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"WHITE PAPER"

on

DUMAND DEPLOYMENT

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AN ADDENDUM TO THE PROPOSAL FOR DUMAND STAGE II.

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DEPLOYMENT OF THE DUMAND PHASE 2 ARRAY

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EXECUTIVE SUMMARY

The feasibility and cost of DUMAND deployment of multiple strings in the deep ocean is reviewed in more detail than is provided in the main DUMAND II Proposal. An overview of recent technical developments in deep ocean engineering is presented, with emphasis on new techniques important to DUMAND; e.g., tethered Remotely Operated Vehicles (ROVs) with manipulators and real-time TV observation, and long (40-km) compact electro-optic cables with multiple fibers. Available deep ocean ROV systems at Scripps, Woods Hole, and (in the near future) the University of Hawaii are described. The cost of deployment, including laying of the cable from shore to the DUMAND site, is estimated. The total cost of deployment is consistent with the DUMAND II proposal estimate of \$0.5 – \$1.0M, or less than 10% of the overall DUMAND II cost.

The successful operation of a single string (the "Short Prototype String" or SPS) in DUMAND I by the DUMAND operational team of physicists and engineers demonstrated capability in deep ocean operations. Use of the Navy semi-submerged SWATH ship KAIMALINO provided a stable platform for the ship-supported SPS operation, which demonstrated the feasibility of detection of cosmic ray muons by Cerenkov light, in the presence of ocean background light. However, DUMAND II contains nine strings, to be permanently installed on the ocean floor, and an explicit procedure for deploying (and replacing, if needed) any string is required.

This document presents a practical plan for deploying multiple strings, based on the SPS experience in deploying single strings. The plan makes use of modern ROVs to connect each string to a Junction Box on the seafloor, which terminates the electro-optic (power, fiber optics) cable from the Shore Station. The procedures involved were worked out in a series of DUMAND Deployment Workshops involving experts from major ocean engineering laboratories as well as DUMAND. It is the considered opinion of these experts that the proposed deployment system is both feasible and cost-effective (and a great improvement over previous schemes). The modular approach enables DUMAND-II to begin operations with only a few strings connected, and add more strings as they are produced and tested.

The same deployment system can be used for repair and/or replacement, by disconnecting individual strings to be returned to the surface. In sum, the deployment plan has matured to the point where its success is a matter of straightforward engineering.

INTRODUCTION

This "white paper," providing detail on plans for the deployment of the DUMAND II array, is a supplement to the DUMAND II main proposal(1). The goals of the White Paper are to provide the reader (especially peer reviewers) with an understanding of the procedure by which the nine strings of Cerenkov detectors are to be accurately positioned at the bottom of the ocean at the DUMAND site, its feasibility, and the costs involved.

Since the hardware and expertise involved in deep ocean deployment are relatively unfamiliar to high energy physicists, a parallel effort is being made to provide a videotape of some of the equipment used and brief interviews with long-term experts in deep ocean engineering and science.

The confidence of the Hawaii DUMAND Center staff in the feasibility of the proposed DUMAND II deployment is based on two factors. First is our experience in successfully deploying and operating the Short Prototype String, culminating a series of 12 ocean operations. Secondly, we have observed, with great interest, the growing sophistication of Remotely Operated Vehicles (ROVs) for deep ocean work at Scripps Institution of Oceanography (SIO), at Woods Hole Oceanography Institution (WHOI), at the University of Hawaii's Institute of Geophysics (UH-HIG), in the Navy's Deep Submergence Vehicle (DSV) program, and in the off-shore oil business. The existence of practical ROV's lends a new dimension to the deployment (and recovery) technique, and results in a great improvement in simplicity, reliability and cost.

The evolution of DUMAND's concept of the most practical method of multi-string deep ocean deployment has continued since the first DUMAND workshop on the subject at Scripps in 1978 (Ref. 2). Our original concepts were derived from the techniques of deep-ocean oil-well drilling and involved large, expensive ships. Our ideas gradually changed as successful deep-ocean operation of smaller ships was demonstrated, and with the advent of tethered ROVs — provided with power and guidance from a surface ship -- a major simplification and cost reduction became possible.

ROVs operating in the relatively shallow off-shore oil depths have been followed by ROVs capable of operating at 20,000-foot depths. The rapid development of fiber optics has made real-time viewing of underwater ROV operations feasible; all new tethered ROVs are expected to have lightweight electro-optic (power and fiber-optic) cables to replace the former massive narrow-bandpass coaxial cables (thus allowing deployment from smaller vessels). DUMAND has followed these developments closely, with direct planning participation by experts in the oceanographic world, through a series of DUMAND Deployment Workshops (see Refs 2–5).

Extensive developments in deep–ocean technology have been demonstrated in recent years: tethered and free–swimming ROVs in the offshore oil business; the Deep Tow acoustic imaging by an SIO group; the UH–HIG developed SEAMARC acoustic survey system in Hawaii; deep–ocean manned submersibles with manipulators and TV viewing by Navy teams; SIO's Remote Underwater Manipulator (RUM); and WHOI's JASON, Jr. tethered ROV system which surveyed the Titanic.

This White Paper details the procedure now arrived at by the Hawaii DUMAND Center for DUMAND–II's multi–string deployment. A single E–O multi–fiber cable from the Shore Station to the DUMAND ocean bottom site terminates in a multi–port Junction Box, into which each array string is plugged (by an ROV) for both power and communication to shore. The strings can be deployed (or recovered) in a modular fashion, one at a time. The ROV performs simple connect/disconnect functions, while the surface ship provides lifting and maneuvering operations. Visual (TV) monitoring and acoustic surveying provide precise location and operation.

The Hawaii DUMAND Center is fortunate in having had the long–term (since 1976) interest and part–time participation in DUMAND progress by George Wilkins, a physicist and ocean scientist formerly with the Naval Ocean Systems Center (NOSC) and now at the Institute of Geophysics of the University of Hawaii. (See Wilkins' vita in Appendix B.) Because of Wilkins's continuous contact with all major USA activities in deep–ocean ROV development, his successful development of E–O cables, and his intimate knowledge of DUMAND's needs in Ocean Engineering, the staff of the Hawaii DUMAND Center have asked him to be the editor of this DUMAND Deployment White Paper. Cooperating with Wilkins in this task are Profs. Vic Anderson, Fred Spiess, and Hugh Bradner of Scripps, Drs. Robert Ballard and Christopher Von Alt of Woods Hole, and Dr. Charles Helsley, Director of UH–HIG. The descriptions of RUM, ARGO–JASON, and FOCUS in Appendix A have been prepared by Wilkins, with information provided by WHOI and SIO teams. The DUMAND HDC staff has of course also been intimately involved in preparing this document.

The deployment plan presented here evolved after a series of DUMAND–sponsored Deployment workshops (see References), particularly those in 1984 and 1988. Important technical participation and engineering planning support were provided by the Naval Ocean Systems Center (headquartered in San Diego) through the continuing interest and encouragement of Howard Talkington, Associate Technical Director of NOSC.

Although there are several alternatives for the ROV stage in DUMAND-II Deployment, we have chosen the Scripps RUM vehicle as the primary illustration of the feasibility (both technical and economic) of our deployment scenario. RUM III is presently operational; it has demonstrated its ability to perform the necessary in-ocean manipulations (see videotape). Furthermore, the Scripps team has a long record of success in deep ocean operations. The Deep Tow program, directed by F.N. Spiess, with long-term NSF and ONR support, has built up an enviable record of oceanographic investigations. The continuing RUM development, led by Vic Anderson, is now in the third phase of ROV sophistication, with ONR, NOAA, and NSF continuous support. (DOE-Sandia also provided support in the design phase of RUM III.)

The Scripps team is now preparing a proposal for using RUM III to deploy DUMAND II; a parallel objective is demonstrating RUM's capabilities for ocean-bottom mining exploration and other applications. This proposal will be submitted to both ONR and NSF in the near future. The costs of RUM deployment in this White Paper are based on data provided by the SIO RUM team. Brief vitae for Profs. Spiess and Anderson are included in Appendix B. The impressive record of accomplishments in deep-ocean science and engineering by this Scripps team augurs well for the success of RUM operations in DUMAND II deployment.

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DEPLOYMENT OF THE DUMAND OCTAGONAL ARRAY

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The deployment and connection of the DUMAND fixed array will consist of four major events:

- I. Survey and selection of the route that the array power/data support cable will follow from shore to the array site.
- II. Laying of the cable between the shore laboratory and the array site.
- III. Lowering and precise positioning of the DUMAND vertical array elements at the array site.
- IV. Optical and electrical connection of these elements to a junction box at the sea end of the support cable.

Interconnection of the array on the 4800-meter-deep seafloor will be carried out using make-and-break electrical and optical conn ectors (described below). The joining of these connectors will be performed by deep-sea remotely operated vehicles (ROVs), described below, and in more detail in Appendix A.

I Cable Route Survey

The DUMAND sensor array is to be located about 35 km west of Keahole Point (the western extreme of the island of Hawaii) at a water depth of 4800 m. An electro-optical (E-O) support cable will run to this site from the Point, which is also the location of Hawaii's Natural Energy Laboratory.

The underwater terrain off Keahole Point is geologically recent, and consists of a superposition of lava flows which have formed a steep offshore slope. The adjacent coast is dry with no permanent streams, so these slopes have experienced very little post-flow erosion. The subsurface slope is generally rough and contains several near-vertical cliffs or "palis".

Detailed bathymetry and photo-mosaics of the bottom off Keahole Point have been obtained to a depth of 700 meters during route surveys for several cold water pipes to support aquaculture and thermal energy conversion experiments. Beyond this depth, acoustic (SEAMARC II) surveys have been performed with moderate resolution along the slope down to the flat and featureless floor of the Hawaiian abyss at 4800 m. The Navy's deep-sea submersible TRIESTE performed a visual survey of the bottom of the slope off Keahole Point several years ago, as well.

Recently the Naval Civil Engineering Laboratory has informed us of plans to install a cable test range off Keahole Point at depths between 1000 and 2000 m. While the precise location for this facility has not yet been selected, it is reasonable to expect that the same bottom surveys which support its choice will directly benefit DUMAND.

Keahole Point's offshore slopes will be acoustically mapped from sea level to the abyssal basin. A swath at least 3 km wide will be surveyed with a topographic resolution on the order of a meter. Analysis of these data will determine first, second and third-level candidates for the DUMAND cable route.

The selected route will avoid the extreme slopes noted above. It will also follow the smoothest topography available along this stretch of coastline, while minimizing the need for precision maneuvering by the cable-laying ship. Candidate routes will be photographed and closely examined before final selection is made. Several survey systems are available to support this inspection:

- Initial acoustic surveys will be performed by the University of Hawaii's SEAMARC II mapping system (or alternatively by a commercial system which is also based in Hawaii). The SEAMARC II sidescan sonar is operated from the UH research vessel R/V Moana Wave. This device has been in great demand for seafloor mapping, and is installed on a UNOLS fleet vessel and facility. Data reduction is a standard procedure at the HIG.

- The manned submersible PISCES -- operated by the Hawaii Undersea Research Laboratory (HURL) -- can dive to a depth of 2000 m. It will probably support the detailed photographic survey of the Navy cable range and, in parallel, will survey the DUMAND cable route to that depth.

- At all depths, video data or TV viewing can be obtained with cable-controlled vehicles, such as ARGO-JASON or RUM. The ARGO-JASON system is operated by the Woods Hole Oceanographic Institute, and is now equipped with a fiber-optic cable (designed by Wilkins). The Remote Underwater Manipulator (RUM) is operated by the Scripps Institution Of Oceanography, and currently has slow-scan TV (due to coaxial-cable link). HIG, at the University of Hawaii, anticipates that a fiber-optic controlled undersea ROV system (FOCUS) will be operational by mid-1990.

- Finally, we have been told that DUMAND may be able to use a Navy manned deep submersible -- the 6000m depth capability SEACLIFF -- during one of that vehicle's working assignments to the Navy underwater range off the island of Kauai.

The DUMAND cable route survey will result in a detailed maneuvering and navigation plan for the cable–laying ship. This plan will include a computer program which relates cable length, cable tension and ship speed to water depth and ship position along the planned cable route, and informs the captain of the proper direction and speed. This will ensure that the cable is laid neither too slack nor too taut, and that the seaward end of the cable (the Junction Box) can be placed in its planned position at the DUMAND site.

During cable laying, absolute location will be provided to the ship by a radar navigation system based on transponders at surveyed sites on the hills behind Keahole Point. (This system was used during the Short Prototype String (SPS) experiment, and has a resolution of 1 m.)

II Cable Laying

The design length of the DUMAND support cable is 40 km –– enough to safely span the route between the laboratory at Keahole Point and the array site about 35 km offshore. The cable's sea end is attached to a power/data junction box. Although the cable's geometry is well established (Fig. 1), its precise design will be fixed when requirements for array electrical power are finalized. The following table below shows two alternative designs, the first of which is the most probable choice at this time. Appendix C discusses cable design and costs.

Power To Array (kW)	5	10
Number of fibers	10	10
Cable Diameter (mm)	9.5	11.1
Cable Strength (kg)	6,600	8,900
Cable Weight (kg/km)		
In Air	357	484
In Water	292	396
For 40 km (kg in air)	14,300	19,400
Minimum Safety Factor*	4.8	4.8
Maximum Static Load (kg)*	1,370	1,860

* For a water depth of 4800 m.

Several choices exist for the cable laying ship, whose cost to DUMAND would be minimized if approved by the UNOLS (U.S. National Oceanographic Laboratories) program. As a mimimum, this ship must have twin screw propulsion, with a bow thruster. Such a cable laying operation does not pose a major techni–cal challenge, and is something that has been carried out numerous times, general–ly with cables much larger and more difficult to handle (e.g. transoceanic telephone, offshore sonar systems for the military, and geophysical arrays).

Before the DUMAND shore cable is laid, divers will have installed and rock bolted a heavy metal pipe from the shoreline at Keahole Point to a depth (30 – 40 m) that is sensibly free of wave forces during winter storms. This approach is commonly used at Keahole Point to anchor the nearshore ends of cold water pipes. The pipe (about 25mm I.D. by 300m long) will contain a "fish line" so that cable can be pulled through it.

Cable laying will begin with the cable ship moored about 300 meters off Keahole Point. The ship will lower to the seafloor a pallet holding sufficient cable to reach the shore station. The end of this cable will be attached by divers to the fish line and pulled back to shore. This pulling phase will be closely monitored by divers looking down from a shallower depth. When the electrical and optical integrity of the 40-km cable have been established, the laying of the cable will begin.

As cable laying proceeds toward deeper water, ship speed, water depth, geodetic position, wind speed/direction, surface (and subsurface) currents, cable tension and cable payout rate will be continuously monitored and fed into the computerized cable laying model. Computer outputs will include repetitive comparisons of planned-versus-actual cable touchdown coordinates and tensions—plus recommendations of corrections to be made in ship position, ship heading, payout rate and payout tension. The deployment speed will be about 2 knots (1.0 m/sec). This will allow the 40km cable length to be laid in daylight hours if desired.

The cable will be stored in a figure-8 pattern on the ship's after deck, and led under low tension to a linear traction winch. The winch will hold the weight of the suspended cable as it is slowly lowered to the seafloor. (In a linear winch, the cable is not bent or flexed as it makes the transition from low to high tension. Also, this type of winch can easily accept and pass along in-line cable connectors.)

As cable payout approaches the Junction Box, that unit will be rigged with a strong but lightweight lowering line, which is to be operated from the ship's conventional after-deck handling system. A carpenter's stop will be attached to a point near the end of the shore cable, then fed through the linear winch, so that the weight of the cable can be transferred to the lowering line. The Junction Box will be lowered to the seafloor while the ship maneuvers to maintain position and to control the setdown path of the cable on the seafloor. The length of the shore cable will include an extra 2 km for safety margin. During lowering this excess can be laid on the seafloor in a giant circle or figure-8. The exact location of the Junction Box on the seafloor is not critical to DUMAND. In fact, the coordinates of this point will determine the final position of the array.

The Junction Box serves as a physical/electrical/optical termination for the shore cable. In this role, it contains half-connectors (see below), which will later be joined to the sensor strings of the DUMAND array. Each string will require three such connections (two optical and one electrical) to the Junction Box.

The cable's electro–optical circuits will be subjected to continuous testing during the laying and lowering operations. When final integrity has been established, an acoustic signal will be sent to the seafloor to actuate a release (standard commercial item) so that the lowering line can be recovered.

[As an option, this line might be laid on the seafloor in a direction perpendicular to the cable route. It could then be snagged with a grapnel to serve as a recovery line. This technique has been used successfully a number of times, particularly with the HIG based Downhole Project.]

Finally, the cable ship will drop at least three Deep Ocean Transponders (DOT's) near the Junction Box to establish a local acoustic navigation network (with a baseline of about 500 m). These DOT's can be queried directly from a similar DOT in the Junction Box, and from the ship, to establish the local coordinate system by which the DUMAND sensor strings will be deployed. Such battery–powered units, available from several manufacturers, have operating lifetimes of several years.

III Deployment of the Array Sensor Strings

The present DUMAND array deployment scheme differs from previous plans in one critical aspect. The array will be placed on the deep seafloor by repetitive guided lowering of already deployed strings (rather than containers) to presurveyed positions on the seafloor. In a separate operation, these strings will then be connected, by an ROV, to the Junction Box at the seaward end of the shore cable. The cartoons following Fig. 1 illustrate the entire cable–laying and deployment process (pp. 16–17).

In lowering these strings to the seafloor, we will use the same deployment technique that was successful during the 1987 Short Prototype String experiment. The support ship of choice will again be the semi–submersible platform SSP KAIMALINO, chosen primarily for its local accessibility, its stability, its maneuverability and (especially) because it has a center well with access from two decks.

The KAIMALINO can deploy only one string per operation. As in the SPS, each string will be configured as a ladder, with the environmental and optical sensors acting as the rungs and the two electro–optical cables as the rails. Except for the anchor and the topside buoyancy module, each string will be folded and stored in a standard shipping container (24 foot van). This will combine low–stress packaging and transport with easy access for calibration and repair. Each sensor module will be hung from a rail in the container, in much the same mode as beef carcasses are hung in a meat packing plant.

The string deployment sequence is as follows. A (SEALINK) crane is used to lower the anchor and sensor modules through the center well. The crane's double winching system allows the modules to be picked up and lowered in a hand–over–hand mode. At the top of the array, tension is transferred to the ship's conventional handling system and to a lowering line. During this time, a battery in the array anchor will power:

(a) Diagnostic circuitry within the array string to check and acoustically report on critical array functions. (In the interests of safety, this subsystem may not be activated until the top of the array is fully submerged.)

(b) A synchronous acoustic pinger to interrogate the seafloor transponders.

As the array is lowered, its acoustic query will elicit coded replies from each DOT. Here we have a choice: the string location can be done either via the acoustic equipment on board ship, or via the junction box, if the latter is provided with a hydrophone whose output is transmitted to shore and relayed to the ship.

In the former case, the time between interrogation and response will include the sound travel time to the ship, which is almost independent of the transponder location within the array. The advantage of this system is that it requires no active equipment in the junction box. It is the system normally used in SIO ocean operations.

In both cases, prior acoustic calibrations will have established the locations of the DOT transponders and the Junction Box. A simple calculation will determine ranges from each DOT to the anchor –– and therefore the anchor's altitude and projected X–Y coordinates on the seafloor. In both systems, the precision and accuracy of these navigation data will improve as the anchor nears the plane of the transponders. Final position error should be better than a meter. (See Fig. 3.)

Positioning of the ship during array descent becomes a matter of comparing the anchor's computed X–Y coordinates with the presurveyed values of these coordinates, then maneuvering the vessel to reduce position errors. Navigation data will be transmitted from shore to ship, and will be displayed on television monitors on the ship's bridge.

Ship maneuvering during lowering of the string will be slow (almost leisurely), since hours will be required for the anchor to reach the seafloor. The lowering line cable will deviate from the vertical because of subsurface currents, and the anchor may be offset by as much as 1000m from its shipboard support point. But such offset distances will be stable over periods of several hours, and the array string at the anchor will be nearly vertical.[1] Finally, with the anchor about a meter above the sea-floor, an acceptable match between actual and planned string X-Y coordinates will be achieved, and the system will be lowered until the anchor is solidly on the bottom. After a last minute checkout of the string system, an acoustic separation command will be sent to the lowering line attachment point, and the line will be winched back to the surface. In the unlikely event that either the lowering line will not detach or the string fail its final checkout, the operations reverse, and the string may be pulled back to the surface (in much the same way that the SPS was recovered.)

If a position error is discovered after anchor touchdown, but before line separation, the string can be (slowly) picked up a few meters, and then maneuvered into a better position. This type of adjustment is safe, but may require an hour or more of additional maneuvering by the ship.

IV Array Deep-sea Connections

After one or more of the DUMAND array strings have been positioned on the seafloor, we will electrically and optically connect them to the junction box at the end of the shore cable. The present plan is to deploy three strings initially, and the remaining six strings some months later (limited by production schedule). These operations will be carried out by a deep submersible which has been equipped with either a one- or two-handed manipulator. Candidate submersibles are described in Appendix A. These submersibles can be either manned or unmanned (i.e., cable controlled).

The anchor section of each array string will contain about 200m of E-O umbilical cable. Each umbilical is connected to string electronics at one end and to electrical and optical connector halves at the other. Assembly of a string into the DUMAND array will consist of pulling the connector end of this cable from the anchor to the Junction Box, then joining the connectors to mating units at the box. The array string will then be functionally joined to the laboratory on shore.

In concept, this operation is simple and repetitive. For it also to be practical, two fundamental capabilities are needed (and do exist):

(a) Electrical and optical connectors which can be mated and unmated in a deep seawater environment. As a minimum, they must allow one-time in situ connections for the initial assembly of the array. If the connectors can allow multiple make-and-break operations, then array elements can later be removed or replaced.

1./ As an option, a Scripps propulsion unit may be attached to the end of an electro-mechanical lowering line. This unit acts as a deep-sea tractor, adjusting the position of (Footnote 1 Continued on Next Page

(b) A vehicle, operating on or near the deep seafloor, which can carry the end of the umbilical cable from the array anchor to the Junction Box, and then join the two halves of the connector while preserving long term electrical and optical continuity and isolation.

DUMAND's powering scheme is simple; requiring a single electrical conductor in the cable from shore, operated with DC voltage and a seawater circuit return (standard practice). The electrical connector between string and junction box can also be simple. It will consist of stab–type male/female connector halves, with a wiping surface to remove any seawater from the connection. To ensure electrical isolation, the wiper will be backed up by a squeezable reservoir to flush dielectric oil through the contact interface. Connectors of this type have been on the market for several years, and are in extensive use by both the Navy and the offshore oil industry. Their operation is independent of hydrostatic pressure.

In recent years, three U.S. companies[2] have developed deep–sea, make–and–break, optical connectors for use with single–mode fibers. These units have performed well during hundreds of make–and–break cycles in salt water at deep–sea pressures (700 kg/sq–cm). Average attenuation loss during such tests have been about 0.5 dB, with a 0.2–dB variance.

The umbilical cable for each array string will contain two single–mode optical fibers, one for communication of command and clock signals to the array and the other to pass event data back to shore. However, if the technology has progressed sufficiently far by the time of design freeze, we may use one fiber bi–directionally for commands and data, with the second fiber possibly reserved for redundant backup. Each fiber would be connected to the Junction Box with a single connector.

The act of joining of a single–fiber optical connector is not difficult. The connector halves are simply pushed together until a detent closes to hold them together. Fiber alignment within the mated structure is completely insensitive to connector azimuth (i.e., to rotation about the axis of fiber symmetry). Off–axis tilt errors during initial contact of the connector halves can be as great as 20°. Final alignment of fiber is determined by components which "float" within the connector housing. The opening of the connection is effected by gripping a detent ring on one connector half, then pulling the other half along the axis of symmetry.

The forces needed to join the connector halves (1 – 2 kgf) also act to pump dielectric fluids across the ends of the optical fibers. This flushes seawater and

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(Footnote 1 Continued from Previous Page)
the top of the array within a horizontal plane. Positioning of the array is now relatively independent of ship's motion or ocean currents. Use of this mode will require a larger support ship — and one not likely to have a center well.

2./ McDonnell–Douglas, Lockheed and TRW. The first two of these have delivered operational units to the U.S. Navy.

contaminating particles away from the fiber/fiber interface, while bridging any gap with an index matching fluid. In practice, we have observed repeated making and breaking of these single-mode optical connectors within a medium which resembled a very thin seawater mud mixture. No increases of optical attenuation were observed in this environment.

The connectors described above were designed for remote operations, that is, to be made and unmade by conventional manipulators aboard remotely operated undersea vehicles (ROVs). Almost any ROV with a two-handed manipulator system can make and break the electrical or optical connectors in the same way that a diver would (i.e., by grabbing the two halves and pushing them together). Opening the connector is equally simple.

Even a one-handed manipulator can perform these operations if the system has access to a spring clamp (like the clamps used to hang up garden tools against a wall). The single manipulator picks up a connector (female) half and presses it down into the clamp. It then picks up the second connector half and pushes it along the axis of common symmetry into the first. Finally, the manipulator pulls the mated connector out of the clamp and places it on the seafloor. This type of operation has been demonstrated by the RUM vehicle (see videotape).

V. Description of the Interconnection Procedure.

In the following we present a descriptive sequence of the interconnection of the array elements. We assume that a remotely-operated vehicle (ROV) will be used to connect the seafloor elements of the DUMAND array. Appendix A describes three choices for this vehicle:

(1) A bottom crawler tethered by a cable to the surface (the Scripps RUM III vehicle).

(2) A hybrid system such as the Woods Hole ARGO/JASON vehicle. Here, a neutrally-buoyant JASON swims at the end of a short tether which is attached to a relatively dense ARGO. The ARGO vehicle hangs at the end of a dense tether cable.

(3) A dense vehicle hanging at the end of a dense cable (e.g., the FOCUS system).

In all cases, the ROV system has sufficient horizontal thrust to maneuver within (at least) a 200 m radius circle in the horizontal plane. It will also be equipped with high resolution television and (at least) a one-handed manipulator. We anticipate the following steps will be required to carry out the interconnection of the DUMAND array:

- The support ship reaches the DUMAND site and activates the DOT units on the seafloor from their standby mode. From this time on, both ship and ROV navigation will be based on the DOT coordinate system.

- The ROV is then lowered toward the seabed 4800 meters below. Position coordinates are displayed on the bridge for the ship, the ROV, the array strings and the Junction Box.

- During descent, the ROV cable is affected by drag due to ocean currents, and it deviates from the vertical. The ship maneuvers in order to compensate for this effect. The ROV follows a near–equilibrium path whose natural end is between the array and the Junction Box. (At the expected low value of near–bottom current, the lowest 1000 meters of the ROV cable will hang nearly vertically.) The offset allowed by vehicle propulsion means that the tether cable can easily be kept from interfering with the array string(s).

- On or near the seafloor, the ROV approaches one of the array anchors, turns a lever to open a hatch and pulls out the connector end of the interconnection cable. This cable has an O.D. of about 12 mm, and has a relatively low in–water weight.

- The ROV carries the connector end of the umbilical to the Junction Box. There, it opens a hatch and pulls out a short cable which contains the mating halves to the three connectors on the array umbilical.

- The three connectors are mated one at a time, using the mode described earlier. This establishes power/data connection of the array string to the DUMAND shore station via the shore cable.

- The ROV holds position while the array string is checked out from shore. If operability is verified, the ROV repeats these interconnection steps with each of the remaining array strings.

- If array operation cannot be verified, two response options are available. If the problem lies with the Junction Box connections, they can be re–peatedly opened and remated (in the unlikely event either the connection or the insulation has been contaminated).

- If the problem is within the string and can only be repaired in a laboratory, then a different recovery mode can be activated. First, the ROV opens the connections to the Junction Box. Then an acoustic command is broadcast which separates the string anchor into two sections, releasing the bouyant string to float to the surface while constrained to a vertical attitude by the partial anchor. (If the acoustic command should fail, the ROV can release a bolt to separate the anchor halves.)

- After repair, the string can again be lowered into the DUMAND array, and can be reconnected to the Junction Box.

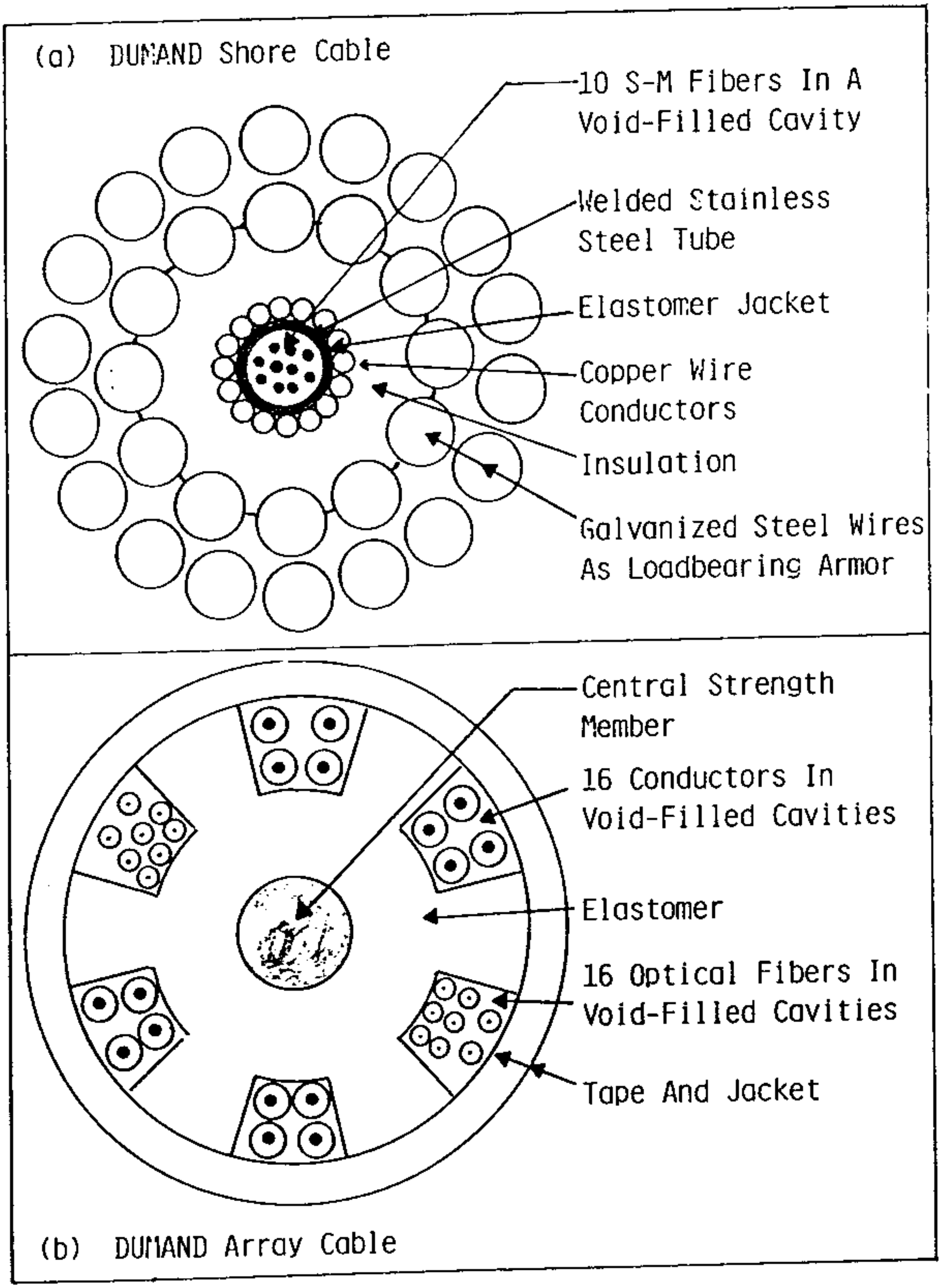
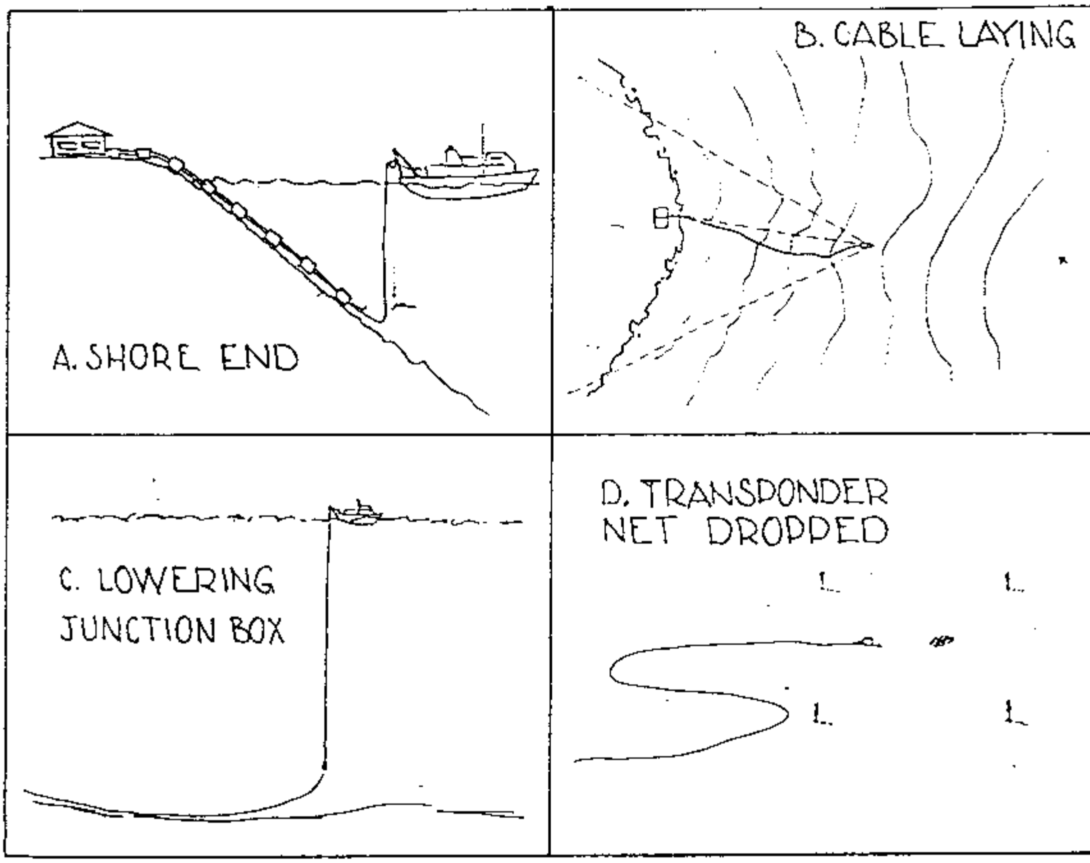
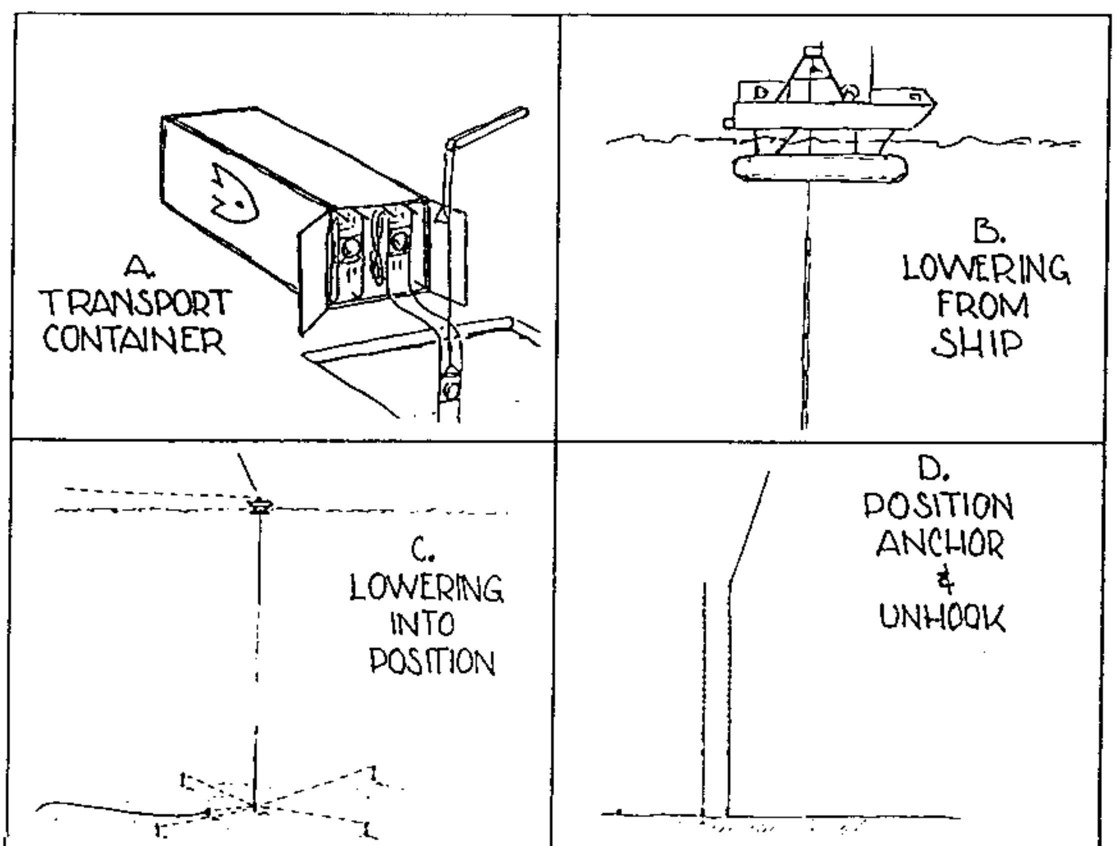


Fig. 1. Cross-Sections of the DUMAND Electro-optical Cables.

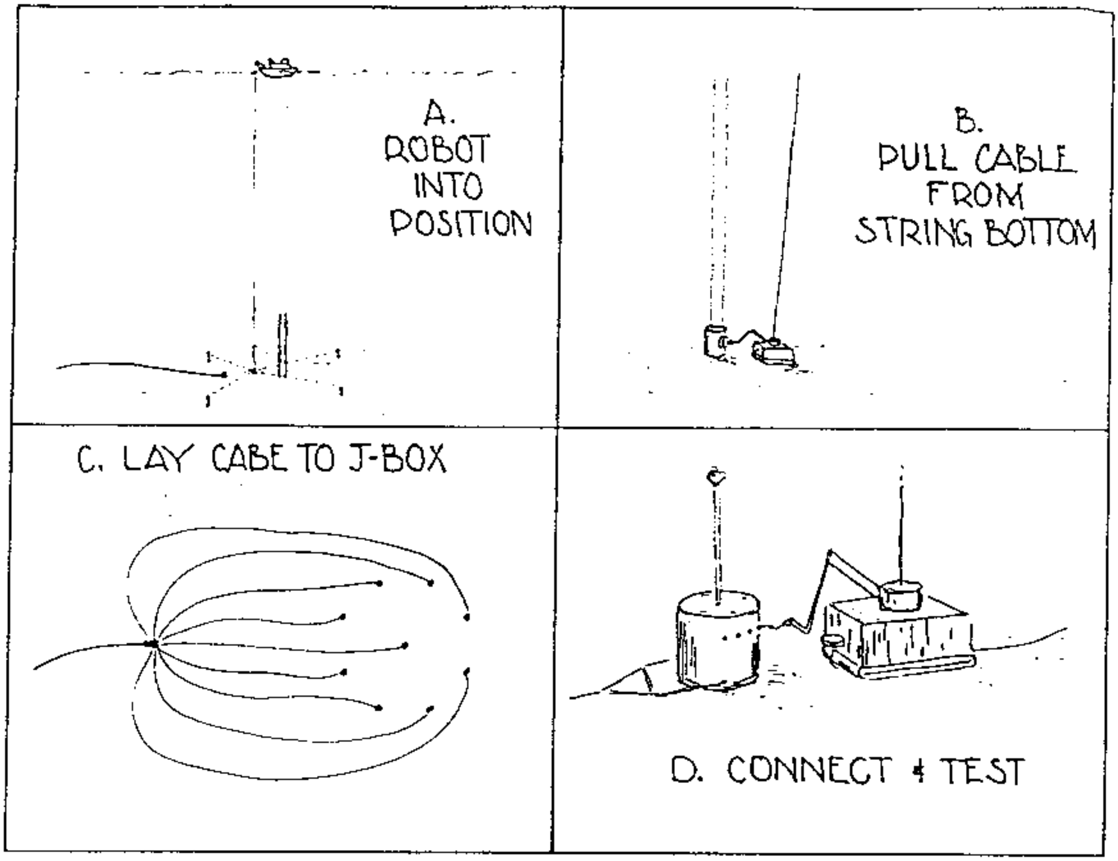

A. SHORE END
B. CABLE LAYING
C. LOWERING
JUNCTION BOX
D. TRANSPONDER
NET DROPPED

I.


A.
TRANSPORT
CONTAINER
B.
LOWERING
FROM
SHIP
C.
LOWERING
INTO
POSITION
D.
POSITION
ANCHOR
&
UNHOOK

II.

III.



Cartoons illustrating the entire deployment process.

I. Laying the Cable

A. The shore end is protected by a pipe extending below the wave zone. It is inserted by a diver, and pulled through to the shore junction by a separate line.

B. Following a carefully planned route, and guided by shore transponders, the cable–laying ship lays the cable out to the site.

C. The junction box is spliced to the cable end, and carefully lowered to the bottom.

D. The acoustic transponder network is deployed, and the location of the junction box determined with reference to the net.

II. Lowering the strings.

A. The strings are carefully removed from the transport container and

B. lowered to the bottom

C. The exact location of the string bottom is carefully determined with respect to the transponder net, and the final grounding of the string anchor takes place only when the location is satisfactory.

D. The string bottom is firmly anchored to the bottom (probably by an explosive harpoon), and the string is then unhooked from the lowering line. (If possible unhooking is delayed until after the string is connected up and tested.)

III A. The robot ROV – e.g. the RUM – is now lowered to the bottom (this may well be from a different vessel than the string deployer).

B. The ROV moves to the string anchor, and pulls out the string connecting cable from its storage in the anchor.

C. The ROV, trailng the cable, moves to the junction box and plugs the end of the cable into the junction box. It will repeat this process for each string deployed.

D. As each string is connected to the junction box, a complete system test is carried out from shore, to verify that all is working OK.

NOTE: (n) = no. of days.	RUM, New Horizon STAGE I	STAGE II	FOCUS, Moana Wave STAGE I	STAGE II (done twice)
(a) Navigation (will use same system employed earlier).	$ 5,000.	$ 5,000	$ 5,000.	$10,000
(b) Mobilization R/T to Hawaii Ship + ROV	$144,000. (19)	$144,000 (18)	———	———
(c) Dockside time in Hawaii	———	———	$10,000(4)	$20,000(8)
(d) Modify handling system for FOCUS	———	———	$15,000.	———
(e) Transit R/T to Big Island	———	———	$18,000(2)	$36,000(4)
(f) Operating time at DUMAND site	$24,000(3)	$48,000(6)	$24,000(3)	$48,000(6)
SUBTOTAL, CONNECT STRINGS	$173,000	$197,000	$72,000.	$114,000.

NOTE: Both New Horizon and Moana Wave are ships in the NSF-funded UNOLS program, and it is possible that basic charges of ship operation may be waived.

DEPLOYMENT COST SUMMARY.

	HIGH	LOW
1. SURVEY CABLE ROUTE	$42,000.	$42,000.
2. LAYING OF SHORE CABLE	$106,000.	$106,000.
3. LOWER ARRAY STRINGS TO SEAFLOOR		
STAGE I, 3 STRINGS	$112,000.	$112,000.
STAGE II, 6 STRINGS	$105,000.	$105,000.
4. CONNECT STRINGS INTO ARRAY		
STAGE I, 3 STRINGS	$173,000.	$72,000.
STAGE II, 6 STRINGS	$197,000.	$114,000.
TOTAL COSTS	$735,000.	$551,000

ASSUMPTION: To save money, the high-cost connection system (RUM or ARGO/JASON) connects the last 6 strings during a single ocean operation. This effort is divided into two operations of the low cost system.

CONCLUSIONS

In summary, we have shown that the DUMAND II deployment plans are feasible, well within the state of the art for ocean engineering, and that these plans employ existing, tested and demonstrated ocean equipment. The availability of ROVs and deep ocean mateable electro–optic connectors has come about in the last two years, and has facilitated a simplification in DUMAND ocean deployment plans. The use of an ROV to carry out the bottom connection of individual strings provides an incremental approach to the array assembly (which was not possible in earlier schemes necessarily employing preconnected strings, bottom released from canisters). An important fringe benefit is that the process can be reversed, and any string can be retrieved for service.

It is the judgment of the DUMAND staff that the area of greatest engineering effort in DUMAND II will be in assuring the necessary component reliability. The deployment operations, while remaining the focus of care and effort, are no longer the major concern. Moreover, the projected deployment costs now represent a small fraction (less than 10%) of the total construction costs.

Several options exist in terms of ships and ROVs, which have economic importance as well as operational considerations; they have been discussed in the foregoing sections. The most conservative scheme, outlined above, employs the HIG R/V Moana Wave for shore cable laying, the SSP Kaimalino for string emplacement, and the R/V New Horizon with RUM III for string connection. The operation is planned for 3 strings initially, and the remaining 6 strings some months later. In this plan the entire DUMAND II deployment cost is $735K. This cost includes full–funding ship time, personnel, and appropriate modifications to the ships as needed for the deployment operations. It does not include the construction of the array components, cable, shore station, etc.

If we obtain funding for ship time from the UNOLS fleet, this could reduce the total amount required by as much as $144K. In the least expensive scenario outlined, employing an assumed locally available ROV, the direct cost of deployment may drop even more.

Given the now experienced team at HDC, and the involvement of experienced ocean engineers and scientists from SIO, WHOI and HIG, we can anticipate that the deployment operations will proceed in a professional and reliable way.

APPENDIX A

CANDIDATE REMOTELY OPERATED SYSTEMS

A1. THE REMOTE UNDERSEA MANIPULATOR (RUM) SYSTEM.

This deep-sea reconnaissance and work vehicle is designed to operate directly on the seafloor, while tethered to its support ship by a heavy duty support cable. The RUM system has been developed by Dr. V. C. Anderson at the Scripps Institute of Oceanography (SIO). RUM III, the latest version, is the result of a design study funded by Sandia Labs. It has been operating since Aug. 1987, to depths greater than 2000m. Operations to DUMAND's 4800m depth should be demonstrated during CY 1989. A photograph is shown in Fig. 1. RUM III's weight in water is 1200 lb.

On the seafloor, RUM is propelled and maneuvered by two wide continuous rubber belts, which operate much like a caterpillar tractor, but which cover the entire bottom suface. These tracks exert low bearing forces on seafloor sediments, and are not likely to cloud or roil the clear water within the DUMAND array. Their pressure on the sea floor is only 0.16 psi, and the shear strength of the ocean floor sediment at the DUMAND site is expected to be well above 0.5 psi.

The system is equipped with two orthogonal black and white, slow-scan TV cameras and with a one-handed manipulator system. It can carry acoustic pingers, deep ocean transponders, as well as a variety of general oceanographic instrumentation.

RUM's primary tether cable is a 17.3mm diameter armored coax. SIO intends to convert the system to the same kind of E-O cable now used by ARGO/JASON. When it is, real-time TV monitoring will be available.

<u>CAPABILITIES.</u> As presently configured, RUM is able to carry out the fundamental seafloor operations — cable hauling and connector mating — required by DUMAND. Its one-handed manipulator utilizes a spring clamp to hold and position one connector half; but this is a straightforward task.

<u>COSTS.</u> Scripps is preparing a proposal to ONR/NSF to fund the use of RUM for the underwater connection phase of DUMAND II.

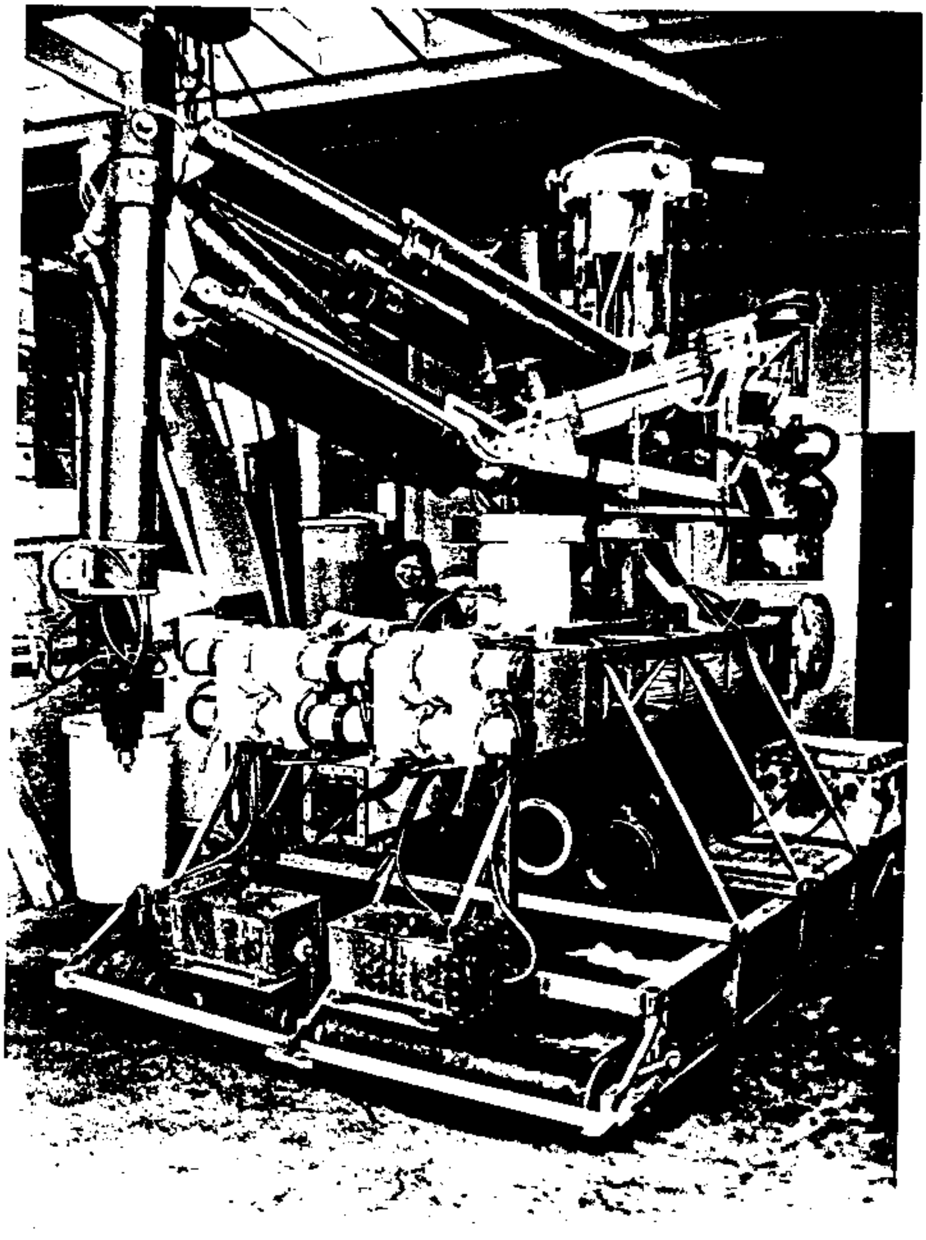


FIG. 1. PHOTO OF RUM III.

A2. THE ARGO/JASON SYSTEM.

This double-tethered deep-sea reconnaissance system is being developed by Woods Hole Oceanographic Institution (WHOI), and should be operational by the end of 1989. It consists of:

(a) A surface handling system, including a control van, a cable traction winch and a cable storage reel.

(b) A heavy duty (17.3mm o.d.) tether to launch, lower, tow, recover, power and monitor the deep-sea system. The electro-optical (E-O) cable has three optical fibers for up/down telemetry, and is capable of passing very-high-resolution digital color stereo television signals.

(c) A deep-sea vehicle (ARGO) which hangs heavy at the end of the primary cable. It contains sonar, navigation sensors, lights, television cameras and propulsors. ARGO is designed to maneuver at a moderate height (10's of meters) above the bottom, while carrying out acoustic and visual searches of the seafloor. It also serves as a transport garage for the much smaller JASON vehicle and for its E-O cable.

(d) A neutrally buoyant swimmmer vehicle (JASON), equipped with digital color stereo TV as well as a two-handed manipulator system. JASON maneuvers within a radius of about 150 meters of ARGO, and operates at the end of its own electro-optical tether cable. It is designed to observe and record phenomena in environments too hazardous or difficult for ARGO to operate, and to perform light work during such operations. (An early prototype vehicle — JASON, Jr — swam 4 decks deep into TITANIC with a TV camera to photograph that wreck.)

Normally, ARGO/JASON operates from the R/V ATLANTIS II. It is, however, designed for air transport, and could be put aboard other (similar) ships of the UNOLS fleet.

<u>CAPABILITIES.</u> When equipped with a manipulator system, the JASON vehicle will easily be able to perform the cable hauling and interconnection tasks required by DUMAND. It is capable of operating to depths of at least 6000 meters.

<u>COSTS.</u> Since it is developmental, the cost of operating the ARGO/JASON system is somewhat uncertain. Total cost of ship plus system will probably be $20,000 to $25,000 per day. If the ship is available at no cost (e.g., UNOLS), this cost might drop to about $10,000 to $15,000 per day.

A3. FIBER–OPTIC CONTROLLED UNDERSEA SYSTEM (FOCUS).

The Hawaii Institute of Geophysics (HIG) has proposed to use a mix of State and Federal (NSF) funds to develop a miniature, cable–tethered, reconnaissance and work system for use to depths of 6000 meters. The HIG design approach will use the full capabilities of fiber optics to achieve major reductions in the size and weight of the system, so that it can be easily transported by air and operated from relatively small research vessels.

The FOCUS vehicle will have an air weight of about 100 kg, and will hang heavy at the end of a small (9.5 mm) but dense E–O cable. When near the seafloor, its X–Y propulsion system will allow the vehicle to swim in a 200–m–radius horizontal plane. FOCUS will be equipped with stereo, digital, color TV, and with obstacle avoidance sonar. It will be able to carry and power acoustic pingers, deep ocean transponders and hydrophones.

During initial sea trials, FOCUS will not be equipped with manipulators. At this level of capability, the system should be operational by mid–1990. During that year, HIG plans to build and install a simple manipulator which — when used with a spring clamp to serve as a second hand — will allow the vehicle to open and close DUMAND'S deep–sea electrical and optical connectors.

<u>CAPABILITIES.</u> FOCUS is specifically designed to perform the seafloor operations required to interconnect DUMAND's deep–sea array elements. Potential problem areas include:

(a) During cable connection maneuvers, FOCUS must sit on the seafloor or maintain position very close to the bottom. The vehicle will have excellent X–Y position/azimuth control. The array anchor and junction box will be designed with simple handles into which FOCUS (or other ROV's) can insert a prod to achieve a short term holdfast.

(b) As FOCUS touches the seafloor, the tension in the tether cable will go to zero. But the cable will have very low torque, so that such a small load change should have negligible effect toward looping or hockling the cable.

(c) The FOCUS vehicle must maneuver near the base of array strings which stand hundreds of meters tall. FOCUS's X–Y propulsion will allow a 200–m offset from the (normally near–vertical) deep–sea section of the tether. This should give excellent clearance between the two cables.

<u>COSTS</u>. The FOCUS system will reside in Hawaii, with consequent lower mobilization costs. It will operate from the KAIMALINO or the R/V KILA, at a ship cost of about $5000 per day. Direct costs for FOCUS have not been determined, but total costs (including the ship) should not be more than $10,000 per day.

APPENDIX B

CONSULTANTS ON DUMAND DEPLOYMENT.

I. GEORGE A. WILKINS

Mr. Wilkins has worked in Hawaii in undersea technology for more than 20 years, as Senior Scientist with the Naval Ocean Sysems Center, as Chairman of planning task forces with the State, and as an adjunct professor with the Institute of Geophysics and the Physics Department of the University of Hawaii. He retired from Civil Service in January 1987, and immediately joined HIG. His primary areas of expertise are quantum radiometry, fiber–optic communications, stable ocean platforms, deep–ocean technology and "big hole" drilling and tunneling systems.

EDUCATION: BA Physics (1956) and MA Nuclear Physics, University of Oregon.

HONORS AND PROFESSIONAL SOCIETIES.

(1) Elected to Phi Beta Kappa as Junior.
(2) Member of Sigma Xi.
(3) Honored by Hawaii Senate and House resolutions in 1974 for work as Chairman of the "HAWAII AND THE SEA" task force.
(4) Nominated in 1975 as Hawaii Federal Employee of the Year.
(5) Federal Meritorious Civilian Service Award (1977)
(6) Retired from Civil Service as a GS–15 Scientist.

TEACHING EXPERIENCE:

(1) Taught three summers at University of Michigan (1964/67): "Advanced Optical Radiometry".
(2) Taught in "Cities In The Sea" class at Univ. of Hawaii.
(3) Has presented many seminars to various University and professional groups.

PROFESSIONAL EXPERIENCE:

1959—1967. Designed optical radiometers and deployed them into space to measure earth– and ICBM radiation in wavelengths where the earth's atmosphere is opaque.

1964. Principal Scientist for "Planetary Observation Experiment" aboard the Air–Force/Navy "Manned Orbiting Lab".

1968. Chief scientist and chief writer for the Navy "Deep Ocean Technology" Technical Development Plan.

1970 — 1972. Member of 6–man Hawaii State Executive Board which designed, built and tested a "Floating City" concept; a very large waterplane–stabilized structure.

1971 — Present. Chairman of the SEAGRANT Research Advisory Council for the University of Hawaii.

1974. Chairman of the Governor's "Hawaii And The Sea" Task Force, which evaluated Hawaii's problems and potentials as an oceanic state.

1977 — 1984. Chairman of Governor's Marine Affairs Advisory Council. This group was composed of leaders in Hawaiian government, industry and academia. It advised Hawaii's governor on new marine affairs initiatives, as well as on technical, political, and economic ramifications.

1983. Designed the armored coax cable used with Woods Hole's deep-sea search system ARGO to find the TITANIC in 1985. This cable is now the National Oceanographic Laboratory (UNOLS) standard tether for deepsea systems.

1985. Designed the neutrally buoyant electro-mechanical cable used to tether Woods Hole's JASON JR remote vehicle when it swam inside the TITANIC in 1986.

1987. Designed and built an electro-optical tether cable to convert the new JASON vehicle to fiber optic telemetry.

1988. Designed and built an electro-optic tether cable which converted ARGO to fiber optic telemetry. This system was successfully used in August 1988 during a search for a Roman fleet which sank off Naples some 2000 years ago.

PRESENT RESPONSIBILITIES AT HIG:

(1) Incorporating fiber-optic telemetry into future deep-sea experiments.

(2) Developing and demonstrating concepts for slant- and curved drilling under our shorelines.

(3) Deployment and telemetry support of DUMAND—a giant neutrino telescope which will be assembled on the deep-sea floor off the Kona coast of Hawaii.

(4) Working member of Presidential Science Advisor's panel to develop concepts and approachs for large, stable, floating ocean bases (about 100 m X 1500 m).

SELECTED PUBLICATIONS

"A Technical Development Plan For Deep Ocean Technology", (with other anonymous co-authors), submitted to Chief of Naval Material, March, 1968.

"Floating Marine Community", (with co-authors), Research Report of the Department of Architecture, University of Hawaii, 1972.

Hawaii And The Sea—1974". Was Task Force Chairman and Editor of this long range planning document, which was submitted to and accepted by the Governor of Hawaii, January, 1974.

"Performance Characteristics Of KEVLAR-49 Tension Members", Proceedings Of International Conference On Composite Materials, Geneva, Switzerland, April 7-11, and Boston, Massachusetts, April 14-18, 1975.

"Production And Performance Of A KEVLAR-Armored Deep Sea Cable", (with co- authors), Proceedings of MTS-IEEE Ocean '76 Symposium, San Diego, Sep. 1976.

"Proceedings Of The 1978 DUMAND Summer Workshop, Volume III: Oceanographic And Ocean Engineering Studies, Scripps Institution, University of California, La Jolla, 21 August to 1 September, 1978 (Co-Chairman and Editor).

"Applications Of New Technologies To Interisland Power Cables For Hawaii", Proc. Of The Pacific Congress On Marine Technology, Honolulu, April, 1984.

"Fiber-Optic Telemetry In Ocean Cable Systems", Chapter in 2nd edition of Handbook Of Oceanographic Winch, Wire And Cable Technology, Alan H. Driscoll, Ed., (to be published by University of Rhode Island).

"Tradeoffs In Optimization Of Deep-sea Electro-Optical Systems", Trans. of ASME, J. Offshore Mechanics & Arctic Engineering, May, 1988 (pp 124/130).

II. FRED NOEL SPIESS

BIRTH:	*Oakland, California, 25 December 1919 Social Security: 075-28-2683*
EDUCATION:	*A.B., 1941, University of California, Berkeley Physics* *M.S., 1946, Harvard University, Communications Engineering* *Ph.D., 1951, University of California, Berkeley, Physics*
PROFESSIONAL EXPERIENCE:	*1941-1946, U. S. Navy, Submarine Service* *1951-1952, Nuclear Engineer, Knolls Atomic Power Lab, Schenectady, NY* *1952-1957, Associate Research Physicist, Marine Physical Laboratory (MPL), Scripps Institution of Oceanography (SIO), La Jolla, University of California (UC)* *1957-1961, Research Geophysicist, MPL* *1958-1980, Director of MPL* *1961-1963, Acting Director of SIO* *1961-____, Professor of Oceanography, SIO* *1964-1965, Director of SIO* *1965-1980, Associate Director of SIO* *1974-1975, Liaison Scientist, Office of Naval Research, London* *1980-1988, Director, Institute of Marine Resources, University of California, statewide*
PROFESSIONAL SOCIETIES:	*Acoustical Society of America (Fellow, 1961)* *American Geophysical Union (Fellow, 1983)* *American Association for the Advancement of Science* *Marine Technology Society (Fellow, 1985)* *Maritime Historical Society* *Society for Industrial Archaeology* *Underwater Mining Institute*
AWARDS & HONORS:	*Phi Beta Kappa, 1941; Sigma Xi, 1949* *L. Y. Spear Prize (USN Submarine School), 1941* *Silver Star (USN Combat) & Bronze Star (USN Combat), 1943 and 1945* *John Price Wetherill Medal (Franklin Institute), 1965 for design and realization of FLIP research vessel* *Distinguished Achievement Award (Marine Technology Society), 1971 for work in underwater acoustics and ocean technology* *Robert Dexter Conrad Award (Navy), 1974 for leadership in undersea research* *Newcomb Cleveland Prize (Amer. Assn. Advancement Sci.), 1980 for outstanding paper published in science (paper on geophysical experiments and hydrothermal phenomena at East Pacific Rise crest)* *Maurice Ewing Medal (American Geophysical Union/U.S. Navy), 1983 for contributions to marine geophysics* *National Academy of Engineering, elected, 1985* *Pioneers of Underwater Acoustics Medal (Acoustical Society of American), 1985* *Marine Technology Society/Lockheed Award for Ocean Science and Engineering, 1985*
RESEARCH ACTIVITIES:	*Underwater Acoustics (sound propagation, underwater communication, sonar system concepts); Ocean Technology (stable floating platforms, acoustic navigation, deeply towed vehicles and instruments); Marine Geophysics and Geodesy (studies of the fine-scale nature of the deep-sea floor (rise crests, trenches, transform faults, manganese nodule areas, sediment erosion and deposition, etc.); Chief Scientist for 2 or 3 oceanographic expeditions per year; Over 100 publications.*

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(PAPERS RELEVANT TO DUMAND)

1. 1964 Search for the THRESHER.Science, 145,(3630),349–355.

2 Apparatus for retrieving oceanographic cable from the sea bottom. U.S. Patent 3,608,947.

3. Fine Scale Mapping near the deep sea floor. Oceans '76, 2nd Ann. Combined Conf. MTS–IEEE, Washington, Sept 1976.

4. Unconventional vehicles for Ocean research. Scinece, Technology, and the Modern navy, 30th Anniv. 1946–1976, ONR, E.I.Sulkovitz, ed. ONR–37, pp.528–346

5. Fine–grained deep ocean survey techniques. Proc. 10th Ann. Offshore Tech. Conf., Houston, TX, May 1977, OTC 3135, pp715–724 (with C.C.Loewenstein and D.E.Boegeman.)

6. Sea–floor referenced positioning: needs and opportunitites, Panel on Oceam Bottom Positioning, Committe on Geodesy, NRC, Natl Acad. Press, Washington, D.C. 53 pp. 1983

7. Seafloor research and ocean technology. Marine Technology Society Jour. 21(2), pp 5–17, 1987

III. VICTOR C. ANDERSON

Dr. Anderson has been associated with the Marine Physical Laboratory of the Scripps Institution of Oceanography, University of California at San Diego, since 1947. He was appointed to the faculty in 1968 and currently is deputy director of the Marine Physical Laboratory and Professor of Applied Physics in the department of Electrical Engineering and Computer Science at UCSD.

His scientific research has been in the field of underwater acoustics with a primary emphasis on background noise in the ocean. Ocean Engineering is another area of research in which he has been involved. He has had a long-term interest in cable-tethered deep sea instrumentation, with the most recent effort being the development of a new seafloor work vehicle RUM III.

He has served as Coordinator for the interdepartmental Applied Ocean Science Curriculum program at UCSD, was department chair in the Electrical Engineering and Computer Science department at UCSD, and was chairman of the Oceans 85 conference.

EDUCATION:

A.B., University of Redlands, 1943
Ph.D., University of California at Los Angeles, 1953
Post-doctoral Fellowship, Harvard University, 1954

HONOR SOCIETIES:

Department of the Navy's Distinguished Public Service Award, 1970
Admiral Charles D. Martell Technical Excellence Award, 1986
Sr. member, IEEE
Fellow, Acoustical Society of America
Member, Marine Technology Society

RESEARCH AND/OR PROFESSIONAL EXPERIENCE:

1943-46 University of California Manhattan Project, Berkeley, California, Oak Ridge, Tennessee, and Los Alamos, New Mexico
1946-47 Teaching Assistant, University of California, Los Angeles
1947-54 Research Assistant, Marine Physical Laboratory
1954-55 Post-doctoral Fellowship, Acoustics Research Laboratory, Harvard University
1955-68 Research Physicist, Marine Physical Laboratory
1968-present Research Physicist and Deputy Director, Marine Physical Laboratory
Professor of Applied Physics and Information Sciences, University of California, San Diego

90 Journal Publications
21 Technical Memorandums
6 Patents

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V.C. Anderson and R.C. Horn, "Tensor arm manipulator design," ASME, New York, NY,, Vol. 67-DE-57 (1967).

V.C. Anderson, D.K. Gibson, and O.H. Kirsten, "RUM II - Remote underwater manipulator (A Progress Report)," Mar. Technol. Soc. J., Vol. 1 (1970).

V.C. Anderson and D.K. Gibson, "Sea-floor soil mechanics and trafficability measurements with the tracked vehicle "RUM"," in *Deep-Sea Sediments, Physical and Mechanical Properties*, Eds. A.L. Inderbitzen, (Plenum Press, New York, 1974), pp. 347-366.

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APPENDIX C

ELECTRO–OPTICAL CABLES TO SUPPORT THE FIXED DUMAND ARRAY

Both the shore cable and the riser cables in the DUMAND array will be electro–optical (E–O). That is, both of these cables will pass electrical power from shore toward the array sensor modules, and both will contain optical fibers to telemeter event data back to shore.

The E–O Shore Cable is shown in Fig. 1a (p. 15). The basic design of this cable was conceived during a DUMAND signal processing workshop in early 1980 (Ref. 1). Since then, its performance and reliability have been steadily improved under a Navy–sponsored development effort (Refs. 2–4).

The cable is extremely small, light and easy to handle. At the same time, it has a high specific gravity (to aid it in sitting hard on a current–swept bottom), and is heavily armored. A comparable commercial transoceanic optical cable will have a diameter of at least 38 mm (versus 9.5 mm) for the same degree of external armoring.

A 1983 prototype of this cable structure was pressure tested to an equivalent depth of 6000m. The cable was then deployed to an ocean depth of 2000m where it operated with no electrical or optical degradation. The 1983 cable also operated with a single conductor and seawater return. That technique is well established for commercial power cables at levels as high as 250 kilovolts, 1000 amperes and 250 megawatts power delivery (Ref. 5).

The general structure of the DUMAND E–O shore cable is derived from the design of an oil–well logging cable. The cable's armor package and the overall diameter of the dielectric are identical to the same structures in The Rochester Corporation's 1H375 oil–well logging cable. As in that cable, the inner armor layer is bedded down into the dielectric during manufacture to stabilize the cable's load/strain performance. Overall cable diameter is 9.5 mm (0.375 in).

Only the electrical conductor is changed in the DUMAND version of the cable. Instead of a single–conductor structure of stranded copper wires, the DUMAND shore cable contains an E–O core. As shown in Figure (C–1a), this core consists of:

(a) Ten single–mode optical fibers in a 1.40–mm–diameter void–filled cavity.

(b) A stainless steel tube—formed from a tape, filled with fibers and void filler, laser welded, then drawn down to an O.D. of 1.65 mm with a 3/4–hard temper. The manufacturer of this E–O core, Armor Tech Division of K–Tube Inc., 10581

Roselle St., San Diego, California 92121, has formed similar tubes into continuous hermetic lengths of more than 20 km, and has successfully placed as many as 20 optical fibers inside multi–kilometer void–filled lengths of this tube.

(c) A thin plastic jacket to serve as a bedding (protective) layer under the electrical conductor wires.

(d) A helix of copper wires to tune the cable's electrical resistance so that—for a given insulation O.D.—the cable will have the largest possible power–length transmission product.

The E–O Riser Cable is shown in Fig. 1b (p. 15). Two of these cables will serve as the vertical ladder rails of one DUMAND array string. The photomultiplier sensors of the array will be clamped between the rails. A cable breakout of (1 each) electrical and optical conductors will be made at each sensor position, and the breakouts will be alternated between the two cables.

It was this need for periodic breakouts – at least 14 per cable – that dominated the design of the DUMAND riser cables. This required that the E–O conductors be readily available through the cable jacket and, in turn, required that the cable's dedicated loadbearing structure be inside the conductor annulus.

(a) The loadbearing section consists of a composite of KEVLAR–49 filaments (60%) in a matrix of thermosetting urethane or thermocuring epoxy.

(b) An elastomer (polypropylene or ethylene/propylene copolymer) which is extruded with grooves fo the cables conductors. The diameter and groove depth of this structure will be dictated by requirements on the electrical conductor.

(c) Sixteen insulated electrical conductors, arranged four to a groove. The design of these units is tuned so that, for given power and length requirements, the insulation diameter will be a minimum. This parameter then determines the minimum and maximum diameters of the grooves. Residual spaces in each groove are filled with a standard void–filling compound.

(d) Sixteen optical fibers are stored (with void fillers) in two of the cable grooves.

(e) The electrical conductors, optical fibers and void filler are packed into the cable grooves in a single (conventional) operation. At the same time an adhesive polyester tape is wound tightly around the structure to contain and seal the void filler.

(f) Finally, a jacket is extruded over the tape to complete the cable. Polyurethane will probably be used here, because of its toughness, bondability and high coefficient of friction. The last two parameters are important in ensuring that the sensors can be permanently clamped to the riser cables.

Manufacturing setup and running costs will probably dominate over material costs for the array cables. Therefore, we expect that these cables will be manufactured in long and continuous lengths, then cut to match DUMAND's final choice (<500 m) for the height of the array.

Cable Performances. The dimensions and performance levels expected for these two DUMAND cables are summarized below. These values—and their supporting designs — are preliminary, and are almost certain to undergo second–order changes before purchase contracts are let. We expect, however, that the general geometry of these cables (Fig. C–1) will remain the same.

Parameter Cable		Shore Cable	Array
Power Delivery (W) Per Conductor		5000	12
Effective Conductor Length (km)		40	0.5
Number of Electrical Conductors		16	1
Number of Optical Fibers		10	16
Cable Diameter (mm)		9.5	19.5
Cable Strength (kgf)		6,600	2450
Cable Weight (kgf/km)	In Air	357	344
In Deep Seawater		292	33.7
Total Wt for 40 km (kgf)		14300	——
Cable Specific Gravity		5.5	1.15
Cable Strength/Weight Ratio (Kg/km)			
In Air		18.5	7.12
In Deep–sea Water		22.6	72.7

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