Advanced Biotechnology for Underwater Operations

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Within the past two decades we have witnessed an upsurge in the universal interest in the oceans. This results from the sophistication of submarines, the development of small diving vehicles and increased diving activities by commercial, military, and sportsmen groups. In the development of the undersea vehicle and of new diving techniques, the biotechnological requirements for these must be continuously brought up to date and resolved. New submarines are underwater from 50 to 75 days, and their environmental problems both in relation to biomedical sciences and behavioral sciences are continually being evaluated for the safety and well-being of submarine personnel. New diving techniques require extensive hyperbaric chamber testing, especially in respect to those dives of a saturation nature and at great depth.

THE Sea, or as some call it, "inner space," is now the "in thing" and is giving space flight a stiff run for popular interest. Those who like to prognosticate speak of the oceans with great variance of opinion. To some, it is loaded with good things, there for the taking. To those of a more practical nature, the problems to be solved in technical design and expensive construction are the more prominent factors involved in our "conquering of inner space." Not the least of these factors are those of a biological nature, trying to fit man into an environment for which he has long ago lost his adaptation.

The airplane and submarine had much in common. They came into being as operational devices at about the same time in history. For many years they were both confined to a limited environment, the airplane to the denser part of the Earth's atmosphere and the submarine to relatively short, shallow dives beneath the sea.

A little over a decade ago, both vehicles became far more versatile. The realm of the airplane, now actually the spaceship, extended into space with the development of rocket propulsion.

The submarine finally became a true submarine with the introduction of nuclear power. Coincidentally with the development of the true submarine and the great expansion of its capabilities, the continental shelf became of interest to to the Navy and oceanographic scientists with the development of small deep-diving vehicles and the so-called habitats.† Commercial interest also developed in the sea bottom primarily for its oil resources, thus stimulating great interest and activity in commercial diving as a necessary adjunct to undersea oil drilling. At the same time, civilian interest in scuba diving became nationwide.

It is obvious, then, that within the past decade and a half we have witnessed a renaissance insofar as universal interest in the oceans is concerned. The factors involved may be briefly classified as: 1) the development of the true submarine with greatly increased ability to remain submerged and with unlimited range; 2) the development of both fixed and free habitations for underwater scientific investigation; 3) the stimulus to commercial utilization of diving procedures and equipment; and 4) the great increase in public interest in scuba diving. Each of these specific areas of undersea work have developed their attendant biomedical problems, which are far from resolved and need a great deal of further investigation.

Before continuing the main theme of this paper, some discussion should be made relative to the many small utilitarian-research vehicles that have been built largely by the aerospace industries in an anticipated upsurge of underwater activity. There are at least thirty vehicles now in existence that have various capabilities of moderate-to-deep observation, exploration, retrieval of objects, and oceanographic study. Unfortunately, the anticipated wide use of these vehicles has not developed and only a few of them have been used in significant underwater work.

This type of vehicle constitutes no major biomedical problem, inasmuch as most of them are constructed for relatively short-term underwater exposures. Categorically, the author assumes the need for this type of vehicle as basic and classifies that need as follows: 1) swimmer transport, 2) underwater search and rescue, 3) retrieval of lost objects, 4) underwater exploration, and 5) oceanographic observation and research.

The following is a brief discussion of the capabilities and accomplishments of some of these small vehicles beginning with the Trieste, which dove to the sea bed at 33,000 ft in 1960 and established the fact that marine life, and therefore oxygen, is present at this depth. Deep Quest, a research submarine, descended to 8310 ft; Alvin is a highly maneuverable research submarine with a depth capability of 6000 ft; Aluminant has 2 articulated manipulators and can operate to 15,000 ft carrying seven men; Deepstar 4000 is a saucer with a spherical shell that can dive to 4000 ft; and *SP3000* with two manipulators can descend to 9500 ft. The French Argyrouste is a combination submarine and habitation. It is, in effect, a self-propelled pressurized habitation in which the divers do not concern themselves with the actual operation and maintenance of the vehicle. The most interesting of the latest deep-diving vehicles in use is the Ben Franklin, which floated submerged for 800 miles in the Gulf stream from Florida to Cape Cod in 2½ months with 6 observers aboard at depths down to 800 ft. Many oceanographic observations of value were made. There is no doubt that the small submersible has and will serve a definite purpose in the development of ways and means of exploring and understanding the oceans.

The advancement of the oceanographic frontier is augmented also by the development and utility of underwater habitations. The underwater habitation as an entity has

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† This is a misnomer. Webster unabridged 1969 calls a "habitat" a place where a species normally lives and a "habitation" where it is presently living. Therefoıe, undersea dwellings should be called "habitations" for humans, inasmuch as these structures are certainly not a place where the species normally lives.

evolved largely from the desire of man to explore and exploit the continental shelves. These underwater land masses surround the continents from a few miles to several hundred and comprise over 11 million square miles of land submerged to a depth of 600 ft or less. The fringes of the continental shelves have been harvested for thousands of years for shells, pearls, seaweed, and sponges, first by free divers and later, in the case of sponge and pearl divers, in the hard hat and rubber suit mode. With the advent of underwater geological survey and the development of undersea oil fields with their attendant construction, interest in providing more economical means of working underwater developed. Since standard hard hat diving required many hours of decompression time compared to the actual work time on the bottom, the concept of saturation diving with men living and working at great depths in the saturated state came into being.

Over the past decade significant strides have been made in the development of saturation diving as a mode and the underwater habitation as a working device.

The U.S. Navy took an early interest in living in the sea on the continental shelf. In 1956, E. A. Link started work on his Submersible Decompression Chamber (SDC). Studies on saturation diving were made at the Submarine Medical Research Laboratory by G. F. Bond and others to assist in this project. In 1962 Link kept one man in his SDC at 200 ft for 24 hr in the saturated state. This was known as the "Man in the Sea" project. In 1964 two men were submerged in another vehicle of Link's called the Submerged, Portable, Inflatible Dwelling (SPID) at 432 ft for 49 hr in the "Man in the Sea" program. In this dive, R. D. Workman provided meaningful professional assistance. Subsequently, Workman's experiments in saturation diving provided the backbone of existing knowledge.

In 1964, the U.S. Navy in Sea Lab I kept four men living and working at 192 ft for 11 days. In 1965 in Sea Lab II, 28 men were maintained at 205 ft for 15- and 30-day periods. Sea Lab III, a most elaborately prepared project, was to be launched last year, but has had considerable delay based on a personnel casualty.

Coincidentally with the U.S. Navy's work, Jacques Cousteau conducted his Conshelf projects. In 1962, Conshelf-I contained two men at 35 ft for seven days. In 1963 Conshelf-2 kept five men underwater for 30 days at 33 ft and two men for 7 days at 85 ft. In 1963 Conshelf-3 housed six men for 22 days at 330 ft.

In 1968 the Office of Naval Research and the U.S. Department of Commerce conducted its Tektite-I experiment in the Virgin Islands. This was a twin-cylindered habitation in 50 ft of water in which four men remained underwater working and living in their habitation for 60 days. Because of the minor depth and the fact that the habitation was serviced from the shore, little of biomedical significance was recorded. Of interest, however, in a medical view, was the prevailing external ear infections caused by pseudomonas invasion. Skin infections that were expected to be a problem did not develop to any great extent. The project, insofar as the Bureau of Fisheries and other oceanologists are concerned, was a resounding success.

At present, Tektite II is underway. The same habitation is being utilized at a depth of 100 ft, utilizing teams of divers covering a 90-day period.

Considering the subject of deep sea test vehicles, the work conducted in the land-based, high-pressure chambers must also be taken into account. Several laboratories with chamber capabilities for simulated deep diving to 1000 ft or more have been conducting saturation diving tests. It is indicated that saturation diving to 1000 ft is possible if not currently feasible. The Naval Submarine Medical Research Laboratory will have a 2000 ft depth equivalent chamber installed within its confines in the next 18 months. This device should provide a means of exploring the problems attendant on diving at great depths.

A. Biomedical Problems in Submersibles and Diving

In the overview of the biomedical research needs of submarine and diving medicine, one is immediately faced with the fact that these occupations are in the throes of a rapid change in configuration and operational capabilities. Until recent years, the fields of submarine and diving medicine have been closely associated yet separate sciences. The recent developments of nuclear power and saturation diving are rapidly bridging the gap between these two disciplines and a mutual development in both fields has become apparent.

Since the development of useable nuclear power for propulsion of submarines, this vehicle has become, as stated before, a true submersible. Currently, a routine submergence of two months' duration is commonplace. Further, the depth limitations of submarine operation has been extended considerably in recent years. Coincidentally, the rapid expanding interest in exploration of the ocean floor has lead to the need for new and improved diving techniques, the most noteworthy of which has been the development of saturation diving. This technique is rapidly gaining recognition as the only feasible means for useful work at deep depths. Many of the problems associated with this new technique have been recognized and are currently under study; however, there are others which remain to be identified and solved.

It is quite reasonable to predict that there will be an extension of routine military underwater operations. These may take on the character of patrols as currently employed, or in combination with saturation diving, and we may well see the development of submarines that have the capacity to lock divers in and out. During the time the divers are aboard the ship they will be maintained at an ambient pressure equivalent to the depth at which they are expected to perform in the water. The submarine then becomes a vehicle with two entirely separate environments, one operating at one atmosphere pressure while the other operates at ambient sea pressure. The necessity to understand the effects of these artificial environments becomes paramount. It is also within the realm of possibility dictated by operational requirement that undersea stationary or roving habitations, located as permanent installations or roving to meet other craft or divers in rendezvous, are in the not too distant future. As a consequence, the category of submarine and diving medicine is discussed in the following operational categories.

1. Conventional Type of Submersible

This is conceived as the present-day attack submarine in which the gross environment tolerances are fairly well resolved. A problem exists, however, in the fact that this type of vessel will become longer ranging, deeper diving, and capable of dives of much longer duration than at present. Taken together, these facts necessitate greater research effort toward problems related to atmospheric contaminants, increased concentration of contaminants, greater concentrations of CO_2, and more sophisticated environmental control systems.

2. The Variable Atmospheric Pressure Environment Submersible

This submarine will undoubtedly be capable of long-term underwater exposure at great depth. It will have compartments which will have the capability of varying the contained atmospheric environments both in total pressure and partial pressure of the component gases. Some compartments will be accessible both from the sea and from the operating spaces of the submarine. This type of submarine will require intensified study in the biomedical aspects of saturation pressure at deep levels on men in these submarine compartments and divers in vehicles having access to the "mother" submarine.

Further biomedical problems envisioned are more sophisticated environmental control requirements, improved decompression patterns, effects of the combinations of breathing gas pressures, effects of higher concentration of trace contaminants, long-term effects of pressure on living tissue, effects of circadian rhythms, long-term confinement effects, and a clearer understanding of the possible psychophysioligical effects of polarization of atmospheric ions.

3. Stationary and Roving Undersea Habitations

These devices possibly will be used as fixed observation stations or as exploratory devices. They will present all of the problems of submarine and diving medicine in their future requirements as found in categories 1 and 2. In addition, many of these will be located at a not too great depth, within a reasonable distance from the shore. The biomedical problems of the long-term, fixed environments will necessarily be intensified in the stationary habitations which will need to cope also with the multiplicity of problems arising from the occupation of a small, bottom-searching, deep diving, roving vehicle which will have the capability of allowing divers egress and entry.

4. Diving Medicine, Free and Ancillary to Submersible Operations

This operation, as discussed in the preceding categories, assumes the application of the concept that divers aboard a submarine have opportunities for free egress and ingress to the vessel at any accessible depth and under most operational circumstances. The problems here are primarily of a diving nature, involving great depths, cold, saturation diving, mixed gas use, and decompression sickness.

Recapitulating (the biomedical research responsibility in the categories discussed previously), the required stimulation of research rests in the following areas: 1) the direct effects of pressure on living tissue; 2) the alteration of breathing mixture under increased ambient pressure; 3) the alteration of toxicological effects of contaminants or normal metabolites; 4) a better understanding of decompression sickness, the normal physiology of decompression sickness, and the normal physiology of decompressing tissue; 5) the effect of thermal changes on tissue at increased ambient pressure; 6) the improved methods of providing thermal comfort under these conditions; 7) the prolonged effects of recurrent and chronic exposure to increased ambient pressure; 8) improved methods of treatment of decompression sickness at increasing pressure; 9) improvement in the provision of greater mobility and communication; and 10) the psychological effects of prolonged isolation at increased ambient pressure.

The operational implications in extended and increased depth of research and development in submarine and diving medicine are obvious. They should result in greater capability and safety in underwater personnel and an assurance of maximum protection of the short- and long-range health of the Naval personnel engaged in these operations. The capability of the submersibles and undersea habitations will only be qualified by the condition of the men that man them.

B. Infectious Disease Patterns and Epidemiological Control in Submersible Operations

For several years the evaluation of infectious microbiological exposure of submarine personnel on extended patrol has been an intermittent, nonprogramed study in the Submarine Medical Center. The studies have been conducted by submarine medical officers afloat.

At present, several epidemiological studies are being conduced aboard Polaris submarines. These studies were proposed by the submarine medical officers of the vessels involved and the protocol was reviewed and approved by the Submarine Medical Center. The investigators have had help in planning their studies from the professional staff of the Submarine Medical Research Laboratory.

It is planned to review the over-all epidemiological aspects of the Submarine Navy in general. After a panoramic requirement for this program is established, specific areas will be mapped out on the basis of expediency for the onboard study of capable medical officers. It is anticipated that a programed and planned approach to this problem will be a great help in the establishment of therapeutic and preventive medical procedures to reduce the incidence of infectious disease among embarked submarine personnel.

The operational implications of this study lie in the likelihood that these data will result in a reduction in the incidence of infectious diseases, thereby enhancing the over-all effectiveness of submarine crews. This epidemiological information will be applicable to all underwater habitations and vehicles.

C. Longitudinal Health Study of Submarine and Diving Personnel

The Bureau of Medicine and Surgery of the U.S. Navy approved a Longitudinal Health Study for underwater environment in 1967.

The organization of the clinical scope of the study establishment of the appropriate methodology, data collection and processing, coordination of participating disciplines, and the problems of subject sampling are at present fairly well in hand. At this time, submarine and diving personnel are being processed through this program.

Knowledge of the involvement of physiologic systems and/or psychologic changes relative to the continuous exposure to the submarine environment will be of great value in correcting the precipitating factors, or controlling the related biological mechanisms. Contributions to medical science relative to the effects of submarine environments and their relation to the aging processes of those so exposed make the operational implications of this study important. The investigation should provide direct, positive results for the health and operating capabilities of submarine and diving personnel.

D. Anthropometric Studies in Submarine and Diving Personnel

The evaluation of anthropometric data relative to submarine and diving personnel has, in the past, been a neglected study area. The Naval Submarine Medical Center has been conducting a program to measure a significant number of submarine personnel for the purpose of securing this anthropometric data. The development of safety equipment for submarine and diving personnel, such as exposure suits, escape suits and other safety gear, as well as a need for human engineering support in the design of equipment wherein the man and machine interface, has clearly demonstrated a need for data of this kind.

A periodically updated anthropometric data bank correlated with modifications in equipment design should result in an optimization of submarine crew effectiveness.

E. Long-Range Predictions of Submarine Safety and Escape

Several different methods of escape from a downed submarine have been used by the U.S. Navy. Individual escape had its beginning with the Momsen Lung, then proceeded to free ascent, followed by buoyant free ascent and finally, the use of the Steinke Hood or the free-breathing, buoyant ascent currently employed by the Submarine Force. The McCann Chamber is the primary system for multi-man escape.

For individual escape, the buoyant-assisted, free-breathing (Steinke) method currently employed has a depth limitation estimated at approximately 600 ft. Although it has been predicted that this system could be used to 600 ft, it has never been tested at that depth. The primary method of escape from a downed submarine remains the McCann Chamber, which has rather marked limitations including the following: a) the chamber must be in the vicinity of the downed submarine; b) it is limited to 800 ft; c) a heavy sea state precludes the use of this chamber; and d) it required that the submarine be nearly level for proper mating. All of the systems currently employed are insufficient for depths between 800 ft and crush depth of the submarine.

There is obviously an urgent need for more advanced methods of escape from downed submarines. The first steps to accomplish this have been taken in the development of the Deep Submersion Rescue Vessel (DSRV), recently contracted by DSSP. In some respects, however, this system has limitations similar to those found in the use of the McCann Chamber. It requires that the DSRV be in the relative vicinity of the downed submarine and required escape allows the DSRV to be transported to the site. Therefore, there remains a very real need for individual or multi-man escape from the submarine, independent of surface support. These methods are currently being investigated and may undergo further development in the next ten to twenty years. One such system is an individual, self-contained suit such as that employed by the Royal Navy as their routine method of escape. There is also consideration of a one-man life raft and escape suit combination being developed at the Naval Air Development Center. These suits may extend the useful depth; however, there still exists a limitation posed by inert gas narcosis, bends, and oxygen toxicity. Needed also are systematic investigations of various gas mixes for the systems of the future. Other proposed systems of escape have been individual or multi-man capsules which are carried within the submarine and then released. These could operate at either one atmosphere or at increased ambient pressure with release of pressure during the surfacing process.

The operational implications are extension of the operating depths of submarines and lengthening the duration of submerged operations. The existing escape systems are inadequate to meet the present requirements, and therefore, improvements in the existing systems are needed as well as development of entirely new systems in the two decades ahead.

F. Auditory Research in Underwater Operations

The general problem has three aspects: 1) the detection of sonar signals in a very unfavorable noise background, 2) the improvement of the sensory capacities of the human ear when under water, and 3) the interpretation and unscrambling of HeO_2 speech at great depths.

In the matter of sonar signal detection, the reduction of background noise has not yet exploited all the possibilities of phase cancellation with multiple microphones or hydrophones having highly directional phase characteristics. Hydrophone arrays which phase out background noise should be explored. The higher the frequency, the more precise the localization; therefore, techniques which shift the human ear one or two octaves upward, or render the higher tones more audible (as with decreased mass in the conductive system, or by electronic frequency shifting), or reduce the masking effect of lower frequencies, would improve all orientation and navigation problems using the human ear. Behavioral techniques have recently been developed whereby animals such as the turtle, bat, monkey, porpoise, etc., are trained to respond in specific ways to acoustic cues. In some of these species, the ear far outperforms the human ear. Possibly we can look forward to a much more integral partnership. Turtles, for example, could signal a human footstep at a great distance. The otter can search underwater as effectively as any other species and can telemeter specific information to a handler, or to a sound-producing torpedo decoy at a great distance, to cite a few possibilities.

The loss of clarity of speech in divers at great depths when breathing HeO_2 under pressure is an important investigative problem at this date. The development of helium speech unscramblers is the present approach to this problem.

Acoustic information impinges on the human ear in all operations, with a bewildering complexity. Problems include 1) the interpretation of faint sounds and 2) the vigilant surveillance of large amounts of information in complex weapons systems. There is vast room for improvement in all these operations.

Computer-assisted instruction (CAI) is now beginning to offer ways to teach the meaningfulness of sounds. Auditory theory can now predict the precise direction from which a sound comes; moreover, cues of interaural time disparity, frequency, phase, and intensity differences can now be integrated, thus allowing for the construction of a rational artificial head for use in auditory investigations. Auditory vigilance research is in its infancy. In forecasting the state of the art, it may be stated that 1) CAI in auditory training should immediately be expanded to underwater activities; 2) artificial heads should be designed to train TV cameras, gun mounts, etc., toward the source of a sound; and 3) EEG pickups from the head, reflecting responses to stimuli impressed regularly to the ear can serve to monitor the altertness of a watchstander and warn of a failure. That is, the outputs of a large number of dials and meters in a complex instrument panel can be compressed into the form of a single complex sound; the operator could note the slightest change in any aspect of this sound, and quickly trouble-shoot on the basis of the auditory cue.

G. Vision with Inadequate Light in Submersibles

Work on physical aids to vision has encompassed both night-time binoculars and more recently, electronic sensors, and electro-optical aids. The latter have been greatly improved in recent years with a considerable reduction in size and bulk.

Electro-optical aids to vision will probably be considerably miniaturized in the future. As such, their potential uses are endless. We can look forward to tiny devices in periscopes and in the windshields of various undersea vehicles. They could also be built into night vision spectacles in diving masks for underwater seeing at depths where little light penetrates or at night with only minimal artificial light sources. A program of research directed toward "field testing" a variety of electro-optical devices under deep-sea conditions, while performing periscope viewing tasks and other operational assignments carried out under minimal lighting conditions, would result in enhanced submarine crew and diver proficiency.

H. Underwater Visual Problems

Underwater adjustment is difficult for a variety of reasons. For one thing, sensory inputs are greatly restricted or distorted, disrupting behavior in a variety of ways. Ways of overcoming these distortions and providing supplementary sensory information will enhance man's ability to operate underwater.

Many physiological changes occurring when man is under abnormally high ambient pressure or confined to a stimulus-invarient environment have been studied rather thoroughly; however, very little emphasis has been placed on the perceptual or psychomotor changes occurring under these conditions. Furthermore, it has not been determined to what extent the effects of these unusual environments can be overcome by training, or by the use of some of the new devices available.

We can expect to see the development of underwater sensors such as TV and sonar to aid individual divers. Too, new communication devices such as lasers and infrared sources used to overcome the scattering effects of the water may soon be a reality. New manipulanda will extend man's ability to work underwater. It will be important to develop ways to monitor and help maintain sensory-motor coordination in an environment which makes it difficult to maintain orientation and accurate perception.

I. Team Performance in Underwater Systems

In present-day submarine and diving systems, there are a variety of ways of assigning operators the responsibility for making decisions or control actions. At one extreme, a system can be manned so that every control and decision agent acts independently, not interacting directly with other crew members. At the other extreme, a team effort may be required in which each individual performs his task and acts as an observer and source of information for all other crew members. The methods selected for organizing the system, transmitting and processing information, and assigning tasks to individuals may be expected to have important consequences for system effectiveness. From a human-engineering-systems-oriented point of view, there is an insufficient knowledge of empirically valid techniques for allocation of functions and for the design of information transmission and processing techniques in multi-man submarine and diving systems.

A research program is underway which is directed toward the development of conceptual models of team interaction relevant to allocation of functions to work stations and systems design and toward the study of team tasks to determine which characteristics of subfunctions are relevant to the decision to combine or separate them. Analysis of information flow between work stations has also been undertaken.

Envisioned for the future are extension of current submarine and diving systems to manned underwater stations and to teams of men and exploratory vehicles disembarking from such stations to explore the ocean depth, to perform salvage and demolition operations, and to service other installations. Future research must be directed toward the optimization of the performance of such underwater systems manned by isolated teams for extended periods of time under stressful and hostile conditions. Present studies of team performance must be extended to determine the effects of such environments upon decision-making and control process as well as upon information processing and transmission techniques. The development of human engineering principles relating to training, systems organization, and systems design is contingent upon such research.

J. Development of Performance Measures Sensitive to Hyperbaric and/or Exotic Gaseous Conditions

Studies have demonstrated that men can survive in helium-oxygen mixes at 25 atm ambient pressure for one to three hours and at 15–18 atm pressure for days. The question arises, however, as to what useful work can be accomplished under those conditions and at what "psychological and physiological cost?"

Substantial data bearing on the question of how arduous a work schedule can be imposed on men under these conditions, and for what duration, are lacking. Similarly lacking are data definitely excluding the possibility of perceptual and cognitive effects which may conceivably adversely affect decision-making and problem-solving capabilities under these conditions.

Valid and reliable methods of measuring performance simulate anticipated performance requirements during periods of deep sea habitation in stationary capsules, as well as in escape and exploratory vehicles, viz., during salvage activities, sea-bottom "mining" oil drilling tasks and other projects. Furthermore, requirements are envisaged for "broad spectrum" performance data banks necessary to assess the feasibility of operating submerged submarine tenders and sea-bottom mooring stations. The result of these studies will have operational implications mainly for personnel management problems, such as personnel and billet classification, and length of task assignments.

K. Determination of Maximum Duration for Submarine Missions

The length of submergence in nulcear submarines is limited primarily by the amount of human accommodations available, and by the limitations of the adjustment potential of the submarine crew members themselves.

Forty-one fleet ballistic missile (FBM) submarines, each with two crews, are now on submerged operating schedules of 50–75 days, with half the ships on station at a given time. Substantive data suggesting maximum duration of FBM cruises are lacking.

Because of the scarcity of submariner volunteers meeting existing aptitude and physical requirements, the selection ratio will remain high, necessitating lengthening the cruise length and/or decreasing crew size and/or reducing submariner qualification criteria and/or reverting to the single crew concept. The most plausible prediction is that the first and last alternatives will become realities. Therefore, a family of studies are indicated to ascertain the submerged duration at which the effects of fatigue, boredom, confinement, and revitalized atmosphere adversely affect individual and crew effectiveness. Coextensive with this general research focus are several additional subareas, namely, 1) evaluations of various approaches for alleviating the stress effects of long submergence (auto-instruction courses, leisure-time activities, applied leadership, etc.); 2) most appropriate work/rest cycles; and 3) manipulation of crew size and rate, and specialty distributions. Estimation of optimal crew size, most efficacious assignment and rotation systems and factors affecting submarine crew cohesiveness constitute some of the operational implications for this research emphasis.

L. Submariner Selection and Retention

In the past decade, circa 5000 enslisted and 350 officers, all volunteers, have constituted the annual U.S. Navy submariner input. Characteristically, over-all retention rate has been of the order of 40% for enlisted and 50% for officers. For critical specialities, e.g., electronics ratings, the retention rate is much lower.

Some of the characteristics identifying career enlisted men and officers across the Navy population as a whole have been delineated. Retention data of this kind are not available for submariners alone. Moreover, comprehensive analytical data needed to estimate aptitude and skill requirements accurately are lacking for jobs in the submarine service.

With respect to electronics specialities, the advent of the transistor and the application of the concepts of micro-circuitry, electronic modules and computerized trouble-shooting techniques have and will continue to effect changes in the skill requirements and their correlate, abilities. Too, the Submarine Integrated Control (SUBIC) concepts promise to become a reality in the future, thus reducing crew size as well as the complexity of the tasks assigned to each crew member.

Taken together, these changes suggest two broad research emphases, viz., 1) studies aimed at attaining the best "fit" of the manpower available to the characteristics of the submarine and 2) achievement of the best design of the submarine to "fit" the characteristics of the existing manpower "pool." Several research foci follow from this reasoning. First, problems related to "matching man to the submarine" suggest: 1) comprehensive studies of the motivational patterns of career submariners (anticipating an era when number of volunteers are insufficient to meet manpower requirements) and 2) assessment of the performance in Submarine School and under operating conditions of the Basic Test Battery Group III's and IV's (below 50th percentile in terms of Navy-wide aptitude norms). Data exists to argue that the retention rates of this population segment, which cuts across lower socioeconomic, racial minority, and less educated groups, is much higher. Secondly, problems related to "fitting the submarine to the man" suggest the following: 1) collaborative job-analytical studies by human factors and personnel assessment specialists to delineate aptitude and skill requirements of the various billets will be needed; [e.g., data is required to determine if the simplification of electronics-related tasks alluded to previously (installing a replacement module to correct equipment failure "diagnosed" by a trouble-shooting computer program) requires 120 I.Q. men who are in short supply and who may be poor retention risks]; 2) human factors studies aimed at integrating and, where possible, simplifying the various processes making up the weapons, control, and atmospheric revitalization systems; and 3) studies focused upon the application of modern simulation and modeling approaches with a view of enhancing simulator fidelity and accelerating training rate and efficiency. Enhanced submarine crew efficiency, optimal utilization of available manpower, and increased efficiency of the submarine subsystems are some of the operational implications of these research approaches.

Before concluding this discussion, some remarks concerning the great popularity of scuba diving with the general public should be made. Professional military and civilian divers are usually well trained, have reliable equipment, and discipline themselves to dive in a safe manner. Although there are many amateur scuba organizations that maintain excellent control over the training and activity of their members, a certain small fraction of enthusiasts exist who, in many cases, have only a vague knowledge of diving, and who perhaps use shoddy equipment in an unskilled manner, thus insisting on drowning themselves. This undoubtedly conforms to the zest for risky living found in a great number of American citizenry since we also have our sky divers, mountain climbers, and stock car racers. It is hoped, however, that greater stringency will develop in public scuba diving in the requirement for reliable equipment and reasonable training before underwater exposure. This may call for some sort of forced training and subsequent licensing program.

In concluding this discussion, it is pointed out that the preceding biotechnical and biomedical forecasts and estimate of research requirements are directed toward the existence of men in the sea, not toward ocean biology per se. There are undoubtedly other biological disciplines whose interests lie in the flora and fauna of the sea and not in man's temporary occupancy. These ocean biologists undoubtedly could add significant scientific oceanic research requirements to this discussion.

It is also pointed out that the opinions, forecasts and estimates of research requirements are those of the author and do not necessarily reflect those of the U.S. Navy.