard Heating, Aft		3.4	-	0	0.5	0	0	0	0	0	0	0	0	0		
Water Heater		32.8	-	28.9	47.0	12.5	38.9	33.8	33.9	-	31.9	42.2	25.1	36.8		
Deck Heating		100	-	99.2	100	100	100	100	100	100	100	97.8	100	100		
D/H Machine, Fwd.		100	-	99.2	100	89.2	100	100	100	100	100	97.2	100	100		
D/H Machine, Aft, Port		100	-	99.2	100	86.7	100	100	100	-	70.8	97.5	100	100		
D/H Machine Aft, Stbd.		100	-	99.2	100	85.8	100	100	100	100	100	100	100	100		
Refrigerator		50.7	-	44.5	28.5	50.0	54.3	51.7	56.5	-	46.4	48.3	40.9	52.1		
Freezer		59.6	-	42.7	32.5	35.0	38.4	40.0	54.8	-	51.9	50.6	94.8	42.7		
Radiant Heater No. 1		6.3	-	7.7	5.0	37.5	17.0	8.3	2.6	-	14.4	8.6	18.6	0		
Radiant Heater No. 2		0	-	3.7	0	0	9.7	0	1.7	-	0	8.0	-	-		
Radiant Heater No. 3		28.3	-	34.3	30.0	6.7	44.9	13.3	17.8	-	48.6	45.6	40.0	74.1		
Radiant Heater No. 4		30.2	-	8.3	22.0	6.7	8.9	2.1	13.9	-	38.6	31.7	27.9	48.1		
D/H Machine, Portable		-	-	-	-	-	-	-	-	-	-	-	-	-		
Average Temp., Berthing	°F	86.8	87.6	88.3	89.8	87.4	87.9	88	89.5	88.8	86.2	86.6	86.8	85.6	No Data Recorded	
Average Temp., Galley	°F	84.8	86.5	86.3	86.5	84.2	85.6	87.1	87.9	87.6	85.8	86.1	86.2	85.5		
Average Temp., Lab	°F	85.4	86.5	87.1	91.1	89.3	88.8	87.9	89.5	89.7	87.6	88.1	87.8	86.9		
Average Temp., Entry	°F	85.9	86.2	88.8	94.8	89.0	88.5	86.9	88.3	89.2	88.4	87.9	88.0	88.4		
Average Temp., Refrigerator	°F	39.9	35.2	39.4	43.2	44.7	39.7	32.4	37.7	45.0	39.6	33.2	37.7	47.7		
Average Temp., Freezer	°F	22.1	-	32.4	52.2	50.8	-	-	47.2	-	21.3	1.6	-0.1	17.1		
Average Humidity, Berthing	% RH	65.1	52.7	63.5	79.6	79.0	66.2	51.8	64.8	68.9	56.5	-	59.7	-		
Average Humidity, Galley	% RH	74.2	60.3	68.8	84.4	84.4	68.8	49.9	65.6	74.2	61.9	65.1	61.7	71.5		
Average Humidity, Lab	% RH	69.4	56.0	65.4	79.1	76.4	63.5	49.9	65.6	66.7	50.6	54.9	55.3	71.5		
Average Humidity, Entry	% RH	Sensor Inoperative														
Average Temp., Habitat	°F	85.7	86.9	87.2	89.1	87.0	87.4	87.7	89.0	88.7	86.5	86.9	86.9	86.0		
Average Humidity, Habitat	% RH	69.6	56.3	65.9	81.0	79.9	66.2	50.5	65.3	69.9	56.3	60.0	58.9	71.5		

*Power period.
Dash indicates reading not available.

Table A4
SEALAB II ENGINEERING AND ENVIRONMENTAL DATA

1500 28 Aug through 2000 9 Oct 1965

Item	Units	Average for Total Time
Total Elapse Time	Hr	1013
Electrical Power	KW	21
Temp., Transformer	°F	74.8
Baseboard Htg., Fwd	Operation Percent of Time	3.9
Baseboard Htg., Amid		17.3
Baseboard Htg., Aft		2.1
Water Heater		29.8
Deck Heating		98.6
D/H Machine Fwd		99.6
D/H Machine Aft, Port		99.5
D/H Machine Aft, Stbd		98.9
Refrigerator		51.9
Freezer		62.0
Rad. Htr. No. 1		6.7
Rad. Htr. No. 2		2.2
Rad. Htr. No. 3		49.0
Rad. Htr. No. 4		35.3
Temp., Berthing	°F	87.0
Temp., Galley	°F	86.0
Temp., Lab	°F	88.9
Temp., Entry	°F	90.5
Temp., Refrigerator	°F	44.8
Temp., Freezer	°F	37.5
Humidity, Berthing	% RH	71.2
Humidity, Galley	% RH	75.4
Humidity, Lab	% RH	69.8
Temperature, Habitat	°F	87.3
Humidity, Habitat	% RH	72.1

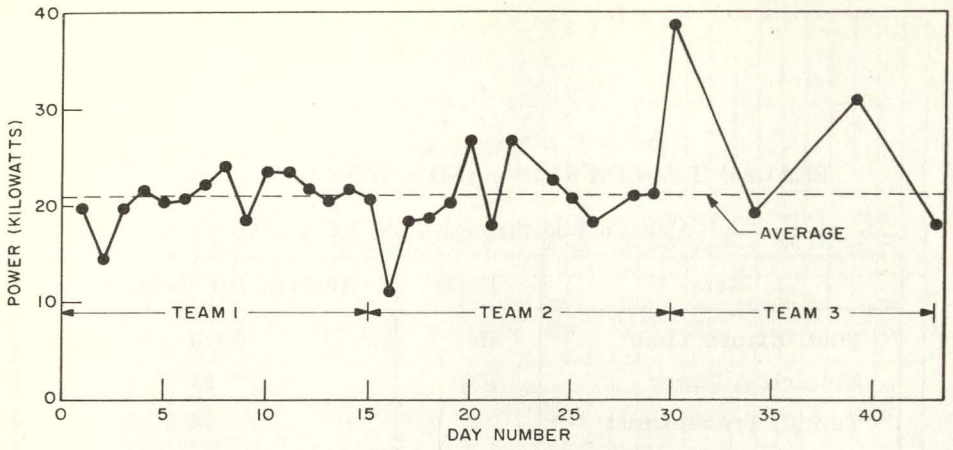


Fig. A1. Sealab II average daily electrical load

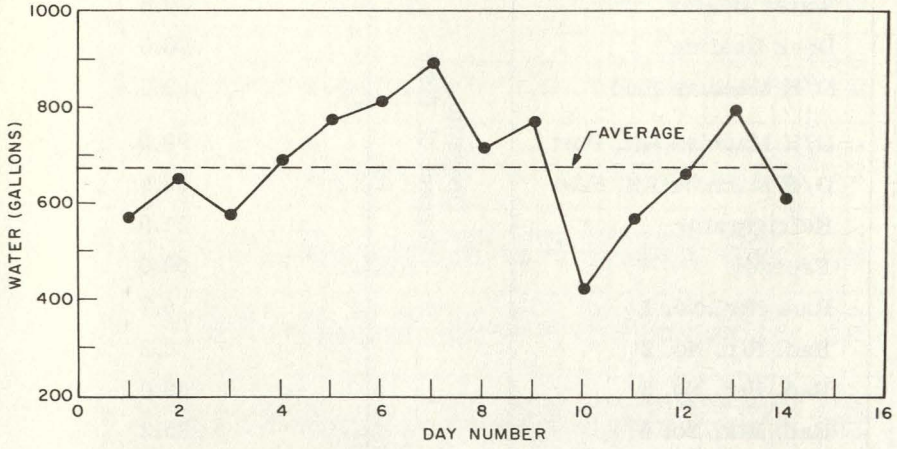


Fig. A2. Sealab II average daily water consumption (Team 1)

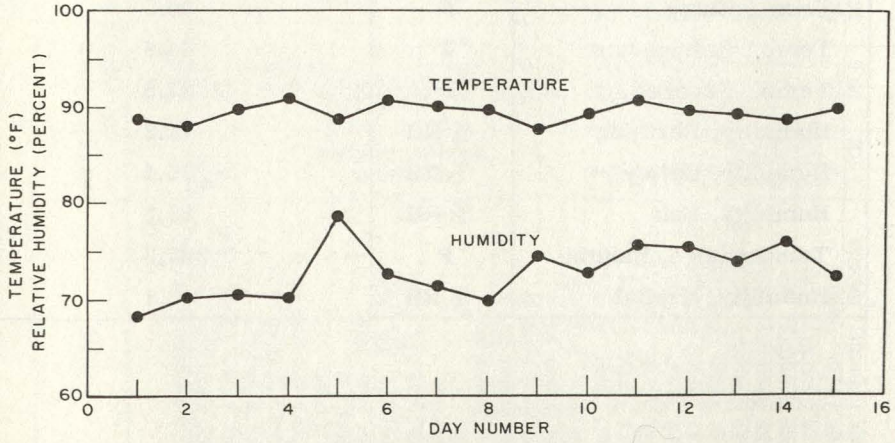


Fig. A3. Sealab II average daily temperature and relative humidity in laboratory area (Team 1)

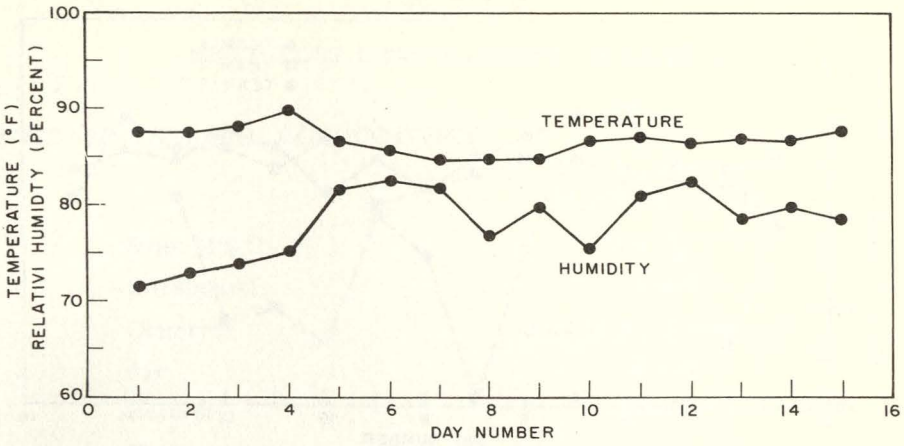


Fig. A4. Sealab II average daily temperature and relative humidity in galley area (Team 1)

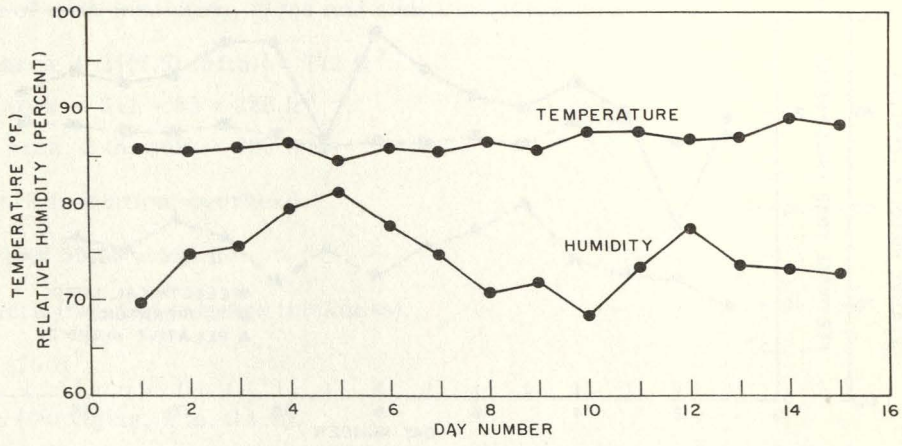


Fig. A5. Sealab II average daily temperature and relative humidity in berthing area (Team 1)

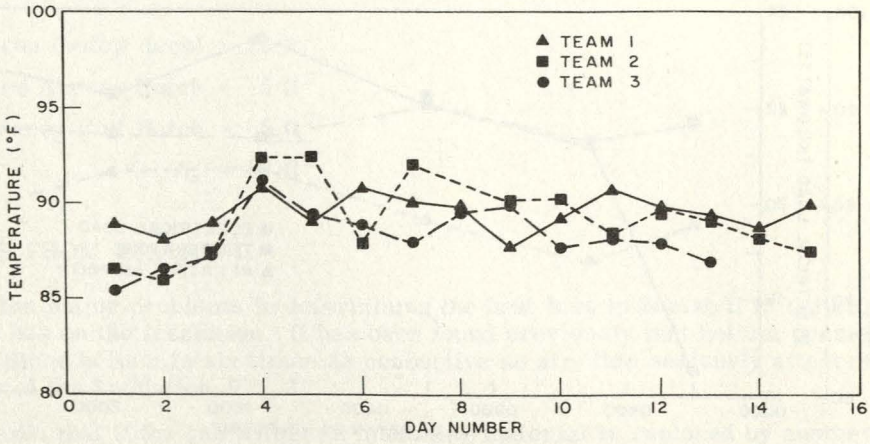


Fig. A6. Sealab II average daily temperature of laboratory area for each team

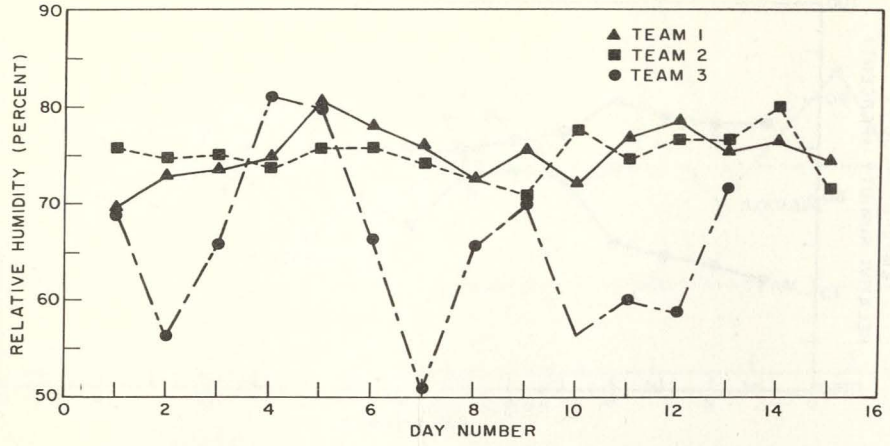


Fig. A7. Sealab II average daily relative humidity of laboratory area for each team

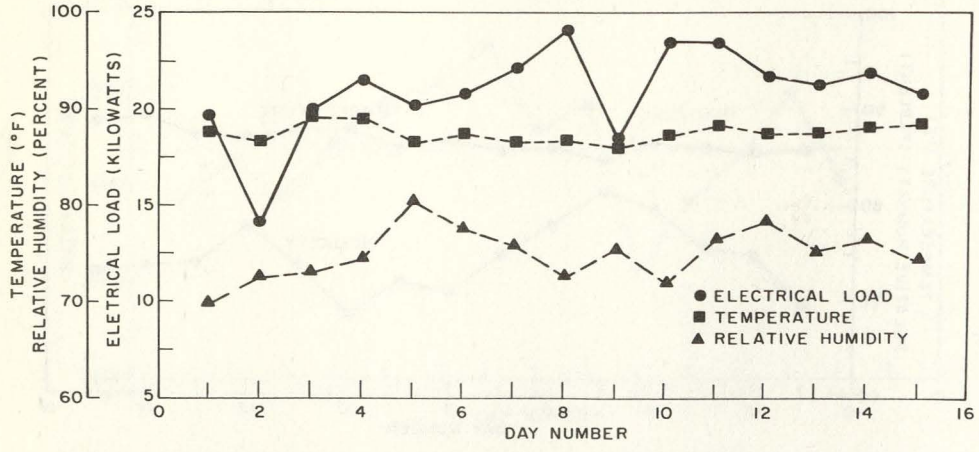


Fig. A8. Sealab II average daily temperature, relative humidity and electrical load in laboratory area (Team 1)

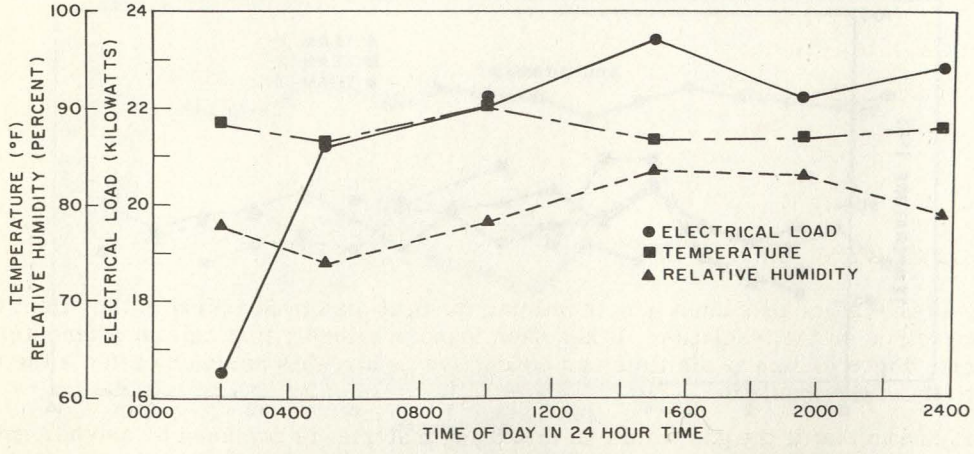


Fig. A9. Sealab II temperature, relative humidity, and electrical load in laboratory area for a typical day

Appendix B

HEAT-LOSS CALCULATIONS—SEALAB II

COEFFICIENTS OF THERMAL CONDUCTIVITY

	K (Btu/hr-ft-°F)
Steel (1% C)	25
Corkboard	0.025
Concrete	0.47-0.81, 0.64 (avg.)
Air	0.015
Helium	0.090
Plexiglas	0.120

HEAT-TRANSFER AREAS OF SEALAB II

Two inches of cork insulation, sides and ends.

Total side area = $2[(7.5)\ (51.5)] = 772\ ft^2$

Total end area = $311 - 85 = 226\ ft^2$

Total area, 2 in. cork = $998\ ft^2$

One inch cork insulation, overhead.

$$A_c = 10 \times 55.25 = 552\ ft^2$$

Concrete deck (one foot average thickness).

$$A_d = 376\ ft^2$$

Port areas (Plexiglas, 1 in. thick).

$$A_p = 11\left[\frac{\pi \times 2^2}{4}\right] = 34\ ft^2$$

Uninsulated Hull Areas.

Entry area (below deck) = $73\ ft^2$

Surface Access Hatch = $5\ ft^2$

Emergency Exit Hatch = $5\ ft^2$

$A_s = 83\ ft^2$

HEAT LOSS FROM SEALAB II

One of the major problems in determining the heat loss in Sealab II is the effect the helium atmosphere has on the insulation. It has been found previously that helium permeates most materials. Since helium is six times as conductive as air, this seriously affects the thermal conductivity of the insulation.

It is known that if the gas within an insulating material is replaced by another gas having a different conductivity, the conductivity of the insulation will be changed by an amount very nearly equal to the difference in conductivity of the two gases.

The thermal conductivity of corkboard in a standard air atmosphere is

$$K_c = 0.025 \text{ Btu/hr-ft-}^\circ\text{F},$$

and

$$K_{helium} - K_{air} = 0.09 - 0.015 = 0.075.$$

Then the new K_c would be

$$K_c = 0.025 + 0.075 = 0.10 \text{ Btu/hr-ft-}^\circ\text{F}.$$

The most difficult quantity to determine in any heat-transfer problem is the film coefficient of the film next to the insulating material. This determines the heat transferred by natural convection. The simplest approach to solve for this quantity is by the following method.

Consider a wall maintained at a constant temperature t_w, coated with a layer of insulating material of a thickness x and of thermal conductivity K. The outside of the insulation is in contact with the atmosphere at temperature t_a. Heat is transferred by conduction through the insulation and by natural convection through the atmosphere. In the steady state, the rate at which heat is conducted through a unit area of the insulation material is equal to the rate at which it is supplied to the air by convection, or

$$\frac{1}{A}\frac{dq}{dT} = \frac{K}{x}(t_w - t) = h(t - t_a)$$

where t is the temperature of the outside surface of the insulation. Besides K and x, t_w and t_a are known. Since h varies as the fourth root of $t - t_a$, the simplest way to solve for t is by trial and error. Thus, assuming t to be any arbitrary value, h is calculated and then multiplied by $t - t_a$. The value of $(K/x)(t_w - t)$ is then calculated and compared with $h(t - t_a)$. If these quantities are not equal, another value of t is chosen, and so on until the equation is satisfied. To apply this to the present problem:

$$\frac{K}{x_2}(t - t_w) = h_2(t_a - t)$$

$$\frac{0.10 \text{ Btu/hr-ft-}^\circ\text{F} \times 12 \text{ in./ft}}{2 \text{ in.}}(t - 48) = h_1(88 - t)$$

$$0.6(t - 48) = h_2(88 - t)$$

$$h_2 = (t_a - 5)^{0.25} = (88 - t)^{0.25}$$

$t_w = 48^\circ$

$t_a = 88^\circ$

$x_2 = 2$ in. (corkboard)

$x_1 = 1$ in. (corkboard)

Assume

$$t = 85^\circ$$

$$h_2 = (88 - 85)^{0.25} = 1.316$$

$$0.6(85 - 48) = 1.316(88 - 85)$$

$$22.2 = 3.95$$

Assume

$$t = 70^\circ$$

$$h_2 = (88 - 70)^{0.25}$$

$$0.6(70 - 48) = 2.05(88 - 70)$$

$$13.2 = 36.9$$

Assume

$$t = 75^\circ$$

$$h_2 = (88 - 75)^{0.25} = 1.9$$

$$0.6\,(75 - 48) = 1.9\,(88 - 75)$$

$$16.3 = 24.7$$

Assume

$$t = 80^\circ$$

$$h_2 = (88 - 80)^{0.25} = 1.68$$

$$0.6\,(80 - 48) = 1.68\,(88 - 80)$$

$$19.2 = 13.4$$

Assume

$$T = 78^\circ$$

$$h_2 = (88 - 78)^{0.25} = 1.78$$

$$0.6\,(78 - 48) = 1.78\,(88 - 78)$$

$$18 = 17.8$$

Therefore a good value for h_2 (2 in. corkboard) is

$$h_2 = 1.79 \text{ Btu/hr-ft}^2\text{-}^\circ\text{F}.$$

For 1 in. of insulation is

$$\frac{0.10 \times 12}{1}\,(t - 48) = h_1\,(88 - t)$$

$$1.2\,(t - 48) = h\ (88 - t)$$

Assume

$$t = 75^\circ$$

$$h_2 = (88 - 75)^{0.25} = 1.9$$

$$1.2\,(75 - 48) = 1.9\,(88 - 75)$$

$$32.4 = 24.7$$

Assume

$$t = 73^\circ$$

$$H_2 = (88 - 73)^{0.25} = 1.97$$

$$1.2\,(73 - 48) = 1.97\,(88 - 73)$$

$$30 = 29.6$$

Therefore a good value for h_1 (1 in. corkboard) is

$$h_1 = 1.98 \text{ Btu/hr-ft}^2\text{-}^\circ\text{F}.$$

For the sides and ends (2 in. corkboard)

$$U = \frac{1}{\frac{1}{1.79} + \frac{1}{0.6}} = \frac{1}{0.559 + 1.67} = \frac{1}{2.23}$$

$$U = 0.448 \text{ Btu/hr-ft}^2\text{-}^\circ\text{F}$$

Area of sides and ends (less port area) = 998 - 34 = 964 ft^2. The heat loss is

$$Q = UA\,\Delta t = 0.443 \times 964 \times 40$$

$$Q_{\text{sides \& ends}} = 17{,}300 \text{ Btu/hr.}$$

For the top (1 in. corkboard)

$$U = \frac{1}{\frac{1}{1.98} + \frac{1}{1.2}} = \frac{1}{0.505 + 0.835} = 0.746 \text{ Btu/hr-ft}^2\text{-}^\circ\text{F}$$

The heat loss is

$$Q = 0.746 \times 552 \times 40$$

$$Q_{\text{top}} = 16{,}500 \text{ Btu/hr.}$$

For the ports (1 in. Plexiglas)

Film coefficient, h_p

$$\frac{K_p}{x_p}(t - t_w) = h_p(t_a - t)$$

$$\frac{0.12 \times 12}{1}(t - 48) = h_p(88 - t)$$

$$1.44(t - 48) = h_p(88 - t)$$

$$h_p = (88 - t)$$

$A_p = 34 \text{ ft}^2$

$K_p = 0.12 \text{ Btu/hr-ft-}^\circ\text{F}$

$t_w = 48^\circ\text{F}$

$t_a = 88^\circ\text{F}$

$x_p = 1 \text{ in.}$

Assume

$$t = 71^\circ$$

$$h_p = (88 - 71)^{0.25}$$

$$2.88(71 - 48) = (88 - 71)\,2.03$$

$$33.1 = 34.5$$

Therefore

$$h_p = 2.02$$

Then

$$U_p = \frac{1}{\frac{1}{2.02} + \frac{1}{1.44}} = \frac{1}{0.459 + 0.694} = \frac{1}{1.19} = 0.840$$

The heat loss is

$$Q = 0.840 \times 34 \times 40$$

$$Q_p = 1{,}140 \text{ Btu/hr.}$$

Concrete Deck

Since radiant heating cables were imbedded in the concrete deck, two inches below the surface, it is logical to assume that this portion of the concrete would be maintained at a higher temperature than the Sealab atmosphere. There a t_a of 95°F was selected for use in this calculation. Film coefficients are neglected.

$$Q_d = K_c \times A_c \times \Delta t = 0.64 \times 376 \times 46$$

$$Q_d = 11{,}100 \text{ Btu/hr.}$$

$A_d = 376 \text{ ft}^2$

$K_d = 0.64$ Btu/hr-ft-°F

$t_w = 48°F$

$t_{ad} = 94°F$

$x_d = 1$ ft (avg)

Uninsulated Hull Areas (Steel)

Film coefficient, h_s

$$\frac{k_s}{x_s}(t - t_w) = h_s(t_a - t)$$

$$\frac{25 \times 12}{1}(t - 48) = h_s(88 - t)$$

$$400(t - 48) = h\ (88 - t)$$

$$h_s = (88 - t)^{0.25}$$

$A_s = 376 \text{ ft}^2$

$k_s = 25$ Btu/hr-ft-°F

$t_w = 48°F$

$t_a = 88°F$

$x_s = 1$ in.

Then if

$$t = 48.25°$$

$$h_s = (88 - 48.25°)^{0.25} = 2.5$$

and substituting for t and h_s

$$4(48.25 - 48) = 2.5(88 - 48.25)$$

$$100 = 99.4.$$

Therefore

$$h_s = 2.5$$

$$U_s = \frac{1}{\frac{1}{h_s} + \frac{1}{\frac{k_s}{x_s}}} = \frac{1}{\frac{1}{2.5} + \frac{1}{400}} = \frac{1}{0.44 + 0.0025}$$

$$U_s = 2.49 \text{ Btu/hr-ft}^2\text{-°F}$$

$$Q_s = U_s \times A_s \times \Delta t = 2.49 \times 83 \times 40$$

$$Q_s = 8{,}300 \text{ Btu/hr.}$$

TOTAL HEAT LOSS

$$Q_{total} = Q_{sides\ \&\ ends} + Q_{top} + Q_p + Q_d + Q_s$$

$$= 17{,}300 + 16{,}500 + 1{,}140 + 11{,}100 + 8{,}300$$

$$= 54{,}340 \text{ Btu/hr.}$$

Appendix C

SPECIFIC-HEAT RELATIONS

Constant-pressure specific heat (C_p) is defined as that quantity of heat required to cause an increase of one degree in the temperature of a unit quantity of material under constant pressure conditions [Btu/lb-°F]. For air at standard conditions, C_p is equal to 0.241 Btu/lb-°F.

The Sealab II environment consisted of 85 percent helium, 11 percent nitrogen, and 4 percent oxygen. The specific heat of this mixture of gases can be determined using the relation

$$C_{P_m} = \frac{C_{P_1}W_1 + C_{P_2}W_2 + \ldots + C_{P_n}W_n}{W_1 + W_2 + \ldots + W_n}$$

$$= 1.25(0.85) + 0.247(0.11) + 0.217(0.04)$$

$$= 1.1 \text{ Btu/lb-°F.}$$

The operating pressure of Sealab II required seven times the amount of gas needed to fill it to standard atmospheric pressure. To remove a given quantity of heat from a unit volume of the gas mixture under Sealab II operating conditions would require 32 times the energy required to remove the same amount of heat from a unit volume of air at standard atmospheric pressure, i.e.

$$\text{Ratio} \doteq \frac{\text{Heat Capacity (SEALAB environment)}}{\text{Heat Capacity (Air at sea level)}}$$

$$\frac{C_{P_m}\text{ (Specific heat of mix)} \times \rho\text{ (Density of mix)} = 1.1 \times .141}{C_P\text{ (Specific heat of air)} \times \rho\text{ (Density of air)} = .241 \times .074} = 8.6.$$

Chapter 39

OCEANOGRAPHIC INVESTIGATIONS

W. H. Tolbert and G. B. Dowling
U.S. Navy Mine Defense Laboratory
Panama City, Florida

INTRODUCTION

Since the U. S. Navy Mine Defense Laboratory has had a long-standing interest and experience in the application of diving for scientific purposes (1, 2, and 3), a program for conducting oceanographic studies from Sealab II was formulated. Development of this program was guided by the following general considerations.

1. Conduct research which emphasized having the trained eye on the spot.

2. Explore the feasibility of Sealab-type habitats as oceanographic platforms.

3. Attempt to take advantage of the potentially longer bottom times at depths afforded by Sealab.

4. Perform research in the area of physical oceanography with emphasis on those aspects which have potential usefulness for application to naval problems.

The proposed program resulting from the foregoing considerations, after several modifications, provided for both the general monitoring of undersea weather and more detailed studies in a number of specific problem areas. In all, it was proposed to record and monitor four general environmental parameters and to investigate, in more detail, 15 specific problem areas.

The writers were aware that there were a number of factors which might preclude the successful accomplishment of all the proposed efforts. Among these factors were:

1. The program was deliberately designed to be overly ambitious, in order to insure maximum utilization of bottom time; e.g., in the event that certain tasks were not possible even to attempt, there would still be sufficient work available.

2. It was necessary to provide flexilility to allow for the inclusion of new research tasks which may be revealed only after gaining experience in the Sealab environment.

3. An undetermined amount of time would have to be diverted from the oceanographic program for participation in humanfactor studies, supply, housekeeping, and watchstanding.

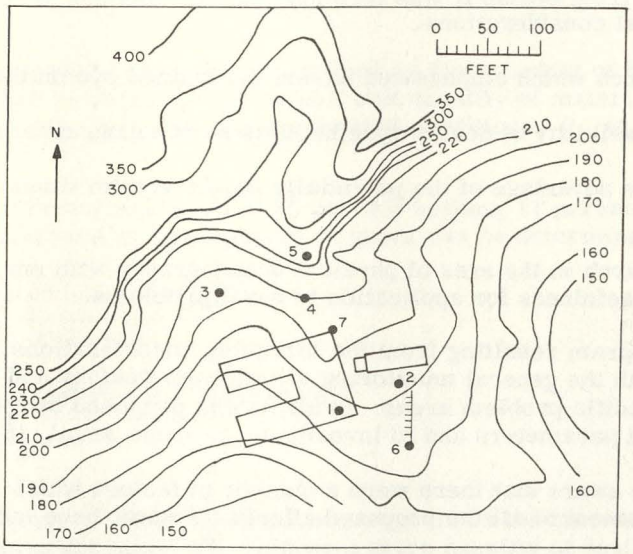
In the sections that follow there will be detailed discussion of the final planned program, including those results and conclusions that are presently available, and/or a discussion, where necessary, of reasons why certain parts of the program were not successfully accomplished.

Following this there will be a general discussion of conclusions and recommendations which hopefully will aid in better planning and execution of future Sealab investigations.

DISCUSSION OF OCEANOGRAPHIC PROGRAM AND RESULTS

General Environmental Parameters

In order to provide general background data commonly needed in support of many phases of the Sealab effort, a number of environmental sensors were maintained sample as often as possible those factors which influences the under seaweather. These sensors, which included both instrumentation provided by MDL and Scripps Institution of Oceanography, were located as shown by Fig. 130. Wherever possible automatic sampling and recording instrumentation were employed. These data were supplemented by measurements obtained by divers and observations from within Sealab. Listed below are those parameters which were monitored along with a brief description of the instrumentation, methods employed and preliminary results. Only MDL instrumentation and results are described; the Scripps program will be discussed in Chapter 40.



1. BENTHIC
2. POWERHIVE
3. WEATHER STATION
4. MDL CURRENT METER NO. 1 AND THERMOGRAPH NO. 1
5. MDL CURRENT METER NO. 2
6. VISIBILITY RANGE
7. SIO WATER CLARITY METER

Fig. 130. Location of Environmental sensors and visibility range in sealab II area

Temperature—The thermal characteristics of the water adjacent to Sealab were measured by recording thermographs, a bathythermograph (BT), and a mercury stem thermometer.

Three recording thermographs made by Braincon Corporation were used to record changes in water temperatures as a function of time. These instruments are self-contained units which record on 70-mm photographic film the position of the mercury column of a glass thermometer with an accuracy of ±0.25°C (0.45°F). The film-advance mechanisms were adjusted to provide a sampling interval of ten minutes. Two of the units were attached to Sealab, one was positioned in the shark cage at the bottom, and the other was located on the catwalk some 6.1 meters (20 ft) above the bottom. The third unit was positioned on the bottom at MPL current meter 1 some 27.4 meters (90 ft) from Sealab. The two units attached to Sealab were recovered, and the data are presently being processed. Attempts to locate the third unit, which had been attached to a

stake near the current meter, were unsuccessful. A concerted search of the nearby area was made, but the instrument was not found. The failure to recover this instrument resulted in a serious loss of valuable data, since it contained the only data made away from Sealab suitable for correlating with thermograph data made at Sealab.

Temperature variation as a function of depth were provided by a standard shallow-water bathythermograph (BT). During occupancy of Sealab by Teams 1 and 3, the writers made BY lowerings from the surface-support vessel. During Team 2's occupancy the writers obtained BT data by operating the instrument in an "upside-down" manner from the bottom. This was done by attaching a flotation bag to the BT, which provided sufficient buoyancy to raise it to the surface. Also attached was a nylon line, which with the aid of a small hand winch, allowed just as easily as from the surface. Additionally, BT's taken from the bottom yielded somewhat better traces in general than those taken from the surface. This was due to the fact that "upside-down BT's" did not exhibit the scratches typical of BT's taken from the surface. Fig. 131 shows a comparison of BT's taken from the bottom and surface. In all, 45 BT observations were made, six of which were made from Sealab.

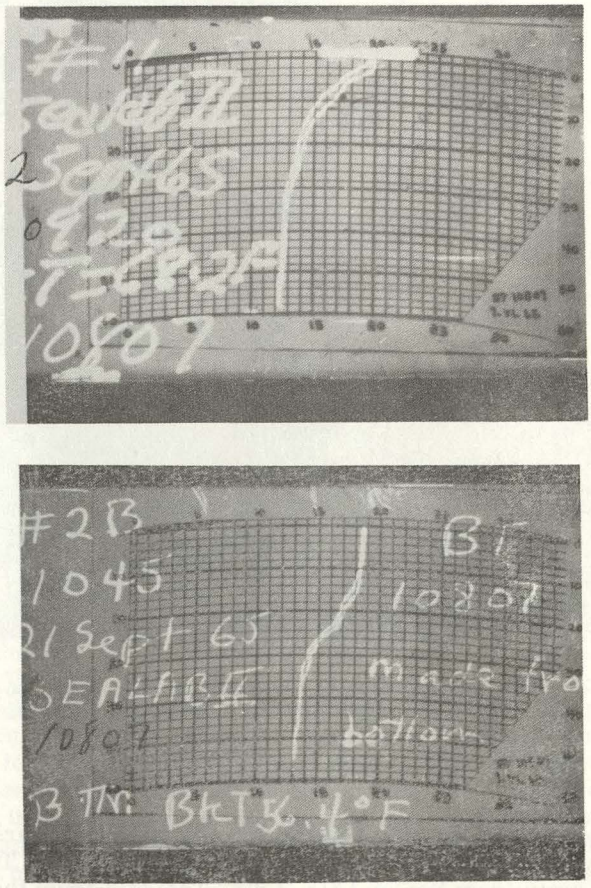


Fig. 131. A comparison of surface and bottom-taken bathythermographs. Upper slide was made from the Surface Support Vessel; lower slide was taken from Sealab II

During Sealab's occupancy, the surface temperature varied from 18° to 21°C (65 to 70-F) with temperatures in the range of 19° to 21°C (67° to 69°F) predominating. Bottom temperatures varied from 11° to 14°C(52 to 58°F) with temperatures in the range of 12° to 13°C (53°

to 55°F) predominating. The variation of the temperature with depth indicated that generally a two-layered water structure was present. The region separating the two water masses, i.e., thermocline, varied both in thickness and depth; however, the maximum depth of the bottom of the thermocline never exceeded 46 m (150 ft). The thermal gradient within 15 m (50 ft) of the bottom was very weak, never exceeding 1°F variation over this depth interval.

In order to monitor the outside water temperature from within Sealab, a mercury stem thermometer was positioned so it could be easily read from a port within the lab area (Fig. 132). Readings were made by the watch crew and were entered in the Sealab log periodically. This thermometer was an immersion mercury stem thermometer in a protective housing. These thermometers, normally used at the surface, may be affected by the pressure at 61 m (200 ft), and a calibration check will be made to determine the depth-correction factor.

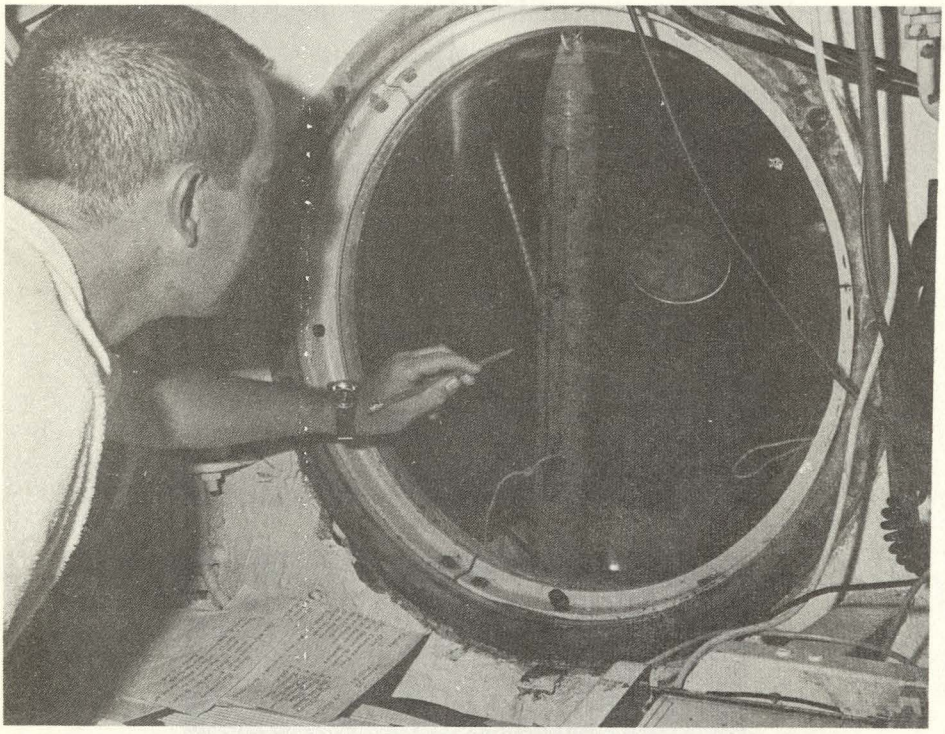


Fig. 132. Aquanaut Dowling checks the outside water temperature from a stem thermometer hanging outside the Sealab II viewing port

Currents—Current speed and direction in the vicinity of Sealab were monitored by two self-contained recording type Geodyne current meters, Model A-100. These were located approximately 27 m (90 ft) away from Sealab (Fig. 130). The data from these instruments were recorded digitally on film at a 15-min sampling interval and are presently being processed for future analysis.

During Team 2's occupancy of Sealab, estimates of current speed were made by the writers while diving by timing the drift of particulate matter over known distances. Maximum current-speed observed by this technique was approximately 5 cm/sec (0.1 knot).

Water Clarity—Measurements of water clarity were made with an S.I.O. water clarity meter (4) which was lowered from the surface to within approximately 3 m (10 ft) from the bottom (Fig. 130). This instrument recorded both the beam-attenuation coefficient and the

scalar irradiance at depth. Data obtained from this instrument are being analyzed for correlation with water-visibility measurements taken by divers.

Tides—Changes in the water level above Sealab were monitored by (a) a Hytech Model 4000 water-level monitor and (b) a Braincon temperature-Depth recorder, Type 148. The Hytech monitor utilizes a precision Mechmetal bellows to alter the tension in a vibrating beryllium copper wire to measure changes in hydrostatic pressure. The output of this instrument was recorded on a Rustrak recorder located in Sealab. This instrument was in operation during Team 2's occupancy. In the Braincon depth recorder the movement of a helical Bourdon tube is contact printed on 70-mm photographic film. This instrument was attached to Sealab; the transducer of the Hytech unit was positioned some 15 m (50 ft) from Sealab. The location of both of these instruments is shown by Fig. 130. The Braincon unit was in operation from Sept. 6 to Oct. 8. The records from both of these units, after corrections for changes in barometric pressure, will be correlated with records from a Coast and Geodetic Survey tide gage located at the end of Scripps pier. The film record from the Braincon unit is presently being processed. The maximum tide range recorded by the Hytech unit was approximately 2.3 m 7-1/2 ft), which was in good agreement with the 2.4 m (7.8 ft) maximum predicted tide range for this period.

Specific Problem Areas

Of the 15 specific research tasks planned, useful results were obtained from eight. In the interest of completeness, however, all of the planned tasks will be discussed giving either preliminary results or reasons why a task was not completed or successful. Also included in this discussion are several problem areas which came to light during the writer's occupancy of Sealab.

Horizontal Visibility measurements by Swimmers—Although considerable progress has been made in recent years concerning the visibility of objects by swimmers, there is a paucity of adequately controlled experimental data with which to verify existing prediction theories. Sealab II offered the opportunity to obtain needed data at depths sufficient to insure uniformity of the radiance distribution, for a time interval of sufficient duration to obtain a wide range of light levels and transparency, and in water of excellent spatial uniformity. In order to take advantage of this opportunity, the S.I.O. water-clarity meter (4) was used to monitor the optical characteristics of the near-bottom seawater, while swimmer measurements were made at a specially constructed horizontal visibility range. This range, located about 21 m (70 ft) from Sealab (Fig. 130), consisted of four visual targets arranged as shown by Fig. 133. The targets consisted of a white square, a black circular disc, a white cross, and a yellow triangle. The three angular targets were of equal area (906 sq cm), 140 sq in), while the black disk was somewhat smaller (707 sq cm) (109 sq in.). The apparent reflectances (R_o) of the submerged targets as measured by the S. I. O. visibility laboratory were: white square and white cross 0.875; black disk 0.506. The origin of a 15-m (50 ft) measuring tape was attached to the support stake of the black disk. The procedure for obtaining visibility measurements was as follows. Two swimmers, starting at the end of the measuring tape, swimming horizontally at or slightly below the target level slowly and carefully approached the targets until some target was first detected. The swimmers' position along the tape was then recorded as the range of detection. The approach then continued in this manner until the detection range of each target was recorded. In like manner the range at which the shape of each target could be discerned was recorded. Since the measuring tape was not in the center of the range, both swimmers swam to the right of the tape in order to minimize error due to the angular spread of the target array. Resulting from each visibility run were two sets (detection and identification) of four ranges for each swimmer. A total of 20 visibility runs was made. Extreme detection ranges varied from a minimum of 2.4 m (8 ft) to a maximum of 9.1 m (30 ft). Extreme identification ranges varied from 1.5 m (5 ft) to 8.5 m (28 ft). A preliminary inspection of the data has shown that the black disk even though smaller in size, was always the first target to be detected and identified. A detailed analysis of these data is being conducted, and an attempt will be made to use these results, in conjunction with the water-clarity-meter data, to verify the Duntley-Preisendorfer underwater visibility range prediction theory.

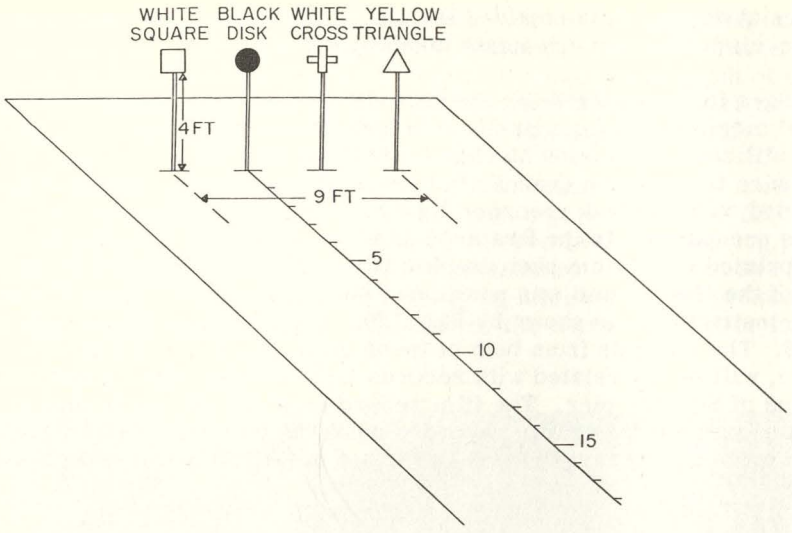


Fig. 133. Sealab II form/color visibility range

Bioluminescence—Bioluminescence, the production of light by living organisms, is a common occurrence in the marine environment. Since the advent of nighttime naval operations, bioluminescence has become a problem of military significance and has received the attention of a number of investigators (5, 6). Actual reports of bioluminescence however are few, and for the most part consist of sightings by mariners of only exceptionally brilliant displays, offering little in the way of quantitative or qualitative information. In 1963, Seliger, Fastie, Taylor, and McElroy (7) developed a portable light-baffled underwater photometer capable of measuring the bioluminescent intensities of planktonic organisms while eliminating interference from ambient light. Several of these meters were made for the U.S. Navy Oceanographic Office, and the writers were fortunate to obtain one of these for use in Sealab II. In operation, water (with its plankton population) is drawn into a light-tight impeller housing and churned rapidly, stimulating luminescent forms into light production. The output of the luminescent organisms is measured by an RCA 1P21 photomultiplier tube. Measurement of the phototube current is made by a transistorized dc amplifier which is included in the phototube housing. Response of the amplifier is such that the integrated signal can be recorded on a Rustrak recorder. During Team 2's occupancy of Sealab, the sea unit of this instrument was attached to the conning tower, and a number of night runs were made to measure the bioluminescent background level. Measurements made after Sept. 15 revealed that the level of bioluminescence was less than the threshold detection capability of the instrument. On Sept. 15 the bioluminescent level was sufficient to cause half-scale deflection on the instrument's most sensitive range. The effective input light level corresponding to this deflection will be determined by calibration data for the instrument.

The measurement of bioluminescent levels made with the meter correlates quite well with diver observations of this phenomenon. On all night dives made between Sept. 12-15 a noticeable amount of bioluminescence in the water was reported. After Sept. 15, the amount of bioluminescence suspended in the water appeared to be much less. One interesting observation concerning the occurrence of this phenomenon at these depths is that the most intense displays were restricted to a very narrow (less than 1 in.) region above any exposed surface. Thus by generating a current a diver could see in detail the surface of a rock at the edge of the canyon or small surface protuberances in the darkened exterior areas of Sealab. Since the organisms responsible for these displays remained near or attached to the surface of these objects, they could not be pumped in and detected by the bioluminescencence meter. Copepods and euphasids appeared to be the primary producers of bioluminescence at these depths.

Sonar Conditions—An important problem from the point of view of naval applications is that of short-range acoustic transmission variability as related to the oceanographic environment. In order to study this problem from Sealab II, tape recordings were made of sonar return, from several fixed targets, for later correlation with environmental parameters obtained from both the NAVMINDEFLAB instrumentation and the SIO weather station. The sonar chosen for this task was the AN/PQS-1B, a diver-held, continuous-wave, frequency-modulated (55 to 85 kc) unit that is, and will be, commonly used in Sealab type operations. Sonar runs were made by pointing the sonar at two preselected, fixed, strong targets which were reliably reidentifiable. By carefully bracing himself against Sealab, the operator could hold the sonar steadily on each target for three to five minutes, during which time a tape recording was made of the sonar's audio output. After this time, the sonar was held pointed upward at the surface and a three-minute recording made. In all, six such runs were made over three days, covering times of day from 1000 to 2145. There were noticeable differences in both target and surface signals from day to day and from morning to night. The tape recordings will be analyzed for relative energy content as a function of frequency, and correlated with oceanographic data. Although the analysis technique will obviate the need for knowing absolute acoustic levels, care was taken during data collection to insure that sonar and tape-recorder gains were constant and/or known, so that comparison of actual signal levels can be made.

General Bottom Conditions and Settlement of Sealab II—A general survey of bottom type and topography was made in the immediate vicinity of Sealab II. Sediment in this area was a dark gray, micaceous, very fine silty sand with few marine shells and a trace of clay. The upper one or two centimeters of sediment contained a large proportion of relatively loose fine silt which was easily disturbed and placed in suspension, with generally a drastic loss of visibility for divers. Analysis of a surficial sediment sample obtained in the vicinity of Sealab II yielded 81 percent sand, 19 percent silts and clays, with a median diameter of 0.095 mm. Laboratory tests of soil-engineering properties of this sample were made giving the following results: angle of internal friction, 22 degrees; cohesion, 976 kg per square meter (200 lb per sq ft); unit buoyant weight, 833 kg per cubic meter (52 lb per cu ft). From these data it was calculated that Sealab should have a safety factor of about three against footing settlement of as much as 61 cm (two feet).

At the Sealab II site the bottom generally sloped up to the southeast at about 8 degrees. Small-scale bottom relief was of the order of one to four inches and was of irregular appearance, consisting largely of mounds and depressions of biological origin. Occasionally seen were scattered debris consisting mostly of remains of sea grasses and kelp from shallower depths; also seen were fragments of shells and echinoderms. Within about 15 m (50 ft) of Sealab, the bottom appearance had been drastically modified and scarred by the presence of Sealab and divers; many of these scars persisted throughout the duration of the experiment.

Measurements of the angles of roll and pitch made inside Sealab with a plumb bob indicated a port list of 6.54 degrees and a bow-up pitch of 5.96 degrees. Similar measurements made during Team I occupancy indicated that these angles had not appreciably changed over a period of three weeks. It was thus apparent that Sealab was stably sitting at a lesser slope than that of the outside bottom, implying a differential footing settlement at its four corners. In order to check this, the writers made careful measurements of footing settlement; the results were as follows (data are with respect to bottom of main footing I-beams to which spades were attached): starboard aft, 23.1 cm (9.1 in.); starboard fwd, 40.1 cm (15.8 in.); port aft, 23.3 cm (9.2 in.); port fwd, 0 cm. Thus the starboard forward corner was dug in more than the others, while the after end settled evenly. These measurements were repeated after an interval of several days, yielding the same data; thus from these settlement data and from the inclination data one concludes that essentially all of the settlement occurred on impact or very shortly thereafter.

General Observations of Near Bottom Underwater "Weather" and Biology—A number of general and somewhat unrelated observations of the undersea weather and the behavior of various marine organisms were made by the writers during Team 2's occupancy of Sealab, which, because of the uniqueness of the situation, should be documented.

Porthole watching became the favorite pastime of the entire crew, and many hours were spent observing the antics of our outside neighbors. Although at 62.5 m (205 ft) the light level

was considerably reduced, there was a noticeable diurnal rhythm in the movement of fish. During the night the white croaker, Gengonemus lineatus, would typically crowd near the port holes, often occurring in such numbers as to completely obscure the port (Fig. 134). With the approach of dawn the croakers would leave the ports but could be seen swimming in large schools, all generally pointed in the same direction, several feet away. It appeared to the writers that the croakers were attracted to the ports to feed on the small crustaceans (Euphausia sp) which gathered at the port holes during the night in great numbers. One curious note concerning the occurrence of these small organisms at the ports is that after the T. V. camera was placed outside the port window in the laboratory area, many would become trapped in the recessed area between the port window and the camera face plate. By morning this area would typically become completely filled with these organisms. After leaving Sealab the writers mentioned this to the psychologists, who continually monitored the TV receivers and learned that they were completely unaware of the presence of these organisms; apparently TV reception suffered little.



Fig. 134. White Croakers, Geneonemus Lineatus, crowd near the viewing port in the Sealab II laboratory area

The small crustacean forms were also a favorite food of the squid, and quite often these strange animals could be seen actively feeding in the company of many types of fish and would thus themselves become food. Such a situation was witnessed by the writers who observed a calico rockfish (Sebatodes dalli) cautiously stalk a squid feeding outside a port in the laboratory area. Very slowly and carefully the rockfish approached the squid until it was only about 15 cm (6 in) from its prey. With a sudden movement the squid's head and tenacles were inside the fish's mouth. The squid then discharged its black ink, which was seen flowing from the sides of the mouth. Very quickly the fish released his hold on the squid and shaking his head, as if the ink was most distasteful, rapidly left the field of view. The squid, however, seemed to be totally unconcerned by his recent experience and remained near the port for several minutes, continuing his feeding activities. To the writers' knowledge, the ink discharge of

squid has been considered to be primarily a smoke-screen defensive mechanism. From this observation, it thus appears that the discharge also serves as a taste deterrent.

Over the short time interval the writers occupied Sealab, there was a noticeable change in the types and density of fish present. Sculpin, Scorpaena guttata, were always present, and several counts were made of their density on the bottom. In the area immediately adjacent to Sealab an average of 2 per 0.1 sq m (sq. ft) was observed. These fish decreased in numbers somewhat at a distance from Sealab. At approximately 15 m (50 ft) away an average of only 1 per 0.1 sq m (sq ft) was observed. Through conversations with CDR Carpenter, the writers learned that these fish were not present during the early part of Team 1's occupancy, but had moved in during the latter part of the first week. The white croakers were always present, but were most numerous during the first week of Team 2's occupancy. About the time the sea lions appeared on the scene, the number of croakers decreased sharply and it is possible that the desirability of croakers as food may have been in part responsible for this decrease. The sea lions were first observed on the night of Sept. 22. This first night they appeared to be somewhat cautious and were seen swimming only at a distance. By the next night, however, the sea lions had apparently decided that Sealab offered no threat and on several occasions they were seen hanging on the diving lights and looking in the ports. All of the fish in the immediate vicinity could somehow sense the approach of a sea lion, and some 10 sec prior to the appearance of a sea lion the fish would rapidly depart from the field of view. Only the sculpin, Scorpaena guttata, seemed to be unaffected by the sea lion's approach, and even though these fish made no attempt to escape, they were never taken by the sea lion. On the night of Sept. 23 a marked change in water color was noted, the water changing from a predominantly green, typical of coastal waters, to an oceanic blue. Accompanying this change in water mass was the appearance of the northern anchovy, Engraulis mordax, which occurred in great numbers, becoming the predominant fish present. These fish were strongly attracted by the outside diving lights, and the protective screen of these lights often became completely filled with anchovies that had gilled themselves. These lights thus became a favorite feeding post for the sea lions, and on several occasions sea lions were seen feeding on the anchovies that had become gilled. By the night of the 25th of September, the water color had changed back to the typical green and most of the anchovies had departed. From conversations with CDR Carpenter, the writers learned that the anchovies had made a similar appearance during Team 1's occupancy of Sealab; this appearance also coincided with the occurrence of oceanic blue water. A check of the predicted tides indicates that in both instances this change in water mass occurred during a period of maximum tide range.

Underwater Surveying and Mapping

A problem of major importance to both the Sealab oceanographic program and to other facets of the Sealab work was that of underwater surveying and mapping. Although, as described in what follows, useful partial solutions have been provided, the problem of accurately positioning, surveying, and mapping the location of underwater objects near Sealab remains as a significant problem yet to be fully solved. The prime reasons for this situation are, of course, that members of an underwater survey team are not only deprived of both aural and visual communication but also of many of the commonly used instruments, such as, e.g., transits. There is a pressing need to provide an underwater survey technique that is accurate, yet independent of visual and audio links, and reasonably simple for use by divers. An approach toward solution of this problem as described below, devised primarily for oceanographic applications, turned out to have usefulness in other areas. For example, it became apparent after Team 2 had entered Sealab that the magnetic heading of Sealab was not known with certainty to within less than about ±20 degrees; we were able to reduce this uncertainty to about ±5 degrees. To do this, two simple devices were used: a 61-cm (two-foot) diameter compass rose mounted on the bottom, and a 30.5-m (100 ft) steel-reinforced surveyor's tape in a reel specially designed for underwater use. The compass rose, which was made of plastic, was marked in one-degree increments and mounted on a heavy platform stake so that once set it did not rotate. In use, it was aligned by having a swimmer go out on a known preselected bearing by compass (to a distance such that his compass was not affected by Sealab or other metal objects) with a string attached to the center of the compass rose; after this the compass rose was adjusted so that the preselected bearing was under the string. In this manner the rose was aligned with respect to magnetic north to an accuracy matching that of the compass

used, and problems of unknown effects due to nearby metal objects were avoided. Subsequently, any desired direction could be measured merely by stretching a string from the rose in the unknown direction and reading the bearing from the rose. By means of this technique the magnetic heading of Sealab II on the bottom was found to be about 78 degrees.

The surveyor's tape is a standard Lufkin tape refill #0506ME mounted in a plastic reel designed for simple and foolproof underwater operation. Use of the compass rose and tape together can provide range and bearing data, and two roses (separated by a known amount) or two tapes (from known positions) can provide triangulation data. The disadvantages of this technique are that (a) the divers are separated (and often out of sight of each other), but are connected by the tape or line so that hand signals may be used, and (b) the tape or line must be pulled straight and is susceptible to hanging on objects near its middle, causing possible unknown errors. Also, this procedure is cumbersome if ranges in excess of several hundred feet are involved.

Another device which proved to be useful for this work was the NAVMINDEFLAB Divers Observation Board (1), which consists of a writing surface combined with built-in compass, depth gage, inclinometer, bubble level, and ruler and which has receptacles for pencil, 1.8-m (6-ft) folding rule, stem thermometer, and 7.6-m (25-ft) circling line.

Ambient Noise Conditions

Due to the presence of generators and other loud sound sources, it was realized from the outset that the true oceanographic ambient noise level could not be measured near Sealab II. However, for future design consideration, and for certain underwater audio experiments, there was the need to know acoustic levels, both outside and inside Sealab II. Records of ambient noise level were made by use of a NAVMINDEFLAB Sound Measuring Set, which provides the capability to record, on both analog strip chart and magnetic tape, sound levels in three filter bands to an accuracy of ±1 dba.* The hydrophone, positioned at the observer's station of the human-factors program acoustic range, was about 40 ft from the after port side of Sealab II. Recordings were made of (a) ambient noise outside Sealab II, (b) ambient noise inside Sealab II both with and without the Arawak pumps operating, (c) helium speech, and (d) calibration level signals from the sound-measuring set. The tape recordings will be further analyzed in narrower filter bands to obtain the spectral distribution of energy. Acoustic levels observed in the water were quite high, namely, of the order of 40 dba (with occasional peaks going to 55 dba) in the frequency range 400 cps to 30 kc. Analysis of sound levels inside Sealab II will be undertaken after obtaining calibration data on the microphone provided with the tape recorder.

Surface Wave Measuring System

A problem of potential importance to future Sealab type experiments for which there is no staging vessel at the surface is that of determining the surface-wave condition. Wave effects directly observable at the bottom (e.g., pressure variations) yield information only about waves of length greater than roughly twice the water depth; hence a method for obtaining information about the shorter, and usually more energetic, wind-generated waves is needed. A very simple, yet effective, approach toward solution of this problem was tried during Sealab II. The technique consists of floating at the surface a small buoy which effectively follows the surface motion; i.e., it rides up and down with the wind waves. This float is attached to a small, light, nylon-covered wire whose length is adjusted so that a small weight (approximately one pound) attached to the lower end is positioned about 4 or 5 ft above the bottom. Divers then observe and measure the up-and-down motion of this weight to obtain surface-wave height data. It proved to be very easy to position the origin of a meter stick at the lowest point of a wave cycle, i.e., at the trough, and then to observe the height on the meter stick of the highest point of motion, i.e., at the crest. In this manner it was feasible to use the standard method of measuring 30 waves and averaging the highest 10 to obtain the significant wave height. To make a measurement of significant wave height requires only about 5 to 10 minutes. It is realized that there is some error in this technique, since such a float-mass system does not exactly follow the surface waves; however, as long as the float remains above the surface, this error can never exceed the height of the float (about 15 in. in the trials described here),

*Reference: 1 dyne/cm^2

and will in general be smaller. Also, considering the fact that needed accuracy is only about ±1/2 ft, it is evident that the system described herein provides sufficient accuracy for most purposes. Once the float has been installed it can be left in place, except that when not being used it should be secured about 15 to 20 ft below the surface.

INVESTIGATION OF THE EFFECTS OF THE SEALAB II ENVIRONMENT ON PLANTS

To determine the effects of the Sealab environment on the germination, growth, and development of plants, an attempt was made to grow barley (avivat), marigolds (Spungold) and Alaskan peas during the submergence of Sealab II. This experiment was designed and directed by the Department of Plant Sciences, Texas A & M University; the writers potted and maintained the plants aboard Sealab, along with a log of their germination, growth, and development. The plant experiment consisted of two 12-in.-square wooden trays, each containing 25 small pots filled with peatmoss, perlite and slow-release fertilizers (Fig. 135). The pots were planted with seed and placed in Sealab prior to germination. Each box initially contained 15 pots of barley and 10 pots of marigolds, while each pot was planted with two seeds. The Alaskan peas were not planted until the second week of Team 2's occupancy of Sealab, at which time ten pots of marigolds were removed and replaced with the peas. A bank of eight 50-w Sylvania rough service incandescent frosted bulbs located some 66 cm (26 in.) from the surface of the boxes provided light. A plexiglas filter 0.33 in. thick was positioned in front of the light source to protect the plants from excessive heat. The plants were watered as required and checked two to three times per week to record germination and growth. During the first week a heavy mold developed and completely covered the surface of the pots. Even though a fungicide was administered two to three times per week, this mold persisted throughout the plant experiment and was, no doubt, an important factor in this experiment.

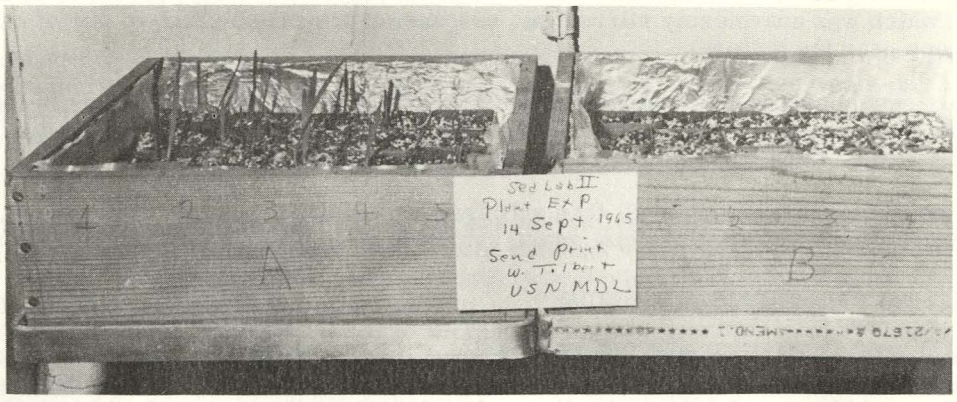


Fig. 135. Sealab II plant experiment

Of the plants tested, barley was the only plant that was able to withstand successfully the severe environment offered by Sealab. Germination was successful in 29 of the 30 pots planted with this seed, and both seeds germinated in 27 of these pots. Only one marigold and two Alaskan peas germinated; these died shortly after germination, reaching a height of only a few centimeters. When Sealab was brought to the surface, the barley, which grew to a maximum height of approximately 18.5 cm (7.5 in.), was cut off at the soil level, dried, and sent to Texas A & M for chemical analysis. A control experiment is planned by Texas A & M in which similar seeds will be germinated and grown under normal pressure and Sealab atmosphere, and under normal pressure and atmosphere. The results of these experiments, along with a complete report of the Sealab plant experiment will be the subject of a report by Texas A & M University.

BOTTOM-ROUGHNESS POWER SPECTRUM

The power spectrum of bottom roughness is a function needed as an environmental input for statistical theories of sound scattering from sea bottoms. Since no such data exist for real ocean bottoms at Sealab II depths, it was desirable to attempt measurement of bottom roughness, using a technique which has been tested at shallow depths and sandy bottoms in the Gulf of Mexico. This technique involves establishing a reference baseline about 3 in. above the bottom in the form of a tightly stretched nylon line; measurements from this baseline to the bottom are then made at preselected equispaced intervals, yielding a series of data points from which variance of the bottom topography as a function of space frequency can be calculated. A suitable area of bottom was located near the visibility range, about 30 m (100 ft) upslope from Sealab II. The general appearance of the bottom revealed random irregularities in the form of depressions and bumps (with relief of approximately 1 to 2 in) probably caused by biological activity, and weak, highly irregular ripples (with relief of approximately 1/2 to 1 in.) probably caused by waves and currents. These features appeared to be isotropic and homogeneous over the area considered. Unfortunately, on the first attempt to make measurements as described above, it was found that the presence of the thin layer of easily disturbed fine silt at the bottom was a critically limiting factor. Invariably and unavoidably, as the two divers adjusted themselves and moved equipment into position to get data, enough silt was stirred into suspension to completely occult the field of view where measurements were being made. For this reason, and for lack of time to adequately modify the measurement techniques, this experiment was not successful, and no useful data were obtained. Modified techniques to get around this problem are being worked on, so that in future work it will be possible to make measurements of bottom roughness in both sandy and silty regions.

DIFFUSION STUDIES OF BOTTOM BOUNDARY LAYER AND NEAR-BOTTOM TURBULENCE

It was planned to photograph dye and/or neutrally buoyant particle movement near the bottom in order to study turbulence in and above the bottom boundary layer. This work was not successful for a combination of reasons.

1. Primarily, as with the bottom-roughness power-spectrum study, presence of the layer of fine silt which was unavoidably stirred into suspension prevented effective use of cameras and dye drops near the bottom.

2. This experiment would have been much more time consuming than others in the plan, so that relative to the limited amount of diving time available (at suitable distances from Sealab) it was felt this study should be of relatively low priority.

3. It proved much more difficult than anticipated to provide accurate and reliable movie coverage for experiments such as this; again, available diving time was a limiting factor.

ULTRAVIOLET FLUORESCENCE STUDY

Sealab II offered a unique opportunity to observe, both at night and in weak daylight, the effect of exposing marine organisms and bottom sediments to ultraviolet light. However, since such a study would be completely qualitative and exploratory, it was considered to be low in importance relative to many others planned. A specially waterproofed ultraviolet light was constructed for use from Sealab II. As it turned out, the difficulty of getting sufficient time in the water to do experiments was such that this experiment, along with several others planned, was never attempted. The desirability of conducting this type of experiment, however, remains for future Sealabs for which, hopefully, there will be a larger ratio of outside-to-inside time.

WAVE-INDUCED BOTTOM MOTION

It was planned that motion of near-bottom particles resulting from passage of surface swells would be photographed in such a manner as to correlate with a simultaneous pressure record from the same swells, thus allowing direct measurement of pressure-velocity phase relationships in or above the wave-induced boundary layer. This experiment was not successfully completed for the simple reason that surface waves were never of sufficient height to

cause near-bottom particle movement of the amplitude needed for adequate accuracy. At the depth of Sealab II, wave-induced bottom motion was observed only for waves with periods longer than 10 sec. On the several days that wave-induced motion was observable at all at Sealab, measurements showed that the period was 11 to 13 sec, and horizontal amplitude of particle motion never exceeded 5 cm (2 in.). It is concluded that in general this type of experiment will be successful only in shallower water, and hence does not lend itself to future Sealab efforts.

MEDIUM SCALE TURBULENT DIFFUSION OF BOTTOM TRAILERS

It was planned to track quantitatively several types of bottom drifting objects undergoing turbulent diffusion in the range of turbulence scale sizes 1 to 100 ft. Such data from the sea floor are potentially useful in developing theories to understand and predict the spread of almost neutrally buoyant objects from marine disasters. The technique for performing this experiment was to have been as follows. After releasing five to ten nearly neutrally buoyant objects at a preselected spot, special small marker buoys would be dropped periodically near each one (as it disperses) to mark its position at known times. Thus, after these objects have dispersed approximately 100 ft from their origin, their paths have been essentially recorded on the bottom. Then, by use of the compass roses and surveyor's tapes (previously described in "Underwater Surveying and Mapping"), the location of each marker would be determined and a map made which is essentially a Lagrangian plot of each object's movement. These data may then be applied to theories of turbulent diffusion. It is obvious from the above discussion, that a large amount of diving time (namely, three to five hours) would be required for each trial of this experiment; prior to entering Sealab it was hoped that such times would be available. As has been pointed out already, of course, such diving times were not available; hence this study was not successfully completed. However, this experiment was carried out in a qualitative manner by releasing standard plastic Woods Hole Oceanographic Institute bottom trailers on a daily basis and observing their general behavior pattern. These bottom trailers are numbered, addressed, and have a reward statement affixed so that if one is found by a trawler, diver, fisherman, or beach comber, its location will be forwarded to Woods Hole, thus providing information about bottom currents. Their design is such that a current of a few hundredths of a knot will move them. In all, about 200 of these bottom trailers were released.

Observation of these bottom trailers indicates that their diffusion rate was typically very slow; on several occasions those released on a previous day were observed a day later within 10 ft of the release point. On Sept. 22 trailers were found in the release area which had been released 1, 2, and 6 days earlier. This slow rate of diffusion was another reason that the quantitative aspects of this experiment were not successful.

The main sources of movement for the bottom trailers were the quasisteady bottom currents (associated with tides or seiches) which, although weak, were sufficient to transport them. Thus, if movement due to such currents is neglected, it appears that an approximate upper limit on the diffusion transport rate by medium-scale turbulence is of the order of a few tens of feet per day. It is expected that current-meter records will yield data about current fluctuations which can be analyzed from the point of view of the turbulent components of the current, and hopefully, correlated with bottom-trailer observations.

FISH-BEHAVIOR STUDIES

Sealab offered the opportunity of making long-term, detailed studies of the behavior, and/or reactions of various marine organisms to manmade objects placed in their natural environment. To take advantage of this opportunity, the writers had planned a number of observational studies. As it turned out, it was not possible to complete any of these investigations, successfully, all of which had a fairly low priority in terms of the overall planned program and naval applications. Data provided by these studies, however, do have direct application in fisheries research and in the utilization of the products of the sea, and these studies should be considered for future Sealab efforts. The primary reason for not attempting these research tasks as planned was that the available bottom time was far less than had been expected; other reasons are described below, along with a description of the proposed effort and the expected results.

Attraction of Marine Animals to Objects Placed on the Sea Floor

It is known that objects placed on the sea floor attract various forms of marine life. For example, the writers have observed that fish are attracted to mine cases within minutes after plant, and the population becomes more concentrated during the first month of exposure. It was planned to place several mine cases at varying distances from Sealab, inspecting these periodically and recording the types, number, and behavior of the various organisms attracted to these objects. The writers were unable to plant these objects as planned (during Team 1 occupancy of Sealab), since the bottom had not been adequately surveyed; hence it was questionable if the mines could be relocated for observational purposes. During Team 2's occupancy of Sealab, the writers surveyed the bottom and inspected several possible sites for this experiment. It was decided, however, that it would be impractical to attempt this study as planned, since Sealab had affected the ecology of a much greater area than had been expected. Hence the mine cases would have had to be placed several hundred feet away, requiring at least 30 minutes bottom time of two divers to make these observations.

Study of the Animal Shadow Zone in the Lee of Sealab

It has been noted that various forms of marine life, fish in particular, are attracted to the upcurrent side of large objects placed on the sea floor. It was planned to study this phenomena during Team 2's occupancy, making population counts on both sides of Sealab, the power hive, PTC, and the benthic lab. The low-current regime which prevailed throughout Team 2's occupancy made this study impractical.

Study of the Reaction of Bottom Fish to a Low Barrier.

It has been noted that certain bottom fish will swim around a barrier that happens to be in their path rather than swim over it. This appears to be true even if the barrier is only one to two feet high, but many feet in length. It was planned to construct a small fence outside Sealab and make observations of the reaction of the fish to this barrier through a porthole window. The low light level and visibility conditions which prevailed near the bottom during Team 2's occupancy of Sealab made this experiment impractical.

CONCLUSIONS AND RECOMMENDATIONS

In this section are presented those conclusions and recommendations regarding oceanographic research from Sealab-type habitats which appear valid and useful at this time. Also included are some discussions of subjects which, while not directly concerned with oceanography, definitely limit the amount and quality of work attainable; these items are discussed from the point of view of providing more diving time per day per oceanographer. It is felt that, as far as doing oceanographic research is concerned, diving time should be at least four hours per day. In Sealab II it was difficult to attain even two hours per day, and much of this time was devoted to logistics and housekeeping. We will not discuss in detail the most critical single "bottleneck" of Sealab II, the entry way and staging area; it is notoriously obvious by this time that these areas need to be several times as large as in Sealab II, that divers need to be able to work all around the entry well, and that the entry ladder needs to be of a type suitable for divers to climb. Several recommendations concerning philosophy and design of Sealab will now be discussed.

The established and recognized policy of Sealab II was that team members be primarily divers; assignments associated with specialization and/or skills were of secondary importance relative to being a diver.* Now that this approach has been tried, it is recommended that the established crew operating policy of the rest of the Navy be utilized in the future, namely, that

*Project Manager's Note: A number of recommendations on team make-up and Sea Habitat organization have been made by the various aquanauts, this being one rationale. Sealab II was conducted as the first multidiscipline saturated diving experiment, and there were even great differences of opinion between divers concerned with the same ocean-floor problem, i.e., salvage divers, as well as differences between Teams 1, 2, and 3.

crew members be assigned primary tasks associated with particular skills and that responsibility for these tasks be at least as important as for diving tasks. It is believed that more efficient accomplishment of work both outside and inside Sealab will result from this approach. Note that this recommendation does not imply discarding the important concept that all crew members be fully trained and responsible for operation and use of all diving gear and all systems which are part of the Sealab.

It is recommended that effort be devoted toward reducing the acoustic noise level both inside and outside Sealab. For future work at great depths it would be highly desirable to have Sealab noise levels sufficiently low that ambient noise of biological origin can be measured without undue masking by background noise.

One or more special-purpose portholes should be provided. One such porthole should be mounted to provide a view of the outside region through which divers enter and leave Sealab, its purpose being to allow determination of whether or not a diver is in trouble. In both Sealab I and II most of the situations in which divers were in real trouble and had critically short time available occurred at or just outside the shark cage. Also, it is nearly unavoidable that divers be occasionally alone in this area for short times. The ability to see such divers from the inside would be a valuable safety feature.

Another type of special-purpose porthole is suggested by the fact that the field of view from any porthole in Sealab II was very narrow. To observe adequately the behavior of active animals such as sea lions was not possible because of the narrow, nonoverlapping fields of view from Sealab II. One way to obviate this problem would be to provide a cylindrical glass port of the pillbox type at the top and/or on each side of future Sealabs. Such viewing ports are mechanically simple and rugged, yet provide much larger fields of view.

It should be noted that the potential of porthole observations for acquisition of scientific data (particularly in biological studies) has not been nearly fully exploited; plans should be made to do so in future Sealabs. It should also be realized, however, that erroneous impressions can be gained from porthole observations, particularly as regards water current and motion. For example, in Sealab II it was noted on occasion that water was going down by one port hole and, at the same time, going up by an opposite port hole. This type of flow, typical of that around a cylinder at high Reynolds number, consists of eddy shedding and unsteady movement of the stagnation point around the periphery of the cylinder. By viewing such flow from inside the cylinder it is very difficult to infer accurately details of the outside flow away from the cylinder. It should be possible, however, to place a set of flow and/or pressure sensors on a cylinder such as Sealab so that (with appropriate averaging techniques) current speed and direction can be accurately recorded. Consideration should be given to the idea of providing such special oceanographic instrumentation for future Sealabs; this concept is discussed more fully below.

Turning from Sealab design features, we now discuss results of evaluating Sealab II as an oceanographic platform and make recommendations for future Sealab oceanographic programs.

In the preliminary proposal for MDL participation in the Sealab II program, it was pointed out that Sealab might well be the long-sought-after stable platform from which to measure waves, currents, and tides and from which to obtain badly needed information on near-bottom features of such scale that the trained and interpreting human eye is needed for decisions about deployment of instruments and correlation of observations. Experience gained through participation in Sealab II yields the conclusion that Sealab platforms do indeed provide the capability to attack effectively these and many other significant oceanographic problems, the solution of which would lead to a better understanding of the marine environment and how to exploit it. Sealab II, however, was not specifically designed as an oceanographic platform, and it is obvious that certain modifications,and/or additions (some of which have been discussed in preceding sections) would greatly enhance its oceanographic capabilities. A particularly valuable specific addition for future Sealabs would be the inclusion, as an integral part of the design concept, of special oceanographic instrumentation. This instrumentation, although initially expensive, can be designed for adaptation to all future Sealab habitats. Included in this instrument array should be sensors for measuring temperature, currents, light level, salinity, sound velocity, ambient noise, pressure fluctuations, tides, bioluminescence, water clarity, and others,

as necessary. Many of these sensors should have the capability of making measurements from the bottom to the surface. There are presently available from commercial sources instrument packages which provide many of the features required; also, the Naval Oceanographic Office has similar instrumentation packages which have been successfully used aboard submarines.

Future Sealabs appear to be particularly attractive as platforms from which to make studies of several difficult and important oceanographic problems which are presently receiving considerable attention and yet are in a poor state of solution, mainly due to lack of suitable platforms from which to collect data. These are: (a) the air-sea interaction problem, (b) the bottom-sea interaction problem, and (c) the open-sea tide problem.

Solution of the air-sea interaction problem critically depends not only on the ability to place sensors precisely just above and beneath the sea surface, but also to do this without having the wind and water flow fields disturbed by either sensor-support devices or by surface platforms. Also, certain chemical and boundary-condition aspects of the air-sea interaction problem depend critically on not having the surface contaminated in the manner which unavoidably occurs near ships or offshore towers. A unique method of solving these sensor-support and sampling problems will be offered by the first Sealab operation which does not have a staging vessel moored above it. In such a situation, the open ocean surface is far enough away that Sealab offers no source of contamination; yet by means of subsurface floats (let up from the bottom), sensors and/or samplers can be placed at the sea surface with accuracy, with minimum disturbance, at sea states for which data would be unobtainable otherwise.

The bottom-sea interaction problem is another boundary problem which requires judicious and accurate placing of sensors and samplers. At the present level of understanding, this problem is best attacked by having the trained scientist make direct observations at the sea floor. Future Sealabs are obviously the best platforms from which to do this, especially for depths greater than 200 ft and for extended times.

The open-sea tides are in an imperfect state of understanding simple because of lack of accurate tidal data from offshore regions. As Sealabs extend to deeper depths and larger distances from shore, there are no reasons why they should not assume major importance as a source of open-sea tide data.

Finally, it should be emphasized that the consideration which gave rise to formulation and inclusion of an oceanographic research program for Sealab II are equally valid and significant for Sealab III. This is especially so when one realizes that the sea floor at Sealab III will be at depths which no scuba-equipped scientific diver has ever explored. Several tasks undertaken from Sealab II, of significance to both the Navy and the oceanographic community, should be investigated further from Sealab III. In short, it is strongly recommended that an oceanographic program be included in Sealab III which takes advantage of experience gained in Sealab II, utilizes as fully as possible the combination of recording instruments and the in situ trained eye, and provides for acquisition of new data from previously unexplored depths.

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Chapter 40

THE SEALAB II BIOLOGICAL PROGRAM

A. O. Flechsig
Scripps Institution of Oceanography
University of California
La Jolla, California

The aim of the Scripps Institution of Oceanography biological program in Sealab II was to describe the biological activity in, on, and just above the sea floor in the vicinity of the habitat and as far away as the divers could operate with safety. The program was designed to describe the normal bottom fauna and to document any qualitative or quantitative changes that took place after Sealab was placed on the bottom. To do this we needed:

1. To determine the identities, abundances, and spatial distributions of the organisms attracted to the Sealab site throughout the operation and to compare and contrast these with the normal sandy-bottom and canyon faunas.

2. To record the activities of organisms and their relationships with each other and with the physical environment. This included studies of schooling, predator-prey relations, the effects of light, etc.

Our program required:

1. That organisms be collected for identification and stomach analysis.

2. That organisms be counted at diverse places and times to determine their abundances and spatial and temporal distributions.

3. That photographic observations be taken of the activities of organisms to study their behavior and their relationships with the environment.

To meet these requirements, the program was planned to use techniques and instruments proven successful in shallow-water diving. In some cases there was anticipation of the need for modification of these for the particular circumstances of the operation. There were also several planned experiments. These included modification of the environment by construction of block pyramids and behavioral studies in large wire-mesh holding cages.

It was possible to carry out an extensive survey of the organisms present around Sealab, although investigators were hampered by insufficient diving time. Available data indicate that an object the size of Sealab provided with lights is a very effective fish attractant. By the end of 44 days some 6,500 fish, representing 15 common species, were present. Over the entire period a total of 47 species were observed. This is a much more rapid buildup of fish populations than has been observed at larger, shallower artificial reefs along the California coast, presumably as a result of the presence of lights. Observations of predatory and other behavioral interactions, and of patterns of distribution, coupled with studies of collected specimens, have given a preliminary idea of the structure and dynamics of the community of animals, particularly fish, attracted to such artificial substrates.

Following is a list of equipment and procedures intended for use during the Sealab II project. Appended to each item is an estimate of its effectiveness and probable causes for inadequate performance.

1. Collection of specimens by spear, net, etc.—performance: good: coverage: adequate for identification purposes. More systematic collections for stomach analysis would have been valuable, but were not taken owing to insufficient diving time and scheduling difficulties.

2. Corer for collecting substrate samples to determine identity, abundance, and distribution of small subsurface dwelling organisms—coverage: good: performance: adequate, but a faster method designed specifically for handling the fine sediment would have saved much diving time.

3. Fish rake for censusing larger animals on the bottom—coverage: barely adequate owing to insufficient diving time: performance: fair, owing to insufficient lead time to test the apparatus and modify the techniques of use for Sealab conditions.

4. Multiple-level plankton net sled for censusing near-bottom plankton—not used because of hazards from scorpion fish on the bottom near Sealab and insufficient diving time to go further away.

5. Permanent station template for independent estimates of abundance and determining movements of small organisms—not used; conditions near Sealab and insufficient diving time did not warrant setting up the stations.

6. Concrete block pyramids for comparison with Sealab as environmental modifications—performance: fair, placed on the bottom much later than desirable owing to insufficient diving time and logistic difficulties.

7. Wire-mesh cages for holding experimental animals—not used because of insufficient diving time.

8. Tagging larger organisms—performance adequate: coverage: poor as a result of insufficient diving time.

9. Chemical attraction of organisms—not used owing to insufficient diving time.

10. General observations, outside—performance: fair, hampered by poor illumination, insufficient lead time to develop tape-recording capability, preoccupation with other tasks while diving, and lack of opportunity to dive at times selected for their relevance to scientific objectives.

11. General observations, inside—performance: good, but hampered by conflict of other duties with maintenance of regular scientific watches.

12. Photography of organisms—performance: only fair owing both to insufficient lead time to modify and test new equipment and to insufficient diving time.

The inadequacies in performance and coverage were primarily due to three reasons: far less time was spent in the water than was anticipated, dives could not always be scheduled at times that would be best for our program, and we had very little opportunity to design, modify, or test equipment or procedures under conditions similar to those around Sealab prior to occupation of the habitat. As a result, some projects took so much more time than expected that coverage was limited and other projects had to be eliminated. Our recommendations, which follow, stress these points.

1. A greater amount of lead time should be allowed in order to develop and test equipment. Funds for acquiring and developing equipment should be available very early in the project.

2. Diver training should put more stress on navigational problems and homing procedures.

3. Diver-to-diver and diver-to-tape-recorder communication should be developed.

4. There should be provision in the training schedule for practicing the scientific techniques insofar as these are modified from standard operations or are unfamiliar to some of the scientist-divers. The practice should be carried out at depths and under conditions that will have some similarity to what will be encountered around the habitat.

*5. Both members of a buddy pair should be scientists. If this is impossible, the scientist should have the opportunity to familiarize one diver with his aims and procedures. Buddy rotation is inefficient.

6. The amount of scientific research that could be accomplished would be markedly increased if there were a crew—as there is on surface oceanographic vessels—to carry out many of the housekeeping tasks and if fewer conflicting projects were planned.

7. Some means should be found to free the scientist from long periods of enforced inactivity and unproductive watch standing during all phases of the operation. Further, assuming that the serious physical shortcomings of the Sealab II operation, such as limited diving facilities, small entryway, excessive surface traffic, etc., are corrected, the scientist should be allowed to schedule and execute his activities to meet the needs of his program.

8. A project in which the scientific results are a primary end should be continued long enough for feedback from the early results to affect the later part of the program. Another approach would be to repeat the operation at intervals of moderate duration.

*Project Manager's Note: Some Scientists felt it preferable to use a Navy diver as a trained observer.

Chapter 41

SEALAB II UNDERWATER WEATHER STATION

E. A. Murray, D. L. Inman, and W. A. Koontz
Scripps Institution of Oceanography
University of California
La Jolla, California

INTRODUCTION

An underwater weather station was installed near Sealab II and maintained by the aquanauts. The weather station measured water current, direction, pressure, temperature, and ambient light. It was intended that these measurements provide the divers with the most essential parameters of underwater weather, as well as necessary background information for other scientific programs undertaken during the operation. In addition, it was hoped that the underwater weather station measurements, when compared with similar measurements obtained synoptically elsewhere on the shelf, would provide insight into the complex phenomena that constitute underwater weather.

There are almost no continuous observations of the underwater environment that are of sufficient scope to be considered as underwater weather. Yet, underwater weather is as important to man in the sea as to man in the atmosphere. The kinds of parameters to be sensed are similar to those in the atmosphere: current speed and direction, pressure, temperature, and light. Their measurement underwater is somewhat more complicated, principally because water is wet. In addition, the underwater environment has greater pressure, viscosity, specific heat, and biological activity of all kinds. The importance of biological activity is frequently overlooked in underwater instrumentation. Every few days, it was necessary to clean organic growth and fouling from the current meters. The current measured underwater appears deceptively weak in terms of air currents. However, "gusts" up to nearly two knots were measured near Sealab and these, because of the increased density and viscosity of water, would have exerted a drag on the diver equivalent to that of a 50 to 100 knot wind in the atmosphere.

Sealab II, with three teams of divers and a total underwater occupancy of 45 days, presented an excellent opportunity to obtain long-period continuous measurements of the underwater environment.

DESCRIPTION OF THE AREA

The site of Sealab II was the continental shelf just north of La Jolla, California, where Point La Jolla forms a small hooked bay which opens to the northwest. The shelf area within the embayment is cut by two main branches of La Jolla Submarine Canyon (Fig. 136). Sealab II was placed on the rim of the northern branch, Scripps Submarine Canyon, where the rim has a depth of about 210 ft; the floor of the adjacent canyon has a depth of 650 ft. Both La Jolla and Scripps Canyons extend across the continental shelf and terminate within a few hundred feet of the beach. The shelf between the two canyons is covered with fine sand in shallow water and with fine sand and coarse silt at the Sealab II site (1). Scripps Canyon is narrow and precipitous, and in many places the walls are vertical as indicated by observations from the diving saucer (2).

For many years it has been known that the heads of Scripps Canyon trapped sand from the adjacent beaches. This beach sand is eventually deposited in the deep water of San Diego Trough, some 16 to 20 miles seaward. The mechanism by which the sand is transported through

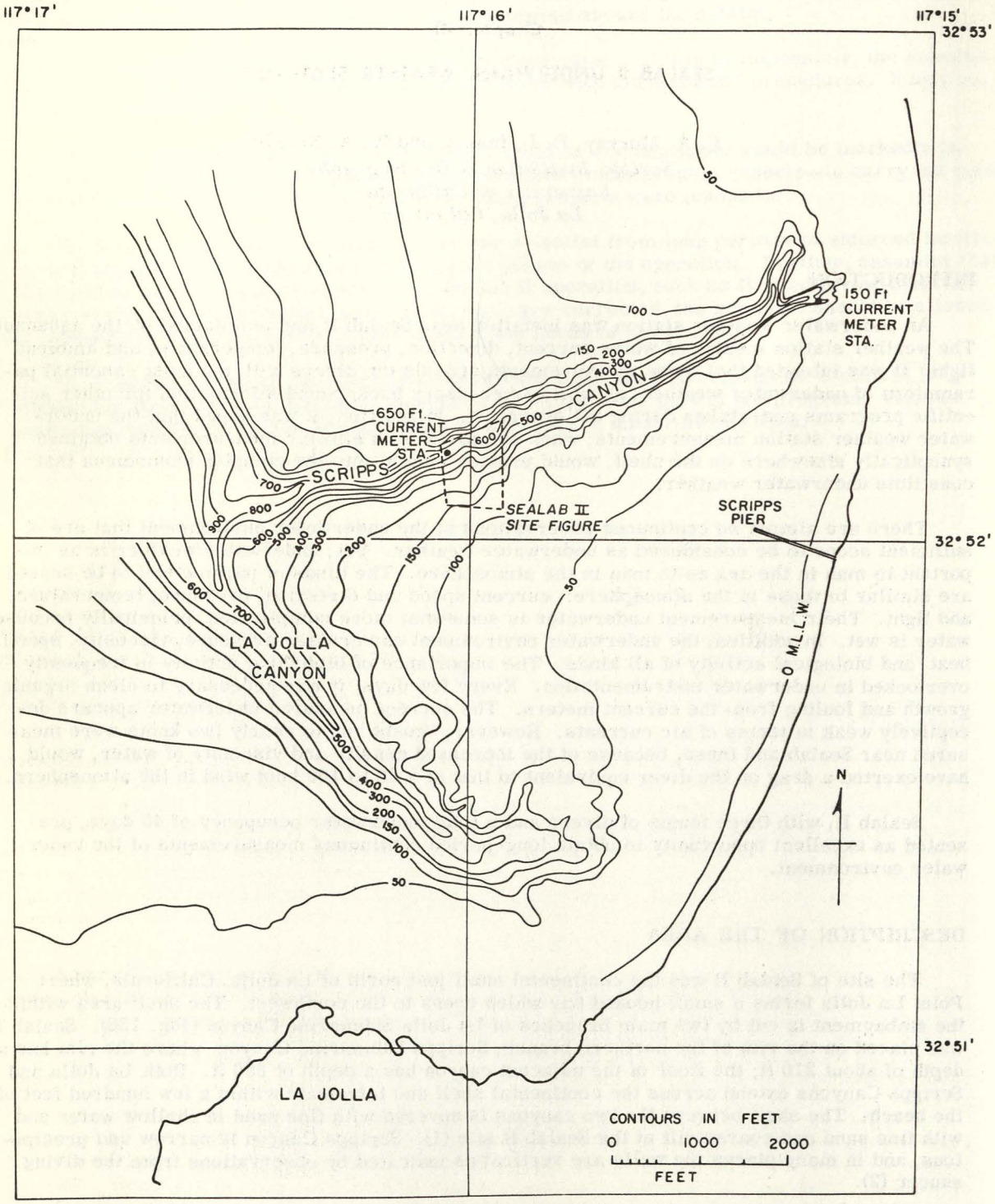

Fig. 136. Index chart showing bathymetry of the Continental Shelf off La Jolla, California. The Sealab II site is indicated by the dashed area, and its position and detailed bathymetry are shown in Fig. 138

the canyon is not understood, although the volume of material transported has been measured. Extensive surveys of the canyon head (3) indicate that about 200,000 cubic yards of sand is lost into the canyon each year. A series of current measurements have been made over periods of days and weeks at several stations within the canyon. One of these stations is within scuba diving depth at 150 ft at the head of the canyon (Fig. 136). Currents have also been measured on the canyon floor just below the Sealab site at a depth of 650 ft. These measurements were obtained by sending a self-contained instrument package down a taut-wire mooring to the canyon floor (Fig. 137). After a predetermined length of time weights are released, and the instrument package returns to the surface, where it is retrieved by scuba divers. The 650-ft station was not occupied during the Sealab measurements because of fouling by the mooring lines from the surface support vessel, Berkone. However, a taut-wire mooring at a depth of 215 ft just northwest of the Sealab II site was instrumented during the Sealab operation (Fig. 138). There data were compared with data from the underwater weather station which was at a similar depth on the rim northeast Sealab II.

INSTRUMENTATION

Data from all sensors except the two current meters at the bottom of the canyon were transmitted to a control center (called "benthic control") at the shoreward end of the pier, where it was recorded in both digital and analog form. Pier-end data were transmitted by direct cable, but data from the weather station were transmitted through a telemetry system which had its seaward terminal in an underwater benthic chamber. Six 2-conductor cables and three 4-conductor cables connected the instrument array on the weather station platform to an equipment rack inside Sealab. The equipment rack furnished power for the sensors and conditioned the signals from the sensors for transmission via the telemetry system. It was essential that the variable-resistance sensors receive a constant excitation current. It would have been impractical to furnish an individually regulated constant-current supply for each sensor, so a single 300-volt constant-voltage supply was installed. Individual 300,000-ohm resisters connected to the 300-volt supply furnished an excitation current of one millampere for each sensor. Since the resistors were mounted in Sealab, the amperage available in the water was very low. A 12-volt power supply, also mounted in the equipment rack, furnished regulated, constant-voltage power at about 3/4 ampere for electronics packages incorporated in the current members and the Vibrotron pressure sensor and for signal power amplifiers in the equipment rack.

An analog-to-digital converter inside Sealab changed the signals from variable-resistance sensors to digital form to be transmitted via the telemetry system. Signals from the current meters and the Vibrotron needed no transformation. All sensors except the Vibrotron could be monitored inside Sealab with Rustrak chart recorders. Digital channels of 12 bits each were sampled every 6 or 12 seconds by the analog-to-digital converter. Some of the more important data channels, including the current and pressure sensors, were connected directly to the telemetry system and could be sampled as often as desired (within limits imposed by the nature of the signals). However, analog signals from the variable-resistance sensors could be telemetered with any great accuracy due to drift in the telemetry channels.

All signals were connected from Sealab to the underwater benthic telemetry chamber via a multiconductor cable. From here they were transmitted to the shore station via an amplitude-modulated, multichannel carrier telemetry system on a single coaxial cable.

Savonius Current Meter

Accurate measurement and recording of low-period, low-velocity undersea currents prompted a modification of the reliable and time-tested Savonius rotor (Fig. 139). A miniature model, designed by Mr. J. M. Snodgrass of the Scripps Institution of Oceanography, was constructed of "Cycolac" plastic sheet and balanced to be neutrally buoyant in sea water. The rotor was mounted on bearings of sapphire and tungsten carbide. Sixty equally spaced holes near the periphery of one rotor end plate interrupted a light beam as the rotor turned, producing 120 electrical pulses for each revolution. One pulse was generated as the beam passed through each hole, and another pulse was generated as the beam was interrupted. This pulsing output signal has proven to be most reliable in transmitting data over long telemetry channels because its information is relatively immune to amplitude modulation caused by normal noise pickup during transmission.

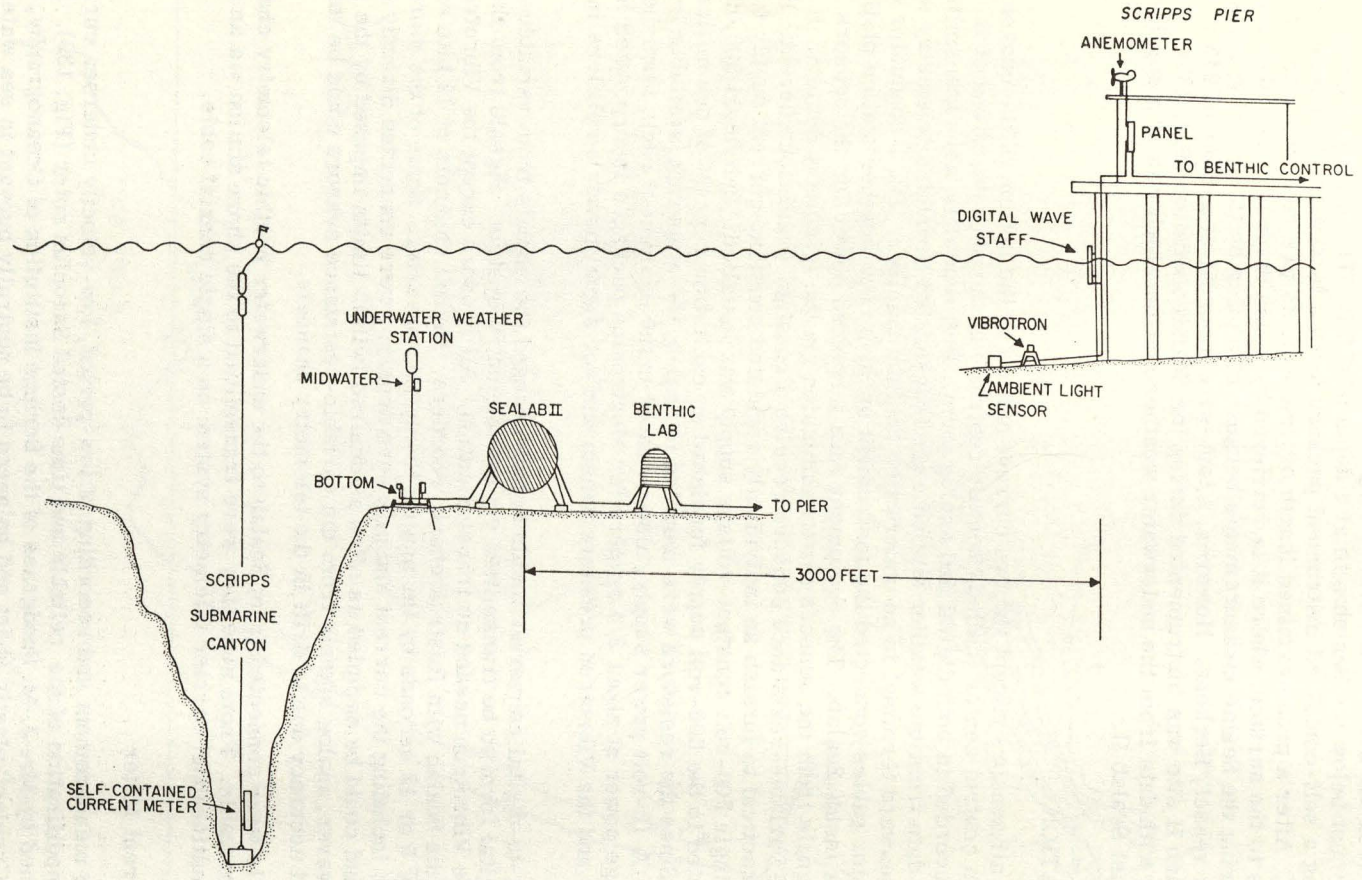

Fig. 137. Schematic Diagram of Sealab II Underwater Weather Station and location of other instruments

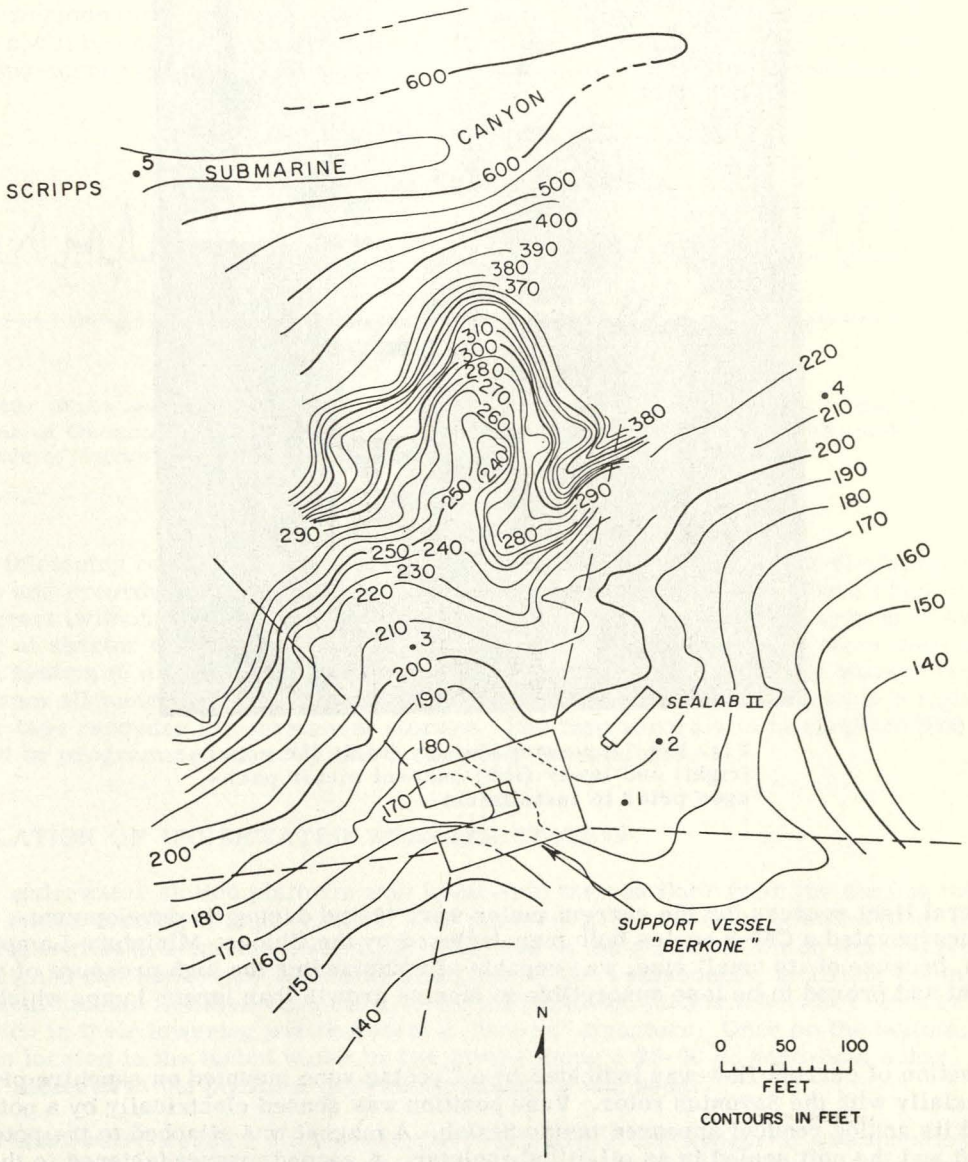

Fig. 138. Detailed Bathymetry in the Vicinity of Sealab II. Numbers show the locations of: (1) Benthic lab, (2) power beehive, (3) underwater weather station, (4) taut-wire mooring on canyon rim, and (5) taut-wire mooring on canyon floor.

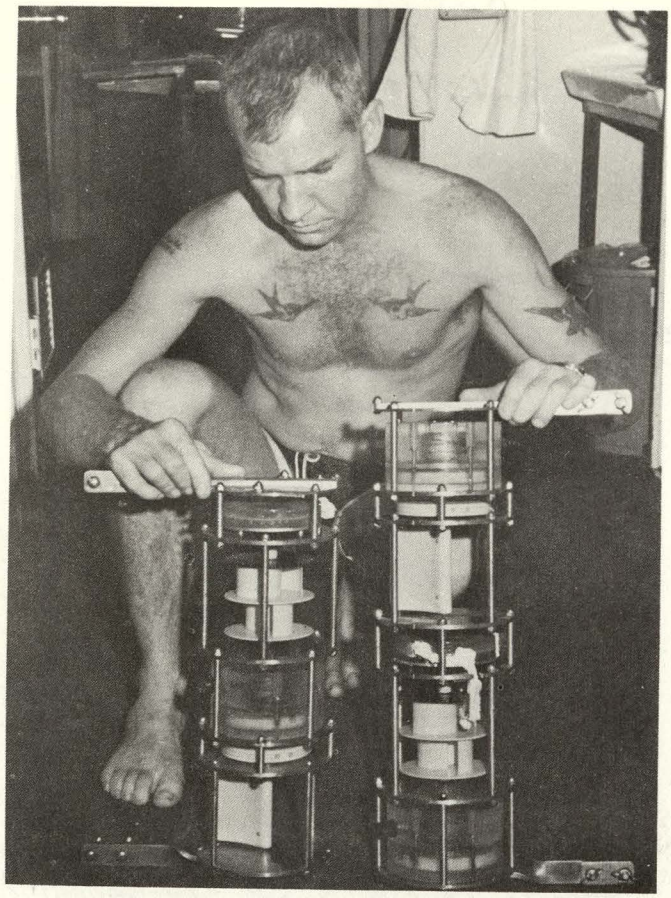

Fig. 139. Aquanaut Murray holds the upper (right) and lower (left) current meter packages prior to installation

Several light sources for the current meter were tested during its development. The final design incorporated a CM-8 series bulb manufactured by the Chicago Miniature Lamp Works. The bulb, because of its small size, was capable of withstanding the high pressure of the environment and proved to be less susceptible to marine growth than larger lamps which were tested.

Direction of current flow was indicated by a Cycolac vane mounted on sapphire pivots and housed axially with the Savonius rotor. Vane position was sensed electrically by a potentiometer, and its analog readout appeared inside Sealab. A magnet was attached to the potentiometer shaft and the unit sealed in an oil-filled canister. A second magnet fastened to the edge of the vane provided magnetic coupling of vane rotation with potentiometer rotation. The oil damping reduced overswing of the potentiometer during fast transitions.

Vibrotron Pressure Sensor

The Vibrotron is a vibrating-wire transducer which converts absolute pressure input to an output signal with a frequency inversely proportional to the applied pressure. It was chosen for use at the sea-floor weather station because of its ability to resolve small changes in absolute pressure while in a very-high-pressure environment. Excitation and signal amplification electronic circuitry was modularized and housed with the transducer in an oil-filled canister. The audio output signal was telemetered directly to the data acquisition system on shore where the frequency variations were digitized and recorded on magnetic tape along with the other measured parameters.

Data Acquisition System

A system of analog and digital recorders, along with necessary amplifiers, digitizers, and logic control units, was located in the benthic control center near the telemetry receiving terminal equipment. A 12-channel chart recorder monitored analog readouts from the underwater weather station and from the pier end anemometer. A separate chart recorder monitored an analog conversion of the output of the pier end digital wave staff. The chart speed of the latter recorder could be changed as desired to obtain short records of wave profile (Fig. 140), as well as long-term records of lower frequency phenomena such as tides and shelf seiche.

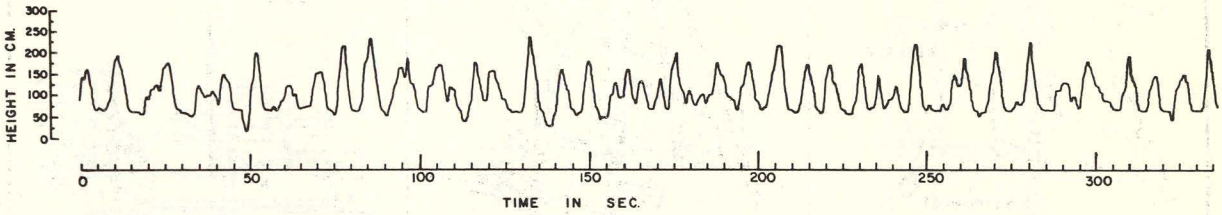

Fig. 140. Wave record from the digital wave staff mounted on the end of the Scripps Institution of Oceanography Pier. Record begins at 1200 PST, Oct. 6, 1965, and is representative of waves contributing to the spectrum in Fig. 144.

The telemetry receiving equipment monitored the output of the analog-to-digital converter in Sealab and recorded the information incrementally on magnetic tape. Data which were telemetered direct (without conversion) were channeled into a data-acquisition system (DAS) for sampling at shorter time intervals. Plug-in, printed-circuit logic boards were used in the acquisition system to digitize the sampled data, to store in memory banks in binary form information from all input channels, and to present the information in increments to a high-speed magnetic tape recorder for permanent storage. The tape record was in standard IBM format and could be programmed directly into a computer for analysis.

INSTALLATION OF UNDERWATER WEATHER STATION

The underwater station platform was lowered to the sea floor from the staging vessel Berkone on the evening of Sept. 4, 1965. The platform in its lowering position (Fig. 141) consisted of a central 1/2-in.-thick steel plate, 32 × 32 in. on a side, to which were welded four leg guides and two instrument mounting brackets. Other components, including the taut wire and its float and the flotation equipment, were lashed to the platform between the four anchor legs, which in their lowering position form a "teepee" structure. Once on the bottom, the platform was located in the turbid water by two divers using a 25-40 kc hand-held sonar. A 37-kc "pinger" attached to the platform provided a target for the sonar.

The underwater weather station was diver-oriented in its design. It was intended that it be easily moved by two divers after inflating four rubber tubes to give it neutral buoyancy. The tubes were inflated by bleeding air from a scuba bottle into holes cut in the tubes near their point of attachment. This arrangement provided the necessary safety control to prevent overinflation and excess positive buoyancy. The air in the tubes could be spilled instantly by squeezing the tube. After inflating the tubes, the platform was transported 165 ft to the installation site by two divers. The site (Fig. 138, position 3), which had been determined previously during reconnaissance dives, was on a slight rise where currents would be more typical of the area than in the valley at the Sealab site. The platform was firmly anchored in place by four anchor pounded legs into the bottom. The taut-wire mooring was then released from the platform and assumed its vertical position, maintained in a taut position by the 75-pound positive buoyancy of the float. At the end of the 45-day Sealab project, all of the underwater weather station sensors were attached to the taut-wire mooring, which was then released from the platform and retrieved on the surface.

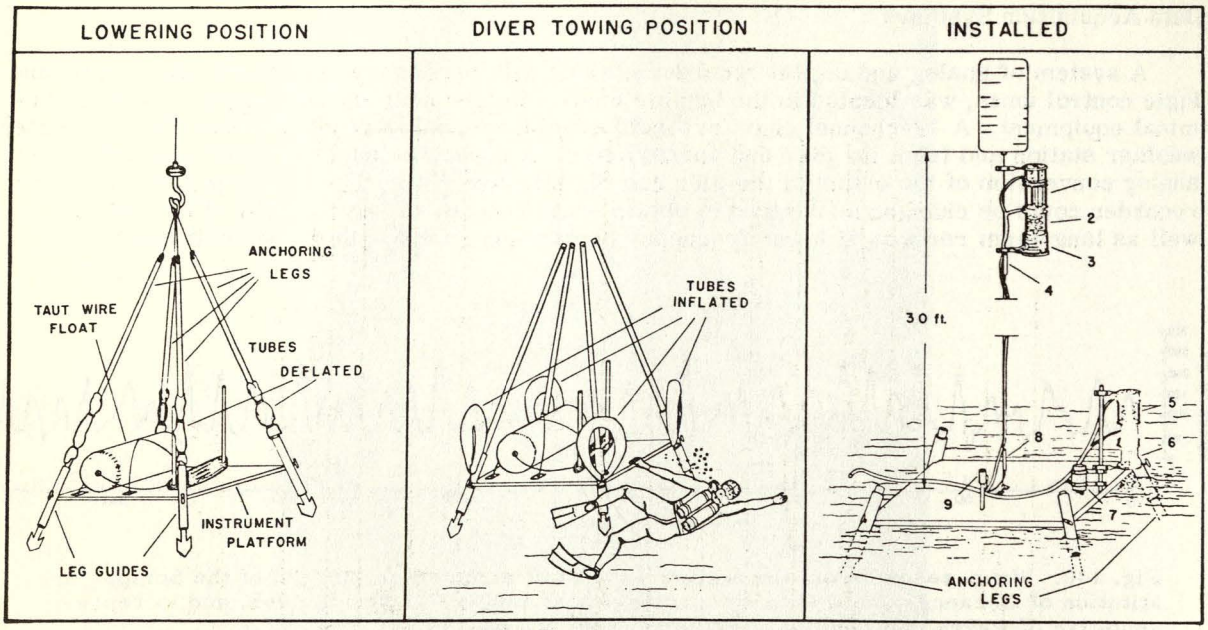

Fig. 141. Schematic diagram of the Sealab II Underwater Weather Station in lowering position, diver-towing position, and installed position. Numbers indicate sensors: (1) upper current speed, Savonius rotor, (3) compass, (4) upper thermistor, (5) lower current speed, Savonius rotor, (6) lower current direction vane, (7) pressure sensor, Vibrotron, (8) lower thermistor, (9) ambient light

Two days were required to install sensors on both the upper and lower weather station. Conductors were run to the station, and underwater weather was recorded in the habitat. Two trips were made daily to service instruments and check sensors. Recorders inside the habitat were checked, and comparisons with observed weather conditions from the 24-inch ports were made.

RESULTS

Data were recorded in analog form in Sealab II and in benthic control center. Also, all data transmitted over the benthic lab cables were routinely sampled, digitized, and then stored on the telemetry system's magnetic tape recorder. Unfortunately, an erratic fluctuation of the time-identification channel made much of this magnetic tape data unintelligible.

The routine analog recording through the long lines of benthic lab had high levels of background noise, as well as long-period, quasi-systematic fluctuations that partially obscured the data signals. Therefore, it was not practical to make a systematic reduction of all of the analog data. Rather, the approach was to (a) analyze those records that presented synoptic information from a number of stations, such as the underwater weather station, the 150-ft station, and the pier end (Figs. 142 and 143) and (b) make detailed analysis during times of unusual phenomena, such as high waves (Figs. 140 and 144). Detailed analysis was facilitated by the use of a high-speed data acquisition system, DAS, which stored data of finite length for future spectral and cross-spectral analysis.

Presentation of Data

Seven days of synoptic measurements of currents at the Sealab II underwater weather station and at the 150 ft deep station in the head of Scripps Submarine Canyon were made (Sept. 22-26 and Sept. 29-Oct. 1, 1965). Comparison of currents from both localities during two days when the currents were most active are shown in Figs. 142 and 144, together with measurements of tide and wind from the Scripps Pier.

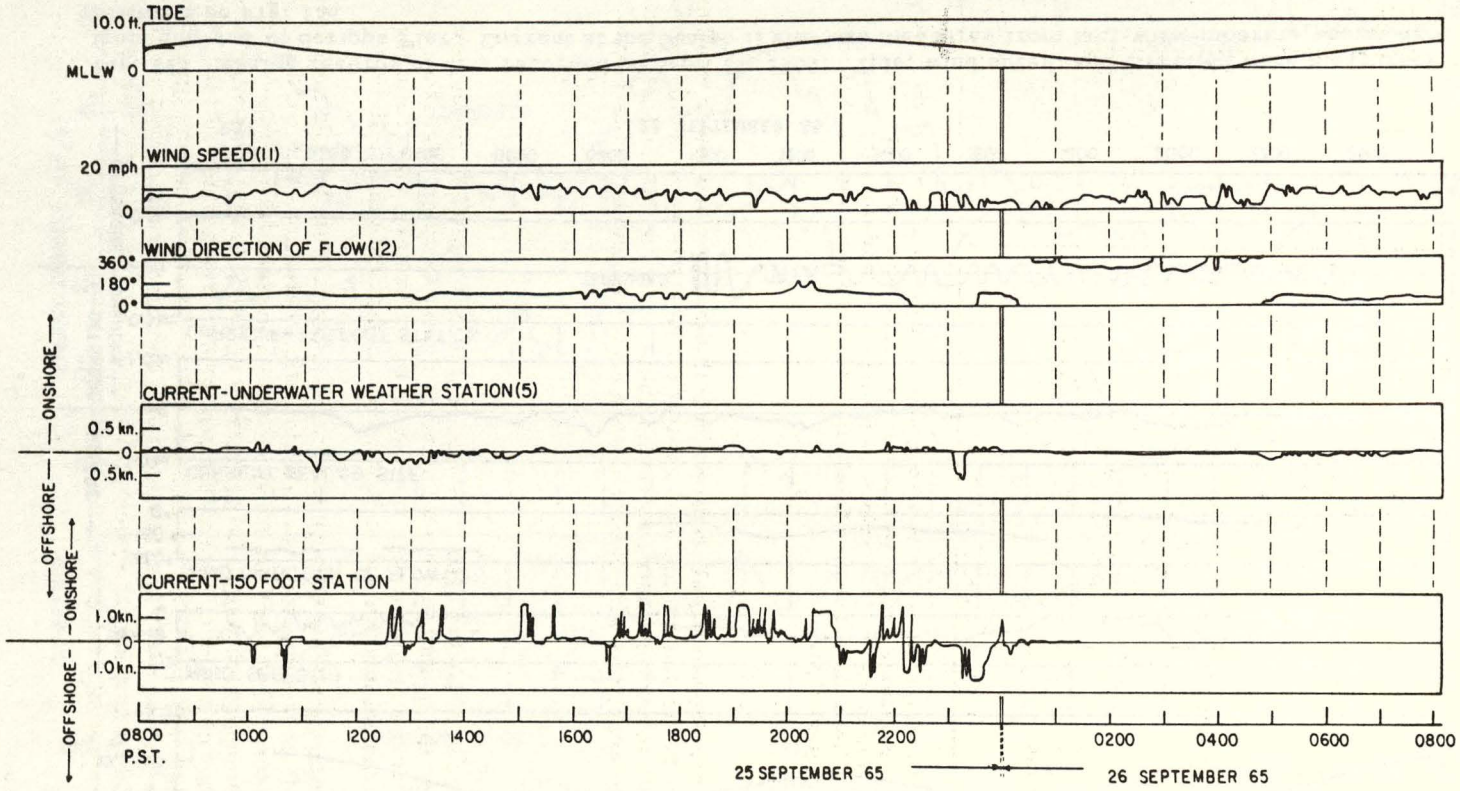

Fig. 142. Analog records of data recorded on Sept. 25 and 26, 1965. Tide, wind speed, and direction were measured from the end of Scripps Pier. Underwater weather station current is from the lower instrument package, sensors 5 and 6

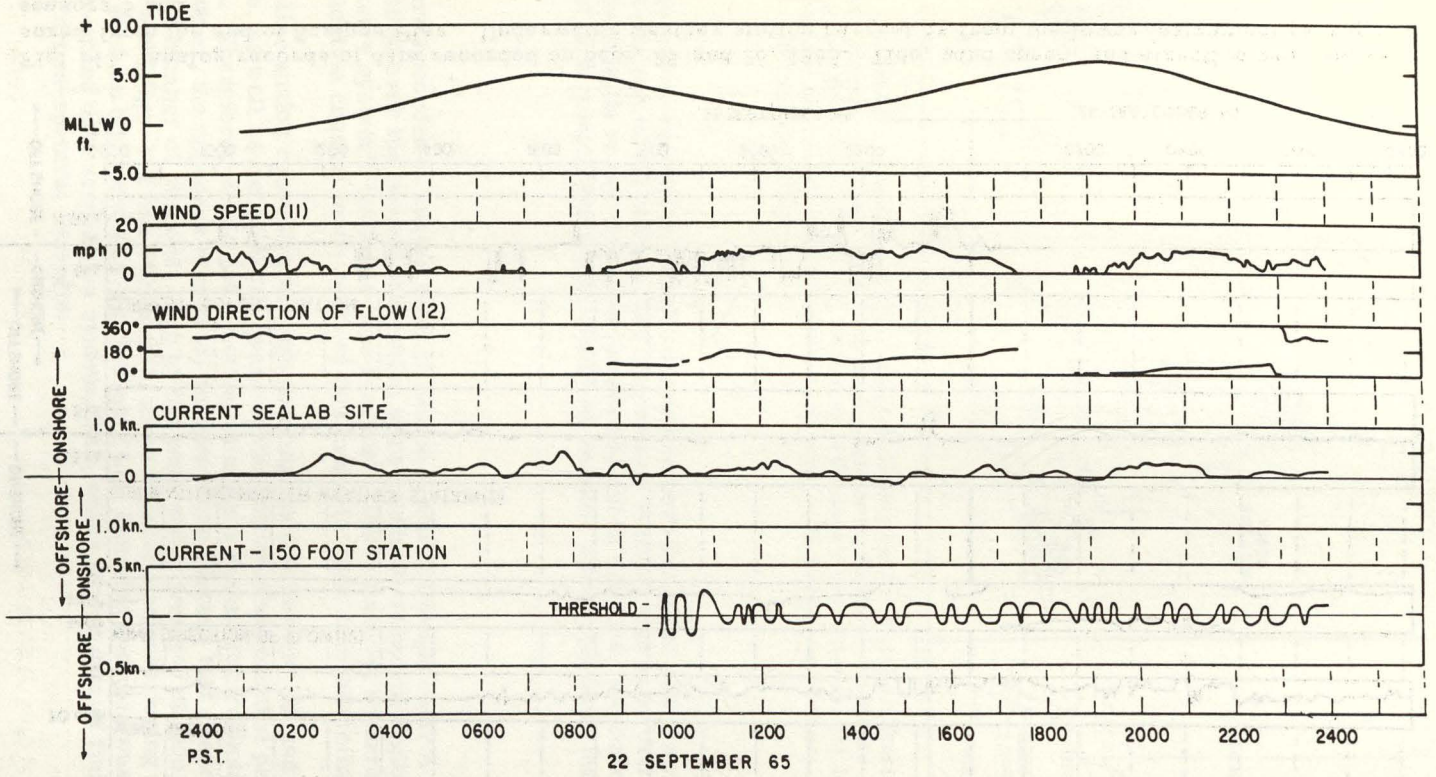

Fig. 143. Analog records of data recorded on Sept. 22, 1965. Tide, wind speed, and direction were measured from the end of Scripps Pier. Current at the Sealab II site was measured from taut-wire mooring shown as station 5 on Fig. 138

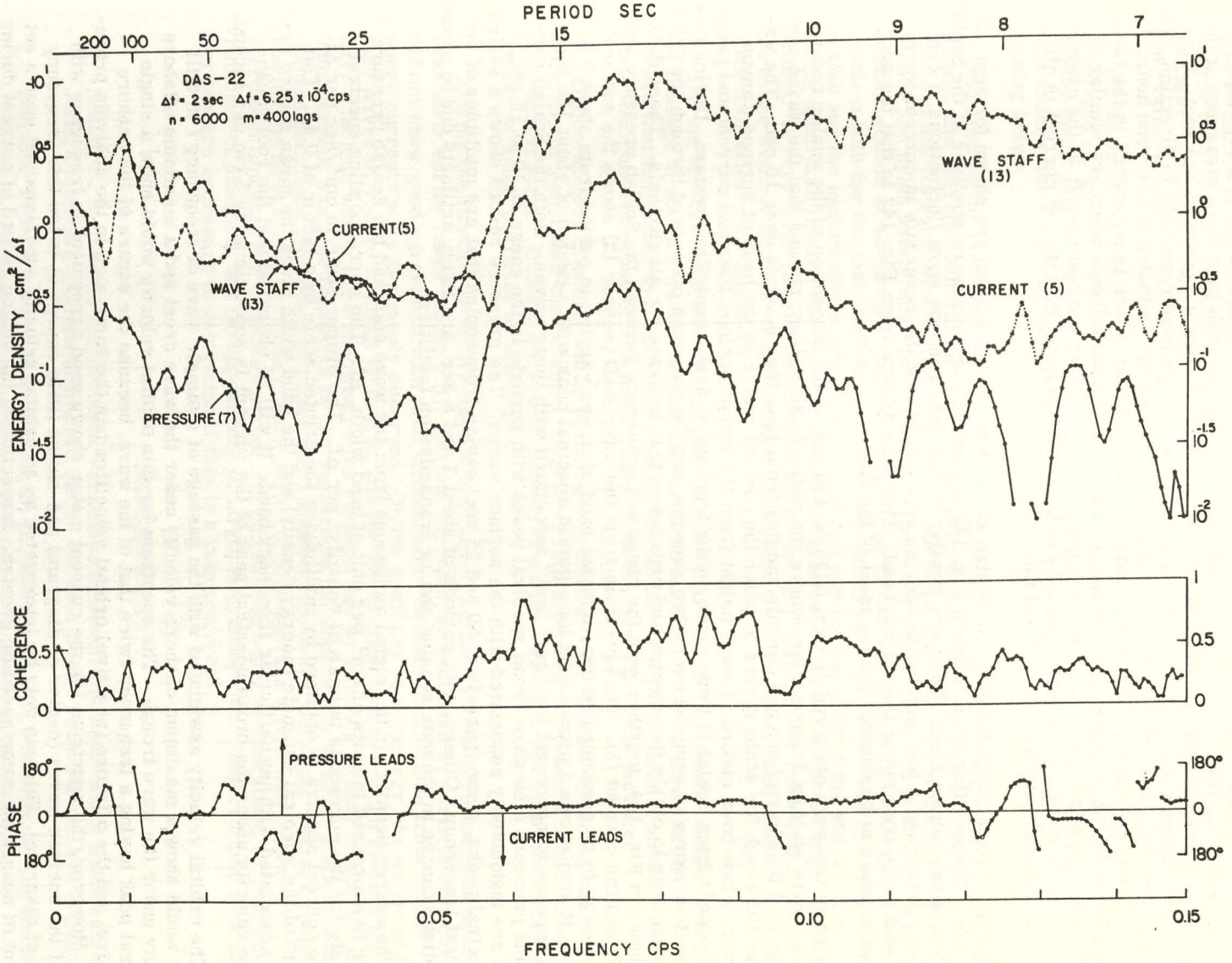

Fig. 144. Power spectra for Sealab II wave staff (13), current meter (5), and pressure sensor (7) for 1130-1330 PST, Oct. 6, 1965. Lower graphs give coherence and phase between sensors 5 and 7

Currents at both stations showed a marked tendency for flow directions to parallel the axis of Scripps Submarine Canyon rather than to cross the axis. This permitted the currents to be plotted as two-dimensional currents using the notations "onshore" and "offshore," where these notations indicate flows in the directions of 060° True and 240° True respectively. On Sept. 25, 1965 (Fig. 142), maximum currents in excess of one-half knot were measured at the underwater weather station, while those in the canyon head were in excess of one knot. Currents at both stations were irregular in speed and showed frequent reversals in direction. The fluctuations at both stations had periods ranging from about five minutes to over one hour. It is impossible to determine from these analog records whether there is coherence in the fluctuations between two stations. It does appear that the fluctuation frequencies are similar at the two stations, and it is obvious in this case that the stronger currents occur at the canyon head. There is some indication, especially at the Sealab station, that the net current is offshore ebb tide and onshore during flood tide.

Similar comparisons between the Sealab site and the 150-ft station are shown for Sept. 22 (Fig. 143). These differ from those in Fig. 142 in that the currents were stronger at the Sealab site than at the canyon head. They are similar in that both records show fluctuations of current with periods of a few minutes to over an hour and in that the reversals in current were somewhat more frequent at the canyon head. This data differs from Fig. 142 in that the net current appears to be onshore during most of the day.

High waves were observed on Oct. 6 (Figs. 140 and 144). Inspection of the analog record from the wave staff on Scripps Pier, where the water is 20 ft deep, showed that the waves were as high as 6 ft (200 cm) and had periods ranging from less than 8 sec to over 16 sec. The water was too rough for scuba divers to place the current meter in the head of Scripps Canyon. However, a two-hour record of wave height from the end of Scripps Pier and current and pressure records from Sealab II were made on the high-speed data-acquisition system. During this run, each sensor was sampled every two seconds, and the data was processed through the CDC-3600 computer to obtain the spectra and cross-spectral analysis for all channels. These data are shown in Fig. 144, together with the phase and coherence between the Sealab pressure sensor (7) and the current (5). The spectrum from the wave staff (sensor 13) shows the surface wave energy to be concentrated over a broad band of waves varying in period from about 8 to 16 sec. It also shows a pronounced long-period spectral peak with a period of about 105 sec which appears to represent the "surf beat" associated with these waves. Both the Sealab current and pressure also show broad spectral peaks with periods in the range of 10 to 16 sec, which are undoubtedly associated with the surface waves. The pressure record shows a series of spectral peaks, some (periods of 50 and 25 sec) having frequencies that are multiples of the surf beat frequency. Others, with periods of about 7 and 8 sec, are likely artifacts due to parasitic disturbances in the data sensing and/or transmission facilities.

The energy density for the signal variations from the wave staff and the Sealab pressure sensor is expressed in units of cm^2 per unit of band width, Δf. The corresponding spectral estimate for the current is in units of velocity^2 per Δf. The proper scale in cm^2/sec per Δf for the current spectra is obtained by multiplying the printed scale by a factor of 0.41. The product of the spectral estimate (energy density) and the band width gives the mean square velocity associated with any particular frequency band. It will be observed that the root-mean-square velocity under the broad spectral peak of the current is approximately 5 cm per second.

The orbital velocity associated with the passage of a simple wave of frequency f in still water would show a maximum onshore velocity under the wave crest and a maximum offshore velocity under the wave trough. The spectrum for this orbital velocity would show a single spectral peak having a frequency twice that of the wave, because the square of the onshore (positive) and the offshore (negative) orbital velocities has the same sign in the analysis procedure. However, the spectrum for the current meter shows good agreement in frequency with that of the surface waves (center of diagram) and shows little energy at twice this frequency (right of diagram). This can only be interpreted as an orbital velocity superimposed upon a net current of nearly the same speed or greater. Inspection of the analog record of current during this period shows that the current had a speed varying between zero and one-quarter knot, and the direction of flow was southwesterly or offshore.

Diver Observations

Observations by divers were made in the vicinity of Sealab and from within Sealab through three of the 24-in. portholes. The first two days' observations were made outside the habitat because the porthole protective covers were in place; but once removed, the forward port, the laboratory space port, and the starboard portholes were chosen for routine observations. The underwater weather station was not set up, and operational until the seventh day of occupation.

On the first two days of occupation a swimmer survey of the lab site was made with Mk-VI mixed-gas equipment. The two relatively higher ridges of sand that extended from the port quarter and starboard bow were explored. Divers carried a safety line attached to Sealab and used underwater sonar that was tuned to a "pinger" frequency previously placed on the Sealab conning tower.

An area on the port quarter 165 ft from Sealab was selected for the underwater weather station, and current observations were made here during each inspection. The weather station platform and its equipment were placed on a sand slope near the rim of the submarine canyon. Anchor and nylon safety line were mainted between the Sealab shark cage and the underwater weather station at all times. Sediment stirred up by the divers during inspection dives was a problem both for the instruments as well as for safety and visibility. The distance between Sealab and the underwater weather station (165 ft) and the capacity of the MK-VI mixed-gas diving apparatus limited the time outside to 70 minutes, or about two round trips to the weather station. A very large part of installation time was spent placing the cables that led from Sealab to the weather station. Once sensors and cables were in place, daily routine cleaning and inspection trips were initiated.

During the first four days it was possible to "hear" or feel pressure changes caused by the passage of surface waves. Simultaneous observations on the surface and in the habitat showed that occupants were able to sense on the surface and in the habitat showed that occupants were able to sense crests and troughs of waves passing on the surface.

Observation of fish that set up permanent occupancy near Sealab portholes showed they definitely oriented with the current. Migratory fish appeared independent of the direction of current and surge. Usually the orbital motion of surface waves is not apparent from the trajectory of small particles at this depth.

During the first three to five days of occupancy, surface waves were low, and tides were near their spring range (about 5 ft). Bottom currents, as indicated by particle trajectories, did not show good agreement with tidal fluctuations. Erratic fluctuations from onshore to offshore currents were commonly observed. On the sixth day of occupancy, the height of the surface waves increased to about 60 to 8 ft, and the waves continued to be high through the tenth day. The high waves were followed on the eleventh day by a strong, steady offshore current. This current was also measured by the sensors on the underwater weather station, which showed maximum velocities of 1 knot and 2 knots on the lower and upper sensors respectively. During the first teams occupancy, each period of high surface waves was followed by: (a) an increased tendency for offshore current, (b) increase in water temperature, (c) increase in numbers of plankton, and (d) appearance of large, migratory fish. Observations over longer periods are necessary to determine if this is a common trend.

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DIVER LOG, AUG. 28, 1965 TO SEPT. 11, 1965

1st Day

No current observed on the bottom. Visibility 30 ft (porthole covers still on; all observations today by divers). Two-in. nylon mooring lines sway slightly with the surge, estimate 1-ft swing. No ripple marks in the silt and sand bottom sediments. Temperature outside about 46°F.

2nd Day

Removed four starboard porthole covers. Visibility 30 ft. Current observations by diver—onshore very slight. Observations through Sealab porthole—trajectory of plankton past glass port is onshore and up. Trajectory interrupted by a pause about every 6 sec, during which plankton "sinks" down, followed by a repetition of the onshore and up motion. Net drift onshore and up at the rate of 1 ft per 15 sec. This condition prevailed all day. However, sometimes in the late p.m., the direction reversed and plankton moved offshore and down.

3rd Day

No observations this date from inside Sealab. Observations outside show very slight drift of plankton in a downslope and southwest direction most of the day, stronger by dark.

4th Day

Net drift of current onshore and up. Plankton moves 24 in. in 15-1/2 sec in the a.m. Current decreased in velocity by noon, increased steadily in p.m. to offshore, 24 in. in 10 sec by dark. Current increased near sunset and was strongest at 1800. Current velocity changed very quickly after dark to a very slight offshore and down movement. There is still no distinct off and onshore surge as is commonly associated with the passage of surface waves. However, about 1800, I could "hear" or distinguish the pressure fluctuations associated with the passage of surface waves. This was verified by topside watch officer. This p.m. was the last time I was able to "hear" the pressure change of surface swell. This is probably because of bad hearing caused by humidity and ear infection (?) or low waves.

5th Day

In the a.m. net current drift was offshore, very mixed and erratic, from high waves on the surface last night (?). Plankton move offshore and sink most of the time. Same condition prevailed all day, current strongest at dark or about 1800. One observation at 2200 shows slight offshore current, plankton sinking down. Low waves, no surge, just steady offshore. Visibility was very good today, and there was no indication of high waves.

6th Day

Wind chop on surface following 8-10 ft swell reported at surface. 0800—no current; 0900—slight current flowing to the north and onshore about 0.1 knot; 1000—current increasing, surge has on and offshore orbital motion, net drift onshore, orbital diameter 4-6 in.; 1030—current increased, net displacement of 4 in. onshore during each cycle of the orbit; 1045—steady onshore or northern drift broken by irregular periods of 10-12 sec of offshore surge. Net is onshore about 15 in. in 15 sec. All offshore motion is erratic. Note: Fish (scorpion or Scorpina Gattata) orient into the current, as a rule, unless feeding or moving which is about two to four times a day. Other small fish, 1/2 cm-1 cm long, and some large migratory fish have no obvious orientation preference so far as current direction is concerned. 1057—slight onshore net drift.

Set five plastic bottom drift indicators outside. In 20 minutes they had drifted downslope 10 ft. Net drift of sediment is also downslope. A steady current, enough to clean off large objects on the bottom, is evident. A 35-pound Danforth anchor on the sand slope has been exposed for two days. Water temperature is 13.5°C, well mixed down to 230-ft depth.

1600—Very steady up and onshore current. Plankton moves 24 in. in 12-15 sec: 1730—current changed to offshore, 24 in. in 13 sec; 1800—current is onshore, changed direction very quickly.

Visibility reduced considerably today following wind waves. Heavy red tide this p.m. Sundown at 1900. Visibility 2 ft with hand-held light.

7th Day

Mixed current—short on and offshore surge. Plankton moves 24 in. in 20 sec. Heavy red tide last evening, came down fast from seaward. Heavy watch day. Very slight onshore current all day. Red tide sinking to sea floor.

8th Day

Little current detected from ports. Fine plankton in early morning drifting down and slightly offshore—visibility bad. By mid-morning, water became very clear, the clearest water we have observed, 30 ft visibility with natural light. Worked locating underwater weather station. Anchored weather station platform.

1800—visibility bad again, more red tide. Visibility changed quickly. Plankton moves 24 in. in 21 sec with offshore net drift. Continuous offshore flow with slight fluctuation in velocity. 1800—dark.

9th Day

Dense red tide. Fish fill the ports, making current observations difficult. Slight offshore and down net drift. Clouds of sediment rise 5 ft above the bottom from divers working on the weather station. Drift is slow to clear sediment from the area. Set underwater weather platform today.

10th Day

Temperature 13.5°C, warm. Visibility bad. Slight offshore current, plankton sink slowly. Trajectory is 8 sec down, 8 sec off, 8 sec down, etc. Net offshore, 8-9 in. in 16 sec. Steady temperature increase for three days, 46-48-50-55°F.

1100—short periods of up and offshore current. Net transport offshore and down, 2 ft in 15 sec. Mid-afternoon to dark—trajectory of plankton shows the following periodicity in cycle: (a) horizontal offshore movement for 8 sec, followed by (b) up movement for 8 sec, etc. The net drift is offshore and up.

11th Day

Upper direction vane (1) and Savonius rotor (2) on weather station in operation. Rustrak recorders in Sealab are recording. Recorded current of 0.8 knot. During diver inspection, sensor 2 turning one revolution in 2 sec and direction vane indicated current flow offshore. Sensor 5 turning one revolution in 4 sec. Analog record of sensor 2 indicates 0.1 knot steady during day, increased at 1700 to full scale (almost 2 knots) on the upper current sensor (2) and to 1 knot on the lower current sensor (5). Current direction offshore.

12th Day

Lower weather station out of order in a.m. Upper weather station appears o.k. Installed thermistors—upper temperature 53°F (11.5°C), lower temperature 51°F (10.05°C).

Sensors 1 and 2 indicate 0.5 knot offshore current; observations from Sealab port indicate 24 in. in 25 sec offshore. Decreased to "0" current by 1200. Plankton sinking down steadily. 1700—observed very slight offshore and down current. 1800—same observation, 24 in. in 30 sec. Temperature at 1600 was 55°F (12.2°C) with thermometer hand held outside. Thermistor records 51°F (10.05°C) on line 36 of Rustrak recorder.

13th Day

Temperature 50-51°F (thermistor o.k. with hand-held calibration). Visibility poor due to plankton. Current—0.2 to 0.6 knot on sensor 5. Direction vane shows offshore flow most of day. Current observations from Sealab port:

0800 offshore and down	
1030 offshore and down	24 in. in 40 sec
1100 offshore and down	24 in. in 60 sec
1200 sinking down very slowly	
1600 current changed to up	24 in. in 30 sec

14th Day

Visibility poor in early a.m. Current upwelling—up and offshore 6 in. in 20 sec. 1100—sensor 5 indicated 0.35 knot steady. Sensor 2 (upper) off scale on high side. Current direction southwest to south southwest. 1145—Sensor 5 reads 0.3 knot, sensor 2 reads off scale on high side. Current direction southwest. Flying fish came in with upwelling? Sediment covers rotors in three-day period. Mica and light material deposit on flat surfaces. Thirty-five pound anchor covered by sediment. One-quarter in. sediment fill on underwater weather station platform in three days. Sensor 5 is dirty; sensor 2 is clean and runs faster than 5 on all observations.

15th Day

Visibility very poor, no light. Many fish at the ports. Current is offshore and up, no surge. Very slight current. Good weather topside for transfer of personnel.

* * *

Diver observations and their comparison with the underwater weather station recordings show a fluctuating irregular current pattern during periods of high waves. This is followed by a somewhat more uniform flow during periods of low waves.

Chapter 42

SEALAB II SALVAGE TESTS

W. F. Searle, Jr.
Naval Ship Systems Command Headquarters
Washington, D. C.

INTRODUCTION

In addition to making his West Coast salvage ship, USNS Gear (ARS-34), available to support the operation, the Supervisor of Salvage, U.S. Navy, sponsored a number of ship-salvage oriented projects in Sealab II. The general objectives of the several tasks were:

1. To demonstrate the feasibility of conducting long-term salvage operations from a bottom habitat.

2. To determine the capability of divers to accomplish strenuous salvage work during prolonged saturation dives.

3. To perform subjective in situ tests and field evaluations of several new or modified tools, systems, and techniques in 205 ft of water.

4. To determine the feasibility of scuba-equipped divers to use these tools in deep water, versus hard-hat equipped divers.

The general objectives were accomplished with considerable success. All assigned tasks were performed during Team 3's tenure on the bottom. Diver tasks in general were performed with dispatch and skill, and consistently in less time than had been programmed. It was clearly demonstrated that the saturated diver, as a man, could handle the tools employed and accomplish the tasks assigned. This is not, however, to say that the tools in each case were optimum. Nor can it be said that all diver-support systems were satisfactory. On the contrary, the lack of adequate diver-to-diver and diver-to-topside communications, and the inadequate body-heating systems hampered the divers in the accomplishment of their tasks. That they nonetheless were able to perform satisfactorily further emphasizes the feasibility of scuba-equipped saturated divers, operating from a bottom habitat, performing typical complicated, strenuous salvage tasks.

In the following sections each of the several salvage tasks and tools will be described.

FOAM-IN-SALVAGE (FIS)

The Foam-in-Salvage (FIS) tasks were included in order to test a new salvage technique. The use of cast-in-place, frothing foams had previously been employed in salvage only in shallow depths, no deeper than 30 ft. The FIS project in Sealab II was oriented toward demonstrating the use of this technique for imparting controlled or fixed buoyancy (as opposed to air bubbles, which migrate) to complicated structures underwater. An aircraft hulk was selected as the principal test bed. It is easy to think of this as a missile, a space capsule, or a submarine. The Sealab II tests were particularly important in the BuShips FIS program in that they permitted a realistic test of the system (Fig. 145) at depth and at low ambient temperatures. Laboratory tests at these depths and temperatures had not been especially realistic.

As stated, the principal test bed was an F-86 jet aircraft hulk which had been made available to the program by the Bureau of Naval Weapons. The wings and most machinery had been

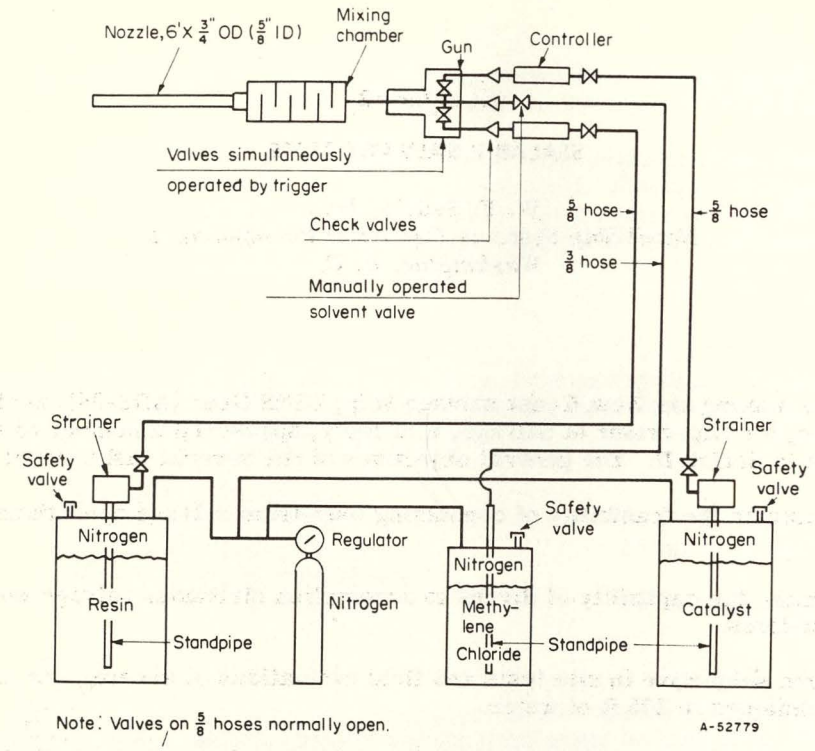


Fig. 145. Schematic diagram of Sealab II foam-in-place equipment

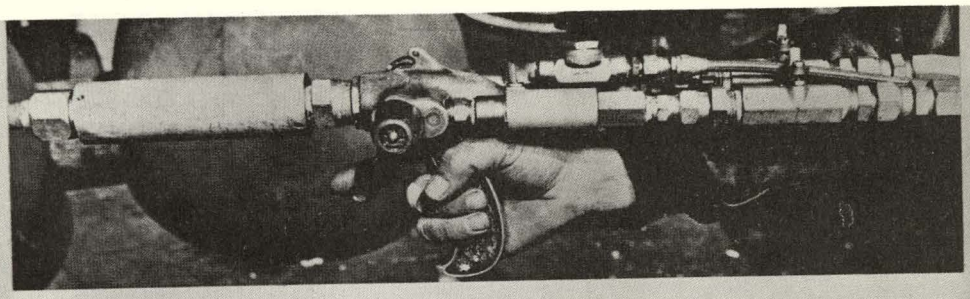
removed. The hulk was made heavy with cement ballast, and a series of holes was placed in the fuselage. A circle was painted around each hole to guide the diver. Each hole was marked with a "time-in-minutes to foam," based on the volume of the compartment and the expected foaming rate. The hole times varied from two minutes to 18 minutes.

In addition to the aircraft hulk, nine empty ordinary 55-gallon oil drums were prepared with cement anchors and placed on the bottom. The drums were to be foamed and raised, singly, over a period of several weeks, in order to study the amount and rate of water absorption (i.e., loss of buoyancy) by the foam.

The technical aspects of the FIS project are reported in detail in the final Foam-in-Salvage Report submitted by the Murphy-Pacific Marine Salvage Company, (Final Technical Report-Contract Nobs 4909 dated 7 May 1965), and will not be discussed here in detail. It will suffice to say that the chemical formulation of the foam used in the Sealab II Salvage Project was less than optimum. Additional testing and formulation was indicated and has, since Sealab II, been undertaken by Murphy-Pacific and BuShips.

Notwithstanding the less-than-optimum foam, it must be concluded that the Sealab II FIS project was quite successful in demonstrating the feasibility of such a salvage system. One of the key features of the project was the demonstration of a system which required a considerable degree of coordination between the divers on the bottom, handling the foam gun and applying the buoyancy, and the surface-support ship (Gear) with its source of bulk chemicals and mixing and hose delivery apparatus. The total lack of diver-to-surface communications was particularly difficult to cope with. An adequate diver-to-surface communication system would be an essential requirement in an FIS operation of any magnitude.

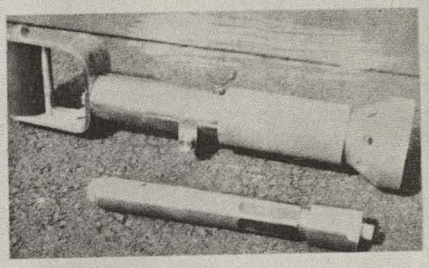
Sealab II divers experienced no difficulty in handling foam guns and hoses; nor was there any difficulty in inserting the gun barrel into the prepared holes in the aircraft hulk, or into the oil drums (Fig. 146). Gun application (triggering and flushing) presented no problem (Fig. 146). These evolutions were easily learned in one preliminary session before Team 3 was developed. The evolutions were easily executed until the diver became overtaken by cold.



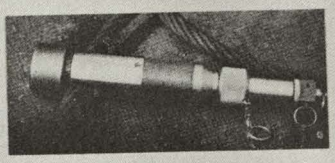
a. Foam in salvage (FIS) gun ready for foaming



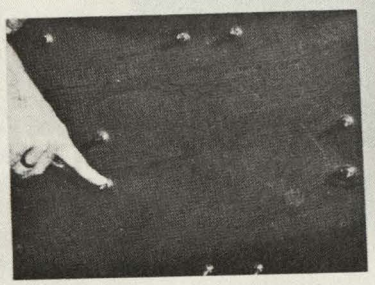
b. FIS gun ready to load foam in test barrel



d. Model D stud driver trigger fired, push-button barrel safety, spoil shield and will not fire at more than 8-degree angle



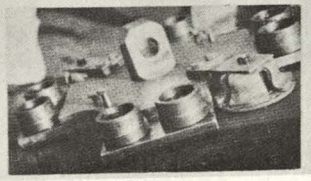
e. MSA wire cutter for 3/4-inch wire rope



c. Model D stud driver penetration through HY-80 plate



f. Ten-ton velocity-power lift pad



g. Ten-ton lift pad with two holding magnets

Fig. 146. Sealab II salvage tools

The aircraft hulk was foamed first. Two divers were employed in the foaming process (Fig. 147). The divers commenced foaming at the tail. They then foamed holes in the fuselage's side, and the hulk soon floated free, 10 ft off the bottom, tethered by wire-rope pendants to its cement-clump anchors. Once the hulk floated, the foaming was stopped, even though the quantity of foam delivered (time of application) was much less than had been calculated to be required. This early cessation of foam application proved to be an error which may be attributed to lack of communications and to cold divers, anxious to "go home" to Sealab.

The foamed aircraft hulk, after several hours, was inspected by surface divers and found to have settled to the bottom. It was, however, found to be "light and lively;" that, is, it was only slightly negatively buoyant. The next day, the aircraft hulk was "foamed" again by Sealab divers. The evolution was essentially the same as the previous day. Again, the hulk floated



Fig. 147. Aquanaut P. S. Wells uses the foam-in-salvage gun to foam an aircraft hulk near Sealab II

quickly and foaming was stopped. The total foaming time (raw materials used) was still short of that which had been calculated to be required to fill the aircraft.

The hulk was scheduled to be raised on the following day, anchors and all. When surface divers inspected it they found the hulk again on the bottom, again "light and lively." Gear's hoisting wire was attached to the hulk's lifting bridle, and the aircraft with anchor clumps attached was raised and placed on deck.

Upon inspection of the hulk, it was found that several holes had not been foamed. In particular, the aircraft's air-inlet cowl, in its nose, had been overlooked. This compartment was the largest single compartment in the hulk, and 18-minute hole. Evaluating the quantity of foam applied, and taking into account that the foam itself was of poor quality, it was concluded that each time the hulk floated it was "just" buoyant, and that the amount of positive buoyancy imparted was but a small proportion of total weight of either the hulk or the foam applied. Thus, a slight amount of total water absorption could cancel out the positive buoyancy. It may be concluded that when using FIS, the total foaming operation (as engineered and planned) must be carried out. So long as the total system—including the buoyant body and its tether and achors—is

negative, all planned buoyancy should be installed.* The tendency of divers to want to quit once the body has floated should be resisted. The Sealab II divers had not been so instructed. Possibly had the foam been of better quality, we would not have learned this rudimentary point so quickly.

The several oil drums were foamed successfully and without incident. All floated to their tethers. The fact that they did not sink again, like the aircraft, is indicative that they were "over-foamed." The small size of the drum required that the diver foam for only about a minute. It was almost impossible to "under-foam." Also the drums, being totally enclosed except on their bottom, presented very little wetting surface for water absorption.

It has been mentioned that the foam was of poor quality. As the foam chemicals were applied by triggering the gun, the exothermic reaction took place, but the freon gas, used as the frothing agent, was not effective. The partial pressure of the freon gas at the depth and temperature of application was too close to ambient depth pressure. The gas did not consistently froth. The foam was too dense and had poor shear characteristics. It appeared that the initial shot of each application did not foam at all, until the exothermic reaction got "heated up." This initial amount of unfrothed foam material quickly solidified as a ceramic-like mass. In at least one instance, it covered the divers' Mark VI breathing apparatus, and completely fouled their breathing bags and exhaust valves. The danger is obvious.

So far as the Sealab II FIS demonstration is concerned, the project is considered to have been quite successful. It was clearly demonstrated that divers, at a dept of 205 ft, could handle the foaming equipment. It was also demonstrated that a diver-topside evolution could be performed, even without communications. The salvage engineering lessons learned were particularly worthwhile. The foam itself was, without doubt, disappointing. In fact, the foam was an order of magnitude less satisfactory than had been obtained during preliminary deep tests held in San Francisco Bay.

VELOCITY POWER TOOLS

Velocity power tools which utilize the energy from an ammunition-type cartridge to drive threaded solid and hollow studs into and through steel plates have been used by divers since the late 1930's. However, because of several accidents during World War II and the unavailability of parts, these tools fell into disuse in the Navy. Prior to Sealab II, few active divers had any experience or appreciation for the utility of these tools. The purpose of the tests covered here was twofold: (a) to demonstrate the utility of the tools as applied to scuba divers in 200 ft of water, and (b) to demonstrate an attachment padeye concept which might be used in submarine salvage.

The single-stud driver (Fig. 146) was an improved experimental model developed by the Mine Safety Appliance Company of Pittsburgh, Pennsylvania, under contract to the Naval Ordnance Laboratory, White Oak, Maryland. The wire-rope cable cutter (Fig. 146) was an older and proven design. The improvements in the single-stud driver in general provided for penetration into various thicknesses of HY-80 steel plate. Other improvements enhanced diver operability and safety by better containment of the explosive gas energy. This last improvement reduced the shock on divers to negligible proportions. However, the single-stud driver still must be fired with the head of the diver held out of the line of sight, to prevent shock loading on the eardrums (Fig. 148). One aquanaut learned this in a painful trial shot, fired in a shallow pool prior to Sealab II. The eight-stud lifting pad array was the prototype of a new design, prepared under contract to NOL.

All tool performance was satisfactory, with the exception of the cable cutter. The latter was never successfully fired because of a defective "o" ring seal. The other prototype development models performed well with only three duds out of 15 shots attempted.

*The on-going BuShips/Murphy-Pacific contract addresses this engineering problem. The salvage engineer must know how much water absorption--both as to rate and quantity (lost buoyancy)--to allow for.



Fig. 148. Aquanaut Meeks fires explosive stud into simulated submarine hull near Sealab

The ten-ton lifting pad (Fig. 146) was successfully attached to a one-thick HY-80 steel curved mock-up of a submarine hull section (Fig. 149). Also, a flat, mild steel patch and gasket was bolted to the threaded studs driven into this mock-up with the single-shot tool (Fig. 146). The lifting pad was tested on site by the aquanauts using the 8.6-ton collapsible Sealdbin pontoon. Structural tests of the pad array were later conducted at Long Beach Naval Shipyard following Sealab II. The patch was also tested hydrostatically.

At the shipyard the padeye device was successfully loaded to 10 tons in all axes without any evidence of studs pulling free. The device was then tested to destruction. The array's plate failed where the padeye swivels. No studs failed. The flat plate patch tested satisfactory to 15 psi hydrostatic pressure without stud slippage.

From a subjective standpoint, all the tools were easily handled and performed to the general satisfaction of the divers.

The results of these tests lead to the conclusion that further development and eventual use of these tools by the salvage forces is warranted. This development should include further containment of shock from the single-stud driver and increased penetrating capability for our heavy submarine hulls. The shipyard tests on the padeye indicate need for redesign of the structural part of the device.*

*The Bureau of Ships, in support of the DSSP program, and with BuWeps concurrence, in support of the DSSP program, has assigned a task to NOL White Oak for the further development of these tools. On-going contracts have been let to MSA by NOL.

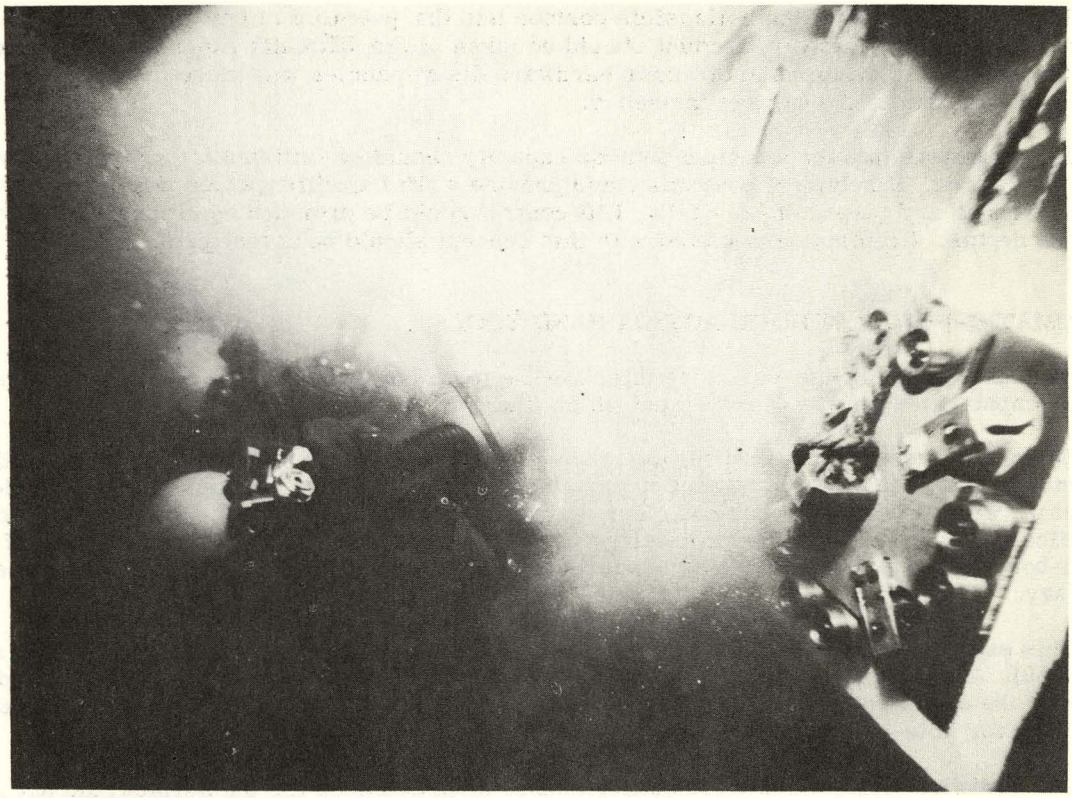


Fig. 149. Aquanaut Meeks fires explosive stud into patch on simulated submarine hull near Sealab II

COLLAPSIBLE SALVAGE PONTOON

The collapsible 10-ton* salvage pontoon is a modified version of U.S. Rubber Company's Sealdbin rubber container used to ship bulk quantities of liquid and granular materials. The off-the-shelf container, with minor modifications, makes an excellent salvage pontoon.

The purpose of these tests was (a) to evaluate the ability of divers to manhandle the collapsed pontoon and to manipulate pontoon hardware when submerged, (b) to test new quick-disconnect fittings for attaching the air hose, and (c) to demonstrate a venturi system of pontoon evacuation to obviate the need for having to pull the pontoon down or weight it down at the start of submergence.

The pontoon successfully lifted the submarine mock-up assembly; however, the divers had considerable difficulty in manhandling or maneuvering the pontoon on the bottom in a collapsed condition. The negative buoyancy in the collapsed (bottomed) state was approximately 250 lb. The pontoon presented a large, cumbersome, and nonpliable package. The quick-disconnect fittings were found to be too difficult to operate in the cold water. In addition, the female fitting on the pontoon for attaching the blow vent hose leaked. A later examination revealed that this female fitting cannot be properly lubricated without removing it from the pontoon—a time-consuming maintenance task. The venturi topside evacuation procedure worked quite satisfactorily.

*The pontoon is classed nominally at "10 ton." In salt water, it has an actual buoyant lift capacity of 8.6 tons.

It was concluded that the collapsible pontoon has the potential of being a versatile and useful salvage device. However, account should be taken of the difficulty experienced by divers in handling this unit. Elimination of minor hardware discrepancies will make the ten-ton pontoon a very useful item in the salvage inventory.

Investigations into the optimum pontoon capacity should be initiated for representative salvage operations. Clusters of pontoons could provide a lift capability which might be quickly transported to any corner of the earth. Lift control could be provided by arranging balloons at various depths. Problems associated with this concept should be investigated.*

PNEUMATIC-POWER ZERO-REACTION HAND TOOLS

To make a man-in-the-sea more effective, he must be provided with powered tools designed for his capabilities and the environment which limits his normal surface abilities.

Since no powered tools had been designed to fill this need, the Battelle Memorial Institute, Columbus, Ohio, conducted preliminary underwater tests in a test pool and in a water-filled gravel pit with commercial pneumatic zero-reaction production tools which were modified specifically for diver use. The promising results of these tests led to the development of an ocean-bottom experiment which was conducted by the aquanauts at Sealab II, at no expense to the Navy.

This experiment included the use of a "reactionless" impact wrench and related test stand (Fig. 150). Also, a pneumatic hammer was modified to drive a coring device of simplified design into the ocean bottom. The impact wrench was used to drill and tap holes, run nuts and bolts, and for hole-saw cutting.

The modified tools, which were adaptations of tools designed for the surface, did not perform all of their functions as well underwater. This reduced performance capability had been anticipated, and some of the causes are readily understandable; however, other aspects will require further study. The initial operation of the tools was degraded somewhat by two defective hose couplings.

The combined effects of depth, near-zero visibility, low temperature, and gas-flow noise in the breathing apparatus masked the feedback of intelligence to the operator necessary to exert proper control over lightly loaded functions such as thread tapping and drilling. The reaction, vibration, and noise from the impact wrench was so slight that feedback could be felt only when the tool was triggered initially for each function, as in final nut and bolt torque up, and while hole-saw cutting. As an example, while drilling, the aquanaut could tell that the tool was working only by closely observing the metal cuttings produced. Perhaps the tools were too reactionless. Feedback intelligence of some type is clearly necessary.

An interesting result of drilling underwater is that it was learned that center punching is unnecessary for drills 3/8 in. or larger. With 1/4 in. and smaller drills, the same technique could result in rapid wear of the drill tip.

The pneumatic-hammer-driven bottom-coring device performed very satisfactorily. Four cores were obtained around the base of the Sealab in less than six minutes.

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*BuShips has adopted this pontoon, with several improvements, as a Standard Emergency Ship Salvage Material Pool item. The improved pontoon has the added feature of being sufficiently strong to permit tiering three high in a lift mode.

†BuShips, with BuDocks concurrence, has assigned the Naval Civil Engineering Laboratory, Port Hueneme, California, as "lead lab" for the development of collapsible pontoons in support of the DSSP project. NCEL has let an on-going contract with U.S. Rubber Company for the adaptation of the larger commercial Sealdtanks (up to 25 tons lift capacity) for use as salvage pontoons. This project looks to the possible use of larger collapsible pontoons in place of the current 80-ton structural submarine salvage pontoons.

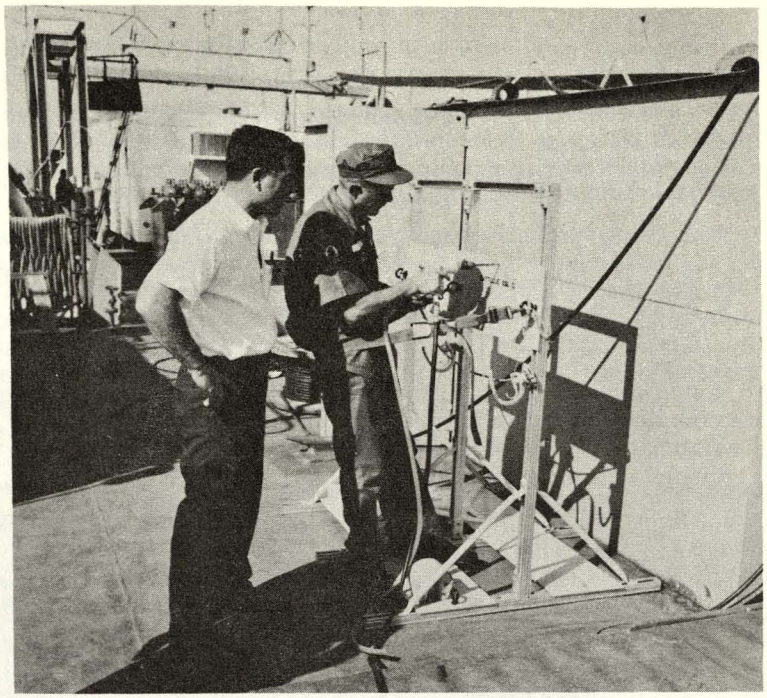

Fig. 150. Aquanaut Reaves tries out underwater tool test stand on the Sealab II surface support vessel

The aquanauts were impressed with the tool performance and the possibility of obtaining suitable tools for their normal underwater work. Many excellent suggestions were received from them on ways to improve the tools. These encouraging results appear to warrant further development of tools designed specifically for the underwater worker in his demanding environment.

Chapter 43

THE BENTHIC LABORATORY

V. C. Anderson
Marine Physical Laboratory
San Diego, California

The benthic lab, as used with Sealab II, is shown in Fig. 151. It is an unmanned, remotely operated electronics complex housed in an oil-filled inverted dome, or "hive", mounted on the sea floor near the Sealab habitat. This complex is connected through a single coaxial cable to the benthic control console, one mile away on shore.



Fig. 151. The benthic laboratory prior to its placement at the Sealab II site

In addition to control and monitor functions associated with the operation of the benthic lab, the electronics provides for the multiplex and demultiplex of quite a number of television video, audio communication, and digital telemetering channels to and from Sealab over the single coax to shore. The ac power required to operate the benthic lab is also transmitted over the same coaxial cable.

The transmission system provides for the transmission of 36 audio communication channels, with a nominal 5-kHz bandwidth: 12 channels from shore to benthic, and 24 channels from benthic to shore. Additional provisions are made for the transmission of five simultaneous,

5-MHz bandwidth TV video signals from benthic to shore. The time-multiplex telemetering system provides 128 channels in each direction with a 60-Hz sampling rate on each channel.

The benthic hive is filled with optically clear acid-washed kerosene. The interior is lighted by 16 lights which are turned on individually and in pairs via the shore-to-benthic time-multiplex channels. Two television cameras with remotely operated pan/tilt capability are located inside the hive and provide vision for inspection and servicing of interior electronics.

All circuits are made up on plug-in cards and are contained in 22 modular assemblies arranged in a ring around a mechanical manipulator which is operated remotely over the time-multiplex channels. The ring assembly is shown in Fig. 152. There are spare circuit cards for all critical circuits stored in the modules for easy access by the manipulator. Other features include manipulator-actuated switches, both rotary and toggle, and an instrumentation patch panel where any one of over 70 voltages and waveforms may be selected for telemetering to shore for system check or trouble shooting.



Fig. 152. The benthic laboratory modular assemblies arranged in a ring around the mechanical manipulator

A completely independent backup telemetering system, providing 24 channels for critical control functions such as manipulator, lights, and TV, could be placed in service for trouble shooting in the event a failure should occur in the primary system.

A pair of hydrophones are mounted, one on each side of the manipulator. The hydrophone outputs are transmitted to shore for stereo listening in order to give the operator an additional sense of certain operating conditions which would not otherwise be available.

The operation of the benthic lab is carried out from the benthic control room located on shore. Fig. 153 shows the configuration of the operators' console.

The initial attempt at manipulation within the benthic hive was carried out on Sept. 1, the day after the emplantment of the benthic lab. The attempt was made using benthic TV camera 2, located between modules 22 and 23, near the TV modulator cards in module 21. This particular TV camera appeared to be faulty, and the picture definition was very poor, indicating either an oil leakage into the optics or a faulty electromagnetic focus circuit. A comparison of

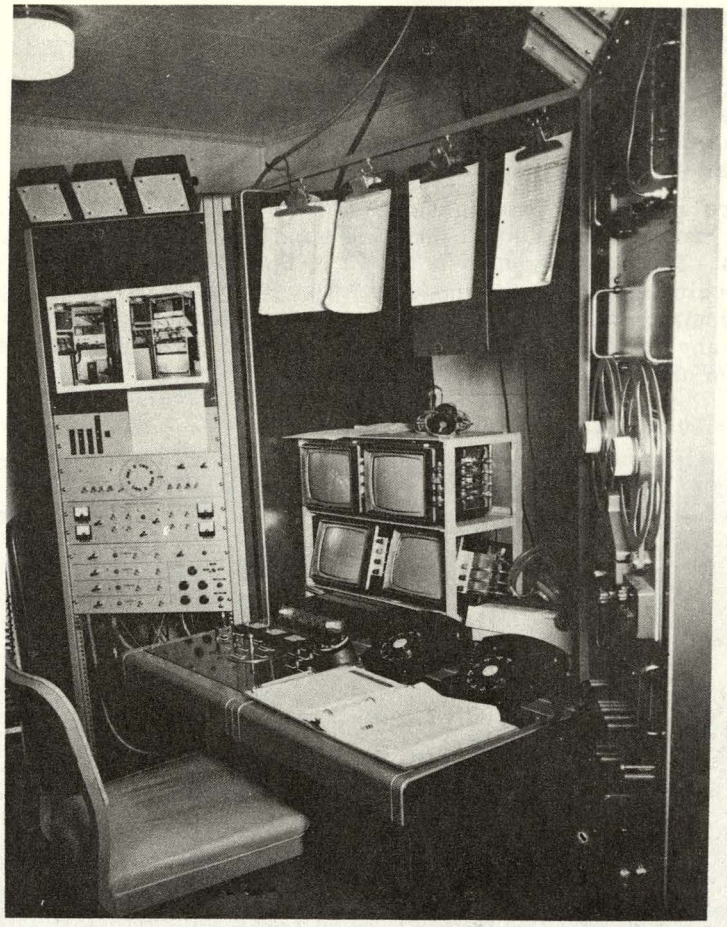

Fig. 153. The benthic laboratory operator's console at Scripps Institution of Oceanography

resolution of the two cameras is made in Fig. 154. The vertical and radial position of the manipulator was first established by use of camera 1 on the opposite side of the hive, then the manipulator was rotated into the field of view of camera 2. After a considerable number of trial approaches the manipulator hand was engaged in the card slot of one of the spare modulator cards, and the card was extracted from its slot. The card was moved down to video 6 module slot and successfully inserted. The engagement of the pins was indicated by the occurrence of a strong interference pattern on TV channel 2. The card was then removed from this slot and an attempt made to return it to the storage slot in its original location. At this point considerable difficulty was encountered in aligning the card with the slot as a result of the poor definition of camera 2. In the process of manipulation the card was dropped and lost from view. A cursory examination of the hive with camera 1 did not disclose the final resting place of the card; however, a more careful examination late that night revealed the card might be lodged in the cable harness near the terminal block area (Fig. 155). Recovery of the card was considered but the complete lack of visibility of this area from the camera 1 vantage point made it virtually impossible, and no recovery attempt was made.

The following day the hydraulic system was checked in an effort to determine the cause of the accidental release of the card from the manipulator jaws. The integrity of the hydraulic lines was investigated by listening to the cavitation of the hydraulic pump through the monitor hydrophones and energizing the negative-pressure solenoid for the various functions intermittently. If the pressure had remained the same in the circuit during the interval of time the solenoid was closed, the flow through the pump would not be changed upon reactuation of the valve. However, if the pressure had relaxed in the circuit, the reduction in pressure when the

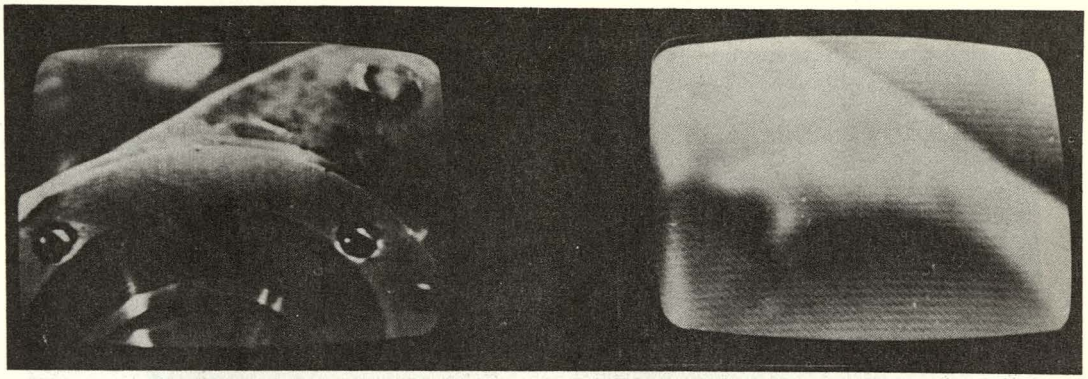

Fig. 154. Comparison of the resolution of the two benthic laboratory TV cameras. The poor resolution of camera 2 was caused by either oil leakage into the optics or a faulty electromagnetic focus circuit

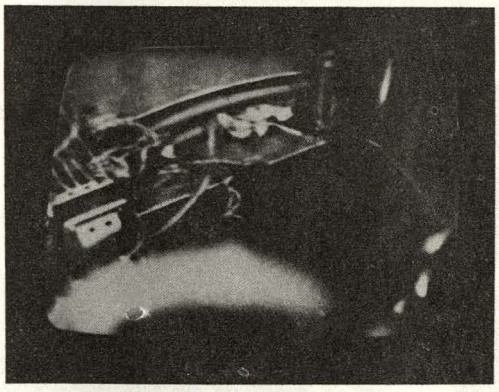

Fig. 155. Benthic laboratory terminal block area

valve was connected across the manifold would be accompanied by a reduction in the cavitation noise. This reduction of sound was observed on the grip hydraulic circuit after a few seconds delay, indicating the presence of a slow leak in the system. In future manipulations this fact was taken into consideration by periodically re-energizing the grip solenoid whenever the grip action was used.

The next manipulation effort attempted was the use of the patch panel to check the performance of the amplitude-modulated communication links. In this operation camera 1 was used. Its location between modules 8 and 9 gave an ideal vantage point for the operation on the patch-panel board located in module 12. The manipulation was successfully carried out and involved the transfer of both ends of the patch cord. One end was moved to the monitor jack on the upper half of the panel from its original position in the monitor jack on the lower half of the panel (Fig. 156). The other end of the cord was then inserted into the desired jack in the panel (Fig. 157). The jack numbers were marginally readable in this particular area, which was in the upper third of the bottom half. The location of the jack was confirmed by counting the jack sequence from a readable number at closer range. During the checking operation it was also necessary to operate the range. During the checking operation it was also necessary to operate the rotary switch in the center of the patch panel (Figs. 158, 159). In one position of the switch, the detent could not be overcome by the wrist-rotate motor torque alone, and thus it was necessary to stall the wrist-rotate motor and then operate the arm-rotate motor to obtain increased torque. Although both functions are driven from identical motors, the loss in the compound gear transmission link, including the worm-gear final reduction of the hand-rotate function, gives rise to a lower stall torque than the spur-gear reduction of the arm-rotate function.

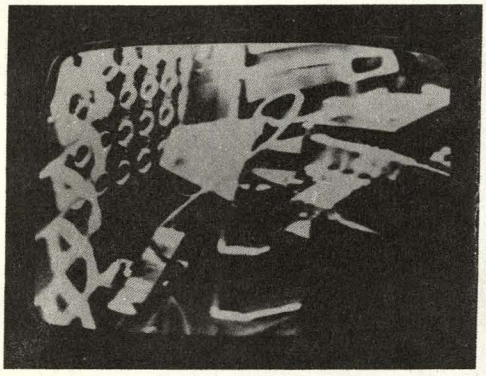

Fig. 156. Benthic laboratory plug-in monitor jack of patch panel

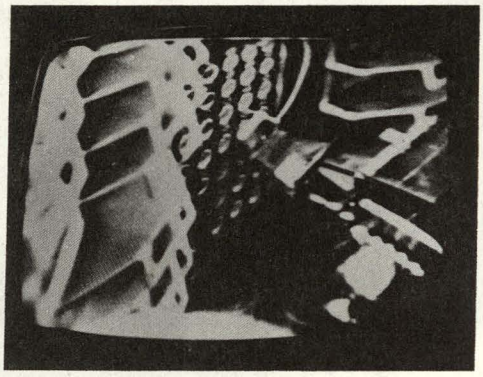

Fig. 157. Plug-in jack number 59

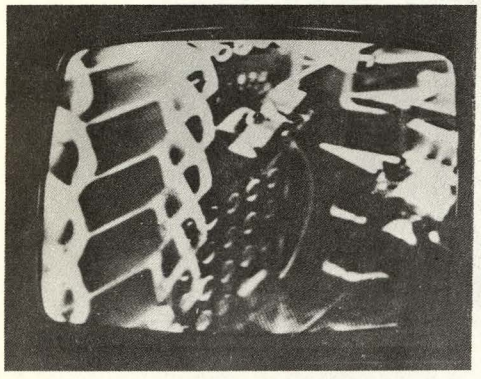

Fig. 158. Benthic laboratory manipulator hand approaching monitor switch

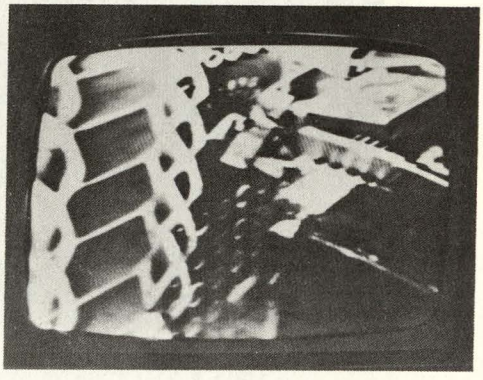

Fig. 159. Benthic laboratory manipulator engaged in monitor switch

The major difficulty which was encountered in working with the patch panel was that of releasing a patch-cord plug handle once the plug was engaged in its socket. It was somewhat ironic that it at times appeared to be impossible to release the patch cord without pulling the plug from its socket, even though several times during the operation the plug nearly fell off the hand while maneuvering it outside of the socket. It is apparent that a more satisfactory method of engaging objects to be maneuvered is required.

The capability of monitoring the circuits in benthic is a powerful tool in the benthic lab operation. Using this patch panel it was possible to determine the total effect of oil immersion, temperature, and pressure on the tuning of three of the receivers and to retune the oscillators in the surface-operating equipment to match the final receiver frequencies. It became apparent that it would be desirable to have even more system voltages and waveforms brought out to the patch panel. In particular, if the voltages of the TV cameras had been available, it would have been possible to determine the cause of the malfunction of camera 2. Also, if all receiver outputs were brought out, a complete system alignment could be carried out.

The first major effort at card replacement in benthic was undertaken on Sept. 23, in an attempt to rectify difficulties encountered with the analog-to-digital converter digital transmission link (see Chapter 21). On the previous day, measurements taken in Sealab had indicated an abnormality in data channels 7, 8, and 10. At 10 a.m. on Sept. 23, the manipulator was engaged in the diode matrix card which was located at the extreme bottom of module 3

(Fig. 160). The card was extracted part way and released from the manipulator, leaving it disengaged from the connector but still in its slot. The operation took approximately 45 minutes. A second check of the voltages on the analog-to-digital converter-card socket showed that the anomalous voltage readings still existed on channels 7 and 8. Following this test, Sealab was requested to disconnect the plug at the rear of the electronics rack so as to permit measurements to be made on the cable itself. At this point the operations were interrupted by preparation for a dive by the aquanaut assisting in the test, Art Flechsig.

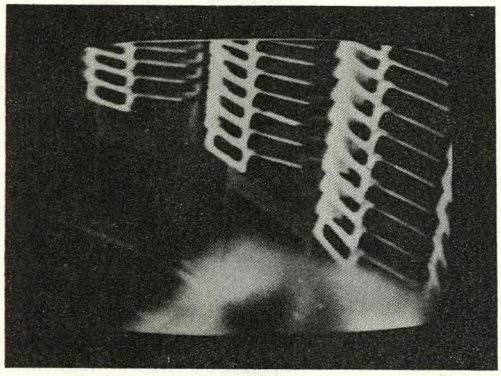

Fig. 160. Benthic laboratory location of faulty card (bottom of module 3)

Anticipating that the diode matrix card could be faulty, the manipulator was once again engaged in this card, and the card was removed from the slot. The card was brought up close to the TV camera and inspected visually for physical damage, particularly any damage to the card pins. No evidence of physical damage was observed. The card was then moved to a vacant slot in module 4 and partially inserted. Fortunately, before the card was plugged in completely, an operator recalled that the particular vacant slot was not a storage slot, but was a spare SCR driver card slot, completely wired, with 110 v ac appearing on the pins. The card was immediately removed from this slot, and a storage slot was located at the top of module 11. This slot was in a very good vantage point from the TV camera, and no difficulty was experienced in storing the card in this position.

During this interruption an attempt was made to use the manipulator to move camera 1 to a new location. The engagement slot for the manipulator fingers is located half way down on the lift bracket, in a position which is completely blind from either camera. In order to prepare the camera for lifting it was first necessary to rotate the lift bracket from its stored position at the side of the camera to the forward position. This was accomplished by wedging the fingers between the bolt heads at the top of the bracket and the camera body (visible in Fig. 154) and rotating both the wrist pivot and the manipulator rotate function to swing the bracket out into position. The wide range of focus provided in the cameras permits the operator to focus on this operation, which takes place only a few inches from the camera lens. Once the lift bracket was rotated into the forward position, the manipulator was retracted into the field of vision of the camera and the arm realigned with the wrist pivot axis vertical, the fingers rotated to the horizontal position, and the wrist pointed directly outward in the radial direction. The fingers were then brought up to the top of the lift bracket to obtain a reference measurement on the vertical scale provided on the manipulator. While observing the vertical scale, the arm was dropped 10-3/16 in. and brought into contact with the lift bracket. The manipulator was positioned so as to maintain a slight pressure on the bracket, and the hand was then moved up and down until the lifting slot was located by "feel." After locating the slot, the manipulator was extended to fully engage the slot, the jaws opened, and the manipulator rotate jogged to center the fingers in the slot to permit full engagement. With the jaws locked in the slot, the TV camera mirror was tilted through the axis of the camera to observe the rear attachment to the module, and an attempt was made to lift the camera from its support hook. The attempt was unsuccessful. Although it was possible to raise the camera, it was not possible to clear the hook or fully support the camera by the manipulator hand. Apparently either the clamp action was not strong enough or else the grip-function hydraulic leakage was

too great to maintain the jaw engagement in the slot. After it was apparent that the camera would not lift free of the support hook, the mirror was rotated back to observe the manipulator, and the manipulator was found to be retracted out of contact with the lift bracket. In view of the extremely high risk of dropping the camera under this type of operation, further attempts to move the camera were suspended. Approximately one hour was spent in working with the camera in this attempt to reposition it.

At 1230 the aquanaut was available once more to resume testing, and a check of the cable at this time indicated that the voltage previously measured on channels 7 and 8 was not present. The plug was re-engaged, a second check made of the voltage at the A to D card socket, and the absence of the voltages confirmed.

At this point the remaining task was to extract the spare card from its position in module 3, five slots down from the top, (Fig. 161), and insert it into the bottom slot in the same module from which the faulty card had been removed. Unfortunately, the vantage point of the camera for the upper slot of module 3 was poor, in that the fingers were hidden by the manipulator body. Accordingly in order to extract the card it was necessary to position the manipulator vertically with reference to the fifth card down in module 4 and time the traverse from corresponding points on modules 5 and 4 until a reproducible traverse could be made by timing. The traverse was then timed from the center of the card handle on module 4 to the supposed position of the card handle on module 5. At this point, the manipulator was extended until contact with the card handle was indicated by a slight shift in the position of the module, and the raise-lower function was jogged until the jaws engaged the slot. Next, the manipulator was extended to stall-out, following which it was relaxed slightly by again observing the motion of the module. With the jaw-open solenoid actuated, the manipulator rotate function was jogged to center the hand in the card handle. By retracting the manipulator slightly, the jaws engaged the notch and locked onto the handle. The card was then extracted. During extraction, the proper alignment of the manipulator was determined by observing the card deflection and jogging the manipulator vertically and radially as indicated to align the card with the slot. Throughout the entire transfer operation the jaw-open solenoid was actuated every two to three seconds to be sure that the card would not accidentally be released. While transferring from the number 5 slot to the bottom slot of the module, the wrist was rotated in an upward orientation so that the card could not accidentally drop from the jaws.

Considerable difficulty was experienced in replacing the card in the bottom slot. Visibility conditions were quite poor, in that the lighting at the bottom of the module was inadequate for a sharp TV display (Fig. 162), and the use of only one camera made it very difficult to estimate distances or orientation of the card at the bottom of the module. A number of tries were required before the card was finally engaged in the slot. Although an accurate measurement of time was not kept on this operation, insertion of the card in this slot required about 20 minutes

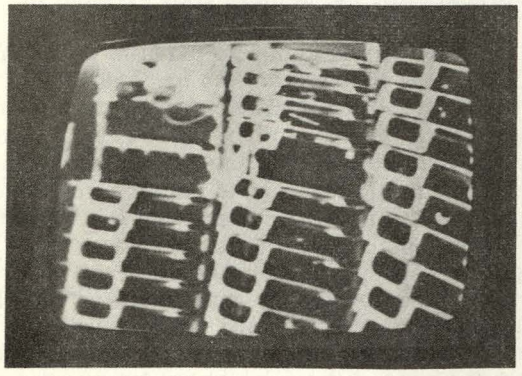

Fig. 161. Benthic laboratory slot from which spare diode matrix card was extracted

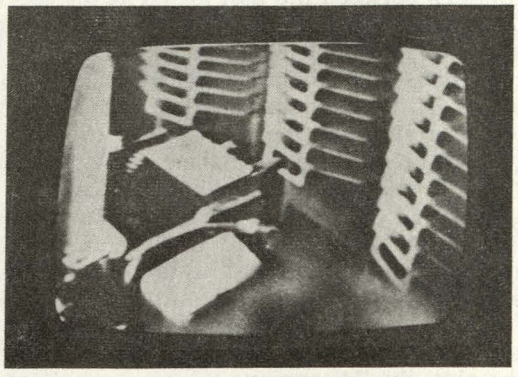

Fig. 162. Benthic laboratory manipulator in position to engage bottom card of module 3

compared to the two or three minutes required for inserting the faulty card in the top slot of module 11 where visibility conditions were ideal (Fig. 163). The card was successfully inserted and homed in place to full-pin contact by the manipulator and the A to D converter card reinstalled in the Sealab rack. The data transmission link was then found to be operating satisfactorily.

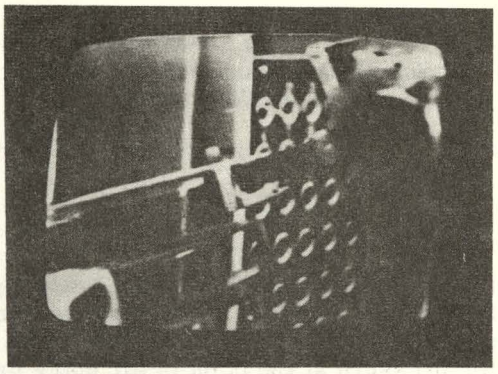

Fig. 163. Benthic laboratory manipulator in position to engage top card in module 11

While the cause of the trouble in the A to D link was not conclusively determined, there is a strong suggestion that a combination of electrical leakage in the connector in the Sealab electronics rack, in conjunction with electrical damage to the diode gate card, were the cause of trouble. The trouble was presumably corrected by both the replacement of the card and by the removal of the plug from the chassis socket, thereby giving it an opportunity to dry out and relieve the severity of the electrical leakage. Manipulation was secured at 2:30 p.m.

Chapter 44

OCEAN-BOTTOM MINING TECHNOLOGY

J. Leslie Goodier
Marine Mineral Technology Center
Tiburon, California

AIRLIFT EXPERIMENT

General Description

In the airlift method of mining on the ocean floor, a recovery pipe line is suspended from a surface craft to the seafloor (Fig. 164), and compressed air is injected into a manifold located on the recovery pipe some distance above the foot or shoe of the pipe (Fig. 165). The air pressure just exceeds the water pressure at the point of air entry into the manifold (Fig. 166). The water above the point of entry of the air into the pipe becomes an aerated froth. This reduction in density in the upper section of the pipe results in a pressure differential and resulting water-sediment flow into the base of the recovery pipe. This flow has such velocity that solids are raised to the surface, where they are discharged into recovery barrels.

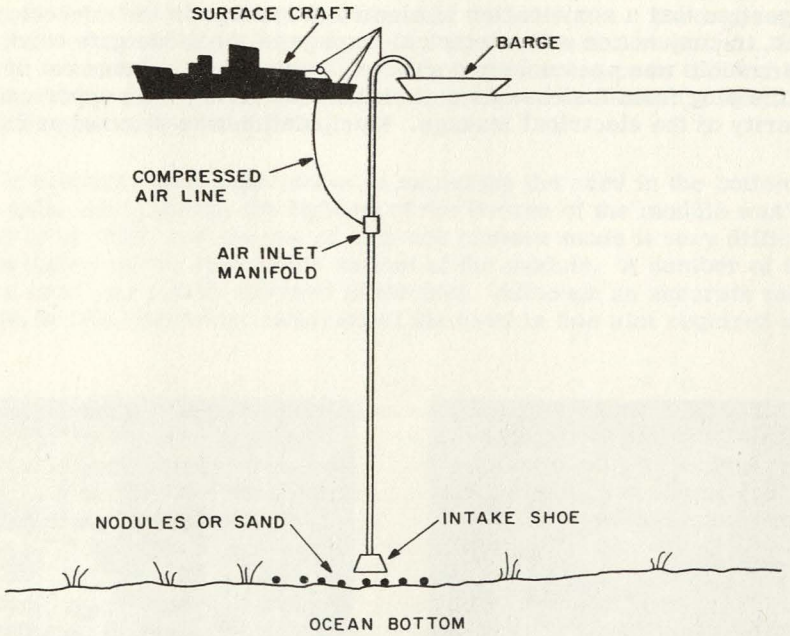

Fig. 164 Air lift method of recovering material from the ocean bottom

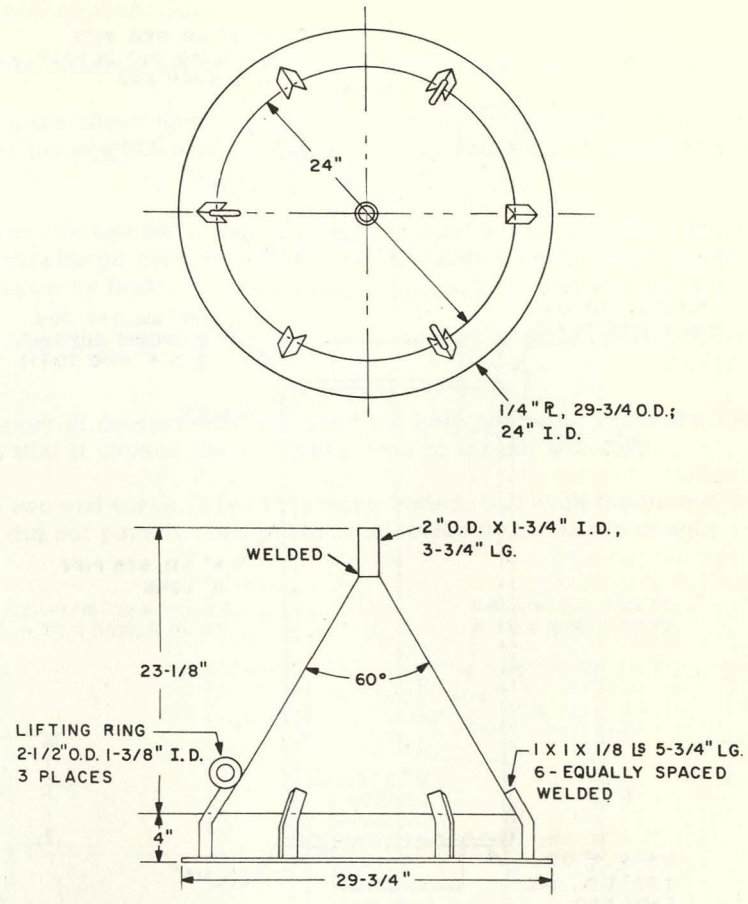

Fig. 165. Conical shoe used on the bottom of the air lift recovery pipe

Sealab II Tests

An airlift with a two-inch recovery pipe was lowered from USNS Gear in 185 ft of water near the Sealab II site. Compressed air was supplied from Gear at 140 psi and 50 cfm. Initial two-phase (air/water) flow was established at 10 gallons per minute, one minute after compressed air was supplied to the manifold. Very few solids were observed in the water flowing into the recovery barrels, and pumping was discontinued after 15 minutes. Examination of the recovery barrels disclosed only a few ounces of very fine sediment, principally mica flakes averaging 2 mm in diameter, and light silica particles.

Observing divers reported that sediments at the location were highly compacted and capable of supporting considerable weight. Based on this information, it was decided to increase the seawater intake velocity by decreasing the effective area of the shoe. The original shoe was modified aboard Gear to Bureau engineer's specifications.

The diving team was then instructed to distribute several pounds of phosphorescent sand over a ten-foot-diameter circle around the recovery shoe and observe the lateral movement of the sand into the system with an ultraviolet light. The divers reported no perceptible movement of the sand; however, phosphorescent sand was observed in the recovery barrel. Airlifting operations were terminated after 10 minutes.

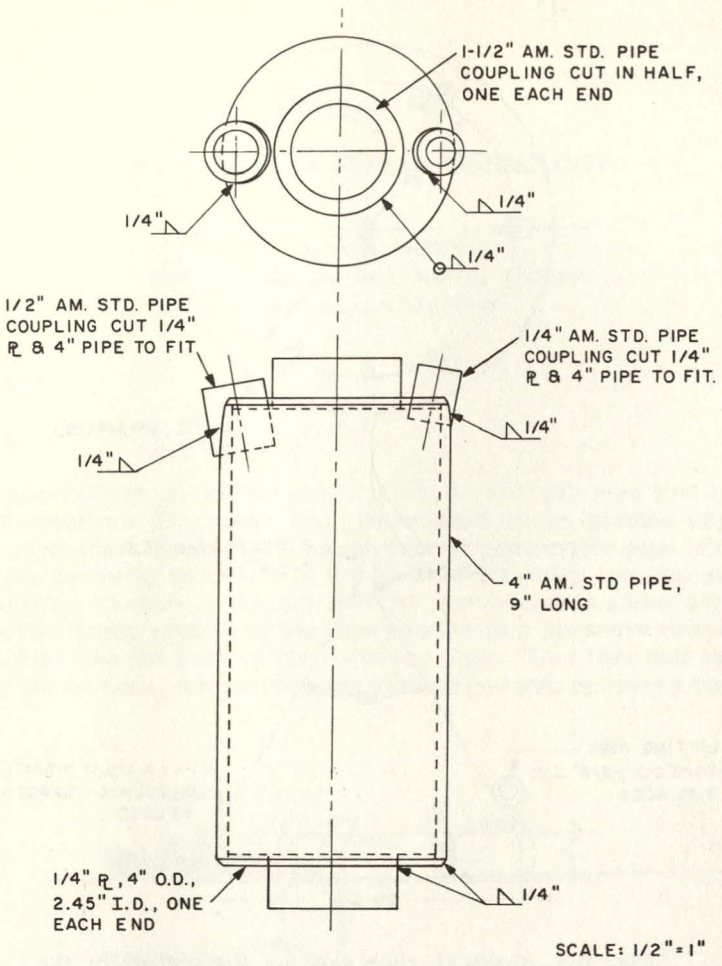

Fig. 166. Compressed air manifold on air lift recovery pipe

The increased velocity of flow doubled the amount of solids recovered. Other factors which caused some increase in the amount of solids recovery were the less compact nature of the phosphorescent sand and disturbance of the bottom by the observing divers.

It was then decided to increase the intake velocity further by removing the suction shoe. This alteration reduced the weight of the assembly so that a diver could maneuver the intake across the ocean floor. The observing divers were instructed to distribute phosphorescent sand and 3/8-in., 1/8-ounce steel pellets, vary the height of the intake pipe above the ocean floor from 0 to 1 ft, and control air-inlet flow with the valve at the air manifold, 28 in. above the inlet.

The duration of the test was nine minutes, during which time two cubic feet of sediment was recovered. Water discharge was black, indicating a heavy sediment concentration. The steel pellets were picked up and discharged against the recovery-barrel deflector plate with considerable force.

Conclusions and Recommendations

1. The ability to observe actual operation of the air lift on the sea floor is very helpful.

2. The greater the shear strength of the sediment, the higher must be the shoe inlet velocity. This points up the need to custom design shoes to suit the physical characteristics of bottom sediments.

3. Baffle plates are needed in the recovery tanks. Solids were lost through the recovery-barrel overboard discharge even though 20 and 40 mesh screens were positioned in the lines between the two recovery tanks.

4. The "man handling" of one hundred or more feet of hose creates a considerable problem.

5. An oversupply of compressed air does not help sediment recovery. Excess air has an adverse effect, in that it causes the recovery hose to thrash and whip.

6. Manifolds two and three (Fig. 167) were tested, and each functioned relatively well. Time limitations did not permit conclusive volumetric flow measurements.

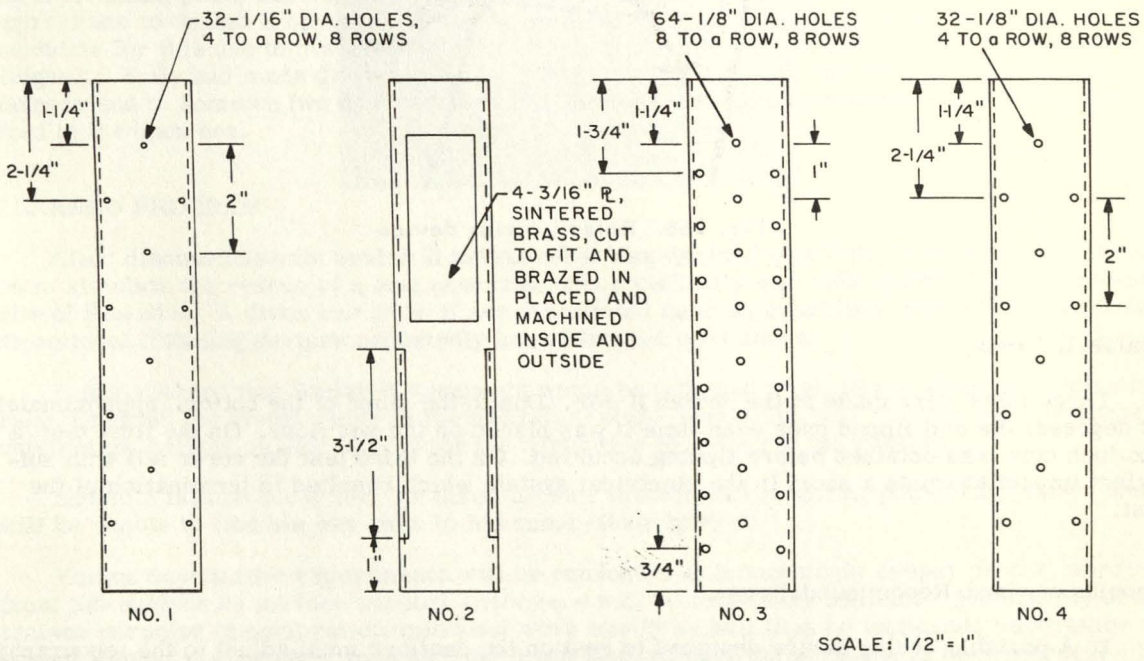

Fig. 167. Types of spools used on compressed air manifold

ROTARY CORER EXPERIMENT

General Description

The rotary coring device (Fig. 168) is 14 ft high and weighs 1,000 pounds in air and 830 pounds in water. It is made up of off-the-shelf components assembled in a frame with tripod legs to sit on the ocean floor and drill a six-foot core of sand, gravel, nodular material, or rock. The unit is lowered and raised from a surface vessel, from which power is supplied to a motor mounted on the device. The motor is controlled by an operating console on the surface vessel. A circulating-water pump on the corer assists the core barrel in penetrating the dense sands and gravels. The core barrel is lined with plastic sheet to facilitate core removal.

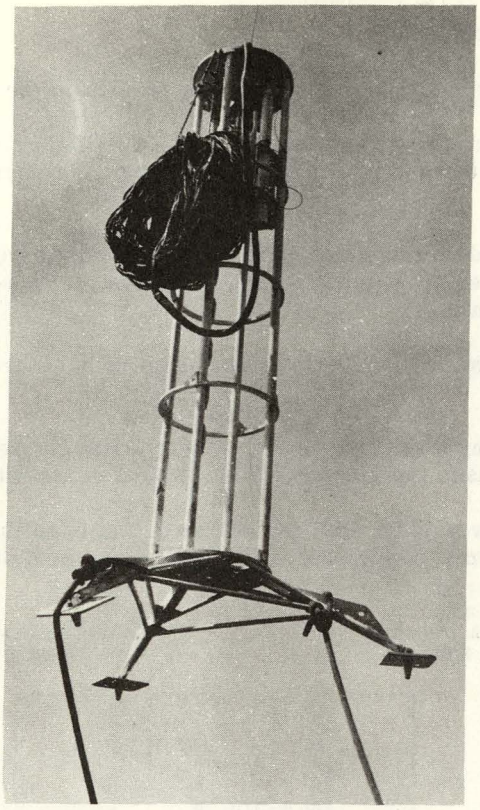

Fig. 168. Rotary coring device

Sealab II Tests

Three tests were made at the Sealab II site. Due to the slope of the bottom (approximately 22 degrees) the unit tipped over each time it was placed on the sea floor. On the first test, a six-inch core was obtained before tipping occurred. On the third test the corer fell with sufficient impact to cause a short in the electrical system which resulted in termination of the test.

Conclusions and Recommendations

1. A portable coring device designed to rest on the seafloor must adjust to the topography of the area.

2. The power cable must be armored to protect it from sudden shocks and abrasion.

3. Some mechanical method of handling the power cable during raising and lowering is required.

Chapter 45

UTILIZATION OF PORPOISES IN THE MAN-IN-THE-SEA PROGRAM

F. G. Wood, Jr. and Sam H. Ridgway
U. S. Naval Missile Center
Point Mugu, California

BACKGROUND

The purpose of an ONR funded "Project Arion" being undertaken by the Life Sciences Department of the Naval Missile Center is to determine the means by which porpoises can be effectively utilized in scientific experimentation directed toward naval application.

Sealab II provided an opportunity to test the feasibility of using porpoises in conjunction with the Navy's man-in-the-sea program. With the encouragement and active support of Sealab II officials, plans were made for on-site field trials with a porpoise trained to perform tasks appropriate to Sealab II operations. An Atlantic bottlenose porpoise "Tuffy" was an obvious candidate for this due to his participation in a diving physiology study directed by Dr. Sam H. Ridgway. Tuffy had made dives to depths in excess of 300 ft. He had been trained to wear a harness and to home on two different acoustic devices. He was accustomed to working untethered in the open sea.

PLANNED PROGRAM

After discussions with Sealab II personnel it was decided that Tuffy's primary task would be to simulate the rescue of a lost aquanaut. Poor visibility was anticipated at the proposed site of Sealab II. A diver has little if any directional hearing capability, and even electronic directional listening devices reportedly are of limited usefulness.

It was planned that Sealab II aquanauts would be tethered at all times while swimming at ranges beyond the visual range of the habitat. Future operations will require that they range untethered, relying on electronic aids for navigation to return to the habitat.

Should a failure occur and the diver become disoriented, a strong possibility exists that he will be unable to find his way back to his ocean-floor habitat.

Future Sealab type experiments will be conducted at increasingly deeper depths, where aid from the surface by surface support swimmers will be extremely difficult. Availability of a trained porpoise to perform certain vital work functions will thus be increased importance as deeper depths are reached, provided the depth limitation of the porpoise is not exceeded.

As planned, for Sealab II Tuffy would be summoned (by a buzzer, one of the acoustic devices to which he had been trained to respond) from the surface to an aquanaut at Sealab II. That individual would snap a line to one of the rings on the animal's harness, then turn off his buzzer (designated the primary signal). The "lost" aquanaut would then summon the porpoise by turning on his (secondary) buzzer signal. After unsnapping the line that Tuffy had carried to him, he would have a guide back to Sealab II.

The "homing" signal to be used by the animal's handler at the surface was the other acoustic device to which the animal had been trained to respond—a small waterproof strobe light (designed as survival gear), the discharge of which produces a broad-band click. Tuffy had reliably come to this signal from distances of over 500 yards in Mugu Lagoon.

Subsidiary tasks to which this training could be adapted included the transfer of tools, message capsules, and other small objects between surface and bottom and between divers.

PREPARATION

Training began at Point Mugu on Aug. 2 and proceeded as planned. Tuffy worked out of a floating pen anchored in approximately 80 ft of water.

Since it would have introduced an undesirable complication to require the aquanauts to reward the animal with fish, this reinforcement, after the initial training, was eliminated at the bottom, and Tuffy was rewarded only after returning to the surface. For the next nine days he continued to work well, with the two divers stationed 50 to 180 ft apart. On the tenth day he accomplished one perfect mission, then refused to respond to the divers' signals. He repeated this performance on each of the next three days. When reinforcement at the bottom was resumed, the animal resumed working. Subsequently a system of random reinforcement at the bottom was established, and at Sealab II Tuffy carried a small bag of fish down to one of the aquanauts on each initial dive.

The participation of Aquanauts John Reeves and Kenneth Conda in practice sessions at Point Mugu greatly facilitated training and helped insure the success of the trials at Sealab II.

On Sept. 11, 1965, the component parts of a floating pen 17 X 17 X 10 ft deep were trucked to La Jolla and assembled on the beach. The pen was towed to the Sealab II site and anchored about 200 yards from the SS Berkone.

On Sept. 13 Tuffy was transported by H-34 helicopter from Point Mugu to the Quivera Basin dock at Mission Bay. There he was transferred to the AVR for its scheduled 1230 run to the Sealab site. The porpoise behaved normally and accepted food immediately after being dropped into his pen.

On Sept. 14 and 15, Tuffy satisfactorily performed practice dives to depths of 110, 150, and 170 ft respectively. Divers of the Operations Support Group of the Amphibious Base at Coronado ably participated on both days. The Sept. 15 practice session was conducted about 100 feet from Sealab, and Tuff's performance (Appendix A) provided no reason to assume that he was not ready for trials with Reeves and Conda the next day.

However, in the first trials held on Sept. 16 the porpoise would not dive. The sixth trial he made a dive, apparently of 4-1/2 minutes duration, coming within sight of Conda, and close enough to Reeves to be touched. But he would not hold still for package or line transfer. Presumably the heaving lines and cables, the noise of SS Berkone's generators, the lights of Sealab II, and other conditions existing at the site deterred the animal. (Details of performance in Appendix B.)

ACCOMPLISHMENTS

On Sept. 17, with Reeves and Conda working in a less obstructed area about 100 ft from Sealab (but moving closer in the last trials), the porpoise performed flawlessly, transferring tools and mail between surface and bottom, and tools and guide line between divers. His seven dives ranged in duration from 1 min 8 sec to 1 min 15 sec.

On Sept. 18 he again made seven successful dives, with Reeves and Conda working just outside Sealab II. Tuffy responded quickly and correctly to every signal. (For details of Sept. 18 and 18 dives, see Appendix B.)

On the afternoon of Sept. 18 Tuffy was required to swim from his floating pen to the landing craft of the Operations Support Group where he was maneuvered into his stretcher and hoisted out of the water (the large crane on the SS Berkone being unsuitable for this operation). He was then transferred by small boat to the AVR at the Berkone, and thence returned to Mission Bay for the helicopter lift back to Point Mugu.

CONCLUSIONS

A porpoise can be trained to perform useful and even vital tasks in man-in-the-sea programs such as Sealab. It can adapt relatively quickly to a strange and in many ways disturbing environment, and once trained will perform with a high degree of precision and reliability.

The potential value of a porpoise (or other deep-diving marine mammal) will increase as future Sealabs are located at greater and greater depths. All of the various ways in which trained marine mammals can contribute to the Sealab program have not been determined; it is anticipated that further investigations will be conducted in future man-in-the-sea tests.

The wild sea lions that on several occasions reportedly surfaced in the well of Sealab II and respired there during the third team's stay demonstrated that these pinnipeds, at least could breath the compressed atmosphere and rise to the surface without injury. It remains to be determined whether a cetacean can do this, at least without special training. However, a capability for making small-package deliveries to and from the interior of a Sealab would vastly increase an animal's value, since this would eliminate the necessity for two aquanauts to don suits and scuba gear and go outside for any transfer of small equipment or materials between surface and Sealab. It would also greatly speed such transfer, a factor of potentially vital importance in an emergency situation.

RECOMMENDATIONS

Porpoise and/or pinniped personnel should become an integral part of the Sealab program. Additional work functions should be investigated and tested in follow-on-at-sea tests.

APPENDIX A

PRACTICE DIVES NEAR SEALAB II SITE

14 Sep 65 - Depth 110 feet.

Morning Session

Dive No.	Time	Remarks
1	1'00"	Line transfer between divers
2	1'15"	Tool delivery & line transfer*
3	Not recorded	Tool delivery & line transfer
4	1'14"	Tool delivery & line transfer
5	1'17"	Tool delivery & line transfer
6	1'10"	Tool delivery†
7	45"	Tool delivery, surface to first diver only

Afternoon Session

1	2'00"	Line transfer
2	1'25"	Tool delivery & line transfer
3	1'12"	Tool delivery & line transfer
4	55"	Tool delivery
5	1'11"	Tool delivery

*In most instances this entry refers to tool or message capsule delivery from surface to first diver, line transfer from first to second diver, and tool or capsule delivery from second diver to surface.

†In most instances, Tool Delivery refers to delivery from surface to first diver, from first to second diver, and from second diver to surface. At each station the tool or capsule was detached and another attached.

Dive No.	Time	Remarks
6	1'00"	Tool delivery
7	1'08"	Tool delivery
8	Not recorded	Tool delivery

15 Sep 65 - Depth 150 feet (Dives 1-3)
Depth 170 feet (Dives 4-7)

1	1'10"	Tool delivery
2	1'05"	Tool delivery to first diver only
3	1'10"	Line transfer
4	1'30"	Tool delivery & line transfer
5	1'30"	Tool delivery & line transfer
6	1'20"	Tool delivery & line transfer
7	1'08"	Tool delivery & line transfer

APPENDIX B

DIVING TRIALS WITH AQUANAUTS AT SEALAB

16 Sep 65 - Depth 205 feet

First diving trials with aquanauts. Sky overcast, moderate swells. Tuffy was harnessed and released from his pen to swim beside the outboard work boat to the NOTS landing craft about 100 feet from the SS Berkone.

Time	Dive No.	Time	Remarks
0935	1	1'10"	Did not go to aquanauts.
	2	45"	Tool Delivery - did not go.
	3	56"	Tool Delivery - did not go.
	4	____	Responded to aquanaut's signal only by diving a few feet below surface. Reeves and Conda returned to Sealab II, Tuffy was taken back to his pen.
1000			
1100			Tuffy brought out again, this time to work from a boat tied to the Berkone directly over Sealab II.
	5	1'45"	Responded immediately to signal; from surface this looked like a good dive, but Tuffy did not go to aquanauts.
	6	4'30"(?)	Responded to signal. Conda, at PTC, reported later that Tuffy came within sight (18-20 feet), made vertical ascent, then returned but wouldn't come close. Reeves touched animal, but porpoise would not hold still for line or package attachment. If apparent diving time was correct this was a record for Tuffy.

17 Sept 65 - Depth 205 feet

0914			Reeves and Conda out.
0921			Tuffy out of his pen. Divers working in more open area over 100 ft from Sealab II initially; in later dives moved closer.
0930	1	1'11"	Responded immediately to signal from bottom, and delivered fish to first aquanaut.
0932	2	1'11"	Delivered mail and returned with an empty pouch.

Time	Dive No.	Time	Remarks
0940	3	1'9"	Carried mail to first diver, life line from first to second diver.
0941:30	4	1'8"	Tool delivery and line transfer.
0944	5	1'15"	Large mail pouch delivery and line transfer.
0947	6	1'12"	Tool delivery.
0948:30	7	1'11"	Line transfer, tool return to surface.

18 Sep 65 - Depth 205 feet

Again the work boat was tied to the NOTS landing barge near the Berkone. Aquanauts Reeves and Conda worked just outside Sealab II. Diving trials began at 0930 and were accomplished in rapid succession.

Dive No.	Time	Remarks
1	Not recorded	Tool delivery.
2	1'20"	Delivered fish, returned tool to surface.
3	1'15"	Coco Cola delivered, mail cylinder returned to surface.
4	1'10"	Delivered mail cylinder, returned tool.
5	1'12"	Delivered tools and mail cylinder, returned tools and fish bag.
6	1'11"	Delivered tools, returned other tools to surface.
7	1'12"	Delivered tools, returned mail cylinder to surface.

These dives were performed promptly and flawlessly; the animal had apparently become well adapted to working in the Sealab II environment.

Chapter 46

DIETARY PROGRAM

W. F. Mazzone
Submarine Medical Center
New London, Connecticut

Although it has long been recognized by the female of the species that the way to a man's heart is through his stomach, too little importance has been placed on food and food preparation as it may affect morale. If man is expected to live and work on the ocean's floor for prolonged periods of time, efforts must be made to improve his well-being and the so-called creature comforts. If man is to be subjected to other than ideal conditions, his motivation must not be stinted by being underpaid and underfed.

In order to appreciate fully the dietary, or lack of a dietary, program for Sealab II, it is necessary to have a mental picture of (a) the galley, (b) storage spaces, both dry and refrigerated and, (c) contamination containment.

The galley area contained a small four-element electric range, without a hood; one double sink with hot and cold water taps; a two-compartment refrigerator with a seven and one half cubic foot chill space and a freezer space of the same capacity. Other than limited shelving for condiment storage, normal day store stowage space was not specifically designed.

Galley equipment consisted of the electric range, a roto-type broiler, Teflon-coated electric skillet, electric sauce pan, and a defective four-slice electric toaster. Needless to say, utensils and other items were available.

Protection against contamination of the atmosphere with potential toxicity hazard contaminants is a very major concern. Under conditions of prolonged submergence in a confined space, such as an undersea dwelling or submarine, environment and habitability may be considered one of the major limiting factors of endurance. Thus, it is and was essential that certain cooking processes be eliminated, such as frying, which may produce acroleins and some of the partial combustion products such as carbon monoxide.

In view of the above factors, it is quite evident that sound dietary programs would be extremely limited in scope.

The U.S. Naval Supply Research and Development Facility, Bayonne, New Jersey, provided assistance in the preparation of a diet (Table 46) and load list (Table 47) suitable for ten men for 15-day periods. In preparation of the menu, it was necessary to keep in imnd those limiting factors previously cited, as well as the following considerations:

1. All foods must be of the easily prepared type

2. Packaging must be compatible with extreme pressure conditions, at least 110 pounds per square inch absolute

3. The tendency to get away from total group feeding in favor of individual preparation and eating.

Table 46
SEALAB II: 10 MEN - 45-DAY MENU

1ST DAY	2ND DAY	3RD DAY	4TH DAY	5TH DAY
BREAKFAST Fruit Drink (Dry Foil Pack) Asst. Dry Cereal Ham Omelet (Dry Foil Pack) Milk Dry (Dry Foil Pack) Coffee (Instant) Crackers LUNCH Beef Stew Peas Carrots Peaches Coffee Crackers SUPPER Spaghetti & Meat Balls String Beans Pineapple, Canned Coffee Crackers	BREAKFAST Grapefruit Canned Cream Chip Beef on Crackers Milk Coffee LUNCH Vegetable Soup, Cond. Chicken Stew & Rice Pears Coffee Crackers SUPPER Ham Chunks Sweet Potatoes Peas Plums Coffee Crackers	BREAKFAST Fruit Drink (Fragile Pack) Asst. Dry Cereal Western Omelet Milk (Starlac) Coffee Crackers LUNCH Spaghetti & Meat Balls String Beans Fruit Cocktail Coffee Crackers SUPPER Chicken Chop Suey & Rice Noodles, Chow Mein Pineapple Coffee Crackers	BREAKFAST Figs Asst. Dry Cereal Mushroom Omelet Milk Coffee Crackers LUNCH Tomato Soup, Cond. Beans & Franks Mayonnaise Pot. Salad Peaches Coffee - Crackers SUPPER Beef Stew Carrots, Canned Peas, Canned Pears, Canned Coffee Crackers	BREAKFAST Fruit Drink Asst. Dry Cereal Cheese Omelet Milk Coffee Crackers LUNCH Beef Ravioli, Canned String Beans, Canned Tomatoes, Canned Plums, Canned Coffee - Crackers SUPPER Vegetables & Meat Balls Potatoes, Whole Canned Spinach, Canned Coffee Crackers
6TH DAY	**7TH DAY**	**8TH DAY**	**9TH DAY**	**10TH DAY**
BREAKFAST Grapefruit, Canned Cream Chip Beef on Crackers Asst. Dry Cereal Milk Coffee LUNCH Vegetable Soup, Cond. Chicken & Dumplings Peas, Canned Cranberry Sauce Peneapple, Canned Crackers - Coffee SUPPER Beef Stew Sweet Potatoes String Beans Peaches, Canned Crackers - Coffee	BREAKFAST Fruit Drink Asst. Dry Cereal Ham Omelet Milk Coffee - Crackers LUNCH Vegetables & Meat Balls Corn Spinach Pears Crackers Coffee SUPPER Tomato Soup, Cond. Beans & Beef in Barb. Sauce Peas Plums Crackers - Coffee	BREAKFAST Fruit Drink Asst. Dry Cereal Cheese Omelet Milk Coffee - Crackers LUNCH Spaghetti & Meat Balls String Beans Pineapple Crackers Coffee SUPPER Beef Stew Peas Sweet Potatoes Fruit Cocktail Crackers - Coffee	BREAKFAST Fruit Drink Asst. Dry Cereal Western Omelet Milk Coffee - Crackers LUNCH Vegetable Soup Beans & Franks Mayonnaise Pot. Salad Peaches Crackers Coffee SUPPER Beef Chop Suey & Rice Noodles, Chow Mein Pears, Canned Crackers Coffee	BREAKFAST Grapefruit Asst. Dry Cereal Cream Chip Beef Milk Coffee - Crackers LUNCH Spaghetti/Tomato Sauce Peas Carrots Plums Crackers Coffee SUPPER Meat Ball Stew Potatoes, Whole, Canned String Beans Pineapple Crackers - Coffee

Table 47
PROVISIONS LOAD LIST - SEALAB II

Items	Source*	Individual Packages or Tins		45-Day Order (to nearest Case)	Total Cube (Cu. Ft.)	No. Rations per Package or Tin
		Total 10-Day Requirement	Total 45-Day Requirement			
Beverage Base, Ass't. Powd., Env-80/case	8960-782-3132	30	135	2 (160 env.)	2.00	2
Grapefruit, Canned #303 case, 24/case	8915-132-7786	30	135	6 (24 cans)	4.38	1
Asst. Dry Cereal, Individual - 10/pack	8920-127-7276	80	360	36 (10 packs)	2.00	1
Ham Omelet - 12 boxes/case	Bordens	20	90	8 (96 pkg)	2.88	1
Cheese Omelet - 12 boxes/case	Bordens	20	90	8 (96 pkg)	2.88	1
Western Omelet - 12 boxes/case	Bordens	20	90	8 (96 pkg)	2.88	1
Mushroom Omelet - 12 boxes/case	Bordens	10	45	4 (48 pkg)	1.44	1
Milk, Starlac, 12 - 6 pkg/case	Bordens	50	225	4 (288 pkg)	0.96	1
Cream, Dry, Coffee-Type (4 oz jars)	8910-845-4338			4	0.52	
Nestle's Quik	Wholesale Grocer			1	0.75	
Figs, 2-1/2 cans, 24/case	8915-191-4704	10	45	2 (48 packs)	2.46	1
Cream Chip Beef, #5 cans, 12/case	Sexton	6	27	2 (24 cans)	2.20	5
Coffee, Instant, 24 - 6 oz jars/case	8955-753-3366			6	7.20	
Beef Stew, #10 tins - 6/case	Sexton	1	5	1 (6 cans)	1.10	10
Beef Stew, 8 oz cans - 24/case	Chef Boyardee	30	135	6 (144 cans)	2.04	1
Ham Chunks, 6 #10 tins/case	Sexton	1	5	1 (6 cans)	1.10	10
Chicken Stew, 12 #5 tins/case	Sexton	2	9	1 (12 cans)	1.10	5
Chicken Chop Suey, 12 #5 tins/case	Sexton	2	9	1 (12 cans)	1.10	5
Beef Chop Suey, 12 #5 tins/case	Sexton	2	9	1 (12 cans)	1.10	5
Spaghetti & Meat Balls 24 - 6 oz/case	Chef Boyardee	20	90	4 (96 cans)	1.36	1
Spaghetti & Meat Balls, 6 #10 tins/case	Sexton	1	5	1 (6 cans)	1.10	10
Beans & Franks, 24 - 8 oz/case	Chef Boyardee	20	90	4 (96 cans)	1.36	1
Beef Ravioli, 24 - 8 oz/case	Chef Boyardee	10	45	2 (48 cans)	0.68	1
Vegetables & Meat Balls, 24 - 8 oz/case	Chef Boyardee	20	90	4 (96 cans)	1.36	1
Chicken & Dumplings, 24 - 8 oz/case	Chef Boyardee	10	45	2 (48 cans)	0.68	1
Bean & Beef in Barb. Sauce, 24 - 8 oz/case	Chef Boyardee	10	45	2 (48 cans)	0.68	1
Spaghetti in Tomato Sauce, 24 - 8 oz/case	Chef Boyardee	10	45	2 (48 cans)	0.68	1
Meat Ball Stew, 24 - 8 oz/case	Chef Boyardee	10	45	2 (48 cans)	0.68	1
Peas, 24 - #303 cans/case	8915-127-9285	35	158	7 (168 cans)	5.11	2
Carrots, 24 - #303 cans/case	8915-634-2437	15	68	3 (72 cans)	2.19	2
Beans, Green, 24 - #303 cans/case	8915-616-4817	30	135	6 (144 cans)	4.38	2
Potatoes, Sweet, 24 - #2-1/2/case	8915-127-3892	15	68	3 (72 cans)	3.69	2
Mayonnaise, Potato Salad, 12 #5/case	Sexton	4	18	2 (24 cans)	2.20	2
Tomatoes, Canned, 24 #303/case	8915-221-0361	5	23	1 (24 cans)	1.23	2
Potatoes, Whole, Canned, 24 #303/case	8915-543-7673	10	45	2 (48 cans)	2.46	2
Spinach, 24 #303/case	8915-285-2546	10	45	2 (48 cans)	2.46	2
Corn, 24 #303/case	8915-257-3949	5	23	1 (24 cans)	1.23	2
Veg. Soup, Cond., 48 #1 Picnic	8935-125-9381	15	68	2	2.96	2
Tomato Soup, Cond., 48 #1 Picnic	8935-125-6307	10	45	1	1.48	2
Peaches, 24 #303 Commercial	Whlse Grocer	40	180	8 (192 cans)	9.84	2
Pineapple, Sliced, 24 #303 Commercial	Whlse Grocer	50	225	9 (216 cans)	11.07	2
Pears, 24 #303 Commercial	Whlse Grocer	40	180	8 (192 cans)	9.84	2
Plums, 24 #303 Commercial	Whlse Grocer	40	180	8 (192 cans)	9.84	2
Fruit Cocktail, 24 #303 Commercial	Whlse Grocer	20	90	4 (96 cans)	4.92	2
Cranberry Sauce, 24 #303 Commercial	Whlse Grocer	10	45	1 (48 cans)	1.23	2
Chow Mein Noodles, Commercial, Cardboard Pack				2	1.00	
Rice, Instant, 12 - #2-1/2/case	8920-965-4423			1	1.00	

*Sources: a. Military if Federal Stock Number is shown.
b. Sexton & Co. (Metropolitan Los Angeles) 18383 So. Susana Road, Compton, Calif., Area Code 213-636-3211.
c. Contact reliable wholesale grocer for:
(1) Borden's Freeze-Dry Omelet and Starlac.
(2) Nestle's Quik
(3) Chef Boyardee (American Home Food).

Table 47
PROVISIONS LOAD LIST - SEALAB II (Continued)

Miscellaneous	Source*	45-Day Order (to nearest Case)	Total Cube (Cu. Ft.)
Sugar, 1 lb. cartons	8925-126-3408	1 case (24 cart)	0.75
Salt, Morton "Salters," Small Shaker Pack		1 dozen	0.10
Crackers, Salted, 1-2 lb. cartons	8920-252-3838	3 cases	9.18
Crackers, Ritz	Whlse Grocer	2 cases (24 pkg)	2.00
Butter	Whlse Grocer		
Pepper, 3-4 oz. can	Whlse Grocer	6 cans	0.10
Mustard, 1/2-1 lb jar†	Whlse Grocer	6 jars	0.10
Mayonnaise, 1 lb jar	Whlse Grocer	6 jars	0.10
Catsup, 12 oz. bottles†	Whlse Grocer	1 case (12 bot.)	0.75
Pickles, 1 qt. jar	Whlse Grocer	1 (1 qt. jar)	1.00
Worcestershire Sauce, 5-6 oz. bottle	Whlse Grocer	1 dz. bottles	0.25
Hot Sauce, 2-3 oz. bottle	Whlse Grocer	6 dz. bottles	0.10
Jams & Jelly (1 lb. jar)	Whlse Grocer	1 dz. asst. 1 lb jar	0.50
Garlic Salt, 3-4 oz. bottle	Whlse Grocer	6 bottles	
Peanut Butter, 1 lb jar	Whlse Grocer	1 dz. 1 lb jars	0.50
Raisins, 1-1/2 oz pkgs (192/case)	Whlse Grocer	1 case	0.58
Peanuts, Dry Roast, 1 lb. jars	Whlse Grocer	2 cases	0.50
Shrimp, Cooked, Freeze-Dried	Kraft	1 case	1.10
Cottage Cheese, Freeze-Dried	8910-082-5734	1 case	1.10
Crabmeat, Freeze-Dried	Kraft	1 case	0.33
Cheese, American, Dehydrated	8910-823-6880	1 case	1.10
Juice, Tomato, Concentrated	8915-616-0204	1 case	1.17
Potted Meat Spreads	Commercial	1 case	0.50
Shortening Compound for Frying, Grilling, Etc.	8945-125-6338	2 - 5-1/2 lb cans	0.33
Pork Chops, Raw, Freeze-Dried‡	8905-253-7328	2 cases (24 cans)	2.00
Beef Steaks, Raw, Freeze-Dried‡	8905-753-6536	2 cases (6 cans)	2.00

*Sources: a. Military if Federal Stock Number is shown.
b. Sexton & Co. (Metropolitan Los Angeles), 18383 So. Susana Road, Compton, Calif, Area Code 213-636-2311.
c. Contact reliable wholesale grocer for:
(1) Borden's Freeze-Dry Omelet and Starlac.
(2) Nestle's Quik.
(3) Chef Boyardee (American Home Food).

†Secure in plastic squeeze bottle, if available.

‡Special procurement, if desired - Defense Personnel Support Center, 2800 South 20th St., Philadelphia, Pa.

By and large, the majority of foods provided for use were of the "heat and eat" variety. Three separate items were included for test and evaluation:

1. Commercial, freeze-dried omelet mix for breakfast meals and sandwiches

2. Commercial tinned whole milk preparation, Sterifresh, marketed by Sausner Foods and provided gratis by the New York Office of the Small Business Administration.

3. Plastic prepackaged meals, frozen, provided by Thomas Distributing Company, Newport Beach, California. This package could be immersed in boiling water for up to 15 minutes for thawing and cooking.

During the bottom stay for each team, aquanauts were requested to comment upon the desirability of meals. In the main, meals were considered palatable and generally good, although midway through each of the periods, some of the aquanauts complained about the monotony of the meals. In subsequent conversations, it developed that variety is in fact the spice of life, and that a good thing can be overdone.

In an effort to overcome some of the minor disenchantments relative to Sealab II being a "feeder," it became necessary to supply additional items such as fresh bread, fresh fruits and vegetables, pastries, and from time to time, meals prepared by verily compassionate inhabitants of the La Jolla, California Area. The daily supply of surface supplied goodies was minimal for team three. Since team three was to have the last bottom exposure for the operation, it was decided that it would be interesting to evaluate how well a team could subsist from the sea. The menu provided a vast assortment of fish, served raw in the style of the Japanese, or cooked in such a manner as to minimize atmosphere contamination.

Body weight was obtained each morning and recorded by the medical officer. Though the specific weights are not available at this time, each aquanaut reported that weight remained approximately the same, and in two cases decreased as much as three pounds.

By general observations via closed circuit television monitors, it appeared as though eating became more than just a necessity. On an average, though specific calorie accounts were not maintained, the aquanauts were of the opinion that they had consumed at least one-fourth again as much food each day as normal. These opinions were confirmed by observation.

The opinions of the aquanauts confirm that a ventilation system should be provided for the galley area which, by necessity, must contain equipment for control of atmospheric contaminants generated in the process of cooking. It is necessary to review the problems and resolutions as applicable to atmospheric control maintained in nuclear-powered submarines. Secondly, it is essential that adequate storage space be included in the design modification. An area such as the conning tower might well be adapted to dry store stowage, with ballast requirements shifted externally.

Thirdly, and again very important, is the requirement for greater frozen storage without a loss of chill space. As the depth increases, it will become more and more difficult to provide surface support. Consequently, if any degree of autonomous operation is to be achieved, storage of essential items is an absolute must.

Chapter 47

MARK–VI MIXED–GAS BREATHING APPARATUS

J. C. Bladh and P. A. Wells
U. S. Navy Mine Defense Laboratory
Panama City, Florida

INTRODUCTION

The initial preparation of gear and the training of Sealab personnel in the use of the Mk-VI Scuba was accomplished under the supervision of the Mine Defense Laboratory Diving Officer. Experience gained from Sealab I dictated that the following preparations and procurement of material must first be accomplished to support the training as well as the Sealab II effort itself:

1. Procure 20 Mk-VI rigs
2. Build a Mk-VI locker and gas rack
3. Procure portable recompression chamber
4. Procure mixed gas (HeO_2 and NO_2) and CO_2 absorbent (Baralyme)
5. Establish a training schedule and lesson plane
6. Schedule boats as required
7. Enlarge present diving locker and shower room to accommodate Sealab personnel
8. Procure transfer pump (PPI) for charging rigs
9. Procure adequate gas analyzers
10. Establish and procure a Mk-VI spare-parts inventory.

PREPARATION

On Feb. 1, work commenced at the Mine Defense Laboratory, fabricating a Mk-VI locker and work area. This included the construction of a gas rack, drying rack, vest stowage, suitable work benches and lockers, as well as a new locker and shower room. This work was completed by Apr. 1. This locker was used as a guide for the construction of the Mk-VI locker aboard the support vessel.

On Mar. 28, 20 Mk-VI units arrived at the Mine Defense Laboratory from the Naval Operations Support Group Pacific and immediately were given a visual inspection, cylinder test, dip test and operational test. In addition to the above, and as an added safety factor, three Hansen fittings from each unit were modified to provide a positive lock to the hose fittings. Two of these modified Hansen fittings are located at the control block and one at the canister.

During March, the following gas and equipment were procured to support the training program.

1. 10,400 cu ft He
   6,160 cu ft 60/40 N_2O_2
   2,640 cu ft 40/60 N_2O_2
   3,960 cu ft 32.5/67.5 N_2O_2
   2,200 cu ft N_2
   4,400 cu ft O_2

2. A two-lock portable Dixie recompression chamber was obtained from Explosive Ordnance Disposal Unit TWO, Charleston. In addition to the above, utility boats, YSD's and MSO's were programmed and scheduled to support the training program.

TRAINING

Mk-VI training commenced on Apr. 5 for the first class of 18 aquanauts and support divers. This was a four-week course broken down as follows:

1st week - 4 days classroom
1 day pool indoctrination

2nd week - 1 day 30 ft Gulf
4 days 60 ft Gulf

3rd week - 5 days 100 ft Gulf

4th week - 1 day 160 ft Gulf
3 days 180 ft Gulf

Each man spent 15 days diving and made 20 dives for a total of approximately 7 hours in the water with the Mk-VI scuba.

This first class used only the appropriate N_2O_2 mix, as authorization to use HeO_2 had not yet been received from the Bureau of Medicine and Surgery. On May 1, authorization to use HeO_2 was received from the Bureau of Ships, provided that a portable chamber and submarine medical officer was present on the scene. On May 3 the second class of 20 Aquanauts and support divers commenced their four-week training period. Their schedule was as follows:

1st and 2nd weeks were the same as for class 1.

3rd week - 1 day 66 ft HeO_2
4 days 102 ft HeO_2

4th week - 1 day 145 ft HeO_2
3 days 190 ft HeO_2

During this second class each man spent 15 days diving and made approximately 20 dives for a total of 8 hours and 30 minutes in the water. The additional time in the water for the second class can be accounted for by the fact of the extra decompression time required while using HeO_2. By comparison, the Mk-VI course conducted at Underwater Swimmers School, Key West, provides for only 2-1/2 hours in the water; however, consideration must be given to the fact that the Underwater Swimmers School course is geared to teach the relatively inexperienced diver. This course completed the initial Mk-VI training. It had been programmed for one additional week of diving for the first class using HeO_2. This did not materialize due to additional training requirements coupled with the tight schedule on the West Coast.

The open-sea dives were conducted in the Gulf off Panama City in 30 to 200 ft of water; visibility ranged from 20 to 60 ft; hard packed bottom sand; water temperature approximately 70 F on the surface and 65 F on the bottom. During the months of April and May not one day of training was lost due to inclement weather. The diving class was supported by the UB-102 (Diving Boat) and YSD for the shallow dives and by Mine Division Eighty-one (MSO's) for the deep dives (over 100 ft).

TRANSPORTATION OF EQUIPMENT

The 20 Mk-VI rigs were originally packed in cardboard containers. Because of the distinct possibility of damage in this type of packing, it was decided to procure fiberboard steamer trunks and outfit them with molded ethafoam packing. Twenty-four trunks were outfitted, 22 for the Mk-VI rigs, one for test kits, and one for oxygen gages. Four hours were required to modify and 30 minutes to pack each trunk.

There was no damage to the rigs, kits, or gages during shipping, either by air to the west coast or by truck back to the Mine Defense Laboratory.

SUPPORT VESSEL DIVING LOCKER

The Mk-VI and open-circuit diving locker were combined in the former Support vessel electrical shop on the main deck, amidships, aft. The working area was 200 ft, which included three work benches, a deep sink, a rack for the two PPI pumps, and sufficient stowage space under the work benches for Mk-VI gear. Baralyme was stowed in a separate compartment. Utilities to the locker included hot and cold fresh water, 440-volt ac, 220-volt ac, and 110-volt ac. General lighting was excellent with the installation of work-bench lights.

Ventilation was supplied with two standard vent-type blowers and ducts. Ventilation was considered adequate for the La Jolla area, but not for tropical areas.

Accessibility to the locker was adequate, and in general it was utilized 12 hours daily by two to four men with no major problems.

Breathing-gas supply to the diving locker is discussed in Chapter 18.

During the stay of Teams 1 and 2 in Sealab, all Mk-VI cylinders were recharged in the topside diving locker. The minimum of 1500 psig which was set for excursion diving from Sealab resulted in many partially filled cylinders being sent to the surface for charging. Handling during the cylinder transfer was unavoidably rough, resulting in many repairs. All diving-gear repairs made in the topside diving locker are listed in Table 48.

Team 3 employed a charging line from topside to the inside of Sealab, allowing the empty cylinders to be charged on the bottom. This method not only saved transfer time, but reduced repairs by 90 percent.

Rigid sterilizing procedures according to Navships 250-538 were scheduled by the master diver and maintained by the personnel in the diving locker. There were no infections or virus from the diving equipment, even though all diving gear was interchanged between the individual team members several times daily.

Drying of diving gear was accomplished in plywood drying boxes which contained a blower and 3000-watt heat lamp. Six vests could be dried completely in 24 hours.

OPERATIONAL DIVING

Diving equipment for the Sealab divers was the same for each team. Three types of diving apparatus were used:

1. Mk-VI scuba. This was the standard semi-closed-circuit Mk-VI with a "K" valve installed in the safety plug access via a double "O" ring brass block. It was used for approximately 210 hours of diving during the 45 days.

2. Arawak hookah Rig. This system utilized the Sealab atmosphere through a pressure and vacuum pump arrangement. It was used approximately 84 hours.

3. Open-circuit scuba. Standard scuba using an Aqua Master DA Regulator. It was used approximately 21 hours.

In general, for deep-excursion diving to 300 ft, the Mk-VI was considered outstanding. All men agreed that the Mk-VI was superior to the open-circuit scuba. In general the men liked the Arawak, but preferred free diving with the Mk-VI.

With the Mk-VI, using 85% He, 15% O_2, gas-supply duration was, in many cases, lower than the expected 70 minutes at 205 ft. Table 49 gives the gas-supply durations for several, but not all, of the dives made by Team 3.

Table 48
Mk-VI REPAIRS MADE IN TOPSIDE DIVING LOCKER

Item	Part No.	Numbers	Remarks
Performed packings	AN6227-1	21	
	AN6227-2	2	Replaced
	AN6227-5	22	
	AN6227-7	11	
	AN6227-8	4	
	AN6227-10	13	
	AN6290-12	22	
	MS28775-002	18	
	Parker #115	6	For K-Valve Block for Buddy Breather
	Parker #104	6	For K-Valve Block for Buddy Breather
	MS29512-3	3	
Vest assembly	55299-1	3	Zippers broken, not repairable
Hose	26202-12	12	Replaced
Hose assembly male	55309-5	5	Replaced
Hose assembly female	55309-7	5	Replaced
Aqua Master DA regulator		5	Overhaul, normal use in way stations
Calypso regulator		3	Overhaul, normal, used on Buddy Breather
70 cubic foot steel cylinder		2	Used in way station, corroded beyond safe use
Spring	56860	1	Replaced
Bypass lever pin and Body Assembly	55390	2	Replaced
Canister, cover assembly	55165	1	To be replaced
		2	To be repaired with epoxy cement
		1	Repaired
Washer	55371	5	Replaced
Shell, outside	55162	7	5 repaired, 2 to be repaired
Diaphragm assembly	55268	1	Replaced
Spring	55275	3	Replaced
Spreader bar handle	55398	1	To be replaced
Exhaust valve clamps	55280	22	Replaced with 10 -/2" 3/8" 22 gauge CRES
Cylinder Stud Leaks	55393*	11	Replaced O ring and tightened
Plain elbow	55230	3	Leaking at weld, replaced

Table 48
Mk-VI REPAIRS MADE IN TOPSIDE DIVING LOCKER—Continued

Item	Part No.	Numbers	Remarks
Safety elbow	55229	3	Leaking at weld, replaced
Differential Pressure Gage	55309-3	11	Unrepairable
Body nipple and nut assembly	57493	4	2 repaired and 2 replaced
Hose	56868	4	Replaced
Test Gage assembly	29717-1	4	Recalibrated
Retainer assembly	57411	3	Replaced
Gasket	57410	8	Replaced
Inhalation bag	55299-5	4	To be replaced
Exhalation bag		2	To be replaced
Diaphragm assembly	57378	9	Replaced
Shim (diaphragm) gasket	57379	9	Replaced
Spring clip	56896	2	Replaced
Nozzle assembly	57344	3	Replaced

Table 49
GAS SUPPLY DURATION FOR TEAM 3
(Does Not Include All Dives—Gas Mix—85% He 15% O)

Length of Dive (min)	Total Gas Used (PSIG)	Pressure After Setting Up the Mk-VI for Diving (PSIG)	Pressure After the Dive (PSIG)
29	1100	2700	1600
29	1100	2700	1600
32	1550	2600	1050
32	1400	2800	1400
27	1350	2750	1400
55	2300	2800	0500
70	2800	2800	0000
40	1450	2500	1050
45	2050	2750	0700
27	1150	2700	1550
27	1250	2650	1400
37	1500	2400	0900
37	1900	2700	0800
33	1200	2400	1200
33	1500	2800	1300
27	1400	2700	1300
27	1300	2600	1300
21	1100	2900	1800

Table 49
GAS SUPPLY DURATION FOR TEAM 3—Continued
(Does Not Include All Dives—Gas Mix—85% He 15% O)

Length of Dive (min)	Total Gas Used (PSIG)	Pressure After Setting Up the Mk-VI for Diving (PSIG)	Pressure After the Dive (PSIG)
21	1500	2900	1400
40*	2900	2900	0000
40	1800	2900	1100
32	1900	2900	1000
22	1100	2600	1500
32	1900	2900	1000
45	2100	2700	0600
40	2000	2700	0750
42	1800	2800	1000
42	1700	2650	0950
29	1950	2850	0900
29	1400	2800	1400
29	1150	2650	1500
29	1200	2800	1600
60	2600	2900	0300
41	1950	2750	0800
42	1950	2750	0800
42	2000	2700	0700
33	1525	2500	0975
33	1500	2900	1400
48	1350	2300	0950
30	1450	2750	1300
30	1400	2700	1300
38	1500	2800	1300
38	1500	2800	1300
35	1500	2800	1300
36	1450	2750	1300
44	1900	2500	0600
44	2100	2600	0500
36	1700	2600	0900
55	2200	2500	0300
55	2100	2800	0700
53	2000	2700	0700
300-ft 50	2350	2800	0450
dives 50	2100	2800	0700
20 min 36	1700	2700	1000
at 36	1500	2600	1100
depth 47	2050	2650	0600
47**	2600	2600	0000
38	1450	2650	1200
38	1600	2700	1100
50	1500	2700	1200
50	2100	2700	0600
50	1800	2800	1000
50	1900	2700	0800
65	2600	2650	0050
65	2750	2750	0000
65	2550	2750	0200

*Forty minutes, no gas left, was found to be caused by damaged exhaust valve. Diver used his bypass often.

**Diver used bypass only one time. Check of rig was ok after dive.

NOTE: Gas supply durations for open circuit using twin 90-cu-ft cylinders was a maximum of 25 minutes at 205 ft. The gas mix used was 85 He, 15 O_2.

Chapter 48

CARBON MONOXIDE IN THE ATMOSPHERE OF SEALAB II

Merle E. Umstead,
Naval Research Laboratory
Washington, D. C.

During the latter part of the Sealab II operation, the occupants of Sealab frequently complained of headaches. The presence of carbon monoxide in the atmosphere was suspected as a possible cause, and tests were carried out for its detection.

Carbon monoxide measurement by means of detector tubes inside Sealab indicated the presence of about 150 ppm of CO. Similar detector-tube measurements on the surface with air from the sampling line from Sealab showed about 25 ppm. This difference is to be expected, since in using detector tubes, a fixed volume of air is drawn through the tube and a color change measured. In Sealab, at seven atmospheres pressure, the sample at STP would contain seven times as much gas as that used in a similar test carried out on the surface at atmospheric pressure. In addition to these tests, a compressed sample of Sealab air was taken on Sept. 28 and sent to the Linde Company for analysis. A value of 25 ppm CO was reported.

In an attempt to remove the CO from the Sealab atmosphere, four of the lithium hydroxide canisters in the CO removal system were partially filled with Hopcalite, a catalyst used aboard nuclear submarines for the oxidation of CO. Later, silica gel was placed in the air stream ahead of the Hopcalite, since it was known that Hopcalite is an effective catalyst for CO removal at room temperature when dry, but is not so effective when wet.

At this time, a Beckman GC-2A Gas Chromatograph that was being used aboard the support vessel for trace organic contaminant analysis was equipped with a molecular sieve column to attempt to monitor the CO concentration in Sealab. By taking a massive air sample and pushing the detector sensitivity to its limit, CO could be estimated reasonably well. The full capability of the instrument was impaired, because the chromatograph's hot-wire detector was sensitive to the wave motion of the vessel. However, it was possible to follow the CO concentration, and it was found that from the time of the installation of the Hopcalite and the chromatographic monitoring, the CO level in Sealab diminished gradually until the end of the operation.

Samples of Sealab air were taken daily by means of stainless steel gas bottles for trace organic contaminant analysis. The evacuated bottles were sent down to Sealab and filled to ambient pressure. Thus, when the bottles were returned to the surface, they were under a positive pressure of about six atmospheres. A number of these samples were retained for later, more detailed analysis at NRL including identification of the individual contaminants. The bottles saved were spaced over a large protion of the Sealab operation. These samples were analyzed at the Laboratory for CO by means of a gas chromatograph equipped with a Karmen electrical-breakdown detector (1, 2) which provides high sensitivity for gases such as CO.

The bottle samples provided sufficient data to obtain a profile of the CO levels over most of the Sealab II operation. The data are plotted in Fig. 169. This figure shows that during the first few weeks, the CO concentration rose linearly at a rate of 1.57 ppm per day. Based upon a free volume of 4500 cu ft, and a pressure of 7 atm, this rate corresponds to the liberation of 1.4 liters (STP) of pure CO per day to the Sealab atmosphere. During the latter few weeks of the operation, the CO concentration gradually decreased. Unfortunately, no samples were available for the intermediate period. As may be seen from the extrapolated line in Fig. 169,

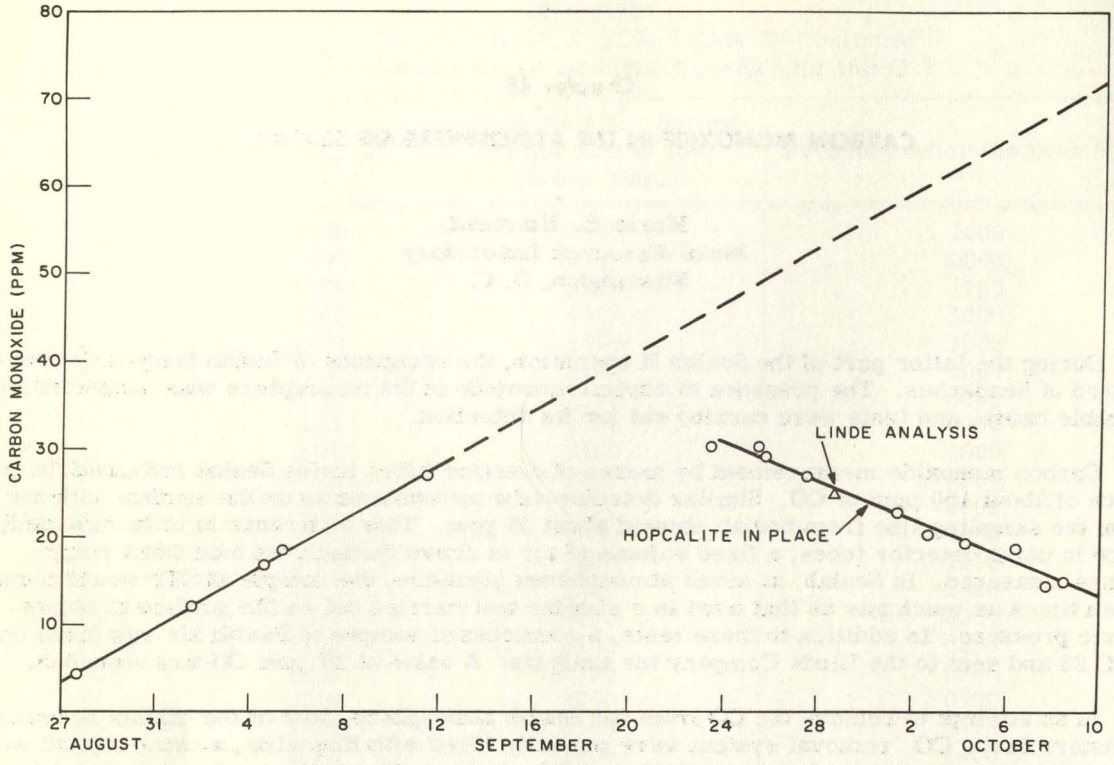

Fig. 169. Carbon monoxide concentration in Sealab II

if CO had continued to build up at the initial rate, the concentration in Sealab would have reached 70 ppm by the end of the operation.

It was very surprising to find that the CO concentration in Sealab had been decreasing for several days prior to placing Hopcalite in the system. Also, there was no noticeable change in the slope of the curve after the Hopcalite was in place. This result raises doubts as to whether the Hopcalite was at all effective in removing CO under the conditions in which it was used. It is possible that CO was generated through some process, such as cooking, which was stopped when CO was suspected of being a problem. After this, the CO was removed gradually by some still unknown mechanism.

It should be emphasized that the CO values reported in Fig. 169 are expressed in parts per million, as is commonly done when considering samples at atmospheric pressure. However, Sealab II was at 7 atm pressure, and the effects of CO at high pressures are not known. If the physiological effects of CO are dependent upon its partial pressure, as is true for oxygen and carbon dioxide, then the physiologically effective concentration of CO in Sealab would correspond to seven times the values given in Fig. 169.

Based on the results found to date, it is recommended that:

1. Investigations be made of possible sources of CO in an enviroment such as Sealab.

2. An accurate and sensitive method of monitoring CO be developed for use for future Sealab.

3. Equipment be developed for removing CO from atmospheres under high pressures and humidity and a low percentage of oxygen, based upon catalytic oxidation or some other principle.

4. Attention be given to studying the physiological effects of CO at high pressures.

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13. ABSTRACT

Sealab II operations conducted by the Office of Naval Research as a part of the man-in-the-sea task of the Deep Submergence Systems Program was an interdisciplinary investigation into the usefulness of ocean floor habitation by the measurement of the ability of man to do useful work while living as a saturated diver in equilibrium with the ocean-floor pressure.

Ocean-floor tasks of the 28 Navy divers and civilian scientists included working dives for studying human physiology and performance, experimental salvage techniques, biological and physical oceanography, and the evaluation of the undersea habitat and associated diving equipment.

The Sealab II operation was conducted between Aug. 28 to Oct. 14, 1965, 300 ft off Scripps Pier at La Jolla, California, in a depth of water of 205 ft. Using a synthetic breathing gas of helium, oxygen, and nitrogen, each of the three aquanaut teams lived under pressure approximately 15 days in an ocean-floor habitat, making forays into the 48° F, 5 to 30 ft visibility bottom waters for periods ranging from a few minutes to an extended dive of 3 hours. Excursion no-decompression dives to 266 ft and 300 ft were accomplished. Diving from the habitat was accomplished using both semi-closed-circuit breathing apparatus and hookah (habitat-connected-hose) breathing apparatus. A decompression complex new to the Navy consisting of a personnel transfer

(Abstract Continues)

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Underwater Underwater Equipment Underwater Habitation Ocean Bottom Diving Saturation Diving						

(Abstract Continued)

capsule mating with a deck decompression chamber was used for accomplishing recovery and decompression of aquanauts.

Sealab II demonstrated that:

1. The concept of ocean-floor habitation to accomplish a wide range of salvage and scientific tasks is compatible with man's ability to perform useful work at these depths.
2. No significant short-time physiological changes occur which resulted in deterioration of the aquanauts physical condition.
3. There is a degradation of human performance which increases with the complexity of the task being accomplished.

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