U.S. DEPARTMENT OF COMMERCE
John T. Connor, Secretary
COAST AND GEODETIC SURVEY
H. Arnold Karo, Director

Instrumented Telemetering Deep Sea Buoys

H. W. STRAUB, J. M. ARTHABER, A. L. COPELAND, and D. T. THEODORE

TECHNICAL BULLETIN NO. 26
June 1965

UNITED STATES GOVERNMENT PRINTING OFFICE • WASHINGTON: 1965

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C., 20402 - Price 25 cents

Technical Bulletin Series

This series of Technical Bulletins was inaugurated to present primarily to the personnel of the Coast and Geodetic Survey and incidentally to others technical information related to the Bureau's scientific and technical activities. Since many of the bulletins deal with new practices and new techniques, the views expressed are those of the authors and do not necessarily represent final Bureau policy.

Technical Bulletin No. 26 is a state-of-the-art report on deep sea buoys. Among the divisions of the text are sections on the mooring system, power sources, instrumentation, fouling, and protection of the mooring, data handling and storage, telemetry, and a summary of recommendations and conclusions. In the context of this bulletin, the term deep-sea buoy is defined as one which is unmanned, moored in the deep water outside the continental shelf, left on station for a period of days to months, and instrumented to measure environmental parameters and to store the data until they are either manually picked up or telemetered to the shore.

NOTE.--The inclusion of the name or description of any product in this Bulletin does not constitute an endorsement by the Coast and Geodetic Survey. Use for publicity or advertising purposes of information from this Bulletin concerning proprietary products or the tests of such products is not authorized.

COAST AND GEODETIC SURVEY TECHNICAL BULLETINS

No. 6. The Tsunami of March 9, 1957, as Recorded at Tide Stations. Garrett G. Salsman, July 1959 . . . . . Price 15¢
No. 7. Pantograph Adjustment. G. C. Tewinkel, July 1959 . . . . . Price 5¢
No. 13. A Singular Geodetic Survey. Lansing G. Simmons, September 1960. . . . . Price 15¢
No. 14. Film Distortion Compensation for Photogrammetric Use. G. C. Tewinkel, September 1960 . . . . . Price 10¢
No. 15. Transformation of Rectangular Space Coordinates. Erwin Schmid, December 1960 . . . . . Price 15¢
No. 16. Erosion and Sedimentation. Eastern Chesapeake Bay at the Choptank River. G. F. Jordan, January 1961 . . . . . Price 40¢
No. 17. On the Time Interval Between Two Consecutive Earthquakes. Tokuji Utsu, February 1962 . . . . . Price 10¢
No. 18. Submarine Physiography of the U.S. Continental Margins. G. F. Jordan, March 1962 . . . . . Price 20¢
No. 19. Analytic Absolute Orientation in Photogrammetry. G. C. Tewinkel, March 1962. . . . . Price 20¢
No. 20. The Earth as Viewed from a Satellite, Erwin Schmid, April 1962 . . . . . Price 20¢
No. 21. Analytic Aerotriangulation. W. D. Harris, G. C. Tewinkel, and C. A. Whitten, July 1962, corrected July 1963 . . . . . Price 30¢
No. 22. Tidal Current Surveys by Photogrammetric Methods. Morton Keller, October 1963. . . . . Price 20¢
No. 23. Aerotriangulation Strip Adjustment. M. Keller and G. C. Tewinkel, August 1964. . . . . Price 30¢
No. 24. Satellite Triangulation in the Coast and Geodetic Survey. February 1965 . Price 20¢
No. 25. Aerotriangulation: Image Coordinate Refinement. M. Keller and G. C. Tewinkel, March 1965. . . . . Price 15¢

Coast and Geodetic Survey Technical Bulletins are available from the Superintendent of Documents, Government Printing Office, Washington, D.C., 20402.

Instrumented Telemetering Deep Sea Buoys

H. W. Straub, J. M. Arthaber,
A. L. Copeland, and D. T. Theodore
U.S. Coast and Geodetic Survey

1. INTRODUCTION

SHIPS are still the most generally used means for investigating the deep-ocean environment. Their operation is expensive, not only because of the cost of depreciation, interest, and operation, but also because the complement needed to operate a vessel consists of more personnel than are necessary to make the required or desired measurements. Moreover, a ship cannot remain stationary at any point on the ocean for long periods of time. But measurements of oceanographic and meteorological data extended over periods of weeks, months, or years in one location are a necessity in order to permit valid, nonaccidental conclusions. On the other hand, certain operations cannot be economically performed from buoys, such as dredging, coring, bottom or plankton sampling, in short--observations of time-independent characteristics or properties--and for these ships will remain in use, as well as for operations outside established buoy networks.

Automated, instrumented, telemetering buoys, especially networks of such buoys, placed at intervals of the order of hundreds of miles, avoid the disadvantages of the use of ships by giving the desired coverage over extended areas for long time intervals. This coverage is difficult to obtain if ships are used, regardless of the amount of funds invested.

It is, therefore, logical that about 10 or 15 years ago many workers began theoretical, experimental, and engineering work on deep sea buoys. It is felt at the Coast and Geodetic Survey that enough material has been generated to make the presentation of a state-of-the-art report on the field of deep sea buoys a desirable publication.

While engaged in the collection of the available material, the authors realized that so much work has been published in recent years that encyclopedism had to be balanced against readability of the report. In the ensuing selection process, emphasis was placed on the system rather than the component aspect.

Caution was exercised in the evaluation of technical literature to avoid the development of a somewhat unrealistic impression. Sales managers do not have a reputation for modesty, and their influence diffuses into the technical literature to some extent. And even the project engineer, while presenting a report on his work at a technical meeting, feels that it behooves him professionally to show enthusiasm and optimism rather than the opposite. But, reality normally lies somewhere in between, as is usually evidenced as soon as the equipment is put to the test of time and oceanic environment.

In the context of this bulletin, the term deep-sea buoy is defined as a buoy which is unmanned, moored in the deep water outside the continental shelf, left on station for periods of days to months, and instrumented with sensors to measure environmental parameters and equipped to store the data until they are either manually picked up or telemetered to the shore (or a passing satellite). For example, the Navy's *Flip* (floating instrument platform) and *Spar* (seagoing platform for acoustic research), and the University of Washington's *Toby* and *Mentor* vehicles, being either manned or powered and tended through a cable link to a ship, have been excluded. Also excluded were classified systems. This is unfortunate because some of them exhibit a more advanced state-of-the-art than those which could be described in this bulletin.

2. MOORING SYSTEM

A mooring system is that arrangement of components located in a body of water such that its location remains within preestablished boundaries for a specific time. Fundamentally, this is accomplished by use of an attachment to the bottom, which effectively resists the forces transmitted to it via the connections between the moored object and the attachment (1). This comprises the anchor, the mooring line (rope), and the moored object (buoy--hulls, floats).

---

[1] Robert Taggart, Inc., Falls Church, Va., Handbook of Underwater Engineering, for Office of Naval Research, Contract Nonr 4228(00), Apr. 1964, pt IV, ch. 1, p. 1.

Mooring systems are classified in a number of ways. The classification here will concern only the physical means of fixing a mooring in place. In this, moorings are classified as the type of mooring by their line arrangement, i.e., taut line or slack line.

A taut line mooring is one in which the rope connecting member running between the anchoring device and the moored object, buoy or float, in proximity to the moored object, is held taut by a large reserve positive buoyancy near the top of the mooring, generally below the water surface. This provides a relatively fixed reference point not prone to large excursions (horizontal or vertical motions) brought on by wind, wave, or current action (2).

A slack mooring allows more horizontal excursions and has a larger scope (ratio of length of line to depth of water at the mooring). Characteristically, in horizontal excursions a taut line mooring changes its inclination to the vertical with little effective increase in tension in response to increased horizontal forces on the mooring, while slack line mooring resists horizontal forces by increased tension in the mooring line (3).

In the application of taut and slack line moorings are many variations. The proper applications are determined by the environment demands, type of moored objects, depth of water, and by the experience and preference of the designer. These variations can assume a multitude of configurations such as: single leg (point of attachment or float) and single line, multiple legs with a single line for each leg, a group of multiple legs with a single line for each group, and any combinations of the above with taut and slack moorings used interchangeably in the combination.

A very common application is the combination of the taut line mooring to a subsurface float, then a slack line to the moored object; this slack line is referred to as a pennant if near the moored object, otherwise, if deep, 50 meters, a catenary. Automatic self-mooring buoys, described later in this bulletin, generally employ the taut and slack line mooring in combination.

One of the most stable underwater platforms to date employs a combination of a single leg (float) and multiple taut mooring lines. This is the Coast and Geodetic Survey Submerged Stabilized Platform (4), which is held in place approximately 30 meters below surface by three 45-degree slope, taut line cables to anchors arranged on the bottom to form an equilateral triangle. To prevent the cables from forming a catenary and thereby increasing the slack, they are supported by glass floats spaced at intervals along the cable length. Excellent stability, both rotational and platform tilt, is maintained.

2.1 Anchor

The fundamental purpose of an anchor is to form the connection to the ocean bottom, and thereby, within limits, fix the position of a moored object (5). Anchors are divided into two classes, gravity type anchors and imbedment type anchors.

2.1.1 Gravity Type Anchor

This type of anchor depends on the weight and friction it develops at the bottom to resist the forces imposed on it. The higher the density of the materials, the less bulky the anchor will be, which naturally allows for a more rapid lowering rate due to less drag. A consensus of oceanographic practice shows there is no relationship between buoyancy of the float and anchor weight (6). The size and material of anchors are due more to the availability of the material, cost, and its physical size. The materials used are concrete, cast iron, concrete filled with iron scraps, or dense heavy scrap materials, e.g., railroad wheels. The economics of purchasing and shipping heavy anchors usually dictates that any convenient, heavy scrap material be used in most cases (7). According to Richardson, et al, "Lumped constants are equivalent to distributed constants" in muddy ground. Inexpensive 360 kg. cast iron clumps tied to each other in a line with polypropylene rope instead of expensive heavy chain as anchor weight were used two per buoy in the Gulf Stream. Buoyancy of polypropylene rope prevented fouling the anchor (8).

2.1.2 Imbedment Type Anchor

This type of anchor depends on its ability to bite into the bottom as well as the holding characteristics of the bottom material to resist any movement. There are many variations of the imbedment type anchor ranging from the simple mushroom type to sophisticated designs employing explosives that drive and expand the anchor

---

[2] Id, at pt IV, ch. 1, p. 2.

[3] Ibid.

[4] Alldredge, L. R., and Fitz, J. C., Submerged Stabilized Platform, *Deep Sea Research*, vol. II, 935, 1964.

[5] Robert Taggart, op. cit. note 1., pt. III, ch. 1, p. 1.

[6] Pickett, R. E. L., Development of Environmental Sensing Buoys, U.S. Naval Oceanographic Office, Report No. 0-19-63, p. 4, Unpublished manuscript.

[7] Ibid.

[8] Richardson, W. S., Stimson, P. B., and Wilkins, C. H., Current Measurement From Moored Buoys, Woods Hole Oceanographic Institute, Woods Hole, Mass., Ref. No. ONR Contract No. Nonr-3351(00)NRO83-501, 63-1, Jan. 1963.

flukes as it is imbedded in the bottom (9). Weight, arrangement of flukes, crown, and stock, and location of fitted stock are the variations employed to increase the anchor's effectiveness.

The horizontal imbedment type anchor is the most common and familiar type. It derives its holding power by biting into the bottom until it builds up resistance primarily to the horizontal component of the mooring line force. Numerous configurations of this type anchor are available for various types of mooring and in sizes and weights in excess of 18,000 kg. The supposed purpose of specially-designed anchors is to provide high drag for their weight, e.g. the Danforth. The U.S. Naval Civil Engineering Laboratory developed a new family of imbedment anchors which has demonstrated good performance in sand and mud. Its outstanding design feature is the concept of field adjustment of the fluke angle to suit bottom conditions (10). The new anchors are named BuDocks *Stato*.

In contrast to the above sophisticated designs, which principally try to achieve the maximum imbedment of a probe or prong (in correct terminology, a fluke) into various bottom materials, is the simple mushroom anchor, constructed of steel or reinforced concrete. It has relatively poor biting capacity particularly in sand. However, it is considered to be a good anchor in very soft bottoms. Mushroom anchors are made in weights exceeding 4500 kg. (11). An interesting fact worth noting is that the largest environmental sensing buoy, *Nomad*, with 16,300 kg. of buoyancy has the smallest anchor, a 225 kg. mushroom (12).

With the horizontal imbedment anchors, the angle of the mooring line with respect to the bottom is a very important factor in performance. To get maximum effectiveness, or bite, mooring lines are attached to heavy clumps first, which rest on the bottom, and then to the anchor, thus forming a line from the anchor approximately parallel to the bottom.

To meet oceanographic needs a number of vertical imbedment anchors were developed. Woods Hole Oceanographic Institution has recently developed an anchor that digs into the bottom, and when pulled from any direction, a bridle turns and forces the anchor to dig deeper into the bottom (13). It is constructed of cast iron and has a "horseshoe crab" shape. Some ordinary grapnels have been successful under special conditions as vertical imbedment anchors.

A more positive and elaborate anchor is the explosive vertical imbedment anchor. Explosive anchors are useful in hard bottoms. One type is basically a projectile shaped affair which is driven into the bottom by an explosive or other force. It then spreads its flukes, which are locked in this position, and thus resists being pulled out of the bottom. The Navy has developed an anchor, called the umbrella pile anchor, which is imbedded in the bottom by a pile driver. One should bear in mind that these mechanical vertical imbedment anchors are complicated and expensive for general use (14). The "Seastaples" (15) were tested by the Naval Ordnance Laboratories and measurements were made of the anchor holding capacity off Santa Barbara, Calif.; Ft. Lauderdale, Fla.; and Solomons Island, Md. Comparisons of calculated holding capacities with measured pullout loads showed that the anchors failed to lock properly on many of the tests. Additional tests are needed of "Seastaple" anchors that operate properly (16).

Some anchors are provided with bottom detecting devices that give warning when they touch the bottom. One such device when it hits the bottom allows a solid steel piston, weighing about 13.5 kg. and with a sharp fluted point, to fall and puncture a hollow glass ball resting on another mass of steel. The rupturing of the glass ball causes a violent implosion that is audible at the surface through the echo sounder.

The above mainly covers one of two important anchor characteristics--its biting capacity. The other important characteristic is its holding capacity, which is largely dependent on the material structure and configuration of the bottom, as well as the anchor design.

Assuming any of the imbedment type anchors with their specialized variations in design are correctly and properly imbedded in the bottom, their respective holding powers then become a function of the bottom materials. Thus, for the same design, but different weights, the lighter anchor, properly imbedded in a similar bottom, will have the same holding power as the heavier one; but properly imbedded in different bottoms, their holding powers will be different. Anchor holding power data were placed in broad material groupings with the following characteristics (17):

(1) Sand--more consistent holding power than mud. Anchor must dig deeply.

---

9 Robert Taggart, op. cit. note 1, at pt. III, ch. 1, p. 1.

10 Towne, R. C., and Stolcup, J. J., New and Modified Anchor for Mooring, U.S. Naval Civil Engineering Laboratory, Port Hueneme, Calif., Final Report, Technical Note No. N-458, Mar. 1960.

11 Robert Taggart, op. cit. note 1, at pt. III, ch. 1, p. 3.

12 Pickett, op. cit. note 6.

13 Ibid., and Robert Taggart, op. cit. note 1, at pt. III, ch. 1, p. 5.

14 Pickett, op. cit. note 6, and Robert Taggart, op. cit. note 1 at pt. III, ch. 1, p. 9.

15 National Water Lift Co., Div. of Pneumo Dynamics Corp., "Seastaple Anchor", Company Bulletin, Kalamazoo, Mich.

16 Bradley, W. D., Field Tests to Determine the Holding Capacity of Explosive Imbedment Anchors, Naval Ordnance Laboratory Test Report--NOLTR 63-117.

17 Robert Taggart, op. cit. note 1, at pt III, ch. 1, p. 18.

(2) Mud--wide range of holding power.

(3) Coral--fairly good holding power.

(4) Clay--good holding power; anchor must dig deeply.

(5) Rock--generally poor for horizontal imbedment type anchors.

In summary, an anchor's performance is related to the design and physical characteristics of the anchor, the bottom soil characteristic, the proper setting of the anchor, and the angle of force applied to the anchor. Best results are obtained when all the information for a mooring position is known, if possible, then selecting the anchor and arrangement available which will perform best under those conditions.

2.2 Rope

Barring collision with, or outright theft of the buoy itself, failures of the mooring cable have been the most common life limiting factor (18). Much work has been done on this aspect. The difficulties are accentuated by the fact that no one type of cable is best suited for all kinds of ocean environment. For instance, currents of different velocities and different directions at different depths affect its curvature and inclination and, consequently, its stretch and scope (length-to-depth ratio). Or, if a buoy is intended to be moored 100 meters under the surface at a known depth of 6,000 meters, and if the stretch is only known to ±1 percent, an error of 60 meters may result. A statement by K. W. McLeod (19) describes the situation: ". . . most underwater instrumentation cable designs, especially in oceanography, devolve into a tug of war between conductivity, weight, strength, hydrodynamic drag, etc." The cable's density (limits 0.75 to 4) determines its submerged weight and payload capacity if vertically suspended. Cables intended for great depths and containing insulated conductors must be made void-free, or else they will compress and deform the interior insulation, and thus increase in density. They must be either flooded or filled with an incompressible, elastic compound.

2.2.1 Metallic Ropes

Nothing much need be said about standard chain and standard steel rope except maybe the instance when some workers discovered to their dismay that they should have used insulator-lined shackles and thimbles for connecting chains or ropes of different materials or having different platings to prevent galvanic corrosion.

In most oceanographic work one end of the cable is left free to rotate. In a bottom moored buoy, it is the upper end. In an instrument suspended from shipboard, it is the lower end. The free end rotates, in either circumstance, the amount depending on the load which results in increased stretch, reduced breaking strength, and the possibility of kinking on recovery. The latter may cause equipment damage and personnel injury. In the event of high moment of inertia loads, long-period oscillatory rotation is also possible. The cause is an unbalance of torque between the inside and the outside windings. An improvement in the wire rope field has recently been reported (20). In the new type cable, the net torque has been made zero by applying in each layer a computed combination of lay angle and wire size. Wire strands and armored electrical cables incorporating the balance design have been manufactured and field tested with the reported result that the rotation problem has been overcome.

In another type of undersea cable (21), galvanic corrosion and also fouling by marine growth has been stated to be prevented by cupronickel cladding the stainless steel wires to give galvanic protection even in the case of a break in cladding. With a corrosion rate of 7 to 8 microns per year, a service life of 2 to 5 years in sea water has been indicated at a tensile strength of better than 22,000 kg. per square centimeter.

2.2.2 Nonmetallic Ropes

Cable consisting of melt-drawn glass fibers (fiberglass) takes advantage of the high tensile strength (20,000 kg. per square centimeter) of the unscratched fiber. The difficulty lies in the avoidance of strength-reducing scratches. In a cable made of uncoated fibers, adjacent fibers will chafe one another during handling and thus produce scratches. It has been found, for instance, that uncoated deep sea mooring cables of fiberglass could be used only once and would break when used a second time (22). The difficulty has been overcome (23) by epoxy coating each individual fiber after it has been drawn from

---

[18] Stimson, P. B., Performance Record of Moored Buoy Systems, Woods Hole Oceanographic Institution, Woods Hole, Mass., Reference No. 64-14, Mar. 1964, Contract No. Nonr-3351(00) NR 083-501.

[19] McLeod, K. W., Cable--The Indispensable Link. Fall Instrument Automation Conference, Instrument Society of America, Sept. 25-30, 1960.

[20] McLeod, K. W., and Bowers, W. E., Torque-Balanced Wire Ropes and Armored Cables. Trans. of the Mar. 1964 Buoy Technology Symposium, Marine Technology Society, p. 233.

[21] Stainless Undersea Cable "C-Clad", Metals & Controls, Inc., Texas Instruments Corp., Review of Scientific Instruments, vol. 35, 1964, p. 1738.

[22] Muga, B. J., U.S. Naval Civil Engineering Laboratory, Port Hueneme, Calif. Oral communication.

[23] Owens-Corning Fiberglas Corp., New York, N.Y., company bulletin of October 1964.

the melt, but before it has come into contact with any other object. The coated fibers are then spun into a rope of the desired size to which a coverall coat of epoxy is applied. Because of the softness of the epoxy before setting, a scratch and void-free cable of 20,000 kg. per square centimeter tensile strength comparable with that of steel, and of 1.6 specific gravity (1/4 to 1/5 that of steel) is obtained.

Drawbacks are low resiliency, requiring the introduction of shock absorbers if resiliency is an important consideration, and the fact that epoxy coated fiberglass cables are difficult to connect to other equipment or to repair in the field when broken. In both cases, it has to be epoxy potted in a drill hole in an adaptor or thimble, but this bonds only to the coating, not the fiberglass itself. Experience will show whether these drawbacks are tolerable or prohibitive.

A further increase in tensile strength should be achievable if a similar technique is applied to fused silica fibers.

Other fibrous materials that have come into use in the past years are nylon and polypropylene. Polypropylene (24) has the attraction of being lighter than water and to prevent, for that reason, fouling the anchor in anchor-first launchings. Also, the buoyancy of the rope, minus the weight of attached sensors, can make a mooring system practically weightless in water. A typical breaking strength is 1,800 kg. for 12-millimeter (½ inch) diameter line. The resiliency of polypropylene tends to make self-regulating the scope (length-to-depth ratio) of a surface mooring.

On the other hand, polypropylene creeps and becomes permanently thinner and weaker when stretched more than 50 percent of its original length. Such a condition, if not noticed during launch, can lead to later loss of the buoy. Furthermore, the material requires special handling when being wound under tension on drums to prevent crushing of the drum or "burning" of the rope, that is, plastic fusing (25), on a conventional winch. The rope buries itself in the preceding layer with evidence of burning. Nor can this type rope, when wound under load over a cat head, be slipped across the drum without burning. To overcome this, specially designed grooved rollers are used which prevent slippage between rope and groove.

Nylon, unlike polypropylene, neither creeps nor burns, but is slightly heavier than water (specific gravity 1.12). One common feature of nylon and polypropylene is their excellent resistance to bacteria, fungi, and other marine growth, and to chemical attack by seawater. Undesirable kinking has occasionally occurred in twisted ropes of either kind. This could be prevented by braided ropes, if they are manufactured and used.

A comprehensive study of the design of various mooring systems, including types of anchors, ropes, subsurface and surface floats and pennants, also launch procedures, has been performed at Scripps Institution of Oceanography (26). The pertinent result is the preference of taut-line moorings employing nylon with a 16 to 17 percent stretch.

2.3 Hulls

In general, hulls (floats, buoys, or platforms) are used in a very wide variety of sizes, shapes, and weights. The applications and requirements are the governing factors in the ultimate design as well as cost. Surface floating requirements impose the more severe restraints on design than subsurface hulls or buoys.

Surface buoys with antennas, sensing instruments, stability demands, and hostile environments require more costly and elaborate systems than subsurface buoys, whose major drawback is electronic or signaling reliability for retrieval. In the final analysis the mission objective for the buoy station, plus the effect of waves, currents, and corrosion on moorings, all determine the design restraints for the complete system.

Variations in hull (buoy) shape and configuration are as many as the requirements (function and environment) and the designers. However, they are discussed here only by their physical (body) outline.

2.3.1 Boat-shaped Hulls

Boat-type buoys are surface stations. Generally, they are designed to turn and face waves and currents. They have the lowest drag to weight factor (27) which is advantageous in that it minimizes excursions from its moored position as well as tensions in the mooring line. Because they are a seaworthy and stable platform, which though good for the function they perform, is the principal cause for their theft. The *Nomad* (28) and the *Mentor* (29) are examples of the skiff and catamaran vessel types.

---

[25] Jones, R. E., Emplacement of the First Submarine Test Unit on the Sea Floor--One Mile Deep, U.S. Naval Civil Engineering Laboratory, Technical Note No. N-458, Feb. 18, 1963.

[26] Isaacs, J. D., Faughn, J. L., Schick, G. B., and Sargent, M. D., Bulletin of the Scripps Institution of Oceanography, La Jolla, Calif., vol. 8, 1963, p. 271.

[27] Uyeda, S. T., Buoy Configuration Resulting from Model Tests and Computer Study, Trans. of the Mar. 1964 Buoy Technology Symposium, Marine Technology Society, Supplement p. 31.

[28] Hakkarinen, W., The World of *Nomad* -1, Trans. of the Mar. 1964 Buoy Technology Symposium, Marine Technology Society, Supplement p. 443.

[29] Badgley, F. I., Fleagle, R. G., Lang, L. D., and Yake, M. M., A Meteorological Research Buoy, Trans. of the Mar. 1964 Buoy Technology Symposium, Marine Technology Society, Supplement, p. 65.

2.3.2 Geometric-shaped Hulls

Geometric-type buoys are used both as surface and subsurface stations.

2.3.2.1 Toroid.--Toroids, generally, are water surface stations with superstructures above the water surface containing instrumentation, antennas, and warning devices (30). The toroid buoy is also used as a subsurface buoy or float, sometimes to provide the major buoyancy for a mooring line, and in other cases as a stable platform for an instrumentation package that can be raised to the surface for data gathering or maintenance and lowered back into a nest in the toroid buoy for use below the water surface (31). Toroids have a high drag to weight ratio and are not very stable in rough seas, however, thin toroids have good wave stability (32).

2.3.2.2 Discus.--The discus buoy is a surface buoy (33). The drag to weight ratio is low, a little higher than the boat type *(Nomad)*, and, like the boat shape and thin toroid, has good stability in waves with minimum resonance (34). It is the configuration that General Dynamics/Convair finalized for the Office of Naval Research's telemetry oceanographic *universal* buoy after extensive research and development. It is 12 meters in diameter and about 2 meters thick.

2.3.2.3 Cylinder.--Cylindrical (Spar) buoys are surface and subsurface buoys with the maximum drag to weight ratios, as well as the highest angular motion because of its resonance characteristic (35). As a compensation, it has the smallest vertical excursions of all type buoys providing a useful vertically stable platform.

2.3.2.4 Spherical and Spheroidal.--Spherical and spheroidal buoys are most commonly employed as surface and subsurface buoys. Many of their applications are as the subsurface buoyant support for taut moorings, to which are attached pennants that connect from the subsurface float to the surface buoy.

Spherical and spheroidal buoys are sometimes employed as subsurface buoys without surface markers. This is an obvious advantage against theft, vandalism, and curious meddlers. In addition to providing buoyancy for a taut wire mooring, being below the surface (40 to 75 meters) of the water, it is unaffected by waves. This also reduces its fouling by ships, shark bites, floating ice, excursions, and forces that cause mechanical stresses, fatigue, and abrasion of the mooring line. However, many buoys are lost because of electronic or power failure, frustrating their location for retrieval.

2.3.2.5 Inverted Cones.--Inverted cones are a popular physical shape for surface buoys and in combination with spherical and cylindrical forms are commonly found in inland waterways and shallow sea shelves. They are made in many different topside configurations depending whether their prime function is to provide an antenna, warning beacon, or whistle.

2.3.3 Automatic Buoys

A number of self-deployment (automatic mooring) buoys are a combination of cylindrical and conical configurations of spar buoys (36). These automatic self-mooring buoys are some of the more popular buoys for limited applications. Many are proprietary products. Significantly, the common characteristic of these automatic buoys is the spar configuration either as a surface float or as a subsurface float with self-reeling winches to automatically payout the anchor, forming a taut moor line and then releasing a surface buoy (cylindrical, spherical, inverted cones, or any combinations of these shapes). The subsurface buoy and automatic winch assembly is designed to set itself at a predetermined depth (approximately 45 meters) below the water surface. After anchoring the mooring line, the surface buoy rises (37). One company claims successful air or boat launched automatic buoys anchoring to depths of 6,500 meters (38). The U.S. Coast Guard--Federal Aviation Agency accordian buoy is a combination cylindrical and conical shaped spar buoy successfully moored in 4,000 meters, providing surface daymark, beacon light, and radar capability (39).

2.3.4 Materials

The great majority of hull, buoy, or float materials are metal. Steel is most common with various antifouling and anticorrosive protection

---

30 Verber, J. L., The Use of Unmanned Fixed Buoys for the Collection of Temperature and Current Data, Trans. of the Mar. 1964 Buoy Technology Symposium, Marine Technology Society, p. 122. Geodyne Corp., Waltham, Mass., Instrument Buoy Toroidal Shape, Bulletin No. S-32, Mar. 1963.

31 Alldredge, L. R., op. cit. note 4.

32 Uyeda, S. T., op. cit. note 27.

33 Ibid. Daubin, S. C., Mooring Design and Performance of Oceanographic Buoys, Trans. of the Mar. 1964 Buoy Technology Symposium, Marine Technology Society, p. 58.

34 Uyeda, S. T., op. cit. note 27.

35 Ibid.

36 Pritzlaff, J. A., and Laniewski, J. P., Development of Self-Contained Deep Moored Buoy System, Trans. of the Mar. 1964 Buoy Technology Symposium, Marine Technology Society, p. 73. E.M.I.--Cossor Electronics, Ltd., Dartmouth, Nova Scotia, Canada, Instrumentation Vehicle for Oceanographic Data Collection, Handbook Brochure.

37 E.M.I.--Cossor, op. cit. note 36.

38 Sanders Associates, Inc., Nashua, N.H., Presentation at Department of Commerce, Weather Bureau, Washington, D.C., Feb. 4, 1965.

39 Foley, W. B., The Accordian Buoy, Trans. of the Mar. 1964 Buoy Technology Symposium, Marine Technology Society, p. 136.

(discussed in Section 7.2 of this bulletin). Aluminum, copper, and other nonferrous metals are employed in special cases. Many toroids and other buoys of the fiberglass wraparound type are filled with a foam core that is a nonabsorbent, nonconnective cellular construction (40).

Other filler materials that have been used are lighter-than-water liquids, such as gasoline, naphtha, kerosene, oil, aqua ammonia, varying in specific gravity from 0.65 to 0.89. Their low compressibility, counteracting the compressive forces at great depths, reduces the requirements on the rigidity of the hull structure. In fact, hull systems have been reported (41) as having been used successfully, being especially dent-resistant, and convenient to handle during transportation that were nothing more than specially designed, oil-filled cylinders of nylon-reinforced rubber plies.

Lithium metal, with a specific gravity of 0.53 the lightest of all metals and lighter than most solids and liquids, and less compressible than water, has recently entered the scene as one of the most promising filler materials. It has been employed in cases where the disadvantage of a relatively high price (about $40 per kg.) is compensated by its advantages, high buoyancy at small size in thin-walled vessels. Being a member of the alkali metal group of the chemical elements, it is corrosive, requiring special handling, and reacts with water to form the soluable hydroxide, necessitating durable protection from chemical attack. It is claimed to require little maintenance and to have long life (42) in its application in deep-sea floats.

Glass spherical floats for deep-sea applications hold great promise. Test results (43) bear out theoretical projections of high strength in deep water. Glass has a very beneficial characteristic in that it becomes stronger as the pressures upon it become greater. This high strength, coupled with relatively low weight, results in a higher strength-to-weight ratio than could be obtainable with hulls made of currently used materials (44).

3. POWER SOURCES

A requirement common to all power sources for deep sea buoys is that they last for the intended life or between-tending intervals of the buoy. Individual requirements are dictated by the specific application.

3.1 Conventional Sources (Batteries)

3.1.1 Primary Batteries

The only low-cost primary non-re-chargeable battery that has survived so far, the leclanche carbon-zinc type, although of a low power retaining capability, still has its legitimate place in deep sea buoy systems, namely where the system comprises only a small number of individual and possibly experimental buoys, and the distance from the service station as well as the expected usable life is short. There the high energy-to-weight ratio of approximately 30 watt-hours/kilogram continues to be attractive, but it has to be traded off against the obvious drawback, that the buoy tender has to carry a full complement of replacement batteries for every buoy in the system.

3.1.2 Secondary Batteries

The 6-month interval between tendings now anticipated for buoy networks, which are being planned by the Weather Bureau, rules out batteries having a low charge retention capability such as the lead-acid cell (down to 50 percent in 55 days) or the nickel-iron Edison cell (25 days) (45). As regards charge retention, storage cells of the silver-zinc and silver-cadmium type (2 years) appear to be unsurpassed at the present time. The picture changes, however, if the energy-to-weight or energy-to-cost ratio are points to be considered. While the energy-to-cost ratio has about the same unfavorably low value of a 2.8 watt-hours per dollar for both type cells, the silver-zinc is better by a factor of 2 in the energy-to-weight aspect (approx. 40 watt-hours/kg. versus approx. 20 watt-hours/kg.) (46).

The nickel-cadmium battery, offering approx. 9 watt-hours per dollar, a charge retention of 300 days (for 50 percent), 20 watt-hours per kilogram, and a life of better than 2,000 charge-discharge cycles emerges as the present day "work horse" for a deep sea buoy network designed for 6-month servicing intervals if secondary (re-chargeable) batteries are to be employed.

---

40 Geodyne, op. cit. note 30.

41 Silverstein, A., and Salton, F. G., Automatic Instrumented Diving Assembly (AIDA), Trans. of the Mar. 1964 Buoy Technology Symposium, Marine Technology Society, p. 489. *Flexibody* Brochure By General Dynamics/Electronics, Rochester, N.Y.

42 Lithium Corp. of America, New York, N.Y., Brochure, Product Sheet #11.

43 Perry, H. A., Future Subs of Glass, Undersea Technology, vol. 5, 1964, p. 40.

44 Krenzke, M. A., Exploratory Tests of Long Glass Cylinders Under External Hydrostatic Pressures, David Taylor Model Basin R&D Report No. 1641, Aug. 1962.

45 Survey of Electrochemical Batteries, Electro-Technology, June 1963.

46 The charge-discharge cycle life aspect (10 to 400 for the silver-zinc, 300 to 1,000 for the silver-cadmium cell) need hardly be contemplated in the deep sea buoy aspect. Even in the worst cases a 10-year battery life (20 cycles at 6-month intervals) appears ample because the entire buoy system may be expected to be obsolete after a 10-year period and to be either abandoned or replaced with a more refined one.

For servicing a large number (100 or more) of buoys, spaced at great intervals (500 nautical miles or more), the buoy tender would have to carry, ideally, only one charged battery. On arrival at the No. 1 buoy of the system it would remove the empty battery and replace it with the charged one, charge the empty battery from the No. 1 buoy during the trip to No. 2, install there the charged one from No. 1. and continue the procedure to finally come out with the empty battery from the last buoy. That would, then, again be charged and used as replacement battery for the No. 1 buoy for the next servicing cycle. Simple as this sounds, one may not expect the procedure to run off without intereference by the sea itself.

3.2 Nonconventional Sources

3.2.1 Internal Combustion Engine

For the 12-meter diameter, discus shaped "universal" buoy, prototypes of whose hulls have been constructed by General Dynamics/ Convair (47) under contract with the Office of Naval Research, and which are presently undergoing ocean-testing, the power equipment has been specified as follows: To supply the power to a planned instrumentation package and a 100 channel telemetering system, the source has to deliver 1,400 watt-hours per 24-hour day. To last for the specified 1-year untended period, a 28-volt chemical battery would need a capacity of approx. 18,000 ampere-hours, would weigh about 25,000 kilograms, and cost about $2.00 per kilogram. Consequently, it was ruled out. Also ruled out for a variety of reasons were steam powered generators, diesel engines, wind chargers, power converters from oceanic currents or waves, solar cells, fuel cells, and isotope (SNAP) devices. Thermoelectric generators and piston engine generators are considered the most promising approaches now. A thermoelectric generator is under experimentation, but a prototype of a piston engine generator has already undergone extensive testing.

The engine generator actually designed for the buoy application operates as follows (48). A 20-cell (25.2 to 30.0-volt) nickel-cadmium battery starts the engine for a re-charge whenever the voltage has dropped below the lower level and shuts it off as soon as the upper limit is exceeded. The engine is a Kohler, 1,000-watt, 32-volt d.c. unit with magneto ignition in which precision ball bearings have been substituted for the original ones. Fresh air is introduced and the combustion products removed by means of snorkels. The use of propane gas as fuel increases the reliability tremendously by reducing the number of moving parts such as fuel pump, automatic choke, and carburetor float. The sinking tendency of propane, which is 1.5 times heavier than air, requires special precautions, for example: a sealed box over the tank valves and the primary regulator, and a special mode of operation, that is, for starting--the engine must be cranked at the same time the fuel is turned on--and for stopping--the fuel must be shut off rather than the ignition. The unit was found to operate reliably between -17° and $+65^{\circ}$ C. The total weight of engine generator plus fuel supply for a 1-year operation is 1,000 kg. (49).

3.2.2 Thermoelectric Generator

Thermoelectric generators are still in the process of development. Because of their basic simplicity, they have great potentialities in unattended buoys. They consist of a number of series-connected, variously doped semiconductor thermocouples (lead telluride, bismuth telluride, zinc antimonide, silver, antimony telluride), which are more efficient energy converters than the conventional metallic ones. Their hot junction is heated using, for instance, the catalytic oxidation of propane gas as heat source, while the ocean water itself serves as an admirable heat sink to cool the cold junction. General Instrument Corporation (50) has built a 10-watt unit for the Coast Guard to be used in shore-based navigation lights as well as in large buoys. Being designed to remain operative in near-hurricane winds and in any position of roll, it is directly applicable to oceanographic research buoys. It has an automatic restart provision in the event that excessive winds or swamping has interrupted the catalytic process, which tries to restart once an hour.

3.2.3 Isotopic Generator

The isotopic generators which utilize the heat energy resulting from the natural decay of radioactive isotopes are usually referred to as nuclear devices. Although not incorrect, this designation tends to arouse, among some nations, unlucky reminiscences and to give food to unfavorable propaganda. It is, therefore, recommended that the word isotopic be used in the buoy context rather than the word nuclear.

---

[47] Devereux, R., et al., Development of a Telemetering Oceanographic Buoy, General Dynamics/Convair, San Diego, Calif., Progress Report, Feb. 1963 (DDC No. AD-404523).

[48] Hoover, W. R., Evaluation of an Electric Power Source for an Oceanographic Buoy. Trans. of the Mar. 1964 Buoy Technology Symposium, Buoy Technology Soc., supplement, p. 83.

[49] Jennings, F. D., Office of Naval Research, Oral communication.

[50] Baumont, M., Thermoelectric Power for Oceanographic Research, Marine Sciences Instrumentation, Instrument Soc. of Am. vol. 1, 1961, p. 289.

Isotopic generators are basically similar to the thermoelectric ones in that they also employ semiconductor thermocouples as generators of electric power and the ocean has heat sink, but the thermal energy necessary to heat the hot junctions is generated by the absorption of the isotope's decay particles in the isotope compound itself. The most promising isotope at this time is strontium-90, a β-emitter of 28-year half-life, enabling a 10-year maintenance-free life of the generator.

Several techniques have been employed to minimize health hazards. The strontium-90 is used as the titanate ($SrTiO_3$) compound, which makes it insoluble in water and reduces to practically zero the hazard of its getting into human bones in case of container fracture. The compound is resistive to radiation damage and has the added advantages of high density, good workability, and high thermal conductivity. The β-generated X-ray bremsstrahlung is absorbed in a surrounding shield of depleted uranium. The nickel alloy, "Hastelloy C", has been chosen as container material. It has been found to corrode smoothly in seawater at a rate of 2.5 microns a year. This means that a container of 6-mm. wall thickness will last for 25 centuries at which time the strontium-90 has completely decayed into stable, nonradioactive zirconium-90.

Several SNAP (System for Nuclear Auxiliary Power) generators have been constructed to power satellites, a weather station on a remote island, the Navy's *Nomad* weather buoy, and a Coast Guard navigational buoy (51). They range in power from 5 to 60 watts, weigh from 760 to 2,100 kilograms, and the dimensions in centimeters are from 40 diameter by 50 long to 56 diameter by 88 long. Their overall thermal efficiency is given as 5 to 10 percent. The present price for the freedom of maintenance over periods up to 10 years is $10 to $30 per kilowatt-hour. It is expected to come down to about $5 per kilowatt-hour in the second generation of SNAP devices, according to the film "Pax Atomis" by the Atomic Energy Commission.

3.2.4 Fuel Cell

A promising, though not yet fully developed, power source for the buoy application is the fuel cell, a field which is still wide open. The cell's operation is based on the direct conversion of the oxidation energy of oxidizable compounds into electrical energy. Suitable materials are hydrogen, methanol (CH_3OH), hydrazine (NH_2NH_2). Companies active in the field are Allis Chalmers, General Electric, Monsanto, Pratt & Whitney, Westinghouse, and Minnesota Mining.

Hydrazine, being one of the most reactive reducing agents known and consequently one of the easiest to oxidize, has been used in most cells under test today with air as oxidant.

Monsanto has demonstrated a 100-watt (8 amperes at 12 volts) cell at U.S. Army Engineer Research & Development Laboratories having the following characteristics:

Weight of cell:	2.5 kg.
Volume of cell:	450 ccm.
Weight of metering pumps and blower:	3 kg.
Hydrazine required for 6-month operation:	200 kg.

In addition to being so highly reactive (and skin etchant), hydrazine has the further disadvantage of freezing at +1.4° C., which makes its application to buoys problematical in cold areas. Emphasis has, therefore, been placed on the development of cells using methanol, whose sole drawbacks are flammability and fatality when confused with ethanol.

3.2.5 Miscellaneous Low-Power Sources

Interesting low-power generators, mostly intended for continuous operation of beacon lights or transmitters, are under development at several places.

3.2.5.1 Ocean Wave Energy Converter (52).--An ocean wave energy converter was proposed to the Navy by the AVCO Corp. A prototype unit has been built and sea-tested in Buzzards Bay, Mass. It uses hydrostatic pressure fluctuations due to waves and consequently is tautly moored about 2.5 meters below the surface. The pressure fluctuations cause a reciprocating movement of a large piston which is flexibly sealed to the bottom of the device. The reciprocating movement actuates a two-cylinder oil pump and generates an initially reciprocating flow of the oil. Four check valves (functionally analogous to a full-wave rectifier) render the oil flow unidirectionally fluctuating. Smoothed by an air-and-oil accumulator (capacitor), it actuates a hydraulic engine and a d.c. generator or rectified alternator.

Pressure fluctuations of 7 millibar, corresponding to a 1-meter wave height or a 40-kilometer per hour wind, generated 0.5 watt of

[51] Stringham, W. S., Radioisotope Power Supplies for Moored Buoys, Trans. of the Mar. 1964 Buoy Technology Symposium, Buoy Technology Society, p. 160. Power from Isotopes, by Mead, R. L., and Corliss, W. R., Atomic Energy Commission, June 1964.

[52] Silvers, J. P., Successful Conversion of Ocean Wave Energy, Trans. of the Mar. 1964 Buoy Technology Symposium Marine Technology Society, p. 173. A Proposal for a Long Life, Low Energy Power Converter Using Ocean Wave Energy as a Source, AVCO Corp., Wilmington, Mass., RAD-MS-63-131.

power. Expected are 0.5 watt at 4.5 meters beneath the surface in open water. Considering the integrated volume of the system components--but ignoring the volume of air between them, which in a buoy will contribute to its buoyancy and be desirable--a total life time energy density of 1.7 watt-hours per cubic centimeter is estimated. This is an order of magnitude better than that of conventional batteries.

The unit was designed for a life of 2 to 3 years. Owing to a rare coincidence of adverse circumstances it was severely damaged after only three months of satisfactory operation. Continuation of this interesting effort is not foreseen.

3.2.5.2 Seawater Cell.--Using seawater as electrolyte in primary cells is not a novel idea. But seawater cells are expensive and have so far proved to be relatively unreliable. D.c. converters (53) have been employed to raise their low voltage to usable levels (54). A refined type using a sacrificial magnesium anode and a nickel-flashed-steel permanent cathode has delivered between 2 and 3 watts (10 amperes at 0.25 volt) from a cathode area of 0.8 square meter. A matte surface (55) as produced by the flashing process (deposition of the nickel by a high-current pulse) substantially increases the effective area of the cathode.

The Naval Research Laboratory is in the process of engineering a seawater-cell operated, intermittently blinking beacon light. Consuming 25 kilograms of magnesium, the cell is expected to deliver 9 kilowatt-hours of energy, enough to operate the beacon for one year (56).

3.2.5.3 Solar Cell.--Solar cells are the only power sources that can "live" entirely off the environment. In the buoy field, they have so far been rejected for a variety of reasons. One of them is that their use has to be restricted to the tropical zone, and the near-tropical portion of the temperate zones which has enough sunshine the year around. Also, the cells must not become obscured by salt water caking, marine growth, or bird droppings, which is difficult to accomplish. On the other hand, their power density of 170 watts per square meter at perpendicular light incidence, or perhaps 40 watts per square meter in the daily average, would make them attractive for large-size buoys where enough surface area could be reserved for them. It appears worthwhile to work out means to prevent caking and growth, perhaps by covering or imbedding the cell array in a clear, transparent, water and growth repellent plastic material.

4. INSTRUMENTATION

A useful list of oceanographic instruments in general, available or under development, has been compiled by Operations Research Inc., with the assistance of Marine Advisors, Inc., under contract with the Coast and Geodetic Survey (57). Not all of the listed devices are usable for automatized deep sea buoys, but only those that permit telemetering, can function unattended and without need of recalibration for periods of months to a year, and have an expected life of several years. Moderate cost is desirable, but seldom a reality. After the sine-qua-non requirements have been considered, the list totaling 99 reduces to 10 usable or potentially usable instruments. This exemplifies how difficult it is to design instruments that can be used with automatized deep sea buoys.

Several companies are making substantial efforts to engineer oceanographic instruments of adequate precision and long term (one year) reliability so that they can be used in automatized telemetering buoys. Within a year or two instrumentation packages with long term reliability of one year should be available for measurement of water temperature, pressure, and salinity, but not of current. At the present rate of development, perfection of instrument capabilities to handle most of the other desired parameters is estimated to take an effort of ten years, by which time the desired order of accuracy probably will have increased correspondingly.

However, present-day efforts are not sufficient to advance sensor technology at a rate commensurate with overall progress in buoy technology. For instance, instrumentation still has to be serviced or replaced frequently. Long term reliability specifications are not now considered in the procurement of instruments, and, if applied, would probably increase the cost to five times the present level. Although this might turn out to be more economical in the long run, the customer is understandably hesitant to suddenly spend so much more money; and, consequently, the manufacturers anticipate no market of sufficient extent to recover the very high development costs. Moreover, sensor fouling is still a major problem affecting long-range reliability.

---

53 Marzolf, J. M., Sea Water Battery Plus Tunnel Diode Converter as a Power Source. Naval Research Laboratory Report No. 5961, May 22, 1963.

54 Using the ocean itself as electrolyte, seawater cells in buoy applications cannot be series-connected to raise the voltage.

55 Goldenberg, L., and Fidelman, M., Magnesium Galvanic Cell, U.S. Patent No. 3,036,141.

56 Marzolf, J. M., Naval Research Laboratory, Oral communications.

57 Greenstone, R., and Nisselson, H., Instrumentation for the Ocean Survey Program, Operations Research Inc., Silver Spring, Md., Technical Report No. 299, Dec. 23, 1965, U.S. Coast & Geodetic Survey Contract No. C&GS-1138(N).

For some operations the concept of expendable instruments is gaining increasing support. Nevertheless, considerable reluctance against it is still present among many workers, mostly because of the implication that expendable units will receive their final calibration at the factory without provision for a last-minute adjustment at the site. Last minute adjustment, however, is unreliable, as practical experience shows, because of environmental factors like salt water spray and wave motion, and the physical and emotional condition of personnel.

The following table (58) is a list of required oceanographic parameters. The following sections review each parameter and describe some typical instruments to measure it, but without claim of completeness.

Measurement Requirements for Deep Sea Buoys

Variable	Full Scale Range	Required Tolerances Absolute	Sampling Interval
Air Temp. (^{o}C.)	-10 to +40	1.0	5 min.
Sea Temp. (^{o}C.)	-2 to +30	0.25	15 sec.
Salinity (‰)	30 to 40	0.05	15 sec.
Pressure (kg./cm.^{2})	0 to 1,000	0.7	5 min.
Density (g./cm.^{3})	1.00 to 1.04	5.10^{-4}	15 sec.
Surface Profile (m.)	0 to 12	--	0.25 sec.
Current Speed (cm./sec.)	2.5 to 250	10	1 min.
Current Dir. (deg.)	0 to 360	15	1 min.
Wind Speed (cm./sec.)	0 to 5,000	500	5 min.
Wind Dir. (deg.)	0 to 360	20	5 min.
Abs. humidity (g./cm.^{3})	0 to 0.03	0.001	5 min.

4.1 Air Temperature

Any type of a transducer using a bolometer wire, thermistor, etc., that is shielded from thermal radiation and transforms the temperature into an electrical signal may be used.

4.2 Wind Speed and Direction

Wind direction is the direction from which the wind is blowing and is determined, on a buoy, with reference to magnetic north. Wind speed is usually measured to the nearest knot averaged over a period of one minute. For winds that have large fluctuations, a 5-minute average or more may be necessary.

There are several wind measuring devices of the anemometer type. An example of this is a 3-cup anemometer built by Geodyne Corp., and designed for micrometeorological work to measure very light wind movement where a fast response to changes in wind speed is required (59). According to the company this is a rugged instrument requiring little or no maintenance. Its jewel bearings do not need lubrication and can be easily replaced in the field. The unit is completely waterproof. Wind speed is continuously presented as a switch closure, with the switch closed during 20 percent of each revolution. The output signal is suited for telemetering.

4.3 Humidity

Of the many different types of humidity measuring devices not one is adequate for unattended deep sea buoy work. There are many different types of hygrometers--mechanical, dew point, electric, gravimetric, thermal, spectroscopic, absorption, and condensing. Of these, the electric hygrometer seems to hold the most promise. At the present time a lithium chloride hygrometer is being used on *Nomad*, but it has a very short unattended life (60). National Bureau of Standards is presently developing a device which is thought to be capable of unattended operation for one year. It is made of thermistor beads coated with a hydroscopic ceramic. It is expected to take 6 months to develop a working model.

4.4 Surface Profile

The surface profile has been measured from spar type buoys, page 5, which have the smallest vertical excursions of all buoys, especially when stabilized with a sea anchor (61). A vertical "wave staff" several meters in length and resistance-wire-wound over its length was mounted on the buoy so that the change in its electrical resistance due to variable immersion and consequent partial short-circuiting indicated the wave height. The signal from an accelerometer mounted in a toroidal float which was carried by the waves up and down the spar mast, has, after time-integration, also been used to indicate wave height.

In deep sea buoys which ride the waves, only the accelerometer technique appears feasible. A wave-measuring device employing it has been developed by the U.S. Navy David Taylor Model Basin (62). It consists of a disposable, telemetering wave buoy *(Splashnik)* which measures the vertical acceleration of surface water particles with an accelerometer installed at the base of the buoy. The acceleration information is telemetered to the ship and then reduced to wave height spectra. In data processing, normal double

58 Gaul, R. D., and Schule, J. J., Oceanographic Requirements vs. Instrumentation Capabilities, Instrument Society of America, Jan. 1962, vol. 9, No. 1, p. 51.

59 Geodyne Corp., Waltham, Mass., Engineering Drawings and Specifications, Sensitive Anemometer, Dwg. No. A-266.

60 Hakkarinen, William, National Bureau of Standards, Washington, D.C., Oral communication.

61 Finkelstein, J. L., Trans. of the Mar. 1964 Buoy Technology Symposium, Marine Technology Society, supplement, p. 5.

62 W. Marks, R. G. Tuckerman, *Splashnik* --The David Taylor Model Basin Disposable Wave Buoy, U.S. Navy, David Taylor Model Basin Report 1423, Dec. 1960.

integration is not necessary due to the fact that the method of analysis only requires computation of the acceleration spectrum. An algebraic operation on this acceleration spectrum function gives the wave height spectrum. The *Splashnik* system has been tested successfully in the field. At present the system has a short life, about 8 hours, and uses line-of-sight transmission, but there is no reason why it should not be able of modification for the special requirements of telemetering deep sea buoys.

4.5 Sea Temperature

Knowledge of the water temperature, in addition to its salinity, at various depths is not alone of oceanographic but also of commercial interest because the growth of plankton and the ocean fauna depend on it.

4.5.1 Thermistor Beads

A popular, and the most common method of measuring sea temperature, employs fast responding thermistor beads (63). The sensor is a small glass-encapsulated flake of material having a high, negative temperature coefficient of resistivity. The temperature is a function of the electrical resistance, which is rendered linear in the circuitry. A 16-channel temperature sensing unit has been developed by the U.S. Naval Electronics Laboratory to measure temperatures at various depths. It includes 16 thermistor beads attached to electrical leads. The temperature at each depth is indicated on a recording potentiometer chart to an accuracy of better than 0.1°C. In operation, the thermistor beads are suspended from a ship, anchored buoy, or a fixed platform. The voltages supplied by the thermistor circuitry can be telemetered.

4.5.2 "Telerecording" Bathythermometer

One type of commercially available temperature sensor is the "telerecording" bathythermometer. This is a transistorized instrumentation system used to measure temperature and depth simultaneously, with separate temperature and pressure sensors. Information is transmitted to the surface recording system by means of an insulated single conductor cable having a sea return and which also serves as a lowering cable. Interchangeable ranges are designed for depths from surface to 10,000 meters. Accuracy is 0.5 percent of full scale for depth measurement. The instrument can measure temperature over a range of 0° to 30°C. with an accuracy of 1.0 percent, and can be modified for telemetering (64).

4.5.3 Digital Temperature Recorder

The digital recording meter is self-contained and capable of sequentially and rapidly measuring the resistances of up to 16 thermistors (or other resistive transducers) to a resolution of 0.015 percent (12 binary digits) and an accuracy of better than 0.1 percent. As presently available, this commercial temperature recorder employs the photographic technique, which means that the recorded data has to be physically retrieved. It records all data on standard 16 mm. photographic film. Upon command from its clock timer the film is advanced and temperature measurements are recorded. The clock timer can be programed to run the film at a rate of 100 feet in 8 1/3 hours up to 1 year. Obviously, this instrument could be modified by eliminating the clock timer and film recorder, and directly utilizing the thermistor resistances for telemetering (65).

4.5.4 NOTS Deep Sea Sound Velocity/Temperature/Pressure Meter

The Naval Ordnance Test Station (NOTS) has developed an electronic frequency-modulated instrument for the continuous measurement of temperature in deep oceans (66). Velocity of sound, and other parameters are also measured and recorded simultaneously with temperature. This meter is transistorized. It has been tested to depths in excess of 2,000 meters, but is capable of operating in all ocean depths.

The NOTS meter employs an acoustic velocimeter for measuring velocity of sound, a Borg-Warner Vibrotron, which is described on page 13, for pressure, and a NOTS thermistor-controlled Wien-bridge oscillator for temperature. Outputs from the three sections are frequency-modulated signals, mixed for single-conductor cable transmission to the surface. Velocity of sound is transmitted in the band, 2775 to 3225 c.p.s., temperature in the band 5000 to 8000 c.p.s.,

---

63 LaFond, E. C., Internal Waves and Their Measurements, Marine Sciences Instrumentation, Instrument Soc. of Am., vol. 1, 1962, pp. 137-155.

64 Walden, R. G., and Frantz, D. H., A Long-Range Oceanographic Telemetering System, Marine Sciences Instrumentation, Instrument Soc. of Am., vol. 1, 1962, pp. 50-54.

65 Geodyne Corp., Waltham, Mass., Engineering Drawings and Specifications, Digital Temperature Recorder Model A-605, Bulletin No. S-47.

66 Martin, H. B. and Lewis, G. R., U.S. Naval Ordnance Test Station, Deep Sea Temperature Meter, NOTS TP 2321 (NAVORD Report 6589), Sept. 8, 1959. Lovett, J. R., and Sessions, S. H., U.S. Naval Ordnance Test Station, An Instrument for Continuous Deep Sea Measurement of Velocity of Sound, Temperature, and Pressure, NOTS TP 2673 (NAWEPS Report 7650) May 9, 1961.

and pressure in the band 9712 to 11,288 c.p.s. Accuracies of measurement in sound velocity of ±0.3 m./sec., in temperature of ±0.02°C., and in pressure of ±1 percent (in selected ranges of 0 to 70 and 0 to 140 atmospheres) are claimed. In operation, the meter is suspended from a monitoring cable lowered by a winch. The electrical signals transmitted over the cable are amplified, separated into their respective frequency ranges by band-pass filters, and recorded. The instrument has all potentialities of being modified for telemetering.

4.5.5 Bissett-Berman Platinum Resistance Thermometer

A compensated temperature bridge is incorporated into a PARALOC-oscillator to give linearity of temperature to frequency conversion of ±0.02 percent for a temperature range of -2° to 35°C. and a frequency range from 2130 to 4190 c.p.s. This corresponds to a linearity of 0.007°C. in temperature (67).

The company's PARALOC-oscillator is a phase shift oscillator, which is characterized by the feature that a small change in the input voltage generates a great change in the output frequency. The oscillator has a stability of ±0.02 percent for temperature variations of ±20 percent.

4.6 Current Speed and Direction

The present state-of-the-art of oceanographic instrumentation leaves a lot to be desired compared to instrumentation in other scientific fields. Current meters have been in use for a long time with little or no improvement. The situation can probably best be summed up by a statement by R. G. Paquette (68) made in 1962 and still true in 1965: "A pessimistic picture has been painted of our ability to measure ocean currents on a continuous basis with suspended current meters and existing techniques. The problems of stray motion and limited dynamic response are extremely serious. Generally speaking, small short period fluctuations will be difficult to find. The large, long period transients may be measured with fair accuracy, but probably not well enough to determine mean currents in those areas where the transients far exceed the means. There is a great need for a current meter of rapid response in both direction and velocity which is insensitive to stray motion and will integrate accurately to zero all of the undesired cyclic motions."

Most of the current meters now in use are mechanical devices using some form of impeller and vanes which are magnetically coupled with gear trains inside the water-tight casing.

One shortcoming of these meters is the fact that they require recalibration after about four weeks in the water, since marine growth attaching itself to the impellers and vanes alters their hydrodynamic characteristics. The shortcoming can be avoided if effective anti-fouling agents are found and applied, see page 16.

Only those instruments that allow telemetering will be described. English units will be used in this section because all described meters are calibrated in knots (1 knot = 51.44 cm./sec.).

4.6.1 Impeller Type Current Meters

4.6.1.1 Roberts Radio Current Meter (69).--The original Roberts current meter, as developed by Capt. E. B. Roberts of the U.S. Coast and Geodetic Survey, measures both current speed and current direction. It employs an impeller rotated by the current about a horizontal axis and can be operated from an anchored buoy or from a ship. The receiving station may be located aboard ship or on land. From radio signals telemetered to the station, current velocity and direction can be determined from the relationship existing between the time reference and the radio signals, which are recorded on a chronograph tape. If two or more meters are suspended at different depths from a single anchored buoy, sequence switches must be used to identify the radio signals. The original model of the Roberts meter had a range of 0.3 to 7 knots.

There have been improvements to the original meter to increase the accuracy and duration of operation (70). One modification can measure current velocities from as low as 0.05 knots up to 6 knots. The accuracies are: speed ±3 percent, direction ±5°. The speed range can be adjusted by use of exchangeable impellers of different sizes. The meter of standard design is capable of measuring subsurface currents down to a depth of 4,600 meters.

4.6.1.2 Snodgrass Meter (71).--The Snodgrass meter was a forerunner of the Savonius meter and can also telemeter current data to shipboard

---

67 Bissett-Berman Corp., San Diego, Calif., HYTECH, 4005, Temperature Sensor, Brochure 0401, Nov. 1964.

68 Paquette, R. G., Marine Sciences Instrumentation, Instrument Soc. of Am., vol. 2, 1962, p. 135.

69 Knox, R. W., The Principal Tide and Current Measuring Instruments Used by the Coast and Geodetic Survey, Proceedings of the First Conference on Coastal Engineering Instruments, Council on Wave Research, Richmond, Calif., 1956, pp. 227-237.

70 Lee, T. T., Structures in Deep Ocean, Engineering Manual for Underwater Construction, Chapter 3, Reconnaissance and Positioning. U.S. Naval Civil Engineering Laboratory, Port Hueneme, Calif., Technical Report No. 284-3, Mar. 15, 1964, pp. 5-26.

71 California State Water Pollution Control Board, Investigation of Current Measurement in Estuarine and Coastal Waters, Pub. No. 19, based on a study by J. W. Johnson and R. L. Wiegel, Sept. 1958, pp. 118-120.

or a shore receiving station. It contains a Savonius impeller revolving about a vertical axis, instead of a horizontal axis as used in the Roberts meter, and a vane as direction sensor. The meter is designed for operation within three ranges: 0 to 3 knots, 0 to 0.3 knots, and 0 to 0.03 knots. Selection of the speed range to be measured can be made by means of a manually-operated switch. This meter can operate automatically with no attendance other than replacement of a chart roll at approximately 30-day intervals when photographic recording is preferred.

The accuracies of the meter are estimated as follows: speed ±5 to ±10 percent; direction $\pm 5^{\circ}$. The meter may be suspended from an anchored ship or from a moored buoy during operation.

4.6.1.3 Price Meter (72).--The Price meter was originally designed by Assistant Engineer W. G. Price, Corps of Engineers, U.S. Army. It is designed to measure current speeds from 0.3 to 7 knots, but not direction.

Similar to an anemometer, the meter consists of a number of cone-shaped cups mounted on a vertical rotating shaft. In a contact chamber an electrical circuit is periodically opened and closed, and thereby transmits a signal to the observer through a 2-conductor cable and a set of earphones. In place of earphones, an automatic recorder with a time-marking system may be connected to the circuit. Power for the circuit can be supplied by dry-cell batteries. The number of revolutions of the cup shaft per minute indicates the speed of the current. This instrument allows telemetry.

4.6.1.4 Geodyne Savonius Rotor Current Transducer (73).--The device measures current speed linearly from 0.01 to 5 knots. It also contains a double-S rotor on a vertical shaft as current sensor and a vane as direction sensor. The output signal is a pulse train obtained by magnetically closing 4-reed-switch relays inside a pressure housing. The repetition frequency is proportional to the rate of rotation. Four square wave pulses are generated for every rotor revolution and 328 pulses are generated per minute per knot of ocean current. These pulses can be sensed as current or voltage changes across a resistive recording load. Output signals from the rotor can be utilized in any of the following ways:

(1.) Transmitted by cable to transmitter for remote data recording.

(2.) Transmitted by cable for recording aboard ship, shore installation, or instrument buoy.

(3.) Recorded in situ by an underwater recorder.

(4.) Used to key a pinger for acoustical telemetering.

(5.) Used to flash an underwater light and monitored by movie or television camera.

4.6.2 Acoustic and Electromagnetic Current Meters

Impeller devices respond slowly to current change. Rapidly responding current meters which apply acoustic principles (74), electromagnetic principles (75), and doppler-shift principles (76) have been proposed. The acoustic ones are based on the simultaneous measurement of the upstream and downstream sound velocities, with the current velocity proportional to their difference. These devices are in the development stage, but will, when fully engineered, permit telemetering.

4.7 Salinity

Salinity, the salt content of seawater, is, together with temperature, one of its commercially important characteristics as plankton growth and the existence of the entire oceanic fauna depends on it. It is usually expressed in terms of parts of salt per thousand parts (p.p.t.) of seawater and is of the order of 33 to 37 p.p.t. As a rule, it does not vary greatly. However, salinities as high as 270 p.p.t. have recently been reported from areas at the bottom of the Red Sea.

The standard laboratory techniques of determining salinity, evaporating the water from a known quantity of seawater and weighing the salt residue, or the wet-chemical approach of determinating its chlorine content by precipitating as insoluable silver chloride or by titrating the chlorides with silver nitrate are obviously not applicable to the buoy environment. But, since it is known from electrochemistry that the conductivity of electrolytes depends strongly upon

---

[72] Robert Taggart Inc., Falls Church, Va., Handbook of Underwater Engineering, prepared for Office of Naval Research, Contract No. 4228(00), April 1964, pt. III, ch. 4, p. 27.

[73] Geodyne Corp., Waltham, Mass., Engineering Drawings and Specifications, Bulletin No. S-63.

[74] Middleton, F. H., and Li, W. H., Design and Development of Estuarine Current Meter, Institute for Cooperative Research, The Johns Hopkins University, May 1954. Middleton, F. H., An Ultrasonic Meter for Estuarine Research, Journal of Marine Research, vol. 14, No. 2, 1955. Suellentrop, F. J., et al., An Instrument for the Direct Measurement of the Speed of Sound in the Ocean, *Marine Sciences Instrumentation*, Instrument Soc. of Am., vol. 1, 1962, pp. 186-189. Suellentrop, F. J., et al., An Acoustic Ocean-Current Meter, *Marine Sciences Instrumentation*, Instrument Soc. of Am., vol. 1, 1962, pp. 190-193. Lester, R. A., High-Accuracy Self-Calibrating Acoustic Flow Meters, *Marine Sciences Instrumentation*, Instrument Soc. of Am., vol. 1, 1962, pp. 200-204.

[75] Von Arx, W. S., An Electromagnetic Method for Measuring the Velocities of Ocean Currents from a Ship Underway, Woods Hole Oceanographic Institution, Woods Hole, Mass., Mar. 1950.

[76] Chalupnik, J. D., and Green, P. S., A Doppler-Shift Ocean Current Meter, *Marine Sciences Instrumentation*, Instrument Soc. of Am., vol. 1, 1962, pp. 194-199.

their concentration, and since seawater is an electrolyte, conductivity methods have become the accepted techniques to measure salinity.

To determine conductivity correctly, several precautions must be taken: As the electrochemist knows, the electrodes of a conductivity cell become polarized under d.c. voltages; a.c. is, therefore, being used universally. Since conductivity is affected by the temperature of the electrolyte (more strongly than that of metals), and to some extent also by pressure, temperature and pressure must be measured simultaneously with conductivity and their influence applied as corrections. Unique to the ocean environment and not necessary elsewhere is the requirement that the electrode configuration or the current path must not be interfered with by marine growth. And marine growth is difficult to prevent, if a conductivity sensor is exposed to seawater for long periods of time. No satisfactory solution of the problem has been found yet.

Because of the fouling sensitivity of instruments having exposed electrodes, the more recently developed instruments are electrodeless and utilize the dependence of the coupling of two transformer windings upon the conductivity of the surrounding medium.

The description of a typical instrument may serve for all (77).

An a.c.-driven toroidal electromagnet core will induce no voltage across the winding of a second similar core which is axially separated from the first by a small distance, if the surrounding medium is nonconductive. If conductive, the medium acts as a one-turn loop encircling both cores and induces a voltage in the second winding, the ratio of the inducing to the induced voltage being a measure of the conductivity. By adding a second winding to each core and series-connecting the two across a variable resistor, thus forming a transformer bridge, the induced voltage can be nulled through proper setting of the resistor. The resistance of this resistor in the null adjustment is a measure of the seawater conductivity. The procedure has been automatized by employing servocircuitry, which permits telemetering. The attained accuracy is of the order of 0.03 p.p.t.

It can be suspected that fouling in the seawater loop between the two cores will affect the current path and falsify the measurement. The literature does not mention this aspect.

Sensors for temperature and pressure, and circuitry for the automatic correction of the salinity measurement for these two parameters, have been incorporated in some commercial instruments (78).

4.8 Pressure

Pressure sensors are being widely used in the nearshore measurement of waves and tidal currents. In connection with deep-sea measurements, however, they are hardly ever employed in their own right, but rather in physical conjunction with, and as ancillary sensors for, others (temperature, current, salinity) to indicate the depth at which these other sensors have been placed. This is necessary as the stretch and the off-vertical inclination of a mooring line due to currents both tend to make the actual depth of the other sensors nonpresettable and unpredictable.

Four types of pressure transducers are presently being tested. These are: The Bourdon tube, piezoresistance, strain gauge, and the "Vibrotron". The tests have not been completed at the writing of this report. However, it is felt that the "Vibrotron" and strain gauge type sensors hold the most promise.

4.8.1 "Vibrotron"

The "Vibrotron" (79) provides a means of measuring absolute pressure changes in terms of a frequency change. A fine wire, stretched between an anchor point and a metal diaphragm, is set into vibration in a permanent magnetic field by an alternating current through the wire. The current is supplied by an associated vibration amplifier connected into an oscillator circuit so that the oscillating frequency is controlled by the vibrating frequency of the stretched wire.

In operation, a change in pressure results in a slight displacement of the diaphragm, which is instantly reflected as a change in the tension of the wire. This increases or decreases the vibrating frequency of the wire inversely with respect to pressure, changing the frequency of the transducer output signal. The signal is amplified and transmitted from any remote point for conversion for direct readout on instruments, or introduction into data processing or logging systems. The Model 8150 has the following specifications: Range 0 to 7,000 atmospheres at accuracies of 0.1 percent with 0.001 percent in special application. The circuitry has been miniaturized.

---

77 Aagaard, E. E., and Von Haagen, R. H., A Probe Type Induction Conductivity Cell, *Marine Sciences Instrumentation*, Instrument Soc. of Am., vol. 2, 1962, p. 11.

78 Bissett-Berman Corp., San Diego, Calif., brochure on HYTECH 6007 Salinometer. Geodyne Corp., Waltham, Mass., Bulletin No. S-172.

79 Borg-Warner Controls, Chicago, Ill., Vibrotron, Absolute Pressure Transducer, Model 8150, Bulletin VF-8150-562.

the clamp-on transformer technique in connection with a single conductor insulated sea cable, which also supports the instrumentation. A more detailed description of this method is presented on page 16.

Specially designed magnetic tape recorders and paper tape punch units are used as standard data storage equipment for buoy applications. The simple technique of periodically photographing an instrument panel, on which the values of the measured parameters are displayed, has been used successfully.

Magnetic core memory devices are sometimes considered for short term data storage between interrogation periods (93). This is usually an indication that the project is either well funded or futuristic in its approach. Although a long term reliability problem may initially arise on account of the unfriendly environment in an oceanographic buoy, magnetic core memories are expected to assume a prominent position among operational buoy data storage devices within a decade.

6.1 Analysis of Data Transmission from Sensor to Buoy

6.1.1 Methods

Conventional sensor methods utilize a d.c. bridge, one arm of which is changed in resistance by variation of the measured parameter (94). Its d.c. output can then be:

(a) Transferred as a d.c. voltage level. The accuracy of transmission through long cables is low.

(b) Digitized and transferred as a number. This method can be implemented either by a digital bridge or a shaft encoder.

(c) Converted to a frequency and transferred as a frequency modulated signal. Implementation is possible by use of a voltage controlled oscillator, or a parameter-locked oscillator.

Because of the extreme accuracy, stability, and reliability requirements for buoy mounted oceanographic sensors, Bissett-Berman chose its parameter locked (Paraloc) oscillator for data conversion in the Universal Buoy program. This method also allows direct incorporation of a.c.-operated sensors into the oscillator.

6.1.2 Paraloc Oscillator

As described on page 13 the conversion of the sensor output to a variable frequency is accomplished in a phase shift oscillator, which has the unique characteristic that its frequency is controlled by the ratio of the output voltage to the input voltage of a four terminal network containing the sensor. The oscillator has a stability of ±0.02 percent for temperature variations of $\pm 30^{\circ}$ and voltage changes of ±20 percent.

6.2 Data Transmission Between Sensor and Office of Naval Research "Universal" Buoy

The electrical signals from the sensors in the instrumentation packages are inductively coupled through a clamp-on transformer into a single conductor, insulated sea cable which also supports the instrumentation (95). This method eliminates the need for underwater connectors, cable splices, and other problems associated with direct electrical connections to the cable. The top of the individual sensor housing forms a small toroidal extension which contains a ring transformer core and a primary winding connected to the sensor circuitry. As a secondary winding, a single wire loop is threaded through the toroids of a cluster of several sensor packages around the supporting cable, and finally, through the core of a clamp-on transformer on the cable to serve as the primary of the clamp-on transformer, with the supporting cable as the secondary. This secondary, which conveys the signal to the surface, is closed through a seawater return.

The interrogation signals for the individual sensor packages follow the same path in reverse. The system can be used to transmit many kinds of data, such as pressure, temperature, salinity, sound velocity, or any other that can be converted to a frequency modulated or digital signal.

The clamp-on technique has not yet been tried out extensively.

6.3 Data Handling in the Oceanographic Buoy Program at Scripps Institution of Oceanography

An airtight military packing case mounted on a buoy platform houses an instrument panel for display of the values of the measured parameters. A camera photographs the instruments at preset intervals.

---

93 The magnetic core memory proposed in the following paper has a capacity of 256 eight bit binary coded words. Johnson, R. E., Acquisition of Oceanographic Data via Meteor Trail Forward Scatter, Trans. of the Mar. 1964 Buoy Technology Symposium, Marine Technology Society, Supplement, p. 115.

94 Cretzler, D. J., et al., Buoy Mounted Oceanographic Sensors, Bissett-Berman Corp., San Diego, Calif., Progress Report No. C104-1, Aug. 1, 1964.

95 Ibid.

Present development under Professor Isaacs' direction is quoted below (96):

". . . The data gathering unit consists of a group of sensors, the data conversion chassis and a paper tape punch. The unit is designed to sense 10 seawater temperatures (thermistors), air temperature, wind speed, wind direction (relative to magnetic north), and barometric pressure. In addition to these parameters, a two digit identification number and time are recorded. The data unit is small (approximately 2.5 cubic feet) and light (25-30 lbs.) and consumes a small amount of electrical power (6 watts average during operating cycle). All electronic circuitry is solid state and operates from a 12-volt d.c. supply.

"The analog signals sensed by the transducers are converted in the data unit to a standard five level teletype code. In this form the data will be recorded on site by a paper tape punch. The output from the data unit will also key a relay for radio telemetry. The data recorded on paper tape can be fed directly into the Control Data 160A Computer for conversion to computer format magnetic tape by writing the proper program. This converted data can be used for any type of analysis at a later time on the Control Data 3600 Computer system. This will facilitate complex and high speed processing of all data.

"The data unit is designed for use with radio telemetry of data in standard teletype format. This type of transmission is compatible with present facilities at radio station WWD and with future installations on Scripps' ships. The shipboard teletype installation will provide direct data output without conversion for survey work.

". . . The data unit will be packaged with the telemetry system in a military packing case similar to the photorecording buoys. This unit will be mounted on a catamaran float and moored in 600 fathoms near Scripps for the first sea test. Development of radio equipment is in progress at this time. The transmitter is of intermediate power (6 to 10 watts) with provision for an added power amplifier of 30 to 50 watts.

"In addition to the capability of transmitting on line data, it is desirable to be able to store data for later transmission. For this purpose a magnetic tape recorder is most suitable."

According to the plans, two separate tape records might be used (97). The first with a closed loop of tape for telemetry storage, which would be erased after each transmission to accommodate a new set of data during the following storage period. The second recorder would continuously and permanently store all the information for final retrieval.

7. TELEMETRY

Telemetry can be divided into two broad categories: line-of-sight and beyond-line-of-sight transmission. Frequencies in the VHF, UHF, and higher ranges, are used for line-of-sight telemetry. Here AM/FM, PPM, PAM, and PDM techniques can be used. For beyond-line-of-sight transmission, the HF region has to be used to take advantage of the reflection (of the energy) from the ionospheric layers. Because of the three layers involved, and their fluctuations in altitude and reflectivity, this type of communication has its characteristic problems. The alternate signal paths cause differential delays of 2 to 3 milliseconds in most cases, but up to 14 milliseconds have been measured (98). This results in smearing of the signal, and places a low data rate limitation on a communication link. Data rates in the order of 50 to 100 bits per second seem possible.

Using line-of-sight techniques for telemetering of information from oceanographic buoys over long distances, would, of course, require aircraft or satellites. For a period of a decade, however, satellite communication systems will probably not be economically competitive with direct HF transmission for oceanographic buoy systems.

Therefore, the HF region will have to be used for long-distance point-to-point communication on the earth's surface. Several tests have been conducted which seem to prove the feasibility of such a system. An experimental 4,300 km. radio link between San Diego, Calif. (transmitting), and Oahu, Hawaii (receiving), was set up by General Dynamics/Convair to simulate a telemetering link from a mid-ocean buoy to a shore station (99). A series of signals were transmitted using pulse-code modulation in frequency-modulated single-sideband operation. Transmissions were made at 7, 13, 16, 20, and 26 mc.p.s., 6 times daily, for 24 days. A single-sideband, suppressed-carrier transmitter was modulated by tape on which a 1500 c.p.s. subcarrier, modulated by 10, 30, 50, and 100 c.p.s.

---

96 Isaacs, John D., Prof., Scripps Institution of Oceanography, La Jolla, Calif., to Dr. Gerald V. Howard, U.S. Bureau of Commercial Fisheries, Unpublished communication.

97 Sessions, Meredith, Scripps Institution of Oceanography, La Jolla, Calif., Oral communication.

98 McLoon, C., The Problems of Reliable Long Range Transmission of Remote Oceanographic Measurements, *Marine Science Instrumentation*, Instrument Soc. of Am., vol. 1, 1962, p. 61.

99 Morgan, K. A., and Devereux, R., Recent Experiments in Ionospheric Radio Telemetry, Trans. of the Mar. 1964 Buoy Technology Symposium, Marine Technology Society, Supplement p. 99.

square waves (equivalent to pulse-code modulation bit rates of 20, 60, 100, and 200 bits per sec.), had been recorded. The transmitter output power was 200 watts into a discone antenna. These tests proved the feasibility of a low data rate telemetering link over long distances.

7.1 Present Status of the Ocean Data Service (100)

The present status of the Ocean Data Service (101) is characterized by a partial quotation from Federal Communications Commission (FCC) Docket No. 15,426:

"In the Matter of

"A Notice of the Pending Establishment of an Ocean Data Service and the Allocation of Frequencies to that Service

". . . As was pointed out in the Notice of Inquiry, the disparity of power between the proposed ocean data stations and existing stations on the wide band, high capacity frequencies, coupled with the extent of present occupancy on those channels, would undoubtedly preclude protection of even our own ocean data stations. Therefore, if the United States is to support the concept of an Ocean Data Service, it would appear that support of the single-sideband frequencies recommended by the [Intergovernmental Oceanographic Commission] IOC would be appropriate. Because the bands initially recommended by the United States failed to receive significant international support, it is now believed appropriate to revise the U.S. recommendation to support, as a temporary measure under paragraph 115 of the Radio Regulations, the following bands for meeting the needs of the Ocean Data Service:

4136.5-4140 kc./s.
6207.5-6211 kc./s.
8276.5-8280 kc./s.
12417.5-12421 kc./s.
16558.0-16561.5 kc./s.
22095.5-22099 kc./s.

"Only an Administrative Radio Conference of the ITU can establish a new international radio service, allocate frequencies to the service, and designate the category of the service; i.e., primary, secondary, or permitted. Prior to such action on behalf of an "Ocean Data Service", the use of *any* frequencies to meet oceanographic requirements would be in derogation of the international Table of Frequency Allocations. Such use would be permitted only under No. 115 of the Radio Regulations, which states in effect that harmful interference shall not be caused to services operating in accordance with the Table. Consequently, any arrangement which may be made, nationally or internationally, to accommodate oceanography would be interim in nature. Initiation of rule-making will not be undertaken until such time as there is general international agreement regarding the choice of assignable frequencies. Such rule-making would look toward determining the relative status to be afforded *nationally* to the "Ocean Data Service" vis-a-vis other radio services presently administered by the Commission. October 1, 1964."

Although the present difficulties of successfully operating an Ocean Data Service are mainly nontechnical and mostly administrative in nature, they should nevertheless not be neglected beside the technical problems. For the technically most perfect Ocean Data Service will be useless without authorization to put it in operation.

With a license from FCC one can now operate an Ocean Data Service in the HF bands outlined above under Code 115 of the International Telecommunication Union. Code 115 amounts to the following reservation: One has permission to operate in a particular frequency band only so long as no authorized user complains about interference. However, in the Western Hemisphere there is very little use of these regions in the Mobile Maritime Bands, so that complaints about interference appear extremely unlikely.

Every group interested in an Ocean Data Service should be urged to put a communication link in the proposed bands into operation to demonstrate an existing need and to establish an accepted operational status in the community of the International Telecommunication Union before other interest groups attempt the same.

The Navy Universal Buoy will transmit data messages in a HF band assigned to the Navy. In addition, at least during the testing phase, the proposed Ocean Data Service bands will be utilized to assist in the general effort of establishing operational status for the Ocean Data Service (102).

The Federal Communications Commission would actually prefer the establishment of a frequency allocation pool outside the FCC to coordinate the use of the proposed frequency bands. Such an arrangement has been used by oil companies for their communication links between field parties, drilling sites, etc. The pool for the Ocean Data Service Stations would require the services of one man, at least as a start, plus a computer facility. The Office of Naval Research is willing to carry the cost, and the National Oceanographic Data Center has indicated the availability of its computer for

100 Snodgrass, J. M., Scripps Institution of Oceanography, La Jolla, Calif., Oral communication.

101 Ocean Data Service: A service of radio communication for the acquisition of data from ocean data stations.

102 Devereux, R., General Dynamics/Convair, San Diego, Calif., Oral communication.

this purpose. The Federal Communications Commission would still police the use of frequency bands in accordance with the pool arrangements.

J. M. Snodgrass of Scripps Institution of Oceanography is also exploring the possibility of organizing such a pool arrangement on an international basis within the framework of the International Telecommunication Union in Geneva, Switzerland. A large computer facility is available there. The success of this plan will depend upon the interpretation of the charter of the International Telecommunication Union with respect to its mission of coordinating the use of frequency bands.

Although the proposed Ocean Data Service would only occupy one percent of the Mobile Maritime Bands (103), the traditional users of these bands have assumed a negative attitude towards the establishment of this new service. It would necessitate communication equipment of higher quality than presently in use for ship service and consequently an expenditure to ship owners; and equipment manufacturers on the other hand feel reluctant about raising the price of new equipment above the level of contentional type for reasons of competition. But despite their hostile attitude these influential interest groups are beginning to realize they cannot hold on to this abundance of frequency range indefinitely. Fortunately for the Ocean Data Service, a rapidly growing new force is disturbing the established equilibrium of frequency allocation among the traditional users of the high frequency region. The many new nations are beginning to petition the International Telecommunication Union for assignment of frequency bands and a major reappraisal of frequency allocations appears unavoidable in the not too distant future. This reorganization would provide the chance for the Ocean Data Service to gain official recognition of its own need.

7.2 Present Efforts to Solve Organizational and Administrative Problems (104)

J. M. Snodgrass is engaged in a very active campaign to convince the respective influential interest groups of the far reaching and unique benefits to be gained from an extensive system of Ocean Data Stations:

(a) Improved weather prediction, made possible through a system of Ocean Data Stations, will effectively facilitate ship routing and result in savings to ship operators.

(b) Improved weather prediction will, in the long run, help everybody.

(c) Tsunami warning systems will require Ocean Data Stations. Ship owners are interested in tsunami warnings to minimize destructive effects to ships in port. Tsunami emergency warnings from Ocean Data stations could be transmitted in the buffer channels of Ocean Data Service bands, as proposed by J. M. Snodgrass (105).

(d) Hurricane and seismic warnings from Ocean Data Stations.

(e) National Aeronautics and Space Administration and Weather Bureau are interested in Ocean Data Stations as calibration and reference stations for Tiros Operational Satellites.

(f) In the face of the population explosions, the "food from the sea" aspect, and its relation to buoy supported oceanography, becomes of interest to many nations.

This intense effort of persuasion appears necessary on account of the fact that the nations interested so far in oceanography command only 40 out of a total of some 160 votes in the International Telecommunication Union.

Many subtle and sometimes frustrating difficulties hamper the administrative progress of the Ocean Data Service. For example, one delegate to the International Telecommunication Union, being uncertain about the proposal for, and the consequences of, an Ocean Data Service in the Mobile Maritime Bands, opposed it only to be on the safe side, as was learned later by accident. Whereupon the delegates of two of his neighbor countries, assuming that his stand was based upon a thorough consideration of the matter, demonstrated the same negative position. Or, when the reliability computations by the National Bureau of Standards for the Ocean Data Service were presented, the Russian delegate expressed lack of confidence in them, because large scale experiments had not been performed to check the computations. Subsequent experiments between California and Hawaii, and between the Woods Hole Oceanographic Institution and Bermuda, showed that the results of the National Bureau of Standards computations were somewhat conservative and on the safe side.

J. M. Snodgrass has made a consistent and deliberate effort to ask for only the absolutely necessary minimum of frequency range for the Ocean Data Service and consequently avoided the hazard of having to modify the requirements under pressure. His factual and realistic presentation to the International Telecommunication Union of the need for an Ocean Data Service was apparently appreciated by many delegates and the administrative situation for its realization is promising now.

---

103 The Mobile Maritime Bands cover 16 percent of the high frequency region.

104 Snodgrass, J. M., op. cit. note 100.

105 Snodgrass, J. M., Oceanographic Communications and Telemetry Involving Buoy Systems, Trans. of the Mar. 1964 Buoy Technology Symposium, Marine Technology Society, p. 285.

7.3 Technical Considerations

James M. Snodgrass of Scripps Institution of Oceanography has expressed the following (106): One 3.5 kc. channel in each of the six Mobile Maritime exclusive frequency bands be allocated for oceanographic service. Each is to be operated on a multiple use basis, i.e., c.w., voice, facsimile, data, etc. Each 3.5 kc. channel will be subdivided into ten 300 c.p.s. wide data channels.

The relatively high power interrogation of Ocean Data Stations should be performed through commercial transmitter facilities. Organizations like International Telephone & Telegraph Corp. (ITT) and Radio Corp. of America (RCA) are interested in such a service and are cooperative. The reception of data messages would ordinarily also be handled by commercial communication links, with the possibility of individual users operating their own receiving equipment, if desired.

For error detection, repetition of the data messages is more reliable than the use of error checking codes, because of the effects of multipath interference in the HF region.

In addition to spectrum conservation, single-sideband operation has the advantage of avoiding heterodyning between carriers from different buoys; especially in view of the possibility of simultaneous transmission in the same band from buoys of sufficient geographic separation to allow individual reception by highly directive antennas (107).

A successful interrogation experiment was conducted by General Dynamics/Convair over a 800 km. range with the interrogation and data transmission in the same band. This technique offers the advantage that the buoy will only respond when the channel is undisturbed.

In general, from two to four different frequencies appear necessary for each individual Ocean Data Station to cope with the variable transmission conditions in the HF region. The information is conveyed by frequency shift keying. With presently employed equipment 75 bits per second appears to be the optimum rate of data transmission, which through further development can probably be increased to 100 bits per second.

The Navy universal buoy carries a discone antenna. For the expected range of antenna tilt due to wave motion, the discone antenna is less sensitive to pattern deterioration than the whip antenna for low angle (long distance) operation. Further advantages are quoted below (108):

"It should be mentioned here that the discone has some practical advantages over the whip in that it is a wide band device, and is fed at the top rather than near the bottom, thus avoiding the wet, salt spray problem. The top of the discone can be grounded so that lights and instruments can be located there without affecting the pattern. Being grounded the discone also gives lightning protection. Full scale tests have not yet been run, but the 100:1 scale model tests indicate that the discone impedance varies much less than the whip as a function of tilt."

The Intergovernmental Oceanographic Commission (IOC) recommended certain engineering standards for data transmission by floating oceanographic data stations as follows (109):

(a) A nominal 300-bit capacity message.

(b) Transmission at a maximum of 100 bits per second.

(c) 300 c.p.s. maximum bandwidth for message.

(d) Antenna input power limited to 100 watts.

The adjoining table (110) lists some of the more basic information of interest to oceanographers (111). As shown, 372 bits would be required. The system of buoys might be interrogated for 5 minutes every 6 hours. At this time the buoys would read back the information they had gathered during the previous 6 hours.

The following is taken from the Ninth Eastern Pacific Oceanic Conference, October 1963 (112). "It was decided that the following measurements should be recorded (in the buoy) and transmitted as soon as networks were available: (1) air pressure, air temperature, wind speed, and wind direction, all at 3 meters; (2) wave and swell height, surface temperature; and (3) temperature at 10 to 20 depths (measured by pressure) down to the depth of no seasonal change. It was recognized that particularly good transmission facilities (e.g. satellite monitoring, suggested by Dr. Tully) would be needed to handle so much data."

Although working in the HF region leaves much to be desired, it is the opinion of most oceanographers that most of the important data can be telemetered. Among others, R. G. Walden of Woods Hole, and J. O. Morin of Concord Control, Inc., have successfully telemetered current velocity, direction vane heading and magnetic heading. The output of each of the sensors was in the form of a 7-bit binary number (113). Pulse

---

106 Ibid.

107 Devereux, R., op. cit. note 102.

108 Devereux, R., et al., Development of a Telemetering Oceanographic Buoy, General Dynamics/Convair, San Diego, Calif., Progress Report, Feb. 1963, (DDC No. AD 404523).

109 Snodgrass, J. M., op. cit. note 105.

110 Crane, H., and Dubinsky, R., An Oceanographic Data Relay Satellite, Trans. of the Mar. 1964 Buoy Technology Symposium, Marine Technology Society, p. 342.

111 The table has been slightly changed from the original. Also, a systematic error affecting the last five columns has been corrected.

112 Reports of the Ninth Eastern Pacific Oceanic Conference, Minutes, Subcommittee 3 Meeting of June 18, 1962.

113 Morin, J. O., and Walden, R. G., Radio Telemetering Buoys, Undersea Technology, vol. 4, Aug. 1963, p. 15.

Required Number of Bits Versus Desired Information

				Per reading			Per report	
	Units	Accuracy	Range	Number of increments	Decimal char.	Number of bits	Number of readings	Required bits
Ocean								
Temp. at surface	°C.	±0.1	-2 to 35	185	3	8	1	8
Temp. at various depths	°C.	±0.1	-2 to 35	185	3	8	10	80
Conductivity at various depths	mmho	±.01	20-60	2,001	4	11	5	55
Surface waves	m.	±0.3	0-12	20	2	5	1	5
Current speed at various depths	m./sec.	±1%	.025-2.5	50	2	6	10	60
Current direction at various depths	degrees	±4	0-356	45	2	6	10	60
Pressure vs. depth	bar	±0.5%	0-80	100	3	7	3	21
Sound velocity at various depths	m./sec.	±0.2	1350-1700	875	3	10	5	50
Atmosphere								
Temperature	°C.	±0.2	-5 to 40	113	3	7	1	7
Barometric pressure	millibar	±0.5	700-780	80	2	7	1	7
Wind speed	m./sec.	±0.2	0-40	100	3	7	1	7
Wind direction	degrees	±5	0-355	36	2	6	1	6
Solar radiation	langleys/min.	±1.5%	.015-15	34	2	6	1	6
						Total		372

code modulation was used to frequency shift key at 2 to 7 mc.p.s.

A. J. Campanella of State College, Pa., successfully telemetered temperature on a frequency of 2398 kc. using frequency shift keying (114). The mark space rate of shifting was made to depend on the temperature. Radiated power was approximately 2 watts.

There has been some experimentation in the VHF region for long distance acquisition of oceanographic data using meteor trail forward scattering (115). Relatively high power output is required from the transmitter, but the duty cycle and therefore the average power are low. The range is 1,600 kilometers. The system utilizes the forward scatter characteristics of ionized trails or "bursts" caused by millions of meteorites entering the earth's atmosphere daily. The system operates as follows: The master station probes with an interrogation signal for 10 milliseconds, then listens for 15 milliseconds. The instrumented ocean buoy is normally silent. When a suitably, oriented meteor trail enables the buoy to receive the probing signal, the buoy transmitter is automatically turned on, and the stored data are transmitted to the master station. When the reply fades, the master station will select the proper starting point in the stored data for the subsequent transmission. In the system developed, the buoy transmitter power is 600 watts at 50 mc.p.s. A 0.4 μv signal at the receiver input results in an intermediate frequency output signal-to-noise ratio of at least 8 db in the data bandwidth.

114 Campanella, A. J., A Telemetering Thermometer, *Marine Sciences Instrumentation*, Instrument Soc. of Am., vol. 1, 1962, p. 39.

115 Johnson, R. E., Acquisition of Oceanographic Data via Meteor Trail Forward Scatter, Trans. of the Mar. 1964 Buoy Technology Symposium, Marine Technology Society, Supplement, p. 115.

8. RECOMMENDATIONS, CONCLUSIONS

Logistic support should be provided by a private contractor equipped to handle all non-military buoy projects (116). Thus a variety of buoys would be available to select from for any particular purpose. It is also recommended that the contractor provide competent personnel to perform the instrument calibrations. The planned installation of buoy systems should be announced well in advance to provide a possibility for interested groups to share the buoy facilities and the cost of operation. It is anticipated that even foreign institutions might be interested in such a cooperative effort.

Better design of research ships to improve their handling capabilities for buoys and instrumentation appears necessary.

A large winch having a diameter of 10 meters and a width of 5 meters should be available on research ships to accommodate an already instrumented cable. The cable would be instrumented during travel between the stations to be ready for rapid lowering at the site.

Simulated high power interrogation signals should be transmitted as soon as possible in the Ocean Data Service Bands by commercial stations to assess the probability of receiving complaints about interference from users of the Mobile Maritime Bands.

In connection with the National Science Foundation Joint Buoy Program, Professor Isaacs of Scripps Institution of Oceanography is interested in the measurement of currents and the variations of depth of the thermocline in the eastern, northern, and central part of the Pacific Ocean. For this effort, he proposes about one hundred buoy stations arranged in strings 100 miles from, and in parallel to, major sea lanes. Telemetry from the buoys would be received by passing ships and relayed by their communication equipment to shore stations. Steamship lines are interested and cooperative, including their radio operators who would not mind earning a bit of extra income on a tediously uneventful voyage.

A plea for simplicity in instrumentation design appears to be in order. Many instrument designers have set their aims toward the admittedly more challenging question of what can be achieved by ever increasing complexity. This approach promises the most spectacular results and therefore appeals to both the designer and customer, especially when in wise anticipation the completed system is complemented by the popular combination of an alarm system and the speedy 24-hour services of alert technicians. However, with systems that do not lend themselves naturally to such tender care--like space probes and deep sea buoys--the excitement about spectacular complexity invariably turns out to be rather short lived, unless the extreme cost for high reliability of complex systems is accepted on the grounds of military or political interests of national scope.

It has become evident during the search that resulted in this bulletin that many workers at many organizations have designed and constructed many types of buoy systems, floats, mooring cables, anchors, as well as of data sensing, storage, and transmission systems, to measure the small number of essentially the same parameters, without paying much attention to, and taking advantage of technical progress achieved by others. The reason for this kind of an approach is the fact that the marine sciences have been, and still are, descriptive sciences, which leaves much room for individualism, and encourages the designing of a new buoy for almost every individual project, which, if successful, is hardly ever used to its full potential or used by others. For the forthcoming large scale attack on the ocean, however, this approach will no longer be economically bearable, and prototype construction and experimentation, to be followed by standardization for the purpose of mass production of a reduced number of types, has become inevitable. Premature standardization can be an evil when it hampers progress. But a great wealth of knowledge and experience in the fields of mechanical, electrical, electronic, instrument and automation engineering has been amassed in the past decades so that the likelihood of premature standardization on the engineer's part is only minimal.

The situation is best described by the lapidary statements made about four years ago, and still valid, by R. D. Gaul of the A. & M. College of Texas and J. J. Schule of the Navy Hydrographic Office (117). They are worth quoting:

"Resulting from diversified breakthroughs in other fields, there now exists a tremendous store of commercially available engineering technology which can and should be translated into oceanographic hardware.

"With recent focusing of national concern on the marine sciences to meet ever increasing defense and economic requirements, the prospect of massive support is an impending reality. If expanded facilities and money are to be intelligently deployed to the best advantage, the load cannot be carried solely by the oceanographers, if for no other reason than lack of numbers. It

---

116 Snodgrass, J. M., Scripps Institution of Oceanography, La Jolla, Calif. Oral communication.

117 Gaul, R. D., and Schule, J. J., Oceanographic Requirements versus Instrumentation Capabilities, Fall Instrument Automation Conference, Instrument Society of America, New York, N.Y., Sept. 1960.

follows that if measurement and data handling techniques are to be modernized concurrent with a build-up of our oceanographic fleet and personnel . . . a working relationship must be promoted which will put the ocean scientist in a position to best utilize the experience and knowledge of the instrumentation technologist."

And:

"Most of the engineering problems associated with sensor development seem to be well within the reaches of industry with the possible exception of those problems pertaining to sampling the oceanographic instruments in situ. This indicates that there should probably be considerable emphasis on prototype building and testing of field systems before proceeding with mass production. For many projects either underway or contemplated by the oceanographic community, mass production of practically identical units meeting pre-set specifications will be essential."

Finally:

"Such a program (in the field of instrumentation and data controlling systems) should be centrally directed, and its magnitude is such that the direction must come from a government agency or an organization supported by public funds. It should draw on the talents and experience of oceanographers who have been developing their own instruments as well as engineers specializing in instrumentation and data handling. Oceanographers are unable to cope with the task alone due to lack of manpower, intimate familiarity with the latest techniques and production engineering and manufacturing capability; nor is industry able to go far without assistance because of deficient experience with the ocean and the complexity of requirements in the field. A cooperative program, however, would result in the development of reliable, widely applicable, standardized instrument systems for support of the increased effort in marine sciences."

9. ACKNOWLEDGMENTS

The authors wish to express their gratitude to the many persons who provided material, technical data, suggestions, opinions, or constructive criticism. They are listed in alphabetical order of their affiliations and names: N. L. Brown and P. C. Stahl, Bissett-Berman Corp., San Diego, Calif.; A. J. Goodheart, J. T. Hickley, Mrs. S. G. Rafter, Dr. H. B. Stewart, Jr., and C. L. Van Haelen, Coast and Geodetic Survey, Rockville, Md.; T. G. Kirkland, Engineers Research and Development Laboratories, Fort Belvoir, Va.; R. Devereux, General Dynamics/Convair Corp., San Diego, Calif.; P. F. Smith, Geodyne Corp., Woods Hole, Mass.; N. Kaplan, Harry Diamond Laboratories, Washington, D.C.; B. A. Gruber and Dr. R. J. Wineman, Monsanto Research Corp., Everett, Mass.; Drs. R. G. Bader and F. D. White, National Science Foundation, Washington, D.C.; Dr. R. W. Drisco, R. J. Jones, T. L. Lee, B. J. Muga, J. T. O'Brien, and J. E. Smith, Naval Civil Engineering Laboratory, Port Hueneme, Calif.; K. E. Breisch, F. D. Jennings, Office of Naval Research, Washington, D.C.; Dr. J. B. Isaacs, M. Sessions, and J. M. Snodgrass, Scripps Institution of Oceanography, La Jolla, Calif.; Dr. R. G. Walden, Woods Hole Oceanographic Institution, Woods Hole, Mass.

☆ U. S. GOVERNMENT PRINTING OFFICE : 1965 O - 776-910