

Summary Report on Project Tektite I

A Multiagency
60-Day Saturated Dive
Conducted by
the United States Navy, the
National Aeronautics and Space Administration,
the Department of the Interior,
and the General Electric Company

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January 16, 1970



OFFICE OF NAVAL RESEARCH
Washington, D.C.

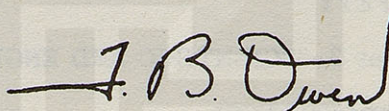
FOREWORD

Tektite I was this country's first multiagency program to exploit man's ability not only to live on the bottom of the sea but to perform meaningful scientific work. Previous man-in-the-sea programs have concentrated on the advancement of under-sea technology, whereas the mission of Tektite emphasized existing technology as a means for obtaining scientific results.

The national interest in future use of the sea, and the significance of Tektite I of furthering this interest, is summarized in President Nixon's message to the aquanauts at the end of their historic mission:

"Your record breaking venture into inner space is another milestone in human achievements. The aquanauts join the astronauts as space pioneers. Congratulations!"

The success of Tektite I constitutes a major step in using man in the sea for the scientific exploration of the nation's continental shelf. The Navy, as the Tektite I lead agency and cosponsor with the National Aeronautics and Space Administration the Department of the Interior, and the General Electric Company, is pleased to present this Tektite I final report.



Chief of Naval Research

AUTHORS' COMMENT

This "Summary Report on Project Tektite I" (ONR Report DR 153 S), although identical to chapters 1 through 5 of the "Report on Project Tektite I" (ONR Report DR 153), is published separately here for convenience. The subjects addressed in summary in this report are treated in detail by the individual investigators in Appendixes, which constitute the additional portion of ONR Report DR 153.

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ABSTRACT

Project Tektite I, under the overall cognizance and management of the Chief of Naval Research, involved the Departments of the Navy and Interior, the National Aeronautics and Space Administration, the General Electric Company, and other government, industry, and academic organizations. An ocean floor habitat at a 49 foot depth and the supporting facilities were established and evaluated for 60 days at a carefully selected, isolated site in the Virgin Islands from February 15 to April 15, 1969. Four marine scientists lived in and worked out of the habitat for the 60-day period, during which their research emphasized marine biology and geology. This was twice as long as men had previously lived under saturated diving conditions and the only such experiment to use a controlled nitrogen/oxygen atmosphere with a normal 0.2-atmosphere oxygen partial pressure. Through continual television and auditory monitoring, medical doctors, psychologists, and diving engineers studied the aquanauts' biomedical responses to the 60-day saturation dive and their behavioral and other psychological responses to each other, to their work, and to their isolated, hostile environment.

The Tektite I experiment was completed with a perfect safety record within minutes of the time scheduled many months previously. The successful operation demonstrated that men can live together and perform safely and effectively on the ocean floor for extended periods and provided specific psychological, physiological, and marine scientific results which can be applied to future space and undersea missions.



Frontispiece

Chapter 1

HISTORY AND OBJECTIVES

"If, instead of sending the observations of seamen to able mathematicians on land, the land would send able mathematicians to sea, it would signify much more to the improvement of navigation and to the safety of men's lives and estates on that element."

Sir Isaac Newton, 1692

INTRODUCTION

The U.S. Navy, the National Aeronautics and Space Administration, the Department of the Interior, the General Electric Company, and many other participating organizations were brought together in project Tektite I with very much the same theme as that given in Sir Isaac Newton's statement of 1692, but with a variety of professions involved. In Tektite I the marine scientist removed himself from his shore laboratory and home and became an in-situ partner with the in-vivo marine life. The behavioral psychologist directly observed this marine scientist removed from his normal environment to determine his responses to the real isolation, stresses, and hazards that were part of his new environment.

The synergistic use of saturation* diving from a habitat to conduct marine science and the observation of the habitat occupants as subjects for behavioral studies evolved from the U.S. Navy's Sealab II man-in-the-sea project.† Two of the conclusions of that project, conducted by the Office of Naval Research in August-September 1965, were:

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

*"Saturation" refers to the state of the dissolved gases in the tissues of the diver. Under a saturated tissue condition, the diver works out of a habitat whose atmosphere is maintained at approximately the same pressure as that of the water in which he will be working. His habitat may be an ocean floor installation maintained at the ambient outside water pressure or maybe a pressurized deck decompression chamber (DDC) on board a surface vessel from which he travels to his work location in a pressurized personnel transfer capsule (PTC). In either case he does not undergo decompression between working dives; he is decompressed only after his total dive sequence. Whether a series of conventional, nonsaturated, short dives are used or a saturated dive is used depends on many factors (even assuming that the equipments necessary for each are available). The primary factors, however, are the time required to accomplish the diving tasks, the number of divers available who are qualified for the specific tasks, and the depths of water of the task.

†D. C. Pauli and G. P. Clapper, "An Experimental 45-Day Undersea Saturation Dive at 205 Feet," ONR Report ACR-124, March 8, 1967.

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

Analysis of the Sealab II behavioral observations yielded significant information for understanding the behavior of small groups of men conducting real work while isolated in a hazardous environment.

To the behavioral psychologist the undersea laboratory becomes an exciting observational situation. Closed-circuit television provides one of the usual modes for operational and engineering monitoring of the habitat as well as a vital communication link between the occupants and the surface support personnel. By simple remote extensions, these closed-circuit links can be used at observational stations. The behaviorist thus is enabled to collect voluminous, valid data on a real situation. The subjects are engaged in real work in a hazardous environmental situation which involves stress and isolation.

To the marine scientist the habitat-laboratory affords the opportunity to investigate biological and ecological processes unencumbered by the need to return to the surface. Thus, by not being encumbered by the restrictions of repetitive surface dives, he can return to the site of his investigations as many times during the day and night that his life support systems will permit. He is no longer physiologically restricted; he is limited only by life-support equipment and human endurance. This becomes a very important factor in considering the applicability of saturated diving to the research to be undertaken. Thus, in Tektite I the study of the behavior of lobsters, for example, was integrated with many other scientific dives which occurred at various times during both day and nighttime. In this manner a cohesive 2-month marine science program became a reality for four scientists to conduct.

HISTORY

The similarity between crew behavioral aspects of a long-duration operational saturation dive and a space mission was suggested in November 1966, in a side discussion between Office of Naval Research and National Aeronautics and Space Administration psychologists at a NASA Symposium on Isolation and Confinement. This suggestion led to ONR/NASA meetings, later in 1966 and early in 1967, to develop a rationale for the validation of a hypothesis that behavioral, habitability, and crew effectiveness data obtained in observations of undersea teams could be used to predict and understand similar problems involving space teams.

Based on these early meetings, NASA in June 1967 awarded two study contracts concerning the validation of extrapolating marine mission data to space missions. Technical progress under these contracts was jointly watched and monitored by NASA and Navy technical and management personnel. The results of these study contracts strongly supported what had been suggested in the original NASA/Navy discussions - that behavioral, crew effectiveness, and habitability data could be obtained in underseas operations.

During the concluding months of the contracted studies it became evident that missions involving real work were required to obtain valid extrapolative data. The Department of Interior, who over the course of 1967 had come to an agreement with the Navy for "cooperative study of problems of mutual interest," was invited to participate in monitoring the NASA sponsored studies and formally became the third member in November 1967.

In December 1967 the General Electric Company formally submitted to the Office of Naval Research, lead agency for the government, an unsolicited proposal to conduct the undersea space/marine mission recommended in the concluding studies. The mission would be of 60 days duration and would study the ability of a small group of saturated

divers to successfully carry out a scientific mission under hazardous, isolated conditions. The project title Tektite comes from the name for small particles of space-born matter which survive the fiery plunge through the earth's atmosphere and come to rest on the ocean's floor. Tektite I would be jointly sponsored by the Navy, NASA, and Interior Department. In addition, the basic Tektite I habitat would be furnished by General Electric, financed primarily by company Industrial Research and Development funds.

AGENCY INTERESTS

The interests in Tektite of the three agencies - Navy, NASA, and the Department of the Interior - relate to their national responsibilities. Generally the Navy's interests were the study of diving physiology and small-crew psychology, for future submersible and saturated diving missions and advances that could be made in ocean technology. NASA's interests of small-crew psychology and behavior were oriented toward long duration space flight, as in orbiting laboratory or post-Apollo missions. The Interior Department's interest was the use of saturated diving to broaden man's capability to conduct scientific work in the sea. A closer look at the roles of each agency shows the areas of interest and responsibility of each.

Navy Interests

The Navy interests in Tektite I were reflected in overall project coordination and management, development of techniques for accomplishing the behavioral and biomedical scientific mission objectives, engineering evaluation of the shallow-water Tektite I habitat, and operational and technological procedures, including safety.

The Navy was the "lead agency" of the three agencies supporting Tektite. Through the Office of Naval Research, the Navy had the responsibility for overall program and scientific management and for administration of the General Electric Tektite I contract. An additional Navy responsibility in Tektite I, and perhaps the most important, was mission safety, both in the operational and scientific conduct of the program.

The Office of Naval Research was responsible for the overall planning of the behavioral and biomedical programs, and integration and coordination of the overall Tektite I scientific program. The Navy, during the Sealab II program, developed basic field observation techniques for the behavioral studies of small crews living in undersea habitats. Tektite I presented opportunity for further development of these techniques and acquisition of additional data. The key scientists from the Sealab II program developed the Tektite I behavioral program in conjunction with NASA and Interior. The Tektite I biomedical program, likewise, was developed by Navy medical personnel, and by contract research scientists of ONR (such as the University of Pennsylvania) working with Navy and NASA biomedical personnel. In addition to the stated scientific goals in the mission objectives, Tektite I also provided the Navy the opportunity for exploration in related areas of underwater technology, such as saturation diver safety, ocean engineering, and construction.

The Navy provided the operational direction for implementation of the Tektite I program. Naval command experience provided the operational experience necessary to support the scientific program. Transportation, logistics, communication, and support construction and facility requirements operation were supplied by various naval organizations.

NASA Interests

NASA's primary interest in Tektite I was the study of the performance of highly qualified scientists under conditions of stress for use in understanding and predicting man's behavior on long-duration space flights.

The four Tektite I aquanauts experienced true locked-in isolation due to their saturated diving condition, which prohibited vertical ascents to the water's surface. Reactions to their living, working, and recreation environments were recorded by systematic observation, by automatic event recording, and by subjective opinion. Measures were made of group cohesiveness and the adjustment of each crew member to the others, to his environment, and to his assigned duties. The marine scientific mission plan provided the scientific crew the goals necessary for maintaining a continuous high level of motivation required for meaningful extrapolation of the behavioral data to space flight. The ability of the crew to conduct their own mission and their willingness to attempt tasks not directly related to their scientific training were evaluated as well as the extent of their dependence on an outside technical crew. Biomedical measures were made to assure crew safety and to evaluate the psychological effects of activities inside and outside the habitat on the measurable physiological functions of the crew.

The NASA scientific responsibilities were reflected in the hematology portion of the biomedical research program and in the sleep and psychomotor studies in the behavior program. The Tektite I data collection program, developed under NASA contract, was the primary means of accumulating daily the crew behavior, biomedical and habitability and engineering data required by each investigator. NASA management responsibilities were in the development of the behavioral program, and in overall program management in concert with the other agencies.

Department of the Interior Interests

The Department of the Interior's fundamental interest in Tektite I was to accomplish a diversified research program with a small group of marine scientists using saturated diving techniques. The two primary objectives were: evaluate saturated diving as a research technique for marine science studies, and conduct an operational research program on the ocean floor to demonstrate that scientists can live and work effectively on the ocean floor.

For years marine scientists have recognized the advantages of having direct access to the undersea environment for extended periods of time. To this end, self-contained underwater breathing apparatus (scuba) equipment and research submersibles have provided only partial solutions to depth, time, and mobility limitations. Manned habitats, such as the Tektite I habitat, using saturated diving have offered a research tool which appears to have many advantages for prolonged studies of the ocean floor.

INTERAGENCY COOPERATION

Although Tektite had been preceded by several underwater living experiments, some at greater depths, several distinguishing features set it apart from these earlier experiments. Primary among these is that Tektite was the first major venture undertaken whose objectives were primarily scientific rather than technological. Close liaison and communication between participating members from all organizations involved was necessary to accomplish a cohesive program. For example, the behavioral and biomedical studies conducted by the Navy and NASA, concurrent with Interior's ocean floor program, were designed for the minimum interference with the marine research activities

of the crew. The mutual Navy and NASA interests in the behavioral and biomedical portions of Tektite required a high degree of interaction between the scientists of both agencies for optimization of efforts and results. General Electric integrated the program needs into a habitat system that could satisfy the divergent requirements placed on it. The success of Tektite I was due largely to the spirit of cooperation that prevailed throughout the entire project, from conception through execution.

The major participating activities and their primary responsibilities and contributions were:

NAVY

Office of Naval Research

Headquarters: Overall project management, scientific program coordination, direction of on-site operations, funding support, logistic coordination, overall safety responsibility.

Naval Biological Laboratory: Planning and execution of the Tektite I microbiological studies.

Naval Research Laboratory: Laboratory analysis of habitat atmosphere, logistic support throughout operation.

Naval Facilities Engineering Command

Headquarters: Design of habitat installation methods, design habitat surface support AMMI barge facility, on-site installation and retrieval of habitat and other equipment, operational responsibility for emplacement and retrieval of habitat and support systems.

U.S. Atlantic Fleet

Amphibious Construction Battalion TWO: Implementation of habitat installation methods and equipment, assembly of support AMMI barge, design and construction of base camp, operation and maintenance of habitat support system.

Amphibious Force, Atlantic Fleet: Transportation of habitat system, base camp equipment and materials, and project personnel to the Tektite site and return.

Bureau of Medicine and Surgery

Chief, Bureau of Medicine and Surgery: Review and approval of medical and safety plans, assignment of medical personnel to project.

Naval Submarine Medical Center: Development of Tektite decompression schedule, participation in biomedical program, aquanaut physical and psychiatric examinations, medical personnel on site.

Naval Medical Research Institute: Planning and execution of behavioral program, equipment and technical assistance for behavioral program, on-site monitors and supervisors, data reduction.

Naval Medical Neuropsychiatric Research Unit: Planning and execution of Navy sleep studies.

Naval Ship Systems Command

Supervisor of Salvage: Decompression facilities and personnel, diving personnel assistance, small boat and equipment support.

Experimental Diving Unit: Atmospheric monitoring equipment and operators, diving officers and personnel.

Philadelphia Naval Shipyard: Assembly of Tektite I habitat, services for assembly of habitat support barge, dock facilities for loading and unloading of Tektite hardware at beginning and end of project.

Supervisor of Shipbuilding, Conversion, and Repair, Tenth Naval District: Critical repair facilities for boats and electronic equipments, logistic support.

Submarine Acquisition Project Office: Material safety review of habitat and support systems.

DEPARTMENT OF INTERIOR

Planning and management of marine science program, program management, funding support, aquanaut crew and two backup crew members, surface scientific and diving support for marine science program, scientific and diving equipment for aquanaut crew, operational site in the Virgin Islands National Park.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Headquarters: Program management, funding support, data management program, behavioral program support.

Manned Spacecraft Center: Planning and execution of NASA sleep studies, development of hematology program, develop emergency decompression tables.

Marshall Spaceflight Center: Crew habitability program.

Langley Research Center: Furnish, install and maintain mass spectrometer atmosphere analyzer, implementation of psychomotor experiment.

GENERAL ELECTRIC COMPANY

Missile and Space Division: Habitat design and fabrication, scientific program integration assistance, preparation of scientific program planning documents, personnel and technical support for on-site operations.

COAST GUARD

Safety diver support personnel, diving watch officer on-site, support in implementation and assessment of safety program.

ASSOCIATED SUPPORT

University of Pennsylvania: Biomedical program coordination and support, biomedical pre-dive base line data, post-dive biomedical diver assessment.

College of the Virgin Islands: Marine science program support, site survey support, backup aquanaut.

Battelle Memorial Institute: Engineering support to the Office of Naval Research, engineering review of Tektite I program.

Particular mention is made of the Navy SEABEES' extensive and energetic work in Tektite I. The SEABEE force was comprised of officers and men from Amphibious Construction Battalion TWO, with additional SEABEE divers from both the Atlantic and Pacific fleets. The SEABEES were active through the project, both in implementing the Navy's engineering program and in supplying construction and maintenance services for all on-site Tektite facilities.

Chapter 2

SYNOPSIS

MISSION

The missions of Tektite I were threefold: (a) to study the behavior and effectiveness of a small group of highly trained men to real work under stressed, isolated conditions, (b) to study biomedical responses of men living under high-nitrogen-partial-pressure saturated conditions in the marine environment for an extended period, and (c) for the men under study in (a) and (b) to conduct meaningful marine science research from an undersea habitat under the advantageous and disadvantageous boundary conditions imposed by saturation diving. Since the three missions are interdependent, equal emphasis had to be placed on each. Coincident with those three scientific missions was a Navy ocean engineering program to advance the scientific utilization of underwater habitats.

The selected mission duration was 2 months, from February 15 to April 15, 1969. During this time the aquanaut scientists were saturated to a water depth of 43 feet. At the end of the mission, a decompression schedule approximately 20 hours long was required to return the aquanauts safely to the surface.

SITE

The site selected for Tektite I was Lameshur Bay, St. John Island, U.S. Virgin Islands (Fig. 1). This site is in the southeast quadrant of the island and within the boundaries of the Virgin Islands National Park, which includes two-thirds of St. John Island and most of the offshore waters. Because Lameshur Bay is within the park, a special "use permit" was required from the National Park Service to conduct the project. The site selection was based on five primary factors:

1. Shallow water. The acceptable depth range of the habitat for conducting the saturation dive on a mixture of O_2 and N_2 over the 60-day period was set at 40 to 60 feet.
2. Biological activity. The biological activity of the area selected had to be abundant to assure the ability to develop a valid continuous, long-duration marine science program. There was a great biological diversity of marine plant and animal species in Lameshur Bay enhanced by the presence of extensive coral reefs. Since the waters of Lameshur are characteristic of the tropical waters of the Caribbean, South Pacific, and Indian Oceans, marine research conducted there would be applicable to many parts of the world.
3. Shelter from storm. In the January-to-May period required for the total Tektite I startup, operation, and withdrawal, the Lameshur Bay area was historically expected to be extremely sheltered from the sea. With the exception of one unseasonable storm, the predicted weather conditions prevailed.
4. Low subsurface water currents. Subsurface current conditions were less than 0.25 knot except during the unseasonable southerly sea condition experienced, when surge currents were estimated to be of the order of 0.5 knot.

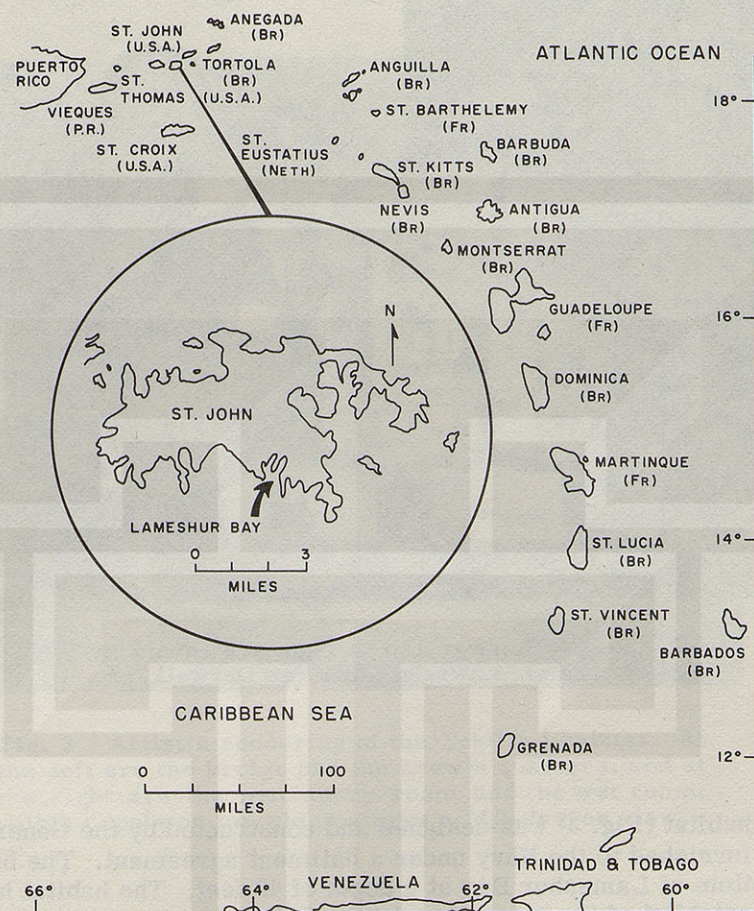


Fig. 1 - Location of Lameshur Bay, Virgin Islands, the Tektite I site

5. Logistics supportability. Logistics is a major problem to a project conducted in a remote location. This was a contributing factor in selecting the Virgin Islands site over other islands in the vicinity. Even so logistics were considerably more difficult than was envisaged. While nearby St. Thomas was the source of most operating supplies that were not originally brought in the installation phase, many components and services unique to this type of operation had to be obtained from the mainland and Puerto Rico, which entailed detailed expediting to minimize time and in-transit loss of materials.

CREW

Four marine scientists from the Department of the Interior were the Tektite I aquanauts (Fig. 2):

Richard A. Waller - Oceanographer, Bureau of Commercial Fisheries
 Conrad V. W. Mahnken - Oceanographer, Bureau of Commercial Fisheries
 John G. Van Derwalker - Fishery Biologist, Bureau of Commercial Fisheries
 H. Edward Clifton - Geologist, U.S. Geological Survey

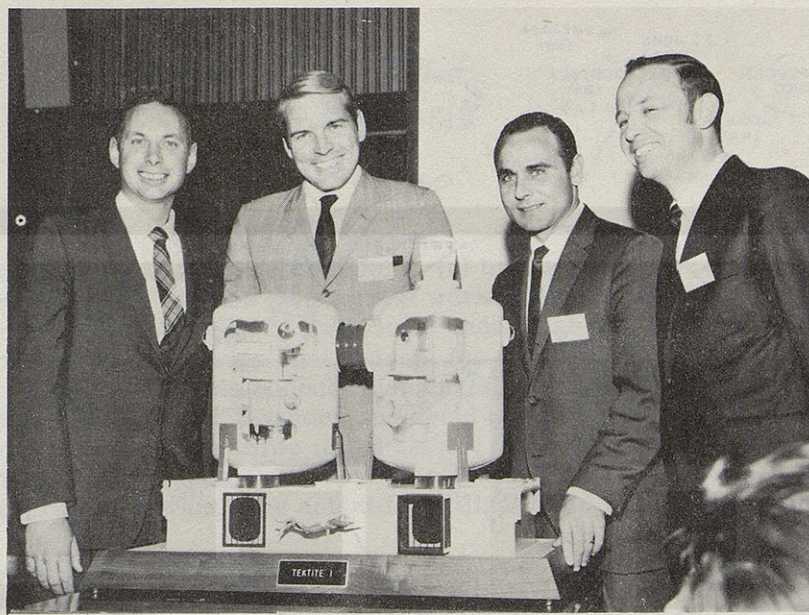


Fig. 2 - Tektite I crew: left to right are aquanauts Clifton, Mahnken, Waller, and Van Derwalker

HABITAT

The Tektite I habitat (Fig. 3) was designed and constructed by the General Electric Company and was furnished to the Navy under a bailment agreement. The habitat was installed on the bottom of Lameshur Bay at a depth of 49 feet. The habitat hatch, 6 feet above the bottom, established the saturation depth of 43 feet.

BASE CAMP

To conduct the total Tektite I scientific mission, approximately 35 scientists and 65 support personnel were required. A base camp was constructed adjacent to Lameshur Bay (Fig. 4). This camp functioned as the living quarters for all Tektite I personnel, military and civilian, except the four aquanauts.

PROJECT ORGANIZATION

Although the Tektite I mission was 60 days in duration, the total time required to plan, execute, and evaluate the project was in excess of a year and a half. Project activities during this time were divided into five phases which describe the evolution of Tektite I.

Phase I: Detailed program plans, equipment design and fabrication, and base camp construction. During phase I, begun in early 1968, the habitat and its supporting systems were designed and built, and the project's scientific programs were planned and coordinated. The facilities required for support at Lameshur Bay were designed and constructed. Baseline biomedical and psychological data were obtained. This phase ran through January 8, 1969, when the Tektite I habitat was loaded aboard the USS Hermitage for shipment to the Virgin Islands.

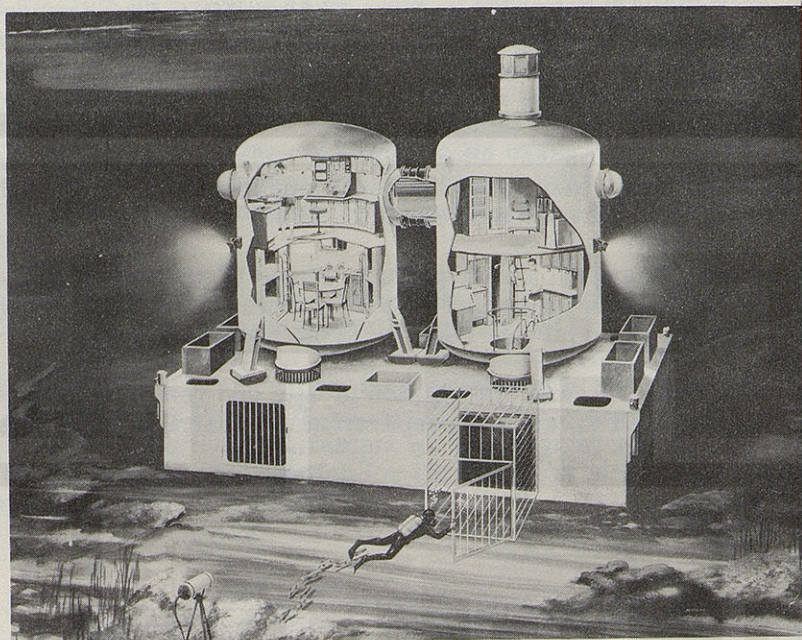


Fig. 3 - Artist's rendering of the Tektite I habitat. At the left are the bridge and the crew's quarters, and at the right are the machinery room and the wet room, with a cupola on top which allows a 360-degree view.

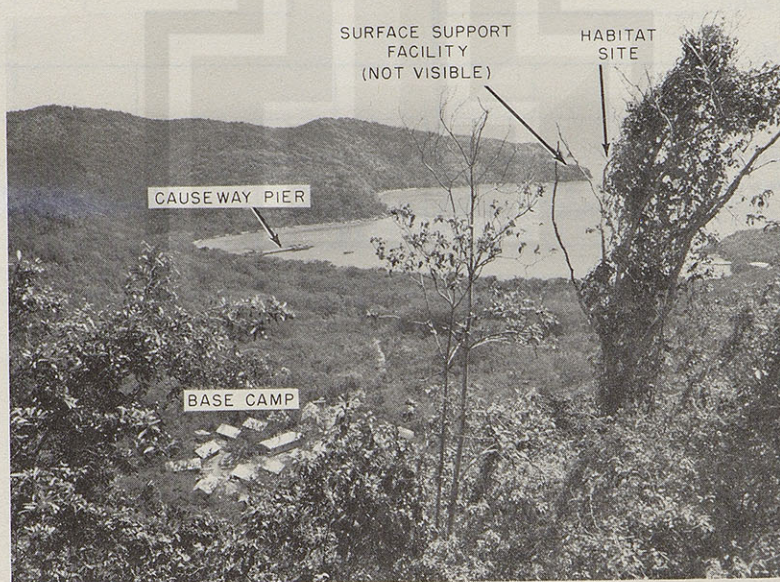


Fig. 4 - Tektite I experiment site, Lameshur Bay, St. John, Virgin Islands

Phase II: On-site preparation, equipment installation, and checkout. The major work during phase II began in January 1969, when the Tektite I habitat and its supporting equipment and personnel arrived at Lameshur Bay. The habitat and supporting equipment were installed. The marine science equipments were readied. The major remaining supporting logistics problems were solved. Upon final approval of the results of the systems checkout of the habitat/surface control complex, phase III was initiated.

Phase III: Major experiment phase. Phase III was, essentially, the 60-day mission. Phase III began when the Tektite I habitat became operational and ended when the four aquanauts completed their decompression on April 16, 1969.

Phase IV: Equipment withdrawal and dispersal. Phase IV was, essentially, the inverse of phase II. Phase 4 began on April 16, 1969, and was completed on June 10, 1969, when the last of the Tektite I material was removed from Lameshur Bay.

Phase V: Reduction, analysis, and distribution of data and results. Efforts during phase V were primarily directed toward the preparation and distribution of this Tektite I final report.

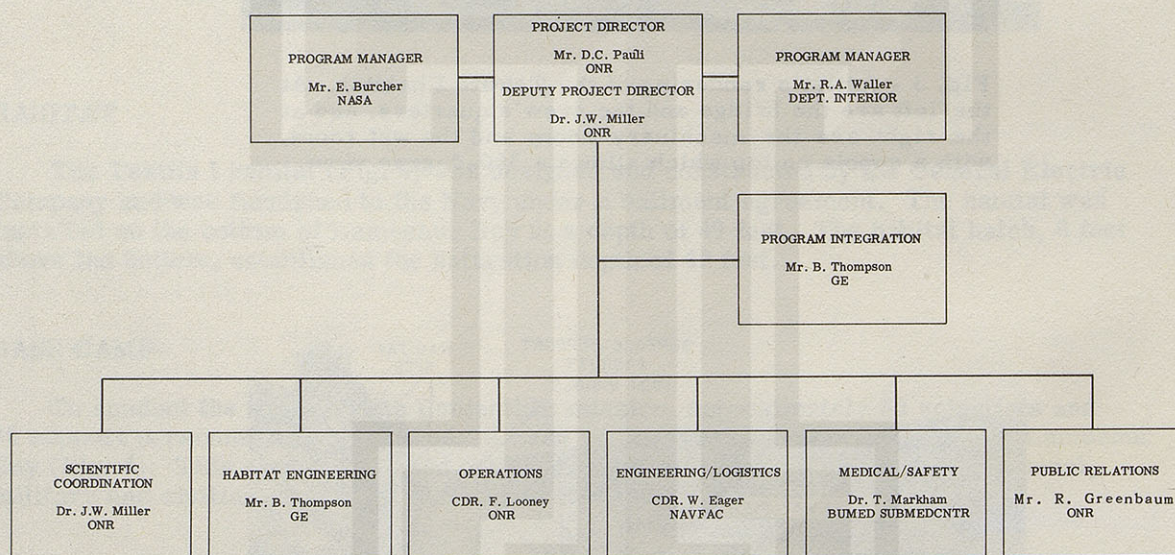


Fig. 5a - Scientific Management Organization Structure

The Tektite I Program Plan and Operation Plan documented the scientific and operational organization and conduct of the project. The Tektite I Program Plan was prepared by General Electric as a part of their contract task, and contained four parts: Scientific Mission Requirements Plan, Safety Plan, Transportation and Assembly Plan, and Emplacement Plan.

The Tektite I Operation Plan was promulgated by the Chief of Naval Research. The Operation Plan implemented the on-site portions of the project, designated command structures, and delineated standard and emergency bills. A primary function of the Operation Plan was the establishment and implementation of project safety standards and procedures.

The Operation Plan identified two distinct organizational authorities: administrative and operational (Fig. 5). The administrative authority (Fig. 5a) was primarily concerned with the scientific management of Tektite I and remained constant throughout all of the project's five phases. The operational authority was in effect only during the three operational phases (i.e., Phases II, III, and IV). The operational authority for Phases II and IV (Fig. 5b) reflects the requirement for engineering responsibility during these phases. The operational organization for the sixty day major experiment phase, Phase III, is shown in Figure 5c.

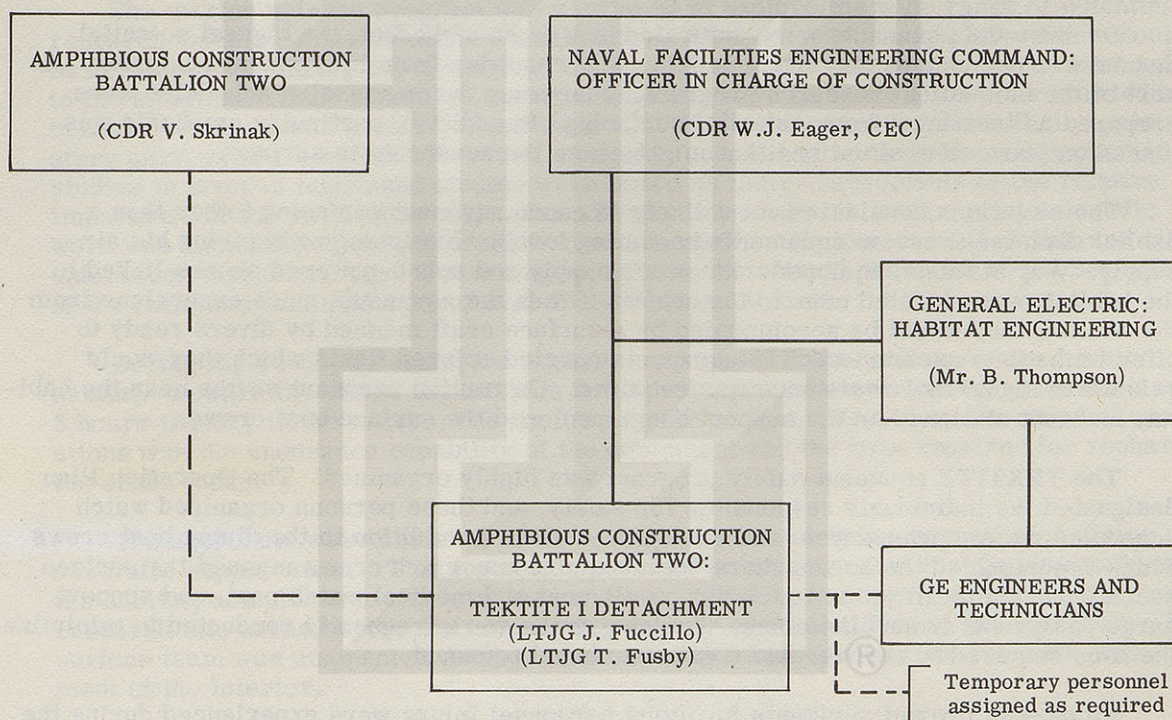


Fig. 5b - Operational Command Structure (Phases II and IV)

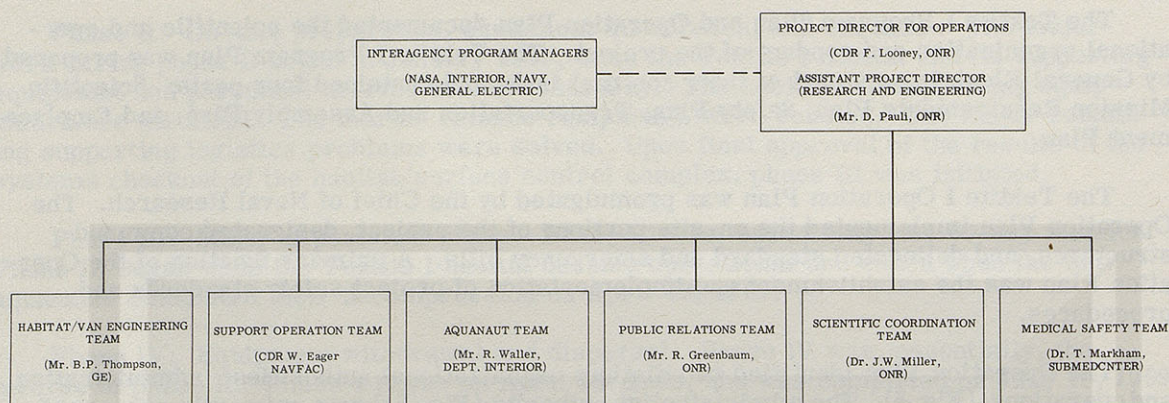


Fig. 5c - Operational Organization Structure (Phase III)

SAFETY

The foremost consideration throughout TEKTITE I was the safety of the personnel involved, particularly the aquanauts. The impact of extensive safety consciousness is evident in all aspects of TEKTITE I.

Because the aquanauts were saturated to a depth of 42 feet, the biggest potential hazard was decompression sickness ("bends") resulting from inadvertent surfacing. As part of the biomedical research program, emergency decompression schedules were prepared as treatment for accidental surfacing. In addition, particular emphasis was placed on preventing situations that might cause the aquanauts to surface.

The situations considered most likely to cause aquanaut surfacing (other than a habitat disaster) were an aquanaut's becoming lost, or his losing or expiring his air supply. Way stations, equipped with an air supply and sound-powered phones linked to the habitat, were located near to the habitat. When the aquanauts made excursions from the habitat, they would be accompanied by a surface craft manned by divers ready to offer immediate assistance. The aquanauts carried colored floats which they would release to signal that assistance was required. On routine aquanaut swims near the habitat, lookouts stationed on the support barge replaced the surface boat crews.

The TEKTITE aquanaut safety program was highly organized. The Operation Plan designated the individuals responsible for safety, and these persons organized watch schedules, safety procedures, and emergency bills. In addition to the diving boat crews which accompanied the aquanauts on their excursions, watch crews manned the surface decompression facility, the watch director's post and medical watch post, and support barge equipment around the clock. Training drills were frequently conducted to minimize the time required to recover and treat a surfaced aquanaut.

No on-site project accidents involving personnel injury were experienced during the entire TEKTITE I operation. Thus it was shown that saturation dives of the TEKTITE type can be conducted safely, provided that a rigorous safety program is implemented. As further experience is gained, the safety factor added for uncertainty can be reduced to a degree, and the advantages of saturation diving may be more fully exploited.

Chapter 3

SCIENTIFIC AND ENGINEERING PROGRAMS

INTRODUCTION

The major program elements of Tektite I were marine science, life sciences, and ocean engineering. The goals and known accomplishments of each of these program elements are given in the following paragraphs.

MARINE SCIENCE PROGRAM

The goal of the marine science program as planned was twofold: (a) a number of individual marine ecological, biological, and geological studies integrated into a 60-day time period, and (b) an evaluation of the use of saturation diving techniques from an undersea habitat to accomplish the studies planned in (a). The wide variety of planned experiments and observations are summarized in Table 1.

The marine science program was developed to explore the wide range of potential research made possible by undersea habitation. More research was planned than could be accomplished during the mission so the aquanauts could select those areas best suited to the situation. Thus several of the experiments shown in Table 1 were not carried out because the aquanauts decided to use their time in studies resulting from their exploratory surveys of the ocean floor. The aquanauts' decisions to exclude certain planned studies in favor of unplanned studies were based on their assessments of the relative importance of the particular work. In addition, time available to carry out scientific work was limited by a variety of other reasons, such as equipment malfunction and other unforeseen circumstances. For example, habitat operational problems at the beginning of the mission consumed a great deal of the aquanauts' time.

During the 60-day mission, the aquanauts spent 432 man-hours outside of their habitat. Toward the end of the mission individual aquanauts were spending as much as 5 hours per day in the water. The limiting factor on this time and on the range of operations was the endurance capability of the equipment and the time required for recharging the scuba tanks.

The aquanauts were assisted in their marine research tasks by a surface diving scientific support team. This team, composed of three alternates for the aquanauts in the habitat, complemented the studies conducted from the habitat by extending the marine research into areas beyond the horizontal range or vertical limits of the aquanauts. This surface team was augmented during the mission by visiting scientists from the Department of the Interior.

LIFE SCIENCES BEHAVIORAL PROGRAM

The behavioral program was planned to provide data on the characteristics of crew behavior which could be extrapolated to future manned missions in space and undersea research. The emphases of the behavior study were: crew size and selection criteria, quarters size and habitability, and use of time in mission performance. The restraint of

isolation (saturated diving) and the reality of the crew's mission (marine science) both contributed to the significance of the study. A qualitative summary of the behavioral program is given in Table 2.

Table 1
Tektite I Marine Science Program

Experiment	Objective
Oceanography	
Environmental factors	Record water temperature, salinity, pressure, current vectors, surface and internal waves, and bioluminescence at the habitat and remote locations.
Plankton analysis	Determine the types and relative abundance of planktonic organisms in the water column, their fluctuations in time, and the extent of their vertical migrations (Fig. 6).
Acoustics	Evaluate a side-scanning sonar for signatures of separate fish species, for animal and diver tracking, and for the effects of environmental variations on sonar performance. (This experiment was not initiated due to equipment difficulties.)
Ecology	
Spiny lobster behavior	Validate tagging techniques for general marine population studies (Figs. 7 and 8).
Spiny lobster population	Understand population size, growth, and mortality.
Lobstering and fishing	Compare effectiveness and selectivity of different gear for catching lobsters and reef fish.
Day-night periodicity	Understand foraging, mating, and predatory activities during the full diurnal cycle.
Effects of the habitat	Calibrate the influence of the habitat on the local fauna and flora.
Light attraction	Evaluate multicolored underwater lights as artificial attractants.
Artificial reefs	Evaluate through periodic sampling the population on prepositioned artificial reefs.
Geology	
Geological bottom mapping	Obtain control data for geological experiments.
Biogenous sand	Relate biogenous sand to the source organisms and study reef growth and destruction.
Reef diagenesis and lithification	Study the reef structure and history.
Effects of organisms on sedimentation	Study the mechanisms and rates of the reworking of sediments by organisms.
Storm modifications	Study the degree of modification of bottom sediments by storms.
Carbonate mud	Determine the rate and type of changes in the composition of carbonate mud as the result of organic decay.
Bottom rock weathering	Compare submarine and subaerial weathering of rocks.
Sedimentology techniques	Develop habitat-based sedimentology experimental techniques and evaluate surface-operated instruments.

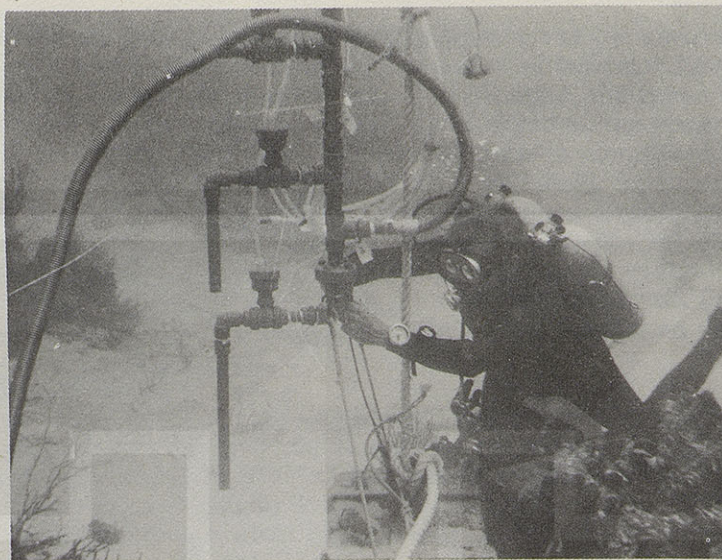


Fig. 6 - Aquanaut adjusting a standpipe in an experiment to measure plankton in the water column at various heights above the ocean floor



Fig. 7 - Aquanauts engaged in spiny lobster studies. The lobsters were captured and tagged with identifying metal tags or tiny acoustic transmitters, and released. They could then be observed and identified to study their migratory habits.

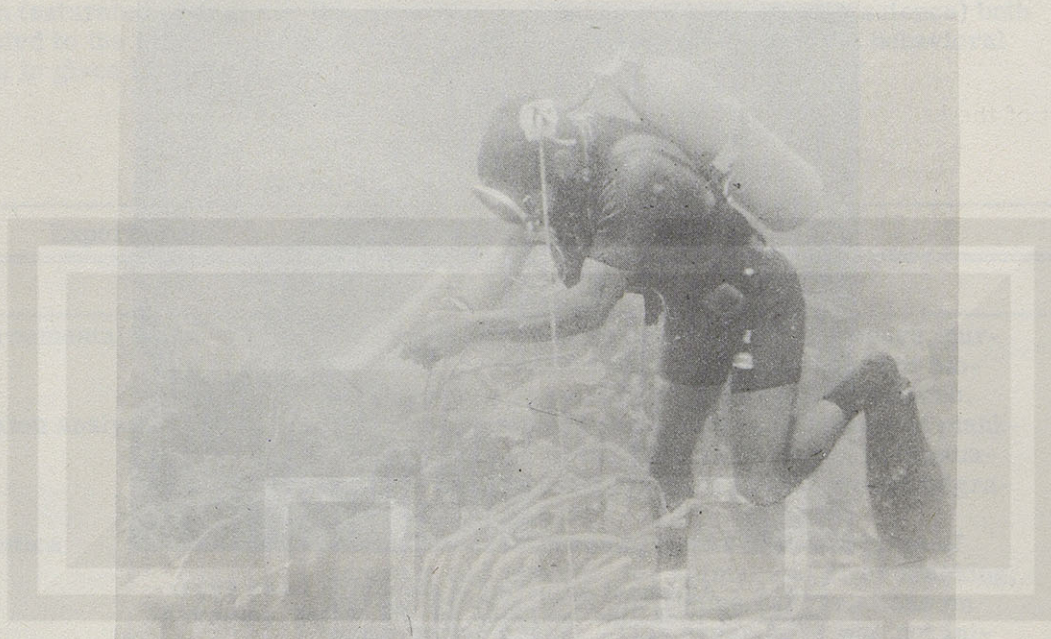


Fig. 8 - Aquanaut tracking a tagged lobster with an acoustic directional receiver

Table 2
Tektite I Behavior Program

Experiment	Objectives
Crew behavior measures: general activity, task performance efficiency, social relations, operational and interpersonal communications, personal habits, emotional adjustment, psychological traits, psychomotor performance, and sleep (electroencephalography)	Evaluate long-term work performance under hazardous, isolated conditions. Relate observed crew behavior to physiological and medical indices.
Crew selection study	Obtain crew selection, composition, and training data for use in later space and undersea missions.
Human performance study	Determine human performance criteria for application to long-duration, high-stress situations.
Habitability study	Measure individual and crew response to features of working and living facilities.
Data collection study	Develop and refine data collection methods in an operational environment.

Paramount to the success of the behavioral program was the accurate identification and collection of data which could be used as a measure of behavior functions. Data collection was automated to the maximum extent. For example, the times that the divers were out of the habitat were automatically recorded. Data based on the observation of the aquanauts were also recorded in real time. Teams of observers monitored the crew for up to 18 hours per day and recorded the visual (television) and audio (open microphone) observations of parameters such as mood, status, and preferences directly on computer cards using predetermined formats (Figs. 9 and 10). During the 60-day mission, over 400,000 individual observations were made and recorded for subsequent evaluation (Fig. 11). In addition to observation by television and open microphones, behavioral and habitability data were obtained from records, logs, and questionnaires completed before, during, and after the operation by the aquanauts.

Another source of behavioral data was sleep research to evaluate the quality and quantity of the aquanauts' sleep for possible correlation with observed behavior. Of particular interest were the possible effect of hyperbaric conditions upon sleep and the relationship of sleep patterns to waking activities. Sleep logs and electrophysiological (EEG) recordings were used for sleep evaluation. Sleep logs were maintained by all four aquanauts, and EEG recordings were obtained from aquanauts Clifton and VanDerwalker using somewhat standard electrodes. Electrodes were fitted to make contact with aquanaut Waller's cranium via a newly developed skull cap, developed by NASA, which incorporated contact electrodes. Brain wave data were recorded on both magnetic tape and paper.

Electronic, real time, partial processing on-site by NASA neuropsychophysicologists of the sleep log and other EEG data indicated that the aquanauts did not have major sleep difficulties. They slept longer (8-plus hours) and stayed in deeper sleep (slow sleep wave) for a longer time as the mission progressed. The Tektite I sleep data indicate that man can adapt to nitrogen saturation and live on the ocean floor for productive work without suffering from sleep deprivation.

LIFE SCIENCES BIOMEDICAL PROGRAM

The biomedical program had as its twofold purpose the aquanauts' medical safety and the evaluation of possible physiological effects of long-term saturated diving on the aquanauts. Throughout mission planning and execution the safety of the aquanauts was always foremost. Prior to the mission each aquanaut was given a detailed medical examination. During the mission, daily and weekly medical status assessments of each of the aquanauts were made to assure their continuing health. Upon decompression a detailed postdive examination was made of each of the divers to ascertain any changes in the aquanauts' physiological condition.

Because of the exploratory nature of a saturated dive using a nitrogen/oxygen mixture, a major objective of the biomedical program was to obtain physiological data on the possible effects of this type of saturation under closely controlled conditions. The aquanauts were saturated at a depth of 43 feet on a habitat gas mixture of 92% nitrogen, 8% oxygen. Their scuba tanks, used for excursions from the habitat, contained compressed air with a composition of 80% nitrogen, 20% oxygen. Particular attention was given to the functioning of the pulmonary, blood, and nervous systems of the aquanauts. A week of detailed medical examinations was administered prior to the mission at the University of Pennsylvania Hospital Research Center by a select group of medical specialists, which provided baseline measurements for each aquanaut. A summary of the biomedical areas of investigation is given in Table 3.

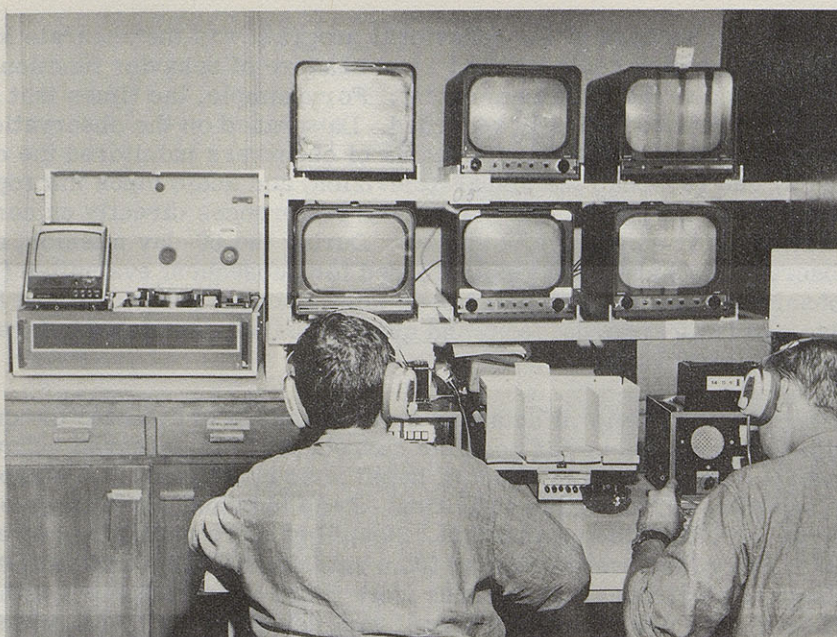


Fig. 9 - Behavioral observers monitoring and recording the aquanauts interactions with the habitat and environment. Four of the six TV monitors present views of each of the four habitat compartments, and two were available for underwater TV cameras. A videotape recorder (left) stands ready to record significant events.

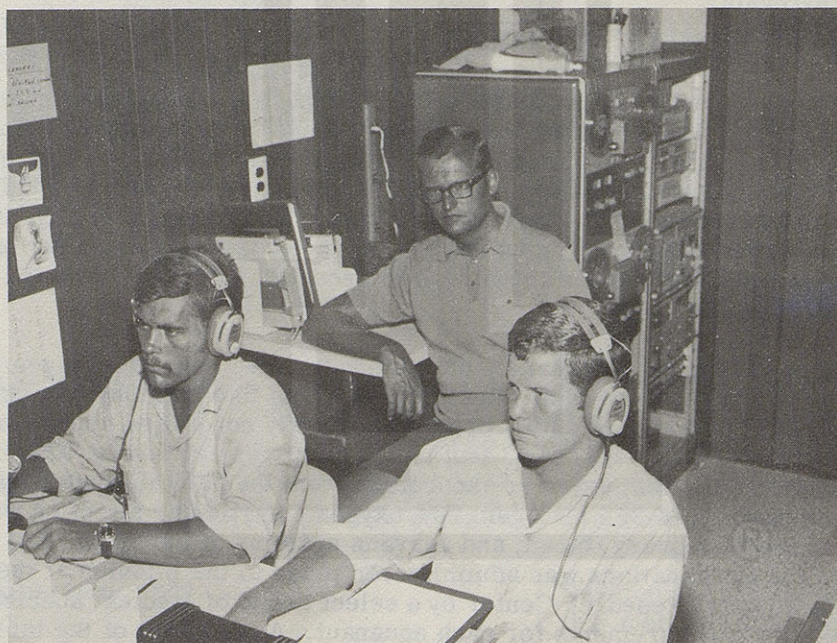


Fig. 10 - Behavioral observers shown in Fig. 9 and a behavioral scientist supervisor. Automatically recorded data is processed by the consoles behind the supervisor's post.

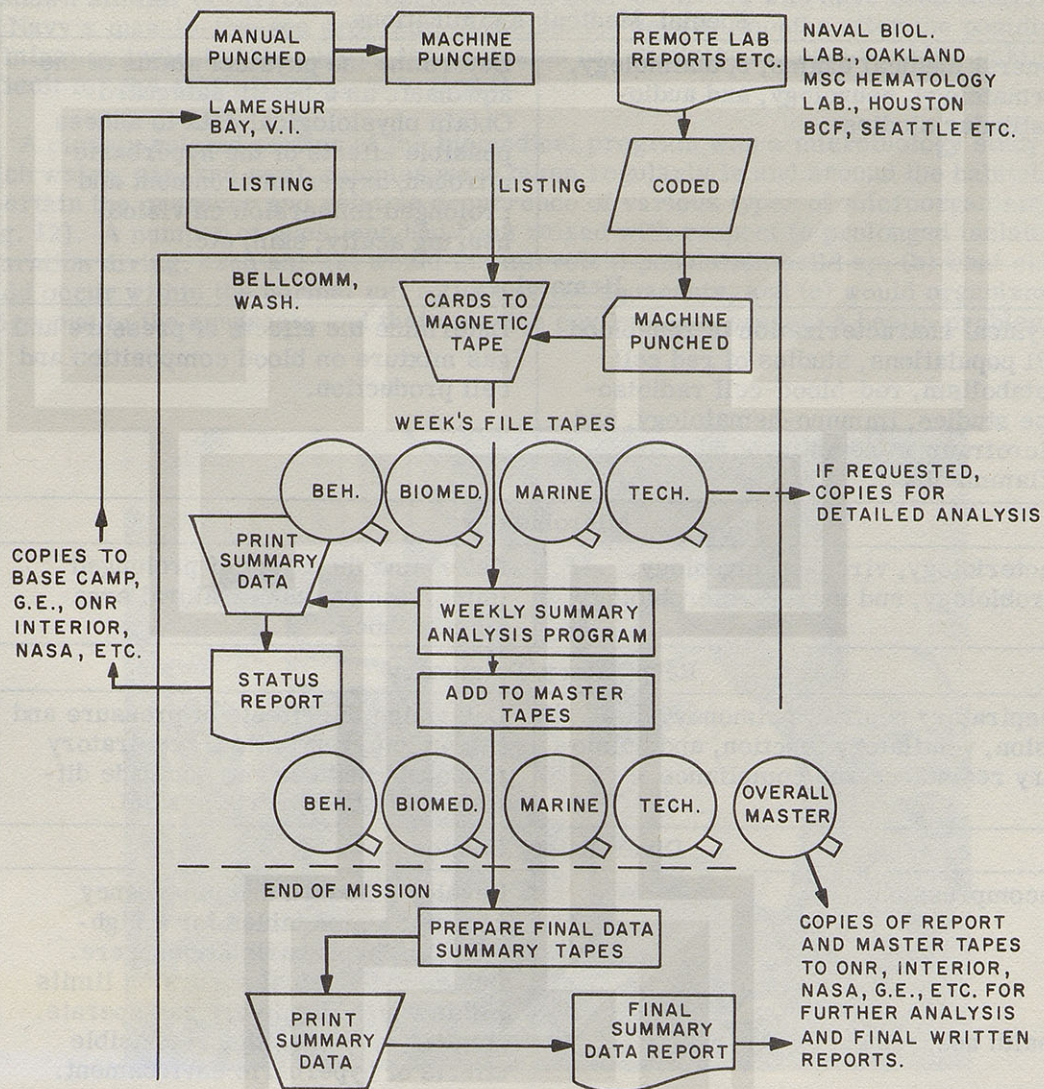


Fig. 11 - Tektite I digital data flow

Table 3
Tektite I Biomedical Program

Experiment	Objective
Special Medical Examinations	
General medical exams, ophthalmology, dermatology, neurology, and audio-vestibular studies	Determine the physical status of the aquanauts as a health safeguard. Obtain physiological data to assess possible effects of the hyperbaric nitrogen/oxygen environment and prolonged immersion on vision, hearing acuity, skin, etc.
Hematology	
Physical characterization of red-blood-cell populations, studies of red cell metabolism, red-blood-cell radioisotope studies, immuno-hematology, and microtrauma and antigen induced inflammation	Determine the effects of pressure and gas mixture on blood composition and cell production.
Microbiology	
Bacteriology, virology, mycology, aerobiology, and marine microbiology	Determine the effect of prolonged immersion on man's natural organism balance.
Respiratory/Pulmonary	
Respiratory control, pulmonary diffusion, ventilatory function, and pulmonary resistance and compliance	Determine the effects of pressure and gas on lung ventilation, respiratory response, and carbon monoxide diffusion into the diver's system.
Diver Safety Studies	
Decompression Health assessment	Develop standard and emergency decompression tables for a high-nitrogen, hyperbaric atmosphere. Determine vertical excursion limits within which the divers can operate. Monitor diver health and possible effects of hyperbaric environment.
General Observations	
Data correlation	Correlate monitored physiological and medical data to observed crew behavior and performance.

Certain functions were monitored during the mission by weekly examinations and samples. In addition, a round-the-clock medical watch maintained close observation of the aquanauts via television. The primary medical difficulty of the aquanauts during their 60-day stay was ear infection, and the primary organism that caused the divers' ear infections was pseudomonas. Fungi did not appear to be involved.

The extensive postdive medical examination conducted on-site was not able to determine any significant variations in life functions which possibly could be attributed to the hyperbaric environment. The postdive examination revealed only one possible detrimental

facit—the discovery of a small occlusion in the right eye lens of aquanaut Clifton. This occlusion was off axis and did not interfere with Dr. Clifton's visual acuity. Dr. Clifton was the only aquanaut of the four having high-normal intraocular tension. Whether or not this occlusion was due to the 2-month saturation dive is not known. There has been no known similar occurrence of occlusions in over 50 divers who have been saturated in the Navy's man-in-the-sea program. Examination several months after the postdive examination indicated the size of the occlusion had diminished considerably, making it difficult for the ophthalmologists to find it.

A closely related portion of the biomedical program was a microbiology study in which water, air, and swab samples were taken regularly in and around the habitat to ascertain the presence and relative occurrence of various types of microorganisms (Fig. 12). A number of questions had been raised with respect to prolonged isolated saturation diving, such as: (a) would the microbial population build up, (b) what changes would occur within the normal microflora of the aquanauts, and (c) would organisms indigenous to the aquanauts and their marine environment present a health problem?

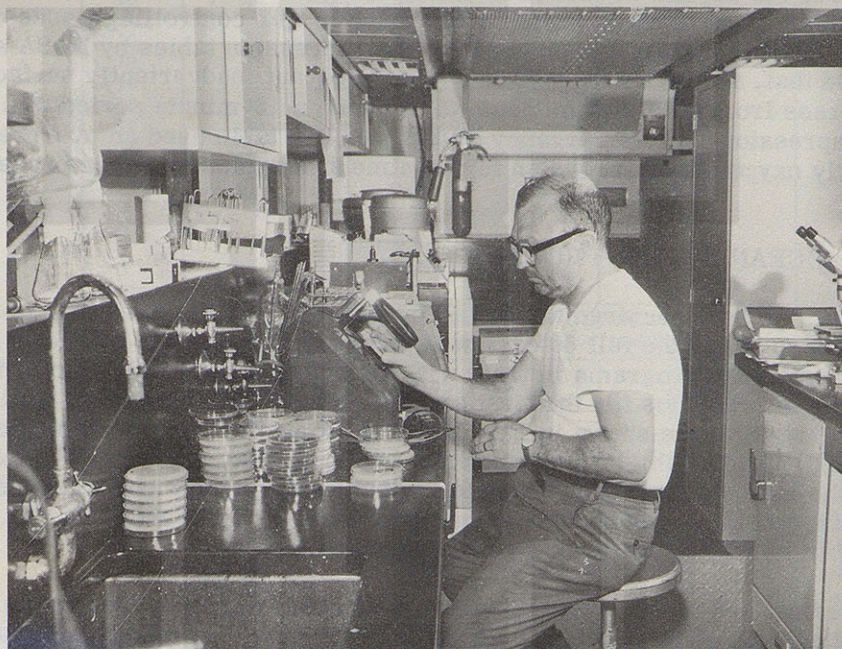


Fig. 12 - Mobile laboratory in a van at the base camp being used for on-site processing of microbiology samples taken in and around the habitat

The microbial carrier state of the aquanaut did not play a part in the transmission of disease in the Tektite I program. This is borne out by a *Staphylococcus* carrier study and the evidence that *Candida* and *Proteus* remained associated with a single individual throughout the entire program.

The microbial population did not build up on the walls of the habitat during the 59 days of the study. The sample sites had not been swabbed prior to obtaining the sample, thus the sample represented the microflora of the wall over an increasingly longer period of time. This microflora was in a state of flux with new organisms continually becoming associated with the wall surface while the older organisms were dying.

The level of coliform organisms from the disposal of sewage into the environment did not attain a level sufficient to become a health hazard to the aquanauts.

Conditions imposed in maintaining the habitat did not induce a latent virus infection, nor did the aquanauts acquire any demonstrable virus infection from the marine environment.

The answers to the questions posed at the beginning of the program show that the prolonged application of the environmental conditions and aquanaut interactions, as carried out in the Tektite I program, did not result in any unusual microbiological hazard. The possible intrusion of a marine organism (*Acinetobacter phenon 4-1*) into the habitat and its establishment was of interest and may present a problem in future long-term studies of this type. Ear infections are common to this type of program and will probably remain so unless adequate prophylactics are used.

The development of normal and emergency decompression schedules was another area of significant biomedical research. The tables developed are shown in Table 4. Although the normal decompression schedule developed for Tektite was prepared for an operational program, it became evident that the controlling tissue for nitrogen saturation decompression is far beyond the 240-minute level suggested by Workman.* The data collected during this series of dives supports the much longer controlling tissue described by Buhlmann.† Preparation of the emergency decompression tables by NASA subcontract‡ indicated that, should a nitrogen-saturated aquanaut inadvertently surface (explosively decompress from a saturation depth of 42 feet), a 15-minute period was available for safe recompression. The emergency decompression table used an overpressure return and early oxygen decompression for treatment of explosive decompression.

INTEGRATED OCEAN FLOOR PROGRAM

The Tektite I project required a detailed intermeshing of the scientific programs. A daily scenario covering the full 60 days was prepared prior to the project's start, scheduling the scientific programs in train with appropriate operational and administrative tasks. Sample scenarios for the first and last days of the mission as well as typical days during the mission are shown in Fig. 13. The biomedical and psychological events were to the maximum possible extent concentrated on one day per week (Wednesday). This allowed the aquanauts maximum uninterrupted time for their own research on the other days of the week. A typical biomedical examination day is shown in Fig. 13 as day 5. Day 17 is typical of the week's remaining days.

The biomedical and psychological programs closely followed the scenario. Although the biomedical samplings on the first such days took longer than planned, the aquanauts and surface personnel soon established smooth routines for taking samples and for promptly transferring them to the surface. The behavioral program was primarily conducted by monitoring from the surface, with minimum interference to the aquanaut crew.

*R. D. Workman, "Calculation of Decompression Schedules for Nitrogen-Oxygen and Helium-Oxygen Dives," U.S. Navy Experimental Diving Unit Research Report 6-65, 1965.

†A. A. Buhlmann, P. Frei, and N. Keller, "Saturation and Desaturation with N₂ and He at 4 Atmospheres," J. Appl. Physiol. 23:458-462 (1967).

‡P. O. Edel, "Delineation of Emergency Surface Decompression and Treatment Procedures for Project Tektite Aquanauts," J and J Marine Diving Co., Inc., Pasadena, Texas, Apr. 20, 1969.

Table 4
Tektite I Decompression Schedules

Depth (ft)	Time at Stop (min)	Decompression Time (min)		Breathing Media
		Total	Oxygen	
Normal Decompression Schedule				
42*				
↓	12†	12	0	Air
30	120	132	0	Air
↓	5	137	0	Air
25	200	337	0	Air
↓	5	342	0	Air
20	170	512	0	Air
20	30	542	30	Oxygen
↓	5	547	35	Oxygen
15	20	567	35	Air
15	30	597	65	Oxygen
15	20	617	65	Air
15	30	647	95	Oxygen
15	20	667	95	Air
15	30	697	125	Oxygen
15	20	717	125	Air
15	30	747	155	Oxygen
↓	5	752	160	Oxygen
10	60	812	160	Air
10	30	842	190	Oxygen
10	20	862	190	Air
10	30	892	220	Oxygen
10	20	912	220	Air
10	40	952	260	Oxygen
↓	5	957	265	Oxygen
5	200	1157	265	Air
↓	5	1162	265	Air
↓		(19 hr 22 min)	(4 hr 25 min)	
Surface	-	-	-	-
Emergency Recompression and Decompression Following an Explosive Decompression (Inadvertent Surfacing)				
60†	20	20	20	Oxygen
↓	5	25	25	Oxygen
55	20	45	25	Air
↓	5	50	25	Air
50	20	70	45	Oxygen
↓	5	75	50	Oxygen
45	20	95	50	Air
↓	5	100	50	Air
40	20	120	70	Oxygen
↓	15	135	70	Air
25	60	195	70	Air
↓	5	200	70	Air
20	90	290	70	Air
20	30	320	100	Oxygen
↓	5	325	105	Oxygen
15	90	415	105	Air
15	60	475	165	Oxygen
↓	5	480	165	Air
10	120	600	165	Air
10	60	660	225	Oxygen
↓	5	665	230	Oxygen
5	150	815	230	Air
↓	5	875	290	Oxygen
↓	5	880	290	Air
↓		(14 hr 40 min)	(4 hr 50 min)	
Surface	-	-	-	-

*Aquanauts will be transferred via the Personnel Transfer Capsule to the Deck Decompression Chamber and held at a depth of 42 feet until all are transferred and topside crew is ready for decompression.

†All depth changes during the decompression will be made at a rate of 1 foot per minute. In the event the depth changes occur slower the time will be added onto total decompression.

‡An overpressure is applied on recompression when an aquanaut inadvertently surfaces.

PROJECT TEKTITE I

Time	Day 1	Day 5	Day 17	Day 59	Day 60
0000		Sleep			
0400					Depart habitat
0430					Begin decompression
0500		Biomedical	Marine science		
0630		Breakfast; baralyme change			
0800		Biomedical	BREAKFAST; BARALYME CHANGE; PSYCHOMOTOR TEST		
0830			Marine science		
1100	Aquanauts occupy Habitat				
1130	Emergency Drills and Habitat Familiarization				
1200		Lunch		Lunch; psychomotor test	
1300	Lunch	Biomedical			
1500					
1700	Habitat engineering evaluation; check emergency air bottles; change baralyme				
1800	Supper, crew conference				
1900	Medical status evaluation			Medical status evaluation; prepare to leave habitat	
1930	Transfer samples to surface; charge scuba tanks; psychomotor test; marine science				
2100	SECURE OPERATIONS; SET NIGHT WATCH				
2130	Mood adjective checklist (behavioral); attach EEG leads			Mood adjective checklist	
2200	Crew retires; sleep				
2400					Complete decompression

Fig. 13 - Typical days from the Tektite I integrated ocean floor program scenario

Postmission analysis has shown that the aquanauts were able to spend almost a third of their bottom time conducting mission-oriented work. The total bottom time was categorized into six major activities and average daily times, in hours per aquanaut, were found for each activity: Scientific work (5.5 hours), habitat maintenance (1.9), self maintenance (2.7), recreation (3.0), rest and relaxation (10.7), and transit (0.2).

ENGINEERING PROGRAM

The TEKTITE I engineering program had a two-fold objective: (a) to provide a habitat system within which the TEKTITE I scientific programs could be conducted, and (b) to gain experience in ocean engineering and in the conduct of underwater programs that would be of future benefit to others. This entailed designing and fabricating the habitat and its supporting systems, transporting the habitat to the project site in the Virgin Islands and emplacing it in Lameshur Bay, maintaining the habitat during the 2-month mission, evaluating its performance during this period, and recovering and returning the habitat and its supporting systems.

General Electric Company was tasked, under Office of Naval Research Contract N00014-68C-0356, with furnishing the Tektite I habitat, integrating the program scientific equipment into the habitat, defining the support service (power, air, water) requirements

for the habitat, assisting in the integration of the habitat with its support systems, and maintaining the habitat for the duration of the mission.

The Navy had project responsibility for designing and constructing support systems to meet the habitat service requirements, integrating the habitat service requirements, integrating the habitat with its support systems, transporting the entire assemblage to the Virgin Islands site and returning it, preparing the ocean floor at the experiment site, and emplacing the habitat and its supporting systems at the experiment site.

Habitat and Support Systems Assembly

The Tektite I habitat was designed and constructed by the General Electric Company at the Missile and Space Division, Valley Forge, Pennsylvania. The habitat was fabricated in three sections: the two habitat cylinders and the base (Fig. 3). The two cylinders were assembled and tested as components in Valley Forge. The base was fabricated under General Electric subcontract in Philadelphia. A more complete description of the habitat will be given in Chapter 4.

The habitat support systems were designed by the Naval Facilities Engineering Command to meet habitat service specifications provided by General Electric. Fabrication of these systems on the support barge (to be described in Chapter 4) was by Amphibious Construction Battalion Two (PHIBCB TWO). Fabrication was initiated at the PHIBCB TWO facility in Norfolk, and completed at the Tektite I embarkation point, the Philadelphia Naval Shipyard.

The three major habitat components were individually transported to the Philadelphia Naval Shipyard, where the habitat was totally assembled for the first time. After assembly of the two cylinders on the base, the base was ballasted and the assembled habitat pneumostatically tested to 28 psig. After completion of the pressure test, each habitat subsystem was operationally tested.

Habitat Transportation

The Tektite I habitat was assembled on a Navy AMMI barge (Fig. 14), and for transportation to the Virgin Islands the barge and habitat were floated into the well-deck of a ballasted-down landing ship dock (LSD) (Fig. 15). Upon loading, the LSD was deballasted, leaving the habitat/barge on the dry floor of the LSD well for the open-sea trip to the site. Upon arrival in Lameshur Bay the LSD was again ballasted down, and the habitat and barge were floated to the habitat launch site. There the habitat and the support systems were fully integrated and checked. The habitat was "launched" by controlled sinking of the AMMI barge from under the habitat (using pilings driven into the Bay bottom as guides) until the habitat floated (Fig. 16). The habitat was towed to the experiment site, and winched to the bottom and the floodable ballast tanks flooded.

Newly developed Navy AMMI barges were selected for the habitat launch barge and the support barge. The AMMI barge, in addition to floating like an ordinary barge, may also be jacked up out of the water on pilings which act as stilts. The AMMI barge is also compartmented, which with only minor modification allows it to be progressively flooded for controlled sinking.

The Tektite I habitat could not be floated directly into the LSD well-deck because the 24-foot draft of the ballasted and assembled habitat (310,000 lb) was deeper than the maximum water depth in a fully-ballasted-down LSD well-deck. Therefore, a shallow-draft barge was required to carry the habitat and to launch it, since high-capacity crane service was not available in Lameshur Bay. The use of the AMMI barge to transport and launch

the Tektite I habitat demonstrated the capability of the AMMI to handle deep-draft, heavy loads, such as habitats and submersibles. It must be recognized, however, that the AMMI launch system is limited to shallow water, since guide pilings to assist in controlling descent must be driven into the bottom. Also, the AMMI launch system is sensitive to sea motions and requires calm water such as found in Lameshur Bay.

Engineering Evaluation

An engineering evaluation was made of how well the habitat and the supporting systems met the requirements of the scientific users. It is generally agreed that the habitat as a whole provided a comfortable and livable home for the Tektite I long-duration, shallow-water, saturated dive. As a laboratory it was not optimum, but it was adequate. Although small problems did occur, the majority of the habitat and support systems equipment functioned as designed, and this contributed significantly to the safe completion of the project.

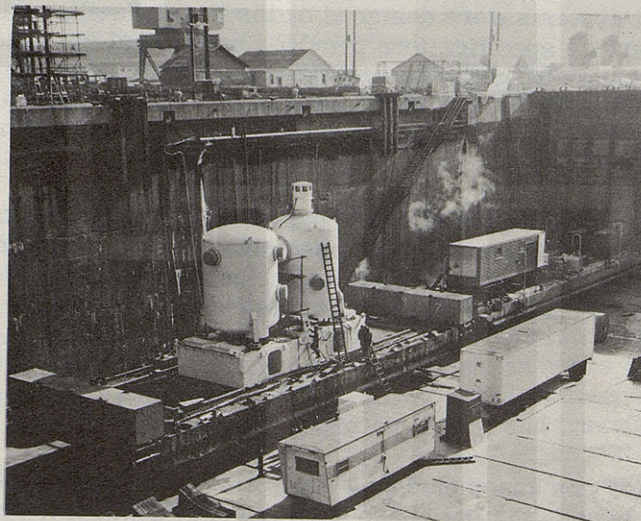


Fig. 14 - Tektite I habitat being assembled on a Navy AMMI barge at the Philadelphia Naval Shipyard. At the right is the support barge with habitat support systems.

A serious problem was in the CO_2 scrubber system. About 36 hours after the aquanauts entered the habitat the CO_2 level rose to 10.2 torr (1.34% surface equivalent by volume), higher than the generally accepted upper limit of 1% surface equivalent in closed hyperbaric environments and higher than the design value of 2 torr. Corrective action, including removal of CO_2 fire extinguishers and use of a makeshift scrubber, lowered the CO_2 to an acceptable level. For the next 2 weeks the baralyme absorbent was changed every 4 hours to keep the CO_2 at a nominal level of 6 to 7 torr. A portable scrubber installed on March 1 allowed 8 hours between baralyme changes. Under actual mission conditions, the scrubber efficiency was considerably lower than during prior tests. The removal of CO_2 from a closed hyperbaric environment remains a critical problem in ocean habitation.

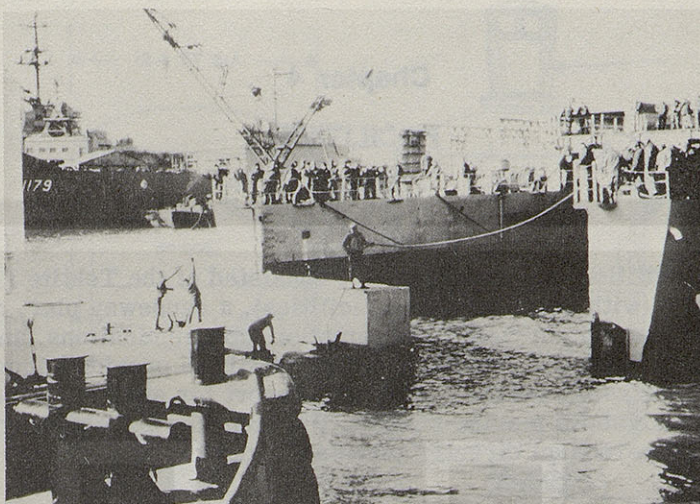


Fig. 15 - Habitat (left) on an AMMI barge being floated aboard the USS Hermitage at the Philadelphia Naval Shipyard for transportation to the Virgin Islands

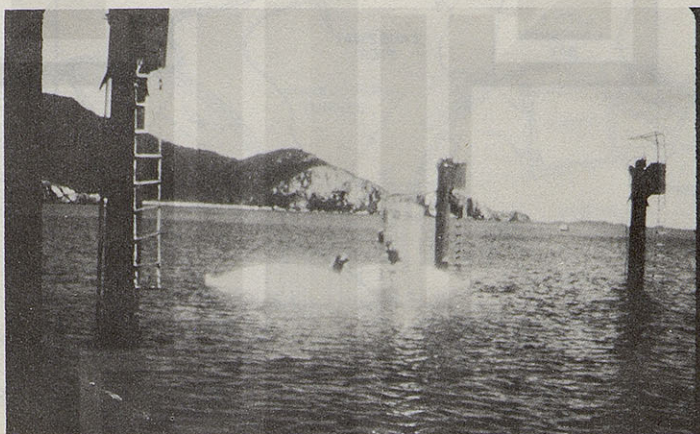


Fig. 16 - Habitat being launched by sinking the AMMI barge out from under it. The four pilings at the barge corners guided and controlled the descent of the flooded barge.

Other lesser engineering problems were encountered. Initially it was planned to place two underwater television cameras outside the habitat. One of these malfunctioned prior to the mission and was not used. The other camera functioned only part of the time during the mission and was of little real value. The sound powered phones in the way stations were susceptible to water seepage through their protective cases, and were seldom used by the aquanauts.

In general, the initial stabilization of the habitat systems, and subsequent maintenance, required more time than planned. This resulted in a reduction of time available for scientific work by the aquanauts. This situation could be alleviated by including an engineer or technician as an aquanaut in future scientific missions where crew isolation is a criterion. Otherwise, maintenance and repairs could be accomplished in diving visits by a surface-based engineer or technician.

Chapter 4

FACILITIES

INTRODUCTION

The Tektite I facilities, shown in Fig. 17, consisted of the Tektite I habitat, a support barge, a crane barge (with decompression facilities), a causeway pier, and a base camp. In addition to these major facilities, transportation, communications, and logistics systems were vital supporting functions provided. These facilities provided support for the four aquanauts in their undersea research mission, support for surface personnel involved in the collection and analysis of marine science, life science, and engineering data, and support for all other personnel directly associated with the project.

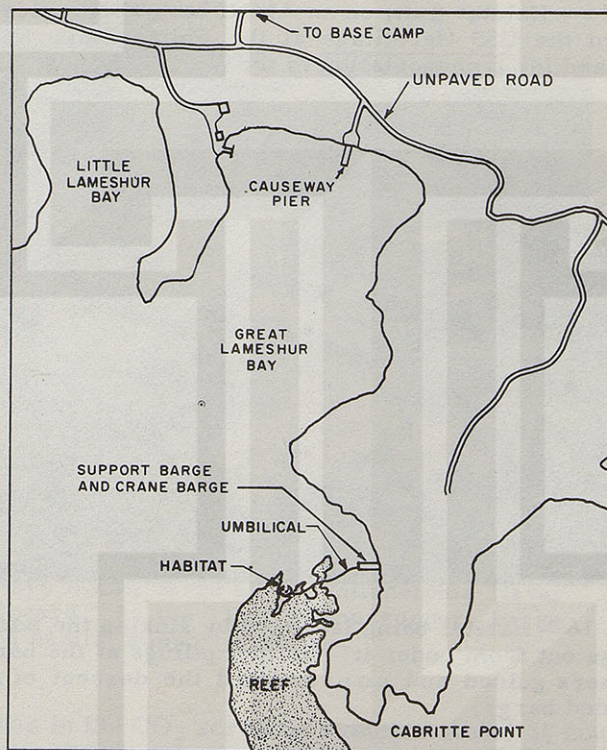


Fig. 17 - Tektite I site at St. John, Virgin Islands

HABITAT

A cutaway view of the habitat was shown in Fig. 3. Elevation and plan views of the habitat are shown in Figs. 18 and 19. The habitat consisted of two pressure hulls attached

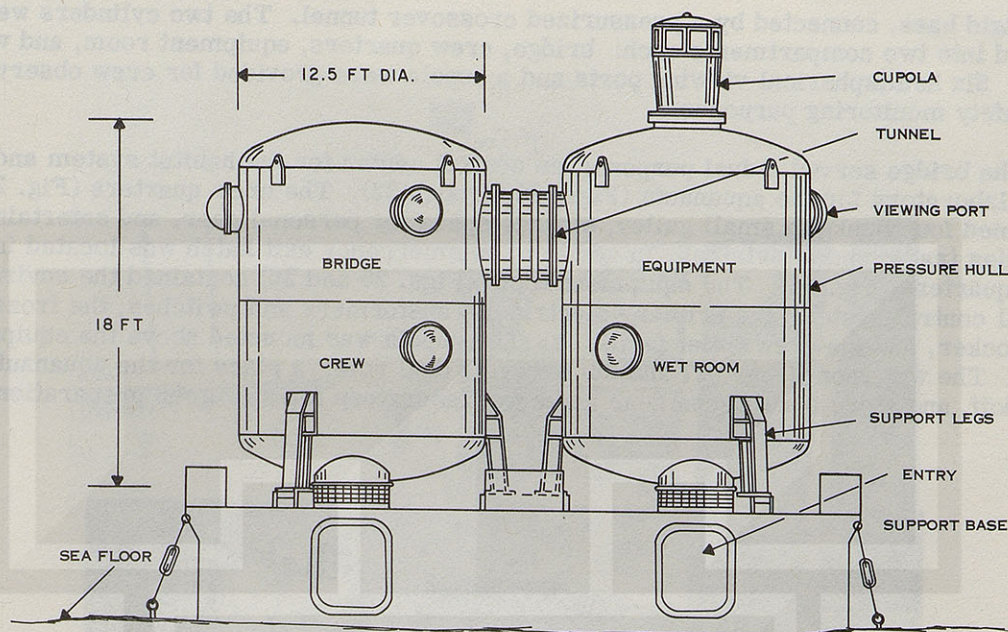


Fig. 18 - Side view of the Tektite I habitat

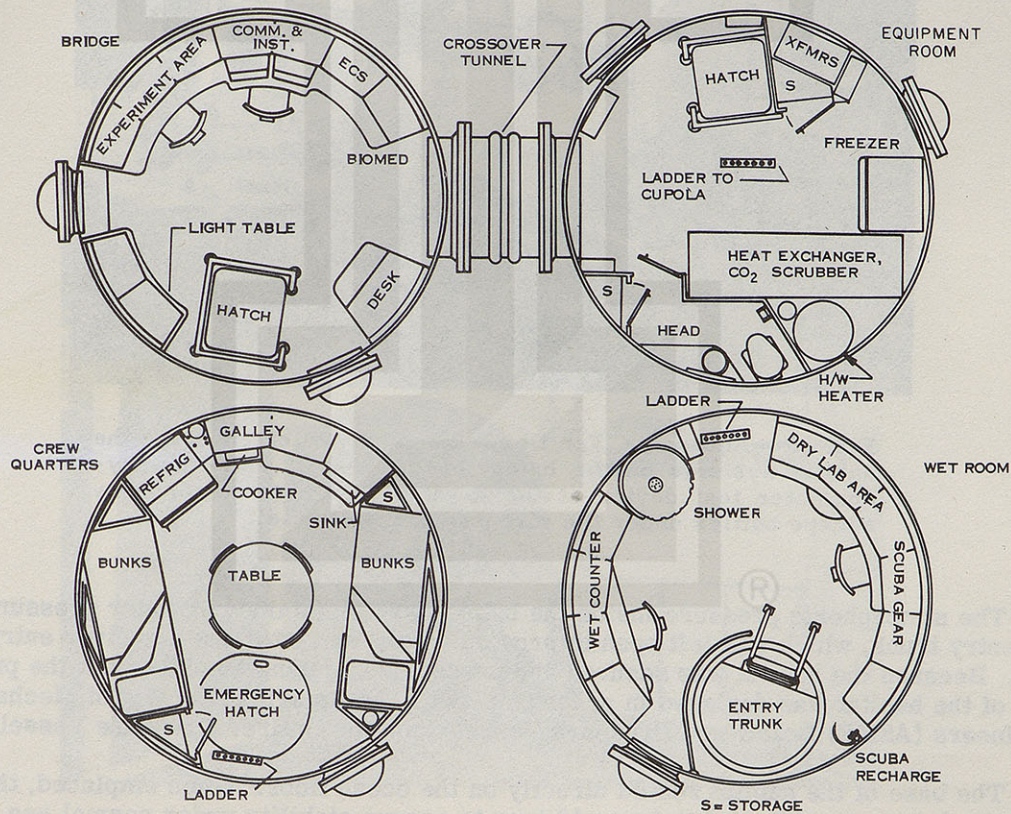


Fig. 19 - Plan views in the habitat of the habitat compartment

to a rigid base, connected by a pressurized crossover tunnel. The two cylinders were divided into two compartments each: bridge, crew quarters, equipment room, and wet room. Six hemispherical viewing ports and a cupola were provided for crew observation and safety monitoring purposes.

The bridge served a dual purpose: as control center for the habitat system and as a dry laboratory for the aquanauts (Figs. 20 through 22). The crew quarters (Fig. 23) contained four bunks, a small galley, storage space for personal gear, and entertainment facilities (radio and television). In addition, an emergency exit hatch was located in the crew quarters (Fig. 24). The equipment room (Figs. 25 and 26) contained the environmental control system, the primary electrical transformers and switches, the frozen food locker, and the crew toilet facilities. The cupola was mounted above the equipment room. The wet room (Figs. 27 and 28) served a dual role: a place for the aquanauts to don, doff, and store their scuba gear and a wet laboratory for specimen preparation.



Fig. 20 - Aquanauts Van Derwalker and Waller checking the habitat systems on the bridge of the habitat. Note the psychrometer test device at the lower right and the emergency escape bottles under the circular port to the left

The atmospheric pressure inside the habitat was maintained at water pressure in the entry trunk, which was left open to provide an air-sea interface for diver entry and exit. Because the habitat was secured and pressurized during emplacement the pressure hull of the habitat was designed in accordance with the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code for Unfired Pressure Vessels.

The base of the habitat rested directly on the ocean floor. When emplaced, the total negative buoyancy of the habitat was 10 tons to assure stability under normal sea conditions. Jetted and clump anchors, to which the habitat was tied, constituted a redundant bottom moor for additional holding force to meet unusual sea conditions.

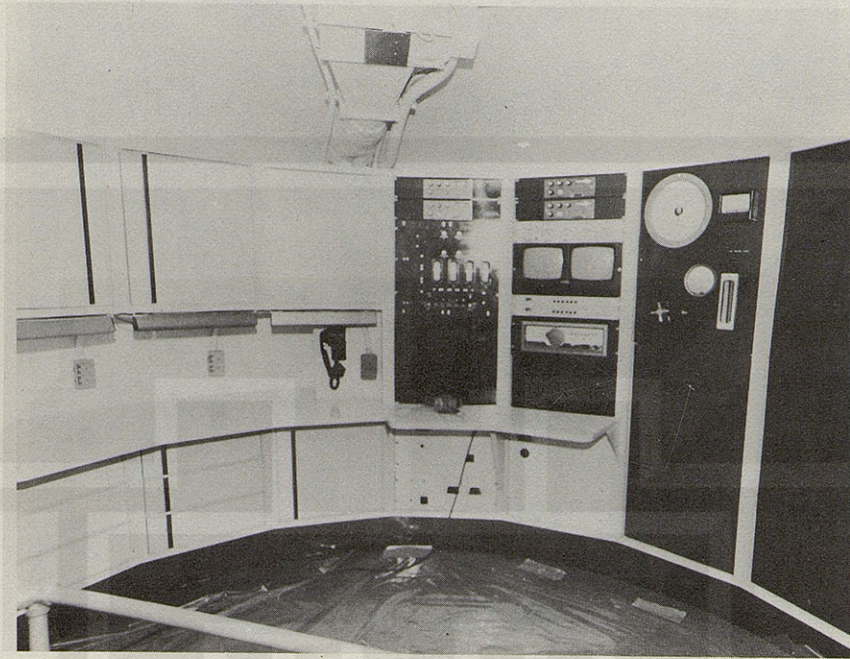


Fig. 21 - Habitat bridge (photographed during construction)

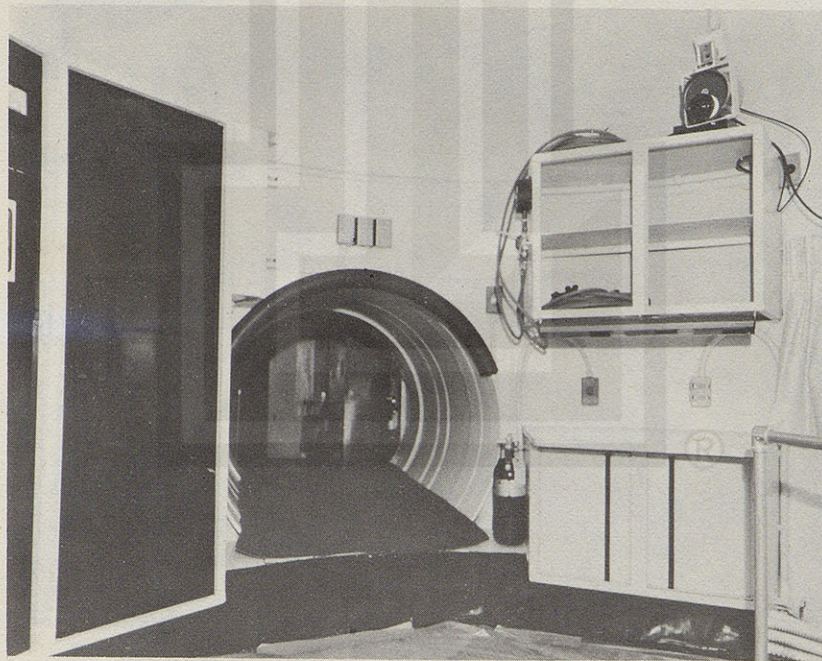


Fig. 22 - Crossover tunnel from the bridge to the equipment room (photographed during construction)

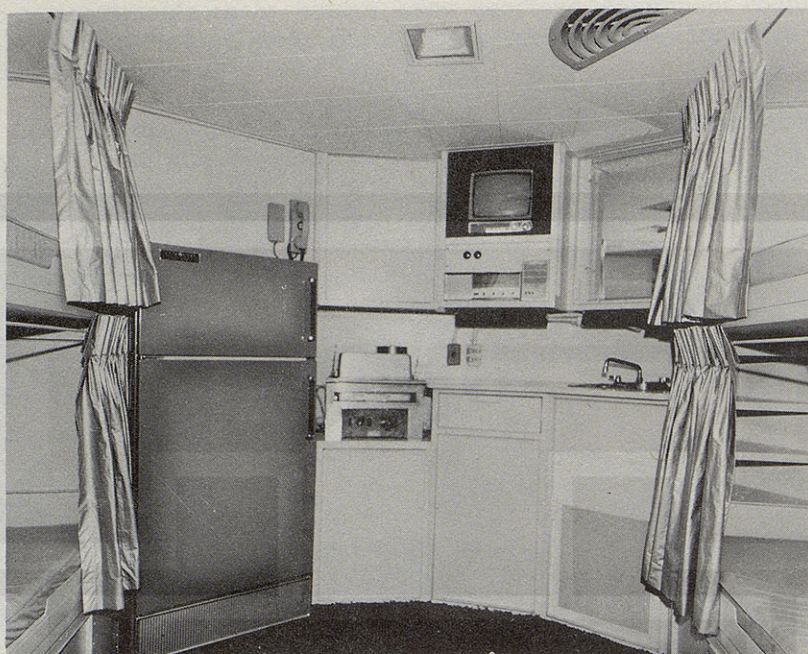


Fig. 23 - Crew quarters (photographed prior to launching) with sleeping, cooking, and entertainment facilities

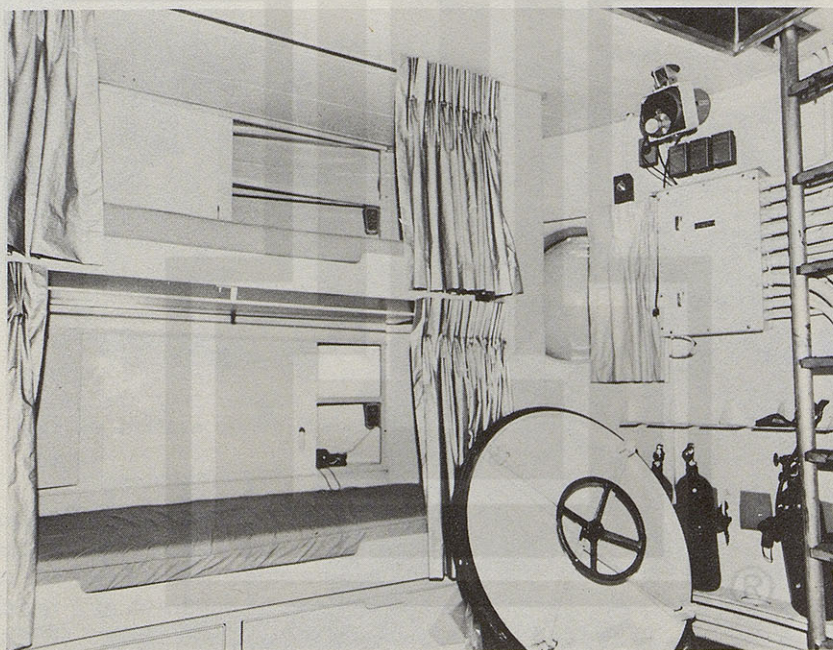


Fig. 24 - Crew quarters (photographed prior to launching, with the emergency escape hatch shown open). Note the storage spaces behind the two bunks and the TV camera at the upper right.

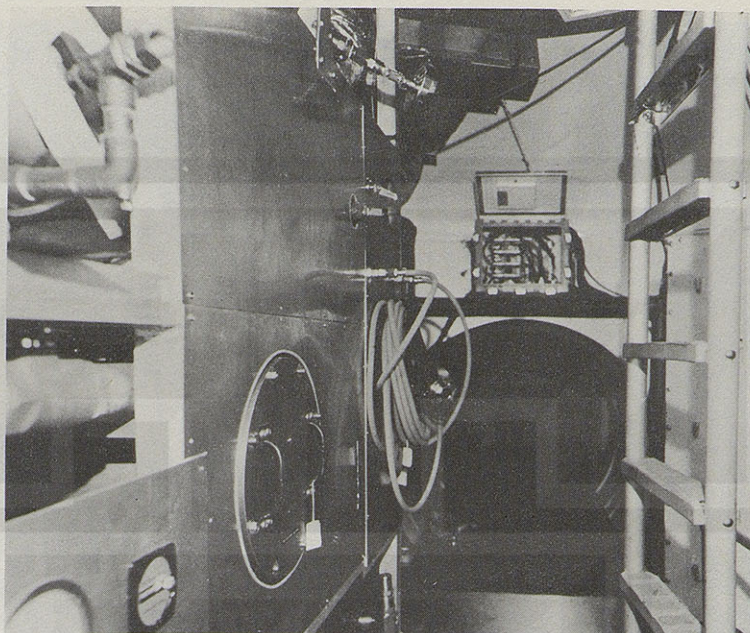


Fig. 25 - Equipment room and crossover tunnel to the bridge (photographed during construction). On the left is air conditioning equipment, and on the right is a ladder to the cupola.

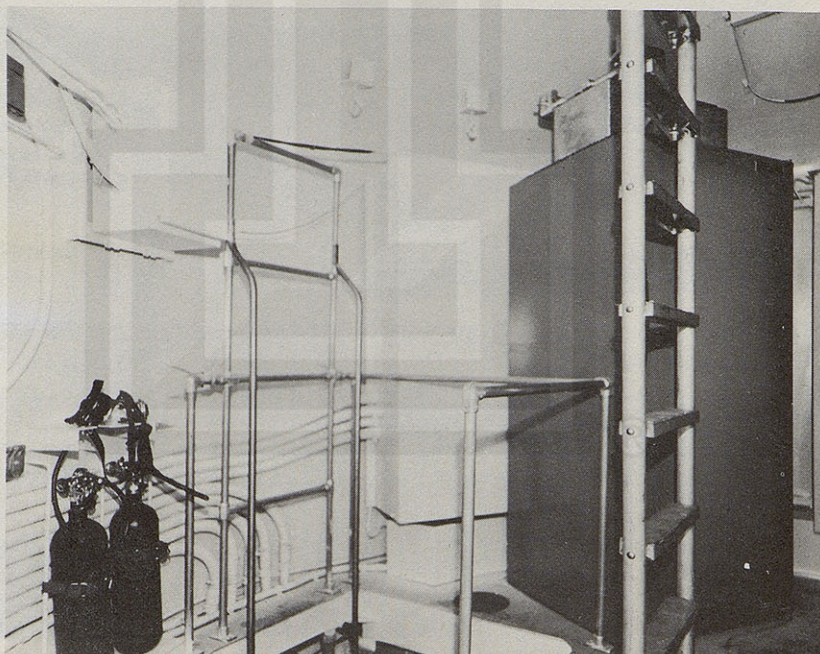


Fig. 26 - Equipment room (during construction). Left to right are emergency air bottles, the entrance from the wet room, the ladder to the cupola, and the freezer.

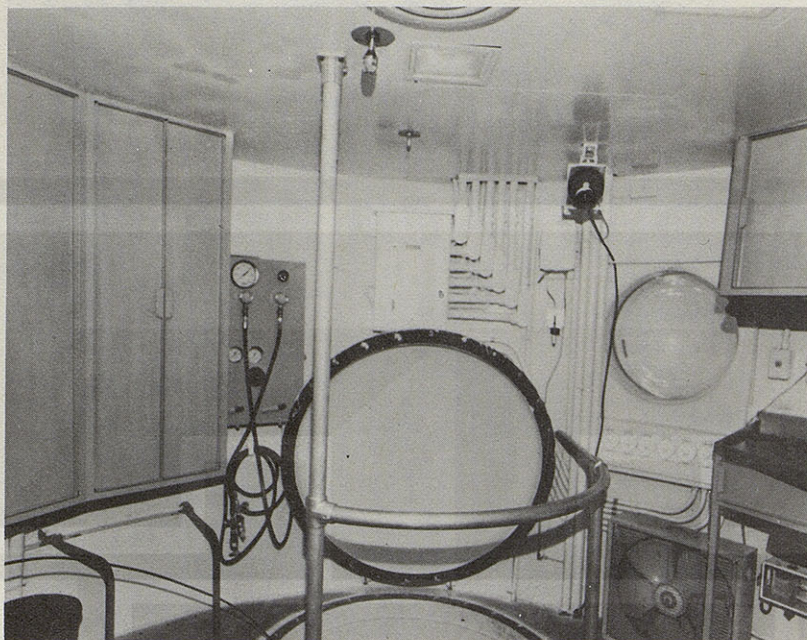


Fig. 27 - Entry hatch into the wet room (during construction). Left of the hatch is the scuba charging station.

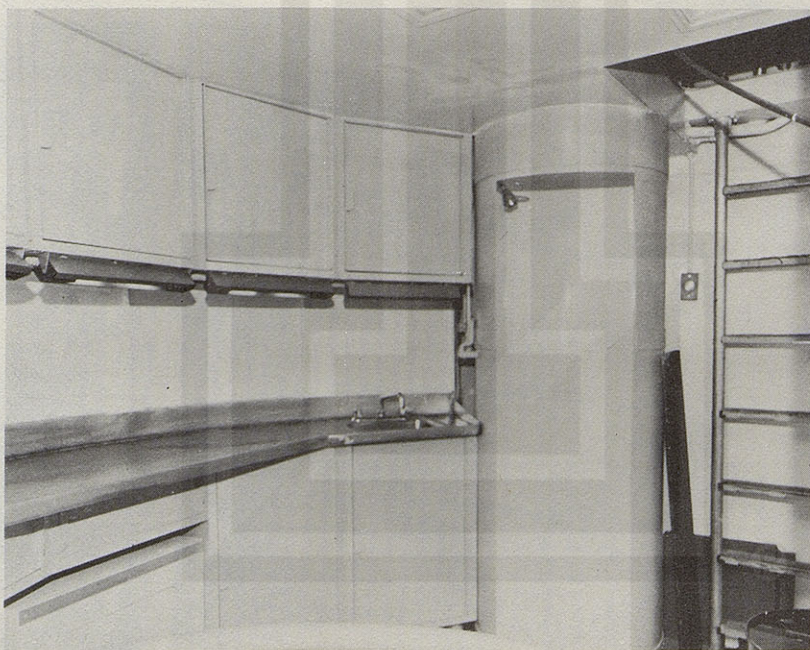


Fig. 28 - Wet room (during construction). Left to right are the wet laboratory counter, the fresh-water hot shower, and the exit to the equipment room.

Air Supply, Pressure, and Atmospheric Control

The habitat was initially pressurized on the surface to the emplacement depth pressure of approximately 2.3 atmospheres by compressed air. The operational habitat nominal oxygen partial pressure (pO_2) of 160 torr (mm Hg) was obtained by displacing air with nitrogen after the habitat was secured to the ocean floor. This resulted in a mixture of 92% nitrogen, 8% oxygen.

During the operation, compressed air was continually supplied to the habitat via an umbilical by low-pressure air compressors on the support barge to provide metabolic oxygen to the habitants and to maintain the pO_2 between 151 and 165 torr. The required flow rate of inlet air to the habitat was 16 to 24 SCF/hr (standard cubic feet per hour). The flow rate was manually controlled but was based on measured pO_2 levels. A continual stream of the habitat atmosphere was dumped through vents in the entrance trunk to the sea, thus maintaining the habitat pressure at the sea pressure at these trunk vents.

Carbon dioxide (CO_2) generated by the crew was removed by a Baralyme scrubber. The scrubber system consisted of two blowers (one redundant), a Baralyme canister, and associated valves and piping. Habitat air was forced by the blower through the Baralyme, where CO_2 was absorbed, and the air then was directed in proportional parts to each of the four compartments. The habitat Baralyme system was designed to operate 12 hours on a chemical charge. However, to maintain an acceptable CO_2 level (8 torr or less) during the mission, it became necessary for the crew to change the chemical approximately every 4 hours. An additional CO_2 scrubber was subsequently used; this reduced the frequency of Baralyme change to once every 12 hours. Baralyme resupply from the surface was necessary because of lack of storage space.

Atmosphere Monitoring System

The habitat atmospheric monitoring equipment, the monitored parameters, and the acceptable parameter limits are shown in Table 5. Early in the mission, the mass spectrometer (NASA atmosphere analyzer) in the habitat failed, requiring additional surface monitoring equipment. After removal by the aquanauts and transfer topside, the mass spectrometer was repaired, retransferred below, and put back into operation. After malfunction again on the 46th day of the mission, the unit was no longer used.

Thermal Control

The thermal control system maintained the habitat air temperature and humidity, removing heat and excess moisture from the air. Four heat exchangers were used, one per compartment. Connected to each heat exchanger were a blower for air circulation, a charcoal filter for odor removal, and an electrical reheater. The air was dehumidified by condensing water vapor on the heat exchanger coils, thus requiring reheating the air to the desired temperature. Relative humidity was maintained between 42% and 60%.

Emergency Air Systems

Emergency air systems provided were a surface air supply system, a purge system, a habitat emergency air supply system, a built-in breathing (BIB) system, and escape air bottles. Upon the first failure of the mass spectrometer, the emergency BIB was used, since the carbon dioxide levels rose abruptly.

The surface emergency air supply was aboard the support barge and consisted of two 8000-SCF (at 2200 psi) compressed air cylinders. This system served as a backup

Table 5
Tektite I Atmosphere Monitoring Parameters and Equipment

Constituent	Equipment Monitoring Range	Acceptable Operating Range	Equipment		Backup Equipment	
			Habitat	Surface	Habitat	Surface
O ₂	0-450 torr	151-165 torr	Mass spectrometer	Servomex AO150 O ₂ analyzer	MSA O ₂ meter	Beckman F3 O ₂ analyzer
CO ₂	0-15 torr	0-8 torr	Mass spectrometer	Perkin-Elmer 810 gas chromatograph	Detector tube	Beckman 1R215 infrared
H ₂ O	0-100% RH	30-70% RH	Mass spectrometer	Perkin-Elmer 810 gas chromatograph	RH gage	CO ₂ analyzer
N ₂	0-2000 torr	1570-1600 torr	Mass spectrometer	Perkin-Elmer 810 gas chromatograph	Pressure gage	-
CO	10-3000 ppm	0-15 ppm	Detector tube	Perkin-Elmer 810 gas chromatograph	-	Detector tube
Hydrocarbons	1-5 times acceptable	See Spec. TEK 17-5001	Detector tube	Perkin-Elmer 810 gas chromatograph	-	Sample to P.R.
Freon 12 and 22	0-2000 ppm	0-1500 ppm	Detector tube	Perkin-Elmer 810 gas chromatograph	-	-
Particulates	0-100 mg/m ³	0-25 mg/m ³	Air Sampler	-	-	Detector tube

to the support barge air compressors. In the event of compressor failure, compressed air would have been supplied automatically from these tubes.

The purge system was designed to change 90% of the air within the habitat within 4 hours in the event of major contamination of the habitat atmosphere and return the habitat atmosphere to 8% O₂, 92% N₂. The system used a 125-SCF/min, 100-psi diesel-driven air compressor and nitrogen storage cylinders located on the support barge to supply gas to the habitat via the air supply umbilical. In operation, air from the compressor would replace habitat air until gas sampling indicated a satisfactory atmosphere had been attained. Nitrogen would then be introduced to the system to reduce the pO₂ to within allowable limits. If practical, normal operation of the habitat would then have been resumed.

The habitat emergency air supply consisted of 23 240-SCF compressed air cylinders in the habitat base. This emergency air supply could be activated by the crew in the event of normal air supply failure. This system was designed such that the emergency air would be introduced into the normal habitat air distribution system in the event of topside compressor or umbilical failure. In the event of atmospheric contamination within the habitat, this emergency air could be supplied to the BIB system.

The BIB system provided 12 breathing stations within the habitat to be used in the event of atmospheric contamination. In this mode, air was available for 12 hours duration. The line pressure to each BIB station was maintained at 100 psi, and demand regulator/hose assemblies and face masks were attached at each station. Of the twelve BIB stations, four were in the crew quarters, four were in the wet room, and two each were in the bridge and equipment rooms. Each BIB had a hose long enough to reach to adjacent compartments.

Eight escape air bottles with regulators, hoses, and mouthpieces were available to provide capability to move about inside the habitat under conditions requiring BIB breathing, and to escape from the habitat to the personnel transfer capsule. Each bottle had an 18-SCF capacity, sufficient for approximately 7 minutes breathing. Four bottles were in the crew quarters, and two each were in the bridge and equipment room. None were required in the wet room, since scuba gear stored there could serve the same purpose.

Communication, Electrical, and Sanitary Systems

The communication systems (Table 6) provided aural and visual communication between the habitat and the support barge. The bridge, which was the habitat communication center, was connected to the surface command facility via intercom, sound-powered phones, and voice sonar. Each compartment was equipped with an intercom station connecting it with the other compartments and the surface, an open mike and closed-circuit television camera for the behavioral program, and audible and visible alarms. The bridge could monitor the open mikes and the closed circuit television cameras. In the wet room was a timer for recording the times that each diver left and entered the habitat, for the behavioral program.

Table 6
Tektite I Communication Systems

Purpose	Quantity	HABITAT EQUIPMENT
Behavioral data acquisition	4	TV cameras in habitat
	2	TV monitors in habitat
	4	Open microphones in habitat
	1	Diver-in/out panel in wet room
	1	Crew activity monitoring switch set in crew quarters
Normal or emergency communication to shore	1	Sound-powered phone link in bridge
	1	Intercom system in habitat
	1	Emergency alarm panel in bridge
	2	Warning bells and horn in bridge
Diver-to-diver communications	1	Hardwire communication to way stations
Entertainment	1	Commercial TV monitor
	1	Commercial radio
Biomedical data acquisition	4	EEG electrodes and amplifiers in crew quarters
	1	EKG recorder/amplifier in bridge

Electrical power was furnished to the habitat via an umbilical from two 100-kilowatt generators (one redundant) mounted on the support barge. The habitat electrical system was a three-wire grounded system. The habitat and all equipment cases and chassis were thus grounded. Flooding sensors were provided to shut off surface power in the event of major habitat flooding. Each compartment was lighted by two separate circuits, and emergency battery-powered lights were available in each compartment.

Potable water was pumped from the support barge to the habitat via a hose. The toilet facilities were of marine type, and waste was chemically treated prior to discharge to the sea through a 1000-foot drain hose laid out along the ocean floor away from the habitat.

Alarm System

The alarm sensors used to monitor the habitat life support systems and the displays triggered by these alarms are summarized in Table 7. Difficulty was experienced with the entry-trunk-water-level alarm, which was replaced.

Table 7
Tekite I Alarm System

Sensor	Habitat-Bridge Alarm		Surface-Control-Center Alarm	
	Visual	Audible	Visual	Audible
CO ₂ partial pressure	Meter/light	Buzzer*	Meter	—
O ₂ partial pressure	Meter/light	Buzzer*	Meter	—
N ₂ partial pressure	Meter	—	Meter	—
H ₂ O partial pressure	Meter	—	Meter	—
120-V power loss	Light	Buzzer*	TV	Speaker
Entry trunk water level	Light	Buzzer*	TV	Speaker
Wet room flooding [†]	Light	Horn [‡]	TV	Horn [§]

*The buzzer may be manually activated in the bridge.

[†]The wet-room-flooding alarm automatically turns off power to the habitat at the shore end.

[‡]The habitat horn may be manually activated from the bridge only.

[§]The control-center horn may be manually activated from the van only.

SUPPORT BARGE

The support barge (Fig. 29) was located at the nearest shore point adjacent to the habitat location. This barge was a Navy AMMI pontoon jacked up above the water surface on driven piles to minimize reactions with waves and to minimize machinery noise being transmitted into the water. The barge was the shore terminus for all habitat umbilicals and provided the platform upon which were mounted the surface-control-center van and all habitat life support equipment. Access to this barge was by boat from the causeway pier adjacent to the base camp. The facilities located aboard this barge were the surface-control-center van, the environmental control and supply system, the electrical generation and distribution system, and the water storage and distribution system.

Surface-Control-Center Van

The surface-control-center van (Fig. 30) was an air-conditioned instrumentation van divided into two compartments, the behavioral monitoring station and the watch director's station.

The behavioral monitoring station, effectively isolated from the watch director's station by a folding partition, accommodated three behavioral observers and the behavioral scientist supervisor. Displayed before the observers were six television monitors, four of which continuously covered televised input from each of the four habitat compartments and two of which were available for external habitat cameras. A video tape recorder was available for recording significant events. Audio monitoring of the open microphones in the habitat's compartments could be recorded on two audio tape recorders. Automatic data recording equipment monitored important behavioral parameters such as time out of habitat, sleep time, stove and oven usage, and entertainment facility usage (Fig. 31).

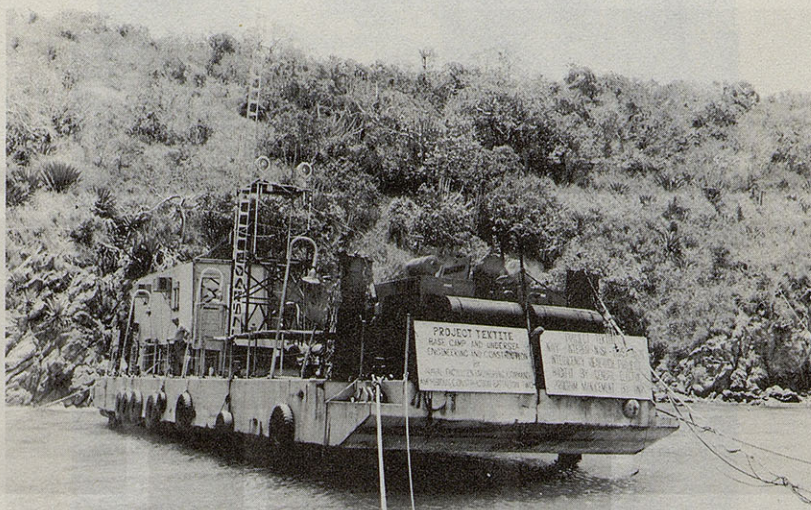


Fig. 29 - Tektite I support barge, which provided all utilities and services for the habitat. The watch director's station and the behavioral monitoring station were in the trailer at the left. The electric generators in the right foreground provided all power for the barge and the habitat. The barge is supported on four pilings for noise control.

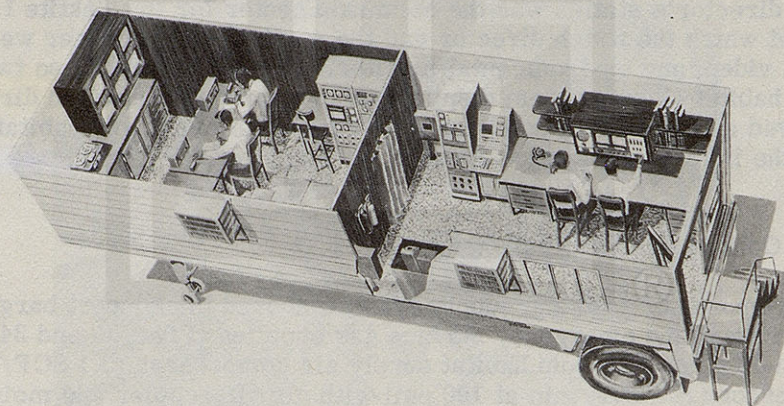


Fig. 30 - Surface control center van on the support barge. The partition between the behavioral monitoring station at the left and the watch director's station at the right provided privacy and quiet for the behavioral program.

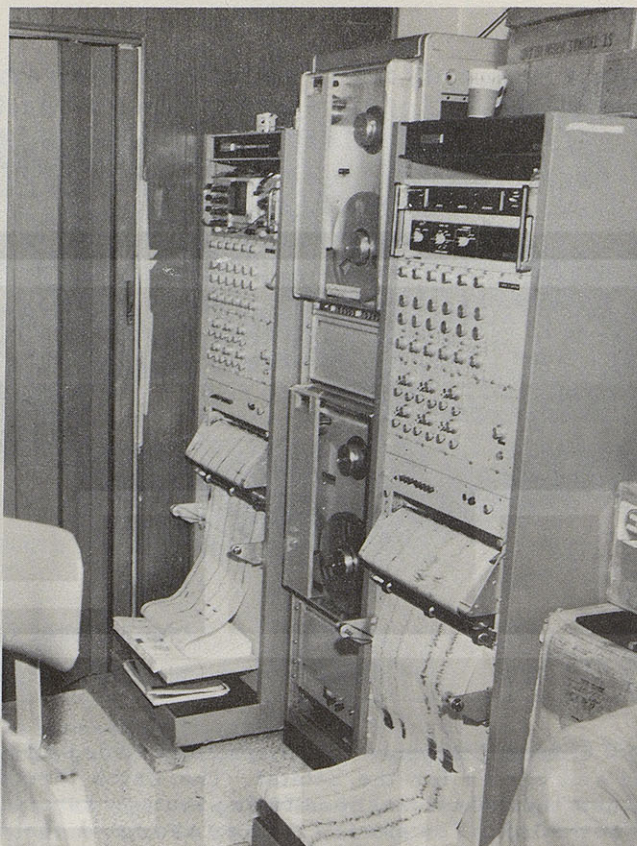


Fig. 31 - Recording equipment used in collecting EEG data from the aquanauts. This equipment is in the behavioral monitoring station, with the folding partition (Fig. 30) at the left.

The watch director's station was the command center for the Tektite I operation. A control panel, at which the watch director and the medical watch officer were stationed, provided audio, video, and environmental monitoring capability for these two officers (Fig. 32). The habitat alarm system displays were located at the watch director's station, which also served as the control point for all communications to the habitat, base camp, mainland, and the immediate surface area.

Environmental Control and Supply System

The environmental control and supply system, aboard the support barge, provided the habitat all normal and emergency surface gas supplies (Figs. 33 and 34). This system included: an on-line and a backup habitat supply air compressor (3.1 SCF/min at 50 psi), a purge compressor (125 SCF/min at 100 psi) with air aftercooler and moisture trap, a surface emergency air supply (two tubes, each 8000 SCF at 2200 psi), a nitrogen habitat charging and purge gas supply (four tubes, each 8000 SCF at 2200 psi), a pneumatic control console (Fig. 35) at which one man could monitor and control the total gas supply to the habitat, and all necessary valves, regulators, and piping.

In addition, the compressors for charging the aquanauts' scuba tanks were located on the support barge, and the high-pressure charging air was sent to the habitat via the umbilical for storage in volume tanks in the habitat base.

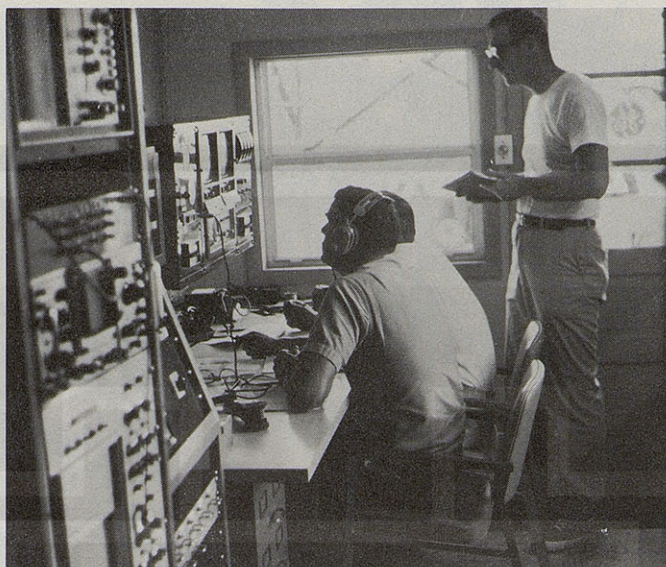


Fig. 32 - Watch director's station in the surface control center van. The two TV monitors could be switched to any of the six signals from the habitat. The intercom provided for audio monitoring of each of the habitat's rooms, and measurements of the habitat atmosphere were also presented on the console. In the foreground are gas analysis equipments.

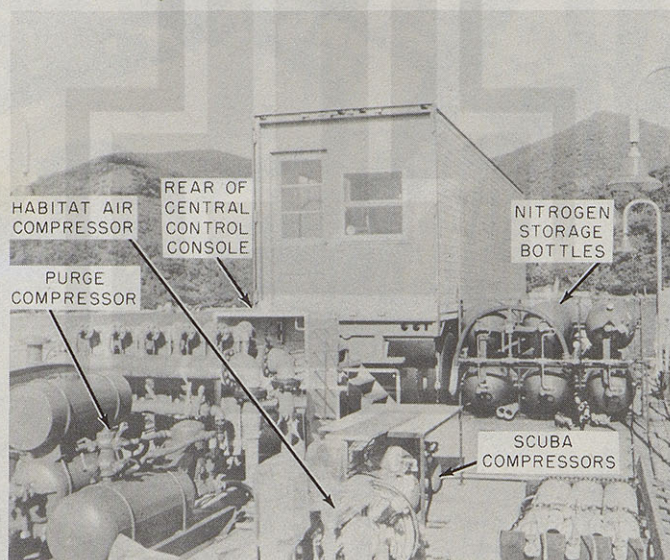


Fig. 33 - Surface control center van and gas supplies for the habitat

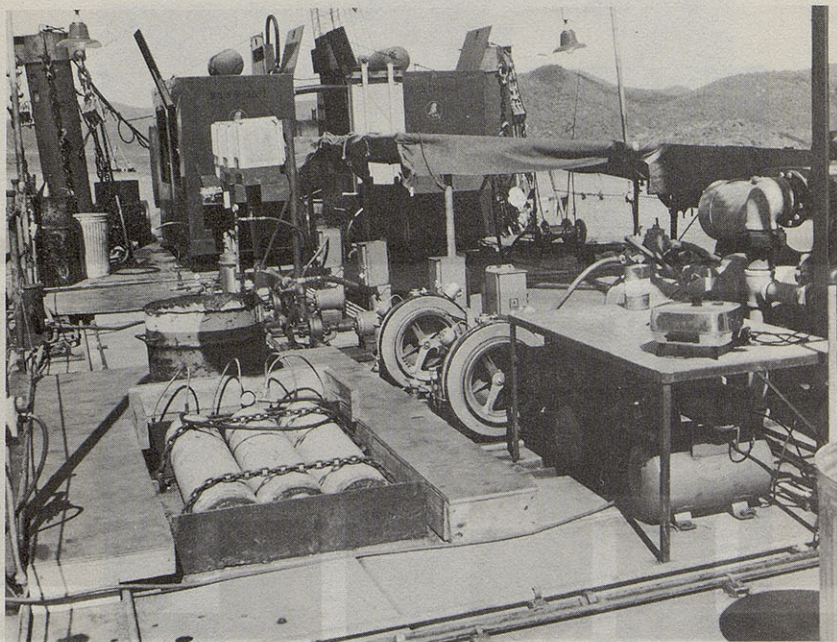


Fig. 34 - Utility sources on the support barge. Scuba charging compressors are beneath the table in the right foreground, and air supply compressors are immediately past the table. Water is stored in a large pillow tank beneath the canopy. Diesel-driven generators are in the rear, with power transformers hanging from the rack at the left center.

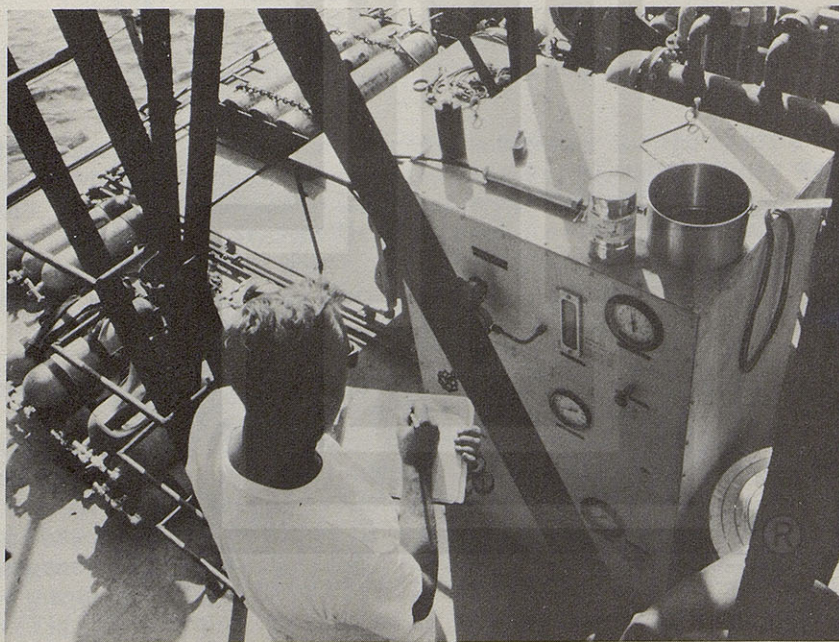


Fig. 35 - Central control console, where flow and pressure of all atmosphere gas to the habitat was controlled, monitored, and recorded

Electrical Generation and Distribution System

The electrical generation and distribution system provided electrical power for the support barge and the habitat. Two 100-kilowatt diesel-powered generators (one redundant) furnished all required power for the habitat, environmental compressors, water pumps, and lighting.

Water Storage and Distribution System

Potable water for the habitat was stored on the support barge in a 3000-gallon pillow tank and was pumped to the habitat via the water umbilical. The pillow tank was refilled from a tank truck, aboard a Navy LCM boat, when required.

CRANE BARGE

The crane barge (Fig. 36), moored adjacent to the support barge, was the platform on which was located the Tektite I decompression system and a 35-ton-capacity crane for handling this system.

The decompression system (Fig. 37) was an Ocean Systems, Inc., ADS IV system consisting of a double-lock deck decompression chamber with its environmental support unit and personnel transfer capsule. This ADS IV system was man-rated to a depth of 600 feet. The decompression mode was that of ventilation, with occasional periods when the aquanauts were on pure oxygen supplied through a mask/regulator breathing system (the decompression schedule used was given in Table 4).

Personnel for the operation of the decompression facility, handling crane, and small boat support were maintained on a 24-hour alert watch, with frequent drills so that if necessary an aquanaut could have been moved from the water into decompression in less than 5 minutes.

CAUSEWAY PIER

The causeway pier (Fig. 38) was the sea/shore interface between the support barge and the base camp. The draft at the end of this pier was such that most craft transporting personnel and supplies from St. Thomas could tie up. This pier was the terminus of the shuttle boat service between the support barge and the shore.

BASE CAMP

The Tektite I base camp (Fig. 5) was a semipermanent facility to house and mess the scientific and support personnel who were on-site throughout the mission. Because of the remoteness of the Tektite I site, the base camp was required to be self-supporting. Additionally, because the camp was located in a National Park, great care was required to preserve the beauty and nature of the park. The camp was set back from the Lameshur Bay beach and beach road to maintain the unspoiled beauty of the beach area.

The camp consisted of 13 wooden tropical huts, 16 by 32 feet (Fig. 39), and one portable, prefabricated aluminum building, 20 by 48 feet, with supporting utility services. Eleven tropical huts were used as barracks, one as the command (OOD) hut, and one as the galley. The wood framing was treated timber, and the siding was redwood. All were screened for ventilation except for the OOD hut, which was enclosed and air conditioned.

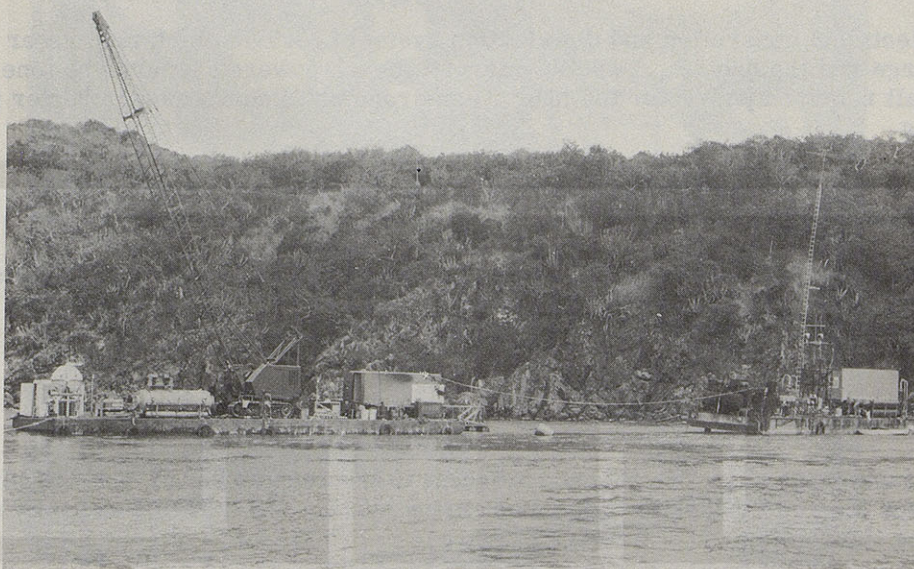


Fig. 36 - Crane barge, moored alongside the support barge with a hand-powered ferry barge between

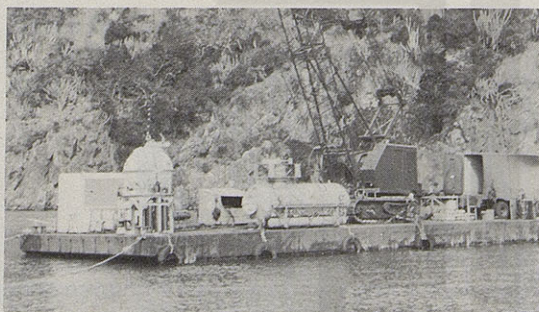


Fig. 37 - ADS IV deck decompression chamber (center), personnel transfer capsule (left), and lifting crane for the personnel transfer capsule

The aluminum building (Fig. 40) was partitioned into three compartments: dispensary, marine science laboratory, and recreation area. During the postdive medical debriefings, this building housed the medical examination facilities. The tropical huts of the base camp will be used in the future by the College of the Virgin Islands, for use as a laboratory and dormitory facility in conjunction with their Marine Ecological Station, also on Lameshur Bay and partly visible at the far right center in Fig. 5.

Potable water for the camp was stored in two 10,000-gallon underground tanks. Water for these tanks was pumped from a water barge alongside the causeway pier to the camp via "invasion piping" over a distance of approximately 1/4 mile. Water was pumped from the storage tanks into a camp distribution system. A well adjacent to the base camp had been outfitted with a pump and plumbing for shower water supply, but this well proved too unreliable for use.

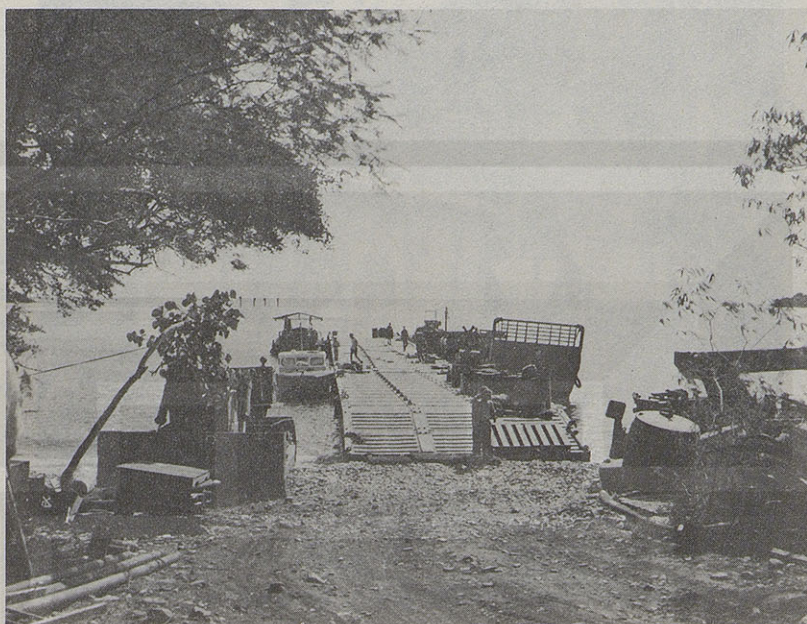


Fig. 38 - Pier, consisting of causeway sections tied end to end, serving as the offloading point for personnel and supplies arriving at Lameshur Bay. The small craft left of the pier shuttled personnel between the base camp and the support barge adjacent to the habitat.



Fig. 39 - Base camp which housed the approximately 60 support and 35 scientific personnel at the site



Fig. 40 - Aluminum building in the base camp which was partitioned into the infirmary, marine science laboratory, and recreation room

Human waste was burnt on a daily basis in half-drums (55 gallons) by covering the waste with fuel-oil and igniting. This system was quite efficient. Waste water from the showers, galley, and dispensary was drained into the ground via a grease trap and drain field.

Electric power was generated in the camp by two 100-kilowatt generators (one redundant) and distributed, where possible, by underground cables.

LOGISTICS, TRANSPORTATION, AND COMMUNICATIONS

The remoteness of the Tektite I site required some degree of resourcefulness and a wide variety of military and civilian resources in the coordination of logistics, transportation, and communication.

Logistics requirements were primarily in the areas of food, water, and petroleum. For the most part, sufficient dry food was landed with the Tektite I party in January 1969. Resupply of dry foods, and continuing resupply of frozen foods, was obtained from visiting Navy ships. Fresh provisions, such as bread and milk, were procured from local vendors on St. Thomas. Water was delivered to the Lameshur Bay site on a weekly basis by the government of the Virgin Islands via water barge. Petroleum was purchased under Defense Contract in St. Thomas. Diesel fuel and gasoline were loaded into 55-gallon drums at Red Hook (St. Thomas) and transported by a Tektite I LCM boat to the site on a weekly basis.

Transportation to the Tektite I site was by two routes: via water over an open 8-mile unmarked and unlighted course from Red Hook Harbor, St. Thomas, and a torturous overland route from Cruz Bay (Fig. 41). The water route was the more desirable of the two,

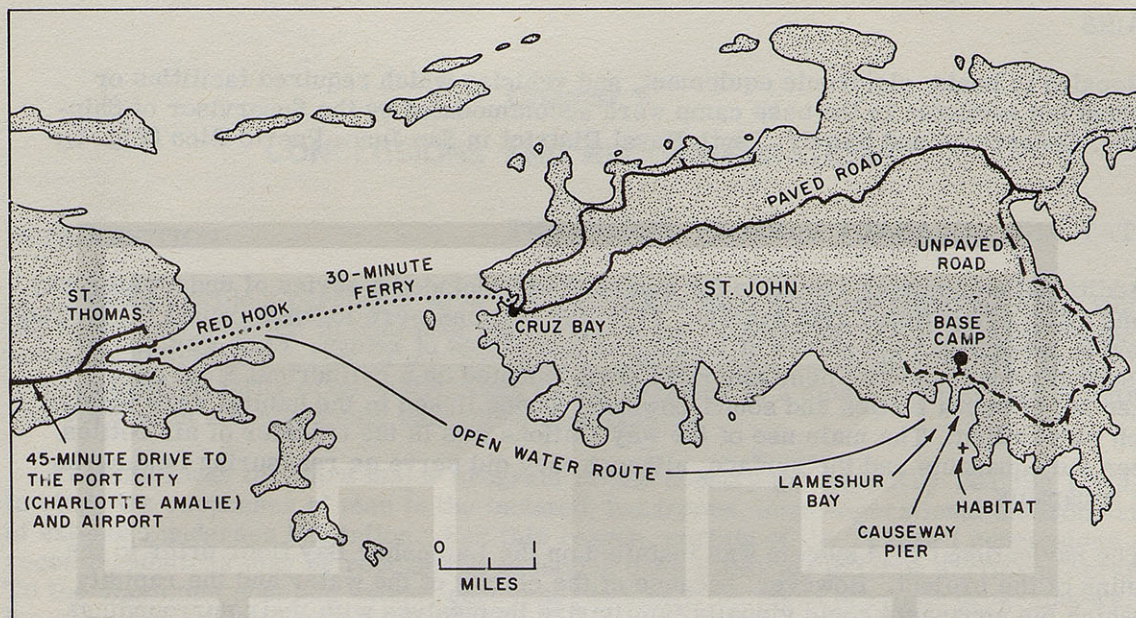


Fig. 41 - Transportation to the Tektite I site

and all supplies and most personnel were transported via this mode. The Tektite I fleet consisted of two LCM-class cargo boats, three LCPL-class personnel boats, and two 18-foot outboard runabouts (primarily for safety diver use). Land transportation on the base camp consisted of one 6 by 6 truck and two 4 by 4 ordnance carriers. One 4 by 4 ordnance carrier was stationed on St. Thomas. These vehicles were furnished and operated by Amphibious Construction Battalion Two.

External communications were by radio, telephone, and commercial marine-operator service. Internal communications (within the base camp area) were by radio, field phones, and sound-powered phones. Mail service was handled through the U.S. Post Office, St. Thomas.

External radio communication using AN/PRC-47 single-sideband radios was on local NORATS frequency 2114 kHz, on which contact was maintained with the St. Thomas Coast Guard Station and with Ft. Allen, Puerto Rico. Telephone service (two lines) into the base camp was furnished by VITELCO. Commercial marine-operator service, which was patched into the VITELCO system in St. Thomas, was leased by General Electric. Telephone service was approximately 60% reliable.

Internal communication was used to exercise command control over the base camp and adjacent areas. Additional AN/PRC-47 radios, located in vehicles, boats, the base camp, and the surface control center operated on the upper sideband on 4073 kHz. Contact between the watch director and the diving and safety watches was maintained on the 39-MHz band using Motorola PT-200 FM transceivers. Field phones linked the causeway pier to the base camp and were a backup to the PT-200 transceivers between the crane barge and the support barge. Sound-powered phones provided an emergency communication link between the watch director and the habitat.

REPAIRS

Repairs to boats, electronic equipment, and vehicles which required facilities or personnel not available in the base camp were accommodated by the Supervisor of Shipbuilding, Conversion and Repair, Tenth Naval District in San Juan, Puerto Rico (Fig. 1).

HABITAT AND AQUANAUT SUPPORT EQUIPMENT

Additional equipments available for aquanaut use included a series of underwater way stations and a navigational grid system. Five way stations were located around the habitat to provide the aquanauts a series of landmarks and places of refuge. Each way station consisted of a clear-plastic hemispherical shell mounted on a cylindrical steel cage. A charged set of scuba bottles and sound-powered phones linked to the habitat were located in each way station. The main use of the way stations was in the transfer of air bottles between the aquanauts and the surface, although they did serve as reassuring landmarks to the aquanauts.

The navigational grid system was installed on the Lameshur Bay floor prior to the beginning of the project. However, because of the clarity of the water and the rapidity with which the aquanauts could visually familiarize themselves with their surroundings, the navigation system was not used to any great extent.

The aquanauts used standard twin-tank scuba rigs. Each 72 cubic foot capacity tank had its own reserve valve and single hose regulator. This double-tank combination had a little over an hour's air capacity at a 50 foot depth. For longer excursions, extra tanks were pre-positioned by surface divers along the excursion route. Before the mission it was anticipated that newly developed, Navy-procured closed-circuit rigs, with approximately a six hour capacity, would be available for aquanaut use. These, however, were not delivered to the Navy in time for completion of evaluation and certification, and thus were not used in Tektite I.

The Tektite I aquanauts had available, in addition to standard scuba equipment, hookah masks with built-in communications equipment. A hookah system is one in which breathing gas is supplied to the diver via an umbilical. In the case of Tektite I, the gas was supplied from a low-pressure source in the habitat through a 200-foot hookah hose. Thus the aquanauts could swim up to 200 feet from the habitat without having to suit-up in full scuba gear. The hookah mask contained communications equipment, linked to the habitat via hardwire cables along the hookah hose. The hookah was used for 41 man-hours of diving, about 1/10 of the total man-hours in the water.

In addition to the tethered hookah communications, the Tektite I aquanauts had two sets of untethered aquasonics equipment. These included two tender and three diver units. These units were seldom used due to range and reliability limitations.

A dumbwaiter system was provided for the dry transfer between the habitat and the surface of items such as food, CO₂ absorbent, mail, and garbage. The system consisted of a floating platform with an A-frame and winch which could raise and lower a series of pressure and waterproof canisters. The canisters were vented for pressure equalization after each transit. Two sizes of transfer pots were used during the Tektite I project. The larger size was capable of moving 300 pounds, but the size and weight of the pot made it awkward to handle. The smaller sized pots, of which there were two, were of 30-pound capacity, and these canisters saw considerable service before and during the project.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

Tektite I project personnel were able to achieve their primary missions of (a) keeping an undersea habitat in operation for a continuous 2-month period, (b) safely conducting a sustained 2-month series of marine science studies from the habitat, and (c) collecting a voluminous quantity of consistent data on the behavior of a small team of men isolated and working in a continuously hazardous environment.

Tektite I was the third major program in this country (preceded by Sealabs I and II) to study the responses of men to the isolated, hazardous, quasi-operational environment of extended undersea habitation. For this reason, certain of the Tektite I conclusions and recommendations may be recognized as having been identified in these earlier programs. To the maximum possible extent, recommendations from these previous programs were incorporated into Tektite I, but schedule and budget limitations precluded inclusion of specifically recognized desirable considerations. Consequently, certain of the conclusions and recommendations to follow indicate areas in the Tektite I program where desirable features were sacrificed. It is emphasized that in no respect was the safety of the aquanaut crew or other project personnel compromised where schedule/budget tradeoffs occurred.

CONCLUSIONS

1. Saturation dives of the Tektite type can be conducted safely, provided that a rigorous safety program is implemented. As further experience is gained, the safety factor added for uncertainty can be reduced to a degree, while freedom from restraints may be more fully exploited.

2. Saturated diving offers great advantages to investigations of marine science. The most impressive feature was the wide range of studies during the project. The application of undersea habitation to studies of marine geological processes, to exploration and exploitation of mineral and other marine resources, and to studies of the sea floor are potentially unlimited.

3. Long excursions by aquanauts from undersea habitats appear feasible and would be applicable to civilian and military needs. The Tektite I aquanauts, swimming in warm tropical water, were physiologically bound only by vertical limits imposed by decompression. Their horizontal ranging from the habitat increased throughout the mission. The horizontal excursion limit on time in the water limit became a function of equipment, not aquanaut, endurance. It should be realized, however, that a similar mission in cold water would have the additional requirements of adequate diver heating.

4. Studies to prepare the Tektite I normal decompression schedule indicated that the controlling tissue for nitrogen saturation is beyond the 240-minute limit. The preparation and experimental validation of the emergency decompression (treatment) schedules indicated that a surface time of 15 minutes was safely available to a diver nitrogen saturated at the Tektite I depth (43 feet) before emergency recompression and decompression treatment was required.

5. Divers can safely live and work in a hyperbaric nitrogen atmosphere saturated at 43 feet with excursions to 22 and 85 feet. Thus, for these depths, which are of considerable interest to the scientific community, expensive three-gas helium-oxygen-nitrogen life support systems are not required to support saturated scientific diving.

6. Man can adapt to the stresses that accompany undersea habitation at 43 feet and the various behavioral interactions involved therein. The aquanauts experienced no severe sleep loss or disruption of sleep cycles. Instead of obtaining less sleep as the mission progressed, the aquanauts appear to have slept longer and deeper.

7. The prolonged application of the environmental conditions and aquanaut interactions, as carried in the Tektite I program, did not result in any unusual microbiological hazard to the aquanauts.

8. The use of mass spectrometer instrumentation in a hyperbaric environment is a technological advance in undersea exploration, where monitoring and control of the life support atmosphere is essential.

9. The aquanauts spent 432.15 man-hours in the water during the mission. This represented an average of 7.2 man-hours per day. Maximum range (horizontal) from the habitat exceeded 1800 feet in the latter stages of the mission. This range was limited by the available gas in the aquanauts' scuba bottles.

10. The Tektite I hookah hose and masks allow the aquanauts ready access to an area within 200 feet of the habitat without requiring them to suit-up in full scuba gear. The masks and communication system allowed the aquanauts to communicate with the habitat bridge while they were out on the hookah. The aquanauts used the hookah system for more than 41 diving hours, about 1/10 of the total diving time.

RECOMMENDATIONS

1. Crew composition for future extended underwater missions should include a diver-engineer to assume responsibility for equipment maintenance and habitat upkeep and resupply. This would allow the marine investigators more diving time and would minimize training and familiarization problems.

2. A longer aquanaut training program in habitat operation than that of Tektite I is recommended if a trained diver/engineer is not part of the crew. The training period should provide the aquanauts a more detailed familiarization with the habitat systems and hardware as well as with aquanaut support equipment. Training should be conducted under conditions simulating as nearly as possible actual mission conditions, and an in-water training exercise is highly recommended.

3. Long-duration (closed-circuit or semiclosed-circuit) breathing equipments, operational swimmer delivery vehicles, and free-swimmer communication units should be developed for use of scientific divers operating from undersea habitats. This would enable them to take fuller advantage of their saturated condition by allowing them longer excursions from their habitat.

4. Medical preparations for future missions should emphasize thorough usage of preventive measures to curb aquanaut ear infections common to this type of program.

5. Design of habitats for future missions should reflect the need for work areas compatible with the needs of the aquanaut users. Where possible, storage space should not encroach upon scientific work space, and maximum effort should be made to make storage spaces in otherwise wasted spaces.

6. Provisions should be incorporated in the design of future habitats to allow leveling of the habitat after it has been secured to the ocean floor.

7. Habitats for future undersea projects should be designed with consideration for transportation and launch in less-than-favorable seas. The use of the AMMI barge/LSD transportation and launch system, while successful in the calm water of Lameshur Bay, would not be as successful in deep or heavy seas.

8. Although Tektite I proved that saturated diving can be a useful tool for marine research, other modes of saturated diving should be considered for scientific work. These include mobile habitats, PTC (personnel transfer capsule) diving from deck chambers to the sea bottom for work, and a habitat in which the aquanauts are compressed and decompressed enroute to and from the working site.

9. Based on the demonstrated capability of MCB/ACB divers in Tektite I, these personnel should be included in future Navy experimental/research activities where applicable.

10. Further development of mass spectrometer instrumentation for undersea application is recommended. Instrument design should provide for simplified calibration techniques. Special emphasis is required in designing a sturdy instrument package that will withstand the operational rigors of an undersea mission. Modular component design would enable aquanauts to make module replacements without specialized training.

11. Special emphasis in future missions should be placed on establishing fully adequate surface and free-swimmer communication systems.

12. Hookah masks, with communication capability between divers and back to the habitat, should be provided in subsequent programs. Adequate, convenient space should be provided outside the habitat for stowage of the long hookah hoses while not in use.