U.S. Navy Man in the Sea Program: Fact Sheet

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NUM.2019.012.001

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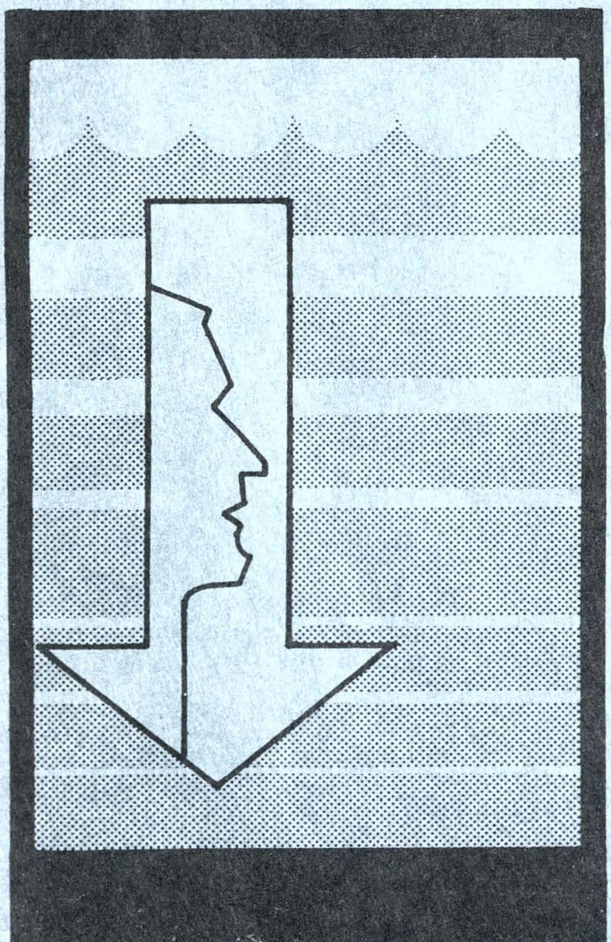
MAN IN THE SEA PROGRAM



FACT SHEET

15 FEBRUARY 1968

U. S. NAVY

MAN-IN-THE-SEA PROGRAM

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MAN-IN-THE-SEA PROGRAM

The Man-in-the-Sea phase of the U. S. Navy's Deep Submergence Systems Project has the purpose of developing the technology and equipment necessary to allow man to live and work in the ocean depths. This capability is required if man is to exploit the enormous economic wealth and military potential of the ocean, especially the continental shelf areas. These shelves are generally considered the offshore regions which slope down to between 600 and 1,000 feet, after which there is a steep drop to considerably greater depths.

This underwater area is alien to man: sunlight and voice communications penetrate only a few hundred feet; artificial lighting, if the equipment can withstand the pressure, penetrates the murky darkness only a few feet; the movement of man or vehicle can further reduce visibility by stirring up bottom mud and sediment; the cold is numbing; and there is abundant marine life known to be dangerous to man.

The U. S. Navy's program to penetrate this "Inner Space" began with laboratory experiments using animals and then human beings, exposing them to prolonged high-pressures and artificial atmospheres. From these laboratory tests came the SEALAB experiments, wherein Navy personnel and specially qualified civilians have lived in underwater habitats and worked and explored in the surrounding water. These in situ experiments, backed up by extensive psychological and engineering studies, are now approaching the point where the ability to work on the ocean floor for extended periods of time will be an operational capability of the U. S. Navy.

The problems facing this effort are formidable. Astronaut Edward White became the first American to emerge in Outer Space when he left his space capsule orbiting more than 100 miles above the earth in June of 1965. Two months later the U. S. Navy's SEALAB II experiment placed an underwater habitat for free-swimming Aquanauts at a depth of 205 feet. Some of the Aquanauts made a brief excursion dive to a depth of some 300 feet -- less than one-tenth of a mile below the surface of the sea.

This comparison of the Astronaut in Outer Space and the Aquanaut in Inner Space demonstrates the bizarre extremes of these programs and man's severely limited ability to enter the sea although he has used the sea for exploration, commerce, food, and war for more than 5,000 years. This use has, until now, been limited essentially to the surface of the sea and man has not ventured very far into the depths without a protective vehicle to withstand the tremendous external pressure encountered in the abyss.

Until recently, man's maximum working depth in the sea was considered to be 380 feet for 30 minutes with "hard-hat" diving equipment. This depth/time limitation is based on the extreme cold, and the accumulation of dissolved gas in the body of a diver, proportional to the depth and duration of his dive.

Diving Physiology

Without proper decompression from depths of the ocean, the diver becomes subject to the painful and sometimes fatal disease known as "bends." This disorder is caused by too sudden a change from high pressure air to ordinary surface pressure. Too rapid a change in pressure will not allow the body to safely eliminate excess gases (such as nitrogen or helium) it has absorbed in the artificial atmosphere at depth. The most common symptoms of decompression sickness are local pains, and to a lesser extent, dizziness, fatigue, shortness of breath, and paralysis. Death can result in severe cases.

Scores of laborers working in tunnel construction and divers were killed or maimed by the disease before the French physiologist Paul Bert discovered its causes in the 1870s and advocated gradual decompression or "recompression." This process provided for a gradual return to the surface. The first recompression chamber -- which simulated changes in air pressure for treating victims of the "bends" -- was installed to aid laborers working on the first Hudson River Tube in New York City in 1893.

As men dived deeper with compressed air, they encountered great difficulties from these gases. Although oxygen is essential to human life, high concentrations can have undesirable effects. To divers the danger from breathing oxygen under pressure is oxygen intoxication, which affects the brain. This intoxication can cause convulsions, which, in turn, can lead to underwater accidents.

Nitrogen narcosis is as dangerous as oxygen poisoning. Under pressure, the nitrogen of compressed air becomes narcotic and interferes with normal mental functioning. The symptoms of this affliction include loss of judgment, a false feeling of well-being, difficulty in performing even minor tasks, and, at great depths, unconsciousness. The nitrogen of compressed air begins to have intoxicating effects at a depth of about 100 feet.

In an effort to solve the problems involved with breathing compressed air in deep-sea diving, the U. S. Navy's Bureau of Construction and Repair, which was responsible for Navy diving operations, and the U. S. Bureau of Mines, which was seeking practical uses for helium, conducted joint experiments with 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's participation in this project was formally designated the U. S. Navy Experimental Diving Unit (EDU) in 1927, and later moved to permanent facilities at the Navy Yard in Washington, D. C. The EDU facility, with its adjacent Deep Sea Divers School, remains the world's principal diving research and training establishment.

The U. S. Navy continued experiments with helium-oxygen gas mixtures for deep-sea diving. In 1938, using a helium-oxygen mix, two Navy divers reached a simulated depth of 531 feet in one of the tanks at EDU.

The experience gained in these dry-land experiments was put to operational use in May of 1939 when the U. S. submarine SQUALUS sank in 243 feet 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 proven far superior to compressed-air breathing.

On the basis of data obtained during the SQUALUS dives, the U. S. Navy established 380 feet as the new limit of 30 minutes on the bottom. Without complications, a dive of this depth/duration requires more than three hours decompression, an unfavorable ratio of working time to decompression of 1:6. This remains the U. S. Navy operational limit for "hard-hat" diving.

Saturation Diving

This unfavorable ratio of decompression to bottom time has been overcome with a technique known as "saturation diving." Saturation diving postulates that the diver should be provided with a habitat on the sea floor which 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. Thus, a diver saturated to 300 feet requires the same decompression time (approximately 2-1/2 days) whether his bottom time is one day or one month.

In the saturated diving situation the diver lives in a chamber or habitat that provides an exit directly to the surrounding ocean environment for work and research. After hours of useful work at depths he returns to the safety and comfort of the underwater habitat. Since there is no appreciable difference between the pressure of the habitat and 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 on a single phase when he returns to the surface after days or weeks of useful work on the ocean bottom.

Saturation diving could also be accomplished with the diver returning to the surface in a pressurized "elevator" and living in a pressurized chamber aboard ship. However, the Man-in-the-Sea concept, with the man living on the ocean floor, provides: (1) independence from surface support, (2) less transit time between chamber and work area, and (3) direct observation of the ocean floor from the living chamber.

The capabilities which saturation diving provide for extended ocean-floor operations will enable the Navy to undertake underwater salvage, construction, search, survey, maintenance, and research tasks heretofore considered impossible for divers.

Project GENESIS

GENESIS was the code name given to the first studies of the effects of saturation diving on man. This project was initiated by Captain George F. Bond, Medical Corps, USN, while he was Assistant Officer-in-Charge of the Naval Medical Research Laboratory at New London, Connecticut, in 1957.

Dr. Bond had become concerned with the prospect of an eventual world shortage of animal protein while in private medical practice in North Carolina. His concern led him to studies of the nutritional and economic potential of the ocean, an interest which continued after he entered the Navy in 1953 and specialized in submarine medicine.

At the Naval Medical Research Laboratory, Dr. Bond's main work was concerned with submarine escape. This in itself required detailed studies of underwater breathing gases and led him to preliminary work in diving time limitations and advanced breathing gas mixtures. Dr. Bond reasoned that if man were to exploit the underwater wealth of the ocean he would have to enter the underwater world and remain there to explore, observe, build, and harvest.

Project GENESIS began during 1957 on a "spare time" basis. GENESIS was selected as the name for the experiments because through them an important step would be taken toward attaining the "dominion over the sea" promised in the first book of the Bible.

The first phases of GENESIS concerned the reactions of laboratory animals to prolonged exposure to high pressure, and to various breathing gases. These Phase A and Phase B experiments took several months during 1957-1958, and involved white rats, guinea pigs, squirrel monkeys, and goats. During the first series of tests the animals breathed a mixture of helium and oxygen at one atmosphere to seven atmospheres of pressure -- the equivalent of a depth of about 200 feet -- for two weeks. The latter tests established that although the test animals could not survive a high pressure of normal air for more than 35 hours, they could tolerate an equivalent exposure to high pressure while breathing a helium-oxygen mixture. The animals lived under these conditions for two weeks without showing any signs of deterioration.

During late 1958, these preliminary studies into saturation diving attracted two other Navy officers to the project, Captain Walter F. Mazzone, Medical Service Corps, USN, and Captain Robert D. Workman, Medical Corps, USN.

Captain Mazzone reported to the Medical Research Laboratory as Training Officer with the collateral duty of Project Officer for GENESIS. Although a veteran submariner, he had no previous diving experience, and for his new billet, attended the Deep Sea Diving School in Washington, D.C., for instruction in diving. (He was probably the first Navy medical administrative officer to undergo such training.)

Captain Workman, a submariner and diver, reported to the Medical Research Laboratory in August 1959 as Assistant Officer-in-Charge.

Studies into saturation diving continued on a "part time" basis. In an effort to obtain the backing for a formal saturation diving program, Dr. Bond submitted "A Proposal for Underwater Research" in which he declared that "new knowledge of inert gas use, and the physiological effects of these gases on man, offers opportunity for development of ecological systems which would permit man, as a free agent, to live and perform useful work to depths of 600 feet, and for periods in excess of 30 days."

After describing the animal experiments, the paper "suggested and requested that the human experimental phase of this ... project be approved." And,

> "Upon completion of the necessary human experimental work, it is believed that operational use of this established human capability might best be effected through development of both mobile and fixed underwater habitations from which scientists, engineers, and military personnel could be routinely deployed in performance of extended underwater tasks, to a depth of 600 feet."

The paper then went on to describe how existing submarines could be modified to provide an underwater, mobile base for Aquanauts and how fixed stations could be established.

The possible uses for a technology developed by these SEALABS would be almost unlimited. Major fields of interest would include marine biology (as the first step toward underwater "farming"), oceanography, deep sea salvage, underwater construction, oil and natural gas exploitation, development of a radiation-free laboratory, and numerous military areas.

The extension of GENESIS to human subjects was not approved.

However, a short time later the Navy's interest in manned space flight called attention to the possible use of a helium-oxygen environment for spacecraft. Additional data on human reactions to a helium-oxygen breathing gas were desired and an extension of GENESIS to provide this data was proposed and approved. Project GENESIS thus became an official Navy program and work continued at flank speed.

Phase C of GENESIS was the first test involving human beings. Two submarine medical officers, Lieutenants John C. Bull, Jr., and Albert P. Fisher, Jr., and a veteran Navy diver, Chief Quartermaster Robert A. Barth (now Warrant Officer) were exposed to a helium-oxygen breathing gas at one atmosphere of pressure for six days late in 1962. The atmosphere consisted essentially of 79% helium and 21% oxygen. Throughout the test period the men were under observation and they were checked continuously for visual acuity, color perception, auditory abilities, voice, and psychomotor phenomena. A complete battery of physiological tests were performed daily.

The ability of the men to talk intelligibly to each other in the helium-oxygen atmosphere was impaired. As had long been recognized, the breathing of helium changes the sound of a person's voice, raising its timbre and creating what is called the "Donald Duck" effect. The subjects in Phase C had difficulty understanding each other's speech during the first two days, but by the fourth day they were able to adapt sufficiently for their colleagues to understand them.

The Phase D experiments of GENESIS were conducted in April of 1963 at the U. S. Navy Experimental Diving Unit in Washington, D. C. This time the subjects were three chief petty officers from New London, Barth (again), Chief Hospital Corpsmen Sanders W. Manning and Raymond R. Lavoie. These men lived in a two-section pressure chamber, breathing a helium-oxygen atmosphere of 6% oxygen, 62% helium and 32% nitrogen for six days.

The chamber at EDU consisted of a "dry" compartment 12 feet long and 6 feet high. This room was linked by a passageway to a cylindrical "wet" room, 10 feet in diameter and 18 feet deep, and partially filled with water. Periodically the men entered the wet room to swim underwater and do special energy-consuming work. The entire EDU chamber was pressurized to three atmospheres, the equivalent of a depth of about 100 feet. The chamber was equipped with a stove and refrigerator, fans to keep the air circulating at a comfortable temperature, and a toilet. Books, magazines, and games were provided to help the men through the six-day stint.

The Phase E test was conducted in August-September 1963 at the Climate-Altitude Chamber at New London. This cylindrical chamber, nine feet long and about seven feet in diameter, can simulate pressures ranging from a depth of 250 feet to an altitude of 200,000 feet, with controlled temperatures, humidity, sound levels, and light levels.

In this phase of GENESIS, three men -- Dr. Bull, Barth, and Manning -- lived at a pressure equal to an ocean depth of 200 feet for 12 days. During this experiment the oxygen content of the test atmosphere was reduced to 3.5% (compared to 21% at sea level) with 79.5% helium and 16% nitrogen.

Once again the test subjects were carefully watched and their condition and reactions were monitored. As in all of the GENESIS tests involving human beings, a medical officer and chamber operators were in continual attendance.

After 11 days in the chamber, at a simulated depth of 200 feet, there was a 27-hour decompression period during which the pressure in the chamber was gradually reduced to the one-atmosphere pressure of the surface. At the end of 12 days the chamber's hatch swung open, and the human "guinea pigs" emerged. They had suffered no ill effects from their prolonged "submergence" and had even gained weight.

The successful Phase E tests completed the laboratory phase of the U. S. Navy's Man-in-the-Sea Program.

SEALAB I

The Navy's first underwater experiment was SEALAB I, conducted from July 20 to July 31, 1964, at a depth of 193 feet.

Putting man into the sea is complicated. Instead of small lab facilities, an underwater experiment requires support divers, a shore base, surface craft, seafloor habitat, diving equipment, etc.

Initial plans for SEALAB I called for four Aquanauts to live on the seafloor at a depth of 200 feet. The Aquanauts -- a term which came into being during GENESIS to designate saturation divers who live in the sea -- were Chief Quartermaster Barth and Senior Chief Hospital Corpsman Manning, veterans of the GENESIS tests and experienced Navy divers; Gunner's Mate First Class Lester E. Anderson, and Lieutenant Robert E. Thompson, Medical Corps, USN.

The site selected was 26 miles off Bermuda in water 193 feet deep, on a portion of the Plantagenet Bank. Adjacent to the Navy's Argus Island (a man-made structure built for sonar research) the site was in warm clear water, and relatively free of storms.

The SEALAB I habitat was constructed from two floats, welded together to form a cigar-shaped chamber 40 feet long and 10 feet in diameter. Two 12-inch portholes were installed on each side of the chamber. Access to the sea was through two manholes in the bottom of the chamber. No intermediate locks were required because the pressure inside the habitat was the same as that of the surrounding water.

End sections of the habitat were fitted to hold water ballast, breathing gas for emergency use, and electrical equipment. Twenty-four feet of "living space" in the center of the habitat was stuffed with bunks, lockers, lab equipment, environment controls, refrigerator, hot plate, oven, food locker, shower, toilet, air conditioning equipment, storage space for SCUBA gear and, of course, the Aquanauts.

Attached to the habitat were various cables for electricity, compressed air and helium, fresh water, telephone, electro-writer, atmosphere sampling line, and a two-channel TV monitoring system. All of these cables terminated on the support ship.

Initial charge of the atmosphere for SEALAB I (80% helium, 16% nitrogen, and 4% oxygen) was pumped into the habitat through the umbilical. Replenishment was accomplished through the stored gas supply.

Surface support for the experiment was provided by a large covered lighter, the YFNB-12. This craft is 260 feet long, 40 feet wide, and equipped to lift large objects. It had accommodations for a crew of 32 plus 30 scientists or technicians.

Also provided was a Submersible Decompression Chamber (SDC) which the Aquanauts used as an elevator. Pressurized to the equivalent of 200 feet, the SDC was also a safety escape chamber and decompression device.

During the experiment, the Aquanauts lived in the artificial atmosphere of the habitat without any special breathing apparatus. While outside working or exploring, they wore the Navy's standard Mark VI semi-closed breathing apparatus. An alternate system was the HOOKAH-ARAWAK system which provided atmosphere from the habitat via an umbilical to the diver. This gave the diver an unlimited supply of breathing gas, although it restricted him to a 100-foot radius of operation. With the Mark VI SCUBA,* the diver had greater freedom, but only 70 minutes of gas supply.

Preliminary testing of the SEALAB I habitat was carried out at the U. S. Navy Mine Defense Laboratory, Panama City, Florida, and in the Gulf of Mexico. Practice lowerings and testings of all umbilicals and systems were also accomplished prior to placing Aquanauts in the seafloor habitat.

On the 18th of July, the habitat arrived off Argus Island, and was attached to the large crane on the tower. Divers removed the habitat floats, and it was lowered to a depth of 62 feet, below the rough air-sea interface, to ride out the night.

On the morning of July 19, 1964, the crane began lowering the habitat into the sea while the gas mixture was pumped into the chamber to avert flooding through its open bottom hatches. At 1:30 p.m., the habitat settled level on the ocean floor at a depth of 193 feet.

The following morning SCUBA support divers went over the side to complete mooring and anchoring the habitat. Dr. Bond and Captain Mazzone entered the SDC and were lowered to a depth of 160 feet. They swam to the habitat for a final inspection, and returned to the surface.

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* SCUBA is an acronym for Self-Contained Underwater Breathing Apparatus. It normally provides free-swimming divers with compressed air from tanks strapped on the diver's back. Compressed air is not used in diving below 150 feet because of the narcotic effect of nitrogen. However, by using a semi-closed, mixed-gas (helium and oxygen) system, the SCUBA principle still allows divers complete freedom at depths to 600 feet for varying periods of time.

Next, the four Aquanauts entered the SDC and were lowered into the sea. At 5:30 p.m. on July 20, they entered the habitat, formally beginning the SEALAB I experiment.

The next morning the Aquanauts checked out communications and controls and undertook other housekeeping chores. They then donned their SCUBA gear and made their first trip into the undersea world outside of the SEALAB. They swam about the immediate area, observing the physical features and marine life on the ocean bottom and making brief sorties around the base of the Argus Island Tower. Underwater visibility was good. When looking up, the Aquanauts could see clearly the hull of the support barge on the ocean surface, almost 200 feet above them. Horizontally, their view extended up to 150 feet.

The men quickly became accustomed to their new home and to the other creatures of the ocean depths. There was a large amount of marine life in the area which occasionally "stampeded" as sharks entered the area. During the experiment the Aquanauts tested a shark-attraction system, but it failed to attract any sharks.

Other projects undertaken by the Aquanauts were placing ultrasonic beacons on the ocean floor, installing current meters, and rigging spotlights for night photography. It was during a photographic mission that Aquanaut Manning almost lost his life.

The accident occurred during the visit to SEALAB I by STAR I, an experimental one-man submersible. The procedure was testing the ability of the Aquanauts to observe the craft's operations and to assist it in landing on a simulated submarine hatch.

Manning's job was to help photograph the event. He had taken about 15 feet of movie film on a 50-foot roll, when he suddenly began feeling lightheaded. Realizing that his SCUBA was not functioning, he swam back to the habitat. (Apparently his gas supply had been cut off, causing him to breathe his own exhalation.) Just as he started to climb up the entranceway, he lost consciousness. Anderson, on watch in the habitat, heard Manning's SCUBA tanks strike the lab as he fell. He investigated and snagged Manning's limp body as it started to drift away. Bringing the corpsman into SEALAB, Anderson had him breathing normally within a minute or so. Dr. Thompson returned and examined Manning. Blood vessels in his eyes had ruptured, turning the whites red, and then black. Kept under close observation, Manning showed no further injuries in his near-fatal accident. It was decided to leave him below, as an active Aquanaut. The experiment continued.

A pressure chamber was used to deliver newspapers, magazines, food, and other items to the Aquanauts. It was also used to transfer various specimens in physiological testing.

Other than an initial slowing in the pace of their activity, the Aquanauts displayed no physical or psychological abnormalities. They seemed to feel a sense of independence from the support vessel, and carried out their tasks as willingly, if slower, as they would on the surface. Man <u>could</u> live on the ocean floor!

On July 31, the eleventh day of SEALAB I, the decision was made to terminate the experiment. The hurricane season was upon them, and a tropical disturbance was reported 700 miles to the South. In the calm, 193 feet below the surface, the Aquanauts went about the chores required to prepare the habitat for return to the surface.

Plans called for the Aquanauts to ride the habitat to the surface, with the habitat serving as their decompression chamber. The crane on Argus Island began the long ascent-lift of SEALAB I. As the habitat neared the surface, rough seas began affecting the chamber, lifting it until the cables went slack, and then dropping it -- whipping the cables to singing tenseness, and putting great strain on the Argus Island crane.

As a safety precaution, at 7:32 a.m. on July 31, the four Aquanauts left the habitat at the 81-foot depth and swam into the SDC. For hours they would have to remain in a vertical position, immobile, cold, and without surface supervision while the habitat was returned to the ocean floor. Finally, at 2:40 p.m. the SDC was raised to the cargo deck of Argus Island, placed in a horizontal position, and the decompression period of 56 hours was completed.

At 8:35 on the morning of August 1, the four Aquanauts stepped out of the SDC into the sunshine. After press briefings, they boarded a helicopter and were flown to the U. S. Air Force hospital at Bermuda for medical tests and special debriefing. All tests indicated the men were in good health. Their habitat was raised to the surface, buoyed, and eventually returned to the Mine Defense Laboratory for use in subsequent Man-in-the-Sea work.

Analysis of the information gathered during the experiment showed some major problem areas: better engineering needed for lowering and raising; lower humidity; helium speech unscrambling; umbilical reliability; communications; swimmer navigation equipment; reliability of equipment in the helium-oxygen atmosphere; and finally, some way to reduce the amount of gear the swimmer has to wear, don and doff, and store in the habitat.

Despite these problems, SEALAB I was a major success. Never before had men worked and lived in the sea at so great a depth for so long. Although cut short by the impending hurricane, the experiment amassed a large amount of physiological data from both instruments and personal experiences.

SEALAB II

Within five months of the completion of SEALAB I, the Navy had established the framework for a second underwater experiment in saturated diving -- SEALAB II.

SEALAB II had three 10-man teams living and working at a depth of 205 feet from August 28 to October 14, 1965, with each team spending 15 days at that depth. An increase in depth was not a primary objective of SEALAB II. More important was the selection of a dark, cold site, close to shore, better physiological monitoring, and greater numbers of men working on the bottom. The site selected was on a ledge of Scripps Marine Canyon near La Jolla, California.

Initial plans called for two teams of ten men, each to spend two weeks on the bottom for a 28-day experiment. However, as the program expanded, plans were changed to provide three 10-man teams. Two of the men would be on two teams, for a total of 28 men taking part in the 45-day experiment. Numbers of men and length of the experiment were increased to handle the additional scientific experiments slated for the Aquanauts to perform.

The two men who spent 30 days at depth were Commander M. Scott Carpenter, USN, on leave of absence to SEALAB II from NASA as team leader for the first two teams, and Lieutenant Robert E. Sonnenburg, Medical Corps, USNR, a physician who was on both the first and third teams. Master Chief Torpedoman's Mate Robert C. Sheats, USN, one of the Navy's master divers, was the leader of the third team.

The other Aquanauts were drawn primarily from the surface support divers of SEALAB I for these men were among the most experienced divers in the Navy. Chief Quartermaster Robert A. Barth, who had taken part in GENESIS and SEALAB I, and ten civilians from Navy activities and the Scripps Institution of Oceanography completed the 28-Aquanaut roster of SEALAB II.

Aquanaut training at the Navy Mine Defense Laboratory, in Panama City, Florida, began officially on April 1, 1965, nearly six months before the experiment. Classroom work included diving physiology and physics, detailed study of the Mark VI breathing apparatus, underwater communications, photography, training with swimmer propulsion units, etc.

After three months at Panama City, the SEALAB crew moved to the Naval Base at Long Beach, California for check-out and commissioning of their new home. The new habitat was a built-for-the-purpose structure, incorporating many lessons learned during SEALAB I. It was 57 feet long and 12 feet in diameter, with "capped" ends and a small "conning tower" which made it resemble a railroad tank car without wheels. It was divided into four areas. The entry area contained the access hatch in the deck, two shower stalls, and swim gear stowage. The laboratory area included communication equipment, test gear, gas monitoring equipment, and work space. The galley area came next, with the final area the living and eating space, containing five double level bunks, lockers and a folding table. Eleven large portholes give maximum viewing area for the Aquanauts to observe their surroundings.

The habitat's floor was made of cement (for ballast) with heating cables imbedded in the cement because of the high heat loss in a helium-oxygen atmosphere. (There were also variable water ballast tanks in the overhead, and the conning tower was free flooding). This, then, was the habitat for SEALAB II. The final touches included the addition of a protective anti-shark cage near the entrance hatch, and installation of external stowage racks for 24 gas bottles.

Appreciating the problems caused by the lack of an adequate surface support ship in SEALAB I, plus the desire to provide an improved system to decompress the divers, a staging vessel used in POLARIS missile "pop-up" tests was obtained for SEALAB II. This vessel was actually two YC barges, each 110 feet long and 34 feet wide, spaced 22 feet apart and connected by a covered structure to form a U-shaped vessel. Existing facilities in the craft included galley, dining and storage spaces; electric power generators; winches; air compressors; and a 50-ton capacity crane. For use in SEALAB II a portion of the missile bay was enclosed to provide a diver ready room and the remainder of the bay was used for installation of a ten-man Deck Decompression Chamber (DDC). This DDC would enable a ten-man team to be brought to the surface in a pressurized Personnel Transfer Capsule (PTC) which would "mate" with the DDC for the continuous decompression aboard the surface support ship.

Two vans were also installed on the support vessel to serve as a command center. Additional communication gear, mooring line tensioning devices, breathing gas storage, and other special equipment were brought aboard.

Thus refitted, the craft was renamed BERKONE for Joe Berkich of the Naval Undersea Warfare Center at Pasadena, California, which controlled the Navy's underwater test facilities off California, and for Captain Walter Mazzone, the SEALAB II physiological Control Officer.

Connecting the BERKONE and SEALAB II habitat would be a PTC "elevator"; a pressurized dumbwaiter to transfer food, mail, and equipment; and an umbilical.

While on the bottom the habitat would be provided with electrical power and water through lines from the Scripps Institution pier; umbilical cable from the support ship would provide breathing gas, communications, and instrumentation lines. The shipboard umbilical would also be a secondary source of electrical power.

The distance from the Naval Shipyard at Long Beach to the SEALAB II site off La Jolla is 92 miles. The habitat was taken in tow at a speed of almost three knots by the Navy salvage ship GEAR and arrived at the site on August 21. The habitat's gas lines were connected to the support barge BERKONE and, on August 26, the habitat submerged beneath the waters off La Jolla. The habitat was held at a depth of 60 feet for an inspection. Some of the sealed ports were developing gas leaks as pressure was being built up inside the habitat. To minimize the gas loss, the habitat was rapidly lowered to the bottom. Upon arrival on the bottom, the structure had a list to port of six degrees and a trim to the stern of six degrees. This position led to the habitat being dubbed the "Tiltin' Hilton" by Aquanauts.

On the morning of August 28, 1965, the ten Aquanauts of the first team donned their SCUBA gear and plunged over the side of the BERKONE to swim down to their ocean floor abode. Inside the habitat the Aquanauts set up house and established communications with the BERKONE. Equipment which had been lashed down for the tow and submerging of the habitat was set up and tested. Then a radio link was established with the GEMINI space capsule on its orbit of the earth. Aquanaut Scott Carpenter, at 205 feet under the sea, spoke to Astronaut Gordon Cooper, whose space capsule was circling the earth at altitudes from 106 to 217 miles. Conversation was garbled, but Scott did comment that his extra vehicular activity was better than that of GEMINI.

Once the seafloor chamber was reasonably habitable, the Aquanauts devoted their main efforts to the scientific programs and equipment evaluation. This included erection of a strength test platform and tests of torque wrenches, a current meter, underwater weather station and sound range, visual acuity range, target array, water clarity meter, fish cages, homing beacons, external TV cameras, bioluminescence meter, photo and diving lights, bathythermograph, and other specialized equipment.

Daily physiological examinations of the Aquanauts were conducted. Samples of their breath, blood, urine, and saliva were sent to the surface in a pressurized dumbwaiter each day for detailed study.

In addition, the daily "housekeeping" chores performed by the Aquanauts included repairing diving lights, adapting equipment to the list and trim of the habitat, replacing leaky valves, cooking, cleaning up, repairing pumps and gauges, and maintaining SCUBA equipment. Before and after each dive, strength and manual dexterity tests were performed in the water. Each evening there were daily activity and mood check lists, and occasionally "brain teasers" and arithmetic tests to determine possible effect of the high pressure, helium-oxygen atmosphere on higher thought processes.

Excursions into the water outside of the habitat were made with Mark VI SCUBA equipment, with the Aquanauts breathing a helium-oxygen mix carried in back-tanks or provided through an umbilical to the habitat (an improved HOOKAH-ARAWAK system). Initially the HOOKAH-ARAWAK rigs were used as a secondary or backup system to the Mark VI, but more and more emphasis was placed on the hose system as the experiment progressed.

The gas mixture breathed by the Aquanauts in SEALAB II consisted of 77% to 79% helium, 18% nitrogen, and 3% to 5% oxygen. Lithium hydroxide was used to remove carbon dioxide from the air and charcoal was used to remove odors.

On the 16th day of the operation, September 12, nine members of Team 1 were brought to the surface in the Personnel Transfer Capsule. The PTC was hoisted aboard the BERKONE and mated directly to the Deck Decompression Chamber, allowing the Aquanauts to enter the DDC without being exposed to surface atmosphere. Nine other

Aquanauts descended into the depths to join Scott Carpenter in the habitat, the Aquanaut/Astronaut having remained on the bottom to serve also as leader of Team 2.

During this exchange of personnel Carpenter was stung on the finger by a scorpion fish. The creature's venom caused Carpenter's arm to swell to several times its normal size and provided a real test of the effects of drugs in a pressurized, helium-oxygen atmosphere. Recovery was complete within 24 hours.

The second team of Aquanauts conducted tests with Tuffy, a porpoise trained to respond to sound signals, to determine whether such an animal could be useful to men in the sea. Initially Tuffy did not respond as expected, probably because of his new surroundings and the noise from the surface support ship. However, he was soon giving excellent performances, making several dives from the surface to 205 feet, delivering mail, tools, and messages.

In another test, Tuffy carried a guideline from the habitat to an Aquanaut who was signalling that he was in need of assistance. On his longest dive the air-breathing porpoise stayed below for 4-1/2 minutes.

Team 2 also conducted tests of electrically-heated wet suits, powered by batteries (worn by the Aquanauts in lieu of weighted belts) or by an umbilical from the habitat. The suits generally extended the Aquanauts' endurance from one hour to about two hours in the 50-degree water. However, the suits were not totally successful. Although the greatest danger to the Aquanauts was being forced to the surface which, in their saturated condition, would be fatal, they were able to descend several atmospheres without ill effects.

While Team 3 was on the bottom, a radio link was established with the CONSHELF III experiment of Frenchman Jacques-Yves Cousteau, which was being conducted with four men at the depth of 328 feet off Nice, France, using saturation diving techniques. U. S. Aquanauts Robert Sheats and Richard Grigg talked with the CONSHELF Oceanauts Cousteau and Andre Laban. This SEALAB-to-CONSHELF conversation, carried on halfway around the world, presages a time when scientists in seafloor laboratories would compare data and exchange information as they conduct related experiments in the ocean depths.

Finally, the Aquanauts in Team 3 prepared their habitat for the return to the surface. On October 10, the Aquanauts came to the surface in the PTC and began decompression. On October 12, the members of Team 3 emerged from the BERKONE's DDC into the earth's atmosphere. Two days later the habitat was raised from the ocean floor and prepared for towing to Long Beach. SEALAB II was completed.

Upon return to the surface, each team of Aquanauts required 31 to 35 hours of decompression. Scott Carpenter's 30-day stint required no additional "desaturation." One diver did develop a case of the bends and remained in the decompression chamber for an additional 12 hours. Exhaustive tests of the Aquanauts revealed no immediate, discernible psychological or physical ill effects after the experiment. Changes that were apparent in measured physiological functions were of a mild, transitory nature and returned to pre-dive levels immediately after the experiment.

Measurements of work performance revealed some decrease in exertive strength, manual dexterity, and two-hand coordination while in the seafloor environment. But there was no change between pre-dive mental tests and those conducted during the experiment.

SEALAB II was a severe challenge to the individual Aquanauts. The water was cold and visibility was poor; the work schedule, requiring long hours of preparation, was often interrupted, delayed or revised; communications were difficult because of the helium-speech distortion; sleep was difficult because of the work schedule. Life in general was made more difficult due to the high humidity inside the habitat.

Meeting and accepting these challenges only added to the overall success of the SEALAB II experiment. The 28 Navy men and civilians spent more than 450 man-days on the ocean bottom. Not only did these Aquanauts live underwater, but they conducted a multitude of physiological experiments and underwater work tasks in salvage, oceanography, geology and construction. More than 400 man-hours of useful work were conducted outside of the habitat. The experiment proved that:

- Reasonably large groups of men were able to live from 15 to 30 days at a depth of 205 feet, have a degree of autonomy, accomplish useful work, be safely decompressed, and show no adverse physical or psychological effects.
- Excursion or "bounce" dives to three atmospheres below habitat living depths were successful.
- There was a significant degree of diver adaptation to cold water.
- Adequate protection against cold water was obtained for extended periods of time by the use of heated suits. (Swimmers without supplemental heated suits were limited to less than one hour of useful work in waters 47^{o} to 54^{o}F.)
- Improved tools and techniques for the ocean environment showed promise for the accomplishment of salvage tasks and other undersea work.
- Porpoises can be extremely useful to Man-in-the-Sea operations to depths of 250 feet, and even deeper with training.

- Ocean floor living offers a new and important methodology to scientific, biological and geological investigations of the ocean bottom.

- A great amount of effort went into SEALAB II, involving naval activities, scientific institutions, commercial organizations, and most important, individuals. The reaction of the participants to SEALAB II can best be summed up in the words of one of the Aquanauts:

> "That was the hardest I have ever worked in my life. And it is the busiest I have ever been. I would go back right now. I didn't want to come up."

Toward SEALAB III

The Navy's third open-ocean experiment in the Man-in-the-Sea program will be conducted during 1968 off San Clemente Island, California. This area is being developed as an in situ Ocean Engineering Test Range for environmental tests and evaluation of deep submergence/ocean engineering vehicles, equipment and techniques.

As part of the test range facilities the World War II built landing ship ELK RIVER has been converted to serve as a range support ship. The ELK RIVER (IX-501) is 225 feet long, has diesel propulsion, is especially configured to provide a stable working platform, and has a center well which can be opened to lower equipment into the sea. To support DSSP programs, the ship is being fitted with a 65-ton-capacity travelling gantry crane, two Deck Decompression Chambers, and two Personnel Transfer Capsules. Each DDC can normally accommodate four men for prolonged decompression. The PTCs can be mated directly to the DDCs to prevent exposing Aquanauts to surface atmosphere before proper decompression. This diving system -- designated Mark II -- is the prototype of a new Fleet system which will greatly enhance Navy underwater capabilities.

During Man-in-the-Sea work, two portable vans, one a command center and one a medical monitoring facility, will be mounted on the IX-501's main deck. These adjoining vans will bring together in one location all of the critical measurements and controls affecting the safety and well-being of the Aquanauts. The inputs to the vans will be provided by an umbilical cable between the ship and habitat. The cable will also carry water, breathing gas, television transmissions, electrical power, and recording signals.

In the SEALAB III experiment, five or six teams of eight Navy and civilian Aquanauts successively will live in the seafloor habitat for 12-day periods. At this time, plans provide for the habitat to be placed at a depth of 600 feet.

The Aquanauts, who participate in SEALAB III, will include Navy personnel, civilian scientists, and technicians from Navy facilities. Experiments, as presently planned, include extensive physiological testing, foam-in-salvage work, underwater construction, marine biology, geology, sonic work, and evaluation of thermal protection. In conjunction with the latter, the Aquanauts will wear three 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. In addition, a prototype radioisotopic heating device which is worn by the Aquanauts, will also be tested.

During excursions from the habitat, the Aquanauts will use the new Mark VIII SCUBA equipment which is provided with breathing gas through the umbilical cables to the habitat. The gas is forced through these umbilicals from high-pressure, mixed-gas storage tanks. Back tanks of 90-cubic-foot capacity will be carried by the Aquanauts to provide a secondary "come-home" gas supply. In addition to mixed gas, the umbilicals will carry an oxygen partial pressure sensor, paired cables for electricity for lights, communications, and heating. Two 600-foot umbilicals and four 200-foot umbilicals will be provided.

The Personnel Transfer Capsule (PTC) will be used both as a transfer capsule and pressure elevator, enabling the Aquanauts to be shifted topside for decompression. Multiple PTC/DDC arrangements will be available on the support ship.

The SEALAB III habitat will be the same as used in SEALAB II with certain modifications. Most significant is the addition of two rooms, each 8 feet by 12 feet, 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 bunk room.) 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. Also, the location of showers in the diving station will reduce the humidity in the living room.

At the 600 foot level the atmosphere is composed of 95% helium, 3-1/2% nitrogen, and 1-1/2% oxygen. A device known as a "scrubber" using lithium-hydroxide, will purge deadly carbon dioxide from the atmosphere; charcoal will be used to remove odors. Additional apparatus will remove carbon monoxide and other dangerous hydrocarbon contaminants. Electrical dehumidifiers will control the humidity in the habitat and heat will be provided by convection heaters and by a radiant heating array imbedded in the cement flooring. The habitat temperature will be maintained at about 88°F, the high temperature being required because of the great amount of body heat loss in a helium environment.

The 60-day or longer SEALAB III experiment, with five or six teams totalling 36 Navy men and 12 civilians living on the seafloor for 12-day periods, will be the most ambitious Man-in-the-Sea project ever undertaken. As is the case with all pioneering operations, future programs must depend upon results of this significant experiment.

The Future of Man-in-the-Sea

The Navy's operational requirements to provide a capability for extended swimmer operations at continental-shelf depths have led to the current goal of 850 feet for an operational saturation diving system. Studies are now being conducted to determine advanced goals and missions for the Navy's Man-in-the-Sea program.

Technologists and equipment will undoubtedly be developed to enable man to perform useful work at greater depths unless (1) definite and insurmountable physiological or behavioral phenomena limit the Aquanaut's ability to go deeper, or (2) there is a clear prediction of persistently unfavorable cost effectiveness in comparison with other concepts for accomplishing required missions at advanced depths.

Ultimately, hardware being developed in the Man-in-the-Sea program will produce operational seafloor habitats which are totally independent of surface support once placed on the ocean bottom. This facility will provide for all-weather, even under-ice operations on the ocean floor. There will also be "semi-mobile" habitats -- crawler or submarine-like vehicles which will enable Aquanauts to range over a relatively wide area of the ocean floor, to pass through a hatch into the ambient water, perform useful work and return to the habitat without decompression. During the mobile habitat's return to surface atmosphere the entire crew could be decompressed.

The possible applications of an extended-duration Man-in-the-Sea capability tend to stress credulity. Beyond the large number of military missions which are apparent are the national-interest projects which, because of the Navy's capabilities in saturation diving, will certainly lead to various combinations of Navy, scientific, and industrial organizations becoming engaged in seafloor operations.

It appears certain that by 1970 man will have developed the technology necessary to work at a depth of 1,000 feet. Although most of the world's protein resources, organic and mineral riches of the oceans, are to be found on the continental shelf, it is unlikely that man will be content to stop if he can develop the capability of diving below this 30 atmosphere level. Below 1,500 feet, helium can probably no longer be used as the inert gas in the Aquanaut's breathing mix since it too becomes narcotic at this depth. The only other inert gas which could then be used is hydrogen, since this gas is theoretically less narcotic than any known inert gas. Ironically, a hydrogen-oxygen breathing gas was used in experimental dives to 14 atmospheres some two decades ago by Zetterström but with fatal results, due to tender error. If such a breathing gas can be developed for practical use, the physical properties of hydrogen might also lead to reduced decompression time for saturation diving. (There would be no danger of explosion from the hydrogen in such a breathing gas because of the extremely low oxygen content.)

Beyond these depths some contend that it is possible, although not necessarily probable, that man may dive freely to 10,000 feet and deeper for brief periods. Man swimming at these depths would breathe an oxygenerated liquid, which would be pumped directly into his windpipe and lungs. Although the practicality of man walking the abyssal plains is a matter for discussion, man's traditional drive to discover new worlds will unquestionably take him farther and farther into Inner Space.

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APPENDIX A

SEALAB I AQUANAUTS

Robert E. Thompson, Lieutenant, MC, USN
Lester E. Anderson, Gunner's Mate First Class, USN
Robert A. Barth, Chief Quartermaster, USN
Sanders W. Manning, Chief Hospital Corpsman, USN

SEALAB II AQUANAUTS

Team 1

M. Scott Carpenter, Commander, USN (also Team 2)
Robert E. Sonnenburg, Lieutenant, MC, USNR (also Team 3)
Berry L. Cannon (Navy Mine Defense Laboratory)
Thomas A. Clarke (Scripps Institution of Oceanography)
Billie L. Coffman, Torpedoman's Mate First Class, USN
Wilbur H. Eaton, Gunner's Mate First Class, USN
Frederick J. Johler, Chief Engineman, USN
Earl "A" Murray (Scripps Institution of Oceanography)
Cyril J. Tuckfield, Chief Engineman, USN
Jay D. Skidmore, Chief Photographer's Mate, USN

Team 2

Robert A. Barth, Chief Quartermaster, USN
Howard L. Buckner, Chief Steelworker, USN
Kenneth J. Conda, Torpedoman's Mate First Class, USN
George B. Dowling (Navy Mine Defense Laboratory)
Arthur O. Flechsig (Scripps Institution of Oceanography)
John F. Reaves, Photographer's Mate First Class, USN
William H. Tolbert (Navy Mine Defense Laboratory)
Glen L. Iley, Chief Hospital Corpsman, USN
Wallace T. Jenkins (Navy Mine Defense Laboratory)

Team 3

Robert C. Sheats, Master Chief Torpedoman's Mate, USN
William J. Bunton (Navy Electronics Laboratory)
Charles M. Coggeshall, Chief Gunner's Mate, USN
Richard Grigg (Scripps Institution of Oceanography)
John J. Lyons, Engineman First Class, USN
William D. Meeks, Boatswain's Mate First Class, USN
Lavern R. Meiskey, Chief Shipfitter, USN
John M. Wells (Scripps Institution of Oceanography)
Paul A. Wells, Chief Mineman, USN

APPENDIX B

DEEP SUBMERGENCE SYSTEMS PROJECT

The U. S. Navy's Man-in-the-Sea program is managed by the Deep Submergence Systems Project (DSSP). The DSSP organization was conceived in the wake of the THRESHER tragedy. After the loss of the nuclear-powered submarine THRESHER on April 11, 1963, the Secretary of the Navy established a Deep Submergence Systems Review Group to analyze naval capabilities in the deep ocean environment, especially in regard to search, submarine rescue, and salvage, and if necessary, to recommend changes in Navy operational capabilities and future plans.

Led by Rear Admiral E. C. Stephan, USN (Retired), formerly Oceanographer of the Navy, the Review Group reported its conclusions in February of 1964. The Review Group recommended that the Navy:

> "Develop the equipment and knowledge required for man to perform useful work down to 600 feet (600 feet has been adopted by the study group as the maximum depth of the continental shelf, although it is recognized that the shelf is deeper in a few locations). This requires physiological and medical research, with particular emphasis on decompression techniques, development of improved power tools, divers dress, and operating techniques, and equipping and operating a diving research ship (and) extended duration of habitation and useful work periods on the ocean bottom in depths below those of the continental shelf."

The Secretary of the Navy accepted the report of the Deep Submergence Systems Review Group on May 28, 1964, and established the Deep Submergence Systems Project (DSSP) under the management of the Director, Special Projects Office. The Special Projects Office, charged with the development of the POLARIS (and later POSEIDON) Fleet Ballistic Missile system, contained some of the best management and technical engineering personnel in the U. S. Navy.

In addition to the Man-in-the-Sea program, DSSP was assigned responsibility for managing the Navy's efforts in other areas of deep-ocean work including:

- Submarine location, escape and rescue
- Object location and small object recovery
- Large object salvage
- Development of the nuclear-powered, ocean engineering and research vehicle NR-1

The increasing scope of these programs coupled with increasing demands being made on the Special Projects Office by the POLARIS and POSEIDON systems, the United Kingdom's POLARIS program, and projected programs relating to the fleet ballistic missile, led to the establishment of DSSP as a separate Navy activity on February 9, 1966. At that time SEALAB I and SEALAB II had been completed, helping to give DSSP wide public and government interest.

The Project Manager of the Deep Submergence Systems Project reports directly to the Chief of Naval Material who, in turn, reports to the Chief of Naval Operations. Although not a part of any of the Navy system commands (formerly called technical bureau), DSSP does receive administrative support from the Naval Ship Systems Command (formerly Bureau of Ships).

Within DSSP an Ocean Engineering Branch has been established to manage the Navy's Man-in-the-Sea program and the Large Object Salvage System, the latter being a primary application of saturation diving technology.

The DSSP Office is located in Chevy Chase, Maryland, just outside of Washington, D.C. In addition, a DSSP Technical Office has been established at San Diego, California, to serve as the home port and training facility for Navy Aquanauts. The Technical Office also provides engineering, research, testing, and technical services for specific Navy requirements outside of the Man-in-the-Sea program.