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PRELIMINARY STUDIES CONCERNING STRUCTURES IN THE DEEP OCEAN

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U. S. NAVAL CIVIL ENGINEERING LABORATORY

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PRELIMINARY STUDIES CONCERNING STRUCTURES IN THE DEEP OCEAN

Task No. Y-R011-01-015

Type C

by

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OBJECT OF TASK

The objective as given in the R and D Project Card under the title of Deep Ocean Studies (Structures in Deep Ocean), dated 15 March 1962, is to develop systems and techniques for construction in deep ocean areas.

ABSTRACT

This technical Note describes the results of preliminary inquiries into Deep Ocean Studies (Structures in Deep Ocean), Task Y-R011-01-015, during the period of FY-1961 and the first half of FY-1962.

Much of the work has been devoted to literature studies and conferences to establish directions for future research in the field of deep ocean structures. Basic design for a tower-like structure known as the Submersible Test Unit (STU) was accomplished. This promises to be a valuable tool for investigating the deep ocean environment as it can be immersed for long time periods.

Some conclusions derived from these preliminary studies are presented as is a broad survey of the state-of-the-art in various aspects of the deep ocean structures problem.

The work was performed at the Naval Civil Engineering Laboratory, Port Hueneme, California.

INTRODUCTION

Since the task assignment was to make appropriate investigations in the field of "Structures in Deep Ocean" as part of a comprehensive task entitled "Deep Ocean Studies", a broad-based survey of many pertinent scientific and engineering disciplines was undertaken. As interpreted at the Naval Civil Engineering Laboratory (NCEL) this required preliminary studies to accumulate knowledge of deep ocean environments and determination of their effects upon undersea structures, to survey the state of the art concerned with present techniques of emplacing any type of underwater structure, and to acquire background information in other fields of technology whose applications would have effect on the design, construction and installation of structures in deep ocean locations.

The work consisted of literature researches, conferences with NCEL staff members, the basic structural design for the NCEL Submersible Test Unit (STU), and communications and visits with personnel of other interested governmental agencies and certain commercial organizations. The investigations have been preliminary in character and concerned with the directions for future research programs. Studies were made in a large number of areas, the general classes of which may be described as: (a) the deep sea environment, (b) materials for deep sea construction, (c) undersea structures, existing or proposed, (d) undersea vehicles and tools, (e) human factors and life support, (f) deep sea communications, and (g) energy sources for deep sea installations. Each of the above-listed areas has many sub-divisions and studies in all of the areas were general. Since the period of FY-61 specific investigations in certain of the above-mentioned areas of study have been assigned to NCEL under Task Y-F015-01-001, Deep Ocean Structures.

THE DEEP OCEAN ENVIRONMENT

Since no rational design of any structure can be undertaken until conditions of loading and environment are known, it was necessary to obtain general information concerning environmental conditions on the ocean floor. Certain existing data, and the methods for gathering data, about the ocean deeps were obtained from texts.[2,3,4,5,6] Specifically, general information was collected about water currents, ocean floor stability, topography, soil bearing capacity, and similar geologic phenomena; properties of sea water such as salinity, chlorinity, density, transmission of sound, absorption of radiation; the heat budget of the oceans, periodic variation of temperature at sub-surface depths; the chemistry of sea water relating to elements present, carbon dioxide system, and geochemistry; sea organisms and the sea as a biological environment.

The literature shows that investigations in some of the above-mentioned fields have not been very abundant and that conclusions in some cases have to be based upon a limited number of observations.

Certain facts may be deduced, however, which are of value to the purposes of NCEL research programs. At this time the following may be stated:

a. Water currents on the floor of the very deep ocean generally are not significant and for design purposes may be reckoned to have a velocity of 1/4 knot.

b. Earthquake zones in the deep ocean have been defined. Localized avalanches of varying magnitudes occur but the susceptibility of a particular site to earthslides may be indicated by studies of topography and soil samples.

c. The bearing capacity of the ocean floor varies widely according to location. In some areas firm rock is found, in other locations loose unconsolidated soil a half-mile deep is present.

d. The temperature at great depths is relatively constant at about 2-1/2° Centigrade.

e. The presence of thermoclines (strata of water at diverse temperatures) is known to depths of about 2000 feet. These cause refractions of acoustic waves and complicate acoustic surveys of the ocean bottom.

f. There are differences in the chemistry of sea water at various sites on the ocean bottom. Whether or not these are of such significance as to imply specialized design or materials for a particular location remains to be determined.

g. Organisms exist at and in the ocean bottom, which have caused some damage to undersea cables, but the effect of undersea life at great depths upon structural emplacements still remains to be studied.

MATERIALS IN THE DEEP OCEAN

The bottom areas of deep oceans offer an entirely new environment for the use of structural materials. Except for signal cables, no man-made structures have been subject to long-term exposure to these conditions. Information about reactions of various materials under combinations of high pressure, constant cold temperature, and immersion in salt water is scant. Reference 7 furnished some information. Available literature on corrosion in ocean waters has mostly to do with shallow depths where the problems of pressure, temperature, oxygen concentration and chemical elements are different from those to be expected in the very deep waters.

Changes in chemical, electrical, and mechanical properties of materials in the deep ocean environment must be known to the designers of undersea structures. The effects of corrosion as these affect the serviceability of components or members certainly would have great influence on design of deep water installations. The susceptibility of certain materials to attack by biological organisms is important in determining suitability. Some work has been done on the reactions of materials to an artificial environment of saline water immersion and high pressure conditions by investigators employing high pressure chambers at the David Taylor Model Basin, the Marine Physical Laboratories, and a few other research centers. Preliminary work employing a very small chamber has been undertaken at NCEL.

Conferences among the NCEL staff indicated a need for immediate research on the problem of materials intended for long exposures to the actual deep ocean environment. Out of these conferences evolved the requirement for a vehicle to expose material and equipment specimens and environment-measuring instruments in the deep ocean for time periods that may last for several months. The configuration most suitable in shape and size for this Submersible Test Unit (STU) was a framed tower which is shown in concept form as Figure 1. Great interest was shown in this proposed underwater structure by all of the NCEL staff who were involved in "Deep Ocean Studies," and many other scientific agencies requested that they be allowed to participate in the use of the facility. The vehicle, while still in the concept stages, promised to be of great value in providing long-term observations of materials reactions and in providing a platform for measurements of fluctuations in environmental conditions on the ocean floor.

The STU as built and loaded for its first long-term immersion which began on March 29, 1962 is shown in Figure 2. The first experiment with the STU, involving a six-month emplacement at 5300-foot depth, will be the subject for a separate technical report.

EXISTING AND PROPOSED OCEAN STRUCTURES

Except for certain classified projects most of the existing underwater construction has taken place in relatively shallow depths ranging to a few hundred feet below the water surface. Most of this type of work has to do with exploitation of petroleum resources or with harbor facilities or military installations such as the Texas Towers. Some study was performed of recent patents in the field of platforms for undersea operations; and Patents No. 2938352, 2938353, and 2938354, all of which are intended for petroleum recovery work, may have possibilities of adaptation for other operations in waters of relatively shallow depths. Some interesting proposals and experiments concerning flexible rubber tanks intended for undersea operations have been made by the Firestone Rubber Company and the U. S. Rubber Company. These are inflatable fuel storage tanks open at the bottom. It has been envisioned that ultimately such tanks

Figure 1. Concept for Submersible Test Unit (STU).

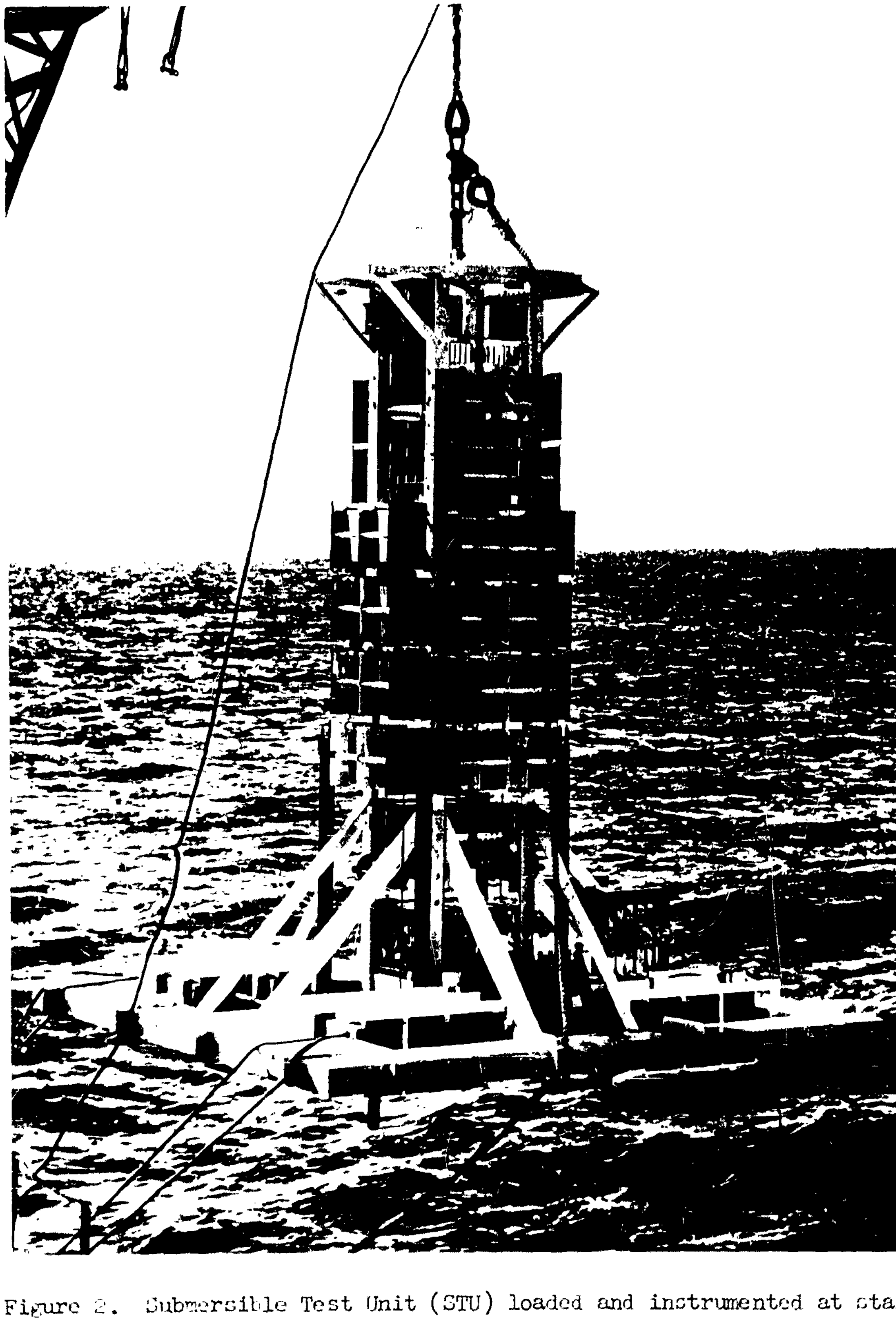

Figure 2. Submersible Test Unit (STU) loaded and instrumented at start of six-months immersion.

will have capacities in the range of 25,000 barrels each. In the field of liquid-filled structures in the deep ocean the Goodyear Rubber Company has proposed a so-called sea ballon which is an immense rubber casing filled with sea water and other appropriate fluids so as to achieve neutral buoyancy and which would be utilized as a supporting structure for certain surveillance and communication equipment in the deep sea regions.

A number of laboratories and other agencies have expressed the need for stable platforms for deep water. A typical requirement is one for a stable deep water platform of 100-ton support capacity with no angular motion beyond 1/2 degree. Studies in the field of stable platforms for ocean surface and intermediate depth regions are being conducted at the Underwater Sound Laboratories, New London, Connecticut and at the Aerophysics Development Division of Curtiss-Wright Corporation.

CONSTRUCTION PRACTICES

The general construction philosophies and techniques for the building of the Texas Towers and for certain petroleum exploration and recovery equipment in relatively shallow depths are already well known. Aside from these fields there was little to be found in the literature concerning construction practices in underwater regions. The LeTourneau Corporation has a so-called bridge building machine which involves a 3-legged platform intended to stand on the bottom of a lake and this is capable of retracting its three legs and being floated into new positions for various construction operations. The Swedish Board of Shipping and Navigation has built a light house which consists of telescoping caissons which may be towed to the final site and erected by sinking the outer caisson and pumping the inner caisson to the desired level. The New York Port Authority has constructed concrete docks which were floated from their fabrication site to the installation sites and were then emplaced by sinking the structures and ballasting them with rock and concrete. The Sound Drive Corporation has sonic drilling equipment which is claimed to be suitable for emplacement of piling in the underwater regions. The Global Marine Exploration Company has contracts for preliminary studies of drilling techniques at 3,000 foot depths.

There have been very few developments of special tools for use in the underwater areas. Some efforts to adapt existing types of manipulative equipment to the deep ocean environment have been made by General Mills Corporation. Hughes Aircraft Corporation, FMC Company, General Electric, General Motors, and perhaps by others. The general philosophy is that control will be by remote means through hard wire signal cables and that observations of the work will be by television. No reports were found concerning the development of sound or touch sensors for use in underwater construction or servicing operations. Representatives of some of the above-listed companies have indicated that pre-programmed controls such as are used in automated industrial machines may some day be developed for use in deep ocean operations.

There has been little improvement in the arts of underwater welding and flame-cutting since the period of World War II. Most of the techniques and much of the equipment for underwater work on metals dates back to that period when wartime salvage and repair work was performed. The depths for these operations were relatively shallow and only rarely was work done any deeper than 40 feet. It may be said that welding and flame-cutting are not presently possible in deep water conditions and that any joining or cutting operations will have to be performed by mechanical means.

PRESSURE VESSELS AND HULLS

Literature and other basic studies were made of vessels and hulls resistant to external pressures of very large magnitudes. A few pertinent conclusions, many of which are contained in Reference 8, concerning exterior pressure resistant vessels are: (a) spheres have a weight advantage over stiffened cylinders of from 10 to 15 percent; (b) cylindrical or spherical forms, of commercially available materials, can withstand pressures at 3-1/2 mile depths and maintain positive buoyancy; (c) at about 2,000 foot depths ring stiffeners of cylindrical vessels may weigh forty percent of the shell weight; (d) for cylindrical vessels weight increases with depth at a lesser rate in great depths; thus doubling the operating depth does not double the weight; (e) for aluminum cylinders at two to three miles depth the buoyancy is approximately double the weight; which implies that all weight carried by the vessel should not be greater than the weight of the hull structure; (f) for spherical shells magnesium, titanium, and fiber-glass reinforced plastic appear to have no weight advantages over 50,000 psi yield strength aluminum; (g) critical difficulties with external pressure resistant vessels occur where openings into the vessel must be made; (h) materials alone cannot provide the strength to weight advantages in conventionally stiffened cylinders and spheres which will permit useful design at great depths. Novel and hitherto unused methods of hull construction probably will be required; (i) there is a possibility of obtaining increased collapse depth by increasing the yield strength of a given material. If a degradation of other properties such as ductility or notch toughness accompanies any increase in yield strength, no gain may be possible.

One of the largest problems in the design of pressure-resistant vessels is the difficulty of forming and joining thick-walled parts. At the present time, facilities for forming 6-inch-thick plates of steel seem to be limited in number. The walls of the proposed aluminum submarine, the Aluminaut, which is under construction, are in the 6-inch to 8-inch-thick range; and thus, at least one facility can fabricate aluminum of great thickness. Welding operations on very thick plates of aluminum or steel present difficulties that current technologies have not satisfactorily solved. Apparently the best joining method at this time is a combination of riveting and adhesives.

FORCES ON MOORED BUOYS

Forces induced on moored buoys at the ocean surface and in subsurface regions were another subject for literature research. It is apparent that the forces induced by waves and current upon location buoys and/or construction buoys or vessels could be such as to cause extreme difficulty for operations in the deep sea. At depths of a few hundred feet wave action is greatly diminished and buoys placed at these depths can be considered free from surface wave forces. The effects of open sea currents upon these subsurface buoys would be dependent upon the conditions at particular locations in the ocean expanse.

DEEP SEA MOORS

Concurrent with the studies of floating buoys, the problems of deep ocean anchorages were investigated. Little information concerning deep moors was to be found although the classified literature touches upon the subject. Some commercial organizations are approaching the general problem; the Cleveland Pneumatic Corporation has developed anchors which used explosive charges to embed the devices deep in the ocean floor, and the Western Company of Fort Worth has equipment capable of "plowing" cable below the ocean floor.

FOUNDATIONS ON THE OCEAN BOTTOM

Foundations for undersea structural installations present an entirely new field for which techniques will have to be developed. Founding may be defined as the immovable attachment of the structure to the ocean bottom. Anything other than a massive, solid construction might imply that the structure be rooted by means of piling or cnchorages to the ocean bottom. If a hollow or relatively lightweight structure relies upon gravity alone for maintaining its location it cannot be said to be founded, only deposited or placed. Consideration must be given to the buoyant effects of the water and to the special environmental conditions of current flow and possible lateral forces caused by contact with undersea vehicles. An important factor in the design of undersea structures would have to be the horizontal shear that may take place between the structure and the sea bottom on which it is placed or between parts of the undersea structure. It may be stated that a conservative figure for the coefficient of friction between concrete materials and the sea bottoms would be 0.5 for undersea structures close to the shore line.[12/] Disturbing factors to be considered are river flow from the land, sea wave action, littoral currents, and tidal currents. So-called training works to divert or guide one or more of these natural forces may be required in the vicinity of an undersea structure.

VEHICLES FOR THE DEEP OCEAN

Emplacement and servicing of sophisticated types of installations on the ocean floor or at intermediate depths will require remotely controlled or pre-programmed manipulative and delivery equipment. The entire concept of remotely operated apparatus is fairly new although some applications have been developed for the nuclear industries and in certain processing or manufacturing plants. Some existing types of manipulative equipment could probably be adapted to use in the ocean environment. Deep ocean work presents an immediate requirement for a neutral buoyancy vehicle of the unmanned, remotely controlled or programmed type; which could be used for reconnaisance and surveying, and which could perform simple manipulative functions. There are a few such vehicles presently available, notably the Vare Industries' "Mermut", and the Vitro Corporation's "Solaris" and a few others on the drawing boards of such companies as the Hughes Corporation, FMC Corporation, General Mills, and U. S. Industries Corporation. At some future time there will no doubt be requirements for large, powerful, sophisticated underwater manipulative machines which might be manned, or controlled by a programming device or from a remote station; and these would be able to perform such work as site preparation, emplacement of structures, repairs, adjustments, recovery of records or stored material, refueling, and the like. Information on underwater vehicles was obtained in part from References 18, 19, 20, 21, 23, and 24.

A comprehensive report on underwater vehicles is currently in preparation at NCEL under Task Y-F015-01-001(f), Structures in Deep Ocean - Service Vehicles.

LIFE SUPPORT

Thus far little information is available concerning life support methods for the deep sea environment. Experiences with submarines apply; these large vessels have facilities that do the job adequately at relatively shallow depths and for relatively short time periods. It is possible that the life support devices intended for use in outer space will have some application to the uses of inner space. The problems are very basic; these are to provide breathable atmosphere at proper pressure, to supply food and drink, and to dispose of waste products.

For occupancy in confined spaces, the concentration of carbon dioxide becomes critical at a much faster rate than does that of oxygen. Present methods of regenerating breathable atmosphere include the use of chemical oxygen generators and carbon dioxide absorbents, carbon monoxide and hydrogen eliminators employing catalytic processes, carbon dioxide scrubbers, molecular sieves, electrolytic generators, algae, and the sodium sulfate process.

Food supplies would have to be of the concentrated ready-to-eat low-residue varieties, some kinds of which are presently available. Water supply would probably have to be reclaimed from the sea or from waste products since limited space would severely limit storage of fresh water.

Waste disposal would probably be accomplished either by chemical breakdown or by mechanical passage into the surrounding sea.

There is the possibility that supplies of breathing atmosphere and food and drink could be delivered to, and waste products removed from, an undersea station by utilizing capsules which could be sent to the station. This solution would require major developments in abilities to guide and attach these capsules to their undersea positions.

Certain information on life support methods is contained in References 25, 26, and 27. No research in the field of life support in the deep ocean is presently assigned to NCEL, but interest is maintained by perusal of the current literature and related studies have been made in relation to protective shelters for ABC warfare.

COMMUNICATIONS IN DEEP OCEAN

Communications with the ocean bottom during the locating, surveying, and preparation of a site, during the emplacement of a structure, and for the use and maintenance of an installation are of vital importance to those who design, install, or use such facilities. The advancement of deep sea communication methods is the concern of specialists but a general knowledge of presently available methods, and their capabilities and limitations, is necessary to all who are involved with the exploitation of the ocean depths.

The most certain method of communication is a hard-wire electrical signal carrier and this type of system can utilize already available components and techniques. For certain types of installations the hard-wire systems may be impractical and it may be necessary to utilize other methods. Radio signals cannot be used because the electrical waves have little penetrating power in water. Light signals have somewhat better transmission qualities in water but these are affected adversely by turbidity and cannot be relied upon for any significant range of transmission. Acoustic signals offer the best prospect for effective communication in the ocean depths. Reports have been made of an acoustical wave traveling through the water for a distance half way around the earth. Considerable sophistication in sound generating and receiving has been accomplished.

The prospect of surveying the ocean floor by the use of Sonar has limitations dependent upon water depth. In deep waters, due to the refraction of signals at the thermoclines, no great accuracy is claimed for depths or directions obtained by acoustical methods. Some greater usefulness may be gotten with these methods if the sound generators and receivers are suspended in depths of water below the influence of thermoclines; but precise positioning of the instruments is difficult.

The use of transponders (responsive signal generators) and pingers (constant signal generators) attached to any kind of deep sea equipment makes determination of approximate location a fairly simple matter, if the location of pinger is first predetermined within about one-mile range.

Use of coded sound grenades to activate certain undersea equipment appears to be a practical possibility and this method will be tried in the retrieval techniques for the NCEL Submersible Test Unit.

Deep ocean television systems are still under development by several firms. The main difficulty is the transmission of the signal over lines of considerable length. It is necessary, of course, in any TV set-up to supply an adequate light source for the camera and this requirement may complicate any system used at remote depths. In order to obtain depth (distance) perception it is necessary to use two or more cameras in a TV system and this is another complicating factor in a deep-sea system. The Oceanographic Engineering Corporation of San Diego has a system embodying repeaters at half-mile intervals in the cable that appears to have considerable promise for work at great depths.[28]

ENERGY SOURCES

Any type of permanent or semi-permanent installation in the ocean depths must necessarily be furnished with energy from some source. At present the only useful methods are to deliver electrical power from some remote source or utilize electric batteries of various types.

Nuclear power as used in submarines probably could be adapted to the environmental conditions of the deeps, but it may be several years before suitable small nuclear power packages are developed. The closest thing to a presently usable nuclear power package is SNAP 4, a 3-megawatt plant which would weigh about 17 tons and be contained in a cylinder about 16 feet long and 7 feet in diameter. This is a project presently assigned to Atomics International. Other SNAP systems intended to give power under an outer space environment propose packages that would create power sources ranging from a few watts up to 60 kilowatts, Ref. 29. It appears that development on these is still in the early stages.

The Avion Corporation has a chemical engine, using exotic fuels, of 20 horsepower capacity which may have some applications underwater.

The Ethyl Corporation proposes a sodium hydride gas generator.

A number of industrial and university laboratories are working on electrical generators operating in the deep water environment and utilizing such phenomena as 1/2 knot water currents, wave motions, differential movement between surface and sub-surface buoys, pendulums on wave-rocked frames; differential temperatures at various depths; and direct electrical generators based on thermo-electric principles.

Reference 13 states:

"A development that offers some potential as a remote power source is the so-called BuShips "bug-battery"where power can be produced through anodic and cathodic doping of anaerobic and aerobic bacteria. We shall first start with a magnesium sea water battery and use anaerobic bacteria to depolarize one of the electrodes. Further feasibility study has shown that the other electrode can be "doped" with a different series of bacteria (these bacteria do not die, seemingly living on themselves or on sea water or hydrogen and oxygen that may be discharged) and obtain a long life system. Bacteria behavior at depth has not been completely studied".

FUTURE WORK

With the publication of this Technical Note work done under Task No. Y-R011-01-015, "Deep Ocean Studies (Structures in Deep Ocean)"is concluded. Further studies will be proposed and conducted when and as appropriate under Task Y-F015-01-001.

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