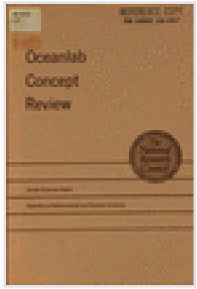

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Oceanlab Concept Review

Report of a Study by a Subcommittee of the
Ocean Sciences Board
Assembly of Mathematical and Physical Sciences
National Research Council

NOAA Oceanlab Steering Committee

NATIONAL ACADEMY OF SCIENCES
Washington, D.C. 1980

NOTICE The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Summary

At the request of the National Oceanic and Atmospheric Administration (NOAA) a panel of the Ocean Sciences Board of the National Research Council, assisted by a number of consultants, has conducted a study and prepared this report relating to the future of the NOAA Oceanlab Program.

TERMS OF REFERENCE

1. Oceanlab was defined as a program to make available facilities to carry out complex undersea observational and manipulative tasks in support of ocean research activities.
2. Emphasis was to be on research of the type normally conducted by academic institutions, although use of the facilities would be open to qualified scientists, irrespective of affiliation.
3. Account was to be taken of the important role played by the man-in-the-sea concept in developing the initial Oceanlab program.

QUESTIONS ADDRESSED

1. Are there sufficient important scientific problems requiring Oceanlab capabilities (as defined in item 1 of the terms of reference)

and sufficient interest among competent scientists in carrying out the implied research to warrant a multimillion dollar program of this type?

2. If the answer to question 1 is affirmative, what general form should such a program have, and what specific management advice could the panel members provide based on their experience with other programs?

CONCLUSIONS

Question 1 was answered in the affirmative. The primary data base considered was composed of abstracts of research ideas gathered by NOAA in several previous Oceanlab studies and by the National Science Foundation (NSF) in their various post-IDOE (International Decade of Ocean Exploration) planning exercises. This material was augmented by the direct participation of active ocean research scientists, many of whom, in addition to their own ideas, brought those of their colleagues with whom they discussed this study.

While appropriate research topics emerged in all the marine science subfields, the bulk of them were in the areas of biological oceanography and marine geology/geophysics. The biological problems ranged from studies of near-shore environments through concern with the scarcely known, fragile, gelatinous zooplankton and plankton and nekton behavior and life cycles to the need to understand the exotic communities found at active hydrothermal sites on the East Pacific Rise and Galapagos Spreading Center. In geology/geophysics the problems could be divided into those concerned with the dynamics of sediment-related processes--deposition, erosion, slumping--and those concerned with interrelated tectonic/volcanic/hydrothermal questions. Intriguing interdisciplinary problems were also identified: the effects of catastrophic events in the atmosphere and the ocean on the geological and biological aspects of the environment as well as the less dramatic interactions between bottom sediment and near-bottom currents; biological intervention into chemical, physical, and geological aspects of the seafloor; and combined physical, chemical, and biological effects at the sea surface. Initial insight into most of these questions has been derived in part from use of diving, submersibles, and unmanned vehicles.

From the program development standpoint, this breadth of scientific involvement produces an awkward problem. No single set of questions emerged which alone seemed able to justify the establishment of an Oceanlab Program. One could probably reach the threshold by lumping all the biological or all the geological questions together, but this would tend to destroy one of oceanography's great strengths--the ability to carry out truly interdisciplinary studies. We therefore conclude that the program must be justified on its across-the-board impact. This creates another problem within the scientific community because the number of scientists oriented to a single problem is too small to support a major effort. The most obvious supporters tend to be those who choose to concentrate on a particular technology (diving, submersibles) and who, as a result, often are not appreciative of the fact that most of the scientific questions are complex, and thus require a diversity of modes of attack. Careful leadership by the NOAA Oceanlab Office will be needed to ensure that these problems do not prevent its being effective on the overall scientific scene.

The functions that fall within the Oceanlab definition and that contribute to the research activities start primarily with direct observation. This almost immediately, however, is coupled with sampling activity. Among the more challenging tasks in this category are the collection of very fragile zooplankton and the sampling of rocks and sediments where finely stratified sections are exposed. After sampling come the more complex activities of placing and operating research equipment on the seafloor or in the water column--essentially adapting laboratory experimental techniques for conduct of experiments in the ocean environment.

PROGRAMMATIC RECOMMENDATIONS

As a result of the impressive array of potential topics suggested by a large number of scientists, consideration of the observational and manipulative tasks involved, and the present status of research support activities and planning in NOAA, the panel recommends two *parallel, evolutionary,* and *eventually merging* lines for the Oceanlab Program:

Line One would be the establishment within NOAA of a broad research program *exploiting the use of existing facilities and enhancing present studies* including saturation diving, submersibles, and remotely controlled unmanned vehicles.

Line Two would carry out the necessary scientific and engineering studies, development programs, and actual procurement necessary to *bring the best relevant technology* that can be available in the next few years *into action* in support of ocean research. This should include the design and construction of broadly useful work systems, special research tools, and a major support craft of advanced design.

MANAGEMENT RECOMMENDATIONS

1. Consideration of the missions and projected funding capabilities of other agencies indicates that they are unlikely to be able to support a significant portion of the accelerated research programs that the assumed facilities imply. Thus, NOAA will need to fund a major part of the reseach activities as well as the facilities to assure the success of this program.

2. NOAA should involve active research scientists in overall program planning, facility development, and detailed research decision-making. In the earlier stages the *ad hoc* working group approach often used by the Office of Naval Research (ONR) would probably be most effective; while in decision-making as to which particular investigations would be carried out, a peer review committee approach more in NSF style would be desirable.

3. A long-range program and fiscal plan should be prepared and submitted to the NOAA Administrator and the Secretary of Commerce for approval. Concurrence at those levels would assure potential users that the Oceanlab Program could be a realistic factor in planning future activities.

4. The Oceanlab facilities themselves should be operated for the scientific community by academic research units having appropriate interest and expertise. This approach would be similar to the situation that has existed for *Alvin, Alpha Helix,* and *Glomar Challenger.*

1
Introduction

Late in calendar 1978 the Ocean Science Board (OSB), after a number of preliminary investigations, agreed to undertake a study for the National Oceanic and Atmospheric Administration (NOAA) of their Oceanlab concept. At the outset this was difficult because of lack of a common understanding of what the term "Oceanlab" actually meant. To some it was a facility, to others a program. To some it was the provision of new man-in-the-sea technology* for science, and to others it was to produce a new rallying point for U.S. ocean research and an incentive for crystallizing our government's policies relative to understanding and using the sea. NOAA's previous concept formulation and engineering studies, however, made it clear that Oceanlab was something different from a number of other major innovative oceanographic research programs, such as the Mid-Ocean Dynamics Experiment (MODE), which focused on a particular scale of typical upper midocean circulation, Coastal Upwelling Ecosystem Analysis (CUEA), which concentrated on a particular phenomenon (upwelling) and its interdisciplinary implications, or the deep-sea drilling program, which provides a new device of use to one part of the marine-science community (the earth scientists).

Oceanlab was clearly born of interests in man in the sea, particularly saturation diving. At the same time, its lack of strong support by any major segment of the ocean-scientist community seemed to

* Technology used in support of and during manned undersea activities.

stem from the narrow range of important problems in which this technique plays an essential role. Those in the OSB who were seeking to assist in analyzing the problem thus believed it essential to find a somewhat broader base in order to have some probability that a study would be fruitful. After discussions between OSB members and involved NOAA staff it was agreed that, in the context of the study, Oceanlab would represent a program to improve the capabilities of U.S. scientists to carry out ocean research requiring complex observational or manipulative activities throughout the ocean. This would imply functions comparable with those that a skilled diving scientist can now carry out over limited periods of time, in favorable weather, in the uppermost part of the water column. During the period in which our study was being formulated, NOAA restructured its ongoing Oceanlab activities in much the same vein, making it a program to provide support for man-in-the-sea research, albeit without as wide a scope (because of budget limitations) as that which this study encompasses. This broadening of viewpoint by NOAA thus moved away from the earlier identification of Oceanlab with a single facility toward a focus on a particular range of types of activities (and a concommittant range of facilities).

The concept of a facility-oriented research support program is a departure from the ideal approach in which a particular scientific problem provides the focus, and a variety of tools appropriate to the scientific goal are used. On the other hand, when particularly costly facilities are conceived (often in the context of a single scientific goal, e.g., sample the material just below the Moho) no single task may be judged important enough to warrant the cost. In such cases the only recourse is to work from the other direction, as in the present case, to see whether there may be a diversity of research problems to whose solution the facility complex may contribute. Both the scientists using the facilities and those administering the research program in which it is imbedded must be broadly enough aware of what is going on in other, more conventionally organized research activities to understand the role of the facility in the overall scheme of things. Actually science rarely proceeds in the orderly fashion suggested by the idealized program planning process in any event. Most particular research efforts only reveal part of the answer to the question being considered, and it is left to the initiative of others, having different skills or viewpoints, to add their contributions.

Generalization of the man-in-the-sea concept opened the range of problems significantly, removing depth limitations by allowing the man to be enclosed in submersible pressure hulls or to operate his surrogates by remote control in all parts of the marine realm.

The agreed goals of the present study, abstracted from the panel's charter, are as follows:

Study Goals

The unique aspect of manned undersea activity (including divers) in support of ocean research, is the ability to carry out complex observational and manipulative tasks. Delineation of research topics whose successful prosecution would include a requirement for performance of such tasks will be the first step in this review. The second step will focus on possible technical needs to improve and support U.S. capabilities to carry out such tasks using man directly in the sea and extensions of his capabilities through use of submersibles and remotely controlled devices.

Our problem thus took on two sequential aspects: first, to ascertain whether there seemed to be enough good research topics in which the generalized man-in-the-sea function would play a significant role to justify initiating a major program; second, if the answer to the first was yes, what would be an appropriate general form for a major program. Included in the latter would be matters of funding, possible new facilities, and how the program would interact with the scientific community.

The OSB appointed a panel composed of three of its members and a nominee of the NRC Marine Board to carry out the study. Additional individuals from various scientific, engineering, and marine operation disciplines gathered with the panel to discuss these questions in a series of meetings that took place during the first half of 1979. Appendix A lists those who took part and indicates the level of their involvement.

The ensuing two sections address research pressure and program structure. They include our major conclusions and recommendations. The subsequent three sections elaborate on the research opportunities, and the final section treats support technology as discussed in our several meetings. It should be emphasized that our primary goal was to provide assessments and advice specifically for NOAA. No other agency was involved.

2
Research Pressure

Research can have a variety of contexts, and NOAA, primarily through its in-house laboratories, is involved in a wide range of activities, from very basic to the most applied. This study included the ground rule that Oceanlab would exist primarily (though not necessarily exclusively) as a program to support basic research. Moreover, a large component would be carried out in the academic institutions. These considerations substantially controlled the types of research activities that were considered.

Our first step was to evaluate the nature and number of scientific investigations that one might imagine as representing the scientific need for an Oceanlab program as defined above. While we were able (as discussed below) to look at today's ideas, one's ultimate conclusion as to whether a program of this kind should involve itself in acquiring major, long-lived facilities requires a certain confidence in the future. Many of the research problems requiring Oceanlab-type functions are of a somewhat exploratory nature. As one begins to learn about a particular matter through use of broadly capable observational or manipulative techniques, one almost always finds it desirable to move into a subsequent stage of investigation in which simpler, specialized devices can be built to carry the research forward into its later stages. The sorts of techniques that we visualize in this study would thus be expected to play only a transient role in any particular research problem. Past experience has shown, however, that as one goes about using versatile methods to attack today's problems we will uncover the beginnings of new questions on which these same tools (or their immediate descendants) will be usefully employed tomorrow. The most recent example of this effect was in the use of the submersible, *Alvin,* to investigate (as a geological/geochemical problem) hydrothermal activity at the Galapagos spreading center. The result was not only the (predictably) successful observation of the effect under investigation but the discovery of associated, completely unsuspected dense, unique biological assemblages in these sites. This, in turn, has opened up another facet of *Alvin* research use for a different part of the oceanographic community. In short, although these techniques may play only a transient part in any given investigation, if we can find enough promising activity for a substantial initial thrust, we can expect that new questions will emerge that would justify continuing use of a major facility, providing it is conceived in a manner that allows for easy adaptation to new function.

Although the panel members and consultants represented a broad range of knowledge of current important scientific problems, it was desirable that our conclusions with regard to research opportunities be based on a larger body of ideas. At the same time, we realized that there has been a proliferation of questionnaires asking what new devices we would like to have magically appear for our use and what research topics we would attack if we had new funds or specific new facilities. We thus decided to make use of what could be extracted from the data base that previous inquiries might provide rather than again querying the scientific community.

As a first step, we thus asked the NOAA Oceanlab staff to go through the answers to Oceanlab scientists surveys made during earlier studies (Savage and Waterfield, 1977) and, more important because of the breadth of the contributing population and open ground rules, to review the individual written research ideas submitted in response to the call made by NSF as a part of the post-IDOE planning process. We acknowledge the help of NSF staff members in making this material available. The NOAA staff picked from these two large lists all the items that appeared to involve use of the generalized man-in-the-sea capability and prepared single-page summaries of all that appeared to satisfy this criterion. About 400 individual items emerged. Their titles are listed as Appendix B, and copies of the item summaries are on file in the OSB offices.

With these summaries and our own ideas plus those of our colleagues with whom we had prior discussions, we assembled our first major meeting, to review the material and assess the quantity and scientific importance of research that might be proposed and carried out within an Oceanlab framework.

The scope, content, and quantity of proposed work were quite substantial. The ideas ranged from study of fragile gelatinous zooplakton in the topmost part of the water column, through questions of the dynamics of sediment moving down the continental slopes, to multidisciplinary investigations at deep-seafloor-spreading ridges and rises. Their implications spanned the range from understanding plate tectonics, animal behavior, and the ways in which near-seafloor currents shape the environment to the man-made problems associated with waste disposal and resource utilization. Similarly, there was a wide range of representation among the scientists themselves. The major oceanographic centers were well represented, as were other institutions in which ocean-oriented scientists are in the minority. The nature of the background source material and the composition of the consulting groups were such as to emphasize the roles of NOAA (fisheries, resource exploitation) and NSF (basic science) rather than, for example, the Department of the Navy (defense). Since our purpose is to provide advice to NOAA, this seems appropriate.

It quickly became apparent that, if the problems were categorized by discipline, the biological and geological predominated. This happens as a matter of both scale and the nature of the observations or measurements involved. Man, or surrogate man, in the water is at his best in dealing with phenomena or objects not much larger than himself. At the other extreme, he can only usefully work at scales much smaller than himself when his physical presence does not disrupt the objects of his investigation. Studies of thermal microstructure, for example, must be carried out with instruments that do not themselves drastically distort the phenomenon. Biological and geological entities are rather less fragile while at the same time being more complex than the physical or chemical conditions in the water, which (although not always easy to measure) can be characterized much more simply than can a small plant or animal. The biologists and geologists can thus gain more from use of man's capabilities as an intelligent observer and collector.

One reason that a much more impressive array of problems emerged in this investigation than in previous Oceanlab surveys was that the generalization of the definition of man in the sea opened up depth regimes that the scientist-diver cannot attain. While few scientists are capable of working deeper than 30 m, it is possible to visualize a wide range of devices that will extend manlike capabilities to the deepest parts of the sea.

The research functions involved were fore-ordained by the selection process. They started with simple observation and documentation of the surroundings in geological and biological (ecological and behavioral) contexts and then split into two different categories of more complex activity--sampling and the placing and operation of instrumentation.

The wide range of problems exposed provides both a strength and a weakness for those who may be involved in making this program a reality. Taken together, the mass of useful activity could contribute substantially to the advance of oceanographic knowledge over a wide front. It could clearly have a more positive community-wide impact than any of the previous facility-oriented programs other than block funding of ships. No single key theme emerges, however, to identify the program with some particular basic research field or with support of a particular applied objective. Thus the argument in favor of the program must still proceed on the basis of providing new technology for a wide variety of scientific users.

3
Program Structure

Since it does appear to this group that there are adequate good research programs that would fit the Oceanlab context, the next topics to be dealt with are of a programmatic nature. While it would be inappropriate for our panel, which has no direct administrative responsibility in this matter, to provide a detailed blueprint for the overall program, there are several general areas that, with our present background, can properly be discussed. These include a suggested ultimate objective, a desirable general approach, and identification of some difficulties that one might anticipate.

As an ultimate objective, to be approached incrementally over a period of years, we suggest assembling and operating at least one major seagoing research support craft and the system that could be used from it: saturation diving, deep submersibles, and unmanned remote-controlled seafloor observation and work vehicles. The submersibles and unmanned remote-control vehicles and possibly the saturation diving system should be capable of being operated under some conditions from other ships. Some suggested forms that these facilities might take are discussed further below. The related program should include NOAA support of a major part of the implied scientific research activity itself as well as funding for operation of the facility. We make this recommendation in full awareness of the fact that it implies a new seagoing element (of advanced design) at a time when research ships are being laid up not for a lack of good programs but for a lack of growth of support for oceanography adequate to keep up with inflation (NSF Division of Ocean Sciences presentation to OSB, July 1979).

Funding has been a topic for discussion at almost every working group session of the present study. The debate has revolved around the fact that support for ocean research has barely kept pace with inflation in recent years and the question of whether the Oceanlab program would represent an additional element of funding or whether we are dealing with a fixed total budget for U.S. programs in basic marine science. We have taken the optimistic position that the new capabilities that the program can provide will not only open up new options (discussed in later sections of the report) to the research community but that these options will be of sufficiently broad interest to attract additional funds, particularly through NOAA, for their support.

In order to move forward with such a program, two parallel evolutionary paths must be pursued. The first is the more important and should be initiated as soon as possible. This would be the development of an actual research program based on the use of facilities that now exist or could be brought quickly into existence but that are now available for conduct of research activity. A particularly obvious example would be the application of saturation diving capabilities, which now exist in the commercial and Navy operational sectors and which could be brought to bear on a charter or other similar basis if funds were available. A second example would be the use of existing stable platforms in support of open ocean diving and observations for biological research in the upper part of the water column. A number of other possibilities related to the nearshore and shelf environments are documented in the set of nine studies carried out by various research groups under NOAA contract within the framework of their National Underwater Laboratory System (NULS) II program. Summaries of these studies, all of which represent viable near-term facility development options, are included as Appendix C. (Our panel did not make a critical review of the scientific or technical content of the NULS II studies.)

The evolutionary development of an Oceanlab research program using these kinds of facility approaches is the essential element for success. Given NOAA's lack of experience in involving the academic research organizations in a major way (other than in the special applied research environment of Sea Grant), there is a degree of skepticism in the ocean-science community as to whether NOAA has the capability to generate and wisely administer a major new academic research program, as well as to provide the facilities for it. Clearly, both the research and facility funding must be provided. No other source capable of development seems to exist. NSF might, in principle, and perhaps properly should, be a major participant. A recent study by their Division of Ocean Sciences, however, asserts that they do not have the funds to support enough research even to keep the existing oceanographic fleet fruitfully employed and that they see no prospect of keeping up with inflation over the foreseeable future. The scientific problems and the scientists exist, but the funding (largely because of inflation) does not. In a world in which good young scientists are emerging and the older generation has not begun to fade, we see NSF supporting fewer investigators every year.

The existing NULS program represents a beginning, however, and can be thought of as the first step in this evolutionary process. To set the scale, NULS funding for fiscal years 1979 and 1980 totals about $2.5 million. These funds are for continuation of NULS I (a seafloor habitat) and to implement, on a phased basis, new regional facilities to support marine scientific research. Viewed by our panel as a pattern for future development, NULS has three shortcomings and one interesting strength. The first negative element is the lack of any scientific program funding capability. As noted above, it would be meaningless to embark on a facility development without a parallel budgetary plan approved at the highest levels in NOAA for support of the implied scientific effort over the next few years. The second shortcoming is that the NULS II studies all focus on existing facilities within the smaller ocean-science centers. They ignore the possible use of well-developed capabilities available outside that sphere from the offshore oil industry and the Navy (including its in-house laboratories).

The third shortcoming is in the management area. The development of a strong research program emphasizing unique facilities requires an input from the research action community. In NSF this is embodied in the peer review system, which plays a major role in allocation of its resources. In ONR this is accomplished through a number of advisory committees, some having broad scope and others assembled (as in the High Energy Benthic Boundary Layer Experiment) to plan specific programs--but all with membership emphasizing the participation of active research workers who know first hand what the opportunities and difficulties may be. The review panels used in selecting the groups to do the NULS II studies and in ranking those finally submitted, while drawing on many good scientists, were almost exclusively composed of individuals from within the government's oceanographic administrative structure. It is recommended that NOAA institute some mechanism within the Oceanlab project for involving scientists who are currently active in the conduct of research. Such mechanisms might include establishment of working groups to formulate plans for specific phases of the program and others to act as reviewers and advisors in the process of allocating the facility use and support funding. Given the fact that the programs being carried out would be part of NOAA's overall activities there should, however, continue to be substantial involvement in such panels by NOAA representatives to ensure that views as to funding and goals fit within the larger context of NOAA activity.

The strong management point in the current NULS component of Oceanlab is the clear commitment to operation by academic institutions of the support facilities being developed. This approach can have pitfalls, however, if the terms under which the operating organizations act are not carefully thought out. These must assure accessibility by a larger community than the operating institution itself while at the same time maintaining institutional interest and responsibility. The degree to which this will be a problem depends on the nature and sophistication of the facilities. Those envisaged in the NULS II studies are all of low mobility and oriented to local problems and thus do not imply broad usage. On the other hand, any major craft supporting saturation diving, submersibles, and deep seafloor work vehicles would presumably serve a much wider public and should be operated more in the style in which *Alvin* or *Alpha Helix* have been. The advantages in having one of the research institutions be the operator are that the facility will draw appropriate attention within the institution and that a much more direct connection with the user community and its needs will exist than would be the case if the operator were some agency within NOAA.

The above text refers specifically to the evolutionary development of a near-term combined facility and research support program. NOAA's success in bringing this along in a timely manner will to a considerable extent influence the scientists' views as to whether an expanded program including a major new facility should be taken seriously in planning their own future research. At the same time, the long-range goal of bringing new capabilities into being must be kept alive since the lead time for accomplishing that end is very long. It would be unfortunate to have the evolving research program arrive at the point at which it could exploit new technology and yet not have the technology available.

The second branch of the evolutionary development of Oceanlab should thus embody the identification and procurement of new technology that is now available, in support of the observational and *in situ* manipulative capabilities that the Oceanlab program envisages. The functions that must be performed in this part of the program should not be carried out as if they were isolated engineering tasks. The scientific community should be involved throughout, with early decisions made as to which of the academic institutions might be the most probable operating agents.

The first step should be the identification of the facility options potentially available in support of Oceanlab functions throughout the full range of scientific problems and working environments that exist in the sea. These should include both actual work systems (habitats, saturation diving systems, submersibles, unmanned remotely controlled devices) and a major vehicle for their support (semisubmersible ships, stable floating platforms, submarines). The work systems should be evaluated against their potential ranges of scientific usefulness and a priority list for their development and acquisition made. Strong consideration should be given to systems that can potentially be operated from a variety of tending platforms in order to maximize their utilization under as wide a range of relevant circumstances as possible.

The major dedicated support vehicle should be conceived as being an advanced type of craft, capable of supporting a wide range of work systems and being of a style that allows for flexibility and growth in both its operational use and in the types of systems it can support. Its design must take into account the realities of cost in construction, operation, and maintenance. Care must be taken not to overspecify its characteristics beyond those essential for the bulk of the immediately foreseeable program requirements. For example, one of our subgroups found that a substantial number of Oceanlab-type problems exist in the under-ice environment. It may be, however, that these should be attacked through development of means for using the appropriate work systems from bases on the ice or from ice breakers rather than requiring that the major project support vehicle include the capability for Arctic operations under extreme conditions. A similar argument can be made in the case of requirements for support of research under extreme weather conditions.

An appropriate approach to this aspect of the program would be the selection of a combined science/engineering panel to lay out the general facility framework and to establish subgroups to produce the more detailed guidance needed for specific vehicle or systems decision making. Here again we can learn from the earlier Oceanlab experience in which the involvement of the scientific user community was detached from real decision making with regard to the facilities implied. Furthermore, there was a lack of emphasis on being able to handle a wide range of work systems and flexibility for future growth.

Several types of work systems--some as simple as providing for safe diving operations in the uppermost part of the open sea and some as complex as providing the equivalent of a man's eyes and hands to work in topographically rugged environments on the deep seafloor--are discussed or implied in the following chapters of this report and in the research ideas listed in Appendix B. Major support vehicle options are also presented in Chapter 7. These should be considered among the concepts to be treated in the facility development portion of the Oceanlab program but have not been examined in sufficient detail by our panel to warrant their being given preference *a priori* over other alternatives.

On this side of the program some early commitments to work system procurement, including developmental programs where necessary (particularly in seafloor work vehicles) should be made. Recognizing that these should be operable, although perhaps in a lesser range of circumstances, from conventional ships, their entry into the program ahead of the major support vehicle will provide the user community with experience with their use and thus a broader appreciation of their research potentials.

In summary, we recommend two parallel evolutionary programs in Oceanlab to bring into action the best available technology in support of research requiring complex observational or manipulative capabilities.

The first is the establishment of a research program exploiting the use of existing facilities in this context, including saturation diving systems and submersibles. Management of this program should include use of working scientists from the user community (academic and NOAA in-house laboratories) both in general planning and in reviewing specific research proposals. The facilities involved should be operated for the scientific community by selected oceanographic institutions having interests and capabilities relevant to the types of research implied by the particular facilities involved.

The second leads toward the establishment of an operational facility complex that will bring the best technology that can be available in this field within the next few years into action in support of the evolving research program, with expectation that further developments will occur in the future and will be incorporated as they become available. This program facet must start with an in-depth analysis of the technical options by a combined science/engineering group including representation from the user community. It should then proceed to procure (including development as indicated) the work systems and to the design and construction of a major support craft.

The establishment of both a research program and an operational facility complex must be the subjects at the earliest possible time of a development plan, including budget projections, that would be reviewed and approved in NOAA, the Department of Commerce, and the Office of Management and Budget. Such approval would signal to the scientific community that the program could be taken seriously in planning future research activities.

4
Shelf and Upper Slope

INTRODUCTION

The shelves and upper slopes are obvious areas for man-in-the-sea projects for several good reasons. First, and most important, this is where the action is. Wave forces are violent, and local currents can be strong; sea life is abundant in and on the bottom as well as in the water column; structures for oil drilling/production and coastal protection have been and will be built; the release of man's chemicals and wastes have the most obvious effects; and mankinds' history in the form of primitive sites and old wrecks can be found.

Second, the shelf area is the nearest part of the ocean to where people live and work and recreate. What happens immediately off our shores is of direct interest to the public as well as to ocean scientists. Moreover, many nonscientists are qualified scuba divers and thus have a feeling of identification with research activities that use these techniques. These factors lead to more supporting interest in science in this regime than in more distant or deeper waters.

Third, much of the diving technology needed to put man in the sea on the shelf and upper slope is already in existence. Some of it is expensive to own and operate and so has been utilized mainly on high-priority construction and oil-production work. For much of the work described here, a relatively small amount of hardware development should be required. Existing diving equipment (bells, submarines, habitats, and saturation systems, for example), could be rented now. To a lesser extent this availability exists for "complex manipulative and observational devices" that would use some combination of sonar, television, and remotely controlled "hands," although even these are beginning to be readily available commercially.

Thus, relative to an Oceanlab Project on the continental shelf, we find (1) the intensity and complexity of the phenomena involved give rise to a wide variety of scientific questions, (2) the impact of nearshore phenomena on everyday human activities is more immediate than for more distant environs, and (3) much of the equipment required to make a beginning already exists.

The shelves of the United States, both continental and island related, vary greatly in width, configuration, exposure to ocean waves, presence of ice, marine resources, and usage by people. Our considerations also led us to include deep estuaries, although a geological purist might not feel that these fell within the original definition. Each scientist seems to have a distinctive mental picture of what the shelf is like. Some think first of the clear warm water over a coral reef or around recently discharged lava; some think of turbid and chilly water over a mud bottom; some think of operating under ice; some think of rocky, weed-hung shoals; and some think on a broader scale--about the tens of thousands of square miles of flat and unrelieved sediment that makes up much of our eastern shelf.

This variability emphasizes that there is an unevenness in the importance of scientific projects from place to place. Relative priorities will become evident as work proceeds, based on the usefulness of the results and the costs of obtaining needed information.

Consider some of the special coastal environments that are available for Oceanlab-type research:

1. Extensive *banks* off the Atlantic Coast (e.g., George's Bank) and the deep reefs off the southeastern United States and the Gulf Coast provide major spawning grounds and bottom fishing areas.

2. *Submarine canyons*--steep sided gullies that cut into the edge of the shelf--are known for their special forms of sea life, special currents, and special erosion/deposition conditions. They often act as conduits to channel alongshore sediment transport out to sea.

3. *The southern California borderland,* which is a series of basins and ranges, 150 km wide and 400 km long with 7 islands and many subsea reefs and hills, 13 basins (some greater than 2000 m deep), petroleum reserves/production, and a huge population of marine animals. All of this is immediately offshore of a coast on which 11 million people live. Its geomorphology is, as far as we know, unique in the world.

4. A variety of types of *deltas and sediment fans* off major rivers--Mississippi, Columbia, Mackenzie--present continually changing environments.

5. *Fjords* on the coast of Alaska, rocky seamounts, and very steep undersea cliffs, each have unusual geological and biological characteristics.

6. *Fresh lava deposits* (occasionally the actual deposition of liquid rock can be observed) exit off Hawaii as do the beginnings of sea growth (often coral) on the new rock.

7. *Large estuaries* are of interest because each has unique chemical, biological, and physical conditions; most are surrounded by heavily populated areas, for example, San Francisco Bay, Puget Sound, Chesapeake Bay, and Cook Inlet.

We considered many kinds of projects, including dozens proposed in the earlier Oceanlab study, and selected a few examples of what can be done in the Oceanlab context. Our criteria for selection were: (1) Is it good science? (2) Does it really require a person (or his surrogate) in the sea? The projects chosen are given below, each with a brief statement of what is to be done, why, and how. This is not intended to be a final judgment but rather the result of a first screening. Whether a project in each of these areas can be developed depends on the competence and energy of the specific scientists who propose to carry them out.

These projects have been divided into two categories. The first category includes those that could be largely or partly carried out with existing support equipment. That is, whenever operational funds are available, it will be possible to charter diving gear, bells, habitats, remote equipment, and submersibles and (after appropriate training) proceed with the science. The second category will require more advanced equipment and capital expenditures for instrumentation and support facilities including ships. The requirements are likely to be within reach of existing technology.

RESEARCH WITH EXISTING EQUIPMENT

The investigations in this category can be carried out without development of new equipment (other than instrument adaption to special circumstances), and even capital expenditures for major facilities can be avoided if one is willing to lease them. If scientific proposal pressure develops rapidly, then procurement of additional facilities newly built may be appropriate, although the time scale for assessing that eventuality is long enough that it should fit into development of more advanced gear rather than replication of existing material.

Changes in the bottom caused by violent transient effects such as storms and tsunamis might be best measured and documented by observers. Attempts to put a few instruments in critical places have been marginally successful; direct observation of wider areas might improve our understanding. Highly detailed before and after comparisons may shed light on the processes involved. Clues as to where to look should come, in part, from satellite observations.

Soft bottom biology (life history) of many kinds of benthic biota that live in and on the soft bottom should be studied, including their life spans, depth variations, metabolic rates, competition, and predation and their overall availability as a food source for higher animals, all of which have scientific interest. Bottom areas can be vastly different from each other, and *in situ* observation, sampling, and measurement would be useful in understanding the interactions among the many animal and plant species present.

Bioturbation refers to mixing of the uppermost layers of sediment by burrowing animals. Acts of man (dragging anchors, trawls) produce similar results. Questions about the importance of this effect on the changes in biology and chemistry of the bottom might be best answered by in-sea observers and experiments.

Nepheloid layer understanding, sampling, and measurement should be pursued. This is a zone of particulates immediately above the sediment that covers some areas of sea bottom. It is easily "blown" away by currents and by most sampling devices. This layer may be important to some kinds of bottom life, and a human observer/sampler can obtain insight leading to understanding.

Chemical measurements (or sampling) should be made above, on, and under the bottom relating to the depth of oxidizing/reducing environments and the transfer of interstitial water, for example. *In situ* activity to place sampling tubes or set test objects may require a person.

Animals living in strong H_2S *or low-oxygen environments* are a puzzlement. It may be possible with *in situ* experimentation to understand how animals live anaeorobically for long periods or extract oxygen from a seemingly anoxic environment.

Hard bottom biology life cycles of the plants and animals that live on, in, around reefs, rocks, corals also need to be better understood in the ways mentioned above. Furthermore, some plants/animals actively produce chemicals that can be used for drugs at certain stages in their life cycles, and the skeletons of the corals themselves are of commercial interest. The times and causes of these cyclic changes should be learned. *In situ* observation over extended periods of time is probably the best way to discover the subtle motions of animals related to feeding, reproduction, and predation.

Burrow and borer identification should be undertaken. Mud and some kinds of rock bottoms are full of bumps, hollows, and holes whose origin is presumed to be biological. Patient observers should be able to provide insight into the roles that these structures play in the lives of seafloor animals.

Artifical reef studies should be initiated. Many artificial reefs have been built and examined by divers, and it has been well established that such structures (often dumpings of old cars, paving stones, or ships) increase the numbers of some kinds of fish. Continuous observations of such reefs from a habitat have proved to be a powerful tool in understanding the dynamic processes associated with attraction of marine life. Further study should provide bases for optimizing the design of such structures.

Environmental impact statements relating to structures or dumping or discharges could, in some cases, be made more meaningful if direct observational reports were included. These might be made by some kind of man-in-the-sea operation. Research in the Oceanlab Program could shed light on what sorts of observational or collecting activities would be most useful in this context.

General observational reconnaissance is an essential element to which some allocation of effort should be made. Based on knowledge of large-scale circumstances (topography and currents, for example) certain types of general fine-scale survey activities using submersibles, or remotely controlled and monitored TV systems should be carried out in order to keep our minds and imaginations open for unexpected situations. There has not yet been enough detailed observational work done to establish the patterns of rare features of the environment.

RESEARCH WITH ADVANCED EQUIPMENT

Scientific projects that require a more advanced support capability (to depths of 1000 m) than is now easily available are suitable for future NULS or Oceanlab operations. Some of theese are listed here.

Bottom-vent exploration and observation should be undertaken. In many regions there are fissures or holes in the seafloor on the shelf and upper slope from which hot and cold freshwater (sometimes mixed with minerals or H_2S) or oil and gas may issue. These have interesting effects on the nearby waters, bottom, and biota that are sometimes confused with pollution by man. These features should be mapped and studied.

Under-ice biological/geological studies should be undertaken. The observation and collection of the biota; the notation of changes with time and season; the determination of processes--can all benefit from human presence. Ice scour effects could be observed and described. This topic is treated in more detail in Chapter 5.

Spawning and reproduction studies should be made of the creatures of the continental shelf. Astonishingly little is known about the life sequences of many common food fishes and invertebrates. Some have long planktonic and larval stages in which they are briefly glimpsed. These give way to tiny juveniles about which little is known until they are large enough to be netted. There is a great opportunity here to learn things about animals of commercial importance by observing their habits in the sea.

Sediment transport dynamics and boundary-layer conditions in various grain sizes of sediments are of great interest to those involved in the study of longshore and offshore transport, slumping in canyons or on the slope, behavior in sudden rapid currents, and the meaning of bottom forms. There are numerous experiments and observations that can best be performed by a man in the sea.

SLOPE DYNAMICS

Matters of importance in continental slope studies are the sediment transport regimes, the boundary-layer energy levels, and the mechanics of sediment movement. Many fundamental questions are yet unanswered because these require either new approaches to their solution or technological advances that will allow not only highly selective and precise measurements but long-term in-place observations.

The research areas presented below relate to extensive features and regional processes in many cases and require study on both regional and local scales. Man-in-the-sea efforts enter into these studies in those cases dealing with the investigation of mechanisms or cause-and-effect processes for which the scale of observations or measurements is quite small. This mode of study is also required when there is a need for high precision or selectivity as to when and where measurements are to be made.

Following are some of the most important research opportunities containing strong observational or manipulative elements:

- Determine relationships between bed configuration versus bottom and near-bottom energy levels, water depth, and sediment grain size, texture, and composition.

• Determine the detailed dynamics of fine particles. Production, modification, and disintegration of fine aggregates as well as precise determinations of their *in situ* settling velocity are important aspects of sediment flux that require study.

• Conduct *in situ* studies to provide a more adequate understanding of animal-sediment relationships and biogenic influences on erosion, transport, deposition, and stabilization of cohesive sediments.

• Determine bed form response to disequilibrium conditions, such as the passage of storms.

A number of the above items are also important when analyzing the effects of resource development, be it the mining of placers or the drilling for petroleum. Each of these efforts results in sediment and/or foreign material being transported on and over the seafloor.

Stability characteristics of slope sediments in respect to gravitational forces are little known. Although many aspects of this problem area are appropriately undertaken by more or less conventional techniques such as seismic profiling, side-scan sonar, and sediment coring, man-in-the-sea plays a vital role in the precise and fine-scale measurements of features associated with slumping and creep.

ARCHAEOLOGICAL DIGS

There are undoubtedly many locations on the continental shelf where underwater archaeology would be most helpful to an understanding of the history of mankind. Somewhere there is evidence of early man in the Americas--both at living sites and along migrational routes that man used during previous lower stands of the sea. There is also wreckage of early ships lost from the time of Columbus to the present, and probably before Columbus. They may hold valuable information about the history and early exploration of the Americas.

For evidence of early man (4000-12000 years B.P.), a search should be made along likely migration routes and at sites where living conditions were probably favorable. For example, stream mouths in protected waters where fishing may have been good, now submerged 20 to 100 m.

The old ships are likely to be covered with sediment, but they may be temporarily uncovered by storms or found by excavation for other purposes or located by remote-sensing devices.

In either of the above cases, once a site or wreck is found, the excavation will probably require many man-months on the bottom. This may be an especially appropriate use for an underwater habitat or perhaps even a special "tent" over the dig. Man's hands are required in the excavation because the value of archaeological results is proportional to the care and delicacy of measurement, marking, and removal of artifacts found.

CORAL REEFS

Coral reefs offer numerous research opportunities that could be pursued within a national man-in-the-sea program. A list would include topics that bear on every aspect of biological oceanography and many facets of marine geology. Biological questions range from species identification to complex questions concerning reef metabolism and productivity. Geological topics relate to long-term processes such as coral growth, atoll formation, and subsidence. Important applied problems concerning multiple use of coral-reef resources include fisheries development and ecosystem management.

Coral reefs pose an interesting and pertinent scientific dilemma. While they are known to be one of the most productive ecosystems on earth, producing about 3 kg of organic carbon/m^2/year (Kinzie, 1977), they rarely produce high fishery yields. Before this paradox can be resolved, considerably more research on energy flux must be done. The development of sound management plans for coral reefs will be dependent on this research. One important objective is to find the appropriate balance between preservation of deep-water fish, shell fish, and minerals.

Another subject of importance in the management of coral-reef resources is episodic events--their frequency, magnitude, and impact. Corals are typically slow-growing and long-lived species. Recent studies have shown that in the lifetime of a coral, which may span decades, the most significant event may be a single hurricane (Maragos *et al.*, 1973; Smith and Harrison, 1977). Hence, before proper assessment can be made of man-induced environmental impacts, biological and geological research concerned with the natural time stability of coral communities is necessary. In this connection, studies of recovery processes, rates of larval dispersal, and succession are particularly important.

Many of the above studies can be accomplished with shallow-water support systems such as snorkeling, scuba, and hooka gear. Undersea habitats are not generally required since flourishing reefs are accessible without saturation and because such facilities are relatively immobile. The most difficult sampling problem is that of obtaining the broad geographic coverage that is best afforded by snorkeling or scuba. A possible exception is the problem of continuous and long-term observation and studies of dynamic processes including productivity. In some areas these aspects might best be accomplished from a habitat or submerged platform.

Other rather specialized problems of biological and geological importance that require extremely deep dives or a submersible include resource assessments. Also, environmental impact studies concerned with ocean outfalls or ocean dumping in proximity to coral reefs or deep-water reef-related resources may require saturation diving, remote-controlled vehicles, or submersibles.

5
Water Column

INTRODUCTION

The oceanic "water column," which extends from the air-sea interface to the benthic boundary layer, represents the bulk of the world's oceans. This vast realm of enormous scientific and economic importance has been traditionally studied from ships by towed devices such as nets or lowered devices such as bottles and other instruments. Recently, man has entered these "blue waters" and has made initial direct observations near the surface using scuba and in the deep ocean using submersibles. An Oceanlab Program that can exploit modern deep-sea technology to further expand these initial direct studies of the water column can do much to supplement our knowledge of the dynamics and organization of this enormous region (Harbison and Madin, 1979).

Several categories of water-column studies that may lend themselves to future investigation by an Oceanlab Program are treated in this section. They include gelatinous zooplankton, macroscopic aggregates or "marine snow," the deep-scattering layer(s), bioluminescence, *in situ* fixation for microscopy, the krill fishery and associated problems of the southern ocean, microscale physical processes, *in situ* organic/inorganic analysis, the air-sea interface, and patchiness and effects of catastrophic weather conditions. Each one is considered in more detail below.

BIOLOGICAL OCEANOGRAPHY

Gelatinous zooplankton. These soft-bodied, transparent animals represent many diverse groups (Hydromedusae, Siphonophora, Ctenophora, Scyphomedusae, Heteropoda, Pteropoda, Appendicularia, Thaliacea, and many meroplanktonic larvae) spanning two or three trophic levels. They have been observed at all depths. Some gelatinous organisms are very fragile and are often damaged by nets or pumps. Others exhibit escape responses. Thus, for some groups, little is now known about their distribution, relative abundance, and role in the ecosystem structure (Hamner *et al.,* 1975).

Macroscopic aggregates ("marine snow"). These aggregations of small particles (algae, foraminifera, bacteria, detritus, for example) in a mucous matrix originate from the secretions of gelatinous zooplankton. They occur at all depths in a myriad of shapes and sizes (0.5 to 200 mm). The aggregates have been shown to be chemically unique microhabitats that make food available to trophic levels that could not otherwise utilize their small individual components (Silver *et al.,* 1978). Because of their extreme fragility, they cannot be adequately sampled by conventional gear such as towed nets (Hamner *et al.,* 1975).

The deep-scattering layer(s). The animals that make up the deep-scattering layer(s) (e.g., myctophids or "lantern fish," siphonophores, euphausiids, and sergestids) migrate each night from roughly 200-1200 m toward the surface to feed. Many of these species (e.g., myctophids, siphonophores) scatter sound in the seas producing strong returns on echograms. The deep-scattering layer animals have been sampled by nets and observed from submersibles, but little is known about the life history, behavior, and physiology of the various groups.

Bioluminescence. Light-producing organisms are present at all depths in the sea. Below the light-scattering layer, nearly 90 percent of the animals found are luminescent and light sensitive, cutting across all taxonomic lines. Bioluminescence seems to have many purposes, including communications, lighting, prey attraction, decoying, and mimicry. The sampling of these species in nets has given good information on their structure, but other factors such as the role of luminescence on behavior and physiology have necessarily been inferred. The observation and photography (with image intensifiers) of these animals *in situ* and the capture intact of healthy (pressurized) specimens from depth would provide a means of testing many hypotheses and would support significant advances in the study of bioluminescence.

In situ fixation for microscopy. In many cases when studying the microbial life in the sea it is preferable to fix these organisms *in situ* in order to prevent their distortion and/or alteration during retrieval. Once collected, they can then be subjected to electron microscopy and analysis. Techniques for *in situ* fixation are now being developed, and this new field promises to yield substantial new information. Fixation can be done either by divers or remote control, and divers have a decided advantage in being able to observe the surroundings and select and care for samples. At the same time, however, the presence of divers will to some extent distort the local environment.

The krill fishery and associated problems of the southern ocean. An intensively developing krill fishery to utilize this enormous food resource for mankind has also raised questions about the possible recovery of the great whale population and the role played by squid in this ecosystem. Thus, there is an urgent need to understand the dynamics of midwater populations, especially krill. For example, baleen whales use two tactics for feeding on their planktonic prey: skimming a dispersed prey or swallowing an aggregation of prey. It has been calculated that an average fin whale feeding by skimming on an average density of krill would need to traverse 7000 km to obtain its "daily bread" (Brodie *et al.*, 1978). Since this is an absurd distance, clearly, these whales must depend on finding aggregations of krill that they can engulf, bringing them into direct confrontation with the technically advanced fisheries. Hence we need much more information on the swarming behavior of krill and foraging tactics of the baleen whales. Technology that would allow oceanographers to understand why krill and other plankters swarm is needed. Furthermore, the ecosystem dynamics of southern oceans will remain mythological until a great deal more information is available for the squid populations currently known only from the stomachs of toothed whales. Direct observation could play a significant role in a program to answer many of these questions.

PHYSICAL OCEANOGRAPHY

Microscale processes. While most questions in this regime can best be studied using a variety of instruments--temperature profiling, acoustic probing (reflectivity, Doppler), dye tracers, for example--the observational capabilities of a man can contribute to our qualitative understanding. For example, the release and subsequent observation of dye traces by scuba divers (Woods, 1968) revealed the complexity of small-scale shear and interleaved laminar sheets of water at the thermocline and in the internal waves. Such studies, when well planned in relation to other measurement programs, can help to unravel the more complicated situations that occur particularly near boundaries or regions of high gradients.

CHEMICAL OCEANOGRAPHY

In situ organic/inorganic. Many substances in the sea undergo chemical changes when removed from their natural environment because of pressure or temperature changes or contamination during sampling. Techniques for *in situ* analysis could be developed to study these substances (natural products, nutrients, and pollutants) more effectively as they appear in nature.

INTERDISCIPLINARY

The air-sea interface. The "microlayer" (i.e., the top millimeter of the ocean) covers over 79 percent of the earth's surface. Through it passes most of the planet's absorbed solar energy and freshwater supply, as well as large quantities of carbon dioxide, oxygen, and particulates, including man-made pollutants (MacIntyre, 1974). Even small wavelets can greatly increase its ability to absorb and transfer gases. This thin film is inhabited by floating plankton (neuston). Observation and sampling of the microlayer from below can be more effective than working from above. First, the diver can maintain a position a short distance from the layer without need for a nearby platform and with greater ease in holding his location in swell and waves than an observer on the other side of the boundary. Moreover, given the normal lighting situation and the sensitivity of the neuston, the submerged observer has a substantial advantage and should contribute substantially to new understanding of this regime.

Patchiness. The sea is remarkably heterogeneous. Patchy spatial relationships occur both vertically and horizontally in the finest to the grandest scales. Physical discontinuities such as thermoclines, current boundaries, microscale gradients, or even floating logs tend to give rise to patchiness of many biological and chemical products, but patchiness need not be associated only with physical processes. Zooplankton patchiness, for example, can occur in an otherwise apparently homogeneous water mass. This prevalent phenomenon is not well understood. Direct observations by divers of microscale patchiness as well as further macroscale studies with towed sensors would do much to quantify the extent of patchiness and help to explain its causes and effects.

EXPERIMENTAL METHODS

Investigations of the above categories may be broken into component tasks that may be performed by various technological means depending on the degree of skill needed. For example, some tasks require *in situ* the complex observational and manipulative skills of a diver who is a trained specialist in that particular field, while others can be satisfactorily performed by submersibles or remote-control vehicles (RCV's). Some tasks, because of their large scale or extreme depth (beyond saturation-diving limits), cannot be done by divers regardless of skill requirements.

Diving scientists have begun studying many pelagic phenomena that are effectively studied only by direct underwater observation. For example, Woods (1968) used scuba divers to study the fine-scale structure of the summer thermocline by releasing and photographing dye traces. Hamner *et al.* (1975) described the biology of gelatinous zooplankton by observing, collecting, and analyzing many specimens and made observations of macroscopic aggregates ("marine snow") with scuba.

Sample collection by scuba-equipped divers has been used to discover hitherto unknown organisms. Madin and Harbison (1978), for example, described a ctenophore belonging to a new order. Since collection by hand is much gentler than other methods, many laboratory experiments are possible that were previously not feasible (e.g., Harbison and Gilmer, 1976; Harbison and McAlister, 1979). However, it is the elucidation of trophic relationship and the study of behavior that use scuba most effectively. Scuba has been used to study the feeding behavior of ctenophores (Harbison *et al.,* 1978), salps (Madin, 1974), pteropods (Gilmer, 1972), and siphonophores (Biggs, 1977). Alldredge (1976) used scuba to study macroscopic aggregates from discarded larvacean houses and observed their use as a source of food, surface habitats, and particulate organic matter. This work has been extended to other types of detrital material by

Silver *et al.* (1978) and Trent *et al.* (1978). That gelatinous zooplankton provide surface and food sources for pelagic amphipods has been documented by Biggs and Harbison (1976), Madin and Harbison (1977), and Harbison *et al.* (1977). Other symbiotic relationships, such as that of two species of the diatom Rhizosolenia (Carpenter *et al.*, 1977), that between polychaete worms and ctenophores (Harbison *et al.*, 1978), and that between decapod larvae and medusae (Herrnking *et al.*, 1976) have also been studied with scuba. It is clear that if open-ocean saturation diving support facilities were available these same activities could be carried out at greater depths.

Manned exploration at depths below about 300 m in the water column must entail the use of 1-atm submersibles. Unmanned research can be done with RCV's, and both can be equipped with manipulators. Many research tasks in shallower waters also may lend themselves better to this type of technology than to diving because of cost, scale, or skill considerations.

Particularly, RCV's can be viewed not only as substitutes for divers but as complementary tools to enhance the effectiveness of men in the water. While the RCV is usually envisaged as operating from a surface ship, one has recently been used from the submersible *Auguste Picard* (J. Bennett, personal communication), and one could even envisage simple units operated by divers. This might be useful, for example, in allowing a swimmer to position illumination to provide backlighting for better observation of suspended matter in the water.

Many techniques developed for studying the shallower parts of the water column with divers can also be modified for use in deep waters by manned submersibles and unmanned RCV's. Indeed, observations of midwater phenomena from untethered submersibles has begun (e.g., Peres, 1959; Barham, 1963; Madin and Harbison, 1978; Backus *et al.*, 1968; Heirtzler and Grassle, 1976). An Oceanlab Program that can put existing submersible, RCV, and manipulator technology to wider use in water-column studies can greatly enhance our knowledge of the deep waters of the sea.

UNDER ICE

This zone, beneath the permanent and pack ice of the polar seas, presents special problems for all the manned and unmanned technologies previously discussed. The logistical problems attendant to polar oceanography are immense. Most ecological questions that are considered important give rise to dependence on technologies that are not now easily available.

The two polar areas are very different, as the northern one basically is an ocean surrounded by land and large shallow shelves, while the southern area is a large land mass with deep narrow shelves around which the southern ocean flows.

All oceanographers studying polar oceans are impressed with the intense biological activity in the pack-ice zone. It has been shown that two days of strong wind across an ice front can cause upwelling from at least 150 m to the surface (Buckley *et al.*, 1979). In addition to localized upwelling, the pack-ice zone offers great physical heterogeneity, which certainly enhances the complexity of biological interaction. The pack-ice zone includes a large geographic area around both poles, yet limits in technology have prevented adequate research in the summer, much less in the winter. These studies must be done throughout the water column to and including the benthic boundary layer and should continue beyond the edge of permanent ice, especially in the Arctic Ocean, which is facing a rapid petroleum development. Traditional samples have been taken in a few areas during the brief summer period, but they are inadequate for even a descriptive, much less a mechanistic, understanding of ecosystem functioning (P. Dayton, Scripps Institution of Oceanography, personal communication, 1979). Clearly, much more advanced under-ice technology is needed.

Techniques for using under-ice scuba diving are well developed and have been used in benthic-ecological studies under the ice in the shallow waters of the Weddell Sea for over 10 years (Dayton, 1974). These same methods might be adapted for limited water-column studies under ice. In many cases, waters under the ice are exceedingly clear (up to 300 m visibility in the Antarctic), and some sort of trapeze-like tether such as that described by Hamner (1975) would be necessary to avoid diver disorientation when working over deep bottoms.

MacInnis (1973) has used the bottom-sitting habitat *Sub-igloo* under the ice in shallow water in the Canadian Arctic. A mobile deep-diving system (DDS) that could be moved about from place to place over the ice on skids might be able to support saturation divers under ice both in the water column and on the bottom. A DDS operated from a sturdy monohull ship with a "moonpool" for launch and recovery of the submersible-diving chamber (SDC) below the water line might be able to operate in the pack-ice zone and, with the aid of an icebreaker, into permanent ice. This ship-type is now in common use in North Sea oil fields.

Diving from a lock-out or 1-atm submersible presents a serious problem under ice, since the sub cannot safely surface except in its "hole" (Milne, 1969).

Tethered (manipulation-observation) bells might be able to operate in the same way as a SDC on a DDS, either supported over the ice on skids or from a surface ship, and with some limitations.

Unmanned RCV's may indeed be the best way to bring advanced technology to research under the ice because of the many safety and logistical problems inherent in manned activities. However, even unmanned RCV's must first, in some way, be delivered to rather inaccessible areas. Delivery of the hardware seems to be the major problem in studying the polar seas.

Consideration should be given to initiating an arctic component within an Oceanlab Program to deliver advanced technology to the polar regions and bring it to bear on its many research problems. Research under (and around) the ice can open many new vistas in the understanding of this vast and important region. Initial emphasis should be in the pack-ice zones, especially in the Arctic. Because of the severe operating conditions in the polar seas, Oceanlab operations should be perfected in more temperate regions first.

6
Lower Slopes and Deep-Sea Floor

The requirements for scientific research on the deep-sea floor, and on the continental or island slopes (below 1000 m), dictate the use of different platforms, systems, and to an extent sensors and instruments from those that might be used on the shelves, and upper slopes, or in the water column, even though there are common elements in the proposed facilities to conduct needed research in all of these regions. The deep-sea floor environment imposes special requirements in respect to man-in-the-sea studies because of extreme pressure, low temperature, and great separation from surface support. There are also special characteristics of the seafloor and its biota stemming from some of the same factors that impose special conditions on the facilities for scientific research in these regions. Yet, in part because the regions are so little known, there is a great demand for research in these areas and, at the same time, a marked lack of platforms from which to conduct this research. Some, but by no means all, can be carried out from surface vessels or using remotely operated vehicles. Other research requires the use of a deep-diving manned submersible. The only such nonmilitary submersible now available in this country is *Alvin,* which has some limitations, particularly with regard to its support vessel and its depth capability (4000 m limit).

Looking at the research programs for the deep-sea floor and lower slope, almost all of them can be characterized as geological, geophysical, biological, or chemical oceanographic studies that require man-in-the-sea tools and techniques (Ballard and Keller, 1977).

The vast expanse of the floor of the world's ocean is the ultimate resting place for matter either falling through the water column or transported there by dynamic processes, such as submarine density flows. This material deposited on the ocean floor may be permanently incorporated into sediments or may be partially released back into the seawater through the benthic boundary layer. The benthic boundary layer is therefore a zone where considerable interfacing takes place, including sediment deposition, erosion, and transportation, significant gradients of velocity, as well as physical, biological, and chemical properties (McCave, 1974).

Studies of the benthic boundary regime of deep oceans refer to the phenomena and processes occurring at and near the water-sediment interface, generally several meters above and a few meters below it. The processes occurring in this regime are complex interactions of geological, biological, chemical, and physical processes, which are at present not well understood, either qualitatively or quantitatively. Yet, they and their interactions are important, as they regulate various major oceanic processes and phenomena, including the chemical and physical flux of the particulate substances rained onto the seafloor back into the seawater, microbial degradation of sedimenting particulates, and the ecological balance of various benthic species. An understanding of benthic processes is also relevant to decisions concerning ocean dumping, radioactive waste disposal, and deep-sea mining (NOAA, 1974).

Many of these deep-ocean benthic phenomena, such as biological activities, including reproduction, rehabilitation of ecological communities, and bioturbation of sediments, occur at relatively slow rates (months to years), whereas other phenomena, such as density or turbidity currents along the deep ocean floor occur sporadically and in short time scales (minutes to hours) when they do occur (Heezen and Ewing, 1952). Some phenomena and environments, such as the Galapagos hydrothermal vents, around which unique biological ecosystems have recently been discovered, are highly localized, to dimensions of a few meters (Corliss *et al.,* 1979; Spiess *et al.,* in press). To investigate and accurately characterize individual processes and their mutual interactions, as well as the relationship between deep-sea biological activities, the biochemical paths and rates for conversion of insoluable to soluble chemical states and the chemical flux from the sediments to seawater, very detailed studies must be made. It is apparent that there is a need for greater precision and resolution of measurements and observations than is now possible from studies directed from surface vessels. Some of this can best be attained by a man-in-the-sea approach.

Following are a number of problem areas relating to the benthic boundary layer to which a man-in-the-sea effort can contribute significantly:

- Variability in the benthic boundary layer.
- Determination of turbulence characteristics and mean velocities in order to define bed-shear stress and eddy-diffusion coefficients.
- Determination of fluxes of momentum and heat, various chemical constituents, and sediment into and out of the boundary layer.
- Interaction of biota and sediments and the resulting alteration of mass physical and chemical properties of the bottom deposits.
- Sediment stability relative to gravitational forces as well as currents.
- Determination of factors controlling the basic geotechnical properties of the benthic layer and their interrelationships.
- Determination of the influence of suspended material and bed forms on the boundary-layer flow and *vice versa.*
- Determination of sediment erosion threshold velocities under a current where the bottom is roughened by ripples or irregularities produced by organisms.
- Determination of the importance of mucous and other excretory products of biological activity on sediment cohesion and erodability.
- Determination of the rates and mechanisms of chemical and biochemical reactions in the boundary-layer sediments.
- Determination of the stages of benthic community succession for which particular processes of stabilization are characteristic.
- Determination of the relative metabolism of the various components of benthic communities (e.g., size group, taxa, metabolic types, and physiological state) in both aerobic and anaerobic conditions.

Other scientific studies on the deep-sea floor and lower slope are related to, or stem from, the processes of plate tectonics. Plate-tectonics models were developed largely in an oceanic context and have been successful in providing a framework interrelating a wide variety of geological and geophysical observations. A number of new questions have emerged, however, as a result of the studies made in this broad context.

The first-order problem is the nature of the forces that drive the entire process. Since these act in inaccessible places it appears that their nature will have to be inferred from a wide variety of answers to more specific questions. Examples of these questions are the following:

• To what extent do the plates act as completely rigid units.

• How does their bulk motion relate to the details of motion in the boundary zones?

• What is the nature and significance of zonation in the chemical properties and superficial forms of the newly emplaced material (e.g., pillars, sheet flows, highly fissured regions)?

• How do transform faults develop and persist?

• What can be learned from older materials occasionally exposed by the transform fault process?

• How do earthquake activity along the transform faults and in the trenches relate to gross plate motion and spreading center processes?

Other new questions of importance resulting from our growing knowledge in this field are those relating to hydrothermal effects and mineral formation. Studies of these and their ramifications are in the exploratory stage in which scientists are still groping, finding new things, and speculating as to the extent that these new phenomena exist as a general rule or are unique and site specific. Examples are the warm-water organisms at the Galapagos Spreading Center (Corliss *et al.* 1979), the metal-rich sulfide mounds on the East Pacific Rise crest at 21° N (Francheteau *et al.*, 1979), the associated intense hot-water discharges (Spiess *et al.*, in press), and the swarm of very shallow focus microearthquakes encountered at the Galapagos Spreading Center (Macdonald and Mudie, 1974). Observations of sufficient detail to address these questions have been made at only two or three locations, accounting for an almost insignificant fraction of the total length of active spreading ridge and rise crest terrain where such phenomena occur. Undoubtedly other discoveries will evolve as this exploratory phase proceeds and develops into more highly focused studies of specific phenomena.

The lower continental slope is also a region where scientific research is required, and where there are special conditions requiring unique observational and manipulative techniques. The continental slope is locally steep and frequently gullied. Its escarpments are defaced by rock avalanches, and its valleys are scoured by tidal surges and density currents. Although the slope and the living creatures that populate it persist through long periods of relative tranquility, these periods are punctuated by instances of bottom instability and violent activity (Heezen and Ewing, 1952), which severely alter the bottom and its inhabitants.

Variability in the characteristics of the substrate caused by erosion-deposition or outcropping of lithified formations are matched by a patchiness and diversity in the bottom-dwelling fauna. Scientific investigations such as stratigraphy or behavioral biology, respectively, call for the collection of rock specimens from specific sites along often near-vertical outcrops and the observation of ecological communities on a site-specific basis.

What are the implications of a facility designed to meet the scientific requirements outlined above? It is evident that a highly mobile and manipulative deep-sea platform, equipped with sensitive observational and other scientific sensory equipment capable of operation in deep ocean conditions at or near the seafloor is needed. This platform, whether directly manned or remotely controlled, should have, at the outset:

- Instrument versatility.
- Long operational duration (8-72 h), particularly in relation to the time needed to deploy and recover the vehicle.
- Fine positional capability (precise sampling and measurement at the sediment-water interface is not possible with conventional sampling devices operated from surface vessels).
- An operational range in terms of operating depth (minimum 6000 m) and geographical distance from port facilities so as not to restrict choice of study sites unduly.
- Precision navigation (it should be possible to emplace instruments and return to them over a period of years).

The major functions in which a generalization of man's unique capabilities would be required are actually quite varied. Those requiring good observational and maneuvering ability are largely oriented toward sampling of strata exposed in various outcrops, investigation of mineral deposits (sulfide mounds, for example), hydrothermal water sampling, and benthic biota studies and collections. Thus, both mobility and means of sampling are required of the platform.

Another important function is the careful implantment and adjustment of instruments to be used for long-term monitoring of various dynamic processes, such as strain-tilt buildup, and hydrothermal activity associated with tectonic activity, as well as to carry out geophysical experiments to determine the degree and depth to which rocks are fractured and flooded with water.

Many conventional oceanographic approaches are not suitable for the finer degree of resolution or accuracy of measurement needed to advance seafloor studies effectively. Examples of such inadequacies are abundant. Benthic trawling is hazardous to the equipment itself, not to mention to the various specimens. Neither geophysical surveys from surface ships nor bottom-towed photographic sleds are able to capture the transient phenomena responsible for the brief but intensive reshaping of the seabed. Rock dredging allows only the collection of random samples and no way of knowing the relationship of the samples to the overall rock sequence.

Man-in-the-sea technology will permit improved design of soil-engineering tests critical to the prediction of slope stability. Submersibles or RCV's can locate the implanted remote monitors at the sites most ideal to experience short-term transient changes. Extended endurance will make possible direct observation of complex interactions and behavior at the time of strong upper-ocean turbulence.

For observation and sustained measurement through diurnal cycles one would like multiday on-bottom duration. The submerged facility needs to be navigated to accuracies of a few meters and to be able to revisit sites for replicate sampling as well as being equipped to handle multiple sensors with automated data loggers. Color video recording, micro and wide-angle photography with stereo options, sampling and manipulative ability using various external tools are all desirable. Large-capacity sample containers such as external tanks with preservative for biological organisms and others with controllable hyerbaric pressure and temperature as well as pumps and filters, remote sensors for temperature, neutron activation, x-ray fluorescence, salinity, oxygen, pH, ambient light, and backscattering are also desirable. Not all of these facilities would be in use simultaneously or even necessarily available on a single bottom-operated platform. The data in Table 1, taken from Ballad and Keller (1977) summarize much of what has been discussed above. Although Table 1 was prepared with a submersible in mind, developing technology implies that these functions could in the future be carried out as well with remotely operated vehicles on or just above the seafloor.

In accomplishing these tasks, man should have the means, and opportunity, of choosing his point of observation in relation to the larger environment. The measurements he will make will be mostly intermittent (except those recorded, for example, by bottom-sited instruments), but he must have the opportunity to use his judgment as to when or how often to sample. Similarly, the accuracy of his positioning, relative to a local reference point, is important in order to document various interrelationships. Finally, he should be able, at the least, to improve his knowledge of large-scale processes, such as slumping, possibly by selectively spaced photographic recordings and instrument implantation.

In this regime, then, there is a wide variety of important questions both in sediment/water interface problems and in relation to plate tectonics. In both classes, opportunities exist by fruitful

TABLE 1 Applications of Submersible Capabilities to Scientific Studies

Studies	Submersible Capabilities (Functions)
Volcanic processes	Inventory, describe, and delineate fine-scale volcanic topography; distinguish volcanic phases of different age; identify axes of intrusion; collect precisely and closely spaced samples to determine petrologic, geochemical, and age gradients showing existence and evolution of magma chambers
Hydrothermal activity, geochemical processes, and metalliferous sediment	Locate active vents; determine heat and seawater budgets; quantify fluxes of matter from seawater into rocks during alteration of midocean ridge crust
Crustal deformation and strain rates	Select sites, secure ocean-bottom seismometers, acoustic benchmarks, and other geodetic instruments to the seafloor, and service equipment
Magnetic characterization of oceanic crust	Investigation of possible short reversals and the Brunhes/Matuyama reversal boundary by detailed sampling of reversely magnetized lavas and by determining crustal polarity in place
Transform faults and transform fault-rise intersection	Sample precisely identified crustal levels and tectonic situations in complex geologic terrains
Metabolic rates of deep-sea organisms and communities	*In situ* innoculation of potential substrates for assimilation by the biota; precise sampling of the water column and sediments; monitor and subsample *in situ* incubations over varying time intervals; placement of instruments with minimum disturbance of organisms or environment; selectively capture animals

Rates of recruitment and growth of benthic populations	Modify bottom (azoic sediments, concentration of organic material) and sample precisely with respect to the disturbance over time intervals of a year and longer; assess natural spatial variability of benthic communities on appropriate spatial and temporal scales
Fluxes of inorganic and organic materials across and in the benthic boundary layer	Study organisms and organic geochemical processes with respect to large concentrations of organic matter such as wood islands or garbage; collect bottom samples in immediate vicinity of sediment traps; monitor operation of sediment traps
Bottom dynamics, sedimentary processes and bioturbation	Place sensitive current meters with respect to bottom topography, sedimentary structures, and organisms; monitor tracers placed on or near the bottom; make visual observations of local irregularities in bottom dynamics and sediment properties; visually assess sediment-organism interactions

investigation by both geologists and biologists. *Alvin, Cyana,* and the bathyscaphes (*Archimede* and *Trieste,* plus simple unmanned survey vehicles (Deep Tow, ANGUS) have already had significant impact, and the future should see the capabilities extended and augmented by use of more sophisticated unmanned seafloor vehicles.

7
Notes on Technological Options

The preceding chapters have outlined a variety of research topics in which observation or complex manipulation play an important role. These functions can be carried out by the scientist working in any of several ways: as a swimmer directly in the water, as an on-site observer/equipment operator in a submersible, or working by remote control from the laboratory of some major support vehicle.

Our prototype is the well-equipped man in the water. In the upper 30 m in clear, calm water the scuba-equipped diver is probably the most cost-effective research system in this category. Unfortunately only a small fraction of the research discussed can be done under such ideal conditions. With auxiliary devices to provide propulsion, heat, navigation, illumination, sonar, communication, shark protection, photography, and data recording, however, he can cope with a much wider range of circumstances. Most of the support requirements are well within the reach of today's technology even though not all scientific diving programs have the full range available. While the Oceanlab Program might lead the way in developing new versions of some of these capabilities it does not seem that any major effort in this arena would be required.

By moving into the saturation diving regime one can achieve an order-of-magnitude increase in depth capability. Mixed gas saturation dives by highly conditioned and trained personnel have gone as deep as 500 m (Buckman, 1977), and one should expect to be able to carry out scientific missions to about 300 m. This approach, however, also requires an order-of-magnitude increase in the direct support facility requirements--either a habitat at working depth or some type of on-ship living chamber with a personnel transfer capsule. The technology involved, however, is well developed and available commercially. It is interesting to note that both the naval and commercial diving groups have gone almost exclusively to the personnel-transfer-capsule (PTC) types of systems. These provide far greater mobility in both the local and large-scale sense than today's habitats. They also allow for delivery of the divers into more complex topographic situations and with minimal alteration of the natural environment. Use of small, lock-out submersibles as locally free-roaming transfer capsules provide the utmost in mobility in this category, at the sacrifice of the ease of the PTC in providing breathing gas, heat, light, and other human-support items.

Within the top 300 m the saturation diver can carry out whatever tasks his unsaturated counterpart can handle in the top 30 m. One difference that is sometimes ignored, however, is that the saturated diver has quite limited upward excursion capability--he is far from capable of working the entire water column. This is not a disadvantage in seafloor research, but if one is studying animals that move substantially in the vertical it may well be. For example, it would be impossible to match the diurnal excursions of the deep scattering layer.

Below 300-500 m there is little possibility that scientific diving will be effective for many years into the future. Two choices are then available to provide the functional capabilities required. Either the man can go to the site of his research in a submersible (free or tethered) or he can remain in the laboratory of his support craft and operate remotely controlled devices (Busby, 1979). In either event he can make his observations, collect samples, and carry out experiments. These same capabilities can clearly also compete with the diver in the upper part of the sea. The relative capabilities, danger, and costs are such that frequently the nonswimmer approach is chosen, and collaborative operations between saturation divers and unmanned remotely controlled observational vehicles have become a preferred operating mode in some oil-industry-related situations.

The free, manned submersible, particularly in the deep-ocean context, is in a more advanced stage of development than the unmanned systems, with *Alvin* operating routinely for research to depths of 4000 m. At least two 6000-m submersibles (U.S. and French) may be realities within the next few years. On the other hand, new technological options and opportunities that relate most strongly to unmanned, remotely controlled vehicles have not yet been assimilated for deep-ocean research. Dramatic improvements in television resolution, possibilities of cables utilizing repeaters or fiber optics to provide high-data-rate transmission links, and integrated-circuit technology are all becoming reality and should be able to be combined to produce systems that can rival the manned submersible. Already in the shallow-water situation unmanned, tethered swimming units are finding application (Busby, 1979) particularly under circumstances in which there would be significant danger for a swimmer or a submersible. Trade-offs between manned vehicles have been discussed in a number of contexts (e.g., Talkington, 1976).

In short, the technology is already well established for three of the four approaches (scuba, saturation diving, submersibles). A program to improve unmanned vehicle capabilities in deep water might be a part of Oceanlab.

While the actual in-water units are in reasonable condition, the availability of the necessary support vehicles in the research context is very poor. *Alvin,* for example, is severely limited by the nature of her support ship, *Lulu.* With some modification a number of ships in the research fleet (*Melville, Knorr, Atlantis II)* could be equipped to handle saturation diving systems and deep ocean research vehicles. *Melville* and *Knorr* in particular have the propulsion flexibility to provide good station keeping and amidships wells through which a properly designed PTC could be operated. FLIP could also provide a unique stable base to support open ocean diving with complementary tethered RCV operation.

The major improvement that Oceanlab could provide would be an independent oceangoing craft capable of supporting (not necessarily simultaneously) saturation diving, small submersibles, and unmanned observation and work vehicles. While a large conventional ship could do this (most commercial diving, RCV's, and submersible support is now provided in this way) there are advantages (particularly in terms of seakeeping capability) in giving serious consideration to other options. Three alternative types have been discussed--each with strengths and weaknesses that should be evaluated against cost and research capability.

First is an autonomous submarine, a close relative of the mobile habitat studied in earlier phases of the Oceanlab program (NOAA, 1978). It has the advantage of weather independence, at least for the duration of its battery charge (we assume that a nuclear submarine would be out of the cost range of the research community) and could serve as an on-bottom or hovering habitat for direct diver access. While small submarines and RCV's could operate from such a craft, it would be quite difficult to bring them on board submerged for repair or major equipment alteration. With proper (although by normal standards, unconventional) superstructure design and attention to ballasting details it should be possible to surface with the tended vehicle on deck when such repairs were necessary and thus not be much worse off than a surface ship. Given the normal weight and pressure hull constraints, craft of this type have limited capability for alteration to meet new needs or opportunities.

Second would be a twin-hulled semisubmerged ship (Lang *et al.*, 1975; Spiess *et al.*, 1976). Such craft, with broad beam, fairly deep draft, and small water plane area, can have good seakeeping capabilities. With access to the air the propulsion, life-support, and communication systems are much simpler than for the submarine, and crew skill requirements are less. The space between the twin hulls would be well matched to launch and retrieval of submersibles and RCV's. The large deck area would be advantageous for equipment preparation.

Third would be a flippable-type craft, having shallow draft while under way and very deep draft while on station (Spiess *et al.*, 1974; Spiess, 1976). Divers, PTC's submersibles, and RCV's could all have access to the interior in quiet water well below the sea surface. In shallow-water situations the tending would be done with the ship in the shallow draft position. Again, access to the atmosphere would have similar advantages as in the semisubmerged ship. Because of its simple barge-like hull form, this would probably be the least expensive option.

A third aspect of technological impact exists, but it is of a more diffuse nature. While the observational function is of fairly direct importance, a large variety of manipulative functions are implied in the research ideas mentioned above. These carry with them the need for a wide variety of sampling, collecting, and *in situ* measuring devices appropriate to the imagined tasks. Since many of these activities will be new, it should be anticipated that a larger than average fraction of the individual research project budgets and efforts will be related to the development of new tools in the context of specific individual research objectives.

In summary, there is a great deal of technology available for Oceanlab in support of important research topics. Some judgment will be required to choose among alternatives and bring forth a useful and cost-effective program.

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Appendix A: Acknowledgments

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APPENDIX B

Listing of Titles of Potential Oceanlab Research Projects

CONTENTS*

*Projects are listed alphabetically by originators. Information provided consists of project topic, name(s) and affiliation of originator(s) and project file number.

BIOLOGICAL OCEANOGRAPHY

1 Great Lakes Research
Allen, David
DOI, Fish & Wildlife Service, Fisheries Rsrch
B 068

2 Biological and Geological Studies
Anonymous
X-1 (Industry)
B 098

3 1. Impact of Human Activity on Marine Ecology
Anonymous
X-4 (Industry)
B 097

4 a. In Situ Respirometry b. Faunal Surveys c. Experimental Ecology d. Growth Rates of Calcareous Organisms e. Sediment Movement Measurement
Avent, Robert M
Harbor Branch Foundation
B 051

5 Porpoise/Tuna Relationships
Barham, Eric; Au, David
DOC, NOAA, NMFS, SWFC
B 089

6 Seamount Ecosystem Study
Barkley, Richard
DOC, NOAA, NMFS, SWFC, Honolulu Lab
B 088

7 Primary and Secondary Standing Stocks and Turnover Rates
Bienfang, Paul K
The Oceanic Institute
B 008

8 Benthic Systems
Boesch, Donald F
Va Institute of Marine Science
B 028

9 Deep Sea Fauna Distribution
Brauer, Ralph W
Institute of Marine Biomedical Research
B 012

BIOLOGICAL OCEANOGRAPHY

10 Survey of Reef Fish Communities
Bullis, Harvey, et al
DOC, NOAA, NMFS, SWFC
B 095

11 Improvement of Harvesting Gear and Techniques
Bullis, Harvey, et al
DOC, NOAA, NMFS, SWFC
B 094

12 a. Benthic Processes b. Lower Photic & Subphotic Zone Photosynthesis c. Sea Ice Primary Production
Bunt, John S
Australian Institute of Marine Science
B 050

13 Growth Kinetics (Kinetic Control of Marine Processes)
Button, D K
Univ of Alaska
B 010

14 Environmental/Ecological Monitoring
Chase, Gilbert L
US Army, COE, New Engl Div, Environmental Anal Br
B 056

15 Reef Ecosystems, New Caledonia vs Hawaii
Chave, Keith E
UH at Manoa
B 007

16 Functional Ecology of Underwater Communities
Childress, J J
UCSB
B 004

17 Galapagos Rift Vent Fish Survey
Cohen, Dan
DOC NOAA/NMFS Systematics Lab
B 054

18 Sustained Yield Studies - Corals
Cooke, Thomas S
DOI, BLM, Pacific OCS Office
B 057

BIOLOGICAL OCEANOGRAPHY

19 a. Microbiology of Sediments b. Coral Community Metabolism as a Function of Depth c. Sediment/Water Column Chemico-Dynamics as a Function of Depth
Cooksey, Keith E
U Miami, RSMAS
B 052

20 Ocean Pulse
Cooper, Richard
DOC, NOAA, NMFS, NEFC
B 096

21 Herring Spawning, Base Line and Biological/Geographical Mapping
Cooper, Richard
NMFS, NE Fishery Center
B 075

22 a. Photosynthesis b. In Vivo Animal Study of Decompression Sickness c. Ca/Sr Ratios in Corals & Their Environments
Cratin, Paul D
Central Mich U, Dept of Chemistry
B 053

23 Investigation of Energy Production
Crecelius, Eric A
Battelle NW, Marine Research Lab
B 055

24 a. Artifical Reef Studies b. Lobster Fishery Assessment c. Tilefish Natural History
Crozier, George F
U of Ala, Marine Science Program, Dauphin Island Sea Lab
B 049

25 Community Ecology
Dayton, Paul K
UCSD, SIO
B 048

26 Coral Reef & Coastal Ecosystems with Interrelationships Between Coastal & Deep-Sea Ecosystems
de Sylva, Donald P
U of Miami, RSMAS
B 011

BIOLOGICAL OCEANOGRAPHY

27 Productivity and Energy Flow through Water Column
DeWitt, Hugh H
U of Maine at Orano, Dept of Oceanography
B 003

28 Marine Mammals
Dunson, William A
Penn State Univ
B 031

29 a. Documenting Ecology & Distribution of Plants & Animals, b. Humpback Whale Behavior, c. Food Webs
Earle, Sylvia A
Cal Academy of Sciences
B 047

30 Photosynthesis Process in Deep Ocean
Earle, Sylvia A
Cal Acad of Sci, Dept of Botany
B 093

31 Ocean Pulse Program
Edwards, Robert
DOC, NOAA, NMFS, NE Fish Center
B 084

32 Extended Alaskan Coastal Studies
Favorite, Felix
DOC, NOAA, NMFS, NW & Alaska Fish Cnt, Resource Ecol & Fish Mgt Div
B 077

33 Shell Fish Surveys
Favorite, Felix
DOC, NOAA, NMFS, NW & Alas F C, Resource Ecology & Fish Mgt Div
B 100

34 Bioluminescence of Midwater Fish
Gibbs, Robert
Smithsonian Institution, MNH, Div of Fishes
B 062

BIOLOGICAL OCEANOGRAPHY

35 Experimental Approaches to the Study of the Biology of Deep-Sea Animals
Gordon, Malcolm S
UCLA, Inst Evolut & Environ Bio
B 019

36 Fin Fish and Shell Fish Population Investigations
Gotshall, Daniel W
Calif Dept of Fish & Game
B 046

37 Coastal Ecosystems
Haines, Evelyn
U of Ga, Marine Institute
B 024

38 Open Ocean Zooplankton and Nekton
Harbison, G Richard
WHOI
B 030

39 Distribution, Behavior and Role of Macroplankton
Harbison, G Richard
WHOI
B 002

40 Effects of Dredge Disposal
Harrison, John
DOD, US Army, COE, Environmental Effects Lab
B 065

41 Spiny Lobster Behavioral Ecology
Herrnkind, William
FSU, Dept of Biol Sci
B 040

42 Sable Fish (Black Cod) Program
High, William
DOC, NOAA, NMFS, NW & Alaska Fisheries Center
B 078

43 Coral Immunology
Hildemann, W H
UCLA, Dept of Microbiology & Immunology
B 033

BIOLOGICAL OCEANOGRAPHY

44 Marine Food Webs
Iverson, Richard
FSU, Dept of Oceanog
B 022

45 Deep-Sea Biology
Jumars, Peter A
U of Wash, Dept of Oceanography
B 027

46 Marine Biomedical Research
Kaul, Pushkar N
U of Oklahoma
B 013

47 Long Term Understanding of System Structure and Functions
Kraeuter, John N
Va Institute of Marine Science
B 032

48 Behavioral Studies
Kutkuhn, Joseph
DOI, Fish & Wildlife Serv, Gt Lakes Fishery Lab
B 064

49 Trophic Dynamics, Marine Birds & Mammals
Lensink, Calvin J
DOI, Fish & Wildlife Serv, Off of Biol Services
B 063

50 Benthic Sampling and Communities. Water Sediment Interface.
Lynch, Maurice P
VIMS, Div Bio Oceanog
B 041

51 Directional Energy Flow From Phytoplankton to Fishes
Malone, Thomas C
Lamont-Doherty Geological Observatory
B 006

52 Invertebrate and Fish Systematics
Manning, Raymond B
Smithsonian Inst, Nat'l Museum of Nat Hist
B 029

BIOLOGICAL OCEANOGRAPHY

53 Food Chain Development
Plankton Microbiology
Mullin, Mike
UCSD, SIO
B 074

54 Effect of Man on Productivity of the Ocean
Neal, Richard A
DOS, Agency for International Development
B 023

55 Mechanisms, Activities and Uses of Marine Bioluminescence
Nealson, Kenneth H
UCSD
B 001

56 Ocean Resource Management
Norris, Kenneth S
UCSC, Coastal Marine Lab
B 005

57 Kelp Biology
North, Wheeler
Cal Tech, Kerckhoff Marine Lab
B 076

58 Kelp Research
Ostenso, Ned
DOC, NOAA, Sea Grant
B 092

59 Oxygen Minimum Zone, Oceanic Upwelling, & Convergence Zones
Packard, Theodore T
Bigelow Lab for Ocean Sciences
B 025

60 Echinoderm and Other Invertebrate Research
Pawson, David L
Smithsonian Inst
B 042

61 Echinoderm Study
Pawson, David
Smithsonian Inst, NHB, Dept of Invert Zool
B 059

BIOLOGICAL OCEANOGRAPHY

62 Structure & Dynamics of Oceanic Deep-Sea Ecosystems
Pearcy, William G
Oregon U, School of Oceanography
B 017

63 Distribution and Transport of Biota
Pilson, Michael E Q
URI
B 034

64 Coral Reefs
Porter, James W
U of Mich, School of Nat Resources
B 043

65 Marine Pharmacology
Powell, B A
NUSC, Undersea Science Dept
B 020

66 Ecosystem Study - Kodiak, Alaska
Pruter, Allen, et al
DOC, NOAA, NMFS, NW & Alaska Fisheries Center
B 091

67 Impact of Expanding Clam Industry on Pacific Walrus
Pruter, Allen
DOC, NOAA, NMFS, NW & Alaskan F C
B 099

68 Fish Migration in Submarine Canyons
Pruter, Allen, et al
DOC, NOAA, NMFS, NW & Alaska F C
B 079

69 Arthropod Research
Purkerson, Lee
DOI, National Park Service, Resources Branch
B 070

70 Biological/Chemical Aspects of Ocean Disposal
Reynolds, Bruce
EPA, Office of R&D
B 045

BIOLOGICAL OCEANOGRAPHY

71 Biological/Ecological Effects
Richards, Norman
EPA, ERL
B 066

72 Cephalopod Studies
Roper, Clyde
Smithsonian Institute, Division of Mollusks
B 061

73 Effect of Light on Coral Reefs
Roth, Ariel
Loma Linda U, Dept of Biol
B 044

74 Mid Atlantic Bight Shelf Ecosystems
Rowe, Gilbert T
Brookhaven N.L.
B 101

75 Deep Ocean Floor
Sanders, H L
WHOI
B 016

76 Invertebrate Life Histories
Scheltema, Rudolf S
WHOI
B 026

77 Marine Mariculture and Toxicity
Sherwood, Bill
DOE, Solar Energy Division
B 067

78 Northwest Hawaiian Islands Survey
Shomura, Richard S, et al
DOC/NOAA/SWFC
B 083

79 Pelagic Fish Communities
Shomura, Richard S
DOC, NOAA, NMFS, SW Fish Ctr, Honolulu Lab
B 085

BIOLOGICAL OCEANOGRAPHY

80 Vertical Transport
Small, Lawrence
Oregon S U, Sch of Oceanog
B 039

81 Origin and Fate of Small Particles in Selected Near-Coast Regions
Small, Lawrence F
Oregon S U
B 009

82 Trophic & Chemical Dynamics of Shelf Ecosystem
Smayda, Theodore J
URI, GSO
B 015

83 Ichthyology/Fish Ecology
Smith, C Lavett
Am Museum Nat'l Hist
B 035

84 Ecological Energetics of Midwater Communities
Smith, Kenneth L Jr
USCD, SIO, Bio Research Div
B 086

85 Oil Production Monitoring
Smith, Melissa
DOI, BLM, New Orleans OCS Off
B 071

86 Biological Mapping
Smith, Melissa
DOI, BLM, New Orleans OCS Off
B 069

87 Distribution & Behavior of Fish in Alaska
Smoker, William
DOC, NOAA, NMFS, Auke Bay Fisheries Lab
B 080

88 Shell and Groundfish Surveys
Smoker, William
DOC, NOAA, NMFS, Auke Bay Fisheries Lab
B 082

BIOLOGICAL OCEANOGRAPHY

89 Evaluation of Fisheries Harvesting Gear
Smoker, William
DOC, NOAA, NMFS, Auke Bay Fisheries Lab
B 081

90 Precious Coral Survey
Smoker, William
DOC, NOAA, NMFS, Auke Bay Fisheries Lab
B 090

91 Sediment Transport & Marine Environment
Soutar, Andrew
USCD, SIO
B 087

92 Reef Species Behavior
Springer, Vic
Smithsonian Inst, MNH, Div of Fishes
B 058

93 Deep-Sea Benthic Ecosystem & 200-Mile Limit Living Marine Resource
Staiger, Jon C
U of Miami, RSMAS
B 018

94 a. Lobster Studies b. Impact of Ocean Spoil Disposal on Biological Communities
Steward, Lance
U Conn, Marine Sci Inst, Marine Adv Serv
B 036

95 Deep Reef Development & Structure
Taylor, Dennis L
U of Miami, RSMAS
B 038

96 a. Ecological Surveys of Petroleum Industry Areas b. Measurement of Light Response of Marine Organisms c. Spawning of Commercial Fishes - Ground Location & Behavior Studies d. Acoustic Behavior of Marine Animals & Acoustic Identification of Commercial Species
Thompson, Thomas W
U Cal Extension Service
B 037

BIOLOGICAL OCEANOGRAPHY

97 Foodchain and Predator-Prey Relationship
Voss, Gilbert L
U of Miami, RSMAS
B 014

98 Deepwater Scallop Study
Waller, Tom
Smithsonian Institution, MNH, Dept of Paleobiology
B 060

99 Energy Transfer up Food Webs
Walsh, John
Brookhaven NL, Oceanog Sci Div
B 021

100 OCS Development Studies
Watson, Jay F
DOI, Fish & Wildlife Service, Off of Biol Sciences
B 073

101 Drilling Effects and Resource Distribution Evaluation
Woodard, Donald
DOI, Fish & Wildlife Serv, Natl Coastal Ecosys Team
B 072

CHEMICAL OCEANOGRAPHY

1 Anaerobic Spaces in the Oceans
Anderson, James J
U of Wash, Dept of Oceanography
C 014

2 Equatorial Circulation System
Arrhenius, Gustaf
UCSD SIO, Geological Research Div
C 019

3 Equatorial Circulation System - Sedimentation
Arrhenius, Gustaf
UCSD SIO Geological Research Div
C 018

4 Equatorial Circulation System - Ore Resources
Arrhenius, Gustaf
UCSD SIO Geological Research Div
C 017

5 Caribbean Basins
Atwood, Donald K
DOC, NOAA, AOML
C 012

6 Gulf of Mexico & Mississippi Outflow
Atwood, Donald K
DOC, NOAA, AOML
C 011

7 Chemical Fluxes at Poles and Rock Weathering
Bankston, Donald C
WHOI, Dept of Chemistry
C 007

8 Deep Atlantic Metabolic Maximum Project
Brass, Garrett W.
FSU, Dept of Oceanog
C 022

9 General Chemical Oceanography
Broecker, W S
Lamont-Doherty Geological Observatory
C 023

CHEMICAL OCEANOGRAPHY

10 Organic Chemical Oceanography and Geochemistry
Butler, James N
Harvard U, Div of Eng and Applied Physics
C 027

11 Spatial Distribution of Chemical Species
Chave, Keith E
UH at Manoa, Dept of Oceanog
C 013

12 Material Transport from Land to Sea
Church, Tom M
U Del, Col of Marine Studies
C 025

13 Continental Shelf Processes
Crozier, George F
Marine Envir Sci Consortium, Dauphin Is Sea Lab
C 010

14 River Plumes & the Sea Floor
Fanning, Kent A
U South Fla, Dept of Marine Science
C 026

15 Chemical Oceanography
Farrington, John W
WHOI
C 029

16 Cycling of Organic Matter in the Sea
Gagosian, Robert B
WHOI, Dept of Chemistry
C 006

17 Chemical Fluxes in the Ocean
Gardner, Wilford
WHOI, Dept Geology & Geophysics
C 005

18 Transport Processes
Harvey, George R
DOC, NOAA, AOML
C 008

CHEMICAL OCEANOGRAPHY

19 Manganese Nodule Program (MANOP)
Heath, Ross for Exec Comm of MANOP
URI, GSO
C 030

20 Chemical Processes and Environmental Variability
Kester, Dana R
URI, GSO
C 020

21 GEOSECS & Estuarine and Near Shore Waters
Moore, Willard S
U of S Carolina
C 003

22 "Interflux" Program
Morse, John W
U Miami, RSMAS, Div Marine Geology & Geophysics
C 004

23 Chemical & Geochemical Studies of Arctic Ocean Sediments
Naidu, A S
U Alaska, Inst of Marine Sci
C 016

24 Chemical Oceanography of Coastal Waters
Nevissi, Ahmad
U WA, Coll of Fisheries, Lab of Radiation Ecology
C 028

25 Benthic Boundary Layer Processes
Quinn, G James
URI, GSO
C 009

26 Seawater Organics and Marine Biota
Risebrough, Robert W
U of CA - Bodega Marine Lab
C 024

27 Evaluation of Volatile Sea Floor Constituents
Robertson, Dave
Battelle NW
C 021

CHEMICAL OCEANOGRAPHY

28 Coral Atolls
Smith, Stephen V
UH at Manoa
C 015

29 Coastal Water & Estuary Dynamics
Stanford, Harold M
Dept of Commerce, MESA New York Bight Project
C 002

30 Cycling of Organic Matter in the Open Ocean
Williams, P M
UCSD, Institute of Marine Resources
C 001

GEOLOGICAL OCEANOGRAPHY

1 Geological Structure Surveys
Ballard, Robert D
WHOI
G 042

2 Physical Properties of Sea Floor
Bennett, Richard
DOC, NOAA, AOML
G 047

3 Southern California Bight Area
Berry, Richard W, et al
SDSU
G 032

4 Slump Morphology & Stability
Bouma, Arnold H, Hampton, Monty A
DOI, USGS, Pacific-Arctic Branch of Marine Geology
G 046

5 Geotechnical Investigations of Marine Sediments
Bouma, Arnold H
DOI, USGS, Pacific-Arctic Branch of Marine Geology
G 045

6 Movement, Dynamics & Stability of Bedforms
Bouma, Arnold H
DOI, USGS, Pacific-Arctic Branch of Marine Geology
G 044

7 General Topics in Geology & Geophysics
Broecker, W S
Lamont-Doherty Geological Observatory
G 035

8 Upper Continental Slope Instability
Clifton, Edward H.
DOI, USGS, Pacific-Arctic Branch of Marine Geology
G 053

9 a. Sediment Transport Processes in Canyons b. Carbonate Platforms c. Precious Coral Stocks d. Nontoxic Waste Disposal e. Artificial Reef Behavior Patterns/Succession
Dill, Robert F
Fairleigh Dickinson U, West Indies Lab
G 036

GEOLOGICAL OCEANOGRAPHY

10 Shelf Dynamics
Duane, David
DOC, NOAA Sea Grant
G 050

11 Marine Geological Research
Field, M E, et al
USGS
G 038

12 General Geological Research
Field, M., Cacchione D., Gardner, J., et al.
DOI, USGS, Pacific-Arctic Branch of Marine Geology
G 049

13 Geologic Research
Folger, David
DOI, USGS, Atlantic & Gulf of Mexico Geology Lab
G 048

14 Elastic Strain in Oceanic Lithosphere
Furumoto, Augustine S
UH at Manoa, Hawaii I of Geophysics
G 034

15 Particulate Flux and Sedimentation
Gardner, Wilford
WHOI, Dept of Geology and Geophysics
G 006

16 Investigation of Margins in Conjunction with Deep-Sea
Gorsline, D S
USC, LA
G 021

17 Convergent Plate Margins
Hawkins, James
UCSD, SIO, Geological Research Div
G 014

18 Intraplate Volcanism
Hawkins, James
UCSD, SIO, Geological Research Div
G 013

GEOLOGICAL OCEANOGRAPHY

19 Manganese Nodule Program
Heath, Ross
URI, GSO
G 017

20 Ridge Crest Studies
Heirtzler, J R
WHOI, Dept of Geology & Geophysics
G 003

21 Bottom Stability of Mississippi Delta
Holmes, Charles
DOI, USGS, Off of Marine Geology
G 043

22 Drilling Effects Investigations
Horowitz, Art
DOI, BLM, Division of Marine Assessments
G 054

23 Geologic Structures Investigations
Horowitz, Art
DOI, BLM, Division of Marine Assessments
G 058

24 a. Fjord Environments b. Placer Mineral Deposits
Hoskin, C M
U of Alaska, Inst of Marine Sci
G 060

25 Extension of Project FAMOUS and Spinoffs in Geological Oceanography
Hubbard, Dennis K
U of S Carolina, Dept of Geology
G 041

26 Ocean Crustal Dynamics
Johnson, Stephen H
Oregon State U, School of Oceanography
G 033

27 a. Physical Oceanography b. Sea Floor Processes c. Biology
Keller, George H
Oregon S U
G 040

GEOLOGICAL OCEANOGRAPHY

28 Comparative Coastal Dynamic Systems
Klein, George deVries
Univ Illinois at Urbana, Dept of Geology
G 030

29 "Quaternary Calcium Carbonate Accumulation and Dissolution in the World Ocean"
Kolla, Venkatarathnam
Lamont-Doherty Geological Observatory
G 023

30 Arctic Oceanography
Kravitz, Joseph H
USN Oceanographic Office
G 009

31 Development of Long Term Study Areas
Lyle, Mitchell
Oregon S U, School of Oceanography
G 022

32 Reef History
MacIntyre, Ian
Smithsonian Inst, Paleobiology Dept.
G 055

33 Continental Shelf Sediment Transport, Source and Mechanisms
Malahoff, Alexander
DOC, NOAA, NOS
G 056

34 Origins of Microbathymetric Features
Malahoff, Alexander
DOC, NOAA, NOS
G 057

35 Earth/Ocean History Related Problems
Margolis, Stanley V
UH at Manoa
G 011

36 Continental Margin Stability
McGregor, Bonnie A
AOML, Marine Geology & Geophysics Lab.
G 005

GEOLOGICAL OCEANOGRAPHY

37 Continental Margin Geology
Milliman, John D
WHOI, Dept of Geology and Geophysics
G 008

38 Paleogeography and Climatology
Naidu, A S
U of Alaska, Inst of Marine Sciences
G 019

39 Circum-Pacific Turbidites
Nelson, Hans
Dept of Interior, USGS
G 010

40 Coral Reef Research Station
Pilson, Michael E Q
URI
G 007

41 Experimental Seismology
Prothro, William
UCSB, Marine Sci Inst, Dept of Geo Sci
G 052

42 Glaciological Problems
Ruddiman, William F
Lamont-Doherty Geological Observatory
G 018

43 Deep Sea Anoxic Areas
Sass, Daniel B
Alfred U, Environmental Studies
G 002

44 Deep Sea Drilling Project
Sclater, John G
MIT, Dept of Earth & Planetary Science
G 001

45 Rock Drilling on Deep Reefs
Shinn, Eugene A
DOI, USGS, Oil & Gas Branch
G 051

GEOLOGICAL OCEANOGRAPHY

46 Shelf Sedimentation
Sternberg, Richard W, et al
U Wash, Dept of Oceanography
G 031

47 Ocean Dumping and Marine Ecosystem Analysis
Swanson, R. Lawrence
DOC, NOAA, ERL, MESA
G 059

48 Sediment Studies
Swift, Don, et al
NOAA/ERL Boulder Hq
G 039

49 Sediment Transport and Shelf Dynamics
Swift, Donald
DOC, AOML, Marine Geology and Geophysics Lab
G 012

50 "Holocene Geochemical Cycle of Biological Debris in World Oceans"
Takahashi, Taro
Lamont-Doherty Geological Observatory
G 004

51 Ocean Crustal Dynamics
Talwani, Manik
Lamont-Doherty Geological Observatory
G 020

52 Sand Transport
Van Andel, Tjeerd H
Stanford U
G 037

53 Seabed Assessment Program: "Benthic Boundary Layer"
Van Andel, Jerry
Stanford U, Dept of Geophysics
G 029

54 Seabed Assessment Program: "Study of Clathrates"
Van Andel, Jerry
Stanford U, Dept of Geophysics
G 028

GEOLOGICAL OCEANOGRAPHY

55 Seabed Assessment Program: "Passive Plate Margins"
Van Andel, Jerry
Stanford U, Dept of Geophysics
G 027

56 Seabed Assessment Program: "Subduction Zones"
Van Andel, Jerry
Stanford U, Dept of Geology
G 026

57 Seabed Assessment Program: "Seawater-Oceanic Crust Interactions"
Van Andel, Jerry
Stanford U, Dept of Geophysics
G 025

58 Seabed Assessment Program: "Thermal Studies"
Van Andel, Jerry H
Stanford U, Dept of Geophysics
G 024

59 Upgrading of DSDP
Vine, Allyn
WHOI, Dept of Geology and Geophysics
G 016

60 Marine Geology Techniques
Vine, Allyn
WHOI, Dept of Geology and Geophysics
G 015

MISCELLANEOUS

1 Insitu Product Testing
Anonymous
X-11 (Industry)
M 032

2 Impact of OCS Oil Explorations, Aquaculture and Instrumentation
Anonymous
X-12 (Industry)
M 031

3 Measurement and Verification of Diver and Diving System Performance
Anonymous
X-13 (Industry)
M 030

4 a. Pollution b. Fish Behavior c. Shelf Dynamics d. Engineering Investigations e. Acoustic Ambient Noise
Anonymous
X-8 (Industry)
M 029

5 Underwater Tools and Mixed Gas Diving
Anonymous
X-7 (Industry)
M 028

6 Monitoring and Equipment Construction
Anonymous
X-6 (Industry)
M 027

7 a. Materials Evaluation b. Acoustic Sensor Development and Evaluation
Anonymous
X-5 (Industry)
M 026

8 Deep Ocean Mining
Anonymous
X-3 (Industry)
M 025

MISCELLANEOUS

9 Impacts of the Quest for Energy
Anonymous
X-2 (Industry)
M 024

10 Commercial & Scientific/Engineering Tasks for the Petroleum Industry and Salvage
Anonymous
K-4 (Commercial)
M 023

11 a. Underwater Oil Well Completions b. Extensive Pipeline Repair
Anonymous
K-5 (Commercial)
M 022

12 a. Deep Water Aquaculture. b. Salvage
Anonymous
K-6 (Commercial)
M 021

13 Commercial Diving
Anonymous
K-8 (Commercial)
M 020

14 Commercial Diving Services
Anonymous
K-3 (Commercial)
M 019

15 Repair & Maintenance Tasks
Anonymous
K-2 (Commercial)
M 018

16 Oil Rig Saturation Diving
Anonymous
K-1 (Commercial)
M 017

17 Commercial Diving
Anonymous
K-7 (Commercial)
M 016

MISCELLANEOUS

18 Ocean Spills and Ocean Dumping
Beller, Bill
EPA, Oil & Special Materials Control Div.
M 046

19 Deep Diving and High Pressure Nervous Syndrome
Bennett, Peter B
Duke U Medical Center, FG Hall Environ Lab
M 045

20 Diving Physiology & Underwater Work Studies
Bennett, Peter B
Duke U, F G Hall Environ Lab
M 010

21 Seabed Waste Project
Boyer, Glen
DOE, Seabed Waste Project
M 047

22 a. Metabolism, Community Structure & Energy Flux on Hard Substrate Outcroppings. b. Experimental Deep Sea Biology
Brauer, Ralph W
UNC, Inst of Marine Biomedical Research
M 011

23 Underwater Safety Program
Cannon, Edward W
DOT, USCG
M 044

24 Structural Integrity and Water Quality Inspection
Cohen, Howard J
DOI, Bureau of Reclamation, Div of Research
M 038

25 Background Studies
Cooke, Thomas
DOI, BLM, Pacific OCS Office
M 048

26 Pipeline and Pipeline Surveys
Cooke, Thomas S
DOI, BLM, Pacific OCS Office
M 052

MISCELLANEOUS

27 Oil Lease Management Survey
Cooke, Thomas S
DOI, BLM, Pacific OCS Office
M 049

28 Underwater Work Systems Evaluation
Egstrom, Glen H
UCLA, Performance Physiology Lab
M 015

29 Environmental Data Collection
Ellison, John
EPA, Natl. Enforcement Investigation Ctr
M 050

30 a. Recurrent Phenomena b. Archeology
Emery K O
WHOI, Dept of Geology and Geophysics
M 042

31 Diving Physiology and Monitoring of Divers
Fife, William P
TAMU, Off of University Research
M 014

32 Lynn Seamount and Cromwell Undercurrent Relationships
Green, Jack
Science Applications Inc, Material Sciences Operations
M 043

33 Educational Facility
Gross, Richard
DOI, Heritage & Recreation Service
M 035

34 Sand Resources, Virgin Islands & Florida
Holmes, Charles
USGS, Off Marine Geology
M 002

35 Pipeline and Pipeline Route Survey
Horowitz, Art
DOI, BLM, Div of Marine Assessments
M 034

MISCELLANEOUS

36 Thermal Protection of Divers
Johnson, Charles E
Duke U Medical Center, FG Hall Lab for Envir Rsch
M 039

37 Oil Drilling Impact on Coral Reefs
Knudson, Myron
EPA, Surveillance & Analysis Div
M 037

38 Artificial Reef Investigations
Knudson, Myron
EPA Surveillance & Analysis Div
M 041

39 Ocean Dumping & Oil Spill Assessment
Knudson, Myron
EPA, Surveillance & Analysis Div
M 040

40 Arctic Ice Scoring Research
Kovacs, Austin
DOD, USA, Corps of Eng, Cold Regions Res & Eng Lab.
M 033

41 Scientific Diver Tools & Instrumentation R
Llewellyn, John A
U of S Florida
M 013

42 Underwater Radiation & Cosmic Ray Detection
Lord, Jere J.
U of Wash, Dept of Physics
M 012

43 Ocean Dumping Assessment, Philadelphia & DuPont Sites
Muir, William
EPA
M 001

44 Drilling Impact Assessment
Muir, William
EPA, Marine Protec Pgm, Region III
M 036

MISCELLANEOUS

45 Diver Safety
Purdy, Allan
HEW, NIOSH, Off Extramural Coord & Special Projects
M 057

46 Ocean Dumping Research
Reynolds, Bruce
EPA, ERL
M 055

47 Sea Floor Engineering & Sedimentation
Saville, Thorndyke Jr
DOD, USA, Coastal Eng Research Cntr
M 006

48 Test and Evaluation of Neutron Activation Equipment
Sentfle, Frank
DOI, USGS, Physics Laboratory
M 056

49 Transfer Processes in Continental & Coastal Waters
Sly, Peter G
Canada Dept of Energy, Mines, & Resources, Cntr for Inland Waters
M 007

50 Long Term Interdisciplinary Studies
Smith, Robert E
S U of Fla, Inst of Oceanog
M 008

51 Archeological Exploration and Retrieval
Stehling, Kurt
NOAA, OE, MUS&T
M 054

52 Subsea Neutrino Activity
Stehling, Kurt
NOAA, OE, MUS&T
M 053

53 Ocean Engineering Programs
Stephan, Charles R
Fla Atlantic U
M 009

MISCELLANEOUS

54 Neutron Gamma Techniques in Underwater Research
Trombka, Jack
NASA, Solar Activity Branch
M 058

55 Effects of Decompression on Human Physiology
Vann, Richard D
Duke U Medical Center, Dept of Anesthesiology
M 051

56 Diving Physiology
Waterfield, Allan
UNH, Dept of Phys Ed
M 003

57 Archeological Surveys
Watts, Gordon P Jr
N Car Div of Archives & History, Underwater Archeological Research
M 004

58 In Situ Sediment Analysis and Pollution Detection
Wogman, Ned A
Battelle Northwest Labs
M 005

59 X-Ray Fluorescence Analyses
Wogman, Ned
Battelle NW
M 059

PHYSICAL OCEANOGRAPHY

1 Benthic Boundary Layer Processes
"Directions for Naval Oceanography"
National Academy of Science
P 003

2 Relation of Ocean Variability to Acoustic Submarine Detection
"Directions for Naval Oceanography"
National Academy of Science
P 002

3 Communication with Electromagnetic Radiation
"Directions for Naval Oceanography"
National Academy of Science
P 001

4 "Shallow Water Oceanography"
"Directions for Naval Oceanography"
National Academy of Sciences
P 031

5 "Regional Polar Oceanography and Southern Ocean Research"
"Directions for Naval Oceanography"
National Academy of Sciences
P 030

6 "Biological Communities, Effect on and Use in Surveillance"
"Directions for Naval Oceanography"
National Academy of Sciences
P 029

7 "Chemical Variables in the Marine Environment"
"Directions for Naval Oceanography"
National Academy of Sciences
P 028

8 "Prediction of Variability and Modeling of Turbulence in Time and Space"
"Directions for Naval Oceanography"
National Academy of Sciences
P 027

9 Continental Shelf Studies
Barnett, Timothy P
USCD, SIO
P 014

PHYSICAL OCEANOGRAPHY

10 In Situ Oceanographic Studies
Dill, Robert F
Fairleigh Dickinson Univ
P 020

11 Ocean Dumping Research
Dyer, Robert
EPA, Off of Radiation Programs
P 036

12 Weddell Gyre Study
Foster, Theodore D
USCD, SIO
P 017

13 Marine Pollution
Gardner, Richard R
NOAA, OCZM
P 032

14 Bottom Boundary Dynamics
Ichiye, Takashi
TAMU, Dept of Oceanography
P 012

15 High-Frequency Acoustic Scattering
Jackson, Darrell R
U of Wash, Applied Physics Lab
P 039

16 Light Transmissivity in Deep Water
Kampa, Elizabeth M
SIO
P 010

17 Variability in Oceanic Planetary Boundary Layer - GARP Related
Landis, Robert C
NOAA, Oceanographic Serv Off
P 004

18 Quantitative Oceanographic Monitoring System by Deep-Sea Coring
Matthews, R K
Brown U, Dept of Geological Sciences
P 034

PHYSICAL OCEANOGRAPHY

19 Coastal Waters Management
McLain, Douglas R
NOAA/NMFS
P 019

20 Prediction of Circulation of Coastal Oceans
Mooers, Christopher N K
UDel, College of Marine Studies
P 008

21 Shelf Slope Circulation
Niiler, Pearn P
Oregon State U
P 005

22 Energy Dissipation
Ostenso, Ned A
DOC, NOAA, Sea Grant
P 038

23 Submarine Canyon Currents
Ostenso, Ned A
DOC, NOAA, Sea Grant
P 040

24 Equatorial Current Systems
Pilson, Michael E Q
URI
P 006

25 Role of Biota in Trace Element Distribution
Pilson, Michael E Q
URI
P 009

26 Trace Elements
Pilson, Michael E Q
URI
P 011

27 The Gulf Stream & Techniques for Dynamic System Investigations
Rossby, Thomas
URI, GSO
P 024

PHYSICAL OCEANOGRAPHY

28 Arctic and Sub-Arctic Oceanography
Royer, Thomas C
U of Alaska, Inst fo Marine Science
P 033

29 Thermal Energy Sources
Sass, Dan B
Alfred U
P 026

30 Ocean Dumping in "Dead Sea" Areas
Sass, Dan B
Alfred U
P 016

31 Physical Environment Characterization Studies
Schroeder, William W.
U Alabama, Marine Sciences Program
P 025

32 Antarctic Bottom Water Flow
Sclater, John G
MIT, Dept of Earth & Planetary Sciences
P 007

33 Basic Oceanographic Research
Stewart, Harris, Deitz, R., Atwood, D., et al.
DOC, NOAA, ERL, AOML
P 041

34 Global Ocean Heat Flux
Stommel, Henry
MIT, Dept of Meteorology
P 013

35 Sea Ice
Weeks, W F
Dept of Army, Cold Regions Res & Eng Lab
P 015

36 Sea Ice Formation in the Greenland-Norwegian Sea
Weyl, Peter K
SUNY, Stony Brook, Marine Science Rsch Cntr
P 035

PHYSICAL OCEANOGRAPHY

37 Formation of Deep Water
Whitehead, J A Jr
WHOI
P 018

38 Air-Sea Interactions
Worthem, Sylvia
NOAA, AOML
P 037

39 Equatorial Studies
Wunsch, Carl I
MIT, Earth & Plan Sci Dept
P 023

40 Mesoscale Eddies
Wunsch, Carl I
MIT, Earth & Plan Sci Dept
P 022

41 Meridional Heat Flux
Wunsch, Carl I
MIT, Earth & Plan Sci Dept
P 021

APPENDIX C

Summaries of NULS II Studies

CONTENTS*

*The material in this appendix was prepared by NOAA staff as background material for this study.

1. California Academy of Sciences:

The proposed program was primarily dependent upon the use of the research vessel, R/V EAGLE (a 221-ft, 1,050-ton world-range ship providing accommodations for up to 36 people), along with its associated diving facilities. It will provide a unique access to the sea for diving scientists and observers conducting scientific research and training personnel, including students, in the application of diving techniques for research purposes.

The Academy and the personnel of the R/V EAGLE have previously had cooperative arrangements for scientific research. It was anticipated that such cooperation will continue, with research staff of the California Academy of Sciences actively participating in the on-going research program of the R/V EAGLE. Further, the Academy would serve as repository for voucher material obtained in the course of the EAGLE's research activities, including the proposed baseline studies.

Through a cooperative arrangement, the California Academy of Sciences accepted from the National Oceanic and Atmospheric Administration an SDS-450 bell and chamber diving system on loan for 12 years for use aboard the R/V EAGLE on behalf of the Ocean Trust Foundation, the sponsoring private organization. The Ocean Trust Foundation was officially incorporated in July 1978 with the stated purpose of supporting scientific research and educational programs fundamental to the formation of world policy as it related to conservation of marine life and the marine environment and the careful management of marine natural resources.

Installation and implementation of the SDS-450 diving bell and chamber will serve as the nucleus of an on-going program of diving research and training that will create a community of experienced diving scientists and other personnel who can continue the nation's commitment to underwater research and exploration in even greater depths as technology and equipment become available.

The diving facilities that would be developed in cooperation with the NULS-2 program will be used to support an on-going program of baseline studies in areas throughout the Pacific Basin, including selected sites in U.S. waters. There would also be research projects that would focus on specific topics and be conducted under the direction of and in participation with senior research scientists.

A concurrent medical program will be developed to take advantage of the opportunities provided to advance the understanding of diving physiology and apply the latest knowledge to best advantage.

The facility will also be a focal point for public communication. The special photo documentation capabilities of the R/V EAGLE will be used to communicate on network television the activities and results of work aboard the vessel.

A five-year plan of research is being developed in consultation with the Trust's Scientific and Technical Advisory Board. Projected are at least 12 locations throughout the Pacific Basin, including sites in the United States, where environmental assessment will be made using techniques that will make it possible to return to the same place for future assessment of change, as well as to facilitate comparisons with other areas.

Permanent reference markers will complement use of pinpoint navigation techniques to ensure that there can be a precise return to locations studies.

A summary of station data will be published annually, and voucher collections and other reference materials will be deposited at the California Academy of Sciences and other collaborating institutions.

Concurrent with ecosystem studies will be specialized research on individual plants and animals, including some on-going projects concerning organisms with widespread distribution such as whales, dolphins, sea turtles, and certain marine plants.

Six research personnel can be accommodated aboard the R/V Eagle, with an additional 30 crew members--diving, medical, and photographic support--who will help implement the research program and provide documentation, both for scientific applications and for public communication. Senior Research Scientists will be engaged to supervise and participate in research projects of their own devising that will serve to complement and enhance the on-going program.

In summary, the Ocean Trust's programs will be supported by the R/V EAGLE, which will be on stations, for periods of between four and five months, at sites selected either because of their potential for research and film documentation or because of their particular importance to conservation objectives. The central purpose is to communicate to the public substantive information about the oceans.

2. Florida Atlantic University:

The findings of the study investigated the feasibility of developing an underwater manned laboratory for the support of saturation diving in the contiguous waters of Florida. It presented a survey of the offshore environment and, based on input from potential user scientists, established the value of having such a facility (NULS-2) available. It included the description of the physical facilities including habitat, life support barge and surface support ship, which have been designed to provide a mobile laboratory system capable of being located in depths to 165 ft.

The aspect of manned undersea activities addressed dealt with the utilization and support of free swimming scientists working in the ocean environment through the use of self-contained breathing apparatus.

While SCUBA techniques have allowed the scientist to visit the marine environment, the introduction of saturation diving techniques into the repertoire of scientific tools has allowed the investigator to become a resident in his or her problem environment. No longer tied to the surface, the scientists and engineers have become free to investigate their particular problems under conditions convenient and natural to the problem.

While considerable experience and success has been gained through previous undersea projects, the habitat programs thus far have suffered from several deficiencies. The purpose of this study was to benefit from past experience and to propose a system which will more completely meet the needs put forth by the diving scientific and engineering community. To this end, the following set of objectives were used for the feasibility study:

1. Develop a saturation habitat facility whose physical characteristics, operational capabilities, management structure, and operating philosophy are as responsive to the needs of the scientific and engineering user community as technology and safety will permit.

2. Develop a facility whose location of operation is in the contiguous waters of the United States in order to provide the opportunity to work in areas of direct relevance to the nation.

3. Select an operating area which will have regional importance and thus justify the commitment of the substantial resources which will be required to sustain the system.

4. Develop a system with sufficient flexibility to support missions throughout the operating area.

The proposed operational sites will be within the overall offshore area of Florida out to a depth of some 50 m. from Cape Canaveral, around through the Florida Keys, and up to Panama City, Florida. Particular attention would be paid to the offshore area in the Boca Raton-Pompano Beach vicinity, an area of high potential research that logistically provides an ideal place to begin the NULS operations. After sufficient experience was gained, the habitat could be deployed elsewhere in the Florida waters. The study gave a very detailed environmental summary of the various operational areas, looking at meteorological conditions, ocean currents and sea surface conditions, winds, and seasonal variations of each on a yearly basis. Detailed descriptions were also provided of the various bottom conditions and characteristics. This effort has identified a wide variety of topical study areas surrounding the state of Florida. In particular, a unique reef structure along the southeastern coast of the state offers not only a unique area for study but one which can conveniently accommodate a habitat laboratory.

The NULS-2 program, deployed and maintained off the coast of Florida, would serve three general areas of scientific underwater need. These areas include a field site for the testing of scientific hardware, a training facility for students and commercial diver technicians, and an in situ observation platform from which marine scientists may perform a wide range of studies.

The most significant application for the habitat was to support the observation, sampling, monitoring, and documentation of the marine environment. With an underwater marine laboratory habitat situated in Florida water, the following topics are representative of those which could be addressed:

1. Reef-fish population monitoring - would produce quantitative data on the standing biomass of both commercially and non-commercially important reef fishes.

2. Monitoring of geothermal springs - would allow observation of flow variations with time and tidal cycles, including the interactions of the plume with the overlying water circulation.

3. Study of effects of an ocean outfall system - would provide more thorough mapping and sampling of the outfall and its effect on pelagic and benthic species.

Due to the short time frame of this study, it admittedly emphasized only the scientific research in Florida. The results and enthusiastic support, however, were very good and an extensive survey of users and topics on a national basis would be even more impressive.

In developing the concept and the initial design of the system two important concepts become apparent. First, it was evident that the operation of a habitat in Florida waters would require a system with inherent flexibility and the ability to be readily deployed to different areas of the State. Second, it became obvious that the optimum utilization of such a facility must include more than just the facility itself. The NULS-2 should be an integrated program which provides for pre and postmission examinations of a candidate site by the user scientist. Also, the user scientist in the habitat may well wish to supplement his saturated activities with surface-based diving efforts.

The laboratory facility is keyed to a habitat structure consisting of a single pressure vessel with two separate compartments. The two compartments will serve as living and dryworking areas and will support positive and negative pressures equivalent to 165 ft of seawater. The vessel will provide access to the sea from the drywork area and through a wetworking and dressing area. Thus the spaces of the habitat will maintain various working and living areas varying from dry to wet in order to accommodate all the various activities envisioned in a typical mission.

The entire habitat is located on a barge which will permit easy raising, lowering and towing. Thus the habitat would be easily capable of deployment throughout the coastal area of Florida to a depth of some 150 ft. Provisions for establishing air or "normoxic" breathing atmosphere would be included.

The habitat would be supported by a surface buoy supplying high- and low-pressure life support gas, electrical power, hydraulic power, and water. The connection between surface buoy and habitat would be through an umbilical. The entire system would be towable by a 30-foot diesel-powered vessel.

The habitat facility, a pressure vessel 25 ft long by 8 ft in diameter, consists of three compartments, a living chamber, a laboratory chamber and a captured bubble for diving operations. The facility will be attached to the ballast barge, an aluminum or steel structure which will provide the ballast required for emplacement of the laboratory chamber. Connected permanently to the chamber, the barge will present a hydrodynamic bow and bottom profile so as to readily facilitate surface towing by the Surface Support Ship. In addition, an LCM-8 type vessel would be equipped with a control station, maintenance shops, a recompression facility, and specimen holding tanks. This vessel would be the primary tow vessel for the habitat's life support buoy.

The habitat will support a four-aquanaut team in a saturation mode at depths to 165 ft of seawater (FSW) for a mission duration of up to two weeks. The breathing media will vary from air to a "normoxic" mixture depending upon the saturation depth. The living and laboratory chambers will be capable of supporting internal and external pressures to 165 FSW to allow for both in-situ and surface decompression. The two chambers will be separable by double acting hatches (i.e., they are capable of taking both internal and external pressure) and will have independent and redundant gas control consoles. This will permit recompressive or emergency treatment of a stricken aquanaut without interferring with the decompression schedule of remaining team members. Each chamber will have independent emergency breathing systems capable of supporting the aquanauts unattended for three days or twice the maximum decompression schedule, whichever is greater. The Diving Compartment is essentially a captured air bubble 7 x 7 x 7 ft located in the hydrodynamic bow section of the ballast barge.

The resources of the University available to the NULS "users" include laboratory and library facilities necessary for instruction and research in biology, geology, chemistry, computer science, ocean engineering, and the marine sciences. The faculty is, in general, energetic and helpful, many having first hand knowledge of the local offshore area. The Colleges of Engineering and Science support three well equipped machine shops and one electronics repair facility staffed with full time machinists and technicians. The Department of Ocean Engineering also supports a 34-ft research vessel, numerous small boats and a related boat repair facility. In addition, equipment such as side-scanning sonar, sub-bottom profilers, wet towed submersibles, and various wave and ocean parameter measurement instrumentation is available.

Given the national aspect of the NULS program and the likelihood that more than one NULS laboratory will be in operation, it is recommended that a national advisory committee be instituted to regularly interact and oversee the operations of the NULS program. A group of peer scientists and engineers of recognized experience should be selected to sit on a committee which is advisory to the NOAA/MUS&T Program Manager and the individual laboratory Program Directors from each of the host universities.

This Science Program Advisory Board would help to set overall policy and goals for the habitat program. It would also act to review proposals and select missions. It would assist in the assessment of the effectiveness of the habitat laboratories in carrying out their missions as well as the overall science program. While the Board would not replace the NOAA/MUS&T Program Manager where ultimate accountability and management authority would be vested, their input would be extremely valuable in the development of effective manned undersea science programs over both the short and long time frame.

The following implementation schedule was proposed from date of start:

			Months
Phase I:			
	a.	Select engineering contractors for design and construction	3
	b.	Design facilities	5
	c.	Complete design and fabrication	7
Phase II:			
	a.	Install habitat at site, deploy all systems, run trial missions	3
	b.	Begin regular scheduled missions	12

3. University of Hawaii:

The objective of this study was to outline the marine capabilities, the facilities, and the need in the State of Hawaii for a national undersea laboratory system (NULS-2). Its intent was to emphasize the advantages, opportunities, and interest in an extensive national and State man-in-the-sea program for the Pacific region that is centered in Hawaii and capitalizes on existing Hawaiian facilities and programs.

The existing facilities that the State of Hawaii would commit to a NULS-2 Hawaii program included the undersea habitat AEGIR, the STAR II submersible, the Makai Research Pier, and use of several surface support vessels. All the essential facilities for a highly sophisticated and flexible underwater laboratory system exist and were included in this commitment. Proposed operational areas specified the Pacific region centered in the Hawaiian Island chain.

The scientific objectives of the proposed Hawaii program were to research the areas of food from the sea, ocean energy, marine resource management, human performance in the sea, development of more effective work and habitation systems, marine environment management and, finally, basic research with potential long-term payoffs. This program would complement the existing NULS-1 program by demonstrating how habitats and submersibles could be used as vital adjunct facilities in already established ocean research and development programs. It would eventually become apparent that these types of systems may be regarded as the best primary tools for given underwater marine tasks.

Initial scientific projects were tentatively proposed representing various areas of marine science and engineering which are actively supported by the State of Hawaii both by direct involvement and interest and/or by ongoing funding, also emphasizing their importance and relevance nationally. Detailed descriptions of the following programs were given.

1. Food from the Sea
    a. Fish aggregation structures, attractant odors
    b. Key commercial fishing areas
    c. Design and construction of fish traps
2. Engineering
    a. Testing ocean laboratory systems
    b. Develop lightweight pressure vessels
    c. Problems related to manned undersea facilities
    d. Workbase for design and operational criteria
    e. Research techniques training utilizing undersea facility

f. Education, use and design of habitats

3. Human Performance in the Sea

   a. Diving medical support

   b. Maximum nitrogen desaturation and saturation half time

   c. Physics of bubble nucleation in gelatin

   d. Gas exchange in hyperbaric environments

4. Ocean Energy

   a. Study of OTEC effluent plume

5. Marine Resource Management

   a. Study underwater aquafers

   b. Black coral investigation

   c. Tropic structure of demersal fish and benthic fauna

   d. Observe ecology, fishes, and invertebrates

6. Marine Environmental Management

   a. Environmental surveys, sewer outfalls

   b. Assess deep ocean dumpsites

   c. Sediment effects on Kaneohe Bay

7. Basic Research, Potential Long-Term Payoff

   a. Marine agronomy, production of seaweeds

Their proposed NULS-2 system was highly adaptable to a wide variety of programs, locations, and disciplines. It could dive almost anywhere from sewer outfalls to coral reefs and could carry large payloads, was easily outfitted between dives, and had ample space with excellent facilities.

Hawaii has built up a substantial inventory of operational facilities to perform work both on and under the ocean, as well as ports, shops and laboratories to accommodate this equipment and the research performed. All submersible equipment is capable of mobility and operating in the high sea states common to the windward sides of the islands and are not restricted to a single location or mission. These facilities, including submersible vehicles, the surface support vessels, harbors and ports, recompression centers and laboratories, will be available for an extensive NULS-2 program.

The submersible vehicles used will be the manned habitat Aegir and the submersible STAR II. The AEGIR will accommodate six aquanauts for two weeks plus another week's reserve to 600 ft (nominal) depth. When fully found for a deep dive, she displaces 200 long tons (surfaced), is 72 ft long and 53 ft wide, and draws 8 ft of water. Her habitable volume consists of three main chambers (each fully independent) plus two emergency transfer capsules. The main habitable chambers are cradled on two 9-ft diameter by 72-ft-long pontoons which are restrained by two large cylindrical variable ballast tanks. Whereas AEGIR was designed for mixed gas diving to 580 ft, she may also be used for shallow dives on air. The three habitable chambers consist of two 18-ft-long x 9-ft-diameter cylinders connected by a 10-ft diameter sphere, one cylinder being the living quarters with the other being the laboratory. The interconnecting sphere is the "wet" area providing the diver with entry and egress.

When fully blown and surfaced, the AEGIR is exceptionally mobile and can be towed to various locations. No cranes or barges are required, resulting in a less expensive operation. No sea bed foundations or winches are required and the system has performed well in sea state 3 and 4. When equipped with a communications console and power generators, any ship of opportunity with several hundred horsepower can act as a surface support ship. Since a towing vessel must be used to move to and from the dive site and since the cost of operating such a vessel (whether moored at the site or to a pier) is essentially the same, the AEGIR was not provided with umbilicals to shore or generator buoys, although there is no reason why such devices cannot be used.

By virtue of its unique design and size, the AEGIR is a very versatile vehicle in terms of accommodating test equipment, carrying heavy systems or subsystems, adapting high-visibility domes or observation chambers and accommodating scientists and their associated equipment. Since the AEGIR has two separate cylinders with a sphere between, it may be used for two separate dry surface dives for physiological programs. In such a case, the sphere would be used as a lockout chamber for each cylinder. This could greatly reduce the cost of hyperbaric study programs. A mating skirt can be fabricated to permit a submersible to mate with the sphere upper hatch with no changes required to the AEGIR hard structure.

The STAR II submersible is owned by the University of Hawaii, but is operated by Deepwater Explorations, Ltd., under contract. It can accommodate only one observer or scientist on each dive, and her maximum depth capability is 1200 ft. The submersible is available to the NULS-2 program for 20 days per year.

Other facilities available include the STAR's launch, recovery, and transport vehicle (LRT), surface support ships for the AEGIR, port and pier facilities, and research laboratories. In addition to the University of Hawaii's involvement, other organizations in the Hawaiian scientific oceanographic community are strongly interested; among these are: the Hawaii Institute of Geophysics, Hawaii Institute of Marine Biology, the Bishop Museum, Waikiki Aquarium, Sea Life Park, Oceanic Institute, Brigham Young University, Community Colleges, State Fish and Game, National Marine Fisheries, Hawaii National Energy Laboratory (OTEC), University of Hawaii, Naval Underseas Center, Look Laboratory, and U.S. Army Corps of Engineers.

All programs and operations will be approved by MUS&T, contracted via the Research Corporation of the University of Hawaii (RCUH) and administered under the control of the Dean of Marine Programs for the University of Hawaii. The NULS-2 Hawaii program is then divided into two parts: the scientific program management and facilities management.

The Director of Scientific Programs will report directly to the Dean of Marine Programs and have management responsibility for selecting and scheduling the scientific research programs on both the STAR II and the AEGIR. His selection and scheduling of programs will be assisted by the Scientific Review Committee, which is composed of eight multidisciplined individuals, both within and outside the University.

The NULS-2 Hawaii program will be advertised nationally for proposals on a regular basis. The proposals will be evaluated by the Scientific Review Committee and rated as to their merit of being a significant scientific endeavor and compatible with the long-range scientific program objectives.

The Director of Marine Facilities is an office under the Dean of Marine Programs, which has responsibility for University marine facilities. Included among these facilities will be the AEGIR, STAR II, NULS-2 port facilities, and NULS-2 surface support vessels. The NULS-2 Director will be responsible for the management of all these facilities. The ultimate responsibility for safety in the dive program will be that of the NULS-2 Director.

The implementation and refurbishment phase will take approximately eight months. These first eight months are associated with establishing the dive operations, the safety program, scientific schedule, and making the facilities operational. The eighth month is used for final crew training (the selected crew will have done the refurbishing over the first seven months) and test dives. After these dives, the crew and facilities are fully operational.

The scientific program in the first year (last four months) would be established early, by the second month, in order to allow sufficient preparation time for the scientific teams. This initial four-month scientific effort will be composed mostly of Hawaiian investigators in order to minimize logistic effort.

The program for the second year of operation will be advertised and selected in the first six months of funding. This allows a minimum of six months preparation time for the scientific crews.

4. University of Michigan:

The University of Michigan's proposed plan, "The Great Lakes Underwater Education and Research Program," essentially consisted of a facility and a program--in an academic environment--for diver training, education and expansion of marine research in the Great Lakes. The University of Michigan has developed and maintained a stong national leadership role in underwater education and research. During the past several years their diver training program has included courses in basic scuba diving, advanced scuba diving, surface-supplied diving, research diving, scuba diving instructor, research diving orientation for instructors, surface-supplied diving orientation for instructors, underwater technology and hyperbaric chamber attendant. Specific diving manuals have been prepared (or are in preparation) for each of the above courses.

The Great Lakes Underwater Education and Research Program was a multi-faceted program which provided a unique approach to regional/national scientific/ academic diver training. It stimulated and supported the development of a coordinated underwater research effort in the Great Lakes. The Great Lakes region could still be considered as a "developing" region in the area of underwater scientific research. Although scientists from the University of Michigan and some other state government research groups have conducted a limited number of underwater research projects, the full potential of underwater research in the Great Lakes is yet to be recognized. The development of active underwater research in the Great Lakes depends on:

1. Availability of high-quality, academically oriented training programs to provide Great Lakes region scientists, graduate students, and support technicians with training in advanced diving techniques and equipment for cold-water research.

2. Availability of a coordination/advisory service for advising individual scientists, schools, and research groups in areas of underwater research. This includes consultation on training, safety, and scientific methodology.

3. Availability of a trained scientific diving team to aid nondiving scientists in the development and execution of underwater scientific research.

4. The development of a cooperative *in-situ* study program in order to acquire scientific data relative to the coastal zone of the Great Lakes region.

The proposed program had been developed to facilitate the development of effective regional and national scientific/academic training programs and to stimulate underwater research programs.

The general objectives of their program were:

1. To develop and conduct a comprehensive polar/cold climate academic/ scientific diver training program.

2. To conduct an umbilical-supplied diver training program for academic/ scientific personnel.

3. To conduct a hyperbaric chamber attendant training program for academic scientific personnel.

4. To develop and conduct a mixed-gas umbilical-supplied diver training program for academic/scientific personnel (second and third year of project.

5. To influence and support the development of a more comprehensive in-situ study program in order to acquire scientific data relative to the coastal zone of the Great Lakes region.

6. To serve as coordinator/advisory center for all Great Lakes academic/ scientific diving.

7. To train and advise academic/scientific personnel throughout the United States and Canada in various aspects of umbilical-supplied advanced scuba, habitat, polar, and research diving.

8. To serve as the Great Lakes center for management of cold water and diving-related medical emergencies.

9. To develop special techniques and equipment for academic/scientific divers using umbilical-supplied diving apparatus and operating from diving bells or submersibles.

10. To provide facilities and vessels for test and evaluation of equipment, techniques, and procedures used in underwater scientific research.

11. To study the feasibility of operating a small ambient pressure underwater structure (habitat) for short term lake-floor scientific work.

12. To study the feasibility of acquiring and operating a bell-saturation diving complex for scientific/academic diving operations in the Great Lakes.

In support of the educational and research activities the existing underwater laboratory, LAKELAB, would be used. It is a simple low-cost underwater habitat which will support two people for up to 48 hours. Its operational depth is 50 ft and is supported (air and power) from modular units on shore.

As part of this program, the University of Michigan intends to request funding for purchase/lease of a bell-type saturation diving system for future Great Lakes research. However, based on interviews and discussions they have had with selected Great Lakes area scientists, past experience, and knowledge of the Great Lakes, it was felt that that use of a bell system at this time was not feasible.

5. University of New Hampshire:

The objective of this study was to establish a cooperative New England regional underwater science diving program with facilities capable of supporting safe, deep (mixed breathing gas) research diving. The program would provide facility support for scientists interested in working on the northeast continental shelf at depths between 100 and 400 ft. It was written in response to a need for a system to support underwater research activities focusing on the assessment and understanding of the topography and biota of the northeast continental shelf. Specific scientific objectives, on the seafloor and in the sub-bottom, were to include fisheries studies from spawning to harvest, invertebrate studies of populations and their interactions, and the physical and chemical studies in the water column.

Aside from scientific needs, there is a need for a facility supporting the training of science-oriented divers using saturation diving techniques. Such a training facility, oriented to scientific needs exclusively, does not exist in the United States at this time.

The specific region to be served by the New England Undersea Laboratory System (NEULS) was the New England coastal region including the Gulf of Maine and a substantial portion of the Middle Atlantic Bight. The Gulf, in particular, is geologically, biologically, and hydrographically unique.

The Middle Atlantic Bight has marked contrasts to the Gulf in that it has gently sloping shelf topography, greater seasonal variation, and much more fresh water run off. It has unusually pressing needs for solutions to its environmental problems. Considered as a whole, the New England coastal area presents problems of interest to marine scientists and engineers and to many Federal and State agencies. Some of these include:

1. Biological

    a. nutrient cycle of shelf waters

    b. role of submarine canyons in transporting wastes

    c. ecology of the canyons

    d. maintenance and management of fisheries resources, including:

        ° great offshore fishery on Georges Bank and along the edge of the shelf

        ° lobster populations, both near and offshore, unique to this area of the United States

        ° development of the shellfish industry and its extension into deeper waters

        ° growing sport fishery of New England

e. potential use of the sea floor, particularly the Gulf of Maine basins, as repositories for waste materials

2. Hydrographical

   a. the relationships between the coastal waters and several major features of the North Atlantic Ocean (Gulf Stream, Labrador Current, Slope Water)

   b. nearshore circulation in the many extensive bays, estuaries, and sounds through which most pollutants must pass to reach open sea

   c. interrelationships of circulation and biological productivity

3. Geological

   a. structure of the continental shelf and slope

   b. sources and transport of sediments

   c. origin of submarine canyons

   d. potential for recovering mineral resources; oil, gas, sand, and gravel

4. Meteorological

   a. effects of northeasters and occasional hurricanes which cause flooding and shoreline erosion, disrupt the fisheries, and disturb normal seasonal patterns

   b. environmental effects of fallout of airborne pollutants into New England coastal waters from the industrial northeast

Four groups have been identified as potential users of NEULS. These groups are (1) long term funded research teams involved in projects such as ocean pulse, (2) short-term funded research projects such as those supported by Sea Grant, (3) archaeological projects (funded and nonfunded), and (4) educational users (training).

The first group is currently limited to two or three, but each has such a need that they would find themselves competing for the facility usage. It is the nature of such projects to return to selected sites on a seasonal and yearly basis with each visit requiring from one day to two weeks. It is felt that these groups would be the primary users. The second group consists of investigators looking at a specific problem in a particular site requiring a relatively short amount of time. While in sheer numbers the largest user population is potentially from this group of short term users, the mobilization/demobilization costs and daily costs as well as the research format will probably reduce the use days to a number less than that of the previously noted long term users. The third group, Marine Archeology, could certainly be considered as a potential significant user of NULS, though the realities of funding for this kind of work probably relegates its usage to a few very special applications. The fourth group of users would be involved in the training of scientists and research personnel in the use of saturation diving systems, giving those individuals using the system an opportunity to train and retrain in equipment they would be using on site. This would also offer the opportunity for science equipment and procedures to be integrated with the field equipment.

Since the sixties, the marine-related activities at the University of New Hampshire have grown from practically none to be a large, strong, well-organized program unit. Their resources include a Marine Program Building with offices, a high bay work area, machine and engineering shops, a diving office with its related resources, and a portable double-lock hyperbaric chamber. University personnel have been involved in manned undersea programs such as designing of EDALHAB habitat; taking part in Project FLARE, TEKTITE, HYDROLAB, PRINUL, HEGOLAND, FISSHH, and OCEANLAB programs, and conducting science trials of JIM suits.

The NEULS system consisted of the following principal components:

1. floating facilities

2. port facilities

3. emergency facilities

4. operating system

A triple lock deck decompression chamber/diving bell/handling system is the main component of the floating facilities having a minimum user capability of supporting two divers and a bell tender to minimum depth of 450 ft. The system would be capable of several modes of operations: deck saturation, bounce diving using deck decompression, 1 atm observation, and surface decompression.

The preferred surface platform for the diving system would be a semi-submersible platform (SSP) because of its enhanced stability both in motion and station keeping. As an alternative to the SSP, a specialized, self-pro pelled surplus barge was considered. A final option for the support system would be a ship of opportunity. However, it is not recommended because lack of a specialized mooring system and stable hull design would greatly reduce the number and nature of scientific tasks that could be attempted. It could be considered as an interim step for NEULS while the SSP was being built.

In addition to the diving systems, the surface support vessel could be used for operating remote controlled vehicles, submersibles, and JIM suits.

As part of the shore facilities, Portsmouth Harbor would be the home port. It is centrally located in the New England coastal region and has all the required port and support facilities and resources. Additional ports would be strategically located along the coastline to facilitate at-sea research activities, while the home port would serve as the site for at-dock training operations and for maintenance and overhaul work.

The emergency facilities are operated by other organizations but are available immediately as required. Prime examples of these include U.S. Coast Guard helicopters and the hyperbaric medical facilities at the Portsmouth Naval Shipyard.

The operating systems would include scientific research, training, and administrative types of tasks.

The overall management of NEULS would be directed by a "board of directors," a committee of the New England Cooperative Coastal Research Facilities Association (NECCRF), responsible for guidance in management and policy formation. Direct management is to be the responsibility of the NEULS director, a full time employee, with sole responsibility in this area. The administrative tasks are to be carried out through the administrative structure of UNH and its Marine Program. NECCRF will form an operating committee (NAOC-2) to handle management functions associated with NEULS. These functions would include direction of the scientific operations such as scheduling, scientific equippage, and research procedures at sea. The selection of the actual missions implemented would be done on a peer review process paralleling the system currently used for NULS-1.

The program implementation will be divided into four phases.

1. Phase I - six months following proposal funding for personnel and contract development including finalization of schedule and required contracts

2. Phase II - 14 months required to complete the support platform and its outfitting. Specific missions and training packages will be developed

3. Phase III - four months for the "shakedown" trials, checking out systems, and training of crew

4. Phase IV - beginning of full operations commencing with training of users

It is planned that this system would have a useful lifespan exceeding 20 years, but with frequent and periodic reevaluations for modifying, updating, and/or relocating the system.

6. University of North Carolina (Wilmington):

The University of North Carolina at Wilmington (UNC-W), in consortium with universities, State agencies, and other institutions in North Carolina, South Carolina, Virginia and Georgia, proposed to establish a NOAA Manned Undersea Science and Technology facility in the Southeastern United States under the acronym SECURE (South East Consortium for Underwater Research). The effort would be directed toward acquiring a diver transfer chamber or diving bell capable of placing marine scientists on the sea floor to depths of 200 m. under saturated conditions. Tasks such as observation, equipment deployment/retrieval, sampling, photography, and other research related activities will be carried out. The facilities would be transported by chartered vessel to selected mission sites from the mid-Atlantic Bight, off Virginia to the shelf offshore from Georgia, encompassing submarine canyons, natural and artificial reefs, scarps and ledges, and open ocean floor.

Following is listed the functional categories for research tasks that would be conducted in the NULS-2 SECURE facility. Only those research efforts which cannot be accommodated by conventional undersea technology such as SCUBA and other shallow-water techniques or surface-directed activities were considered.

1. Fishery resources management

    a. Hard-bottom population assessments

    b. Evaluation of gear used in assessing hard-bottom fish populations

    c. Field evaluation of commercial Black sea bass traps

    d. Evaluation of snapper/grouper traps in the South Atlantic Bight

    e. Assessment of near-bottom fish larvae and juveniles

    f. Evaluation of efficiency of sampling gear used in estimating species composition and biomass of fish populations on live-bottom communities

    g. Visual sampling evaluation for artificial reefs and changes over different hours, tidal stages and days

    h. Benthic fish populations of live-bottom communities in Outer Onslow Bay, North Carolina

    i. Seasonal distribution and potential fishery resources of midwater fishes off the Carolinas

    j. Evaluation of potential fishery resources of live-bottom communities off the Georgia Outer Continental Shelf

2. Ocean dumping and dredge spill disposal

    a. Experimental recolonization of in-situ defaunated sediments

    b. Animal-sediment relationships on the Continental Shelf

    c. Small-scale distribution patterns with benthic faunal communities and sediments

    d. Sediment movement off the North Carolina coast

3. Offshore oil operations impact, especially as it affects live-bottom communities

    a. Petrology and stratigraphy of outcropping rocks on the Continental Shelf between Cape Lookout and Cape Fear, North Carolina

    b. Rates of recolonization of benthic organisms after crude oil intrusion

4. Live-bottom communities research

    a. Barnacle reef communities on the North Carolina Continental Shelf

    b. Photographic documentation of Southeastern United States reef fishes

5. Medical/Safety research

    a. Verification of predictive heat transfer formulations for estimating regional supplemental heat required for divers at a prescribed depth

    b. Evaluation of the effects and effectiveness of decompression schedules

    c. Nitrogen narcosis during saturation at 60, 200 and 250 ft

    d. Evaluation of JIM suit for marine research

    e. Underwater radio communications link for diver location

6. Submerged cultural resources research

    Development and testing of electronically supported on-site archaeological assessment and techniques for surveying cultural resources at saturation depths

7. Ground truth (in-situ) validation

Current offshore research efforts of many scientists in the four-state consortium require either extended diving time at moderate depths (20 to 50 m.), extended operating time at greater depths (to 100 m.), or combinations of both. An additional requirement is that many areas of regional concern, such as the reefs off North and South Carolina, the Mid-Atlantic Bight off Virginia, or the South Atlantic Bight off Georgia, must be individually studied at many sites, making a fixed, shallow water habitat impractical. The diving bell type of system has proven invaluable in undersea petroleum and mining operations, suggesting its easy adaptation to manned undersea research.

The proposed diving system will basically consist of:

1. Mobil surface work platform (ship)

2. System for transferring divers to the sea floor

3. Deck decompression chamber

The objective of the program is to begin with a simple system of basic components and, as the facility is utilized and greater versatility is needed, the basic unit would be upgraded and modified. Commercially available systems would be considered from both purchasing and leasing approaches. As a minimum, the system would be able to transport two divers to a 400-ft depth.

The entire system would be integrated so as to allow easy installation and removal off a surface support ship. It was proposed that UNC's research ship R/V ADVANCE II would be chartered for this program.

The equipment will be stored and maintained at the UNC-W and deployed to the dock prior to a mission by flatbed truck. Commercial cranes will be used to place the required facilities on board the chartered vessel.

The Marine Sciences Program, under the direction of the SECURE Program Director, is housed in a new 40,000 square foot building at UNC-W and is served by a group of faculty researchers, the William M. Randall Library, and a number of small, university-owned 15- to 30-ft vessels moored at nearby Wrightsville Beach. The building has modern laboratories and scientific equipment suitable for use by visiting researchers and a large museum reference collection of southeastern marine organisms and geological specimens. It is anticipated that office space and facilities suitable for the SECURE Program will be made available in the Marine Sciences Building.

Other additional facilities and resources would be available through the other consortium members some of which are:

1. F. G. Hall Environmental Laboratory

2. Institute for Marine Biomedical Research

3. The Virginia Institute of Marine Science

4. South Carolina Division of Marine Resources,
   Marine Resources Research Institute

5. Cape Fear Technical Institute

6. Duke University Marine Laboratory

7. Georgia Department of Natural Resources,
   Coastal Fisheries Section

8. North Carolina Office of Marine Affairs,
   Marine Resources Center

9. Research Triangle Institute

The SECURE Program under the Program Director, would be administered by the UNC-W Vice Chancellor for Academic Affairs, and coordinated by the Director of Marine Science at that university. Management procedures are subject to policy and regulations of the University of North Carolina and the State of North Carolina, and pertinent federal policy and regulations.

The Management Program would consist of the NOAA Manned Undersea Science and Technology Office Program Director and SECURE components: Program Director, Advisory Board, Program Manager, Science Program Coordinator, Medical Safety Coordinator, Operations Director, and the UNC-W Aquatic Safety Officer.

All candidate research proposals will be reviewed and final selection made by the SECURE Advisory Board consisting of scientists representing many institutions and agencies within the four-state consortium concerned with undersea research.

It was planned that the implementation of the system would only take about four months so that a maximum of 165 operational days would be available the first year.

7. University of Southern California:

This study from the University of Southern California (USC) proposed to add a saturation diving capability to its existing undersea research facilities. USC presently conducts a multidisciplinary undersea science program at its off-shore campus at Santa Catalina Island, supporting a year-round scientific SCUBA capability, supplemented by manned submersibles when feasible. They offer to scientists an immediate access to a variety of near-shore habitats, substrata and biological associations. This manned complex would be the first such habitat to routinely support undersea research in temperate waters.

The proposed Catalina habitat-saturation complex was presented as one part of a multifaceted undersea science program to complement, and be complemented by, surface-oriented diving and manned submersibles. It was intended to fill a single need, extension of underwater time, not presently being met by any other system. In fact, the entire philosophy of the research diving program at the Catalina Marine Science Center (CMSC) was based on using all the latest techniques and technology to safely and accurately do high quality science underwater.

The habitat component of this NULS-2 system would sit at a depth of 16 m. in a lush bed of giant kelp approximately 30 m. offshore from CMSC, adjacent to an extensive rocky reef and a biologically productive softbottom of shelly sand. The giant kelp forest is considered by many to be one of the most productive, yet least studied, of all the major biomes: a dynamic, three-dimensional entity which supports and influences a great number of associated biological communities. The sea bed around the proposed habitat site is under direct control of CSMC and is considered a preserve. The area is sheltered from inclement weather, offering year-round access to the open sea, and excellent underwater visibility.

For the past 13 years, studies at USC's Catalina campus have centered around the kelp forest, providing a broad, well-documented base of biological and physical data upon which to build a NULS-supported science program. Although the major research thrusts would probably be biological, studies in oceanography, human physiology, and near-shore geological processes are equally compatible and feasible.

The habitat-based saturation dive system of NULS-2 would be integrated into the existing undersea research program at CMSC, providing another dimension for both regional and national undersea research. Within the restrictions imposed by such factors as depth and thermal exposure, NULS-2 would be able to do midwater and benthic work, behavioral and reproductive studies, long- and short-term comparative seasonal investigations, etc. In many cases the organism/habitat combinations peculiar to the NULS-2 site could be used as model systems upon which to demonstrate principles applicable throughout the entire biological world.

Following is a list of projects and research disciplines, in a broad context, which have been suggested as candidate tasks for the USC program:

1. Biology

   a. Comparative studies of the biota associated with various substrate altitudes and angles.

   b. Behavioral interactions between selected species of fishes and invertebrates.

   c. Studies on the dynamics of the rock-sand ecotone community.

   d. Documentation of the diurnal-nocturnal changes in the biota of the kelp bed, rock substrate and soft bottom.

   e. Discrete sampling of the subsurface plankton and its relationship to the sessile and motile resident species.

2. Geology

   a. Experimental investigation of the processes contributing to the formation of a shelly debris substrate.

   b. The importance of physical scouring at the sand-rock interface and its implications in sediment formation.

   c. Comparative studies of bioturbation in muddy sand and shelly debris.

   d. Studies in near-shore sediment processes and transport mechanisms.

3. Oceanography

   a. Development and testing of micro-oceanographic instruments and methodology.

   b. Detailed documentation of the habitat reef water mass.

   c. Dye studies of water movement at water-sand and water-rock interfaces.

   d. Studies on the effect of sea-surface texture and sunlight attenuation of temperature at the water-sand and water-rock interfaces.

4. Human Physiology

a. Long-term oxygen toxicity studies.

b Body temperature changes associated with prolonged saturation diving.

c. In-water nitrogen narcosis studies.

d. Work-performance limitations during excursion diving.

As part of the science program CMSC would see to the completion of up-to-date species lists, preparation of descriptive materials and photographic aids, establishment of study-site markers, and continuation of long-term physical and biological monitoring programs.

With respect to the NULS-2 facilities, CMSC is extremely well-equipped.

The Marine Science Center itself is located on 45 acres situated back of Big Fisherman Cove. The actual facility consists of a dormitory-apartment-cafeteria complex, a 30,000 square foot laboratory building, a 2400 square foot administration building, a waterfront-pier-diving-locker-hyperbaric chamber area, and associated supportive outbuildings and storage areas. Double-occupancy dormitory rooms and cafeteria-style food service are available year-round, and will be the primary pre and postmission living facility for aquanauts. The laboratory building is used for graduate and undergraduate teaching and research, and its many support capabilities will be made available to NULS-2 participants upon request and with prior arrangement.

The fully equipped diving locker has adequate space for NULS-2 participants in addition to its regular complement of CMSC research divers.

Technologically, it is anticipated that refinement of temperate water saturation diving support capabilities, especially environmental controls developed as a part of the NULS-2 operations, will lead to a generation of undersea laboratories capable of routinely operating in the cold-temperate-subpolar regions.

A detailed set of plans and specifications for the new habitat have not been prepared, and therefore only a general outline description was available. The basic habitat would be a steel cylinder 8 meters long and 3 m. in diameter, with a pressure rating to allow operations to 30 m. Guidelines associated with the design, construction and certification of hyperbaric facilities will be utilized. It will have a "dry" room and a "wet" room with a connecting door-type hatch. The entry hatch will be in the floor of the wet room. There will be a large observation port in the dry room with several smaller ports in both rooms.

The habitat will be designed for routine submerging and recovery with a submarine-type ballasting system. A launch and recovery system will be designed incorporating the existing CMSC marine railway winch and waterfront hangar. The habitat support will be provided via a 500 m. umbilical from the hangar. The umbilical will include power, water, communication, low-pressure breathing air, high-pressure air, and data-gathering cables.

When not in use, the habitat will be housed in the hangar where routine maintenance and repair can easily be performed. At the start of a mission, the habitat will be prepared, stocked and checked out in the hangar. It will then be launched unmanned down the marine railway, towed to the site (a distance of 330 m., submerged to the bottom, and secured to the anchoring system. At the termination of a mission, the reverse process would occur except that the aquanauts will have closed the hatches and started their decompression prior to floatation and retrieval of the habitat.

Directly over the habitat site will be moored a small (approximately 8 x 8 foot) support platform. This will be a simple "dock" design and will be used for tying up support boats while at the site, a terminal for a "dumbwaiter" system of dry transport of supplies and equipment down to the habitat, support of radio antennas, site of warning signs and lights to keep away boat traffic, and any other support functions required.

As demonstrated by NULS-1, the technology already exists to build, equip, and routinely operate a functional undersea laboratory in tropical waters. The CMSC staff consulted a number of marine engineers (NULS-2 Advisory Board) and received confirmation of the practicality of building a similar structure for use in cooler, temperate areas. Once such a system is in operation, it will serve as a focal point for technological research and development, possibly even in subpolar areas.

The CMSC is the section of Institute for Marine and Coastal Studies (IMCS) into which the NULS-2 Program will be integrated. The Director of CMSC will have on-site control over the NULS-2 Program. The NULS-2 Program Director is also the Associate Director of the CMSC. The primary responsibility of the CMSC Director with respect to the NULS Program will be its integration into, and coordination with, the other programs and operations of CMSC. The NULS-2 habitat will be viewed as an "extension" of the laboratory into the ocean. As such, its function must be coordinated with the Hyperbaric Chamber program, the Diving Program, on-going marine research and education programs, and the support and logistic functions. The faculty and staff of the CMSC will be called upon by the Director of CMSC as necessary for smooth and continuous operation of the NULS-2 Program. Policy decisions involving coordination of NULS-2 support with the requirements of the rest of CMSC will be made by the CMSC Director in consultation with the departments of Physical Plant (Operations and Maintenance) and Auxiliary Services (Housing and Feeding). The Director will also coordinate the NULS-2 Program needs with the Departments of Biological Sciences, Geological Sciences, Ocean Engineering, and other academic units of USC when pertinent.

Decisions concerning project selection, research sites, and facilities usage must be based primarily on scientific merit, applicability, and available resources. Thus, both a peer review process and program management by respected scientists must be established to assure scientific integrity. As with NULS-1, efforts will be made by the Peer Review Board and the NULS-2 Program Director to schedule missions which are appropriate for the season and weather conditions and, where necessary, to combine and "piggy-back" compatible activities.

It is expected that 18 months will be required for implementation, installation, and testing of this new habitat system. This includes site preparation, procedure development and other program prerequisites. Twelve 7- to 10-day missions per year would normally be scheduled.

8. <u>"Project TEKTITE"</u>:

This study presented the feasibility of utilizing the former undersea habitat, TEKTITE, of the TEKTITE II program for the NULS-2 system in a location off the northern California coast. The study included an assessment of the refurbishment, modification and updating, safety procedures, surface and shore support, and overall operations procedures of the entire system. The data and information on the modifications and refurbishment were obtained by submitting blueprints, photographs, and written descriptions of the habitat to various agencies and commercial firms and requesting final bid-quotes for services and materials. The end result was that the modernization and subsequent utilization of the TEKTITE habitat in the Calfornia Northwest Pacific region was feasible and highly desirable.

The main purposes for reactivating the TEKTITE habitat were to:

1. Begin a comprehensive study of the biology, geology, and ecology of the waters of the Pacific Ocean off northern California, including studies of the continental shelf

2. Develop in-situ field methods for scientists using saturation diving techniques and an underwater habitat

3. Further the development of ocean science and technology

Anticipated program accomplishments would be a better understanding of our natural marine environment and its sensitivity to man's encroachment, utilization, and pollution of it. It is expected that program-derived information would be highly useful to geologists, environmentalists, biologists, animal behaviorists, and the scientific community as a whole.

Site surveys were conducted with the required information being reviewed by aquanauts, geologists, and engineers. It was concluded that there were at least 12 potential site areas very close to San Francisco, off the Pacific coast, which could be of great interest to the marine science community.

One of the primary purposes of the TEKTITE program would be to train scientists in saturation diving techniques to permit direct and time-dependent research for the development, conservation, and protection of the undersea environment. With proper training and the availability of the habitat as a base, a whole new aspect to underwater research would be made available to the researchers and many types of projects impossible to do under nonsaturated conditions would suddenly be made possible.

Three main areas of research will be encouraged:

1. <u>Geologic</u> - Projects concerned with the development of an accurate site mapping, including strata, age of substrate, generation of substrate, movement, mineral composition and possible energy development, will receive top priority for the first three missions

2. Biologic - Projects concerned with marine ecosystems and man's impact, present or future, on the marine environment including fisheries and aquaculture will receive priority for following missions

3. Human Physiology - Man's ability to function in the marine environment will be the subject of many missions

In each case, projects involving applied research would receive top priority.

The equipment is classified into two categories: major, that which directly accommodates the on-site research program; and support, that which supplies all necessary services to the major. Those items which bridge on interface will be classified as support equipment.

The aquanaut/scientists will live in and work from the TEKTITE habitat. The habitat will consist of two vertical cylinders standing on a base and interconnected by a crossover tunnel. Each structure is divided into two living levels. The habitat is located on the ocean floor at a depth of 60 feet and will house a crew of five. The habitat will be supported by an overhead barge connected by an umbilical. An environmental control system regulates the habitat internal environment, which is continually checked by an atmosphere monitoring system. The communications system provides oral and visual links between the habitat to the surface. Other systems in the habitat include the electrical system, the plumbing and sanitary system, personal equipment and furnishing, and emergency equipment.

Each of the two pressure hulls is a vertical cylinder with torispherical heads and having a maximum dimension of 12.5 ft in diameter and 18 ft in length. Each vertical cylinder is divided into an upper and lower compartment. In one cylinder the lower compartment contains the crew quarters and includes the cooking, sleeping, eating, and nonmission communications equipment. The upper compartment contains the habitat bridge, with its station monitoring, communication and scientific mission equipment. The interconnecting tunnel on this upper level leads to the equipment room in the second pressure vessel. This compartment contains environmental control equipment, electrical power equipment, a food storage freezer, and the toilet. The lower level houses the wet room, which, in addition to being the normal ingress-egress from the habitat, contains storage volume for diving and mission equipment and facilities for biological specimen preparation.

The habitat contains six two-ft diameter plexiglass hemispherical windows. These windows are located strategically around the habitat to provide almost 360° visual inspection capability of the surrounding water and ocean floor. The hemispherical windows are for scientific, recreational, and diver safety observational use. An observation cupola is mounted on top of the equipment room with access gained by a ladder. This elevated viewing tower has windows around its circumference providing full 360° visibility. There are two 1000 watt underwater lights provided for night viewing.

Normal entry into the habitat is provided by an open four-ft diameter entry trunk into the wet room. A normally closed three-ft diameter hatch in the crew quarters is used for emergency underwater egress. Support to the habitat is provided by both barge-based and land-based facilities, including project offices, laboratories, a visitor dormitory, dockage, and a decompression facility. A six man double-lock hyperbaric chamber will be installed next to the Tektite office and laboratories. This chamber will be used for training topside personnel in decompression procedures and for the treatment of support personnel as needed. It is also a backup for the barge based chamber. The barge, steel hulled with 50 x 30 ft dimensions, will serve as the ocean-based support platform.

The offices and laboratories would be located in four mobile home modules. Arrangements have been made with the University of California as well as the University of San Francisco and San Francisco State University for the use of their library and cafeteria facilities. An agreement has been made with the U.S. Army for use of dormitory spaces at Fort Baker, located near the project headquarters.

The anticipated management scheme includes a Project Director responsible for the entire project and system operations followed by a group of individuals responsible for various subcategories such as:

1. Science programs
2. Safety
3. Finance
4. Medical
5. Operations
6. Systems engineering
7. Public relation

Mission selection will be determined by a board. All proposals will be presented to a seven member review board. It will consist of the program director, medical officer, systems engineer, three members of the academic marine science community and one member from NOAA. The last four members are to be selected by the first three members of the board. Their selection will be based upon their knowledge of and credentials in the marine science field, their active concern, and their past demonstration of a high degree of objectivity in marine science and/or technology.

It is planned that with the required support and resources the habitat system could be on-site and operational within 10 months from the "go-ahead."

9. <u>Texas A & M University</u>:

Known as the "Gulf of Mexico and Caribbean Undersea Research Program" this NULS-2 study considered the use of an underwater habitat and a submersible as tools for undersea research. The results of a survey of interested scientists and certain existing facilities concluded that a mobile submersible, as compared to a fixed habitat, was preferred for the NULS-2 underwater laboratory for the following reasons:

1. Submersible preferred by majority of scientists contacted

2. Submersible offers high mobility

3. Submersible can serve as research platform for the nondiver scientist

4. Submersible can easily reach depths (50 to 150 meters) of interest

5. Low visibility in shallow waters of Gulf of Mexico discourages habitat use

6. Submersible could be converted to lockout capability to facilitate diver-assisted research

It was therefore decided that the Texas A & M University's submersible Diaphus was the underwater laboratory which better fits the needs of the scientist in the Gulf of Mexico and Caribbean area containing the proposed operational sites and that it should be converted to a lockout capability in order to expand its capabilities for undersea research.

The overall objective of the undersea research program is to conduct scientific and engineering undersea research using a research submersible and its necessary support facilities. The submersible and support facilities would also be used to train personnel in undersea research procedures.

The subject areas of undersea research are numerous, but those which could specifically be addressed are reef ecology, vertebrate and invertebrate biology, geology, ocean turbulence, hydrography, nautical archaeology, decompression table development, and ocean engineering. In general, the research projects would be conducted by principal investigators from the Gulf of Mexico and Caribbean region, and their projects would normally be conducted in this same region. However, this is not an absolute requirement. A possible example of this is a nautical archaeology project in the Mediterranean Sea.

It is proposed that 100 days of submersible-ship time per year be allotted to qualified marine scientists on a competitive basis in support of meritorious research projects requiring the use of a submersible. The need for this type of support is reflected in responses to a "request for expression of interest" sent to 50 marine scientists in the Gulf States. Over 15 scientists responded with statements of interest and research briefs. The project titles from these responses are listed as follows:

1. *In situ* assessment of Gulf of Mexico reef fish populations

2. Studies of reef fish biomass in the northern Gulf

3. Survey of coral diseases below 30 meters off Florida

4. Experimental studies on coral diseases

5. Genesis and diagenesis of Caribbean carbonate platform margins

6. Descriptive biological and geological reconnaissance of deep reefs of Florida Keys

7. Studies of organic bank reefs and coral communities in the eastern Gulf of Mexico

8. Geological origin and history of upper continental slope topographic features

9. Descriptive ecology of topographic features in the northwestern Gulf of Mexico

10. Environmental monitoring of hard-bank biotic communities below 50 meters depth adjacent to offshore drilling activities in the northwestern Gulf of Mexico

11. Benthic ecology of artifical reefs off Texas

12. Neuston and zooplankton ecology and behavior in the northern and eastern Gulf of Mexico

13. Ecology/systematics/zoogeography of marine fishes

14. Supplemental shelf resources of Gulf of Mexico

15. Ecology of fish and invertebrate communities in the estuaries and continental shelf

Ideally, each mission would be planned for 25 days with a minimum of 15 days between missions for maintenance, repair, and crew rest.

The research proposals, due the first of the month, would be shown to and reviewed by the Research Advisory Board. The principal investigators would be notified during the month immediately following the Board meeting.

Mission report briefs would be completed by the principal investigator and submitted at the end of each mission. The final report or notification of submission of papers to scholarly journals would be due 6 months after the end of the mission.

It should be noted that an individual need not be a qualified diver to participate in a sumbersible research mission. This makes it feasible for a large number of qualified scientists to take advantage of the program described here.

The proposed Gulf of Mexico and Caribbean Undersea Research Program could obtain the use of numerous major facilities located in the region for the purpose of conducting scientific and engineering research. The majority of these facilities are affiliated with Texas A & M University and other well suited research facilities affiliated with the University of Texas and the University of South Alabama. There are facilities at other regional institutions which could be used in this research program, and if necessary, these facilities will be identified in the future. It is believed that a productive undersea research program could be accomplished with current facilities.

In order to expand the research capabilities, it is proposed to convert the research submarine R/V Diaphus to a lockout submersible and thus permit researchers to lockout of the submarine to accomplish desired in situ research goals.

The conversion of the Diaphus to a lockout submarine is relatively convenient because the tail section is bolted to the main body at approximately the three-quarter-length location. Therefore, it is planned to separate the two sections and insert an 8-ft by 54-in-diameter lockout chamber. This will allow saturated diving operations to a depth of 600 ft.

The lockout conversion also necessitates the use of a decompression chamber which must be capable of being installed aboard the support vessel for mating with the Diaphus. The present chambers at the hyperbaric laboratory are in use for diving and medical research and therefore are not readily accessible. However, arrangements are possible if the situation is absolutely necessary. Consequently a decompression chamber for the program is practically essential and would avoid scheduling problems.

Texas A & M has extensive existing facilities at their Galveston Marine Operations Facility for the operations of their R/V Diaphus and support ship, R/V Gyre. These resources include waterfront pier space, dockage, enclosed storage areas, cranes, buildings with office space, communications center, well-equipped maintenance and fabrication shops, and hyperbaric recompression facilities. In addition, their marine research laboratories are available to the NULS program for its related oceanographic operations and research.

The Texas A & M Research Foundation, which is a legally separate entity associated with the University, will be the formal contracting body. The Research Foundation will oversee fiscal management, purchasing procedures, and other contractural matters. Scientific and technical matters will be under the Program Manager. He will be responsible for coordinating and assisting in the acquisition of necessary resources, dissemination of information, and ensuring that reports and other activities are conducted as scheduled.

To help ensure that NOAA funded submersible ship time is utilized in the most efficient and productive fashion, a Research Advisory Board will be established to: (1) set broad program goals and objectives, and (2) review and select the research projects which will be conducted using the research submersible.

The Board will be responsible for reviewing proposals for scientific and engineering research and submitting the proposals to the Program Manager to be undertaken by the program. The Board is headed by a Chairman who is responsible for distributing proposals for review and for arranging board meetings three times a year for the purpose of making proposal selections. The Board will also review mission reports, overall program goals and procedures, and make recommendatioins to the Program Manager on an annual basis.