THE OCEAN ENGINEERING PROGRAM OF THE U.S. NAVY

Accomplishments and Prospects

SEPTEMBER 1967

OFFICE OF THE
OCEANOGRAPHER OF THE NAVY
Alexandria, Virginia

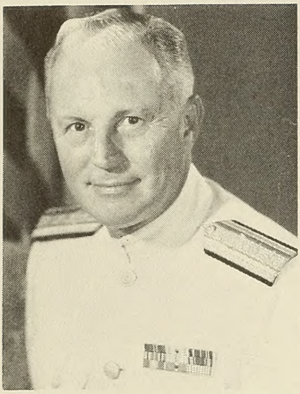
THE OCEAN ENGINEERING PROGRAM OF THE U.S. NAVY

Accomplishments and Prospects

SEPTEMBER 1967

OCEANOGRAPHER
OF THE NAVY

OFFICE OF THE
OCEANOGRAPHER OF THE NAVY
Alexandria, Virginia



Rear Admiral O. D. Waters, Jr., USN
Oceanographer of the Navy

Foreword

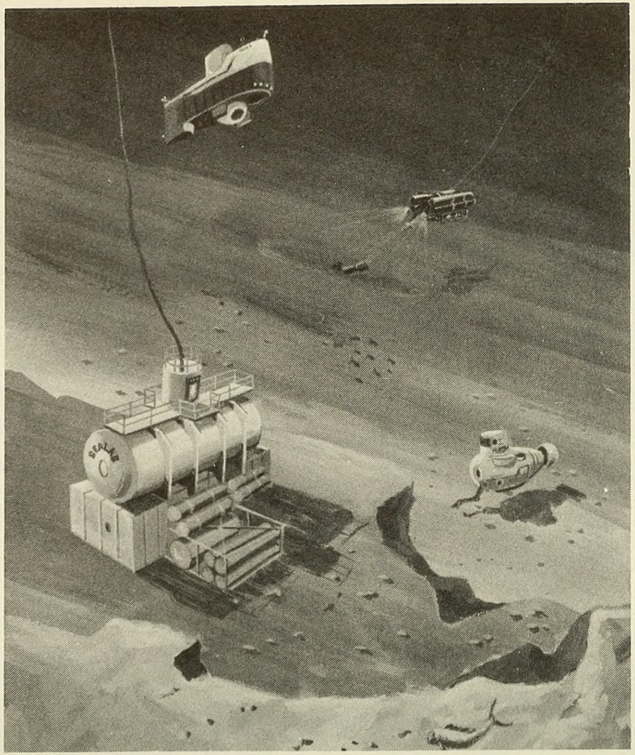
The United States Navy's operations on, above, under, and from the ocean are vital elements in national security. Although all Navy activities are concerned with the ocean, Navy ocean engineering is concerned specifically with the development and support of advanced equipment and technologies for underwater search, rescue, salvage, construction, environmental prediction, and related underwater endeavors.

The purpose of this report is to provide the Congress, the Executive Branch, and the public with a comprehensive view of the Navy ocean engineering program, present and future. It includes those efforts managed by the Oceanographer of the Navy and closely related efforts monitored by him. The report outlines capabilities and technological developments, and includes short descriptions of representative engineering test and support facilities.

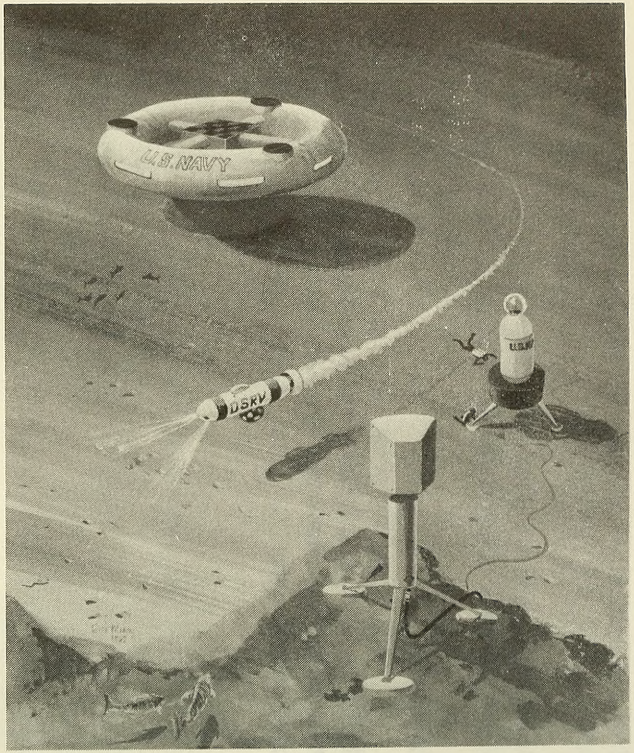
The Navy program necessarily makes demands upon many fields of technology and involves large segments of industry and academic institutions in its execution. The Navy plans to continue its leadership of ocean engineering and to share its knowledge with other national oceanographic programs to the maximum extent consistent with national security.

O. D. Waters, Jr.

CONTENTS



Accomplishments



Prospects

Frontiers of Ocean Technology

The Ocean Engineering Program of the U.S. Navy

Accomplishments and Prospects

INTRODUCTION

BACKGROUND

The Navy's daily use of the oceans requires its interests in ocean engineering to be comprehensive and immediate. The Navy has performed salvage missions since Revolutionary War days, and Navy environmental prediction and charting predates the Civil War. Submarine development and diving have been actively fostered by the Navy since before World War I. Technological changes since World War II have extended Navy missions from a surface or near-surface arena down into the depths of the ocean. Increased numbers of longer range, deeper diving submarines have generated new requirements for underwater search, rescue, salvage, and construction that did not exist ten years ago when the Navy purchased the bathyscaph TRIESTE. This is the purpose of Navy ocean engineering: to develop the vision and resources to produce the undersea capabilities that are required now and will be required in the future. Operational emergencies such as the loss of THRESHER and the Palomares bomb incident lent urgency and emphasis to existing programs in ocean engineering.

Daily the nation is becoming more aware of its economic, social, and defense interests that lie on our one million square miles of continental shelf and our surrounding oceans. In 1966 the President's Science Advisory Committee Report, "Effective Use of the Sea," was published containing concrete recommendations for national, federal, and Navy programs in oceanography. In 1966 the National Council on Marine Resources and Engineering Development was established to provide a stronger policy and organizational framework and to give new momentum to marine science activities.

In recognition of the magnitude and importance of the Navy Oceanographic Program, and to assure program integration, the Secretary of the Navy in 1966 established the Office of the Oceanographer of the Navy, who is directly responsible to the Chief of Naval Operations. The Oceanographer of the Navy acts as the Navy Oceanographic Program Director for the Chief of Naval Operations, under the policy direction of the Secretary of the Navy, through the Assistant Secretary of the Navy (Research and Development).

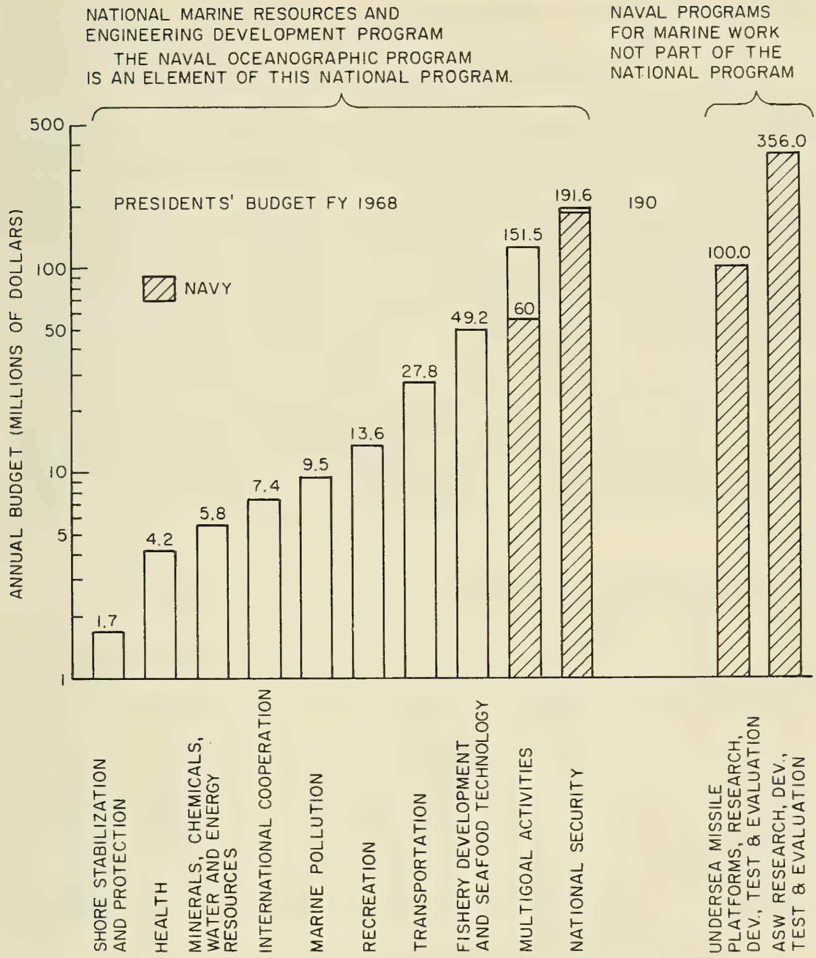
PURPOSE OF NAVY OCEANOGRAPHY

Within the Navy, the oceanographic program encompasses that body of science, engineering, and operations, and the personnel and facilities associated with them, required to explore and to lay the basis for exploitation of the ocean and its boundaries for national defense and other national objectives. The urgent need for worldwide knowledge of the operational environment of its forces, and the variety of operations affected by one or another facet of that environment, impel the Navy to support studies in every major oceanic area. Marine engineering and technological development, and theoretical and laboratory studies, complement these field investigations and are equally comprehensive. In addition to efforts in support of the fleet and other defense forces, the Navy must meet responsibilities in the area of search, rescue, salvage, and ocean charting.

The basic policy of the Navy is to provide the capability for the Department of Defense to fulfill its assigned mission of maintaining the security of the nation. The prime objective, then, is to increase the effectiveness of present operations. In fulfilling this objective, highly diverse oceanographic efforts are carried out through industry, Navy laboratories, universities, and nonprofit institutions.

RELATIONSHIP TO THE NATIONAL OCEANOGRAPHIC PROGRAM

The Navy Oceanographic Program is an important element (about half) of the national oceanographic program, which includes the marine science programs of all federal agencies under the coordination of the President, with the advice and assistance of the National Council on Marine Resources and Engineering Development. Navy participation in the national



Budgets for the Navy Oceanographic Program, an element of the National Marine Resources and Engineering Development Program, and other Navy programs for marine work, not part of the national program.

program is concentrated in the category of national security, and in the subcategories of multigoal activities such as oceanographic research, education, ocean environmental observation and prediction services, and mapping, charting, and geodesy. The Department of Defense has accepted the national responsibility for ocean technology, and has offered to accept such responsibility in certain other areas where Navy has major programs, facilities, and competence.

RELATIONSHIP TO OTHER NAVY PROGRAMS

The Navy Oceanographic Program is composed of many distinct efforts which are drawn from a cross section of total Navy effort. In addition to these components, work related to that of the Navy Oceanographic Program is pursued as minor accompaniment to other Navy program areas, such as antisubmarine warfare and strategic deterrence. Such efforts are usually either so closely integrated with the weapon-system development being carried out or so limited in time or funding that their separation from their parent development for management purposes is not warranted. They are, therefore, monitored to insure that their effort is not duplicated and that their data and results are made available to others who require them. These efforts are usually performed by Navy laboratories and industrial firms which also provide key technical capabilities and facilities for the oceanographic program.

INTERACTION WITH INDUSTRY AND ACADEMIC PARTICIPANTS

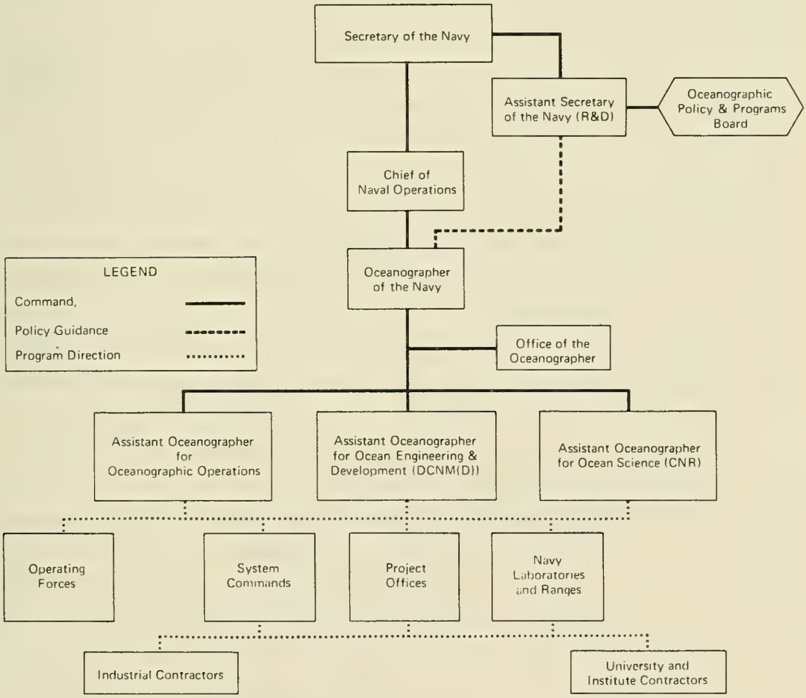
The incentives for industrial development and use of the ocean are substantial. These incentives emanate from economic, social, and military needs. Over the past five years private corporations have increased substantially the extraction of petroleum and minerals from the ocean floor bordering the United States. In addition to the corporations actually conducting operations in the ocean, a multitude of manufacturers provide both the Navy and industry with equipment and technology. The demand for these services by the Navy and industry is expected to expand throughout the foreseeable future.

For the expansion of industrial exploitation of the ocean, investment security is essential. Investment security for commercial projects expanding into the ocean depths also requires that the technology and systems for operating underwater be safe. The engineering for deep submergence must be of assured quality, for there is no room for failure in the hostile environment of the sea. The Navy has established a group to work closely with industry and to provide guidance to designers of undersea vehicles without imposing standards on non-Navy submersibles. The Navy recognizes its responsibility to make available to industrial and academic communities to the maximum extent possible the data and results of its science and technology.

NAVY OCEANOGRAPHIC ORGANIZATION, MANAGEMENT, AND FUNDING

The Oceanographer of the Navy is responsible for direction and control, including control of resources, of the Navy Oceanographic Program. To further these objectives, the Chief of Naval Research has been assigned additional responsibility as the Assistant Oceanographer of the Navy for Ocean Science, and the Deputy Chief of Naval Material (Development) has been assigned additional responsibility as the Assistant Oceanographer of the Navy for Ocean Engineering and Development. The organizational structure includes an Assistant for Oceanographic Operations, whose appointment is pending.

In accordance with the above organizational structure, the Navy Oceanographic Program has been aligned into three major functional areas: Ocean Science, Ocean Engineering and Development, and Oceanographic Operations. Detailed organization charts are presented in Appendix A.



The Navy's organization for command and policy guidance of the Navy Oceanographic Program

The Assistant Oceanographer for Ocean Science is responsible for a broad scientific and technical program through support of academic and institutional scientists and engineers throughout the country and within Navy laboratories. This program provides the base of knowledge about the ocean environment upon which naval systems are developed and perfected. The program itself is composed of a number of identifiable efforts designed to meet the Navy's needs for knowledge and understanding in such areas as ocean dynamics, air-sea interaction, chemistry of the ocean, benthic boundary studies, sea floor topography and sediment studies, crustal and subcrustal studies, oceanic biology, underwater sound, and scientific platforms and instrumentation. A report on the ocean-science program was issued in June 1967.*

The Assistant Oceanographer for Ocean Engineering and Development is responsible for the development of major programs in undersea search, rescue, salvage, and construction and in environmental prediction and oceanographic survey. The Deep-Submergence Program is designed to give the Navy the capability to operate at any depth, location, and time within the ocean. Within this program the Deep Submergence Systems Project manages a major effort to advance the Navy's underwater search, rescue, and salvage capability. A major new Navy initiative in fiscal year 1968 is the Deep Ocean Technology Program. This program is to provide the Navy with a technological base from which options for improving present undersea warfare systems and developing future ones can be selected. In addition to these formal programs, a wide range of development programs are carried out by Navy laboratories and contractors in support of basic ocean engineering missions.

The Assistant Oceanographer for Operations is responsible for that part of the program consisting primarily of oceanographic and hydrographic operational surveys and services in all ocean areas. These survey and service operations are carried out to provide environmental data, charts, and oceanographic publications necessary to support key naval operations such as southeast Asia, antisubmarine warfare, strategic deterrence, mine warfare, and amphibious warfare. They also satisfy requirements to provide environmental data, charts, and oceanographic publications for the Navy and the merchant marine.

---

*"The Ocean Science Program of the U. S. Navy–Accomplishments and Prospects," Office of the Oceanographer of the Navy, Alexandria, Virginia, June 1967.

Naval Oceanographic Program Funding, President's Budget Fiscal Year 1968 in Millions of Dollars

Funding Category	Ocean Science	Ocean Engineering and Development	Oceanographic Operations
Operations	0	36.2	104.4
Development	14.5	64.3	
Research	30.1	0	0
	44.6 +	100.5	104.4
			Total 249.5

NATIONAL NEEDS AND OCEAN ENGINEERING

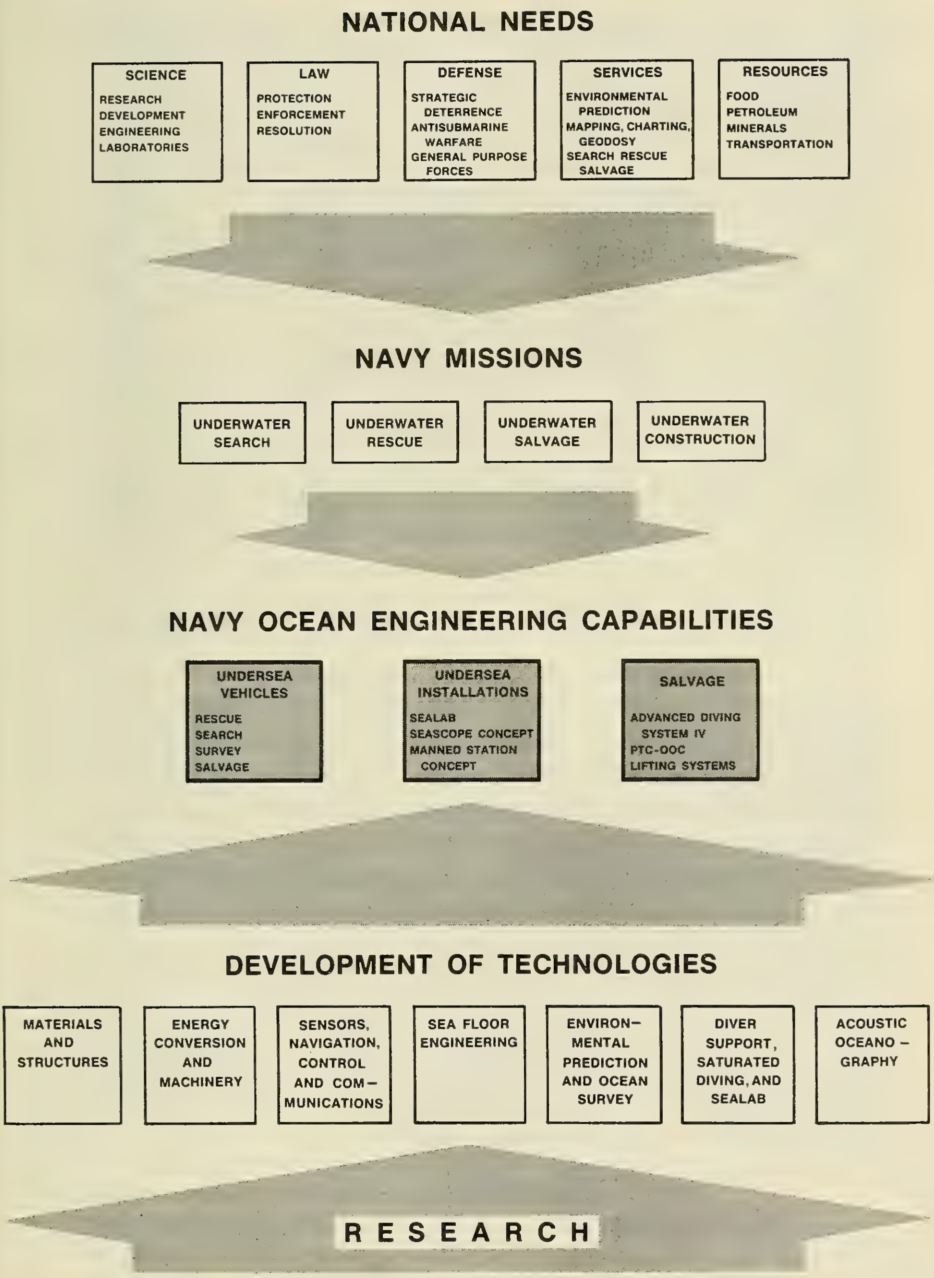
National needs related to marine science affairs can be conveniently classified into five major areas: defense, law, public service, science and technology, and resources. These needs are addressed through the national oceanographic program, in which the Department of Defense participates closely.

Within the Department of Defense, the Navy performs operational missions responsive to defense and other national needs. The operational missions of underwater search, rescue, and salvage, in particular, are supported by ocean engineering. Navy ocean engineering, then, is concerned with developing specific capabilities to meet operational requirements in underwater search, rescue, and salvage. The general requirement for a capability in underwater construction is being further specified through analyses underway during 1967.

Capabilities in ocean engineering in being or in development can be characterized by undersea vehicles, undersea installations, and salvage. In addition, certain Navy facilities are uniquely qualified to support ocean engineering and are listed to demonstrate a capability and a commitment.

The technologies which are the building blocks from which capabilities are developed are categorized into seven major areas for convenience. These are: materials and structural design; energy conversion and machinery; sensors, navigation, control, and communications; diver support; environmental prediction and oceanographic survey; acoustic oceanography; and sea floor engineering. Certain of these technologies support oceanographic operations missions, rather than ocean engineering. However, all oceanographic programs are centralized in their development phase under a single manager to ensure coordination and to eliminate duplication.

World land masses (black), water less than 6000 ft (shaded), and water greater than 6000 ft (white)


NATIONAL NEEDS
SCIENCE
RESEARCH
DEVELOPMENT
ENGINEERING
LABORATORIES
LAW
PROTECTION
ENFORCEMENT
RESOLUTION
DEFENSE
STRATEGIC DETERRENCE
ANTISUBMARINE WARFARE
GENERAL PURPOSE FORCES
SERVICES
ENVIRONMENTAL PREDICTION
MAPPING, CHARTING, GEODOSY
SEARCH RESCUE
SALVAGE
RESOURCES
FOOD
PETROLEUM
MINERALS
TRANSPORTATION
NAVY MISSIONS
UNDERWATER SEARCH
UNDERWATER RESCUE
UNDERWATER SALVAGE
UNDERWATER CONSTRUCTION
NAVY OCEAN ENGINEERING CAPABILITIES
UNDERSEA VEHICLES
RESCUE
SEARCH
SURVEY
SALVAGE
UNDERSEA INSTALLATIONS
SEALAB
SEASCOPE CONCEPT
MANNED STATION CONCEPT
SALVAGE
ADVANCED DIVING SYSTEM IV
PTC-DDC
LIFTING SYSTEMS
DEVELOPMENT OF TECHNOLOGIES
MATERIALS AND STRUCTURES
ENERGY CONVERSION AND MACHINERY
SENSORS, NAVIGATION, CONTROL AND COM-MUNICATIONS
SEA FLOOR ENGINEERING
ENVIRON-MENTAL PREDICTION AND OCEAN SURVEY
DIVER SUPPORT, SATURATED DIVING, AND SEALAB
ACOUSTIC OCEANO-GRAPHY
RESEARCH

NAVY CAPABILITIES IN OCEAN ENGINEERING

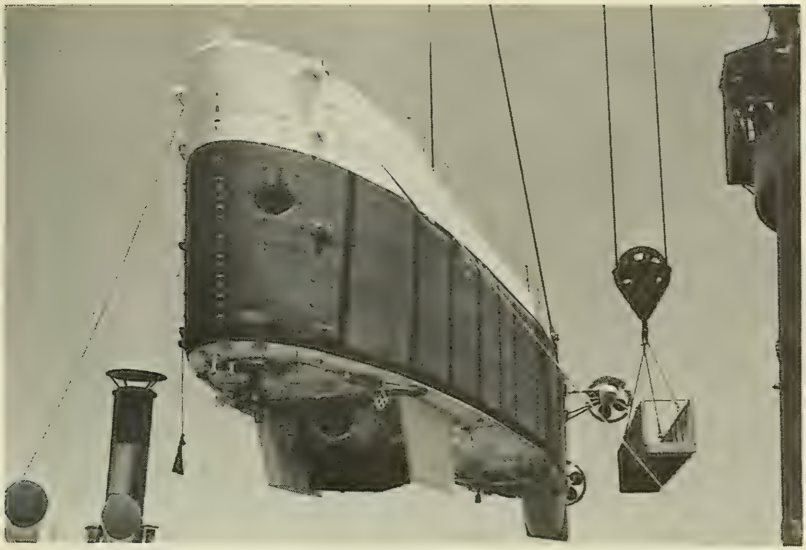
Navy capabilities to perform undersea missions in search, rescue, salvage and construction constitute a major part of ocean engineering. The word capabilities as used here implies those existing and those in development.

UNDERSEA VEHICLES

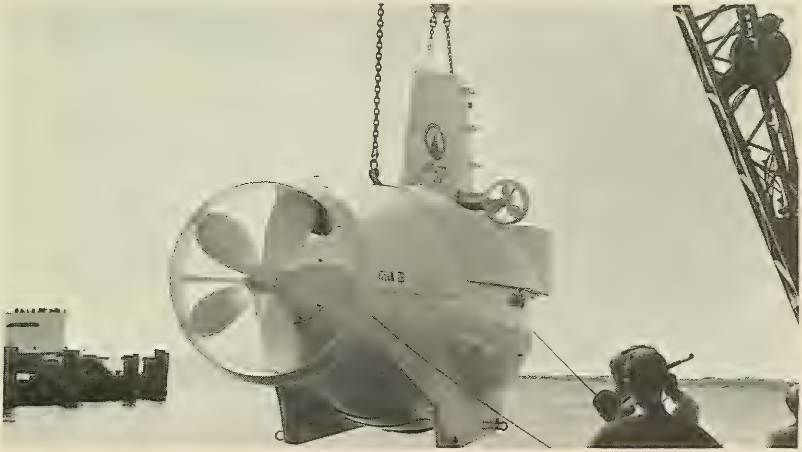
Undersea vehicles comprise the core of present Navy development effort to provide the operating forces with undersea search, rescue, and salvage capabilities. Undersea vehicles, manned and unmanned, are being considered for use in underwater construction. Undersea vehicles in this context are noncombatant submersibles, including bathyscaphs, search vehicles, rescue vehicles, and salvage/recovery vehicles.

The ability of submersibles to make effective use of the sea depends on such key operational characteristics as depth, mobility, speed, endurance, sensors, tools, and payload. Man's accomplishments in understanding the ocean's water and sea floor have been limited by vehicle mobility and sensing equipment. Man's accomplishments in working in the ocean have been limited by vehicle mobility and work machinery. The manned submersibles currently in operation or under construction represent a number of approaches for providing the capability to observe and work underwater.

The Navy has been an extensive user of deep submersibles. This use started in 1958 when the TRIESTE commenced operations for the Navy at San Diego, California. TRIESTE and its successor, TRIESTE II, demonstrated the capability and usefulness of undersea vehicles. TRIESTE II is now operated by Commander Submarine Force, Pacific Fleet. In 1964 the Navy launched ALVIN, which is operated for the Navy by the Woods Hole Oceanographic Institution. As the applications for these submersibles have grown in number, the Navy has increased its participation in the sponsorship of submersible design and construction. Navy requirements in development of undersea search, rescue, and salvage have taken on



U. S. Navy TRIESTE II, successor to TRIESTE I, a bathyscaph with modern navigation and control equipment, TV cameras, lights, and mechanical arm. TRIESTE II located and photographed portions of the THRESHER in 1964.



ALVIN, a deep-submergence vehicle capable of working in depths of 6000 ft. It is operated by the Woods Hole Oceanographic Institution.

287-778 O - 68 - 2

enough importance to be given direct management by a separate Navy organization, the Deep Submergence Systems Project, under the Chief of Naval Material.

DEEP SUBMERGENCE RESCUE VEHICLE (DSRV)

The Deep Submergence Rescue Vehicle (DSRV) will carry man to ocean depths greater than 3000 ft, and this capability will be extended to 20,000 ft by the Deep Submergence Search Vehicle (DSSV). Although the primary missions of these two vehicles are different, they will both give man the capability of working in the depths of the ocean while protected within a shirt-sleeve environment.

Both submersibles, because of their operating depths and operational requirements, are pioneering new developments in materials, machinery, underwater sensors, and navigation and control systems. Both the DSRV and the DSSV will be relatively small and highly maneuverable and will establish new capabilities for man to work in the oceans.

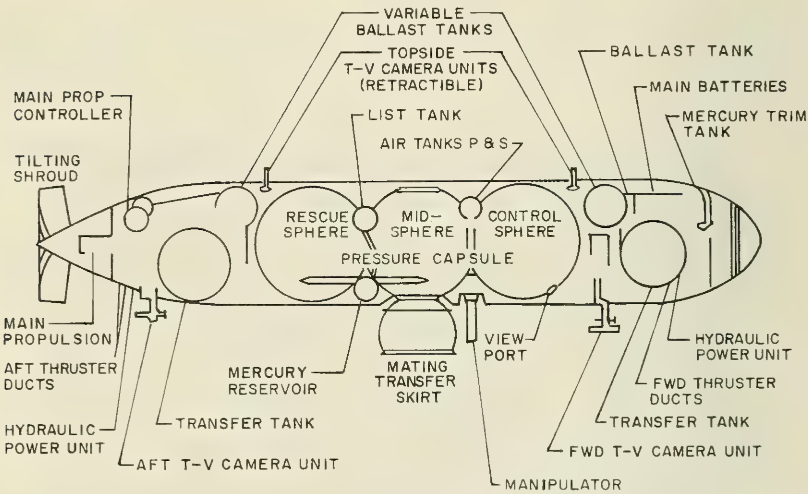
The requirement that the DSRV be carried piggyback on a nuclear-powered submarine and mate with submarines is establishing new procedures for underwater operations. The mating requirement–joining a transfer skirt on the DSRV to the escape hatch of a disabled submarine to transfer its personnel to safety–was the principal factor governing the design of the DSRV subsystems.

Other requirements that set severe design constraints were rapid response time and all-weather operability. These constraints required the DSRV to be air transportable and piggyback transportable underwater and then supported at the rescue scene by a submerged nuclear-powered submarine.

As a result of the air-transport requirement, the DSRV makes use of titanium and aluminum for ribbing and stiffeners.

The most difficult and challenging problem facing the DSRV involves underwater mating with a disabled submarine. Design requirements specify that the DSRV must be capable of effecting a mate, in the presence of a one knot current, to the deck of the disabled submarine. The first step in mating sequence involves finding the exact location of the escape hatch of the stricken submarine using optical and sonic sensors to penetrate the darkness. The next two steps in the sequence–cutting the disabled submarine's buoy cable and "landing" on the hatch seat–require the DSRV to hover within a small area; in effect, to operate as an underwater helicopter.

The first planned Deep Submergence Rescue Vehicle (DSRV) to be built by the U. S. Navy. This prototype deep-submergence vehicle, now under construction, will have a rescue capability of up to 24 men at a time, and is designed to be air transportable as well as carried "piggy back" aboard a nuclear submarine. In this view the DSRV is shown mating to the escape hatch of a submarine for transferring personnel.



Deep Submergence Rescue Vehicle (DSRV), arrangement of major components

The DSRV propulsion and maneuvering system was designed to gain this capability. The DSRV's stern propeller and four ducted thrusters provide power in any of five degrees of freedom–pitch, yaw, surge, heave, and sway. The sixth degree of freedom, that of roll, is controlled by a mercury trim-and-list system.

To provide the pilots with the precise control required in this difficult maneuver, an Integrated Control and Display System (ICAD) has been developed to permit two operators to control this vehicle. All sensing, navigation, and propulsion equipment will provide electrical signals into a computer in the ICAD. To control the vehicle, the pilot and copilot will command direction and rate, and the computer will translate and transmit their control signals to the inidvidual propulsion control units.

The next step in the mating sequence brings touchdown. To prevent excessive impact stresses or damage to the hatch seat, a hydraulic shock-attenuation system has been developed.

DEEP SUBMERGENCE SEARCH VEHICLE (DSSV)

The design of the DSSV incorporates many developments from the DSRV, but further advancements in materials, structures and power supplies will be required. The primary mission of the DSSV is underwater search with an additional mission for small-object recovery.

New ASR (foreground), shown alongside today's ASR-16. The catamaran hull configuration provides a stable and suitable platform and a large working area necessary for launching, retrieving and supporting the Deep Submergence Rescue Vehicle (DSRV) and the Advanced Diving System (ADS IV).

The DSSV design will aim at an operating depth of 20,000 ft. High-strength steels or titanium will be developed for the pressure hull, and developments in buoyancy material are required to meet severe weight constraints.

An advanced power source for the DSSV is required to achieve the desired endurance on the bottom. Because of weight constraints, a fuel cell appears to be the most promising candidate for this service. The Navy is planning to initiate a development program for a fuel cell specifically designed for a 20,000 ft DSSV.

Of paramount importance in a search mission is a reliable sensor to find the target, and a precise positioning system to pinpoint its location. One of the prime search tools being developed is a side-looking sonar. Side-looking sonar can find objects on the sea floor by sending out a narrow beam, wide in the vertical plane. Since the beam is sent primarily laterally, the energy of the beam is reflected away from the source. Very little energy is scattered from the sea floor back toward the receiver, except when an object or outcropping is encountered. These contacts cause a shadow when the side-looking-sonar returns are viewed on a recorder.

Present side-looking sonar designs can search up to 800 ft from the track of the submersible, for a total search width of 1600 ft with one transducer on either side. The vehicle must travel relatively near the bottom, and must maintain precise positioning to avoid gaps in the search pattern.

Search sonars other than the side-looking variety include improved forward-scan sonars similar to the horizontal-obstacle sonar used on the DSRV. If buried objects must be found, then a sediment probe or bottom-profiling type of sonar must be used. For high-resolution acoustic search, an improved short-range sonar must be considered. All of these acoustic equipments require development to obtain reliable and lightweight systems that can be carried on deep diving vehicles.

For the visual identification of targets, significant improvements must be made in existing TV and film cameras and methods of illumination. Present undersea TV or, for that matter, visual observation from a viewport is usually limited by light backscatter to distances under 50 ft. Turbidity can further reduce this visibility to the point where visual search is not practical. Extended-range optical systems are under development to overcome some of these difficulties. A variety of techniques are being considered, including circularly polarized light, range gating, and even the application of lasers to underwater illumination.

DEEP OCEAN SURVEY VEHICLE (DOSV)

The primary purpose of the DOSV program is to conduct surveying operations with undersea vehicles in order to evaluate the instruments and vehicles available for underwater surveys. The eventual output of the program will be performance specifications for a Deep Ocean Survey Vehicle. The DOSV will be designed with the survey instruments incorporated to prevent later expensive modifications. The tasks performed to date have encompassed those missions which a Deep Oceanographic Survey Vehicle will eventually perform on a routine basis, e.g., stereo-photogrammetric and sonic mapping, sub-bottom profiling, gravity and magnetic measurements, measurements of sediment mass physical properties, and water properties affecting sound propagation. Underwater visibility measurements and bottom-sediment sound-loss studies have been conducted. Existing navigation systems have to be evaluated.

To date the following undersea vehicles have been employed for these operations: ALUMINAUT, ALVIN, CUBMARINE, and STAR III. Available underwater navigation techniques are completely inadequate for oceanographic surveying, and the majority of vehicles are also unable to accommodate, in space, payload, or power, the instruments required to conduct undersea surveys. Contracts have been established with industry and private institutions to provide the following: a local navigation system, a pod for sensing water characteristics (temperature, salinity, sound speed, depth), a pod for sensing ocean characteristics at the bottom (sound speed/attenuation, pH, temperature, density, bearing strength), and design requirements for gravity and magnetic measurements. As in past operations, all tests and evaluations will be conducted in those geographic and scientific areas which provide information required by other projects. In this manner, immediate results are obtained which offer insight into many environmental problems now confronting the oceanographer, as well as accomplish the objectives of the DOSV project.

Future contracts will be let to provide bottom slope-measuring equipment and sonic mapping devices, ambient noise and ambient light sensors, sediment and biological sampling devices, a sub-bottom profiling instrument, and portable synoptic current sensors. Upon receipt of these instruments, at-sea tests and evaluations will be performed to determine the performance required of a DOSV to employ these instruments in undersea surveying. In addition to the hardware procurement, research and evaluation will be performed to determine in what aspects of undersea surveying the DOSV surpasses classical surface techniques.

NUCLEAR POWERED RESEARCH AND OCEAN ENGINEERING VEHICLE (NR-1)

On April 18, 1965, President Lyndon B. Johnson announced that the Atomic Energy Commission and the Department of the Navy had undertaken the development of a nuclear-powered deep submergence research and ocean engineering vehicle. The capability of this manned vehicle, designated the NR-1, will be far greater than any other developed or planned to date because of the vastly increased endurance made possible by nuclear power. The experience gained by its development will provide the basis for development of future nuclear-powered oceanographic research vehicles of still greater versatility and depth capability.

The NR-1 vehicle, which will be able to move at maximum speed for periods of time limited only by the amount of food and supplies it carries, will carry a crew of five and two scientists. The vehicle will be able to perform detailed studies and mapping of the ocean bottom, temperature, currents, and other oceanographic parameters for military, commercial, and scientific uses. The development of a nuclear propulsion plant for an oceanographic research vehicle will result in greater independence from surface-support ships, essentially unlimited endurance of propulsion, and auxiliary power for detailed exploration of the ocean.

The submarine will have viewing ports for visual observation of its surroundings and of the ocean bottom. In addition, a remote grapple will be installed to permit collection of marine samples and other items. With its depth capability, the NR-1 is expected to be able to explore all areas of the continental shelf, an area which appears to contain the most accessible wealth in mineral and food resources in the seas. A ship with its depth capability is capable of exploring an area several times that of the United States.

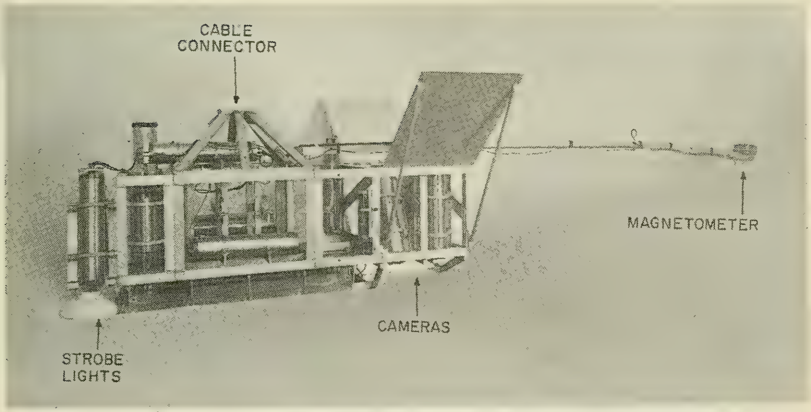
UNMANNED VEHICLES

To augment the DSSV, unmanned instrument platforms, either towed or self-powered, will be used during a search mission. Both the manned and unmanned vehicles may utilize some of the same search sensors. Manned submersibles have the advantage of direct investigation of target contacts, while unmanned vehicles eliminate human hazard, are less expensive, and, in the case of towed vehicles, are of almost unlimited endurance.

Navy accomplishments with towed search systems have included experimental developments by the Naval Research Laboratory. One of these towed systems both located and identified much of the debris from the THRESHER at about 8500 ft depth. The integrated design of this system consisted of a framework of aluminum and nonmagnetic stainless steels which held instrumentation including cameras, television, magnetometer, side-looking sonar, and a battery. The tow cable for this system contained a coaxial center section for transmission of telemetry signals between the surface ship and the towed sled. A similar towed sled was used to search much of the sea floor near Palomares, Spain for the unarmed nuclear weapon. This nuclear weapon was found by the manned submersible ALVIN and recovered by the unmanned vehicle CURV.

CONTROLLED UNDERWATER RECOVERY VEHICLE (CURV)

The CURV development stemmed from a requirement for recovery of test ordnance, a highly important function in the development of underwater weapon systems. CURV has an operating depth capability of about



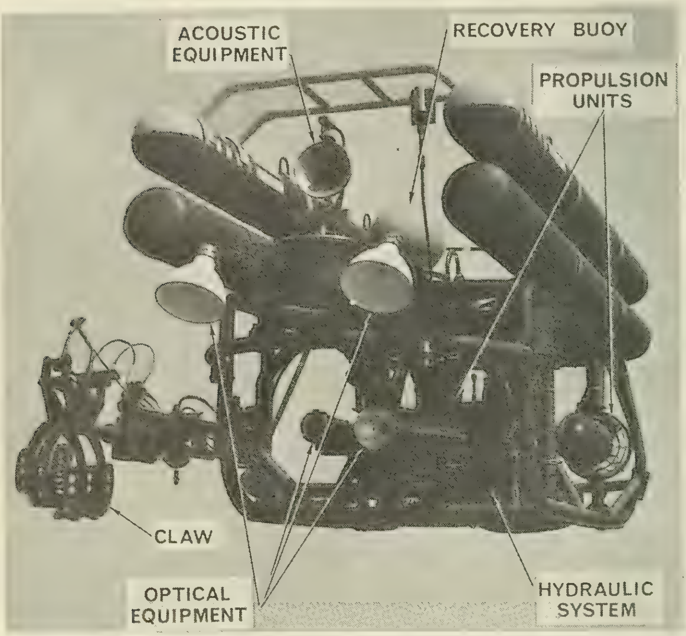
The Naval Research Laboratory towed "fish" is used for underwater search missions. It incorporates several sensors, including either a TV or photographic camera, a magnetometer, side-looking sonar, and a battery.

2500 ft, has unlimited endurance, and can be operated day or night. Operations are conducted from a mother ship which contains an acoustic locating device, handling gear, and the control and monitoring consoles.

CURV dramatically demonstrated its capability by recovery of the missing unarmed nuclear weapon near Palomares, Spain in 1966. Its potential extends to applications such as underwater survey, inspection, maintenance, and construction of underwater equipment and facilities.

This tethered, unmanned vehicle is 6 ft wide, 5 ft high, and 13 ft long. A number of subsystems are mounted on its tubular aluminum frame, including propulsion units, optical equipment, acoustical equipment, a hydraulic system to operate a claw, and a recovery buoy. Four large buoyancy tanks are mounted on top of the vehicle. Maneuvering is accomplished by three propulsion units on the vehicle. The propulsion system not only powers the vehicle, but also keeps it down, since it operates with 10 to 15 pounds of positive buoyancy. The acoustic search equipment consists of a high-resolution sonar that can be operated in either an active or passive mode. The optical system includes lighting, a television camera, and a 35-mm camera and associated strobe light for documentation of recovery.

The CURV concept is being vigorously pursued with a near-term goal of a 7000 ft operating depth and increased search, location, and manipulation capabilities. CURV provides a unique capability for performing useful tasks at ocean depths, and represents a relatively unexploited technological approach to the working ocean.



Controlled Underwater Recovery Vehicle (CURV). CURV, an unmanned recovery vehicle, was used to pick up the unarmed nuclear weapon at Palomares, Spain, in 1966. The claw and propulsion motors are controlled from the surface by personnel using closed-circuit TV for direction.

Submerged Object Recovery Device (SORD). SORD can be used in deep-ocean recovery and salvage. Objects are picked up with a snare manipulated from the surface by personnel using closed-circuit TV for direction.

UNDERSEA PROBE

A free self-propelled, unmanned, undersea probe has been developed by the Applied Physics Laboratory, University of Washington. The torpedo-like vehicle, designed for use in oceanographic and acoustic research, follows a controlled trajectory and acquires data on sound velocity, thermal and other physical properties of the sea which are recorded internally. Its operating depth capability is 14,000 ft, endurance is five hours at six knots, and it carries an instrument payload of approximately 100 pounds. The vehicle is 122 in. long and 20 in. in diameter. Propulsion is electrical.

An internal guidance system uses a gyro for course control, and pressure and pitch-angle sensors are utilized for depth control. An acoustic link with the surface vessel provides tracking and command capabilities for navigational control. Override commands may be sent through the acoustic tracking link for changes in heading and depth. Position with respect to a surface ship is measured acoustically to a slant range of 15,000 ft.

The capability and dependability of the vehicle have been demonstrated in operational runs during the past several years. Environmental data have been recorded digitally on magnetic tape, which can be processed immediately and economically by direct play into a computer, or converted back to analog voltage for visual display of direct recordings.

Development of the unmanned probe will continue, and will ultimately provide sensing capability at all depths and greatly extended ranges by remotely controlled, and by automatically controlled programmed techniques.

UNDERSEA INSTALLATIONS

Prototype underwater manned installations are planned to develop construction techniques, equipment and methods. Submerged military support bases have application with submersibles requiring replenishment and exchange of personnel, where access of submersibles to traditional surface support craft cannot be reliably guaranteed because of sea state disturbance or where the distance to weather-independent harbors is too great for submersible endurance capabilities. Other potential uses of submerged military manned installations are as command centers, weapon sites, and surveillance-network headquarters. Further, where work is taking place on the ocean floor, temporary habitats near the work site can have real value as personnel support installations.

Two characteristics of bottom and sub-bottom structures give them a great utility: (a) they are separated from the sea state disturbances at the air-sea interface, and (b) they are situated in the sea environment. Manned habitats placed on or near the bottom can provide an opportunity to put to advantage these two characteristics. Potential types of manned habitats include laboratories, military support facilities, recreational facilities, and industrial installations.

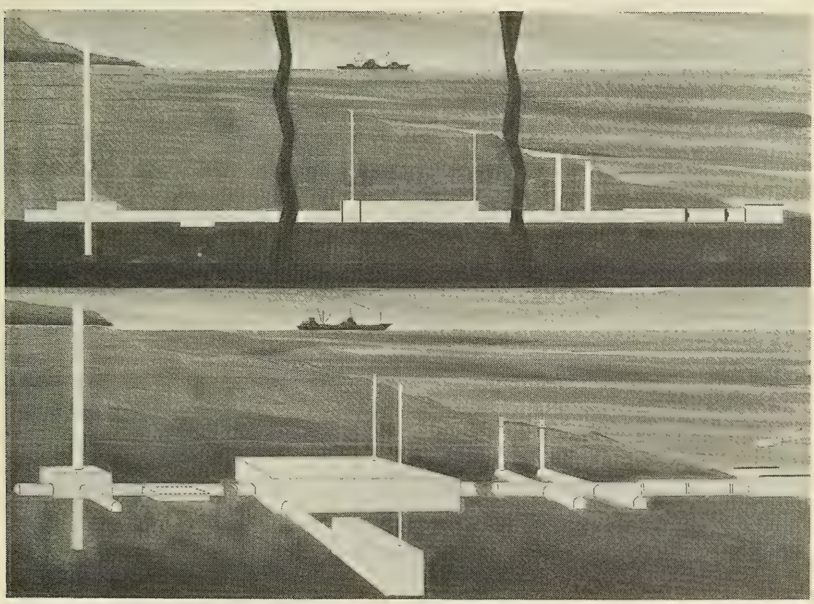
The construction of a manned underwater station could be accomplished in several ways, such as excavation under the sea floor, or a structure prefabricated on land and submerged to the ocean bottom. A third way would be to develop underwater construction techniques.

Concept for a manned underwater station using a toroid-shaped hull. The toroid would have a 40-ft overall diameter and a 10-ft annular diameter. The habitat would rest on a conoidal foundation, allowing it to adjust to any bottom with a slope of 15 degrees or less.

SUB-BOTTOM STATIONS

A sub-bottom installation could consist of a room or a series of rooms, excavated within the bedrock beneath the sea floor, using the natural bedrock for the basic structure. The station would be a relatively self-sustaining installation, possessing a power plant, possibly nuclear, as well as work facilities and maintenance capabilities. Access to sub-bottom installations near land can be achieved through tunnels and shafts to the land surface. For shallow continental shelf installations, access can be achieved through a tube to the surface. Access to deeper installations, which are isolated from land, can be by means of a lock system passing through the sea-floor-water interface. Lock systems could also allow direct entry of a submersible into the installation. An alternative lock system would be one that permits temporary mating of the submersible to the installation.

Sub-bottom entry into the sea floor requires that the lock tube or entryway be set in some sort of rock that is at least competent enough to permit consolidation by grouting or other cementing operations. Virtually any location on the sea floor that consists of consolidated sediments strong enough to stand as an open bore can be entered to yield one-atmosphere working sites.



An undersea experimental laboratory tunneled into bedrock, with a land access

Once the sea floor has been entered, and a working atmosphere established, the use of available boring machines can be used to extend such a base. These boring machines are capable of forming tunnels of from 15 to 20 ft in diameter in most types of rock.

BOTTOM STATIONS

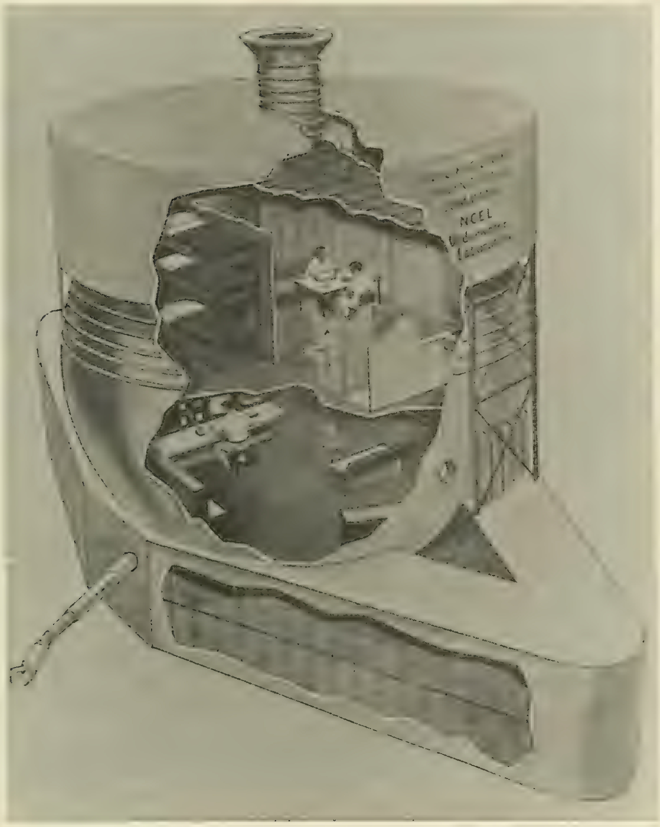
Concepts for a manned underwater station which would allow the Navy to establish fixed habitats on the sea floor on the continental slope at depths down to 6000 ft have been developed. The initial criteria defined a station capable of supporting five-man crews at a pressure of one atmosphere in a shirt-sleeve environment for an indefinite period of time. The station would have a self-contained power source and a self-contained life-support system which would make it independent of the surface. Resupply of the station would be on the sea floor. Upon completion of its missions, the station would be capable of being recovered and moved to other locations. Studies to develop the one-atmosphere manned underwater station have revealed several feasible approaches.

Each approach can be considered as a system composed of subsystems such as structure, power, life support, placement and recovery, and communication controls and instrumentation.

Structural shapes feasible with today's technology which have been considered are the sphere, the cylinder, and the toroid. Each design assumed the use of a high-strength material such as HY 140 steel.

Foundation requirements for each structural shape are different in design, concept, and materials. The toroid will rest on the bottom on a cone-shaped foundation which adjusts to a bottom slope. The cylindrical station is supported by three legs which adjust to bottom irregularities. Emplacement modes for all three shapes could be either free-descent technique, utilizing negative buoyancy, or the winch down. This latter method would keep the station positively buoyant at all times and would require winching against a sea floor anchor.

Life support and power requirements are a function of station mission and duration. Power systems considered for use include nuclear reactors, radioisotopes, silver zinc batteries, and surface conventional power with a surface buoy and umbilical. Using today's technology life support systems for a 30 day, five-man mission require approximately 500 gallons of potable water, 330 cubic feet of compressed oxygen, 560 pounds of lithium hydroxide for CO_2 removal, and 200 pounds of dehydrated precooked food.

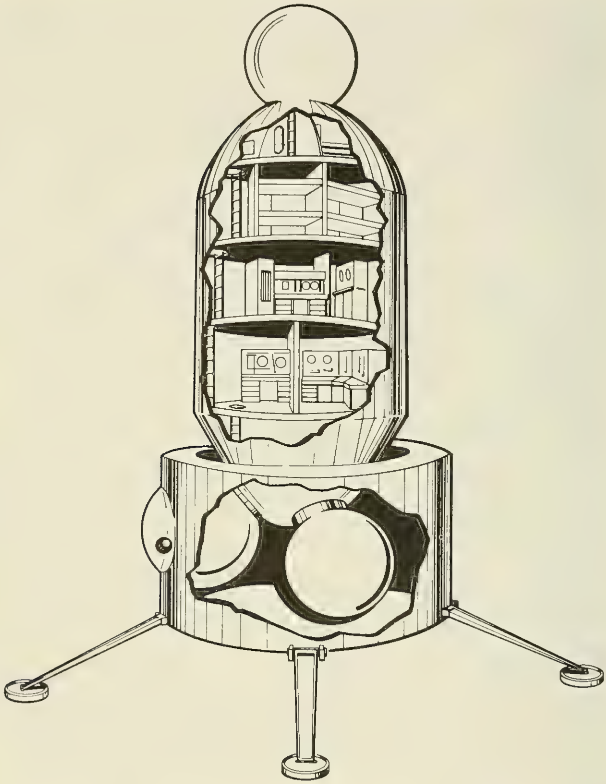


Concept for a manned underwater station using a 20-ft-diameter spherical hull. The station would use silver zinc batteries and would be placed on the sea floor using a winch-down mode. Overall height of the station is 50 ft.

System characteristics selected for further studies of the manned underwater station are: a vertical cylinder for the main hull, a winch-down emplacement mode, and a nuclear reactor power supply. Access would be through the mating of a DSRV-type vehicle with the habitat.

DEVELOPMENTS IN SALVAGE

The Navy has had a salvage mission since the earliest days of our Navy. Since the 1920's salvage and diving have been closely related. Recent advances in saturated diving techniques have led to advanced diver systems in fleet operational use and in development.



Concept for a manned underwater station using a 16-ft-diameter cylindrical hull. Access to the habitat is through the sphere at the top, with the sphere at the bottom used for observation.

Current planning calls for development of three subsystems of the salvage operation: surface ships, the lifting system, and the diver-support system. Surface ships to be used in salvage and diving work include a new class of submarine rescue ships (ASR) and a new class of fleet salvage ships (ATS).

To lift objects from the sea floor, the use of buoyant pontoons is being considered in conjunction with winch equipment. The lift ships–two to a system–will each have two 75 ton winches. The object to be recovered will be attached to a series of high and low pontoons which will provide most of the lift force, with the winches providing control more than lift. The pontoons will have a combined buoyancy of 1000 tons, in addition to the breakout forces.

The major work of positioning and rigging objects on the continental shelves for return to the surface will be performed by divers. By 1972, the Navy envisions diver teams working at depths of 850 ft, equipped with tools and devices appropriate for undersea salvage work, possibly including manned submersibles. The diving system has three major components:

- A Deck Decompression Chamber (DDC), for saturated diving and decompression to normal surface pressure.
- A Personnel Transfer Capsule (PTC), for transferring divers between the DDC and the submerged work area.
- A control console, to monitor and control the living conditions in the deck decompression chamber and the personnel transfer capsule, and also to provide communications between personnel in the diving operation.

Deck Decompression Chamber

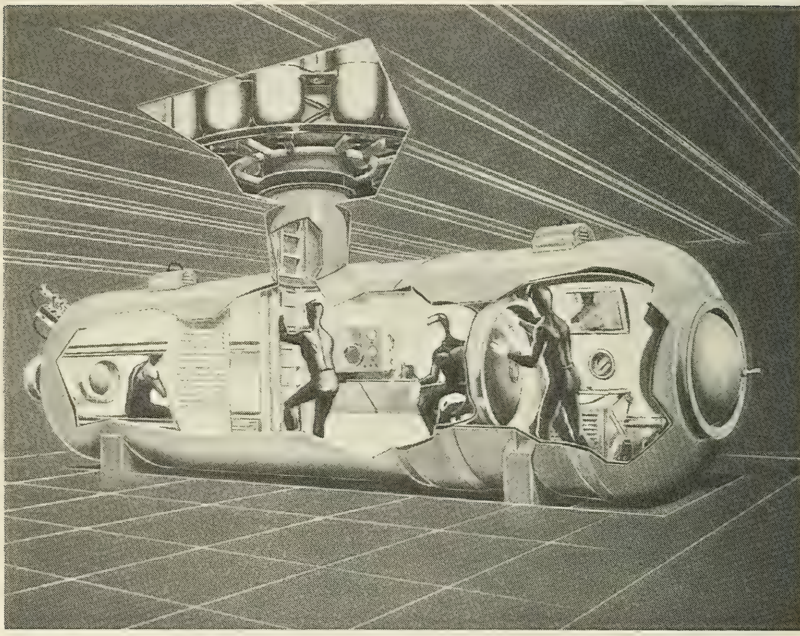
The chamber is designed to house four men under pressure equivalent to continental shelf depths for periods of up to 14 days under saturated diving conditions, plus such decompression time as may be required from these pressures.

The saturated diving technique allows the body to absorb its maximum amount of inert gas, subsequent to which the bottom time can be extended without any significant increase in decompression time, whereas a nonsaturated dive is of shorter duration and shorter decompression time. Equipped with an inner and outer lock and separated eating, sleeping, and sanitary facilities, the chamber is approximately 24 ft long and eight feet in diameter. A medical lock is provided for passing equipment, food, and other small items either into or out of the DDC. An access hatch is provided in the top of the DDC for mating with the personnel transfer chamber or a specially configured underwater submersible.

Personnel Transfer Capsule

The capsule transfers diving personnel from the deck decompression chamber to the underwater working area and supports them during their working period. The capsule is being designed to withstand both external and internal pressures equivalent to continental shelf depths.

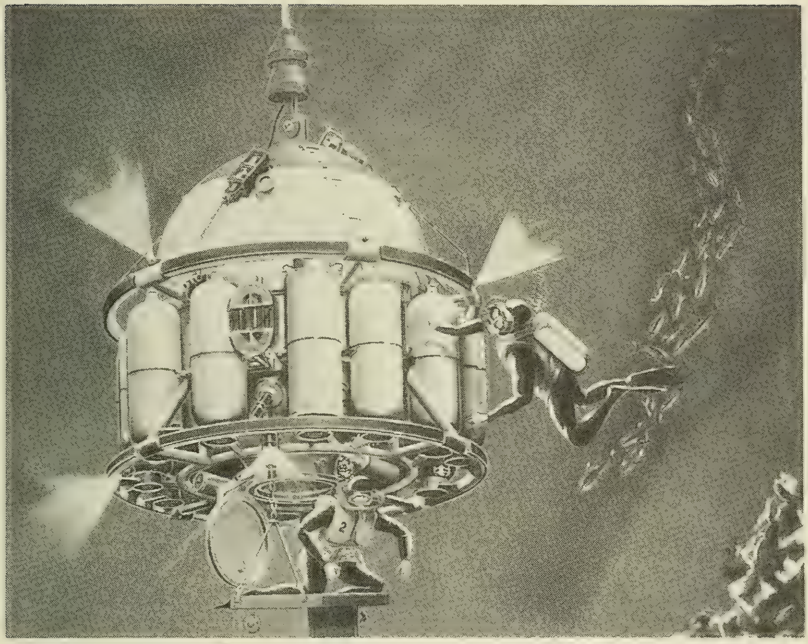
287-778 O - 68 - 3



Four-man Deck Decompression Chamber (DDC). The decompression chamber is a double-lock chamber. The outer lock provides a means of entrance for support personnel or for the medical treatment of divers. Normally, the outer lock is used as part of the overall living quarters for saturated divers. A medical and food lock is located at the left, in the berthing area. The Personnel Transfer Capsule (PTC) is shown mated at the upper deck cutaway.

As currently designed, the capsule consists of a short cylinder with endcaps which can house four occupants in diving dress along with their necessary working equipment and the PTC operating gear. Gas bottles are mounted on the exterior of the capsule.

A winch capable of raising and lowering the PTC, when positively buoyant, is provided along with an anchor implanted on the ocean floor. The winch may be disconnected and a brake used to control the ascent of the PTC should the motor fail. Design considerations for the PTC include: (a) the PTC must float upright if its cables are cut free; (b) the PTC must be positively buoyant, except when ballasted with releasable ballast for penetrating the ocean surface; (c) the PTC shall supply power, light, and other services to the men who are working in the water.

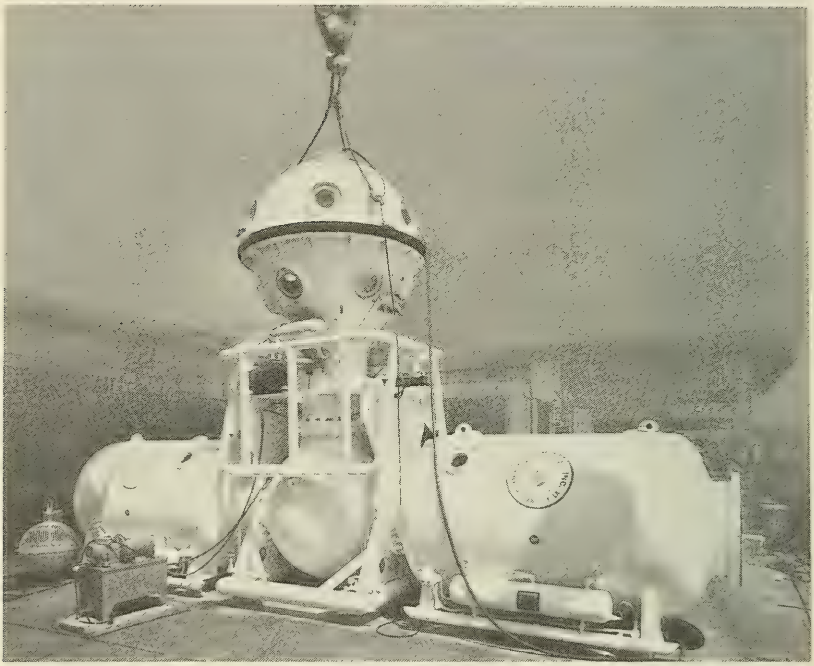


Four-man Personnel Transfer Chamber (PTC). The PTC, an elevator-like diving station for divers working on the bottom, provides transportation from the ocean surface to ocean bottom. Its artificial atmosphere is pressurized equal to the pressure of the depth of the ocean environment at which the divers are working. When closed the lower hatch shown in this artist's concept allows the divers to descend in the PTC at normal pressure for exploratory dives. A hatch at the top of the access trunk, not shown provides a means of locking divers in at ambient sea pressure while transferring to the surface deck decompression chamber for mating.

OPERATIONAL SALVAGE AND TOOLS

To fulfill operational requirements for ship salvage, the Navy has leased an advanced diving system that can provide a saturated diving capability to all fleet salvage ships. The highly portable features of the system enable it to be airlifted to any place in the world and quickly installed on a Navy salvage ship of opportunity.

In August 1966 a deep-dive demonstration using this system was conducted to 450 ft from a fleet tug, over the prospective site of Sealab III, near San Clemente Island, California. In July 1967, after delivery of the system to the Navy, a series of open sea training dives to 300 ft were successfully accomplished from a salvage repair ship near Hawaii. Now considered fully operational, this system, called Advanced Diving System IV

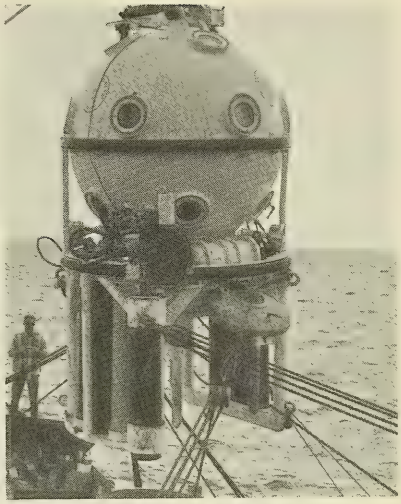


Complete Advanced Diving System (ADS IV), showing the spherical PTC mated to the DDC. The system is self-contained and highly portable, and can be used anywhere in the world.

(ADS IV), when used with decompression tables presently under development will enable Navy salvage divers to dive anywhere on the continental shelves.

ADS IV consists of two basic components: the PTC and the DDC. The PTC is a single spherical chamber which locks on to the DDC. This arrangement allows two fully equipped divers to accomplish their decompression in the three-lock DDC, in which they can be comfortably supported during extended decompression. In addition, this technique frees the PTC for immediate reuse by a second crew of divers. The ADS IV unit is materially certified safe for Navy personnel to 600 ft. Self-contained oxygen, battery power, and a carbon dioxide removal system permit hours of life support without external assistance.

The PTC is a single, 6000 pound, pressure-proof, helium-tight spherical compartment on a support frame. This support frame is designed to provide easy entry to and exit from the PTC for the divers when it rests on the bottom.



The leased Advanced Diving System (ADS IV) Personnel Transfer Capsule being hoisted aboard a Pacific salvage ship, during a series of recent 300-ft demonstration dives off Hawaii. The PTC is fully certified to 600 ft for Navy operations.

There is a single bottom access trunk, with a double hatch arrangement. The outer hatch seats with external pressure and is designed to swing clear of the flange yoke during mating. The inner hatch seats with internal pressure and allows the divers to pressurize the chamber upon reaching the work site, exit, and then return to the surface under pressure.

Viewports and external lighting provide 360 degree visibility from the PTC.

Electric power, communication, and television control are supplied to the PTC through a composite cable. The breathing mixture is surface supplied by a separate hose to the PTC. All lifting is accomplished through use of a separate cable. The communication system incorporates a three-wire design to allow the diver, the PTC occupant, and topside control to be on the same circuit concurrently.

The outer lock of the DDC is primarily used as an entrance lock providing pressurized entry to or egress from the mated PTC on deck. The lock is large enough to permit medical personnel to enter if the diver needs medical treatment.

The inner lock is a chamber providing life support for two divers during decompression from dives up to 600 ft in depth. Interior arrangements of the living chambers are based on human-engineering studies previously conducted during the design of chambers for commercial and U. S. Navy use. Each DDC living chamber is provided with heating and air conditioning, a communication system, and life support equipment.

A weatherproof control console permits centralized topside control of both diving and decompression phases. Breathing mixture control, communications, power, and television monitoring are included.

Salvage Lift System

An underwater salvage lift system has been developed whose concept includes power-actuated attachment devices (to allow attachment of a lift point with a minimum amount of work by a diver or deep submergence vehicle), a buoy which can be ballasted to neutral buoyancy to support the attachment device (while it is being positioned and which will carry an internally stowed messenger line to the surface after the attachment device is attached), and a remote coupling device which may be lowered down the messenger line to attach a heavy lift cable to the attachment device. The power-actuated attachment device was tested successfully at a depth of 200 ft in Sealab II.

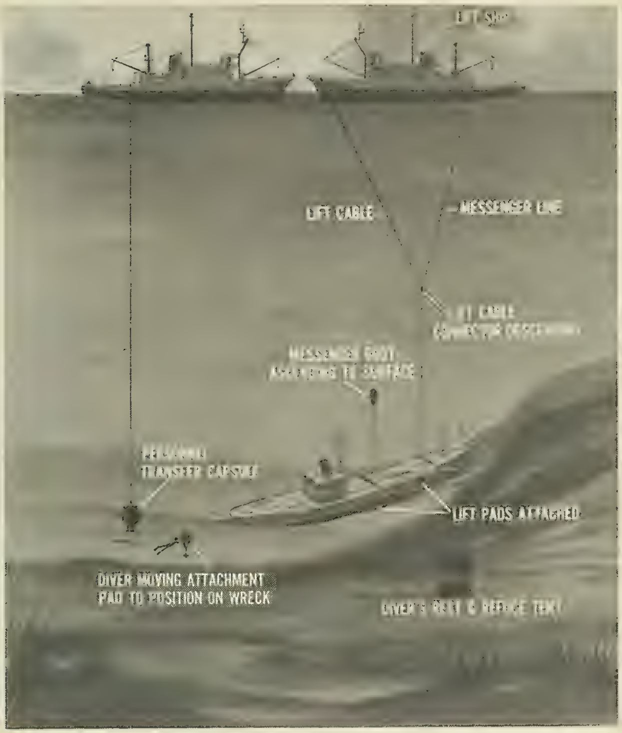
Use of this system will significantly reduce the amount of work required by divers in making lift attachments underwater. It eliminates the requirement for handling heavy attachment fittings and making mechanical connections by drilling and bolting or welding. It also eliminates the requirement for divers to position and connect heavy lift cables suspended from a surface ship moving in response to surface waves.

The variable-buoyancy buoy has been built in prototype form and given preliminary tests in about 100 ft of water. The complete lift system will be tested operationally in Sealab III at a depth of about 430 ft.

Diver Tools

Most diver tools used to date were originally designed for sea level, dry air operation. When such equipment is exposed to an environment which is chemically corrosive, highly pressurized, 800 times more dense than air, and populated by marine life with fouling and other destructive characteristics, severe engineering problems are to be anticipated.

Divers, unless anchored in place with restraining devices, are subject to undesired effects from tool reaction forces. This fact means that all tools to be developed must have torque-free characteristics if they are rotary in character, or of special design if they are to be of the explosive impact type.

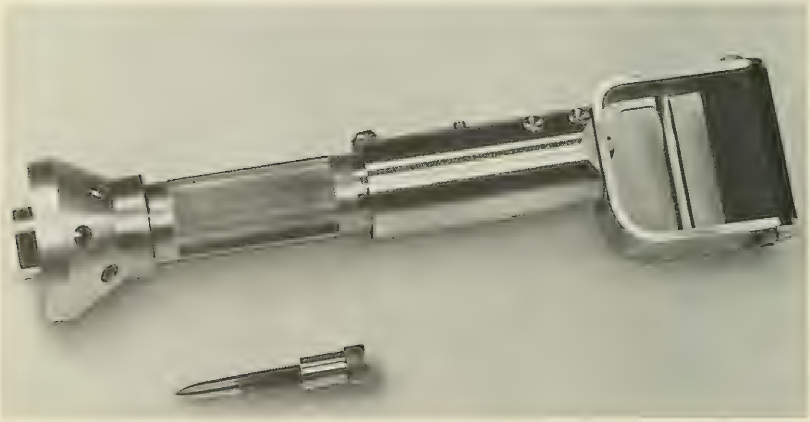


The new underwater salvage lift system. This newly developed concept greatly reduces the diver's efforts needed in attaching lifting lines to a sunken object.

Velocity power tools which utilize the power from an ammunition-type cartridge to drive threaded, solid, and hollow studs into and through steel plates have been used by divers since the late 1930's. An improved single-stud velocity-powered driver was tested during Sealab II. The improvements in this device generally related to an increase in its penetration ability into various thicknesses of HY 80 steel plate. Other improvements, however, enhanced diver operability and safety by better containing the explosive gas energy. This last improvement reduced the shock on divers to negligible proportions.

The usefulness of magnets in ship salvage and other underwater work is also being investigated. The general conclusions to date suggest that large electromagnets will prove valuable in the salvage of ferrous cargoes from sunken ships, where the repetitive nature of the operation greatly reduces the requirement for divers and simplifies the attachment problem. Smaller magnets, mostly of the permanent type, provide a productive area of development for use as divers' aids. They can be readily used as anchoring devices for swimmer-divers and for positioning and holding aids for divers' tools.

Sea tools can be designed to be neutrally buoyant or essentially so. An example is a device called the underwater fork lift, presently in development. The underwater fork lift is essentially a variable-buoyancy platform that a diver can control to assist him in lifting and performing work.



Large-velocity powered stud gun. Capable of operating to 1000 ft, this gun can drive solid steel studs into 1-1/8-in. thick mild steel plate.

Small-velocity powered stud gun, a lightweight, underwater hand-held tool used to punch holes in steel plate or attach studs to metal objects underwater

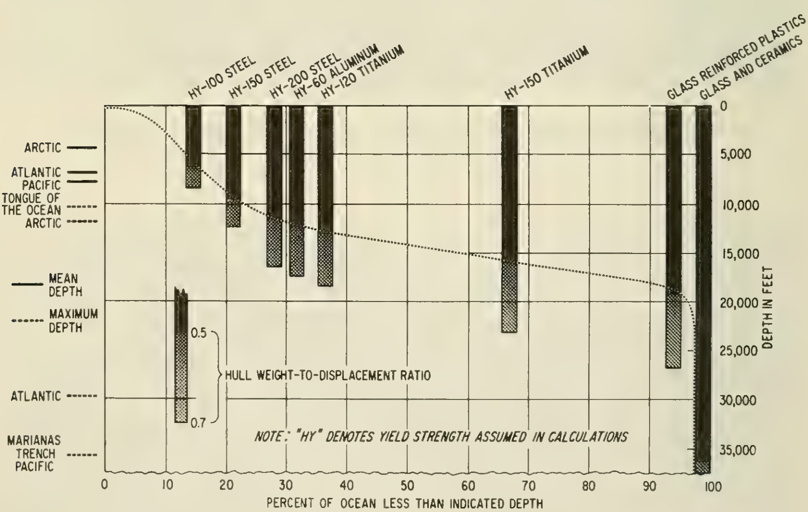
Diver in a magnetically anchored jacket working with a small chipping hammer

DEVELOPMENTS IN TECHNOLOGY FOR UNDERSEA MISSIONS

STRUCTURES FOR DEEP SUBMERSIBLES

The primary function of the deep-ocean pressure hull is to provide a one-atmosphere living space for the crew and equipment. The second function of the pressure hull structure is to provide buoyancy for the vehicle.

Hull configurations which are feasible for the 600 to 9000 ft depths include the spherical shell, stiffened cylinder, and prolate spheroid. Buoyancies of these configurations are essentially the same at these depths for any given material; the choice of a structural shape is based on overall arrangement considerations, rather than minimum weight. At great depths, the sphere has the most efficient weight to displacement ratio.



Depth capability as a function of hydrospace vehicle materials. The solid bar indicates a hull weight-to-displacement ratio of 0.5. The cross-hatched bar indicates a ratio of 0.7.

Small undersea vehicles are usually composed of a single spherical shell or a number of spherical shells either nested or connected by short stiffened cylinders. Additional structure consists of reinforced openings for such items as hatches, penetrating shafts, and electrical fittings. Submarines, however, are basically structural cylinders. Submarines and small undersea vehicles represent the only major engineering structures with small hull-thickness-to-hull-diameter ratios that are subject to relatively high external hydrostatic pressures. The submersible design must ensure structural stability, because buckling of the shell can occur at pressures considerably less than those required to cause yielding of the hull.

A submersible designed with a safety factor as high as required for most commercial pressure tanks would be so overweight that it could not accomplish its mission. On the other hand, a serious responsibility rests with the designer to assign a realistic margin of safety. The Navy has supported theoretical analyses which provide upper and lower boundary predictions for the strength of pressure hulls. These have been well publicized and discussed in various technical reports and publications. Certain strength-reduction factors must be applied to the theories in the design of a submersible. This step is necessary because the strength is susceptible to such manufacturing variables as unavoidable local deviations from circularity or sphericity; residual stresses locked in the structure during fabrication due to rolling, machining, and welding; and mismatches of structural elements (such as frame hull connections, penetration reinforcements, etc.) which do not satisfy conditions of simple or fixed support assumed by theory. Additional factors influencing the design of a submarine include fatigue life, variations in physical and mechanical properties of materials, and various dynamic disturbances and local loadings. Because of these variables, design formulas cannot be derived entirely on the basis of theoretical calculations. Suitable empirical relationships must be used where manufacturing and service variables exist. To establish these empirical relationships, the Navy has conducted and continues to support model tests to simulate the actual conditions which are prevalent in pressure-hull fabrication and which have an influence on service performance and on the ultimate collapse strength.

HIGH-STRENGTH STEELS, TITANIUM, AND ALUMINA

The prime requisite for achieving the capability of "going deep" is the development of new materials. The current state of the art in material technology has permitted the development of vehicles with useful payload capability for only modest operating depths and limited maneuverability. Extending our deep ocean capabilities will require advancement in material technology far beyond that required for any other application, including aerospace.

A variety of materials are presently undergoing exploratory development. Materials with high compressive-strength-to-density ratios are required to provide deep-submergence pressure hulls which will be buoyant and resist the high compressive loads imposed by great depths. Materials are being evaluated under environmental conditions simulating those to which the material will be exposed in actual operation. In this context, environmental conditions are taken to include not only the physical characteristics of the medium in which the material functions, but also the loads to which it may be exposed during its useful lifetime.

The material requirements for "going deep" are numerous and include the development of materials for pressure hulls, piping and machinery systems exposed to submergence pressures, and materials to augment deep-submergence vehicle buoyancy.

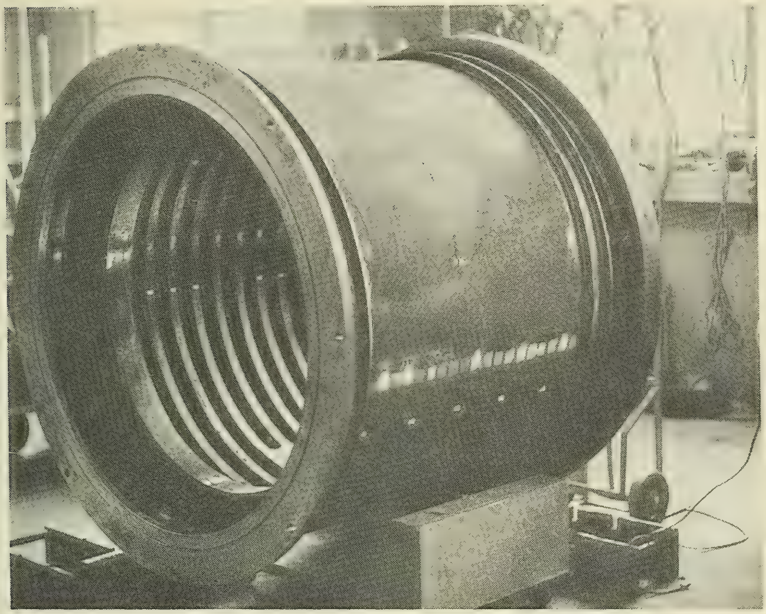
It is important to note that for most applications not only must the structural material have a high strength-to-weight ratio, but also it must be weldable, tough, corrosion resistant, have good endurance properties, and be available in heavy sections at a reasonable price.

High-Strength HY 130/150 Steel

The Navy has sponsored the development of a 5% Ni-Cr-Mo-V steel with a yield strength of 130,000 to 150,000 psi. This steel has been given extensive evaluation testing at Navy laboratories.

The HY 130/150 is a quenched and tempered steel which has been metallurgically customized to have an optimum combination of strength and toughness for a given thickness. In comparison to the conventional submarine hull steel, HY 80, HY 130/150 steel features slightly lower Cr, higher Ni, and addition of V, lower carbon, and tempering at 1050° F rather than at 1225° F. Welding development at the low end of the range (130,000 psi) has been successful, and work is proceeding toward improving the weld filler metal to a point comparable with or higher than the base metal (150,000 psi).

HY 130/150 steel has been specified as the hull materials for the Navy's Deep Submergence Rescue Vehicle (DSRV), which will be able to descend to



HY 130/150 steel cylinder model. This model was used to study fabrication and the structural performance of welded HY-130/150 steel, the hull material to be used in the Navy's Deep Submergence Rescue Vehicle (DSRV).

at least 3500 ft. The DSRV pressure hull is made up of three small spheres (less than eight feet in diameter), which are joined together. High precision procedures are being used to fabricate the DSRV, and will be required on all deep submergence pressure hulls, regardless of size. The fabrication of deep submergence pressure hulls in shipyards will require extensive developmental work, including fabrication trials to familiarize and train shipyard personnel in large scale prototype construction for fatigue models and explosion-implosion and impact tests.

HY 180/210 Steel

Higher strength steels for the hulls of deep-submergence vehicles are being developed and evaluated. These steels are in the yield strength range of 180,000 to 210,000 psi (50 ft-lb Charpy-V-notch impact value). The steel plates should be weldable in sections up to four inches thick.

Also being evaluated is HP-9Ni-4Co-XC steel, which is a quenched and tempered steel in which the cobalt is added to low carbon steel containing more than 5 percent nickel. The special vacuum arc melting and special carbon deoxidation technology of this steel assures ultra-cleanliness and freedom from nonmetallic inclusions and such embrittling interstitial elements as oxygen, nitrogen, or hydrogen.

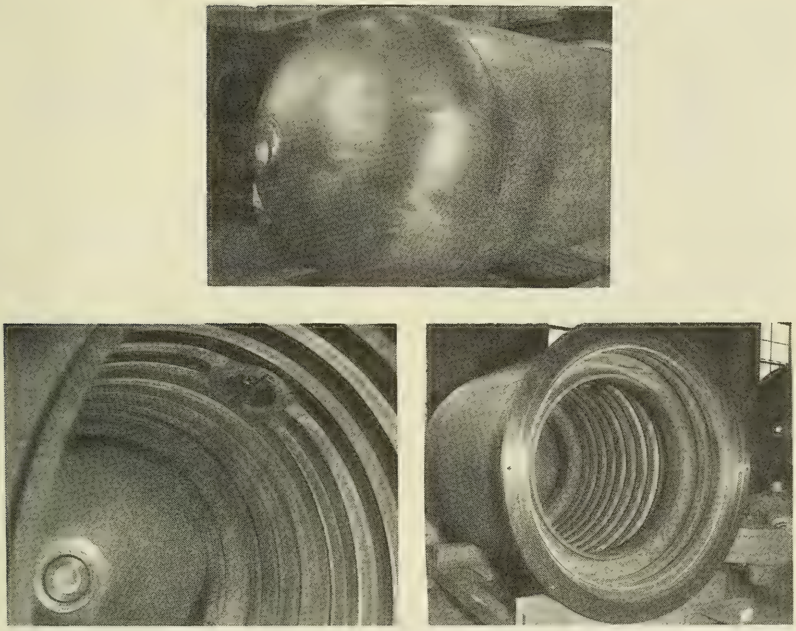
Maraging steels in the 180,000 to 210,000 psi range represent a new family of steels that have little similarity to the quenched-and-tempered steels. The strengthening mechanism involves a precipitation of microscopic particles throughout the matrix as the result of heat treatments known as "aging." When the steel cools from austenitizing temperatures in the range of 1500° to 1900°F, it changes to an almost carbon-free soft and ductile martensite. Maraging steels have an advantage over quenched-and-tempered steels for small deep submergence pressure hulls, because such hulls are small enough to fit into the heat-treating furnaces, which permits aging after fabrication. Quenched-and-tempered steel pressure hulls are generally welded in the heat-treated condition, without postwelding heat treatment; this arrangement presents the problem of introducing excessive residual stresses.

Titanium Alloys

For the past five years the Navy has been supporting exploratory development of titanium alloys. Because of its high specific strength (low density compared to steel and its 95,000 to 140,000 psi yield strength), titanium is an attractive material for deep submergence vehicles.

Unalloyed titanium exists in the alpha (hexagonal close packed) crystal form up to 1620°F. Above this temperature, it becomes a beta (body-centered cubic) phase. Alloying elements can be added to strengthen the alpha structure or to modify the room temperature structure to an all-beta or mixed alpha-beta structure. The type of structure existing at room temperature determines whether the titanium alloy will respond to heat treatment, and whether it is sensitive to thermal embrittlement, which interferes with weldability.

A 7A1-2Cb-1Ta titanium was tentatively selected as the hull material for the Navy's first Deep Submergence Rescue Vehicle, with capability of descending to 6000 ft. Evaluation of the 7-2-1 titanium revealed that the alloy was susceptible to stress corrosion cracking in sea water at relatively low stress levels so HY 130/150 steel was selected for the hull material. The HY 130/150 steel has a depth capability of approximately 5000 ft, while that 7-2-1 titanium is 6000 ft.



Titanium alloy cylinder, hemisphere model. This model was used to study fabrication and structural performance of welded titanium hulls. Titanium, having a high specific strength, is undergoing considerable exploratory development as a future material for deep-submergence applications.

The modification of the 7-2-1 titanium alloy to a 6A1-2Cb-1Ta-0.8Mo titanium has resulted in an alloy which is for practical purposes insensitive to stress corrosion but has lower strength. The 6-2-1-0.8Mo titanium alloy is now being evaluated for the Navy.

An important part of the titanium program has been the fabrication work carried out at the Naval Applied Science Laboratory, Brooklyn, N. Y. The largest out-of-chamber weldment ever produced in 3 in. thick titanium alloy was produced at this laboratory.

Alumina (Aluminum Oxide)

A limited number of tests have been conducted on 10 in. alumina spheres, weight displacement equivalent to 0.25, fabricated by ceramic technique by an industrial contractor. The results showed high strength and little scatter. However, the spheres exhibited static fatigue behavior; i.e., strength varied with speed of testing.

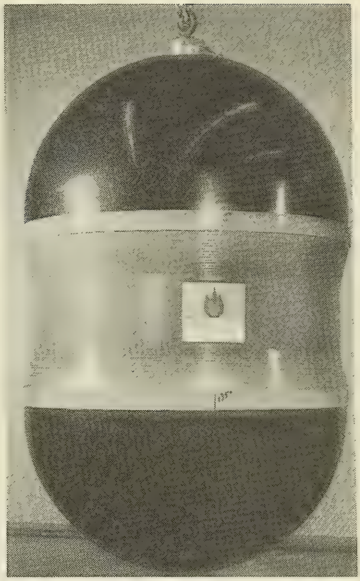
Alumina has considerable potential on a strength-weight basis, but more testing is required to determine its fatigue strength and corrosion resistance, and to firmly establish strength characteristics. The use of alumina, as in the case of glass, depends upon the successful application of a proof test to eliminate defective structures.

GLASS AND REINFORCED PLASTICS

Glass-Reinforced Plastics

The Navy has been investigating glass-reinforced plastics for very deep (greater than 15,000 ft) operating pressure hulls. As a result of this investigation the compressive strength of glass-reinforced plastics has increased from approximately 75,000 psi in 1961 to over 200,000 psi at the present time. This increase is attributed to improved fabrication and testing techniques as well as to significant steps in improving the plastic matrix material.

Fiberglass reinforced plastic sphere, a recently developed low-density material for use as auxiliary buoyancy in deep-submergence vehicles



Three-foot-diameter glass-reinforced plastic deep-submergence pressure hull model awaiting hydrostatic pressure test. This model was hydrostatically tested to failure at 11,500 psi, equivalent to approximately 25,000-ft depth.

Much development work remains to be done before this material can be considered for a manned pressure hull. Problems such as interlaminar shear, fatigue, water absorption, fabrication scale-up, and nondestructive test methods and standards are being investigated.

A reinforced plastic cannot be characterized as a homogeneous material because it does not behave as a composite material until a structural element has actually been fabricated. Therefore, it is difficult to divorce structural response from performance characteristics of the material.

New reinforcing fibers such as carbon fibers and high-strength metal fiber, as well as improved plastic matrix materials, are being developed. As a result improvements in the overall performance of composite materials for deep-submergence hulls are expected.

Radial-fiber spheres uniquely utilize glass-reinforced plastic. Spheres are fabricated by a process which results in radial orientation of all glass monofilaments held in place by an epoxy resin matrix. Compressive stresses of 200,000 psi have been achieved in these structures without failure.

Massive Glass

Because glass is almost perfectly elastic, and completely brittle, there are formidable problems in design, fabrication, and testing. While the

287-778 O - 68 - 4

theoretical tensile strength of massive glass is on the order of 1,000,000 psi, the practical tensile strength of massive glass is very low.

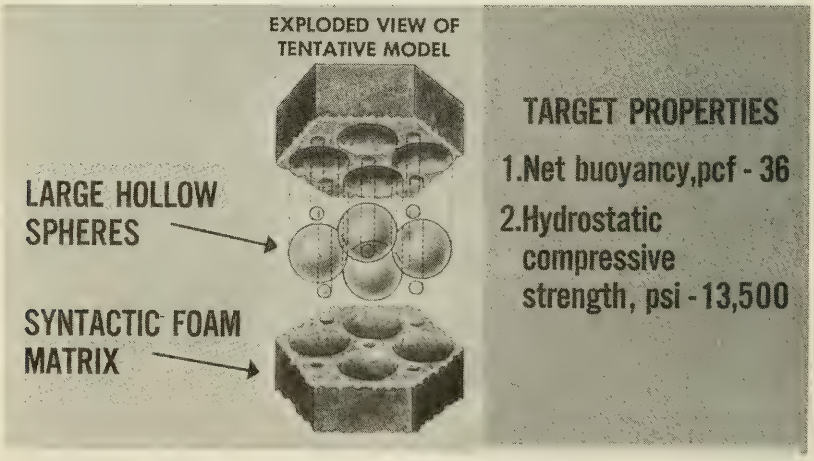
This apparently contradictory situation is due in part to flaws on the surface of the glass which effectively reduce its strength. Surface-removal experiments have confirmed the surface-flaw theory. The surface of soda-glass rods 6 to 8 mm in diameter was carefully ground, which increased the tensile strength from 12,000 psi to over 400,000 psi. In order to retain the strength, the ground surface must be carefully protected.

Another technique for increasing the tensile strength of glass is to place the surface in compression by chill tempering or by an ion-exchange process. In this way, the material can withstand tensile loading, the amount depending upon the process and depth of the surface layer.

BUOYANCY MATERIAL

In order to develop a low density material to be used for auxiliary buoyancy for deep-submergence vehicles, the Navy is investigating a number of approaches: syntactic foam, hollow massive glass spheres/syntactic foam modules, and radial-fiber-reinforced plastic spheres.

Syntactic foam consists of extremely small hollow ceramic or glass spheres having an outside diameter of 20 to 90 microns embedded in a plastic matrix. This material in a bulk form has a density of 42 to 46 lb



Buoyancy module. Low-density materials are used as auxiliary buoyancy for deep-submergence vehicles. This one is composed of a closely packed arrangement of large hollow glass spheres (all larger than ¾-in. diameter), with the voids between spheres filled with syntactic foam.

per cu ft. The material has been tested to pressures equivalent to a 20,000 ft depth.

The hollow massive glass spheres/syntactic foam material consists of hollow spheres of various sizes (all larger than ¾ in. in diameter) in a close-packed arrangement. The voids between the spheres are filled with syntactic foam which is cured to form a solid module. The larger spheres are considered to be pressure hulls whose wall thickness is calculated to withstand the external hydrostatic pressure. The syntactic-foam encapsulation may enhance this aspect as well as cushion the spheres from damage. This material is more efficient than syntactic foam alone, because it provides a larger air void per unit volume. Several problems remain unsolved: sympathetic implosion of the close-packed spheres, reproducibility of the spheres' collapse strength, and a means for nondestructive testing.

Syntactic foam, one of the low-density materials being developed for use as auxiliary buoyancy for deep-submergence vehicles. It is composed of hollow glass microspheres embedded in a plastic matrix and has a density of 40 to 46 lb/ft^3.

MATERIAL PROPERTIES FOR DEEP-SUBMERGENCE PRESSURE HULLS

To perform its function, the hull must withstand the pressure of the sea. Demands on the hull material are thus unique, and combine high values of stiffness, strength, lightness, toughness, and corrosion resistance. Modes of the collapse failure of the pressure hull include elastic buckling, plastic buckling, and fracture. Elastic buckling implies that the material recovers its previous shape as the load is decreased. Plastic buckling implies non-recoverable change in shape without increase in load. Fracture failure implies catastrophic crack propagation.

Toughness and Fracture

To date, pressure hulls for deep submergence vehicles have been fabricated from relatively low-strength metals such as HY 80 and HY 100 steels, because of their availability, fabricability, and toughness. These metals satisfy the requirements of the fracture-safe philosophy; i.e., the material can deform plastically in the presence of a through-the-thickness crack without catastrophic crack propagation and failure.

For high-strength steels, toughness properties improve with special processing such as vacuum melting. However, toughness decreases sharply with increased strength. Above the 200,000 psi yield level, fracture will propagate under essentially elastic stresses. It is possible to utilize fracture-safe metals for buoyant hulls to depths of around 6000 to 9000 ft. Beyond this, for a limited depth span, the high strength, relatively brittle metals can be used, provided that new toughness standards which, for example, relate flaw size to working stress, can be developed. It now appears that nonmetallic materials hold the greatest promise for vessels designed to go to great depths.

Since tensile stresses may occur because of local bending near stiffeners, or because of elastic deformations in small cavities in the material, or follow from local plastic upset in compression, it is necessary to guard against brittle fracture in tension.

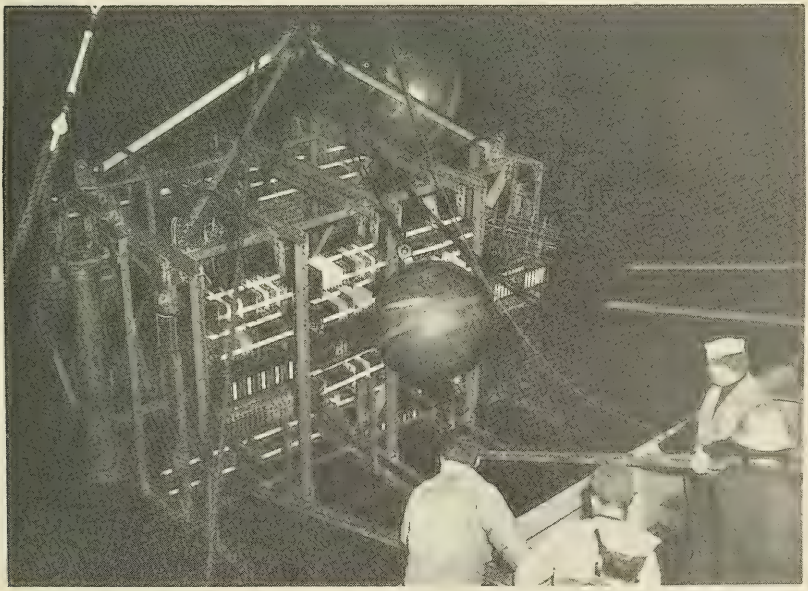
Corrosion Fatigue

Test results for HY 140 steel show that the crack-growth rate plotted against total strain range falls off in salt water in the region of the proportional limit and approaches the rate in air. The Ti 7-2-1 alloy undergoes an increase in crack-growth rate well below the proportional limit in sea water as compared to air.

STRUCTURES AND MATERIALS FOR UNDERSEA INSTALLATIONS

The design of an undersea installation requires analysis of the structural and environmental behavior of materials in the deep ocean. Materials such as steel, aluminum, concrete, ceramic, plastic, and wire rope are presently available for building undersea installations. The behavior of materials in the deep ocean when exposed for long periods of time must be determined.

Engineering experiments are underway to determine the effects of the deep ocean environment and bottom sediments on the corrosion of construction materials. Submersible Test Units (STU's) carrying specimens of metal, plastic, ceramic, wood, wire, rope, and fiberglass have been placed on and retrieved from the ocean floor. The Navy under this program has exposed 11,000 samples of 800 materials at depths of 2500



Submersible test unit 1–4 being brought aboard after 13 months exposure at 6780 ft. This unit contains approximately 1800 specimens of metal, plastic, ceramic, wood, wire rope, and fiberglass.

and 6000 ft. The 2500 ft depth was chosen because it is the level of minimum oxygen concentration at the test site. The 6000 ft depth represents a deep-sea environment on the edge of a major basin beyond the range of present construction operations.

Results of the STU exposures indicate that corrosion rates for mild steels and high strength, low alloy steels at 6000 ft depths are about one third those at the surface for periods of 400 days or more.

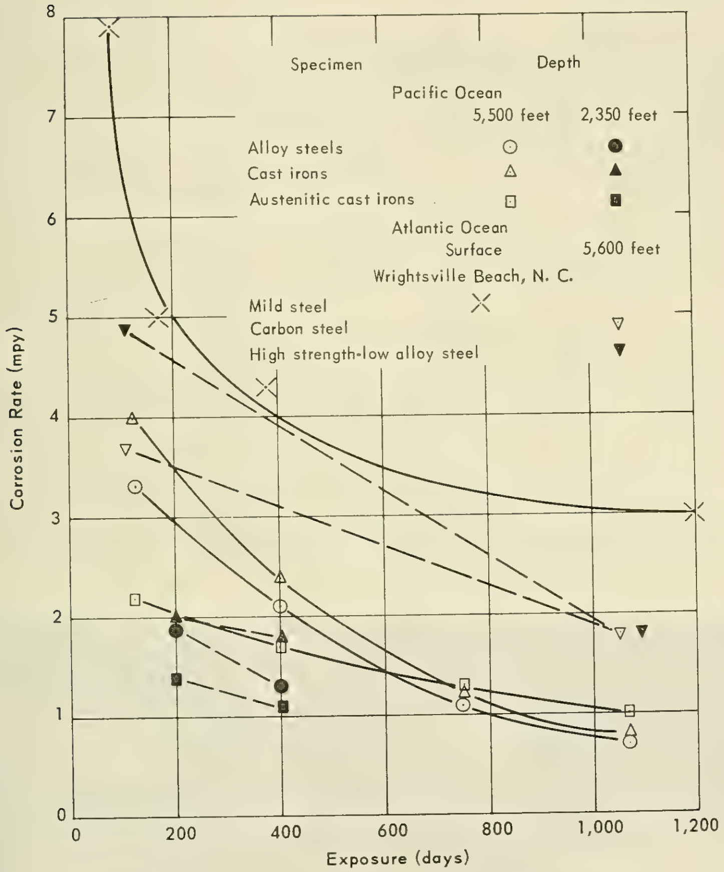
Additional results to date indicate: (a) the corrosion rates of the copper-base alloys decreased with time; (b) pit depths and corrosion rates of most aluminum alloys increased with time; (c) titanium alloys with one exception were immune to corrosion; (d) depending upon the chemical composition, some nickel-based alloys corroded, while others were uncorroded.

Application of concrete hulls to undersea installations requires the design, fabrication, and testing of typical spherically shaped models. Experiments with spherical concrete hulls of 16 in. outer diameter and one-inch shell thickness have shown that concrete may be suited for underwater applications to depths of about 3500 ft. In the models tested, the concrete spheres failed at depths of 7000 to 7400 ft, which represents a stress level 46 percent higher (biaxial compression) than identical control cylinders (uniaxial compression).

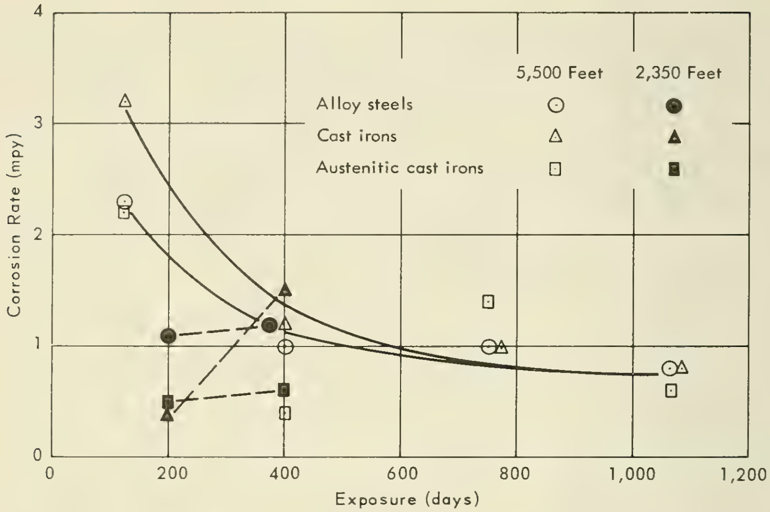
The seepage of seawater through unprotected concrete at depths of 3500 ft was found to be 6×10^{-3} milliliters per square inch of surface per inch of thickness per hour—very slight. Precoating the spheres with epoxy or self-vulcanizing rubber compounds stopped the seepage completely. Other compounds, such as asphalt or tar, promise much more economical waterproofing for large concrete structures.

To determine the extent of creep under high compression, several concrete spherical models were pressurized to 80 percent of their short term critical pressure. When subjected to long term hydrostatic pressurization at a 6750 ft depth, the creep rate immediately after pressurization was high, but declined rapidly and became constant after approximately 50 hours. The creep rate at a 13,600 psi stress level was 30, 4, 0.3, and 0.02 microinches per inch per minute after five minutes, one hour, 30 hours, and 60 hours of pressurization, respectively.

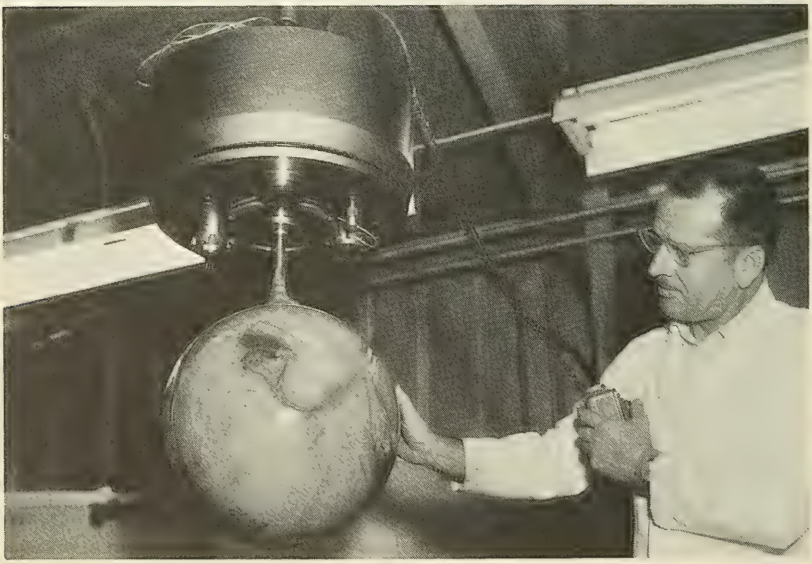
To provide engineers with data on the safe operational pressure for acrylic windows employed in deep ocean installations, engineering experiments are underway on the most important dimensional parameters. The first phase of experiments examined the strength of cone-shaped acrylic



The statistical median corrosion-rate curves for three classes of alloys exposed in the Pacific Ocean are plotted to show the effect of time at depth and the effect of depth in seawater. Corrosion rates are given in mils per year. Surface data for mild steel exposed in the Atlantic Ocean at Wrightsville Beach, N. C., and data from a depth of 5600 ft are shown for comparison. The corrosion rates at both depths in the Pacific decreased with increase in time of exposure. At a nominal depth of 5500 ft, the rates became asymptotic with time.



The statistical median curves for the materials in the bottom sediments at a nominal depth of 5500 ft are the same as those in sea water at this depth. However, the corrosion rates tended to increase slightly in the bottom sediments at the 2350-ft depth.

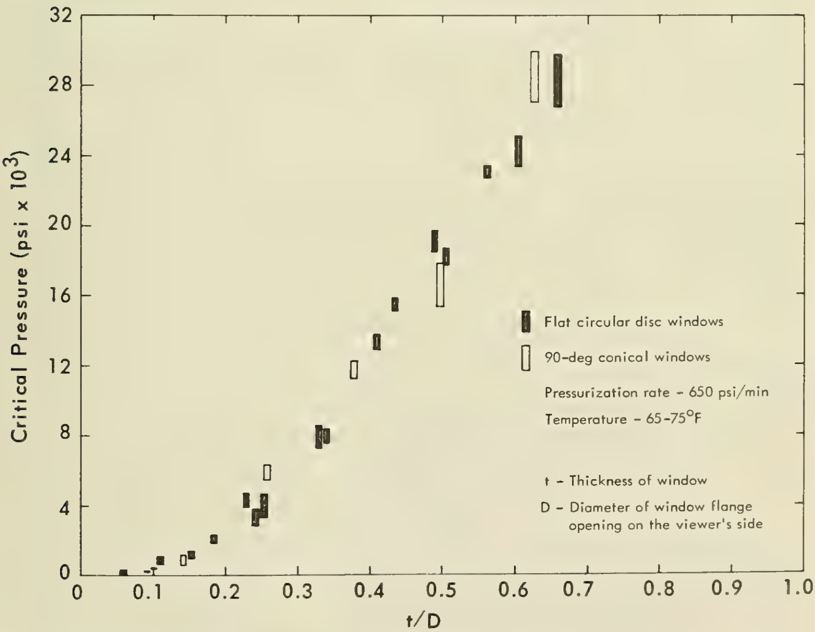


Concrete sphere specimen (16-in. diameter) being lowered into 18-in.-diameter pressure vessel at NCEL for hydrostatic tests at an equivalent ocean depth of 7000 ft.

windows under short term hydrostatic loading at room temperatures. Specimens consisted of 30, 60, 90, 120, and 150 degree included-angle, conical, acrylic windows.

Approximately 40 specimens were tested for each included angle. Results show a considerable gain in critical pressure for most windows when the included angle is increased from 30 to 60 degrees, but less gain from 60 to 90 degrees. Any gain in increasing to 120 and 150 degrees is not significant. For all practical purposes, the 90 degree angle appears to be a significant design factor for windows exposed to near-critical pressure over long periods of time. The factor will be examined in long-term window developments.

The second experimental phase produced design criteria for flat acrylic windows for any ocean depth under conditions of short-term loading. The flat windows under short-term hydrostatic loading were found to be comparable in performance to conical windows with a 90 degree included angle.



Design chart for two types of acrylic windows subjected to short-term hydrostatic pressures. For example, a 90-degree conical window designed for 16,000 psi must have a t/D ratio greater than 0.5, or a thickness of not less than 2 in. with a diameter of 4 in.

The third experimental phase, in progress, is examining a series of specimens of conical acrylic windows of 30, 60, 90, 120, and 150 degree included angle exposed for periods of 500 and 1000 hours. The windows are instrumented to provide data on their rate of displacement through their mounting flange.

Other engineering analysis on the application of concrete has included the testing of typical spherically shaped models for 1500 psi operational pressure. A 16 in. diameter waterproofed concrete model, with operational windows, hatches, and wire feedthroughs, under simulated design depth, was tested as an indicator of how well a concrete pressure hull with penetrations can withstand hydrostatic loads. Several identical models with solid steel, aluminum, and plastic penetration inserts were tested.

The models, with operational windows, hatches, and feedthroughs, failed under short-term pressurization at simulated depths of 7400 ft, the same depth at which models without any penetrations failed. When the solid inserts possessed rigidity equal to or greater than the concrete, the models failed at the same or higher pressure than models without penetrations; on the other hand, when the inserts were less rigid than the concrete, the models failed at significantly lower pressure.

Acrylic hull models are being tested as part of the program to investigate acrylic plastics as underwater hull material. Evaluation of acrylic plastic hulls consisted of subjecting a series of 15 in. outer diameter, one-half-inch-thick spheres with metallic hatches to long-term submersion at simulated 560, 1120, 1680, and 2240 ft depths. Only the hull model subjected to a simulated 2240 ft depth failed, after ten hours of continuous pressure application. The models under simulated 560 and 1120 ft depths did not fail after 3000 hours of pressurization, and the model at the simulated 1680 ft depth was still intact after 1000 hours.

Underwater lights, instruments, and electronic assemblies require both waterproof and pressure-proof packaging for successful operation. Due to the high cost, limited availability, and limited variety of commercial deep-sea instrument housings, experiments were undertaken to explore the applicability and usefulness of commercially available glass closures, such as those used in vacuum technology and the chemical industry. These items have the advantages of wide distribution in the laboratory supply industry and low unit cost. Investigations are continuing to determine their capability to withstand high hydrostatic pressure and to demonstrate their utility in the undersea engineering field.

ENERGY CONVERSION

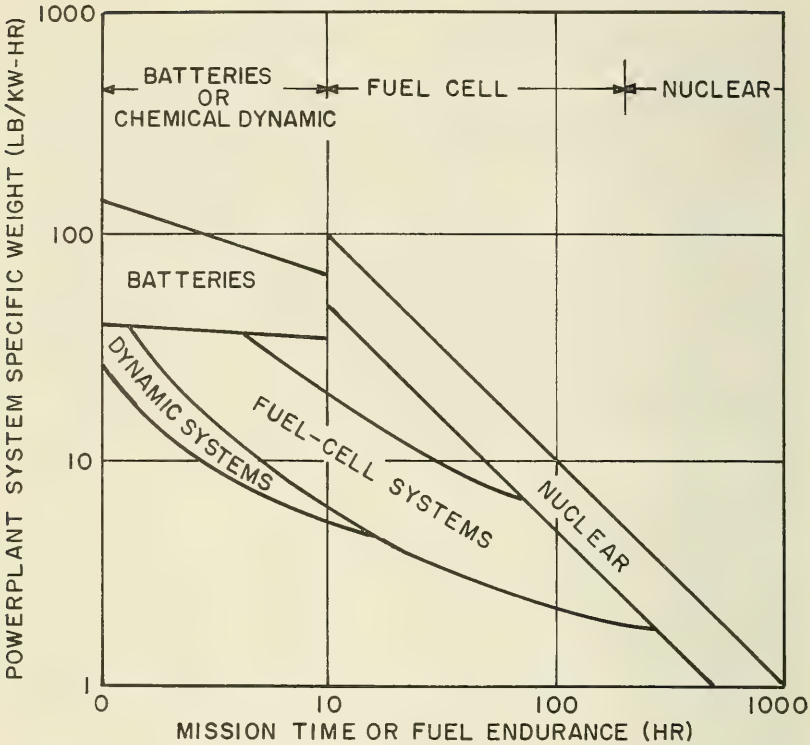
The major candidates for deep ocean power applications are secondary batteries, chemically fueled dynamic-machinery powerplants, fuel cells, and nuclear powerplants. Analysis of specific weight versus mission time curves shows clearly the time ranges that best fit the major candidate systems. The curves are based on comparative parametric analyses of several battery, chemical (fueled dynamic-machinery), fuel cell and nuclear systems with an assumed 50 kw maximum sustained power output. The curves give the weight for fuel and oxidant with associated tankage. In considering the weights of the systems in air, no allocations for material necessary to achieve neutral buoyancy were included, nor were weights of any pressure capsules required, other than atmospheric tankage for oxidant and fuels. These factors may alter the relative attractiveness.

Dynamic-machinery systems considered cover the range from high power density turbomachinery systems fueled by cryogenically stored hydrogen and oxygen to lithium hydride thermal energy storage with a Stirling-cycle engine. The low machinery weights potentially achievable with high-speed dynamic systems could provide superiority in specific weight over other plants for fuel endurance times in the range of ten to 20 hours.

Efficiency of fuel energy conversion becomes a dominating factor in overall powerplant weight for chemically fueled systems when mission times exceed ten hours. This fact is demonstrated in the lower specific weights obtainable with fuel cell systems. Fuel cell systems represented by the range of weight-to-energy data considered include hydrogen-oxygen systems supplied by cryogenically stored reactants, alkali metal amalgam-oxygen systems, and hydrazine-hydrogen peroxide fuel systems. They also represent a range of systems designed for one-atmosphere operation, which must be protected from deep ocean pressures in hardened pressure cases, to those designed for operation at ambient sea pressures.

Analysis of the data available indicates that fuel cell systems are particularly attractive for deep submergence vehicle power supplies with endurance requirements in the range of 20 to approximately 200 hours.

Radioisotope power sources are needed as small power sources for long-life acoustic beacons and various types of oceanographic instrumentation. A program of test and evaluation in both laboratory and undersea environments of state-of-the-art radioisotope power sources is underway.



Preliminary tradeoff analyses indicate that batteries and fuel cells merit the most consideration for application to relatively small deep-ocean submersibles that will be operational within the next decade. The other candidate systems, particularly nuclear powerplants, will require more development effort and will probably be considered for larger deep-ocean vehicles and bottom installations. Battery data are for the one-hour discharge rate.

The rechargeable wet-cell battery is the only energy source in use on present small deep diving submersibles. Based on energy density and the state of the art, four couples merit consideration as power sources: nickel-cadmium, lead-acid, silver-cadmium, and silver-zinc. Energy density varies from approximately 15 watt-hours per pound for lead-acid to approximately 35 watt-hours per pound for silver-zinc. Navy-sponsored studies being conducted on silver-zinc cells show promise of higher energy-density figures.

In selecting a power supply for the DSRV, capacity attainable within restrictive size and weight limitations were important design considerations. The silver-zinc battery was selected because it will produce more energy per pound than other available batteries.

Progress has been made in the development of open- and closed-cycle dynamic powerplants in recent years. A number of solid, liquid, and gaseous fuel/oxidizer combinations are feasible for closed-cycle energy-conversion loops. However, it appears that chemical-dynamic heat engines cannot approach the efficiency of fuel cells. Lightweight conversion equipment for this type of powerplant which will allow a relatively low fixed weight is available or realizable.

MACHINERY FOR OCEAN ENGINEERING

The extreme weight sensitivity of small deep-sea vehicles imposes severe restraints on the machinery-system designer from concept to the end of construction. Small, lightweight systems must be achieved without degrading the safety, reliability, efficiency, maintainability, and many other factors which contribute to the overall suitability of the vehicle.

To minimize pressure hull penetrations, much of the machinery is located outside the pressure hulls. This equipment must either be encapsulated in a pressure-resistant container or designed to operate at sea pressure in a compensated system. The first alternative permits the use of more conventional equipment at the expense of the weight of the pressure container, the provision of high-pressure seals, and the inherent risk of flooding the container. The second alternative avoids these risks but raises other problems in design of machinery which must operate over a range of ambient pressures varying from sea level atmospheric to the maximum design depth of the vehicle.

Equipment that is inherently resistant to sea water erosion may be directly exposed to the sea water. However, much equipment (electrical equipment and speed reducers) must be surrounded with a more compatible liquid (insulating oil) and compensated to sea pressure. The efficiency of high-speed rotating equipment is significantly affected by the hydraulic losses encountered in such a system. The requirement for guarding against contamination of the compensating liquid introduces additional system complexities.

These considerations are particularly important in the propulsion area, because the overall suitability of the vehicle to perform useful tasks in the hostile deep-sea environment will depend in a large degree on its speed, maneuverability, endurance, and reliability. Many comparative studies are required to provide a basis for selection of the optimum propulsion plant.

The design of the nonpropulsion machinery systems for deep vehicles which places emphasis on lightweight, high-performance systems is the same. At the start of most deep vehicle design efforts, many of the performance requirements are not firm. Each system must be investigated over a wide range of possible design goals. The development of such information requires a much more detailed analysis of the systems than normally is required for large-ship preliminary designs. Shortcut methods of estimating weights and performance of systems are not adequate to provide the precise weight, space, and performance data essential for small deep vehicle designers. Conventional large submarine approaches to the problems of heating, cooling, and atmosphere control are often not feasible due to the extreme space and weight limitations. As such, the actual endurance of many deep vehicles is limited by these life support systems.

Electric Motors

Applications for undersea motors include mechanical power for construction machines and mechanical power for vehicle and fixed installations. The electric power sources available for use on small deep-submergence vehicles are direct current sources. In order to eliminate shaft penetrations, decrease the size of pressure spheres, and increase buoyancy, the propulsion and thruster motors can be mounted exterior to the pressure hull. The motors are subjected to full submergence pressure. Most of the motors being used in deep submergence applications are dc, oil-immersed, pressure-compensated motors. These motors have not been satisfactory because of brush wear, brush arcing, and oil carbonization. In addition, contamination of oil by sea water may render dc motors inoperative.

A Navy contract has been awarded to design, construct, and test a prototype ac system for the DSRV. The system will include pressure-compensated ac motors and inverter/controllers for each of the motors. The contract provides for purchase of one 15 HP propulsion motor, two 7½ HP hydraulic motors, four 7½ HP thruster motors, and the inverter controllers for each of the motors.

A contract has also been let to construct and evaluate a feasibility model of a "Nadyne" propulsion motor and converter unit suitable for use on deep submergence vehicles. These motors are ac but promise good speed regulation.

Propeller Systems for Submersibles

To date, several propeller and thrust-producing components have been developed for naval application. They include conventional thrusters, such as stern propellers and propellers mounted within a pod, and also fluid thrusters, such as water jets. At present, the technology and design capability is available to develop an advanced propeller concept, the tandem propeller. Future submersibles performing work tasks will need to be able both to maintain depth position and to exert with precision large forces and moments. Development is planned of the tandem propeller concept for providing submersibles controlled thrust in the six degrees of freedom.

Developments to provide reliability in electrical components are underway in critical areas such as electrical hull penetrators, electric cabling, underwater connectors, insulating materials, and fluids and encapsulation materials for use in a high pressure sea water environment. Usable examples of each of these components have been successfully tested in the environment by the bathyscaph TRIESTE to about 8500 ft, but reliability remains a goal which must be achieved to provide for operational safety.

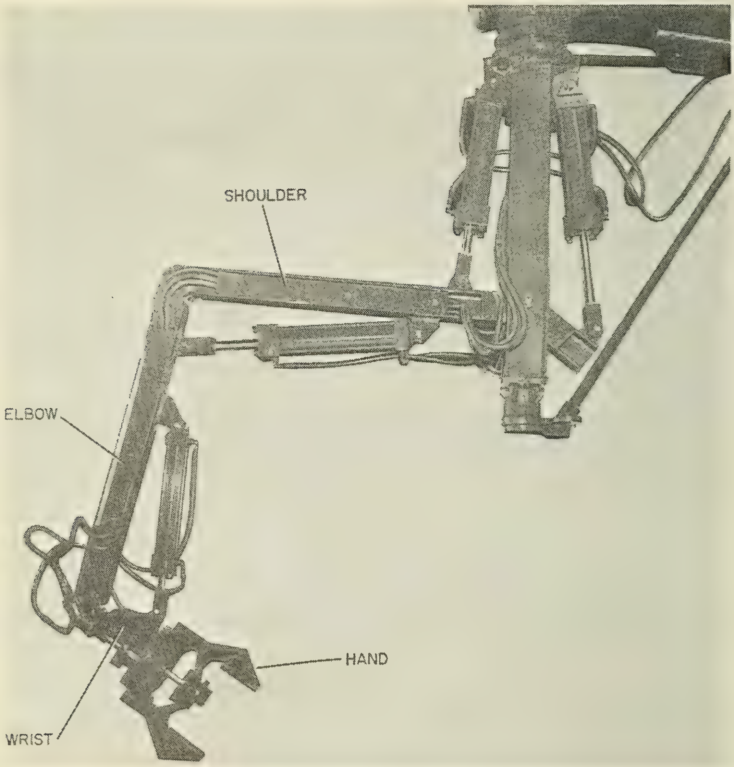
UNDERSEA MANIPULATORS

The first manipulator fitted to a Navy manned submersible was a modified nuclear hot-cell mechanical arm. This manipulator was used on the TRIESTE I and in 1963 recovered a piece of pipe from the submarine THRESHER in 8500 ft of water. The arm was oil filled and pressure compensated to exclude sea water. It was designed to handle weights up to 50 pounds at a 39 in. reach with a two-jaw clamping grip. All motions of the manipulator were powered by electric motors.

The TRIESTE II manipulator had a lift capacity of 500 pounds at a reach of 10 ft. It was hydraulically actuated by a remotely controlled external hydraulic system mounted on top of the float structure. Because of TRIESTE II's arrangement, the manipulator was mounted aft of the personnel sphere and viewed with the aid of a television camera.

With knowledge gained from the efforts on TRIESTE I and II as a basis, Navy turned to industry for a study to integrate the operator, the controls, manipulators, tools, and viewing aids into a coordinated system.

Using this study the manipulators were designed for the AUTEC vehicles. These vehicles, now under construction, will have a pair of arms

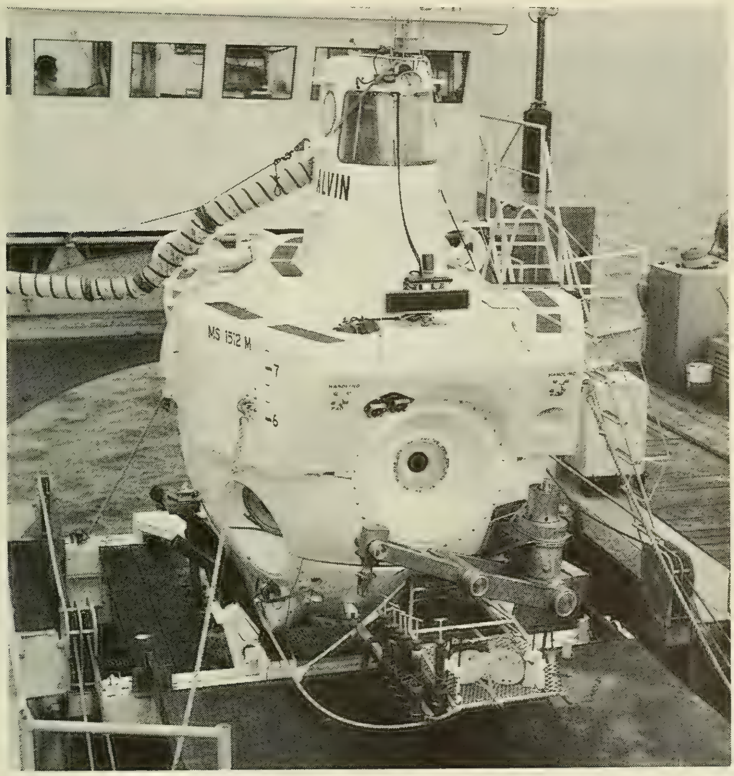


Manipulator developed for TRIESTE II and used in the THRESHER search

mounted near the viewports and a set of tools for underwater use. The manipulators have seven degrees of motion and are anthropomorphic in design. Hydraulic power is used for actuation. Controls inside the personnel sphere allow the operator to control the arms to perform tasks. The manipulators also have the capability of exchanging tools underwater. This ability allows several tools to be used without surfacing for tool change. A sample basket is also available so that geological samples or living specimens may be brought back. These manipulators are part of a continuing effort to provide the Navy with a manipulator system to do useful work in the ocean.

ATMOSPHERE CONTROL

The atmosphere control program embraces all aspects of control of atmospheres in submersibles to insure viability and comfort of personnel.



Deep-submergence vehicle ALVIN rigged for a science mission. Droppable working tray is shown in place, with mechanical manipulator and bottom working tools for a geologic dive.

Chemical and electrochemical devices for oxygen replenishment have been developed for limited or unlimited submergence periods. These developments include not only means for oxygen supply alone but also research into devices which provide dual or multiple functions such as CO_2 and CO removal. Other important problems include effects of oxygen concentration on combustibility of materials and the characteristics of oxygen and inert gas mixtures, under various conditions of pressure. Regenerative and nonregenerative physical and chemical systems have been developed for removal of carbon dioxide from the submersible atmosphere. Another requirement is the elimination of odors and contaminants such as carbon monoxide, volatile hydrocarbons and organics, aerosols, and particulates. This requirement can be met by physical and chemical

287-778 O - 68 - 5

means such as catalytic burners, activated carbon, electrostatic precipitators, and filters. Important elements of this problem include source control by materials selection and development of nontoxic materials, and toxicological studies to determine outgassing, dangers of submersible materials, and allowable limits of atmospheric contaminants. Atmospheric monitoring instruments and controls and systems for heating, cooling, and dehumidification of the environment are also included.

SENSORS, NAVIGATION, CONTROLS, AND COMMUNICATIONS

Navigation is essential to any vehicle operating in any medium. It is particularly significant for undersea vehicles because of (a) the environment in which they operate, and (b) the complex operations required to accomplish their missions.

Operations in the ocean depths are conducted essentially in total darkness, with man-made lighting capable of penetrating only a few feet if the equipment can withstand the pressure, and if sufficient energy sources are available. There are no stars or other visible landmarks on which to base accurate navigation. Operations near the ocean floor, which are essential for most ocean engineering missions, tend to stir up bottom sediment which completely obscures what view is possible. Minute marine life, attracted by light, can also cloud viewports and camera lens.

Coupled with these natural limitations are the complex operational requirements associated with deep submergence and ocean engineering. For example, effective search and survey missions require that a submersible be able to return to a precise location on the ocean floor. Several of the submersibles now being developed will be required to locate and then mate with fleet submarines—both underway and on the sea floor. The smaller submersible must come to rest directly atop the larger submarine's hatch, an operation which calls for precise navigation and control. These requirements have led to an entirely new system of submersible sensors, navigation and control.

Sensors and Navigation

The early submersibles had basic sensors, and navigation and control systems. The primary sensor was the human eye looking through a viewport, possibly supplemented by a simple sonar system. Navigation was based on a compass and stopwatch–assuming the vehicle's velocity through the water was known. Control of the submersible's movement and direction was by direct on/off control of motors.

Improved equipment was available for second-generation submersibles, such as the ALVIN and ALUMINAUT, but their sensors, navigation equipment, and control systems were not integrated. An advanced and integrated sensor-navigation-control system has been developed for the DSRV because of the many complicated maneuvers required of this particular submersible.

The DSRV will be equipped with a total of six different kinds of sonars, all integrated with a timing coordinator, to avoid signal interference, and a master display system. It will use horizontal and vertical obstacle-avoidance sonars to detect objects in the path of the submersible. The vertical sonar, in addition to determining the height of obstacles ahead of the DSRV, will be used to interrogate a transponder carried by the mother submarine or surface-support ship during recovery operations.

An altitude-depth sonar in the DSRV will have two transducers, one to determine distance from the submersible to the ocean floor and the other to determine distance to the surface. The DSRV pilot can select altitude or depth, or he can alternate the sonar pinging. These signals will be used to compute depth for digital display to the pilot and to produce an analog trace on a chart recorder. This sonar will be the prime sensor for maintaining a constant altitude over the sea floor, and will serve as an alternative to the pressure-depth gages for depth measurement.

Once near the sea floor the DSRV will use its doppler to measure ground track. This four-beam system determines fore-aft and athwartship velocities. It can also be used to find vertical velocity, which is required during the final stages of mating with the disabled submarine's hatch. Velocity information will be displayed to the pilot and used by the central processor in dead reckoning navigation computations.

Directional listening hydrophones, mounted on each side of the DSRV control sphere, will permit the submersible to home on acoustic signals from a disabled submarine. As the DSRV closes with the disabled submarine, the submersible's short-range sonar can be used to determine the attitude of the disabled submarine and locate its escape hatches when the water is too turbid for effective use of optical systems. This sonar will be equipped with two scales, one a 150 ft range and the other a 15 ft range. Two transducers, located in the DSRV mating skirt, alternately scan the area below the DSRV. The fore-aft scan will provide a cathode-ray tube trace of returns parallel to the DSRV axis, and the athwartship scan will give a trace of the contour in the perpendicular direction. Near the disabled submarine the DSRV pilot will switch to the 15 ft high-definition scale to attempt to determine features on the submarine hull.

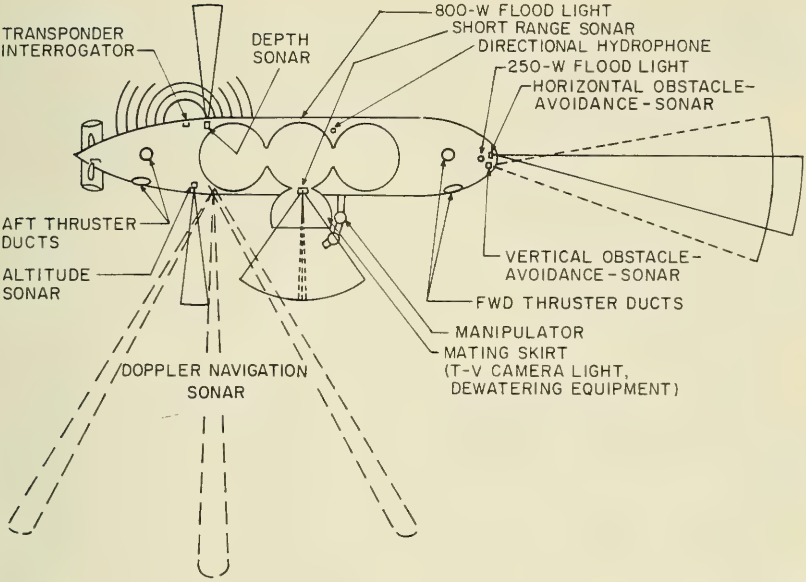
If visual contact is made with the submarine, then the DSRV's TV cameras and lights will be used in place of the short-range sonar. During the final stages of mating and hauldown on the submarine hatch, the forward pan-and-tilt assembly with its TV camera can view the submarine hatch area and the DSRV's manipulator. Another TV camera will be located in a porthole in the mating skirt, and a second pan-and-tilt unit will be located aft of the mating skirt. The pilots will have the choice of using any of these TV cameras or remote-viewing optics to look directly out the viewports.

In addition to the doppler sonar, the DSRV will have a miniature precision gyrocompass to provide an accurate indication of heading. This is a three-axis system, using three integrating gyros and two accelerometers as its sensors. This compass can furnish attitude information for the submersible's stabilization system, provide a reference for computation of velocities from the doppler system, and provide position information by operating as a miniature inertial system.

Computations for the various navigation modes are performed in a central processor. This computer has both digital differential-analyzer and general-purpose subsections. A wide range of signal processing and computation can be accomplished by the computer, relieving the operators of many of the more time-consuming or difficult aspects of navigation. Prelaunch check out is also performed in large measure by the computer. As an alternate to dead reckoning and homing, the DSRV can navigate by means of transponders dropped from the support ships and homing transponders carried by the rescue submersible itself.

Once the DSRV has located the disabled submarine, the submersible will be able to release one or two homing transponders to facilitate return to a precise position. A tracking transponder in the DSRV will home in on the expendable transponder.

The Deep Submergence Search Vehicle will carry out its coordinated search tasks while navigating with respect to one or more transponders, usually deployed from a support vessel. The transponders can be used either singly to reset a dead reckoning navigator or in groups as shown in the drawing. Groups of transponders are usually placed in rectangular patterns, one to three miles apart. Position fixes are obtained by range



Deep Submergence Rescue Vehicle (DSRV) sensor, navigation, and control equipment locations. Many of these systems will be incorporated into the DSSV, which is presently in the planning stage.

measurements from two or more transponders. Replies from several transponders are distinguished by either different interrogation or reply frequencies.

A typical navigation transponder when released by the DSRV would drop to the sea floor, and a float would lift the acoustic transducer about 300 ft above the bottom. The float is designed as a maximum buoyancy, minimum drag body to limit the watch circle (uncertainty) in float location caused by the ocean current.

One of the limitations on range measurement arises from the bending of sound rays. In deep water, especially at depths greater than 6000 ft, sound signals are refracted upward. As a result, a shadow of the bottom masks signals from navigational transponders at ranges greater than two to three miles for submersibles operating in the vicinity of the bottom.

Multipath interference causes another problem. Beacon returns usually include both the direct sound rays and rays reflected off the bottom. Since a typical beacon pulse width is 4 millisec, the reflected signal is only slightly delayed, and thus comes in almost simultaneously with the transmitted signal. This action can cause fading or complete cancellation of the signal, depending on the exact nature of the sea floor. A number of techniques are being investigated which would improve the situation, including space-diversity reception and detection of the leading edge of the pulse.

Transponder navigation is the only technique which offers accuracies to a few feet in deep ocean work. The beacons have both a high initial cost and high replacement cost, and are susceptible to shadow zones, multipath, and other interference in the transmission medium. However, the technique is the best method available of relating an ocean floor to geographic coordinates or relating a surface or subsurface vehicle to sea-floor-referenced coordinates.

In addition to transponders, the DSSV will use the miniature precision gyrocompass and central processor developed for the DSRV. Because of the stringent navigation requirements for search, an effort will be made to improve these very promising systems. Navigation of unmanned vehicles will be accomplished in a similar manner. The towed vehicle can interrogate the same navigation transponders and telemeter replies to the towing vessel. Compatible navigation will be essential if the DSSV is expected to investigate contacts obtained by an unmanned vehicle.

Controls

The DSRV and DSSV will operate in a three-dimensional environment and undertake a number of complicated maneuvers. On a typical rescue cycle the DSRV will perform at least ten principal functions:

- Takeoff from mother submarine (underway)
- Navigation
- Communication
- Search
- Hovering and maneuvering
- Television/viewport viewing
- Manipulator control
- Mating with disabled submarine
- Takeoff from disabled submarine
- Landing on mother submarine (underway)

The two DSRV operators would have a difficult time performing all of these functions if separate controls and instruments were used. Thus, an Integrated Control and Display (ICAD) system is being developed to coordinate sensors, navigation, display, and controls. All sensors, navigation, and propulsion equipment will provide electrical signals into the ICAD computer. The data will then be translated into displays for the DSRV pilot and copilot. To control the vehicle the pilot and copilot will order direction and rate and the ICAD computer will translate these signals and provide exact control signals to the vehicle's individual propulsion control units.

This vehicle control system must operate satisfactorily in the presence of disturbances such as ocean currents. Other critical control problems arise from crosscoupling between thrusters and from coupling terms in the equations of motion. The effect of the disturbances has been reduced to a tolerable level by such compensation techniques as high rate-loop gains and the use of decoupling networks.

One of the difficult problems for submersible pilots is the relatively slow vehicle response. To reduce this effect and to avoid limit cycling which can arise from actuator saturation, the ship control system will use both command-rate limiting and forward-feed decoupling. An assisted manual control mode also helps the pilot hold station with respect to a target which is visible on his TV screen. Here, the pilot will position a synthetic marker over the desired location of the DSRV.

In addition to the manual modes, the pilot can choose an automatic altitude and position-hold mode or an automatic maneuvering mode, where the DSRV is under the control of the central processor. When under computer control, the pilot merely provides translational commands to the computer.

The search vehicle (DSSV) sensor, navigation, and control requirements will be similar to those of the DSRV. The ship control requirements for the DSSV will depend to some extent on the choice of vehicle design and propulsion. A search submersible must hover and maneuver at least as accurately as the DSRV. Side-looking sonar requires very low yaw and roll rates to ensure proper coverage. Further, the DSSV is expected to operate from a mother submarine, and thus must perform the same mating operation as the DSRV.

Although operator display and control panels for the DSSV will be functionally similar to those of the DSRV, new sensors make an integrated and well organized display even more important. Methods will be developed to allow the operators to note possible sonar or optical targets, record their position, and still follow a coordinated search plan. Human-engineering techniques become important, since search missions are generally long, and physical size of vehicle may limit crew rotation.

Communications

Communications are essential for operational coordination between submersibles and their support ships. Development of underwater voice and telemetry links for search and recovery operations have been initiated. These operations are planned to keep distances between submerged vehicles and their support ships close enough to permit the use of underwater sound for communication transmissions.

This development for the DSRV and the DSSV will extend the range of underwater "telephones" now used by the Navy. The development is directed toward the provision of a communications capability at all depths down to 20,000 ft, with lateral separations of the submerged and support vessel up to three miles. The capability is to be provided for sea state 3 surface conditions, and for a reasonably uniform sound velocity profile across the transmission path. Along with the voice capability of the telephone, provisions will be made to enable the use of a transmitter-receiver for sending and receiving telemetry signals on a time-shared basis with voice signals. The telemetry portion of the system will process and transfer data on navigation, life support, and other submersible operations.

The growing importance of saturation diving and underwater search, rescue, and salvage techniques creates the need for improvements in relatively short-range communications between the underwater base and surface support ship base and free swimmers, and between swimmers.

Communication links from the underwater base to a surface support ship are now accomplished via a cable to a telemetry surface buoy. Unfortunately, the surface motion at high sea states degrades communications through umbilical cable links. Operational acoustic links are limited to one mile ranges for voice-grade information transfer.

The link from the underwater base to the free-swimming diver is operational for short ranges (up to 300 ft) by direct voice acoustic transducers. For longer swimmer excursions, electronic receivers of the acoustic signal currently in use will give reliable performance and have been suitably miniaturized. When diver-to-base communications in excess of one mile are required, investigation into the use of a telemetering buoy system will be necessary.

Diver-to-diver communications present a significant problem. In this case the development effort is directed at an adequate oral-nasal mask, a bone-conductive receiver-transmitter, and a solution to the problem of synchronous breathing. Solutions to these and related problems are being undertaken by the Navy.

Voice distortion caused by the helium-oxygen atmosphere used by divers causes many unique problems in communications hardware development. The human voice in a helium atmosphere assumes a "Donald Duck" quality. This phenomenon becomes more pronounced as the pressure increases and eventually makes intelligible speech almost impossible. In an effort to overcome this difficulty, electronic devices have been developed which effect a frequency shift transformation on the voice, adjustable according to depth. Work is continuing in the miniaturization and improvement of this helium voice unscrambler.

Navigation for Divers

Navigation systems are required for divers or diver-controlled vehicles just as in the submersible search operation. To be effective the divers must know where they are, how to get back to their habitat or transfer capsule, and which way to go on a search mission. For the individual diver, navigation can be a matter of life or death, since his breathing apparatus gives him a limited time in the water. Present limitations in this area may force the continued use of tethered divers—a serious restriction on the aquanauts.

Techniques developed for submersibles approach the accuracy needed for divers—a matter of a few feet. However, submersible equipment is far too heavy and requires too much power. Furthermore, it would be unrealistic to expect the diver to perform significant computations while swimming. For this reason, simple ranging and directional systems will have to be developed that are lightweight and easily carried by the diver or his support vehicles.

SATURATED DIVING AND SEALAB

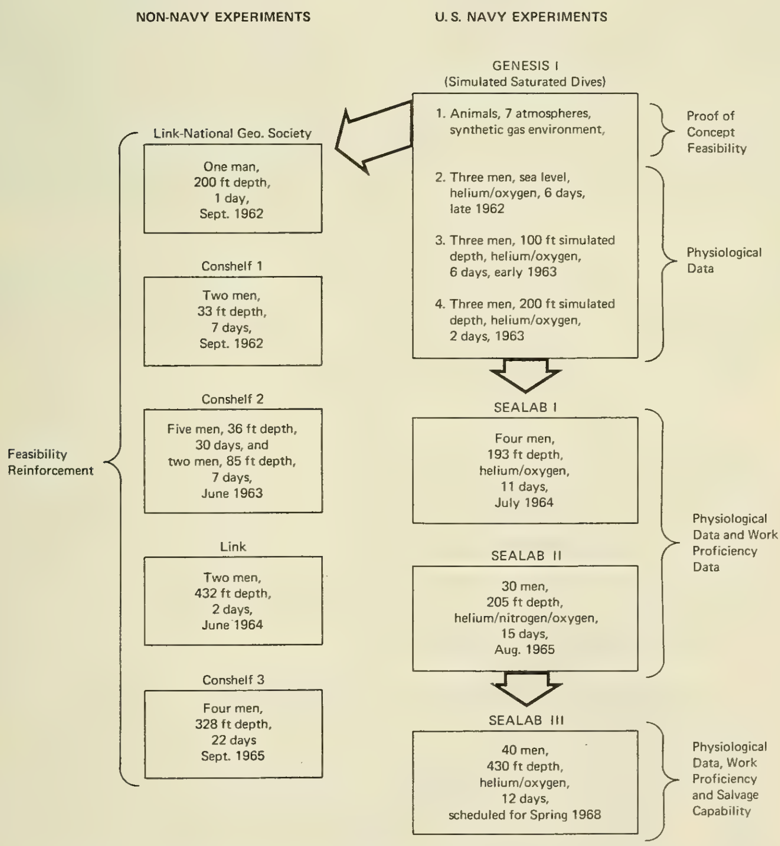
Until the late 19th century man's efforts to penetrate the ocean depths as a diver were bound to developments in machinery such as diving helmets, diving bells, and air compressors. As divers went deeper and remained longer, their efforts were paced by physiological problems rather than engineering problems. In the 1870's the cause of the "bends," or decompression sickness, was diagnosed and a cure proposed: gradual decompression. Other physiological problems arose involving oxygen poisoning and nitrogen narcosis.

In an effort to solve the problems involved with breathing compressed air in deep-sea diving, in 1924 the Navy and the Bureau of Mines conducted joint experiments with subjects breathing helium-oxygen mixtures under pressure. Animals were used in the early experiments, and by 1927 the work had progressed to the point where human subjects could be used. The Navy continued experiments with helium-oxygen gas mixtures for deep-sea diving. In 1937, using a helium-oxygen mix, two Navy divers reached a simulated depth of 500 ft in one of the tanks at the Navy Experimental Diving Unit.

These dry land experiments were put to operational use in May of 1939 when the U. S. submarine SQUALUS sank in 243 ft of water off the New England coast. Initial dives at the disaster scene were made with compressed air, but most of the 640 dives employed helium-oxygen mixtures. There was not a single death or serious injury suffered during this intensive deep-sea diving operation. The new technique was proved far superior to compressed air breathing. On the basis of data obtained during the SQUALUS dives the U. S. Navy established 380 ft as the new limit for operational diving with the time limit of 30 minutes on bottom. Without complications, a dive of this depth and duration requires more than three hours decompression, an unfavorable ratio of working time to decompression time of 1 to 6.

This unfavorable ratio of bottom time to decompression time has been overcome with a technique known as "saturation diving." In saturation diving the diver is provided a fixed capsule on the sea floor or a personnel transfer capsule which transports him to the deck decompression chamber of a ship. The capsule is pressurized to the outside water pressure and provided with a suitable breathing gas mixture. After about 24 hours of exposure under pressure, all tissues of the diver's body have a gas saturation equivalent to the surrounding atmosphere, and the diver is considered to be "saturated." Once he has been saturated, the diver's requirements for decompression are based on depth rather than duration of the dive. A diver saturated to 300 ft requires the same decompression time (approximately 2½ days) whether his bottom time is one day or one month. After hours of useful work at depth, he returns to the safety and comfort of the underwater habitat or ship decompression chamber. Since there is no appreciable difference between the pressure of the habitat and that of the outside water, there is no requirement for decompression of a man entering the undersea chamber. Rather, decompression of the saturated diver for his total time spent at depth is accomplished in a single step when he returns to the surface after days or weeks of useful work on the ocean bottom.

The first experiments in the field of saturation diving were begun by the U. S. Navy in 1957, using a standard decompression chamber and then the climate-altitude chamber installed at the Naval Medical Research Laboratory in New London, Connecticut. These experiments were given the code name Genesis I, and the first phases were concerned with the reactions of animals under pressure. After four years of experimental work it was shown that while test animals could not survive normal air at a pressure of seven atmospheres for more than 35 hours, they could tolerate an equivalent exposure to high pressure while breathing a synthetic gas.



Major U. S. Navy and non-Navy experiments which helped lead the way to an advanced diving system

Late in 1962, three men were exposed to a helium-oxygen breathing mixture at sea level pressure for six days. Although the breathing of the low density helium changed the timbre of the participants' voices, creating what is known as "Donald Duck" effect, there were no other physiological or psychological changes noted in the subjects.

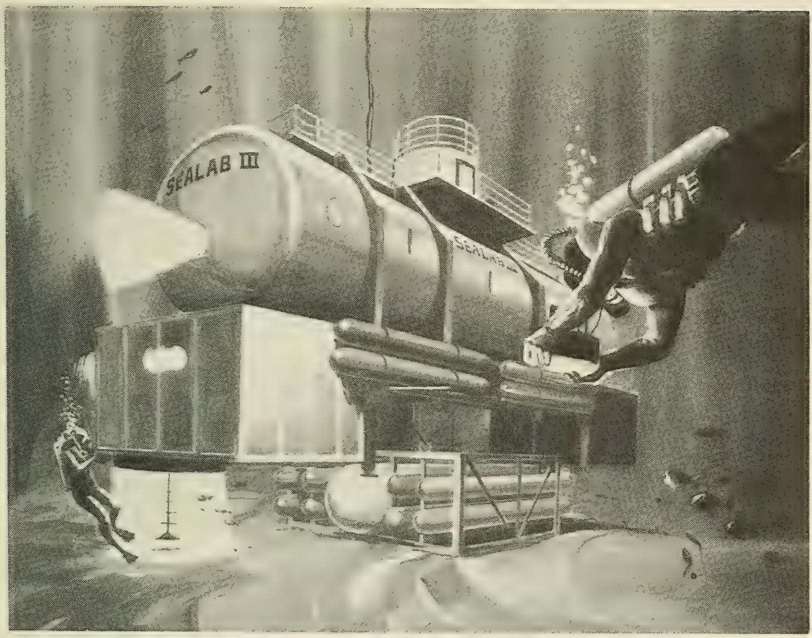
In the next phase of Genesis I, conducted in early 1963, three Navy men lived for seven days in a two-section pressure chamber at the Experimental Diving Unit. One chamber was a dry living area with a helium-oxygen atmosphere. There was an adjacent wet room, partially filled with water, where the men periodically performed special energy-consuming work under pressure. The pressure in the connected chambers was similar to that encountered at 100 ft depths.

The final phase of Genesis I was conducted at the Naval Medical Research Laboratory Test Chamber, with a medical officer and two enlisted men spending 12 days at a simulated ocean depth of 200 ft, again breathing a helium-oxygen gas mixture. As in all previous phases of Genesis I the experiments were completely successful.

The Genesis I experiments under Captain George Bond, USN provided the sound physiological base for the present Sealab program. The American inventor Edwin Link, and the French oceanographer Jacques Yves Cousteau have each produced significant work to advance saturated diving techniques. Their experiments, performed independently, were designated "Man-in-the-Sea" and "Conshelf I" respectively.

In the summer of 1964, the U. S. Navy conducted its first in situ experiment, designated Sealab I, near the Oceanographic Research Tower, Argus Island, off Bermuda. Participants lived in a 40 ft-long chamber at a depth of 193 ft for eleven days. During this time the Sealab I aquanauts lived a nearly autonomous existence, with minimum assistance required from the surface-support crew. An extensive program of physiological studies was successfully pursued, and the overall health of the aquanauts proved excellent throughout the project.

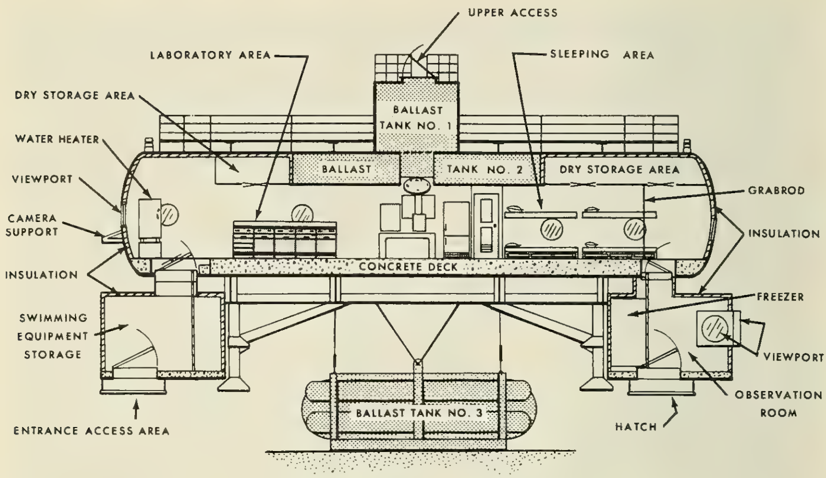
During the Sealab II experiment, carried out in the fall of 1965 at La Jolla, California, three ten-man teams remained at a depth of 205 ft for 15 days each. This experiment too was an unqualified success. In addition to living underwater and conducting a multitude of physiological experiments, underwater work tasks in simulated salvage, oceanography, and construction were performed. In all, the three teams achieved more than 300 man-hours of useful work outside the habitat.



The Navy's Sealab III habitat. Sealab III is the third phase of the open-ocean tests of the Man-in-the-Sea program. During the experiment, five teams of eight aquanauts, civilian scientists, and Navy divers will occupy the habitat for 12-day periods during the scheduled 60-day experiment. The habitat, a modification of the Sealab II capsule, is a nonpropelled, seagoing craft, with a living compartment, a diving locker, and an observation room. The habitat has a pressurized helium-oxygen atmosphere equal to the surrounding sea water pressure.

Sealab III, the most ambitious saturated diving experiment to date, will be conducted during the summer of 1968 at the Navy range off San Clemente Island, California. In the Sealab III experiment five teams of eight Navy and civilian aquanauts will live successively in the sea floor habitat for 12-day periods. The habitat will initially be placed at a depth of 450 ft for use by two or three of the eight-man teams. The habitat will then be moved to a depth of 600 ft for the remainder of the experiment, with two or three teams living and working at the greater depth.

The 40 aquanauts who participate in Sealab III will include Navy personnel and civilian scientists and technicians from Navy facilities and other government and private agencies. Their biomedical experiments will include extensive psychological testing, research in marine biology, sonic work, and evaluation of thermal protection. In conjunction with the last,



Sealab III interior arrangement

the aquanauts will wear two types of garments to protect them from the cold, one a resistance-wire suit which resembles a form-fitting electric blanket (an improved version of the suit tried in Sealab II), and the other a tube suit which circulates warm water over the aquanaut's body. Both suits will be powered by electricity from an umbilical linking the diver to the habitat. However, a prototype isotope heating device worn by the aquanaut will also be tested. The breathing gear worn by the aquanauts will consist of the improved Mark VII equipment, which can use gas carried in tanks by the aquanaut or pumped through the umbilical from the habitat.

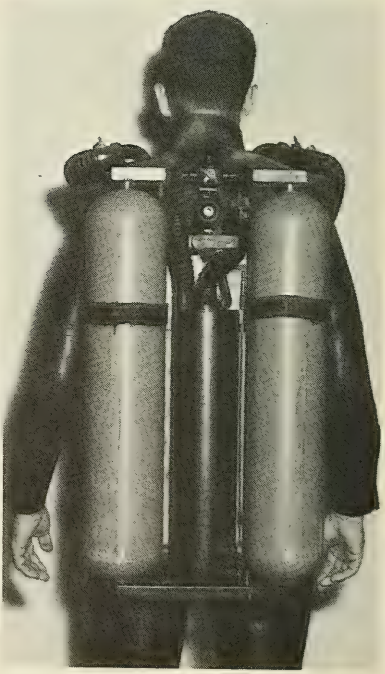
The Sealab III habitat will be essentially the same as used in Sealab II, with certain modifications. Most significant is the addition of two rooms, each 8 ft by 12 ft, to the bottom of the habitat. The after room is a diving station and the forward one an observation and storage compartment. The main habitat is divided into a laboratory, galley, and bunkroom. The additional rooms will provide more living and working space in the habitat and remove the awkward work of putting on and removing scuba gear from the main compartments.

Sealab III will be logistically supported by the surface ship ELK RIVER, especially configured to perform this type mission. ELK RIVER will be fitted with two Deck Decompression Chambers and two Personnel Transfer Capsules.

The Sealab experiments, with related studies and development efforts, have the purpose of providing the Navy with the technology and equipment to enable aquanauts to perform military and other national interest missions. However, the saturation diving technique is not considered the most effective method of working underwater for all missions, but rather for those of extended duration. This capability for extended ocean-bottom operations will enable Navy aquanauts to perform underwater salvage, construction, search, survey, maintenance, and research tasks heretofore considered impossible for divers.

The demand or open-circuit scuba is a militarized version of the commercial model. The unit is nonmagnetic, rugged, and capable of supporting hard-working swimmers to a depth of 130 ft.

Diver with Mark VI semiclosed-circuit mixed-gas scuba. The Mark VI is a recirculating scuba using mixtures of nitrogen-oxygen or helium-oxygen. Exhaled gas is forced through a CO_2 removal canister and reused. Excess gas is bled off through a relief valve. This apparatus permits the diver more time at depth than the scuba equipment commonly used by civilian skin divers.



Back view of the Mark VI semiclosed-circuit mixed-gas scuba. Utilizing special breathing fixtures, this apparatus permits the diver more time at greater depths than the standard scuba rig.

DEEP SUBMERGENCE BIOMEDICAL DEVELOPMENT

The Navy program, Deep Submergence BioMedical Development will direct and coordinate tasks directed toward the solution of problems inherent in or associated with diving and working at deep salvage operational depths, diving and working in deeply submerged high pressure free swimmer habitats, operating small sea-level atmosphere deep diving vehicles and isolated fixed installations, and combat swimmer operations. Specific areas include personnel casualty treatment, biomedical aspects of life support and medical aspects of crew selection and performance.

Personnel casualty treatment, decompression and related medical techniques, procedures and equipment will be developed to provide an acceptable support capability for diving operations with a goal of about 1000 ft. Improved capability will be provided in the areas of: breathing gas mixture technology; computer aided decompression procedures; decompression sickness and air embolism prevention and treatment, and emergency medical care in the underwater environment.

Biomedical systems, subsystems and components integral to the provision of life support, health maintenance and environmental control, at 1000 ft. underwater equivalent pressure for up to 30 days will be advanced through prototype development and laboratory evaluation phases. The objective is to improve capabilities in the areas of cardiopulmonary physiological monitoring techniques; body temperature control techniques; nutrition and fluid balance maintenance; disease control and prevention; habitat temperature, humidity, gas composition, and a toxic contaminant environmental control system.

Advances in medical selection techniques and procedures, human factors engineering, and crew performance assessment are vital to the effective utilization of manpower resources in the deep submergence environment. This phase of the work shall include the following: special aptitude assessment, psychiatric screening, and group composition determination; unique stress and related fatigue detection, measurement, prevention and control techniques; bio-electronic sensor aids for sight, smell, hearing, touch and equilibrium, and biomechanical locomotion aids and work tools; work-rest-sleep-cycle determination; environmental medical services related to living and work space design; pharmacological enhancement of crew performance.

Medical care services in support of diving systems will be developed including the techniques, procedures, materials, equipment, therapeutic and anesthetic drugs, and biologicals for treatment of shock, respiratory and cardiac syncopy, and traumatic injury; general drug therapy; poison marine life injury prevention and treatment; disease and injury diagnosis and prognostication; emergency control and treatment of acute psychiatric cases.

287-778 O - 68 - 6

SEA FLOOR ENGINEERING

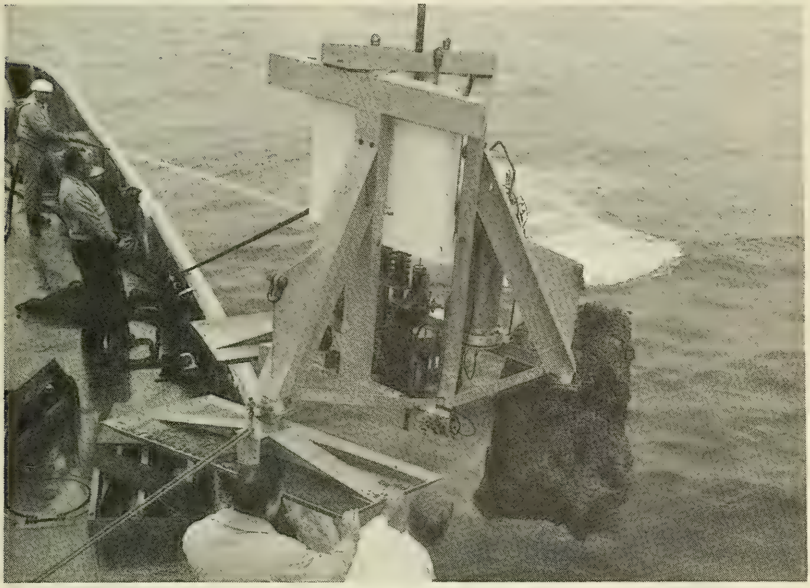
The ability to design and construct facilities for the ocean bottom requires developments in sea floor engineering. Problems include site selection and survey, structural analysis of fixed structures, fabrication and assembly of components, bearing capacity of bottom sediments, and the design and placement of anchors, and foundations on the ocean floor.

The data on soil properties will be applied to the engineering design of foundations for underwater installations. Primary concern in foundation design and construction will be with safe bearing capacity based on tolerable settlement, rather than on the ultimate bearing capacity, which is the bearing stress necessary to rupture the soil mass beneath footing. Bottom soil properties are being studied to define their engineering characteristics. Sediment cores are taken from the bottom of the sea to determine the significant parameters of the soil which will affect the design of a sea floor installation. Core samples retrieved by the Navy Civil Engineering Laboratory from various depths in the ocean have indicated varying mechanical properties.

Laboratory test data alone will not be sufficient to determine the ocean floor bearing capacity. Environmental investigations to determine soil properties are required, and methods to accomplish this are being developed.

One device which will aid in determining the engineering properties of marine soils is the in situ plate bearing device. This device is capable of determining the short-term bearing pressure and settlement response of marine sediments as it operates on the sea floor while connected to a surface vessel only by a load-bearing line. Tests with this plate bearing device have been performed on both cohesive and noncohesive soils in depths to 1200 ft. It was found that the size of the bearing plate was the most significant parameter affecting the bearing pressure and settlement response in both major sediment types.

A second tool being developed for engineering investigations is the in situ vane-shear device. This device will be capable of performing vane-shear tests to a depth of 10 ft below the sea floor in a maximum depth of 6000 ft of water. Research will be performed (a) to obtain in place measurements of soil strength properties, (b) to relate in place data to laboratory tests of cores taken from the test sites, and (c) to determine the relationships between environmental vane-shear measurements and the more rapidly obtained core-penetrometer measurements for the various sediment types.



NCEL in situ sea-floor plate bearing device after test in 1200 ft of water. The device is capable of determining the short-term bearing pressure and settlement response of marine sediments.

Soil tests are also being conducted in pressure vessels to determine the effects of a high-pressure, low-temperature environment on the engineering properties of ocean bottom soils. The environmental effects were investigated through consolidation, direct-shear, and vane-shear tests on four different ocean bottom sediments within pressure chambers at hydrostatic environmental pressures up to 10,000 psi. The pressure chambers were also refrigerated to provide a 1° to 3°C environmental temperature. Results obtained have confirmed that soil properties vary with increased environmental pressure.

Concrete foundations have been constructed in shallow water for many years for bridges and dams. Two methods of placing concrete have been used in the past. One method is by pumping concrete into forms which have been placed on the ocean bottom. The second is by the assembly of precast concrete units on the bottom. Both of these techniques will have to be studied for application to deep water.

The placement and recovery of heavy loads in deep water pose problems. The mechanics of raising and lowering heavy loads in the deep ocean require special precautions but are within the state of the art.

The NCEL "Padlock" anchor being lowered into the water. This anchor is designed to support a load in any direction and will have a depth capability of 6000 ft.

Deep ocean anchors will be of use in sea-floor construction for use as foundation anchor or as a mooring for construction equipment. In the design of deep ocean anchors certain constraints must be considered. These constraints are concerned with the type and degree of restraint, holding power, permanence, and simplicity of placement.

As a solution to these constraints, an investigation was undertaken into the development of an anchor that could be rapidly and surely placed by free fall impetus and could be used to secure small to medium sized objects such as buoys, floats, and barges on station in deep ocean areas. A free fall anchor was tested unsuccessfully, and as a result it was concluded that means additional to, or independent of, free fall impetus would be necessary to achieve the depths of imbedment required to develop sufficient holding power.

Another concept under consideration is that of the propellant-imbedment anchor. This anchor is a self-contained device similar to a large caliber gun consisting of a barrel, a recoil mechanism, and the projectile, which is the anchor. Experimental observation of these devices under test loading to depths of 6000 ft have demonstrated their potential for deep water application; however, the tests have also pointed out limitations in reliability and capacity. Currently a larger propellant-embedment anchor rated at 50,000 pounds capacity is being investigated. The anchor, developed by the U.S. Army Research and Development Laboratory for use in coastal waters, is being modified by the Navy for use at greater depths, with the target depth set for 6000 ft.

To provide an anchor point in the sea floor that is totally fixed and will support an applied load from any direction, the propellant-imbedment-anchor concept was applied to an anchorage complex for bottom-mounted structures. The design as produced is a tripod frame with articulated bearing pads at the extremities and is referred to as the Padlock anchor. Propellant-actuated imbedment anchors are mounted in each of the three arms above the bearing pads. The anchors are driven into the sea floor through openings in the pads. The other end of the cable that is attached to the anchor is connected to a cable-rewind mechanism at the center. The rewind mechanism pretensions the anchor lines after the anchors are imbedded.

The Padlock anchor has been demonstrated to be feasible and has functioned satisfactorily in shallow water. This anchor can be used as a foundation component when set down in a group of three or more. Three Padlock anchors can be joined by a framework and can support a large load of perhaps a few hundred tons.

These methods for anchoring to the ocean floor can be roughly termed static, in that the anchors firmly attach themselves to the sea floor and from then on require no expenditure of energy to maintain their positions. In contrast to this method is the dynamic positioning method, which has been used successfully in positioning certain ships and barges. Dynamic positioning uses propellers located advantageously such as bow thrusters to position the ship precisely and to maintain this position on the open ocean.

During recent years, the Navy has installed several permanent ship moors in depths as great as 6000 ft. From these moors has evolved a design technique suitable for holding large ships in a relatively fixed position against wind, waves, and current. Six moors were designed and installed by the

Navy. These moors, in chronological order, have been designated as: Hardtack (1958), TOTO I (1959), Squaw (1959), TOTO II (1962), and Squaw (1965).

The Hardtack installation, in water as deep as 6000 ft, consisted of a number of moors which held test ships for an underwater nuclear shot. This program provided the initial concept for permanent deep sea moorings. An experimental ship moor based on this concept was subsequently evaluated in the Tongue of the Ocean, from which it received the designation TOTO I. The Squaw moors positioned a buoyant, but submerged, model submarine hull for sonar training exercises. The Artemis and TOTO II were specifically designed for positioning large ships in connection with other underwater programs.

Although each of these moors is representative of a somewhat different design and installation problem, together they represent a logical sequence in development of the current mooring technique. These moors will provide guidance for design and installation of future deep-sea ship moors.

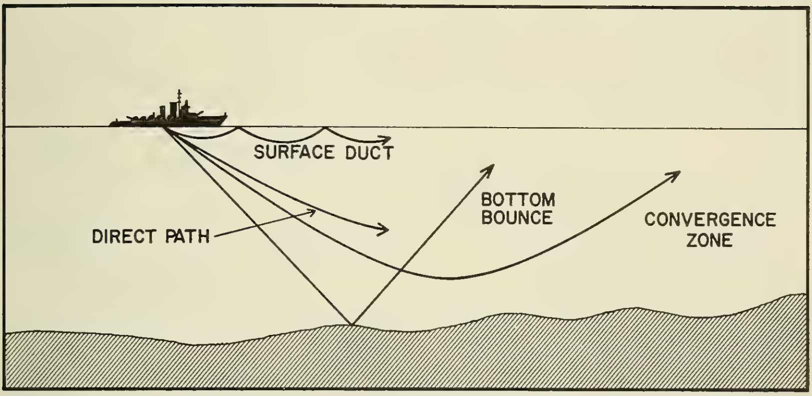
ACOUSTICAL OCEANOGRAPHY

Since World War II, the Navy's underwater detection capabilities have increased greatly. Increased knowledge of the effects of the ocean environment on underwater sound propagation, due primarily to the acoustic investigations of the Navy Ocean Science Program, has been an important factor in the advancement of long-range sonar and underwater weapon systems.

In addition to the direct path commonly associated with a sonar beam, long-range sonars can take advantage of phenomena which exist under certain conditions:

1. Surface ducts, shallow layers of warm water near the surface, which carry sound waves long distances, as they are unable to penetrate the colder water beneath.
2. Convergence zones, which occur at regular intervals as the sound is alternately refracted upward by penetrating colder water, and reflected downward from the surface.
3. Bottom bounce, in which mode the sound waves are bounced off the bottom at an angle of incidence which projects them farther through the water.

Surface-duct transmission requires a strong, shallow thermocline, convergence zone transmission requires deep water with the depth of minimum sound velocity well clear of the bottom, and bottom bounce requires that the ocean bottom be relatively flat and hard. Hence, continuous



Propagation of sound energy through an ocean environment is a complex process and one that is not fully understood. The Navy acoustical oceanography effort continues to gain working knowledge of the effect of the ocean environment on underwater sound propagation.

developments are undertaken not only to improve the equipments themselves but also to measure the environmental characteristics of the world's oceans so the operators may select the appropriate mode of operation.

On June 30, 1966, Projects Artemis and Trident were combined, and the research and development program and the existing facilities (the Tudor Hill Laboratory, Bermuda, Argus Island, and the USNS MISSION CAPISTRANO) were transferred into an acoustic surveys project. The Navy is conducting research and ocean engineering leading toward the development of equipment and systems to meet specific requirements for ASW surveillance.

The current program emphasizes research and at-sea experimentation to resolve acoustic, environmental, and engineering uncertainties prior to the development of subsystems and/or systems. In general, investigations are being pursued in the areas of wave-front behavior, target characteristics, ambient noise, propagation, reverberation, signal processing, design of underseas structures and components, and undersea power transmission techniques.

Typical oceanographic efforts carried out under the project are acoustic surveys, in areas of interest to determine bottom roughness, depth, and composition, surface temperature throughout the year, sound velocity profiles in the immediate area and as a function of season, ambient noise directivity, spectrum, coherence, energy levels and statistics, reverberant reflectors and scatterers, and the energy level and coherence of their returns.

Bottom-reflection processes are being studied by means of theoretical models to determine the influences of composition, layering, roughness and acoustic frequency on reflection losses. Experimental measurements are being made at sea to provide accurate data and new techniques for measuring bottom roughness, reverberation, and reflectivity, and to determine relationships between these properties.

In addition to these major advanced development programs, various supporting programs are leading to innovations in underwater acoustics. Improved acoustic data collection and analysis techniques are being developed. Airborne acoustic survey methods are under evaluation for the rapid collection of acoustic propagation and reverberation data. Various acoustic data collection techniques have been developed for deep and shallow water, and, more recently, acoustic transmission measurements are being made from deep research vehicles.

Measurements of the acoustic and other properties of the ocean are being made to investigate environmentally induced amplitude fluctuations of acoustic signals as a function of range and frequency. Physical properties are measured by means of buoyed current and thermistor arrays. The lateral variability of acoustic and sediment properties is being investigated in a variety of physiographic provinces using seismic reflection methods and deep research vehicles.

Considerable work is underway in the acoustics programs to investigate biological scattering. Experiments are being conducted to determine the abundance and distribution of the organisms populating the deep scattering layers and to determine their effect on sound propagation. These experiments are revealing that biological scattering is dependent on season, time of day, acoustic frequency, and geographic location.

Accomplishments in the exploratory development area include:

1. The derivation of a mathematical model which explains the nature of the acoustic field and the propagation loss in subsurface ducts (this model is known as the Normal Mode Theory).

2. The development of techniques for performing real-time shipboard analysis of the propagation and echo-ranging data.

3. Development of programs for computing propagation loss by ray or wave theory.

4. Experiments to measure bottom-reflection loss, reverberation levels, ambient noise levels and characteristics, submarine target strength, sound velocity profiles, etc.

Continuing experiments will reveal more about the complex nature of target strengths of submarines, leading to the ability to synthesize a complex target into more simple ones. Distortion in the waveform of various types of acoustic signals is being investigated, as is the relationship between signal phase stability and environmental parameters.

The results of these experiments are being correlated with data acquired by the Marine Geophysical Surveys program. Begun in 1965 by the Naval Oceanographic Office, the goal is to make a comprehensive study of about 15 percent of the ocean floor and determine its effect on sound propagation. Measurements are being made of both acoustic and physical properties of the ocean bottom.

Measurements in various environments are being made to determine effects of oceanographic conditions on range and bearing accuracy of long-range sources, with a view to improving the accuracy of fire-control solutions in long-range antisubmarine weapon systems.

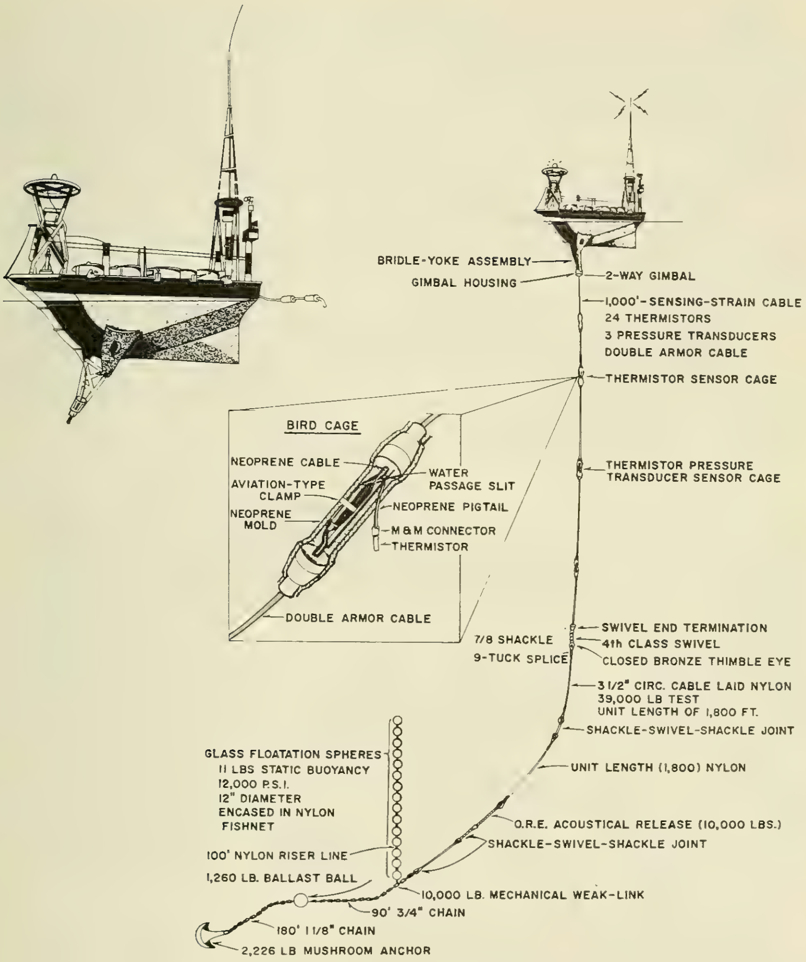
DEVELOPMENTS IN ENVIRONMENTAL PREDICTION AND OCEANOGRAPHIC SURVEY

The Assistant Oceanographer for Ocean Engineering and Development directs the developmental program in environmental prediction and oceanographic survey. Upon completion of the development effort these systems are integrated into the programs of the Assistant Oceanographer for Oceanographic Operations.

PREDICTION OF THE MARINE ENVIRONMENT (ASWEPS)

In order that the operating forces may effectively plan and execute naval operations, availability of predictions of environmental parameters is extremely important. The Antisubmarine Warfare Environmental Prediction Services (ASWEPS) program consists of: (a) development of instrumentation for use aboard ships, aircraft, and buoys to measure oceanographic parameters, (b) development of thermal-structure analyses, prediction techniques, and displays, and (c) application of the products to ASW planning and tactical operations. The forecasted oceanographic data provided to ships at sea by Navy fleet broadcast and facsimile can be directly converted to tactical indexes, such as expected range capability of a particular sonar.

The earliest effort of the Navy in the area of oceanographic prediction was in the prediction of sea ice conditions. To minimize the considerable damage being sustained by ships operating in arctic waters, the Naval Oceanographic Office in 1952 and 1953 instituted an experimental ice observation and prediction program. Today, synoptic ice observations are acquired by ice-reconnaissance aircraft throughout much of the Arctic, and selected Antarctic areas. Sea ice reports are also received from ships and helicopters, and satellite pictures are used experimentally for gross features such as boundaries of ice masses and open water. Analysis of observations by ice forecasters enables them to furnish synoptic ice predictions covering large areas, enabling ships and submarines to select appropriate areas and



ASWEPS deep moored telemetering oceanographic/meteorological buoy

tracks. In addition to reducing ship damage, ice prediction has reduced the time required for completion of naval operations in these remote areas. New ice forecasting methods and increased knowledge of ice formation, behavior, and deterioration will, as a result of more data from satellites and other more conventional sources, further benefit polar and under-ice operations.

The early success of the synoptic approach to ice observation and forecasting led to exploration of other facets of oceanographic forecasting.

In 1954, the first synoptic wave charts, showing wave height contours for the entire North Atlantic, were constructed from the ocean wave reports which had, for some years, been submitted in six-hourly synoptic weather reports by commercial and naval vessels. By 1956, radio-fascimile synoptic and prognostic wave charts were being regularly transmitted to the Fleet. The Optimum Ship Routing Program, developed in 1955-1956, uses wave predictions in routing ships along tracks of maximum operational efficiency. Using wave heights, ocean current, and surface wind predictions, the Navy today routes between 1200 and 1400 ships annually in the North Atlantic and North Pacific. The 14 to 16 hours saved by following the recommended trans-Atlantic route can save the owners of a vessel 2000 to 5000 dollars per crossing in operating costs. This service will be improved by recent developments in predicting wave heights, wave periods, and ocean currents.

Sea surface temperature and layer depth analyses of the western North Atlantic began in 1957. It was realized that analysis and prediction of the thermal structure would be of value to ASW planners and tacticians, since temporal and spatial changes in the ocean environment greatly affect sonar capabilities. Enthusiastic reception by the ASW forces of these first efforts contributed to the establishment, in 1959, of the formal ASWEPS program. ASWEPS environmental and operational forecasts now available for the North Atlantic, North Pacific, and Mediterranean give ASW commands an indication of areas favorable for operations and an opportunity to employ optimum disposition of forces. The shore-based network, which provides evaluated daily and long-range information, is supplemented by tactical on-scene networks directed by ASWEPS teams embarked in flagships of ASW carrier division commanders.

The value of predictions is dependent upon the amount and quality of synoptic environmental data available to the forecasters and analysts. An increase in the ocean areas covered, as well as an increase in the quality of predictions, has led to a development of instrumentation to provide raw data. The concept of system engineering is followed in instrument design; that is, integration with existing equipment on various platforms whenever possible, with the data recorded in digital format and transmitted automatically to users. New instrumentation developments include:

1. Salinity-temperature depth system, which records the salinity and water temperature at various increments of depth
2. Expendable salinity-temperature depth system, which need not be recovered after making its measurements

3. Integrated shipboard expendable bathythermograph display system, which provides instant, automatic retransmission of digital temperature versus depth profiles to stations remote from the ship, as well as providing on-site reading for immediate tactical use
4. Automated shipboard forecasting system for use under the supervision of mobile ASWEPS teams aboard major Task Group flagships
5. Near surface reference temperature device, which provides a measure of water temperature immediately below the surface
6. Airborne radiation thermometer, including digitization of the data output which, measuring the sea surface temperature as a function of infrared radiation, enables an aircraft to amass data over a large area over a short time
7. Airborne wave height recorder, essentially an accurate radar altimeter to measure sea states
8. Buoy temperature sensor cables
9. Expendable bathythermographs for surface and airborne platforms.

The Deep Airborne Expendable Bathythermograph (DAXBT), with a digitized output, is a follow-on to the AN/SQS-36 expendable bathythermograph, and will increase measurements of temperature versus depth from 1500 to 5000 ft depth. The Shipboard Expendable Bathythermograph (SXBT) is currently replacing the mechanical BT which has been in use by surface ships, essentially unchanged, since 1939, and is to be modified to be adaptable to installation in helicopters, and the Helicopter Expendable Bathythermograph (HXBT), also to be provided with automatic digital readout. Through automatic data links, the flagship ASWEPS team will have at its disposal a complete profile of temperature-depth parameters in the area of interest.

Developments in the prediction of the marine environment are being carried out by other Navy offices as well. Naval Air Systems Command, in the interest of improving airborne ASW capabilities, actively coordinates with the Oceanographer of the Navy in this field, and in developing techniques for the rapid, accurate prediction of ranges to be obtained from airborne sonar systems. The feasibility of developing an expendable device to measure propagation loss is being investigated.

To increase the synoptic data which are essential to the effectiveness of ASWEPS, a "Ships of Opportunity" program employs merchant vessels not primarily engaged in oceanographic research and survey operations. These vessels provide data in areas not covered in the normal course of naval operations, as an adjunct to the system, and in the process of their

A radiation thermometer mounted on the wing of a S2E aircraft permits measurement of the sea-surface temperature over a large area in a short time period.

normal transit from port to port. Among the equipments being developed for placement on these ships is a self-contained sensing and recording package which can be conveniently shipped to any location in the world and hand-carried aboard a designated ship of opportunity. The system will be capable of measuring conductivity and temperature at increments of depth to 1200 ft, and of storing these data for 60 or more observations. The system, known as the Suitcase CTD system, will have a weight such that one man can easily carry it, and a design such that it can be operated by untrained personnel. Upon completion of a CTD survey operation, the entire package will be shipped back to the Naval Oceanographic Office, where the stored data will be converted to magnetic tape for computer data processing.

Other plans for the ships-of-opportunity program include development of expendable instruments, meteorological instruments, and a van housing an integrated central control station for all measurements taken on a survey.

Quantitative information on the effectiveness of ASWEPS, and guidance for its future direction, will be gleaned from the results of an 18-month

Fleet Operational Investigation (FOI), being conducted by COMASWFOR-LANT. Progress reports of the FOI, and a recently completed operational research study of ASWEPS, demonstrate that the program provides significant increases in the effectiveness of ASW tactics such as barriers, convoy escort and screening, and air-sea coordinated searches.

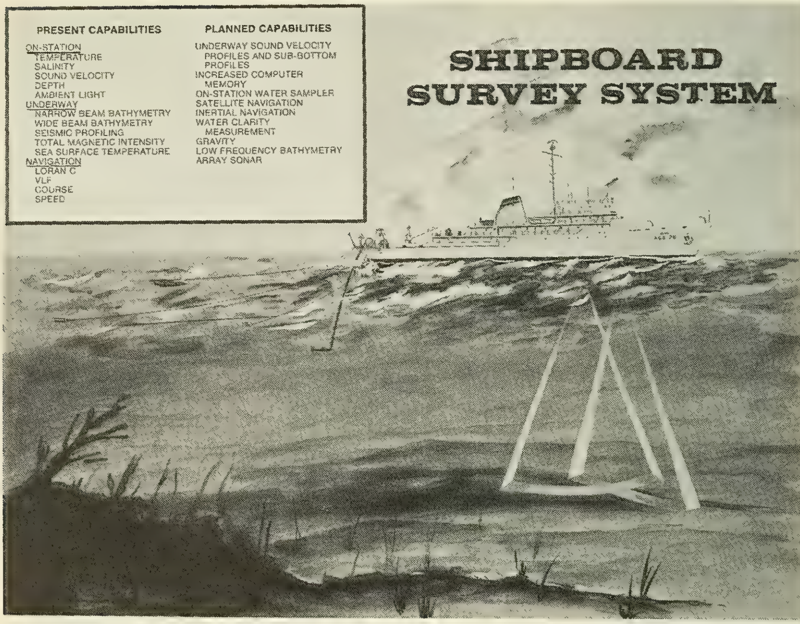
Techniques and procedures developed in ASWEPS are being extended to further applications, particularly in ASW in a shallow water environment, and to a study of marine life to develop a false target prediction capability. ASW tactical doctrines are being reviewed to accommodate considerations of support provided by environmental prediction.

Although ASWEPS products are now used effectively by the operating forces, room for improvement exists. Additional synoptic environmental data can and should be provided daily to improve analysis and prediction accuracy. Planned instrumentation for ships, aircraft, and buoys will greatly enhance the quality and quantity of synoptic oceanographic observations in the next few years. Development of new and revised forecasting models will be accelerated by increased use of computer techniques and automatic data processing as more synoptic data becomes available.

Although designed for ASW support, ASWEPS has been a source of ancillary benefits. The Bureau of Commercial Fisheries, for example, is making profitable use of ASWEPS predictions in selecting areas of maximum horizontal sea surface temperature; four-fold increases of catch have been reported as a result of consulting environmental charts.

SHIPBOARD SURVEY SYSTEM

An integrated shipboard data-collecting and recording system, the Shipboard Survey System, is a most significant development in ocean surveying. Prior to the early 1960s, oceanographic surveying, was performed by instrumentation which was largely an accumulation of items, evolving largely from projects supported in the Ocean Science Program. In 1962, Navy development funds were provided to initiate a program for modern, sophisticated instrumentation to complement and accelerate the effort of the Navy's TENOC plan, first outlined in 1961 as a ten-year program in oceanography. The USNS SILAS BENT, the Navy's first ship built for this purpose, has been joined by a second new oceanographic survey ship, USNS ELISHA KANE. With this system, measurements of sound velocity, temperature, depth, salinity, ambient light, magnetics,



The Shipboard Survey System permits recording of measured data both on-station and underway in a form that is easily adapted to modern high-speed computer processing.

gravity, surface temperature, and bottom and sub-bottom profiles are recorded in a form easily adapted to modern high-speed data processing. Data are gathered by the on-station instrument package, referred to as a fish, which is capable of operating to depths of 6100 meters. As the fish is lowered into the water at a rate of up to two meters per second, a profile of the characteristics of the ocean is made by the sensors in the fish. A remote readout device for displaying essential data, also part of the system, is mounted on the bridge of the ship. A total of eleven such vessels, equipped with the shipboard survey system, are planned.

AIR-SEA INTERFACE

Scientists have inferred striking analogies between physical phenomena in the ocean depths and those in the earth's atmosphere; both are fluid masses acted upon by pressures, currents, insolation, rotation of the earth, and other internal and external forces. The boundary layer between these somewhat similar, but extremely different, environments—the air-sea interface—is the subject of extensive investigation. The Navy is studying meteorological prediction methods and ocean-atmosphere conditions affecting missile launch restrictions, aircraft and ship route forecasting, hurricane prediction, polar weather techniques, and radio/radar propagations over water. Hardware developments are being made incident to sensing, recording, and telemetering observations of atmospheric and related oceanic parameters. This increased knowledge of the interactions between sea and atmosphere will be of benefit to mariners everywhere.

MAGNETICS AND GRAVITY

Two general areas of great interest to the Navy, in such applications as undersea navigation and ocean surveillance, are the earth's gravity and magnetic field. Developments are directed toward techniques that improve the measurement, analysis, and display of the earth's magnetic field. The accuracy of the spherical harmonic surface at sea level has been verified from the data incorporated in the 1965 World Variation Charts. Spatial coherence of short-period variations in the magnetic field is being tested by simultaneous records made at two or more stations. Finally, a geological interpretation of the total magnetic field data of the U. S. East Coast Survey is underway in cooperation with the U. S. Geological Survey.

In response to Department of Defense requirements, The Navy is developing improved methods for measuring, analyzing, and utilizing the earth's magnetic field. Among its objectives are to utilize magnetic field characteristics to position aircraft, ships, and submarines, and to analyze magnetic anomaly effects on bombing and navigation devices. Future plans include preparation of detailed magnetic variation charts, which will assist navigators everywhere, both surface and aircraft. The present Project Magnet airborne survey system will eventually be expanded to an airborne geophysical survey system capable of providing precise, accurately positioned magnetic measurements in any area of the world.

The Navy has been assigned management control of the Department of Defense project for development of a helicopter gravity-collection system. Test equipment has been selected, and the test, plans for which are well underway, will be carried out jointly by the Army, Air Force, and Navy. In response to this task, the Naval Oceanographic Office has plans for a

287-778 O - 68 - 7

program to increase speed, accuracy, and efficiency of gravity data collection. A helicopter gravity equipment configuration is to be developed which will permit rapid response to requirements for gravity data on a worldwide basis. It is anticipated that the program will eventually develop methods to perform direct measurement of the deflection of the vertical from a moving platform, and to perform gravity data analysis in response to Department of Defense requirements in areas such as navigation, positioning, guidance, and control.

RADIOLOGICAL SURVEYS

The distribution of certain artificial radioisotopes, resulting from nuclear events, deposited on the sea surface as fallout has been under investigation since early 1965. Developments are also in progress to measure the mineralogical properties of matter in the sea and bottom sediments and the distribution of radioisotopes in the marine biosphere.

As part of the overall program of chemical and radiochemical investigations, the Navy under a cooperative agreement with the U. S. Atomic Energy Commission, acts as a consultant and tests and evaluates systems utilizing radioisotopes, in the marine environment. Those systems which are presently under study are the Deep Water Isotopic Current Analyzer (DWICA II) Nuclear Sediment Denisty Probe and an in situ oxygen analyzer.

COASTAL ENGINEERING

Riverine warfare, amphibious operations, and mine warfare are examples of naval operations requiring a definitive understanding of coastal oceanographic and hydrographic conditions. Developments are underway which will provide a greater understanding of the dynamic processes, morphology, composition of coastal and riverine bottoms, and other factors affecting mining, mine-hunting, etc., in shallow water and riverine areas. Preliminary work includes testing a nuclear sediment-density meter in both shallow and abyssal environments and performing stress-controlled laboratory consolidation experiments. Tests involving the nuclear sediment-density meter indicate that nuclear devices for environmental measurement of certain mass properties show considerable promise for both analytical and correlation purposes. Consolidation tests to determine the stress history of a particular sediment regime are presently being performed in the laboratory on sediment samples from various riverine and oceanic environments.

Techniques are being developed for inferring from oceanographic conditions in surveyable areas those parameters affecting mines and mining; search and detection; swimmer activity; and amphibious and other naval operations in shallow water areas, including straits, river mouths, estuaries, and open coasts.

A program is being undertaken to develop, test, and evaluate advanced riverine survey techniques and oceanographic/hydrologic data analysis methods to provide predictions on tides, currents, and water levels in support of naval operations in Southeast Asia. This development, testing and evaluation effort is carried on in South Vietnam as part of the River Survey Team effort. This team is composed of Marine Corps surveyors and Naval Oceanographic Office civilian specialists who operate in direct support to Commander, Naval Forces Vietnam for the purpose of providing necessary oceanographic, hydrologic and charting information for the rivers of South Vietnam.

Better equipment and techniques to improve data-collection capability and the quality of the data collected will lead to production of more accurate combat charts. Plans exist for development of prototype sensors and equipment which can be utilized in the development of automated hydrographic survey systems, and in which advanced techniques and equipments will be employed for precise positioning in data acquisition.

As the rapidity with which data acquisition can be accomplished increases, techniques will enable accurate surveys to be made of recreational areas, such as small boat marinas, which will increase the safety and equipment of this rapidly growing activity.

HYDROGRAPHIC SURVEYING AND CHARTING (HYSURCH)

Development of a Hydrographic Surveying and Charting (HYSURCH) system has been initiated to support fleet needs for rapid production of hydrographic data in coastal areas during amphibious and mine warfare operations. Design of the HYSURCH system will be based on a shipboard command/control concept for rapid hydrographic and topographic (coastal) data acquisition, correlation, compilation, reproduction, and dissemination. It is anticipated that the HYSURCH system will be composed of an aerial survey subsystem, a hydrographic survey subsystem, and a shipboard cartographic compilation and reproduction subsystem. The prototype

HYSURCH system will provide a hydrographic survey unit with the capability for ready acquisition and display of sounding data. A contoured hydrographic chart will be available for distribution to the fleet within one week after such data acquisition.

AERIAL SURVEY TECHNIQUES

A comprehensive project for water depth determination and recording of ocean bottom detail by employing aerial color photography as a remote sensor has been continued. Aerial color photography was obtained over a test range established in the Key West, Florida, area in March 1967. These films showed bottom detail to a depth of 65 ft. The accuracy with which water depths can be measured by photogrammetric techniques will be determined. Preliminary results indicate that blue light is a deterrent to sharp image formation and good contrast in water penetration photography. Future studies will use narrow band filters to eliminate the blue light and obtain photography with only green and red light. Development of a new color emulsion that has no blue-sensitive layer may provide a means for greater water penetration with aerial photography. Tests with the narrow-band filters and such a new color emulsion will determine the spectral quality of light that will yield considerable detail at deeper depths than was formerly possible.

AUTOMATION OF CHART PRODUCTION

The demand for charts and special products of all kinds has increased steadily in recent years as a direct result of the rapid increase in numbers of ships and aircraft and in their performance capabilities. The solution to production problems was found in the employment of high-speed computers, not only for computational purposes, but also for preparation of input data into automated cartographic production systems.

The initial steps to automate cartographic production were taken in 1960, when development was begun on a precision automatic digital coordinatograph system. The first such system was placed in operation in the Naval Oceanographic Office in June 1963. The system is capable of drawing, scribing (engraving), or photographically exposing continuous straight or curved lines; printing numerical data with a mechanical print head; and photographically exposing alphanumeric data on large sheets of sensitized film. A director unit processes the information supplied to it and controls the coordinatograph and the operations of its interchangeable instrument heads. The plotter operates on the principle that any curved line that can be described by a mathematical equation can be automatically produced by the system.

The final output of the automatic plotter system consists of inked plastic or paper sheets, a photographic film, or a scribed negative. The detail on these outputs is plotted and delineated at a speed and to a tolerance that cannot be matched by manual methods.

Considerable progress has been made in developing a library of computer programs to construct different types of cartographic functions. Computer programs already developed and in use on the digital coordinatograph are:

1. Construction of electronic navigational position lattice systems, both hyperbolic (loran, etc.) and circular (shoran, etc.) for charts and oceanographic/hydrographic survey plotting sheets.
2. Construction of over 30 different map projections.
3. Annotation and plotting of soundings resulting from hydrographic surveys, automatically plotting the soundings in their proper latitude and longitude position and annotating the correct depth in fathoms and feet.
4. Plotting and scribing of geographic shoreline and other map features.
5. Delineating the major great-circle sailing routes and underwater cable routes of the world.
6. Production of magnetic variation and declination charts of the world.
7. Scribing of various metric plotting grids and military reference grids for overprinting on nautical charts.

Numerous requests for automatic services have been filled from other government agencies, private institutions, and foreign governments. In addition to providing production assistance, technical information, guidance, and computer program documentations have been supplied freely to help others develop similar capabilities.

By using unique computer programming techniques, an automated cartographic system can produce in eight hours as many as twelve chart originals, completely plotted, scribed, and ready for photolithographic production. Stops are required only for changes in scribing materials and magnetic tapes. In the four years the plotter has been in operation, over 7000 individual original drawings and color separation originals have been produced.

Automatic cartographic production systems will be added in 1967 to provide more advanced capabilities, automatically placing names and symbols in any desired position and using various type sizes and styles. Among the components of these systems are digitizers which will provide the capability of storing cartographic source data in such a manner that it can readily be retrieved from a library file, processed by a computer, and graphically produced on the coordinatograph within a matter of minutes or hours. Future plans will provide a color separation capability, whereby each color plate of a printed chart can be digitized and recorded separately, and stored for chart compilation or revision use.

Cartographic automation at the Naval Oceanographic Office will play an ever increasing role in supplying the fleet and the oceanographic community with accurate and up-to-date charts. The high-speed production capabilities of automated systems will make it possible to supply needed charts more quickly and economically than ever before.

OCEAN ENGINEERING AND TEST FACILITIES

To carry out development programs in ocean engineering, the Navy is particularly dependent on certain laboratories* and activities with special engineering and test facilities.† No attempt will be made in this report to describe either the Navy laboratories or all the facilities that the Navy owns. Each facility addressed in this section is unique. It may be the largest Government facility of its kind in the nation, or it may be the only facility of this size and scope. Navy laboratories and activities with missions related to ocean engineering perform research, development, test, and evaluation in broad areas of technology. For example, the programs addressed in this report are performed directly by these laboratories and activities or indirectly through them by universities and industrial firms.

OCEANOGRAPHIC INSTRUMENTATION CENTER

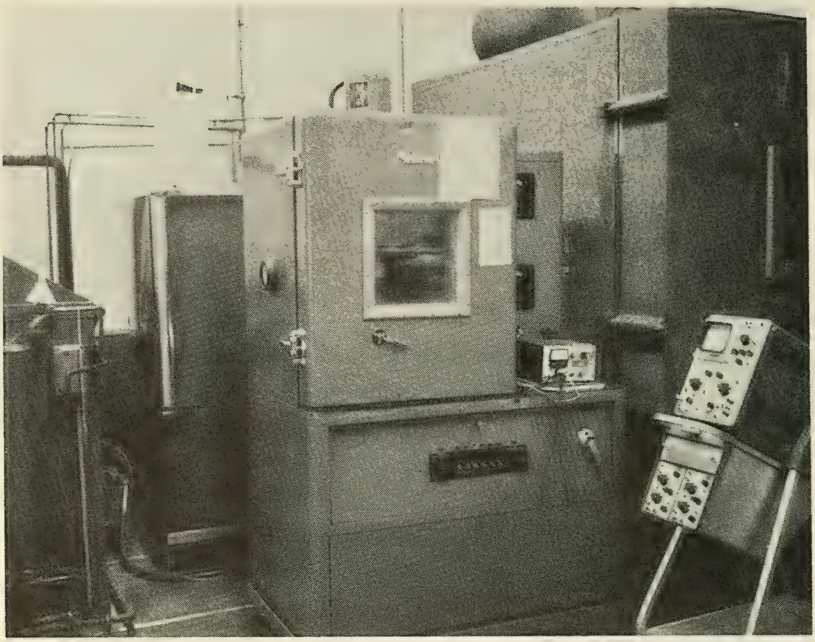
Since its formation in 1963, the Oceanographic Instrumentation Center, Washington D. C. has been engaged in solving instrumentation problems of importance to Navy laboratories and to other government, academic, and industrial laboratories. The Center carries out three major functions: testing, development, and field services.

The testing program is designed to determine performance of oceanographic instruments and related devices. New facilities which allow for the laboratory simulation of the ocean environment have been acquired. Typical of these facilities are large water baths in which temperature and pressure may be varied in a manner similar to the deep ocean. Salinity chambers and salt spray baths test the effect of the saline quality of ocean water on instruments and equipment. A flume which simulates ocean water flow from 0.01 to 5.00 knots is a recent acquisition. The information gathered from this test program is available to all government,

---

*Navy laboratories and activities and their addresses are listed in Appendix A.

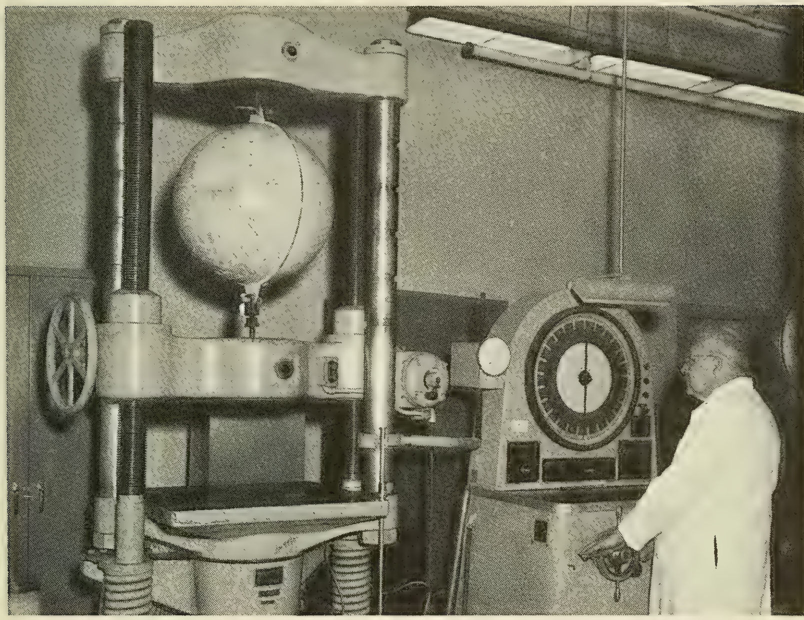
†Facilities in this context refers to particular pieces of hardware or equipment.



Environmental chamber used for simulating various temperature and humidity conditions. The chamber size is 17½ in. high, 19½ in. wide, 18 in. deep. The controlled temperature range is -30°F to 250°F, with a regulation of ±2°F. Relative humidity can be controlled in the range of 20 to 95 percent.

academic, and industrial laboratories. This information has made a significant contribution to the development of such devices as the expendable bathythermograph, self-contained current meters, precision graphic recorders, and a number of other oceanographic devices. In addition, a great wealth of information has been assembled and distributed regarding the performance of off-the-shelf oceanographic instruments. This information is distributed through the Instrument Fact Sheets which are sent to over 2000 users in government, industry, and institutes. There is continuing, unanimous, and enthusiastic comment from users about the importance of and the need to expand this program.

The development program has for the most part been directed toward systems engineering the data collection process on oceanographic survey ships and related platforms, such as the shipboard survey systems that are installed on the USNS SILAS BENT and the ELISHA KANE. Other development programs which the Center has undertaken are the design and



Tensile-compression tester used to test the strength of oceanographic cables, floats, and associated equipment

fabrication of an optical reader and converter for ocean current data recorded on film; the adaptation and evaluation of the NASA-developed Interrogation, Recording, and Location System (IRLS) as an oceanographic measurement system; devices to prevent loss of overside instruments; and suitcase-sized, simplified instrument systems for use aboard ships of opportunity.

The field services function is devoted to installing and maintaining a thirty million dollar inventory of oceanographic survey instruments and related equipment for ships under the technical direction of the Commander, Naval Oceanographic Office. The Center operates a service to calibrate reversing thermometers. Thermometers are calibrated on a reimbursable basis for government and civilian activities in the United States as well as for laboratories of other nations. Cooperative programs have been conducted with other U. S. laboratories and with the British National Institute of Oceanography.

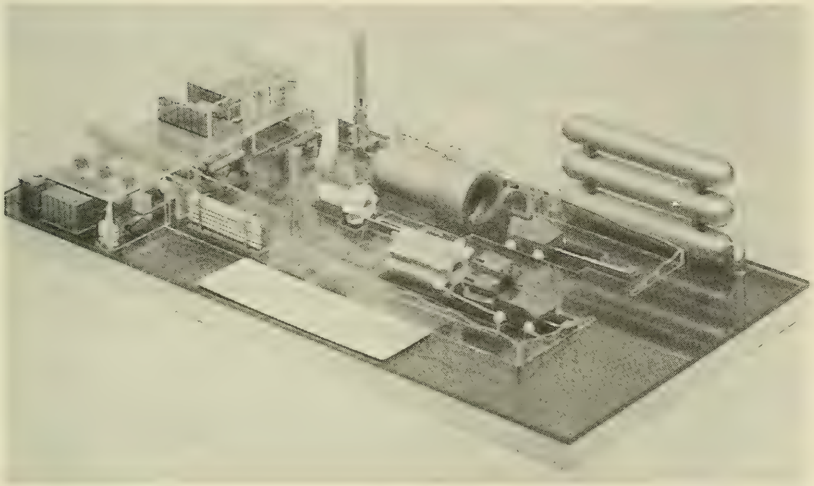
The Oceanographic Instrumentation Center is the Navy's focal point regarding the availability and performance of a wide variety of oceanographic instruments and related equipment. The Navy has proposed that this center become a national center for oceanographic instrumentation. These instruments produce one of the essentials of oceanography: precise, reliable data.

OCEAN PRESSURE LABORATORY

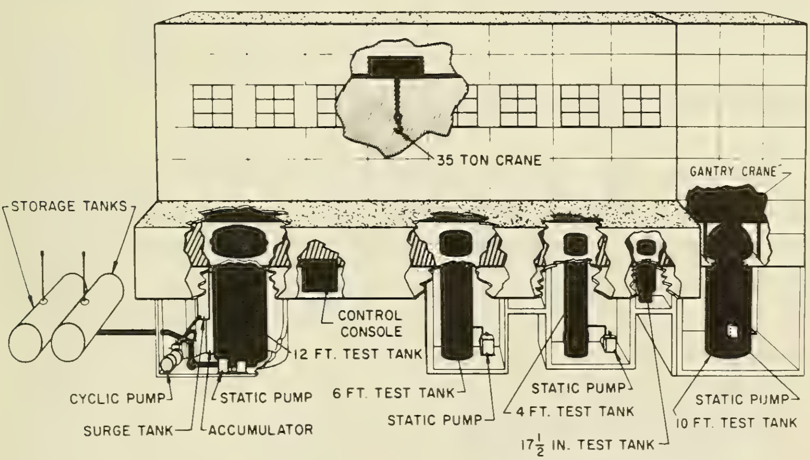
The Navy Ships Research and Development Center, Annapolis Division, Annapolis, Maryland, is in the process of installing the largest and most complete deep-ocean pressure testing complex in the world. This ocean pressure laboratory for research and engineering creates in the laboratory the pressure, temperature, and salinity environment encountered in the depths of the ocean. The pressure laboratory consists basically of three horizontal pressure chambers. It is unique in the combination of pressure-chamber sizes and high-pressure capability. The largest of the three vessels involved forging parts unequaled in size and complexity. The chamber will weigh 750 tons, and its internal diameter will be 10 ft and overall length

Partial List of Navy-Owned Pressure Test Facilities

Name of Facility	Static Operating Pressure (psig)	Static Proof Pressure (psig)	Volume (ft^3)	Inside Length (ft)	Inside Diameter (ft)	Notes
NSRDC Annadiv BLDG 177	1000	1250	7590	40	14	62 penetrations adaptable for either electrical or mechanical use
NSRDC Annadiv 3D-A	12,000	15,000	1990	22	10	7 highly versatile penetrations for both electrical and mechanical use plus 2 hydraulic penetrations
NSRDC Annadiv Bldg. 11 (3)	5000	7500	103	21	2.5	10 electrical penetrations
NASL	3000	4500	295	8	6	7 electrical penetrations 8 viewports, 2 in. dia.
NSRDC Cardiv	15,000	22,500	284	19.7	4	Temp. cycling 0°-90°F 7 electrical penetrations
NSRDC Cardiv 10 ft Tank	10,000	15,000	673	11.17	10	14 electrical penetrations
NSRDC Cardiv 6 ft Tank	6000	9000	673	20	6	Temp. cycling 0°-100°F 7 electrical penetrations
NCEL	5500	8250	360	10	6	6 electrical penetrations 1 viewport, 4 in. dia.
APL Penn State Univ. #1	16,000	24,000	266	15.5	5	2 electrical penetrations
Portsmouth Naval Shipyard	578	750	46,000	45	30	175 electrical penetrations
USN Submarine Medical Center Groton, Conn. Pressure-Altitude Chamber	135	140	1120	8.96	9	3 electrical penetrations 4 viewpoints, 12 in. dia.



Model of the deep-ocean pressure laboratory under construction at Navy Marine Engineering Laboratory. It will have facilities for testing machinery systems and equipment up to 10 ft in diameter and 17 ft long at pressures corresponding to 30,000 ft ocean depth.



DIAMETER (FT)	THICKNESS (IN)	LENGTH (FT)	OPERATING PRESSURE (PSI)
[illegible]*	[illegible]	[illegible]	[illegible]
6*	[illegible]	[illegible]	[illegible]
4*	[illegible]	[illegible]	[illegible]
1-1/2	[illegible]	-	[illegible]
10	[illegible]	[illegible]	[illegible]
*AVAILABLE FOR BOTH STATIC AND CYCLIC TESTS			

Deep-submergence test pressure complex at Navy Ship Research and Development Center, Carderock, Maryland

27 ft. Its static pressure capability will be 12,000 psi, equivalent to 27,000 ft depth. This pressure can be attained in two hours. It will be able to take most of the present generation of small submersibles intact, and the pressure hulls of larger vehicles. This chamber's cycling capability will be 4000 psi, at one cycle per minute.

A medium tank will have an inside diameter of 4 ft and an overall length of 12 ft. It will have the same static-pressure capability of 12,000 psi, but will be able to achieve this pressure in nine minutes instead of two hours. Cycle pressure and time ranges will be the same as those of the large chamber.

Still in the design stage is the superpressure tank. With dimensions the same as the medium tank, its pressure limit will be 26,000 psi. The cycling limit will be 10,000 psi, at one cycle.

All of the vessels will have closures that are quick opening. Each will contain inside the tank a 500-channel digital data-acquisition system and a closed-circuit TV to monitor the test item.

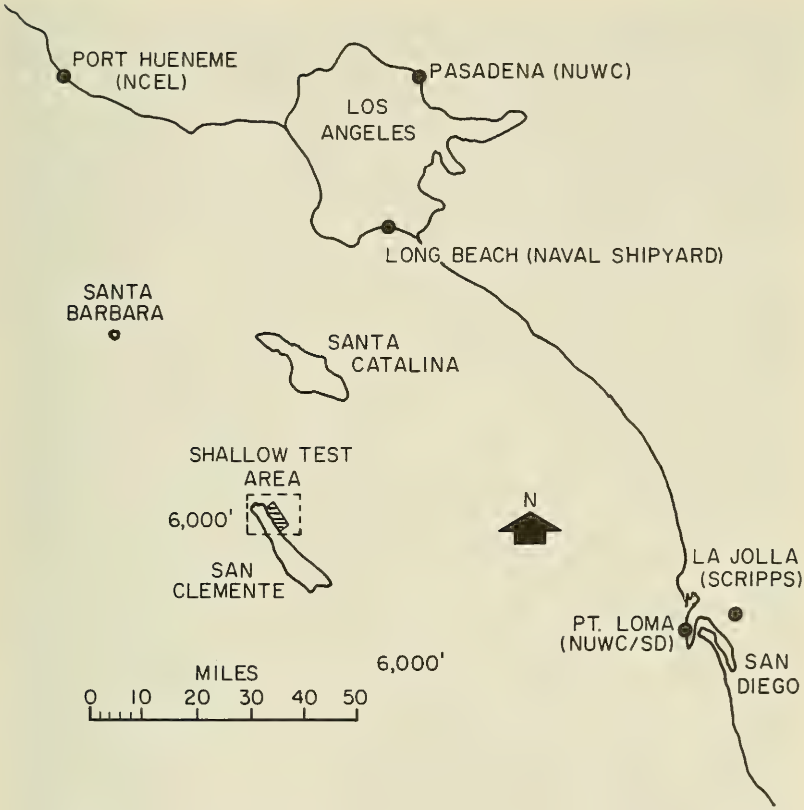
A survey has been completed of all government agencies and activities interested in the ocean environment in order to obtain information for coordination scheduling and efficient utilization of the facility.

OCEAN ENGINEERING TEST FACILITY

The Ocean Engineering Test Facility has been established on San Clemente Island off the southern California coast. The Test Facility is operated by the Naval Undersea Warfare Center, Pasadena, California.

For the entire spectrum of national undersea technology effort, it is important to have facilities where the equipment being developed can be tested in the actual sea environment. Many pieces of equipment which work well in the laboratory or in a pressure-test facility fail to operate properly when they are placed in the corrosive, hostile, and relatively unknown environment associated with the depths of the sea. Marine life starts to grow on delicate sensors, electronic cells are set up between different metals, with the sea water serving as an excellent electrolyte, and equipment performance degrades due to marked changes in pressure, temperature, and salinity with depth.

It is anticipated that this facility will be open to the scientific and technological communities, public and private. Users will be expected to pay a prorated share of operating costs and depreciation.



Channel Island area ocean engineering test facility. For the entire spectrum of national undersea technology effort, public and private, the Channel Islands are ideally situated for actual sea environmental testing of equipment being developed. The Channel Island test facility offers favorable weather conditions, support available from naval activities, a range of ocean depth easily available, and a general clarity of the water.

This geographic location provides a wide variety of ocean depths and bottom conditions. Six thousand foot depths are available in several locations, while depths in excess of 12,000 ft can be found 50 to 60 miles southwest of San Clemente Island. The island is within 65 miles of Los Angeles and San Diego, is convenient to the Navy fleet, Navy laboratories, and industrial and oceanographic complexes of the area. Facilities available on the island include an airplane runway, berthing and messing, communications, and a 550-ft-long pier. Scheduled airline flights are available daily to the island.

The primary test area for ocean engineering experiments is a four-by-five-mile area located off the eastern side of the island. This is the area where the full-scale Polaris underwater launch tests are conducted, and where tests on the Navy's new Poseidon missile are being run.

In this test area, graduated depths down to 4000 ft are available. A bottom-mounted, two-dimensional underwater positioning system has been installed, which is composed of precisely located navigation transponders which can be used to track submerged objects and evaluate the accuracy of vehicle sensors. In addition, portable underwater television and photographic equipment can be provided to observe and record test operations. Other tests, primarily for radar equipment, underwater communications, and telemetry, can be conducted in this area or in the generally uninstrumented area on the west side of the island.

Future Sealab experiments are planned for the offshore area commencing in the spring of 1968 with Sealab III.

DEEP OCEAN SIMULATION LABORATORY

The Deep Ocean Simulation Laboratory at the Navy Civil Engineering Laboratory, Port Heuneme, California, has been established to simulate the deep ocean environment in order to investigate the behavior of materials and structural components. The facility consists of six permanently mounted, 9 in. ID, 26 in. long, pressure vessels, one 18 in. ID, 26 in. long, pressure vessel and three portable 9 in. vessels. All vessels have a 20,000 psi safe working capacity and use seawater as the pressurizing medium. The permanently mounted vessels have the capability of varying the temperature from ambient to 0°C and monitoring factors such as salinity and oxygen content. Provisions have been made for optical viewing, internal lighting, and instrumentation connection inside these vessels. Plans for expansion include a 72 in. ID, 120 in. inside length, 5,500 psi pressure vessel for use with sea water.

The Deep Ocean Simulation Laboratory has been used to examine the short and long term hydrostatic effects on structural materials and equipment, such as concrete spherical hull models, acrylic windows, miniature lights, lights and cameras for Sealab III, and buoyancy spheres for the CURV vehicle. A Deep Ocean Test Instrument Placement and Observation System (DOTIPOS) has been designed to assist in situ investigation of the ocean bottom to a 6000 ft depth. Tests will be performed such as in situ vane-shear measurement of bottom soils and long-term settlement behavior of bottom soils.

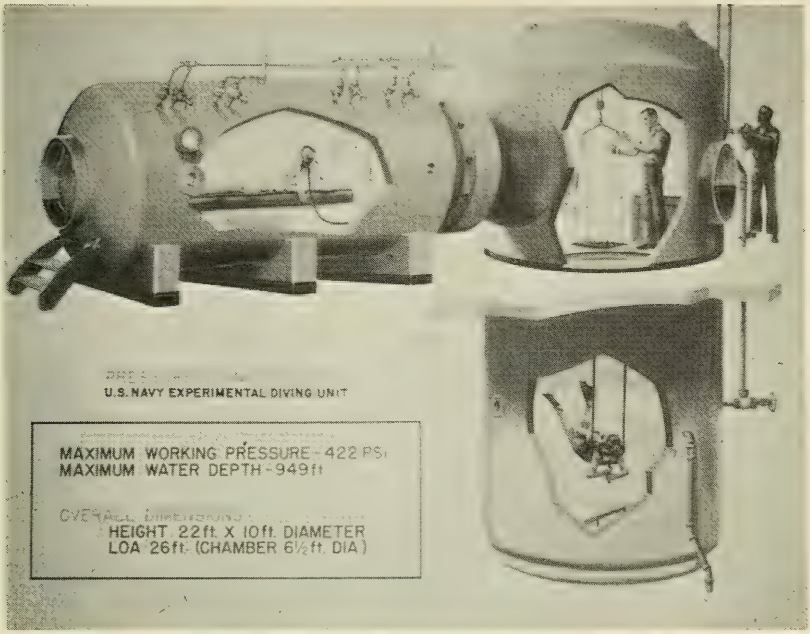
The former Landing Ship Medium (Rocket) ELK RIVER (LSMR-501), which is being modified to serve as the surface-support ship for Sealab III. The support ship, to be redesignated the IX-501, is being lengthened from 203 ft to 225 ft, and will have a center well. In addition, it will be equipped with a 65-ton-capacity traveling gantry crane. Eight-foot sponsons are being added to both sides to provide additional work space and stability. In support of diving operations, the ship will have two Deck Decompression Chambers (DDCs) and two Personnel Transfer Capsules (PTCs). Shown on the deck of the IX-501 are the command and medical vans which will monitor the Sealab III aquanauts.

The Deep Ocean Simulation Laboratory at NCEL, showing six 9-in.-ID pressure vessels and one 18-in.-ID pressure vessel used to simulate the deep-ocean environment. Tanks in the background are for sea water storage.

DOTIPOS consists of a bottom-resting underwater observation, control, data transmission, and power supply system. The bottom-resting part of the system is a support platform to which a TV camera, a photographic camera, a data and command telemetry package, and suitable lights are attached. Provision is made to supply up to 15 kw electrical power to in situ sensors, tools, and other devices which may be needed in support of various studies. The platform is connected by multiconductor coaxial armored cable to a deck console aboard ship from which all control is exercised and through which all data are received.

EXPERIMENTAL DIVING UNIT

The U. S. Navy Experimental Diving Unit, an activity of the Naval Ship Systems Command, Washington, D. C., is charged with the responsibility to perform experimental work in connection with diving and other related matters, conduct development and testing of diving suits, face masks, and associated equipment, and to develop diving methods and procedures. To accomplish this mission the staff consists of medical doctors, engineers and divers.



The Navy Experimental Diving Unit (EDU) test complex. Pressure facilities like these are used in development and testing of diving equipment, diving methods, and procedures.

The present active projects at the Experimental Diving Unit include the technical evaluation of several types of sophisticated scuba, portable air compressors, depth gages, communication equipment, face masks and mouth pieces. In diving physiology, experiments are conducted to determine the proper use of multi-inert gas, synthetic breathing mixtures, to extend knowledge of carbon dioxide elimination, to find more efficient methods of decompressing after exposure to high pressure, and to investigate the means of decompressing after the human body has become completely saturated with inert gas on a very long dive.

The basic equipment used for the work consists of two wet/dry pressure vessels. Each is made up of a water tank approximately ten feet deep with a dry lock on top and facilities for locking personnel into or out of connected recompression chambers. Tanks and chambers have a simulated working depth in salt water of 1000 ft.

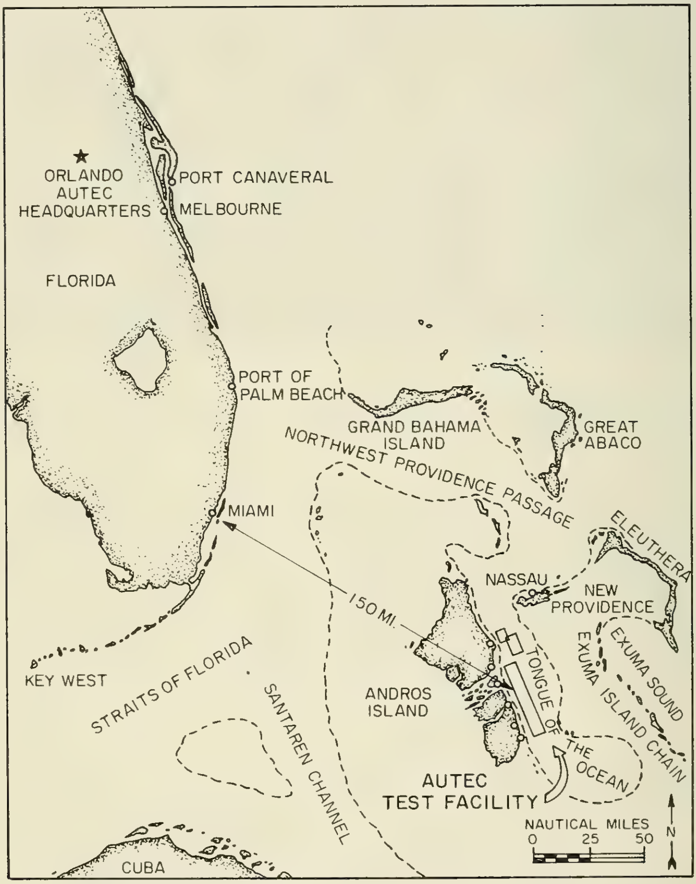
The dive profile in the tank can be made to suit either unsaturated dives or saturated dives. The lengthy decompression times involved in saturated diving require complete logistic facilities for the divers.

287-778 O - 68 - 8

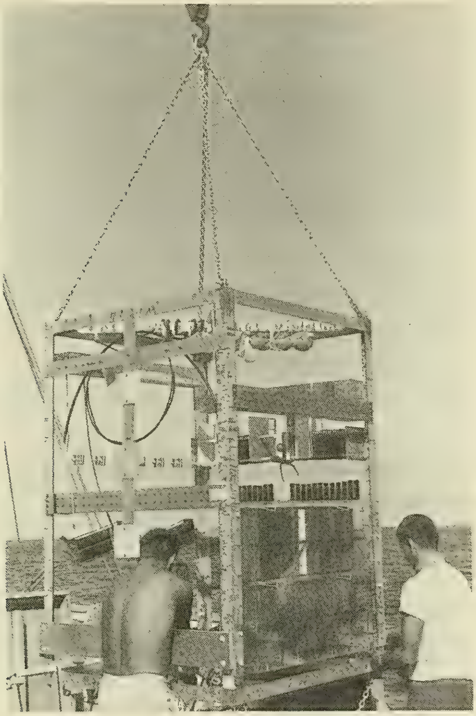
ATLANTIC UNDERSEA TEST AND EVALUATION CENTER

The Atlantic Undersea Test and Evaluation Center has been established with headquarters at West Palm Beach, Florida.

An extensive center which is located at Andros Island, Bahamas, for testing undersea vehicles, weapons, and weapon systems is partially operational, with completion planned for 1970.



Atlantic Undersea Test and Evaluation Center (AUTEC), an extensive center for testing undersea vehicles, weapons, and weapon systems, offers many fringe benefits to the Navy and private industry in ocean engineering and oceanography. The problems of installing and monitoring equipment at depths on the test center will assist in developing ocean engineering techniques. In addition, biological, chemical, fish and many other needed studies in the sea can be conducted at AUTEC.



Plates of structural and machinery materials being mounted on a rack. The rack with plates was submerged in the Tongue of the Ocean (TOTO) off the Miami, Florida coast. TOTO offers mooring depths to 6000 ft. The material plates will remain submerged and exposed to the undersea environment for five years (in some instances longer) and then recovered and tested to determine degradation.

The test center was established to carry out the following functions:

- Perform operational evaluations of advanced undersea weapon systems and components.
- Measure submerged submarine tactical characteristics.
- Measure submarine noise and target strength.
- Calibrate large, low frequency sonar transducers and test sonobuoys.
- Evaluate attack effectiveness of submarines, surface ships, and aircraft in competitive type exercises.

The test center can also provide the Navy with an Atlantic test range capability for oceanographic instrumentation and ocean engineering developments.

OCEAN ENGINEERING AND A NEW INITIATIVE: DEEP OCEAN TECHNOLOGY

OCEAN ENGINEERING AND DEEP SUBMERGENCE

It is obvious that while pursuing national defense objectives, the Navy has an obligation to the national interest in ocean technology. The Navy would like to see its dollars perform double duty in supporting the civilian sector as well as the military. The Navy has accepted the responsibility for helping to develop the undersea technology needed for effective use of the sea in the military, economic, social and political sense. This must be a corporate venture: a science-industry-Navy team. The PSAC oceanography report recommends that the nation's oceanographic activities be supported by the Navy "in discharging its mission of national security through its laboratories and industry and through ONR support of civilian institutions, as well as by its supporting role in the development of undersea technology and provision of national test facilities."* The Navy Ocean Science Program has actively and intensely pursued knowledge of the ocean environment and pioneered the use of manned undersea vehicles.

Knowledge of the ocean environment is not synonymous with ability to exploit this environment. Exploitation depends on man's ability to live and work in the ocean environment. This definition is broad enough to cover ocean engineering in general. Navy ocean engineering is that technology which enables the Navy to operate at any depth, at any time, anywhere in the ocean.

Recent history provides two classic examples of need for a Navy capability in underwater search, rescue, and salvage. The loss of the submarine THRESHER in 1963 occurred beyond collapse depth of the hull and precluded rescue of any personnel. It was, however, in the Navy and national interest to locate the hull to determine if possible the cause of the casualty. THRESHER was located in 8500 ft of water, and much of the hull was photographed by instruments towed from Navy research

*"Effective Use of the Sea," Report of the Panel on Oceanography, President's Science Advisory Committee, The White House, June 1966.

ships and its bathyscaph TRIESTE. This casualty focused national attention on Navy capabilities underwater, and while it showed that much had been accomplished it was determined that more should be done.

The second event was the loss of an unarmed nuclear weapon off the Mediterranean Coast in 1966. This event accentuated the tremendous difficulty of exploring and searching the ocean depths, even though the latest sensors were being employed and services of the then operational United States deep diving vehicles were being utilized. These craft included ALVIN, which located the weapon on the sea floor, Reynolds ALUMINAUT, which located significant pieces of aircraft debris in its underwater search, and the shallow diving Perry CUBMARINE, which located numerous pieces of debris from the aircraft. The weapon was recovered by the unmanned vehicle CURV. CURV is a product of ocean engineering work at the Navy Undersea Warfare Center, Pasadena, California.

In 1966 the Office of the Oceanographer of the Navy was established to provide a better focus for Navy oceanographic programs and to better mobilize our resources within the Navy to face the many challenges ahead. The Deep Submergence Systems Project (DSSP) was established as a separate Project within the Naval Material Command. The DSSP was launched in 1964 to develop and deliver to the fleet new underwater capabilities: a new rescue system, a large object salvage system, diver tools, the techniques of saturated diving for extended operations on the continental shelf, and new submersible vehicles capable of searching the ocean floors.

In development is a rescue vehicle capable of transferring personnel between two fully submerged submarines, the Deep Submergence Rescue Vehicle (DSRV). This vehicle will be delivered to the fleet in 1968-1969. The DSRV will be air transportable and submarine transportable and will be deliverable anywhere in the world.

A large object salvage system will substantially increase recovery capabilities from the continental shelf. Employing saturated diving and other advanced diving techniques and hardware developed during the Sealab experiments, these systems represent a radical improvement in the Navy's continental shelf and deep ocean recovery capability.

The Navy is developing plans for a Deep Submergence Search Vehicle (DSSV) whose mission is ultimately to conduct sea floor search to a depth of 20,000 ft, providing coverage of 98 percent of the worlds oceans.

The NR-1, a small nuclear-powered research and ocean engineering vehicle, is being developed jointly by the Navy and the AEC. The long submerged endurance capability will add a new dimension to ocean engineering and research.

These preceding major development programs are underway in underwater search, rescue and salvage. These programs are of some urgency and are the Navy response to Navy operational requirements, with developments leading to a specific operating capability in a specified time frame.

A NEW INITIATIVE: DEEP OCEAN TECHNOLOGY

The result of a recent Navy study which proposed a plan for the Navy's future role in undersea technology, is the Deep Ocean Technology Program, established in the FY 68 budget request. The Deep Ocean Technology Program is broadly based. The objective of the program is to provide the Navy with a technological base from which options for improving present undersea warfare systems and developing future ones can be selected. Since the ocean technology required to support national security objectives is exactly similar to that required for economic, commercial, and political purposes, this program will also provide a large measure of support to other national objectives.

The Navy is developing a comprehensive program which will identify the ocean technology required to improve the Navy's capability to meet the future threats and fully exploit the potential of the undersea environment. To this end a focal project philosophy has been established to identify and encourage development of the broad range of technologies involved.

The focal project established for the Deep Ocean Technology Program is Seascope, an experimental manned sea floor base. The technologies required to establish this project will support the Navy missions in strategic deterrence, antisubmarine warfare, antishipping warfare, underwater reconnaissance, search, location, rescue and recovery.

The Seascope technologies will provide direct support to many of the other eight program areas selected by the National Council on Marine Resources and Engineering Development for increased emphasis in its first report to the President. These areas include:

- International cooperation
- Food from the sea
- Surveys of mineral resources
- Ocean observation and prediction

As nations undertake major programs in ocean exploration and exploitation, the military role of powers may change. Major changes may be sought in the scope and interpretation of current laws and conventions pertaining to the oceans and their resources. Historically, the presence of effective military power at strategic locations in the oceans has exerted a significant influence on the negotiations to effect such changes.

Factors which could contribute to an international confrontation reresulting from competition in exploitation of petroleum, mineral, and fish resources of the sea are:

- Substantial increase in world population will result in an accelerated resource utilization.
- Increasing industrialization of nations will result in an increase in mineral resource consumption.

The Army Corps of Engineers has requirements relating to the thorough understanding of the near shore environment as it affects beach construction and similar Army activities. The Army and Air Force in the operation of certain test ranges have requirements for acoustic impact and tracking systems and, in some cases, require deep ocean location and recovery capability. The Bureau of Mines is adapting terrestrial drilling and sampling techniques to the waters of the continental shelf, and may be expected to maintain a strong interest in technology which may have impact on undersea mining capabilities.

Beyond supporting specific Navy operational requirements, the Deep Ocean Technology program will support additional national objectives.

- The ocean technology developed to support military requirements in the area of sound scattering in the ocean will also be useful in determining the density, distribution, and migratory patterns of life in the sea. This capability will provide direct support for exploitations of food resources.
- The technology developed for supporting military hydrographic and oceanographic survey requirements are complementary with those required for surveying mineral resources of the sea floor and below.
- Military requirements in support of ocean observation and prediction have and will continue to provide technological spin off to other national interests—commercial shipping, fishing, etc.
- The technology developed to establish a manned one-atmosphere sea floor laboratory will provide options for improving man's use of the shoreline by projecting commercial marine facilities seaward from urban areas.

The Deep Ocean Technology Program is specifically oriented to provide the advanced undersea technology necessary to assure national preeminence in undersea warfare. This technology includes coordinated development of materials, structures, energy conversion, sensors, navigation, communications, machinery, and control, and sea floor engineering.

In fiscal year 1968, the following developments were initiated.

CURV–Development of a 7000 ft unmanned recovery system for locating and recovering objects, surveying and inspecting underwater facilities, and constructing and maintaining underwater facilities.

Tandem Propulsion–A program is underway to design and construct a small submersible utilizing a tandem propulsion system to enhance maneuverability vital to near-bottom operations.

Glass Pressure Hulls–A project has been initiated to utilize the tremendous compressive strength of glass for lightweight deep submersible pressure hulls.

Fully Submerged Electric Drive System–A self-synchronous, brushless motor with dc characteristics will be evaluated under simulated deep-submergence operating conditions.

Fixed Structures–Site surveys and selections of potential sites for the Seascope installation will begin. Structural configurations, and the engineering aspects of the ingress-egress system, will be studied.

The FY 69 program will, in addition to the FY 68 projects, include initiation of other projects identified as directly responsive to defense needs, oriented around the framework of specific experimental systems. These include advanced power sources such as fuel cells and Stirling or Rankine cycle engines, massive glass and high strength metals, unmanned submersible developments based on CURV, and optic/acoustic imaging systems.

* * *

EPILOGUE

The Report of the President's Council on Marine Resources and Engineering Development* noted: "The major challenges which lie ahead of this Nation do not terminate at the water's edge. Neither do the solutions." It is clear then that the Department of Defense will continue to have a major role in developing and implementing the policies which the federal government follows in using the oceans to achieve national objectives. The development of these policies is the responsibility of the federal government in concert with state and local governments as well as the industrial and academic communities.

The Council report further states: "The time is ripe to apply our knowledge of the sea. To be sure there is much that we still do not know—this will always be true—but we know more of the sea than our actions towards exploitation might suggest. The technology is ready—new structural materials, miniaturized electronics, computers, nuclear power, underwater vehicles. These tools await utilization."

The Navy, as the principal agent of the Department of Defense concerned with the oceans, has a strong program which has developed or is developing many of these tools. Certain of these tools, such as nuclear power for propulsion and underwater vehicles, were developed initially for national defense systems, but the technology was then applied to Navy oceanographic problems. The spin off value to the national oceanographic program of developments such as the Deep Submergence Rescue Vehicle, and the nuclear powered research submersible, NR-1, is obvious. Engineering developments such as these take several years and millions of dollars. They come about through the interaction of scientists and engineers, acting in the government—industry—academic milieu. The Navy will continue to share its knowledge and developments such as these with the other participants in the vital and expanding national oceanographic program.

---

*"Marine Science Affairs—A Year of Transition." The First Report of the President to the Congress on Marine Resources and Engineering Development, Feb. 1967.

APPENDIX A

Partial list of Navy and Navy-Supported Organizations concerned with the Navy Ocean Engineering Program

NAVAIR	Commander Naval Air Systems Command Headquarters Washington, D. C. 20360
NAVELEX	Commander Naval Electronic Systems Command HQ Bailey's Crossroads, Virginia 22041
NAVFAC	Commander Naval Facilities Engineering Command HQ Washington, D. C. 20390
NAVORD	Commander Naval Ordnance Systems Command HQ Washington, D. C. 20360
NAVSHIPS	Commander Naval Ship Systems Command Headquarters Washington, D. C. 20360
DSSP	Project Manager Deep Submergence Systems Project 6900 Wisconsin Avenue Chevy Chase, Maryland 20015
OCEANAV	Oceanographer of the Navy The Madison Building 732 N. Washington Street Alexandria, Virginia 22314

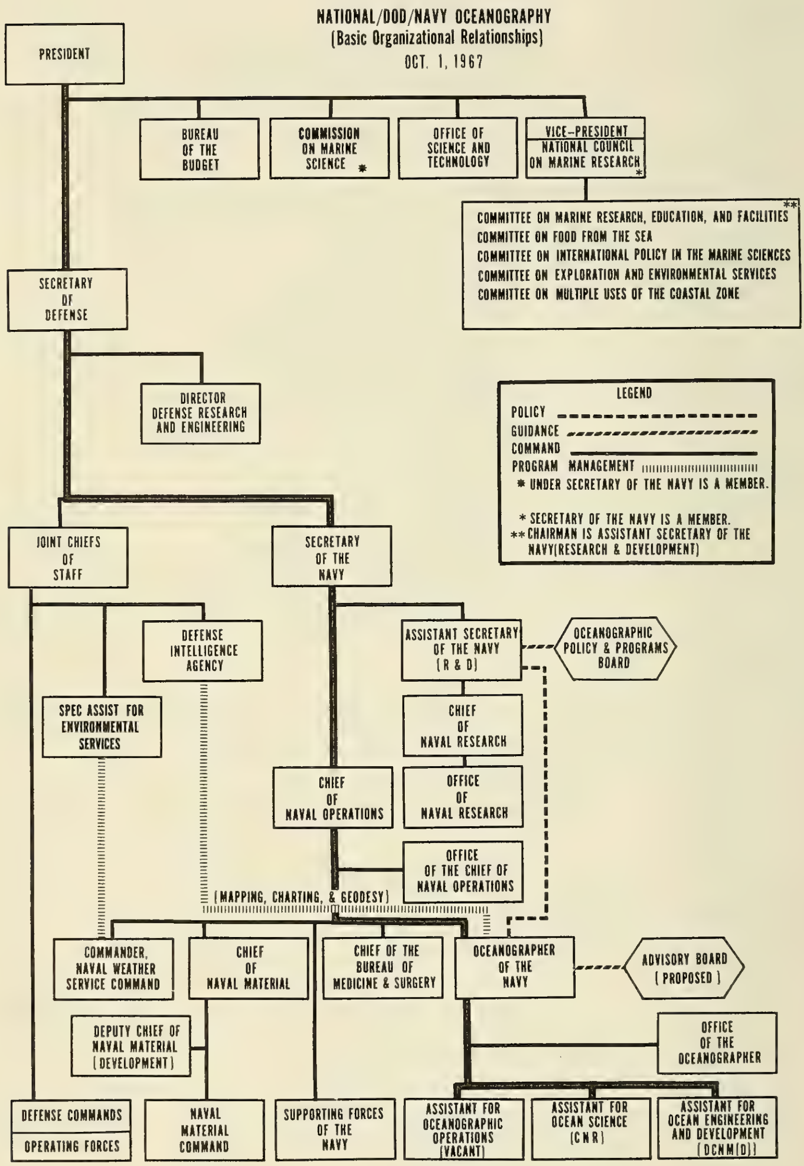
NCCCLC	Commander Naval Command Control Communications Laboratory Center San Diego, California 92152
NSRDC	Commanding Officer and Director Naval Ship Research and Development Center Washington, D. C. 20007
NSRDC/A	Officer in Charge Annapolis Division Naval Ship Research and Development Center Annapolis, Maryland 21402
NMDL	Commanding Officer and Director U. S. Navy Mine Defense Laboratory Panama City, Florida 32402
NADC	Commanding Officer U. S. Naval Air Development Center Johnsville Warminster, Pennsylvania 18974
NOL/WO	Commander U. S. Naval Ordnance Laboratory White Oak Silver Spring, Maryland 20910
NWC	Commander Naval Weapons Center China Lake, California 93555
NWCCL	Commanding Officer Naval Weapons Center Corona Laboratories Corona, California 91720
NUWC	Commander Naval Undersea Warfare Center 3203 E. Foothill Boulevard Pasadena, California 91107

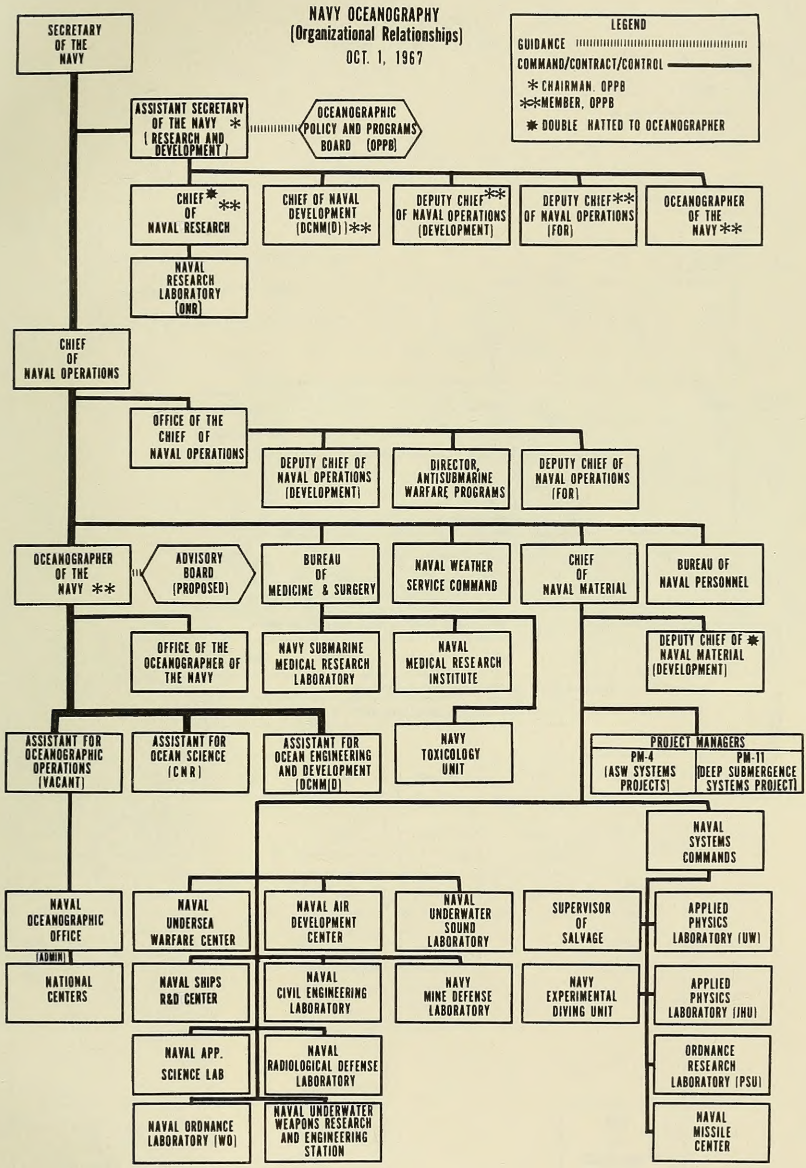
NUWC/SD	Officer in Charge San Diego Division Naval Undersea Warfare Center 271 Catalina Boulevard San Deigo, California 92152
NCEL	Commanding Officer and Director U. S. Naval Civil Engineering Laboratory Port Hueneme, California 93041
NUWRES	Commanding Officer U. S. Naval Underwater Weapons Research and Engineering Station Newport, Rhode Island 02844
NUSL	Commanding Officer and Director U. S. Navy Underwater Sound Laboratory Fort Trumbull New London, Connecticut 06321
NASL	Commanding Officer and Director U. S. Naval Applied Science Laboratory Flushing and Washington Avenues Brooklyn, New York 11251
NRDL	Commanding Officer and Director U. S. Naval Radiological Defense Laboratory San Francisco, California 94135
NATF(SI)	Commanding Officer U. S. Naval Air Test Facility (Ship Installations) U. S. Naval Air Station Lakehurst, New Jersey 08733
NRL	Director Naval Research Laboratory Washington, D. C. 20390

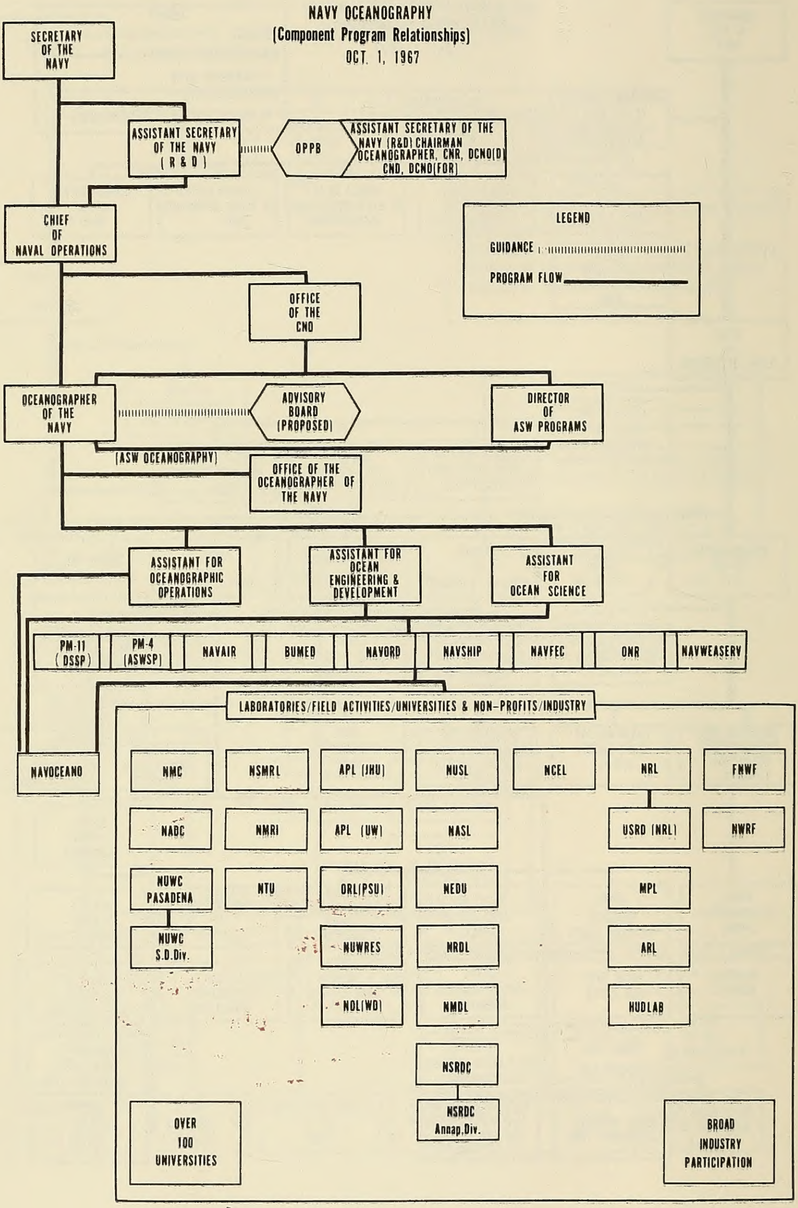
NARL	Director U. S. Naval Arctic Research Laboratory Pt. Barrow, Alaska 99723

Government Owned, Contractor Operated Laboratories

APL/JHU	Director Applied Physics Laboratory Johns Hopkins University 8621 Georgia Avenue Silver Spring, Maryland 20901
APL/UW	Director Applied Physics Laboratory University of Washington 1013 Northeast 40th Street Seattle, Washington 98105
ORL/PSU	Director Ordnance Research Laboratory Pennsylvania State University P. O. Box 30 State College, Pennsylvania 16801


NATIONAL/DOD/NAVY OCEANOGRAPHY
(Basic Organizational Relationships)
OCT. 1, 1967
PRESIDENT
BUREAU OF THE BUDGET
COMMISSION ON MARINE SCIENCE ✱
OFFICE OF SCIENCE AND TECHNOLOGY
VICE-PRESIDENT
NATIONAL COUNCIL ON MARINE RESEARCH *
**
COMMITTEE ON MARINE RESEARCH, EDUCATION, AND FACILITIES
COMMITTEE ON FOOD FROM THE SEA
COMMITTEE ON INTERNATIONAL POLICY IN THE MARINE SCIENCES
COMMITTEE ON EXPLORATION AND ENVIRONMENTAL SERVICES
COMMITTEE ON MULTIPLE USES OF THE COASTAL ZONE
SECRETARY OF DEFENSE
DIRECTOR DEFENSE RESEARCH AND ENGINEERING
LEGEND
POLICY
GUIDANCE
COMMAND
PROGRAM MANAGEMENT
✱ UNDER SECRETARY OF THE NAVY IS A MEMBER.
* SECRETARY OF THE NAVY IS A MEMBER.
** CHAIRMAN IS ASSISTANT SECRETARY OF THE NAVY(RESEARCH & DEVELOPMENT)
JOINT CHIEFS OF STAFF
SECRETARY OF THE NAVY
DEFENSE INTELLIGENCE AGENCY
ASSISTANT SECRETARY OF THE NAVY (R & D)
OCEANOGRAPHIC POLICY & PROGRAMS BOARD
SPEC ASSIST FOR ENVIRONMENTAL SERVICES
CHIEF OF NAVAL RESEARCH
CHIEF OF NAVAL OPERATIONS
OFFICE OF NAVAL RESEARCH
OFFICE OF THE CHIEF OF NAVAL OPERATIONS
(MAPPING, CHARTING, & GEODESY)
COMMANDER, NAVAL WEATHER SERVICE COMMAND
CHIEF OF NAVAL MATERIAL
CHIEF OF THE BUREAU OF MEDICINE & SURGERY
OCEANOGRAPHER OF THE NAVY
ADVISORY BOARD (PROPOSED)
DEPUTY CHIEF OF NAVAL MATERIAL (DEVELOPMENT)
OFFICE OF THE OCEANOGRAPHER
DEFENSE COMMANDS
OPERATING FORCES
NAVAL MATERIAL COMMAND
SUPPORTING FORCES OF THE NAVY
ASSISTANT FOR OCEANOGRAPHIC OPERATIONS (VACANT)
ASSISTANT FOR OCEAN SCIENCE (CNR)
ASSISTANT FOR OCEAN ENGINEERING AND DEVELOPMENT (DCNM(D))


NAVY OCEANOGRAPHY
(Organizational Relationships)
OCT. 1, 1967
LEGEND
GUIDANCE
COMMAND/CONTRACT/CONTROL
* CHAIRMAN, OPPB
** MEMBER, OPPB
✱ DOUBLE HATTED TO OCEANOGRAPHER
SECRETARY OF THE NAVY
ASSISTANT SECRETARY OF THE NAVY * (RESEARCH AND DEVELOPMENT)
OCEANOGRAPHIC POLICY AND PROGRAMS BOARD (OPPB)
CHIEF ✱ ** OF NAVAL RESEARCH
CHIEF OF NAVAL DEVELOPMENT (DCNM(D))**
DEPUTY CHIEF ** OF NAVAL OPERATIONS (DEVELOPMENT)
DEPUTY CHIEF ** OF NAVAL OPERATIONS (FOR)
OCEANOGRAPHER OF THE NAVY **
NAVAL RESEARCH LABORATORY (ONR)
CHIEF OF NAVAL OPERATIONS
OFFICE OF THE CHIEF OF NAVAL OPERATIONS
DEPUTY CHIEF OF NAVAL OPERATIONS (DEVELOPMENT)
DIRECTOR, ANTISUBMARINE WARFARE PROGRAMS
DEPUTY CHIEF OF NAVAL OPERATIONS (FOR)
OCEANOGRAPHER OF THE NAVY **
ADVISORY BOARD (PROPOSED)
BUREAU OF MEDICINE & SURGERY
NAVAL WEATHER SERVICE COMMAND
CHIEF OF NAVAL MATERIAL
BUREAU OF NAVAL PERSONNEL
OFFICE OF THE OCEANOGRAPHER OF THE NAVY
NAVY SUBMARINE MEDICAL RESEARCH LABORATORY
NAVAL MEDICAL RESEARCH INSTITUTE
DEPUTY CHIEF OF ✱ NAVAL MATERIAL (DEVELOPMENT)
ASSISTANT FOR OCEANOGRAPHIC OPERATIONS (VACANT)
ASSISTANT FOR OCEAN SCIENCE (CNR)
ASSISTANT FOR OCEAN ENGINEERING AND DEVELOPMENT (DCNM(D))
NAVY TOXICOLOGY UNIT
PROJECT MANAGERS
PM-4 (ASW SYSTEMS PROJECTS)
PM-11 (DEEP SUBMERGENCE SYSTEMS PROJECT)
NAVAL SYSTEMS COMMANDS
NAVAL OCEANOGRAPHIC OFFICE
(ADMIN)
NATIONAL CENTERS
NAVAL UNDERSEA WARFARE CENTER
NAVAL AIR DEVELOPMENT CENTER
NAVAL UNDERWATER SOUND LABORATORY
SUPERVISOR OF SALVAGE
APPLIED PHYSICS LABORATORY (UW)
NAVAL SHIPS R&D CENTER
NAVAL CIVIL ENGINEERING LABORATORY
NAVY MINE DEFENSE LABORATORY
NAVY EXPERIMENTAL DIVING UNIT
APPLIED PHYSICS LABORATORY (JHU)
NAVAL APP. SCIENCE LAB
NAVAL RADIOLOGICAL DEFENSE LABORATORY
ORDNANCE RESEARCH LABORATORY (PSU)
NAVAL ORDNANCE LABORATORY (WO)
NAVAL UNDERWATER WEAPONS RESEARCH AND ENGINEERING STATION
NAVAL MISSILE CENTER



U. S. GOVERNMENT PRINTING OFFICE : 1968 O - 287-778