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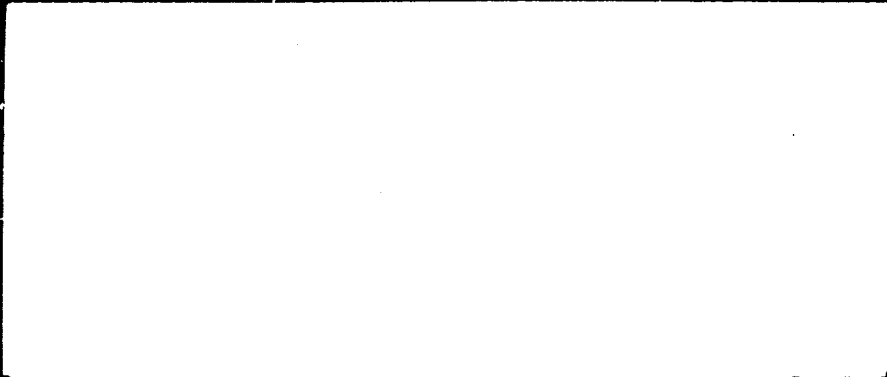
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TECHNICAL DIAGNOSTIC ANALYSIS
OF LRAPP TEST BED PROGRAM
FAILURE (U)

2 August 1971

Sponsored by: Office of Naval Research

Contract No. N00014-71-C-0329

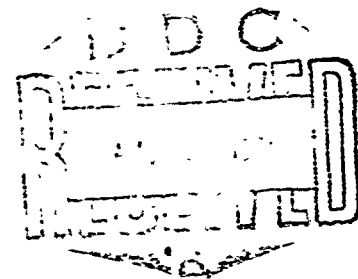
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1. SYNOPSIS

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1. SYNOPSIS

(U) B-K Dynamics, Inc. (BKD) was tasked by ONR Code 469 on 1 March 1971 to assist Code 469 in conducting the LRAPP TEST BED Review Analysis and to prepare a diagnostic report. The requirements for the LRAPP (Long Range Acoustic Propagation Project) were established by TDP R24-08 dated 30 May 1969. The project's initial effort to implement acoustic measurements using a major suspended array was the SEA SPIDER Program. The implantment of SEA SPIDER north of the Hawaiian Islands in 1969 was unsuccessful. The LRAPP TEST BED Program grew directly out of the SEA SPIDER Program through a series of meetings held early in 1970 between ONR Code 102-OS, ONR Code 480, CNM, and OPNAV. The objectives and implementation of the SEA SPIDER Program were reviewed and a plan initiated to design, fabricate, test and install another suspended mid-water array, this time in the Atlantic rather than in the Pacific. The TEST BED Program was assigned by ONR Code 102-OS, through ONR Code 469 to ONR Code 480 for overall management. ONR Code 480 selected the Naval Underwater Sound Center (NUSC) at New London, Connecticut, to conduct the engineering, fabrication and implantment of the LRAPP TEST BED off Bermuda.

(U) As part of the diagnostic analysis conducted by BKD, an engineering review of the TEST BED Program was made which included the design, development, and implantment of each of the components, including the experienced electrical failures. The purpose of this engineering review was to determine from an engineering point of view: 1) those elements of the program that proved to be good to excellent and should be used for future implantments, 2) those elements that were deemed adequate for this program and may or may not be recommended for future programs, and 3) those elements that proved inadequate, may have contributed to the failure, and thus must be corrected in any future operations.

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(U) The hydromechanical engineering was excellent. The test programs based on the schedule limitations were properly executed and the overall construction of the Array was adequate. The fuse protection had extensive pressure testing but had not had sufficient experimentation to guarantee zero hosing over long periods of deep sea exposure. The coaxial coupling of external instruments and its penetration into the electronics packages needs further analysis to insure long life in the ocean environment. Problems were experienced in attaching the larger 16-inch diameter glass ball floats to the cable; the smaller floats were attached without any trouble.

(U) The acoustic and engineering packages along with the line drivers were well engineered but the schedule forced acceptance of some components that did not meet the planned reliability. For future implantments, the command and control units in all the packages should be modified by replacement of the ceramic filters and the high current relays.

(U) The systems testing was examined as a separate element of the overall TEST BED Program because of its extreme importance in the development of a highly reliable electronic system. Insufficient time was available for total systems testing and, based on the instrumentation log, the Array was not in proper electrical condition for implantation, if the goal of obtaining 3 - 5 years of data was to be met.

(U) In regard to operations evaluation, the site selection, the implantation plan, the bathymetric surveys, the soil mechanics analyses, and the charts were more than adequate to allow for a favorable implantation. The actual implantment of the Array was carried forward with great dexterity and with surety at every phase. This was largely due to a pre-computed mathematical model that allowed the determination of ship's speed, cable payout, ship's position and cable array configuration at any time during the implantment. The Array was implanted in its

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predetermined form and in approximately its predetermined position which was a successful conclusion to a complex engineering and sea-manship problem.

(U) The cable laying vessel, the NAUBUC was chosen for several reasons, mainly because of its availability, its unique position holding and maneuvering capabilities, and because of the fact that its crew, which had been highly trained on a previously similar program, could be recalled for the LRAPP TEST BED Implantment. The cable laying vessel and its cable laying machinery proved adequate for the deployment task and although there were some disadvantages in the selection of the vessel in regard to sea state response and the limitations for messing and berthing of the crew, the overall selection of the ship was a reasonable choice.

(U) The basic problem with the Array implantment arose not from the preplanning, training, or from the selection of the ship or cable handling equipment, or from the electronics or hydromechanical design of any of the components, but rather from insufficient field tests of the conductor cable. It is strongly felt by BKD that a highly torque balanced, double-armored, coaxial cable which had never been used for such a complex implantment as was planned in the TEST BED Program, should have been carefully tested. The torque-tension characteristics of the cable were not fully understood at the time of implantment and the cable handling procedures necessary to insure smooth implantment of such a complex system involving a double-armored coaxial torque resistant cable had not been fully analyzed.

(U) The LRAPP TEST BED Cable was a cable that had never been used before in a similar array implantment. Its torsional-tensional properties were essentially unknown and it was subjected to repeated cycles of coiling and uncoiling and bending that must have resulted in differential movement of the inner and outer cable wires.

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Until empirical testing of the LRAPP TEST BED cable type can be conducted satisfactorily, and until the LRAPP TEST BED Array can be physically analyzed for failure, no conclusive solution can be found as to why the LRAPP TEST BED cable behaved badly under handling. At most stages of the handling, twisting could not be prevented from occurring in the cable to the extent that these twists developed into hockles and, in some cases, kinks.

(U) During coiling and uncoiling, which involves both a bending and a twisting of the cable, the twist induced by coiling may not be balanced by uncoiling. This residual torque can be passed along the cable by any bending surface or any abrupt interface such as the fleeting knives or the Hold-Off Draw-Back Machine. Although the cable lay well in the cable tank aboard the NAUBUC, upon payment of the actual Array, many problems were encountered in handling the cable. In one case, these problems were absolutely responsible for electrically parting the cable and the cable was cut and respliced at that point. At several other points, although electrical failure did not occur, mechanical distortion of the armored wire did and, although the exact cause of the failure of the LRAPP TEST BED Implantment cannot be concluded at the present time, it is most likely related to the failure mechanically and electrically of the TEST BED cable due to the excess twisting during implantment.

(U) There are several major options that exist in regard to the presently installed LRAPP TEST BED Array. These options vary from abandoning the project and leaving the Array and the SDC cable in place to fabrication of an entire new array and deployment in the same location at the same time that the present Array is retrieved. However, BKD recommends that the Array be retrieved, the SDC cable be left in place for future engineering projects and the Array be examined for its electronic components and cable continuity with the purpose to better

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determine the cause of the LRAPP TEST BED failure and better determine future methods of handling suspended array configurations.

(C) It is recommended that the Array be retrieved through recovery of the offshore grapneling line, the offshore ball anchor, the offshore riser leg and the horizontal leg. Then, using an auxiliary small vessel to maintain tension on the inshore riser leg, the main cable recovery ship will proceed six or eight miles shoreward and grapnel for the SDC cable. The final recovery of the inshore riser leg would be made by pulling the SDC cable aboard the cable ship, lifting the inshore ball anchor with the SDC cable and then bringing aboard the cable ship the inboard riser leg. The key to this very complex retrieval operation depends upon constant tension being maintained upon the cable at all times so that it does not throw itself into loops and kinks.

(U) The purpose of the recovery of the cable is to allow a better understanding of the engineering technology of mid-water array deployment by making a diagnostic analysis of the actual components and their failures in several steps. It is proposed that preliminary examinations and testing be made aboard the cable retrieval ship as the Array is being retrieved, that secondary examination and testing be made on shore in Bermuda prior to packaging and shipping, and that the final complete component analysis be made on the Array and possibly partial sections of the cable in the continental United States at a later date. BKD has examined the characteristics of foreign, national and governmental cable laying and retrieval ships and recommends that the SENTINEL, now based in Bermuda, be used for the retrieval of the LRAPP TEST BED Array, however her tonnage and single screw will allow problems not encountered in a specialized ship such as the NAUBUC.

2. INTRODUCTION

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2. INTRODUCTION

2.1 BKD's Assignment

(U) BKD was tasked by ONR Code 469, on 1 March 1971, to provide technical and managerial support required to assist Code 469 in conducting the LRAPP Project TEST BED Review Analysis and to coordinate the preparation of a Diagnostic Report of the LRAPP TEST BED Failure. In the course of preparing this Diagnostic Report, BKD was to review all available data pertinent to the failure and convene necessary symposia and panel reviews among those groups that participated in the LRAPP TEST BED Implantment in order to better understand the circumstances surrounding the failure itself. Several governmental and private groups associated with the implantment were to provide separate diagnostic reports which BKD was to review and then integrate the results in the final BKD report. Also as part of its review it was anticipated that critical areas would be uncovered that would require additional diagnostic efforts. These critical areas were to be called to the attention of Code 469 so that tasks could be defined and executed to assure completeness of the diagnostic effort.

(U) Specific tasks to which the BKD project was directed were:

1. Review the LRAPP TEST BED design and fabrication in sufficient detail to suggest to Code 469 possible causes of failure.
2. Critique all subordinate reports submitted by selected governmental agencies and private industries tasked by Code 469 to participate in the LRAPP TEST BED Failure Analysis, and integrate pertinent information in the BKD report.
3. Make Cost Review analyses and summarize, Logistics, Procurement, Seamanship, and other pertinent technical management functions.

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4. Make technical evaluations of the Cables, Hydro-mechanical Units, Ground Tackle, Electronics, and Implantation Procedures.
5. Analyze and evaluate the implantment plan together with the basic scheme and associated engineering data developed for the implantment operation.
6. Survey and evaluate candidate ships for the purpose of recovery and/or retrieving the LRAPP TEST BED Array and provide general costing and availability estimations.

2.2 LRAPP Project History

(U) It was decided that the LRAPP TEST BED would be an inline prefabricated and tested array. Every attempt would be made to improve the technology of previous research systems without sacrificing reliability. In keeping with these goals, a set of design criteria were established, a policy of selecting only proven equipment, hardware or techniques was adapted whenever possible under the constraints imposed. Planning included completely assembling the TEST BED Array in New London and to perform a full series of systems tests prior to departure to the implantation site.

(U) ONR Code 102-OS and the Naval Underwater Systems Center mutually agreed upon several constraints based upon cost considerations (Reference 27). They can be summarized as follows:

1. The system was to be installed in the late summer of 1970.
2. Maximum utilization would be made of PACIFIC SEA SPIDER components, both electronic and hydro-mechanical.
3. Design of the system needed to be flexible enough to adapt to one of several implant methods, and one of several types of implant vessels, the latter to be determined by availability.

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4. The design needed to be versatile enough to adapt to any of several geographic locations and to permit later reconfiguration without total retrieval.

(C) It was eventually decided to install the TEST BED Array in the Atlantic, southeast of Bermuda. The Array was installed in December 1970 and some of the objectives were met. It was determined that the calculations that were used to predict the forces involved were correct, and the Array was actually installed in the configuration initially envisioned. However, an electrical failure which occurred five days after implantation has prevented the use of the LRAPP TEST BED for experimental purposes to date.

2.3 Current Status

(C) The LRAPP TEST BED, Figure 1, is a trapezoidal taut cable structure with a horizontal segment suspended 3,800 ft. below the surface and two inclined legs anchored in 14,400 ft. of water (Reference 27). The configuration, as depicted in Figure 1, was achieved by the use of cable, several types of anchors, two 8 ft. diameter syntactic foam buoys, and 1,623 glass ball floats. The horizontal portion of the Array is 3,000 ft. long, and the inclined legs average 14,500 ft. in length. All three units are instrumented as shown in Figure 1, and Table 1. Table 2 lists the major characteristics of the system. The base of the inshore leg is connected electrically to NUSL Tudor Hill, by 42.5 nautical miles of SDC List 1 unarmored cable, 3.76 nautical miles of SDC List 4, single armored cable, and 0.5 nautical miles SDC List 5 double armored shore cable. The interface between the double armored Array cable and the SDC cable is at a line driver 500 ft. inshore from the inshore anchor.

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o = Hydrophone
x = Engineering Sensor
T = Tension
I = Inclination
C = Current
D = Depth
V = Vibration

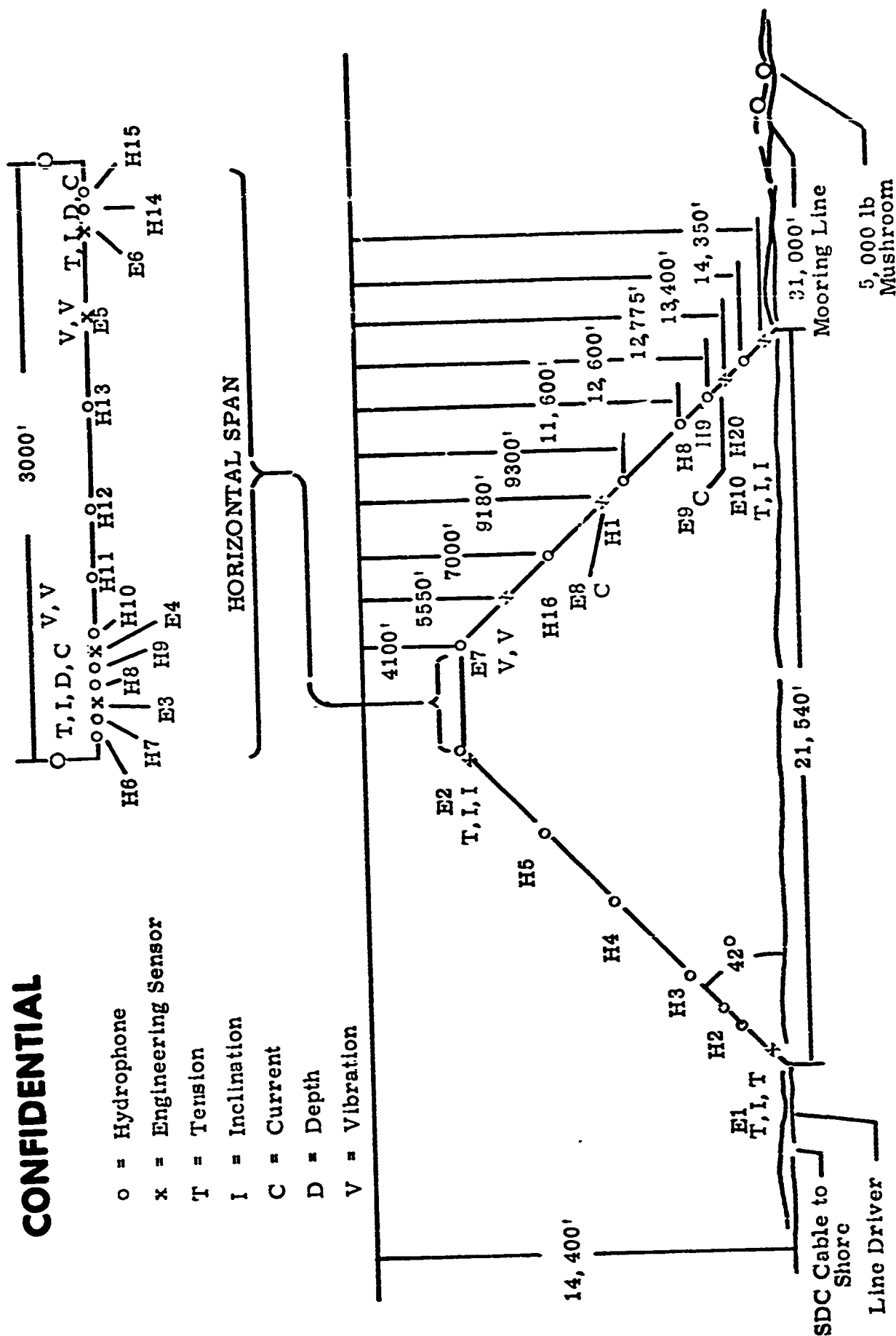


FIGURE 1. LRAPP INTENDED CONFIGURATION AND INSTRUMENTATION

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STATION	LOCATION ALONG CABLE	DEPTH LOCATION (ft)
--	47 NM FROM SHORE	14,400
1E1	500' PAST LINE DRIVER	14,400
2H1	50' ABOVE INSHORE ANCHOR	14,360
3H2	1,500'	13,350
4H3	2,700'	12,600
5H4	4,200'	11,600
6H5	7,640'	9,280
7E2	11,680'	7,000
--	15,380'	4,110
8H6	15,400'	4,100
9H7	50' BEYOND INSHORE BUOY	
10E3	70'	
11H8	87'	
12H9	100'	
13E4	175'	
14H10	265'	
15H11	360'	
16H12	830'	
17H13	1,430'	
18E5	1,830	
19E6	2,330'	
20H14	2,910'	
21H15	2,950'	
--	3,000'	
22E7	13,230' ABOVE OFFSHORE ANCHOR	5,550
23H16	10,060'	7,000
24E8	7,800'	9,180
25H17	7,620'	9,300
26H18	4,200'	11,600
27H19	2,700'	12,600
28E9	2,350'	12,680
29H20	1,500'	13,350
30E10	50'	13,360
--	33,800' FROM INSHORE ANCHOR	13,400

TABLE 1. LOCATION OF TEST BED INSTRUMENTATION

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I. Lengths and Weights in Sea Water

A. Grapnel Line Assembly

1. Length
 - a. Specified - 31,095 ft
 - b. Indicated - 34,000 ft
2. Weight - 10,154 lbs (calculated)

B. Offshore Anchor Assembly

1. Length - $\approx$ 95 ft
2. Weight - 6594 lbs (Measured)

C. Offshore Vertical Leg

1. Length - 15,486 ft (Measured)
2. Weight - 710 lbs (Calculated from measurement of typical components)

D. Offshore and Inshore Buoys

1. Diameter and Height - 8 ft x 4 ft
2. Net Buoyancy - 2,825 lbs (Measured-including Tether Assy and Bellmouth)

E. Horizontal Leg

1. Length - 3000 ft (Measured)
2. Weight - 97 lbs (Calculated from measurement of typical components)

F. Inshore Vertical Leg

1. Length - 15,400 ft (Measured)
2. Weight - 702 lbs (Calculated from measurements of typical components)

G. Inshore Anchor Assembly

1. Length - $\approx$ 50 ft
2. Weight - 4,054 lbs (Measured)

H. Array Cable, Inshore Anchor to Line Driver

1. Length - 502 ft (Measured)
2. Weight - 150 lbs (Including line driver, calculated from measurements of typical components)

I. Unarmored Sea Cable

1. Length - 258,783 ft (Indicated)
2. Weight - 0.317 lb/ft (Specified but previously checked for SD list 1 cable)

TABLE 2. SPECIFICATIONS OF LRAPP ARRAY

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J. Single Armored Sea Cable

1. Length - 5,394 ft (Indicated)
2. Weight - 1.93 lb/ft (Specified)

II. Positions of Significant Components

A. Mushroom Anchor (Ship position at Touchdown)

32° - 00' - 12" N

64° - 05' - 22" W

B. Offshore Anchor (Measured)

32° - 03' - 48" N

64° - 10' - 21" W

C. Inshore Anchor (Estimated)

32° - 06' - 32" N

64° - 14' - 07" W

D. Inshore Splice

32° - 13' - 09" N

64° - 53' - 02" W

III. Depths of Significant Components

A. Mushroom Anchor - 14,700 ft

B. Offshore Anchor - 14,400 ft

C. Inshore Anchor - 14,330 ft

D. Inshore Splice - 60 ft

IV. Array Configuration

A. Depth of Inshore Corner - 3,800 ft

B. Anchor Spacing (Estimated) - 25,600 ft

V. Installation - 2 - 6 December 1970

A. Time from deployment of mushroom anchor to cutting and dropping the cable at the inshore splice position - 92 hrs.

B. Primary NAVAIDS - Decca Hi-Fix

C. Ship Position Control - Automatic

D. Maximum Tension - 15,000 lbs

E. Ship Speeds - 0-2 kts - Controllable in 0.1 kt increments

F. Total Distance Traversed - $\approx$ 300,000 ft

TABLE 2. SPECIFICATIONS OF LRAPP ARRAY (Continued)

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(U) At the time of implantment, the Array cable contained several straightened and reinforced hockles, a splice, and several points at which twists had occurred but were not permitted to become hockles. These known defects in the cable are shown in Figure 2 and listed in Table 3 (Reference 34). Table 3 also shows the nature and cause of the defect and the remedial action taken at the time.

(U) At the completion of implantment, the Array was in operation and could be interrogated out to Station 21. Voltage, current and resistant measurements were normal and the fault finder measurement clearly indicated the end of the Array. Upon retrieval of the cable ends for cable splicing on 10 December 1970, voltage, current, and resistant measurements were again taken with acceptable results. It was noted at that time, however, that a 1,040 Hz interference developed when line voltage exceeded 165 volts, a condition which had previously occurred with a lower amplitude and thought to be caused by grounding, voltage surges and interference from the machinery of the NAUBUC. In addition, frequent dropouts began to occur in the signals, a condition not previously observed (Reference 34).

(U) Splicing the SDC cable to the shore end of the Array required approximately 35 hours, after which time power was again applied to the system. Less than two hours later deterioration of Array performance was noted followed by abnormal voltage, current and resistant readings. Finally, the Array ceased to function at all and the cause was determined to be due to a sea cell short circuit between the center and outer conductors of the Array coaxial cable (Reference 34).

(U) At the present time, the Array is completely nonfunctional electronically, and it is not known whether it is still in the upright position, has collapsed and is lying on the bottom, or has drifted to another location.

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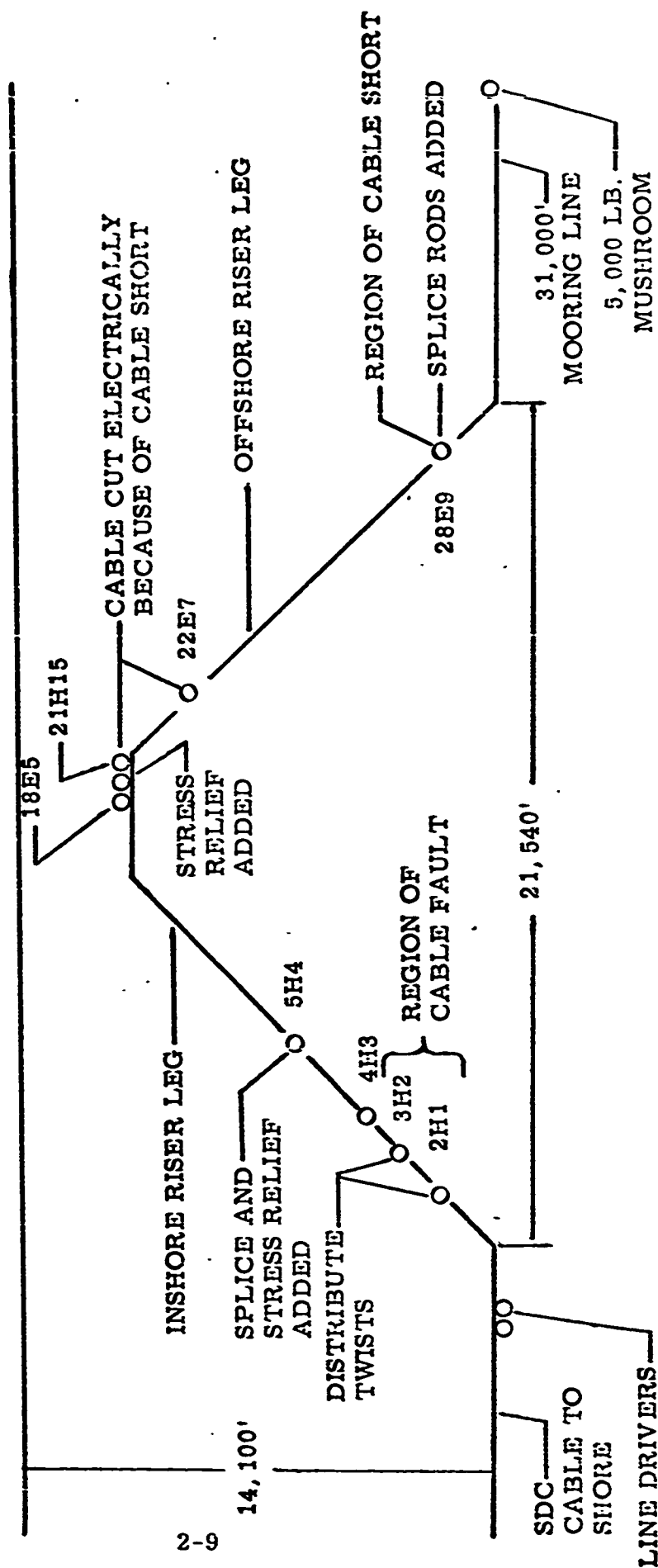


FIGURE 2. LOCATION OF KINKS AND TWISTS

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LOCATION OF DEFECT	NATURE & CAUSE OF DEFECT	REMEDIAL ACTION TAKEN
Below Station 28E4 2178' above outboard anchor*	Outer armor wires of cable distorted due to hockle in cable tank	Cable straightened, armor realigned. 24" PLP splice rods placed over distorted armor.
Outboard of Station 22E7 7500' above outboard anchor	Internal short between coax conductors. Believed to be at hockle near 28E9.	Electrical cable cut; Fault Finder and resistance measurements made to locate short.
Inboard of Station 22E7	Mention of minor cable kink in rough logs. Details not clear.	No action taken
Station 21H15 14,541' above outboard anchor	Cable electrically cut and terminated outboard of 21H15 because of short.	Array terminated by molding. Outboard leg electrically eliminated from array.
Outboard of Station 18E5 770' from outboard end of horizontal span	Armor wires distorted due to hockle in cable tank.	Strain relief added using cable stoppers and wire rope sling.
Outboard of Station 5H4 7700' above inboard anchor	Armor wires severely distorted due to hockle in cable tank.	Cable cut and respliced. Rearmored with 13' PLP splice rods. Wire rope strain relief added.
Outboard of Stations 4H3, 3H12 and 2H11	Twists occurred in cable but did not form into hockles. No distortion of armor noted.	Twists removed from cable by bringing bight out on deck.

* Values taken from NAUBUC's cable payed out indicator.

TABLE 3. SUMMARY OF LRAPP TEST BED ARRAY CABLE DEFECTS

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2.4 Acknowledgements

(U) The following BKD personnel were responsible for the majority of technical analyses, conclusions and recommendations of this report: Messrs. P. Bernard, S. Kulek, R. Hovey, J. Kelly, Dr. T. Chamberlain, G. Baum, I. Kuhn, and R. Cheuvront.

(U) Mr. G. Pickens of NUC, San Diego, California wrote a report for BKD in the hydromechanical element of the Test Bed Array. This report has been included nearly verbatim.

(U) Captain H. Wyeth of General Electric Corp., Philadelphia, Pennsylvania, made contributions to many parts of the report but most specifically in the section that deals with the Test Bed Array Retrieval.

(U) Parts of Dr. M. Balaban's report (Reference 22), from TRW of McLean, Virginia, were reproduced and included directly.

(U) Others that made contributions indirectly to this report, through correspondence and personal interviews, were: Messrs. T. R. Cummings, R. Welsh, R. Martin, A. Morcroft, R. LaPlante, and R. Smith of NUSC, New London, Connecticut; and Mr. A. H. Crane of the Rochester Corporation, Culpeper, Virginia. In addition, NUSC made available to BKD their entire files.

3. ENGINEERING EVALUATION

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3. ENGINEERING EVALUATION

3.1 Introduction

(U) An engineering review of the TEST BED Program - design, development, implantment, electrical failure - was conducted. The purpose of this review was to determine, from an engineering point of view:

1. Those elements of the Program that proved to be good to excellent and should be used for future implantments,
2. Those elements that are deemed adequate for this Program and may or may not be recommended for future programs,
3. Those elements that proved inadequate, are candidate components that may have contributed to the failure and thus must be corrected in any future operations.

The results of this review are as follows.

(U) The transmission cable was properly designed and implanted. The Array cable was extensively engineered and tested, yet insufficient data and experience were available to properly plan and implement the Array implantment. The Array cable handling is the most likely candidate for the cause of the failure.

(U) The hydromechanical engineering was excellent; the basic test programs, based on the schedule limitations, were properly executed; and the overall construction of the Array was adequate. In afterthought, some basic engineering and testing can increase the confidence level of sea protection for future implantments. The fuse protection had extensive pressure testing, but has not had sufficient experimentation to guarantee zero hosing over long periods of deep sea exposure. The coaxial coupling of external instruments and its penetration into the electronics packages

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needs further analysis to insure long life in the ocean environment. The only mechanical problem seems to be the 16 inch diameter glass ball floats and the technique of attaching them to the Array cable. For future implantment, the buoyancy of the Array might be achieved by some other technique.

(U) The acoustic and engineering packages along with the line drivers were well engineered but the schedule forced the acceptance of components that did not meet the planned reliability. In addition, the delivery dates of the voltage controlled oscillators that were experienced caused a major delay in the Array assembly. For future implantments, the command and control units in all the packages should be modified by replacement of the ceramic filters and the high current relays.

(U) The systems testing was examined as a separate element of the overall TEST BED Program because of its extreme importance in the development of a highly reliable electronic system. The conclusion that insufficient time was available to conduct total systems test, must be drawn based on the instrumentation log. The Array was not in proper electrical condition for implantment if the goal of obtaining 2 to 3 years of data was to be met.

3.2 Systems Testing

(U) This section briefly outlines the system and component testing that was performed throughout the design, fabrication and preparation for deployment of the TEST BED Array. The NUSL, in addition to normal acceptance tests, requested tests on critical components. Tests performed by individual manufacturers or suppliers of commercial components were not analyzed, with the exception of those specifically requested by NUSC in addition to normal acceptance tests.

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3.2.1 Introduction

(U) During fabrication of the TEST BED Array at DeBell & Richardson, Inc., each of the 32 electronic/instrument packages was given an operational test as it was attached to the Array. The results of these tests are recorded in the Atlantic Test Bed Record (Reference 21), which was maintained by NUSC. In addition, the overall performance of the assembled system was checked as each unit was attached. The Array attached to the SDC was evaluated at the pier in St. Georges, Bermuda. A compartment on a crane barge at St. Georges' pier provided below deck working and storage for electronic equipment. NAUBUC, with the SDC in the cable tank, was tied outboard of the crane barge. A section of coaxial cable was used to connect the outer end of the SDC cable to the electronics system. This arrangement provided a test method for evaluating the entire TEST BED Array and transmission system. The equipment was later transferred to the NAUBUC for use during implantment.

(U) Although extensive checking of individual packages was performed in the development of the Array, the basic measurements as they were performed at the Bermuda site and on the ship, were not adequate from a quality control point of view. Both time and money constraints resulted in insufficient test data and inadequate engineering analysis of troubles that were experienced in the Array prior to implantment.

(U) In reviewing the instrument log (Reference 37) starting with system test at Bermuda, several electrical problems were experienced. A few of the most significant troubles are reviewed here.

(U) On 18 November the Array was plagued by excessive cable noise (Decca Hi Fix transmission) and intermittent spikes in

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both power supplies. The power supplies were modified (resistor-capacitor filter) to correct for the spikes.

(U) The first appearance of noise (approximately 1000 Hz) that intermittently appeared was on 20 November. This trouble was never located and corrected and was a source of trouble throughout the implantment.

(U) While loading the Array on the NAUBUC, a short circuit, versus a low resistance reading from shield to ground, in the coaxial cable was experienced. This occurred at 0915 on the 24th of November, and at 1930 on the same day suddenly the short cleared itself and the actual fault was never located.

(C) At 0605 on 3 December, while deploying the Array, package 22E7 was about to be deployed, a short in the Array was experienced. This proved to be a direct short circuit (no sea cell) which could not be fuse cleared, and caused the Array to be electrically decoupled at packages 22E7 and 21H15 so that the remainder of the Array could function.

(U) On the same day, at 1435, much difficulty in controlling the line driver was experienced, this was also a recurring trouble. The instrumentation engineer decided to place the line drivers in the by-pass configuration until after the shore connection was made.

(C) Finally, on the 10th of December the sea cell short that terminated operations was experienced at 1750. This center conductor to outer conductor short was measured to be approximately 43 nautical miles out from the seashore splice, or 46 nautical miles from the shore station. This was later confirmed by a Western Electric measurement.

(U) In summary, the Array was not in good electrical condition at the time of implantment.

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3.2.2 Cables

(U) The Array cable was mechanically tested in two ways at NUSC (Reference 27): The first test measured the cable's ability to sustain the dynamic load of a free-falling weight. A 6,000 lb. anchor was attached to the mid-point of a 100' length of cable. The weight was then suspended over the edge of a pier by a crane and the cable ends were tied down at the pier in such a manner that free fall of the anchor was possible to a depth of 36' in the water. Dynamometers were used to record the tension in the cable. The crane lifted the anchor to heights up to 30'. Maximum dynamic tensions of 19,500 lbs. were achieved this way with no electrical or mechanical damage sustained.

(U) In testing the electrical characteristics of the Array cable, the leading end of the first cable segment was connected to the line driver, the assembly was tested electrically in a fresh water trough, and then was unreeled out of the plant and into an annular tank whose inner and outer diameters are 6 ft. and 20 ft., respectively. The remaining cable on the first reel was then successively unreeled, led out of the plant and coiled into the tank.

(U) The cable transfer was stopped as soon as all the cable was unreeled. The end of the first cable segment and the beginning of the next segment were now connected to the first instrument package. The electrical connections were encapsulated in a mold and the assembly was tested electrically in a water trough. The instrument packages themselves had been pressure-tested previously. Units on the horizontal leg were tested for pressures corresponding to 11,000' depth while those on the inclined legs were tested for pressures corresponding to 16,000' depth. Finally, all electrical cans were tested for leakage at 14 psi internal pressure. All splices were X-rayed for electrical continuity, voids in the molds and distortions. The

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transfer into the tank was now resumed until the second cable segment was entirely unreeled, and so on. Eventually, all the instrument cages were connected, the assemblies tested electrically, and the entire Array formed and coiled into the tank.

(U) The tank was filled with fresh water on (approximately) 5 different occasions in order to test the instrumentation electrically. Although salt water was not used, the electrical conductivity of the water was high nevertheless. A water leak of the pressure housing would change the resistance across a typical instrument package from 5 megohms down to as low as 20 ohms.

(U) In the assembly building each instrument cage was refitted. All the D. G. O'Brien connectors were overmolded and both a fuse and T-splice were added to every line. Each refitted package was now tested in salt water.

(U) A plywood rim was built around the flatbed in order that the instrument packages might be flooded again for electrical integrity. The truckbed was flooded once with salt water, a second time with fresh water and a third time again with salt water.

(U) After shipment to Bermuda and in loading the Array onto the ship the test procedure was, as each instrument package approached the middle of the deck, the cable was stoppered off near the stern with a preformed line grip. With the drum and fleeting knives providing the driving force and the DOHB exerting an additional back-up traction, the cable was tensioned at each package to values ranging from 14,000 lbs. to 20,500 lbs.

(U) Each package was dipped in a salt water trough and tested electrically after tension was released - in some cases the testing took place before tension was applied while in other cases the test was administered both before and after application of tension - there is no record of the procedures followed in each case.

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3.2.3 Hydromechanical Systems

3.2.3.1 Flotation Units

(U) The Ellipsoidal Float material (Reference 31) was tested extensively to determine exactly how much water absorption would be experienced at the anticipated depths of the floats. The test procedures (Reference 27) were the best that could have been taken and the results indicated that the floats would perform as desired.

(U) Ten 16-inch diameter and ten 10-inch diameter spheres were checked in fresh water for buoyancy and a mean buoyancy value in salt water was calculated for use in determining the number and spacing of elements on the Array. An eyeball test of the most stable attachment configuration for the 16-inch balls led to the use of spherical plastic covers instead of the originally supplied "streamline" covers. A random sample of fifty 10-inch diameter spheres was pressure tested to 7,500 psi for several cycles. No failures occurred.

3.2.3.2 Sensor Protection

3.2.3.2.1 Pressure Housings

(U) Twenty-two pressure housings left over from the PACIFIC SEA SPIDER Program were refurbished to house the hydrophone electronics and the two line driver units. Fourteen new housings were designed and manufactured for engineering sensors. Every pressure housing was visually inspected after manufacture, assembled without electronics enclosed, pressurized with helium to approximately one psi, and given a two hour vacuum test at 24 to 26 inches of mercury in a belljar in accordance with pre-established leak test specifications. The pressure housings were then loaded with the appropriate sensor electronics including a leak detector circuit, sealed and electrically tested. Every housing was then

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hydrostatically tested for 24 hours at 5000 or 8000 psi depending on its location in the Array.

3. 2. 3. 2. 2 Support Cages

(U) The first cage assembled was checked for fit through NAUBUC's machinery and for fit of all internal components and wiring. Several modifications were made to the structural parts as a result. One cage without active components was used throughout crew training which involved many cycles through the machinery and overboard under tension. An attempt to pull this unit to destruction was not successful because prior to failure the cable terminations slipped. Before deployment every cage assembly and preform dynamometer was tested by applying loads ranging from 9000 to 22000 lbs. tension.

3. 2. 3. 2. 3 Moldings

(U) Every electrical splice made external to a pressure housing was molded in polyethylene so as to make the jacket material continuous from the Array cable to the interconnecting cables. A sample of splices of each type was tested under hydrostatic pressure for periods ranging from twenty-four to seventy-two hours. Some of these tests included an open end of cable exposed to as much as 8000 psi to test the water blocking ability of the splices. This test was particularly made on the T-splices of the type used to connect each package to the Array. Every molding in the Array was visually inspected, dipped in a water tank and tested electrically and X-rayed in several views but lack of time and facilities prevented pressure testing every one.

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3.2.3.2.4 Interconnecting Cable Bulkhead Terminations

(U) In addition to the manufacturers' tests, each bulkhead termination was installed in its respective housing and pressure tested. No failure of the penetrator portion of the termination occurred but the failure of several moldings was detected by this test. Several more moldings failed under subsequent testing in water under no hydrostatic pressure. Bond failure in the molded portion was found to be the cause. Subsequently, overmoldings were made, tested and found satisfactory, thus correcting this problem.

3.2.3.2.5 Fuses

(U) Samples of the fuses used inside of each pressure housing and in the T-splices were pressure tested, tested under heat up to 150⁰ F for periods of eight hours for several cycles and also tested for current overload resistance after being molded.

3.2.4 Sensors

3.2.4.1 Acoustical

(U) All hydrophones used in TEST BED Array were tested at the Naval Underwater Sound Reference Station, Orlando, Florida, for receiving sensitivity as a function of pressure and temperature. All of the units tested met the design specifications.

(U) Beam patterns as a function of frequency were recorded for one spare hydrophone (having similar characteristics to those act used in the Array). Tests were conducted on the bare hydrophone, on the hydrophone in a supporting cage and on the hydrophone in a cage with one sixteen inch buoyancy sphere attached. No degradation of performance was noted due to the cage and sphere. This

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testing was performed at the Center's Dodge Pond Field Station.

(U) Extensive vibrational testing was carried out in air and in water to determine the low frequency (5 Hz to 1 kHz) motional response of the hydrophones, and frequencies of maximum radiated noise from the cage structure. Both axial and transverse motions were included and several types of vibration isolation mounts were investigated. As a result, two isolation mounts were selected for inclusion in the TEST BED Array, at two hydrophone stations (9H7 and 13H9). A 1/8 inch non-isolation "Fabrica" gasket was found to be the quietest type of mounting for this Array and was used at all remaining stations.

(U) Hydrophone electronic tests were conducted at the NUSC Laboratory prior to Array assembly at DeBell & Richardson, Inc. These tests involved measuring the system noise of the hydrophone package and the shape of the pre-emphasis curves. Because this is an FM system a discriminator is required at the shore end. The tests were conducted with the discriminator amplifier set so that a calibration signal of -69 db//1V at 800 Hz produced a level of $\div 17$ db at the output of the discriminator. The reason for this particular setting was to provide maximum dynamic range without causing an overload condition. The pre-emphasis curve was also calibrated to show terminal sensitivity for an acoustic pressure wave of 1 bar at the hydrophone.

3.2.4.2 Engineering

(U) Each of the engineering sensors was given a thorough mechanical and electrical checkout and a bench calibration when received from the manufacturer. The only exception to this procedure was the tensiometers which were installed in their pressure housings and calibrated at the Oceanic Industries factory with a Center observer

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present. All sensors were finally calibrated in conjunction with their associated electronics during engineering sensor bench tests. The tensiometers were calibrated in their cages under static load conditions at AOK Testing Division of AKO Corporation, Enfield, Connecticut.

(U) After each engineering package had been fully assembled, it was checked for proper operation and calibrated.

(U) The standard T-connection of each package into the Array cable has a characteristic impedance of 50 ohms. One end of the cable automatically terminates the other end with the engineering package appearing as a relatively high impedance (1. K ohm) at the junction to prevent appreciable mismatch. A 1. K value was chosen for the hydrophone packages as a compromise between low cable loading loss and high coupling loss for telemetry signals from the package to the Array cable. The package "sees" a 25 ohm load presented by the two cable ends, so bench tests used a 25 ohm resistor in series with the low impedance power supply. Carrier signals were capacitively coupled to test equipment for the measurement of both carrier levels and frequencies.

(U) The command control signals were coupled to check power on-off control. The address level was set for 0.5V peak to peak at the package input and the latching power relay should toggle at the end of each address signal. The 28 volt line voltage was checked for variation (less than .1 volt) as the load was switched on and off. While these tests were being conducted some of the protection fuses were blown due to the charge or discharge of the storage capacitor used in conjunction with the command and control relays. Also during the overmolding of the bulkhead terminators, hot air was used in drying out the polyurethylene, causing heat to flow through the copper conductors which destroyed the 1/4 amp fuses.

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(U) Original plans called for VCO carrier level adjustments to be made by using the built-in level potentiometer in the VCO module. However, when this adjustment was used to reduce carrier level more than approximately 3 db below maximum, zero crossing transients appeared on the carrier signal. These transients would produce interference in the higher frequency telemetry bands, so the VCO modules were left at maximum output which eliminated the transient problem. Carrier level adjustments were made by selecting summation resistor values. Also, an input resistor was increased from its 2.2K nominal value for increased amplifier gain of up to 6 db for the most distant packages. The individual VCO level potentiometers were then used for the fine tuning adjustment.

(U) The packages which provide built-in VCO calibration levels required trimming of the calibration divider resistors as detailed on USL Dwg. No. E-01318-C16. A digital voltmeter was used to monitor voltage with respect to shield, and trimming resistors were installed as required to develop $+ 5. V \pm 20MV$ for the first 30 second calibration period after package power is applied.

(U) Three sensor types (tension, inclination, and water current) require a dropping resistor to develop $+ 4V \pm 20MV$ from the 28 volt supply. Appropriate resistors were chosen and mounted as on the calibrator board.

(U) Each sensor was operated through its range, or the VCO input voltage was externally varied to simulate the sensor operation while monitoring the related VCO frequency. A wave analyzer and frequency counter permitted both carrier level and frequency to be accurately recorded for this calibration reference. Also the DC line current was recorded. All boards and parts were checked visually for loose parts, etc., before installing the electronics portion inside the pressure cans.

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3.2.5 Positioning Systems

(C) The TEST BED was implanted in the Atlantic Ocean approximately 30 miles northeast of Bermuda. The TEST BED objectives were to support oceanographic, acoustic and engineering measurements and thus acquire basic correlated data on the ocean environment. The success of the TEST BED as a measurement device was dependent on accurate knowledge of position and then accurate establishment of the actual placement on the ocean floor.

3.2.5.1 Decca Hi-Fix

(U) The primary navigation system used to establish the accurate positioning of the Array was a pair of Decca Hi-Fix systems and two fixed transponders located on Bermuda. These systems were tested for accuracy and proved capable of determining the ship's position to ± 50 feet during the total implantment.

3.2.5.2 NASA Radar

(U) As a secondary backup to the Hi-Fix, the Bermuda tracking radar was used and combined with the primary navigation. Although the radar is not quite as accurate as the Hi-Fix (± 5 yd) in range and in azimuth 0.02-.05 MILS depending upon the particular radar used, the two plots maintained very high correlation throughout the testing process and the implantment.

3.2.5.3 Acoustic Transponders

(C) Although the navigation systems operated correctly during implantment it was planned and executed that acoustic transponders located at the riser leg anchors and an acoustic pinger located on the horizontal leg would be used after implantment to

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verify the exact location of the Array. Preimplantment tests were not required but post implant tests established that the outboard anchor is located at 64° 10.44' West and 32° 04.74' North, which is 630 yards bearing 293° true from the original planned position. The transponder that was planned for the shore anchor was inadvertently released prior to implantment and could not be used to pinpoint the true position. The pinger established the proper depth of the horizontal leg.

3.3 Cable Systems

3.3.1 Introduction

(U) The cable systems, with the exception of the Array cable, were selected from standard deep ocean coaxial cable. The techniques for splicing the Array to the SDC cable and the SDC to the shore connection, both electrical and mechanical, were adequate for this operation, but allow great room for improvement in the end electrical characteristics.

3.3.2 Array Coaxial Cable

(U) The Array cable (Reference 27) is a double-armored torque-balanced underwater coaxial cable manufactured by the Rochester Corporation of Culpeper, Virginia. The cable is comprised of a copper center conductor, dielectric, copper shield, jacket covering, and two layers of armor. The center conductor consists of seven twisted 0.04-inch bare copper conductors and is covered with a dielectric insulation of low density, high molecular weight polyethylene 0.09 inches in thickness. The return shield is physically laid over the dielectric and consists of braided copper covered by a 0.025-inch thick polyethylene of the same material as the inner dielectric. For torque balance and strength, two

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layers of armor are wound opposing each other, e.g., in the clockwise and counterclockwise directions. The armor is made of improved plow steel and has a breaking strength of at least 30,000 lbs. The inner armor is comprised of twenty-two 0.065-inch steel strands in a left hand lay and the outer armor is thirty-six strands of 0.05-inch thick steel strands in a right hand lay. The maximum rotation of the cable under 10,000 lbs. tension is 156 degrees per 500 ft.

(U) The DC resistance of the center conductor is 0.99 ohms per 1000 ft. and the resistance of the return shield is 0.87 ohms per 1000 ft. The dielectric insulation resistance between the center conductor and shield is 48.9 megohms per 1000 ft. Between shield and the inner armor, the insulation resistance is 16.3 megohms per 1000 ft. The cable capacitance is 40.1 picofarads per ft. and the inductance of the cable measured at 1 kHz is 0.062 millihenries per 1000 ft. The inner polyethylene dielectric is capable of withstanding at least 15,000 volts DC for a period of 5 minutes. The jacket insulation is capable of withstanding at least 2000 volts DC for 5 minutes. The attenuation of the cable was measured at frequencies of 10 kHz, 100 kHz, and 1 MHz. The respective values of attenuation are 0.195 db per 1000 ft., 0.470 db per 1000 ft., and 1.86 db per 1000 ft. The characteristic impedance of the cable is 53 ohms, 49.7 ohms, and 42.2 ohms respectively for the above frequencies. Termination of the Array cable is made at package 30 and at the line driver. Each termination consists of a capacitor and a 51 ohm resistor to provide the proper characteristic impedance. The RC termination for the line driver is for the active mode when the Array is receiving acoustic information. When the Array is being interrogated, the line driver is bypassed and the termination circuit is removed.

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3.3.3 SDC Cable

(U) The SDC cable is a deep ocean coaxial cable exhibiting high strength and stable electrical characteristics. The first section of SDC cable from Tudor Hill is 3.216 nautical miles of double armor followed by approximately .92 nautical miles of single armor. The remaining cable to the line driver is unarmored SDC cable and is 42.514 nautical miles long. The cable consists of an inner conductor composed of copper jacketed steel strands, a polyethylene low density dielectric, a concentric copper outer shield, and a high density polyethylene plastic jacket. The center twisted steel strands have an overall diameter of 0.33 inches and the polyethylene dielectric has an O. D. of 1 inch. The outer copper conductor covers the dielectric and has a longitudinally overlapped seam of 1/4 inches. The polyethylene plastic jacket covers the copper shield and has an O. D. of 1-1/4 inches. The strength member of the center conductor is composed of 41 steel wires having various O. D. 's ranging from 0.030 to 0.69 inches. The length of lay for the steel strand is approximately 6 inches and the direction of lay is left hand. The minimum bending radius for the composite inner conductor is 36 inches. The armored cable consists of a neoprene jacketed steel armor wire over the basic SDC cable. The SDC "List 1" cable has a breaking strength of 19,500 lbs., and weighs 7.22 lbs. per ft. in air.

(U) The attenuation of the cable at frequencies of 1 kHz, 10 kHz, 100 kHz and 1 MHz is 0.311 db/nm, 0.4 db/nm, 0.75 db/nm and 2.39 db/nm respectively. The DC resistance of the inner conductor is 1.76 ohms per nm and the resistance of the outer conductor is 1.375 ohms per nautical mile. The capacitance of the cable is 0.214 microfarads per nautical mile. Minimum insulation resistance requirements are 100,000 megohm miles for the dielectric

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and 15,000 megohm miles for the jacket.

3.4 Hydromechanical System

3.4.1 Introduction

(U) In general the mechanical designs of the components of this system are considered (Reference 32) to range from good to excellent but the overall plan involving the hydromechanical considerations is felt to have some unfortunate flaws.

3.4.2 System Design Criteria

(U) It is believed that there were three general choices which have been the root of most of the TEST BED problems, either directly or by related effects. These were:

- (a) The decision to have a completely molded in-line array assembly versus plug-in electronics.
- (b) The unwritten decisions regarding recovery facilities.
- (c) The decision to use the NAUBUC and associated machinery (without major modification).

(U) The argument in favor of completing an assembly on shore and never separating the parts after testing has merit in many situations. In this case, however, the transporting and difficult handling of the large Array coupled with the later need for additional tests to isolate noise sources and undesired low resistances resulted in diagnostics hardships which outweighed any advantage of maintaining physical and electrical integrity. Perhaps a secondary bad effect was the appeal of the NAUBUC's cable tank which had capacity to contain the complete Array assembly plus the SDC cable. Had it not been for this combined desire for a completely assembled system and the availability of the

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NAUBUC there may have resulted the logical choice of reel storage. A preferred procedure is to carry the Array system on reels with coaxial inter-reel jumpers for overall testing, and additional reels of spare cable for replacing (sans sensors) any one of the segments, should cable damages occur. The SDC cable, having a suitable twist-torque characteristic, could be spiralled into the ship tank before.

(U) A recovery procedure was clearly in the plans at several points and mentioned again in a post-mortem, but little was actually done. The only vestige of a recovery mechanism is the grapnel line leading from the mushroom anchor. But, what is more germane, are the related effects of not properly preparing for recovery at all stages of the design. This attitude may seem pessimistic, but an implantment plan which was reversible at most any point would have properly influenced the team to backtrack as soon as problems occurred in the very first end of the Array.

3.4.3 Compound Design Criteria

(U) The sensors were designed to be pre-assembled into the line in order to simplify periodic system testing and avoid a last-minute flail as the Array was payed into the ocean. There is little* quarrel with this reasoning, except that the separation into about seven sections is still favored for the ease of handling, trouble shooting and storing on reels.

*There is a school of thought which considers the introduction of compact fittings which will more easily pass through a given traction machine. The sensors would then plug electrically into these fittings and clamp adjacent to the cable prior to disappearing over the final roller.

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3.4.4 Ground Tackle

3.4.4.1 Anchors

(U) The mushroom anchor was a good choice for holding in the soft silt and clay bottom reported by the University of Rhode Island.

(U) The ball anchors should have been heavier so as to ensure a firm touch down during implantment. The bend radius which this anchor gave to the cable together with the self-aligning feature of a ball supported above its center of gravity are desirable characteristics. The position of the cable attachments points relative to the center of mass would result in a fairly good restraining torque to combat a cable's tendency to twist, provided that the cable tensions and directions were properly maintained.

3.4.4.2 Chains

(U) There is no criticism on the use of the chains.

3.4.4.3 Grapnel Line

(U) "Sampson 2-in-1 Stable Braid" grapnel line was a good choice for the ease of handling and for expected long life and utility on a bottom which is essentially free of outcroppings of jagged rocks. If the touch down point of the seaward ball anchor was so critical, the engineering group should have witnessed the method of measuring the line length. Such line is normally sold by weight and the conversion factor to length is subject to question. If a measurement was actually made the tensions needed to be properly considered, although the elasticity of this particular line could not have accounted for all of the reported error in length.

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(U) The chain and corrodable-link arrangement near the mushroom anchor is one of the planned recovery techniques that was actually implemented.

3.4.5 Flotation Units

3.4.5.1 Ellipsoidal Floats

(U) There is no criticism to the use of these floats since extensive tests were performed and they are known to give satisfactory service at the required depth. The low drag profile is not a great benefit in this application because the drag on the cables and protuberances is much greater in the predicted current profile. The method of linking these two floats to the Array appears to be satisfactory with the strain member which acts as a safety for the elastic link.

3.4.5.2 Glass Floats

(U) One of the first reactions studying the TEST BED Array is to try to find a way of replacing the numerous glass floats with some other (near) uniformly distributed support. The balls were troublesome to add to the cable as it was payed out and will probably constitute a far greater problem when and if the Array is retrieved. The net conclusion, based on the present state-of-the-art, (barring a breakthrough in neutrally-buoyant, deep-sea, torque-balanced electrical cables) is to continue using glass balls for support. Worthy of reconsideration are: (a) the use of the larger 16-in. balls throughout, so as to increase the interval between attachment points, and (b) the use of the acoustically-quiet, quick-attaching connectors. The

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photographs showing the floats attached to the line cause some concern that some of the 1623 units are likely to oscillate in the slow current and cause acoustical noises as they contact the cable or linking hardware. This possibility rests on the likelihood that a few of the balls will be in unstable equilibrium (having their attachment points in random rotation positions on the cable) because of aspect angle of drag of the large flat flange emanating from the spherical surface.

3.4.6 Sensors

3.4.6.1 Pressure Housings

(U) It can be argued that the pressure housings could have been much smaller, but from a mechanical and cost standpoint they were just right. The design, construction and testing program appear to be excellent.

3.4.6.2 Cable Entries

(U) It is understood that "stainless steel" bulkhead connectors were used against mild steel bulkheads. The proximity of these dissimilar metals is not considered good ocean engineering practice but it will probably not be a problem in this situation, particularly if the interface is well greased between the first and second O-ring seal.

3.4.6.3 Support Cages

(U) The cage and method of attaching to the cable seemed to be of good design as was borne out by testing.

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3.4.7 System Dynamic Analysis and Implantment Control

(U) The computer rehearsals of the implantment together with the excellent navigation and ship control seem to leave very little to desire in this part of the endeavor. The reports which compared physical results with predictions have evidenced that most of the parameters and equations were well in hand before the implantment began.

(U) With any good thing there is a challenge to find some faults. The dependency on automation and the preconceived control guides may have gone a little too far. There are two basic ways of accomplishing a physical feat and, in electrical or mechanical terms, one uses feedback and the other one does not. Generally, a mixture of the two methods is used as was the case in the TEST BED Implantment. It is felt, however, that there was a little too much delay in the feedback network several times when problems cropped up, but although it had its imperfections it was useful during implantment.

(U) In summary, the dynamic analysis and plans which preceded the implantment seemed to be very good, but there mere existence may have caused the complacency which resulted in the incomplete preparation for contingencies which, in turn, could have been countered by well-esiablished feedback loops.

3.5 Acoustic Packages

(U) The acoustic sensor package documentation was examined to determine the adequacy of the engineering, the operation during construction and implantment, and the reliability of the actual circuits. The hydrophone packages were designed to operate as individual units using standard electronics to convert the output of the sensors into the FM signals for transmission through the coax cable. The

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basic engineering of the hydrophone package is good. There are, however, a few basic considerations which are described in the following sections, over and above the NUSC recommendations in "Summary Report of Design, Fabrication, and Deployment of Long Range Acoustic Propagation Program Atlantic TEST BED Array." (Reference 27), that should be considered before any future implantment should be attempted.

(U) Within the Array, twenty hydrophone packages were dispersed along 34,816 ft. Each hydrophone package was mechanically mounted in line and electrically connected in parallel with the other hydrophone packages and contained a hydrophone, pre-amplifier, calibration circuit, command and control unit, and telemetry electronics.

3.5.1 Hydrophone

(U) The hydrophone sensing element is lead metaniobate and is encased in a double booted configuration to insure long life and reliability. At least two years of operation was expected at water depths of 20,000 ft. or 10,000 psi. The hydrophones are designed to operate with a maximum sensitivity change of 1/2 db over the specified pressure differential and over a temperature variation from -2°C to $+30^{\circ}\text{C}$. The frequency response is typically ± 3 db at 5 Hz and 50 kHz. The hydrophone is basically omnidirectional except at extremely high frequencies, above the bandwidth of interest, where some vertical directivity is evident. The physical size of the hydrophone is less than 2.5 inches O. D. and weighs less than 4 lbs. Size and weight are extremely important from the mechanical viewpoint because of the buoyancy involved in the Array. The electrical characteristics of the hydrophone has an equivalent capacitance of 220 pf with a receiving sensitivity of -94 db/1V/microbar.

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(U) The NUS Model 1140-105 deep sea hydrophones (lead metaniobate) were selected because they are the only deep sea hydrophones that could meet the TEST BED specifications with proven performance. In checking the specifications and the experience behind deep sea hydrophones, the personnel at NUSC concluded that these devices were adequate in performance in that NUS had demonstrated equipment reliability.

3.5.2 Pre-Amplifier

(U) The hydrophone is connected to a NUS Model 2000-006 low noise pre-amplifier that has a noise floor of approximately -155 db//1V in a one Hertz band at 1000 Hz. The pre-amplifier gain is set at +16 db to insure adequate signal to noise at the telemetry system input. The input impedance of the pre-amplifier is 1000 megohms shunted by 15 picofarads. The pre-amplifier employs a field effect transistor for low input noise, a single stage with feedback for gain and an emitter follower stage for output driving capability. This amplifier was specifically designed for the TEST BED system and incorporates the proper matching impedance between the hydrophone and telemetry electronics.

(U) The pre-amplifier electronics consist of proven elements and, unless exposed to sea water or excessive shock and vibration, were adequately designed for this operation and could be used in further implantments.

3.5.3 Calibration Circuits

(U) Each hydrophone package contains a calibration circuit that provides calibration levels at different frequencies to the

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pre-amplifier input with the hydrophone connected in a series arrangement. The calibration circuit is under telemetry control and is commanded by the shore electronics. The calibration circuit provides signal levels of -69, -79, and -99 db//1V at frequencies of 100, 200, and 800 Hz. Any combination of level and frequency is available by using the proper address at the terminal equipment. As shown in the block diagram of Figure 3 (Reference 27), the output of the 16 db amplifier is sent to a hydrophone pre-amplifier and then to a Voltage Controlled Oscillator (VCO) pre-amplifier. These stages increase the gain to a maximum of + 86 db in increments from 0 to 30 db. This feature permits hydrophone reception of high acoustic pressure levels such as underwater explosions.

(U) The calibration circuit required the use of two time-delayed relays. The basic circuit giving a single step voltage calibration to each of the hydrophone VCOs follows standard engineering practice for this type of measurement. There is insufficient data to determine the reliability of the two time-delay relays so that further use of this circuit requires some reliability and life-cycle analysis and testing.

3.5.4 Telemetry Electronics

(U) The VCO pre-amplifier contains a high and low pre-emphasis circuit so that system signal to noise can be improved at the high frequencies and dynamic range can be increased for measurement of high acoustic pressure levels. The VCO pre-amp output is fed to a low pass filter having a frequency cutoff of 2 kHz. The deviation limiter circuit limits the drive voltage to the voltage controlled oscillator. The center frequencies of the VCO's range from 40 kHz to 325 kHz in 15 kHz increments. The deviation is ± 4 kHz

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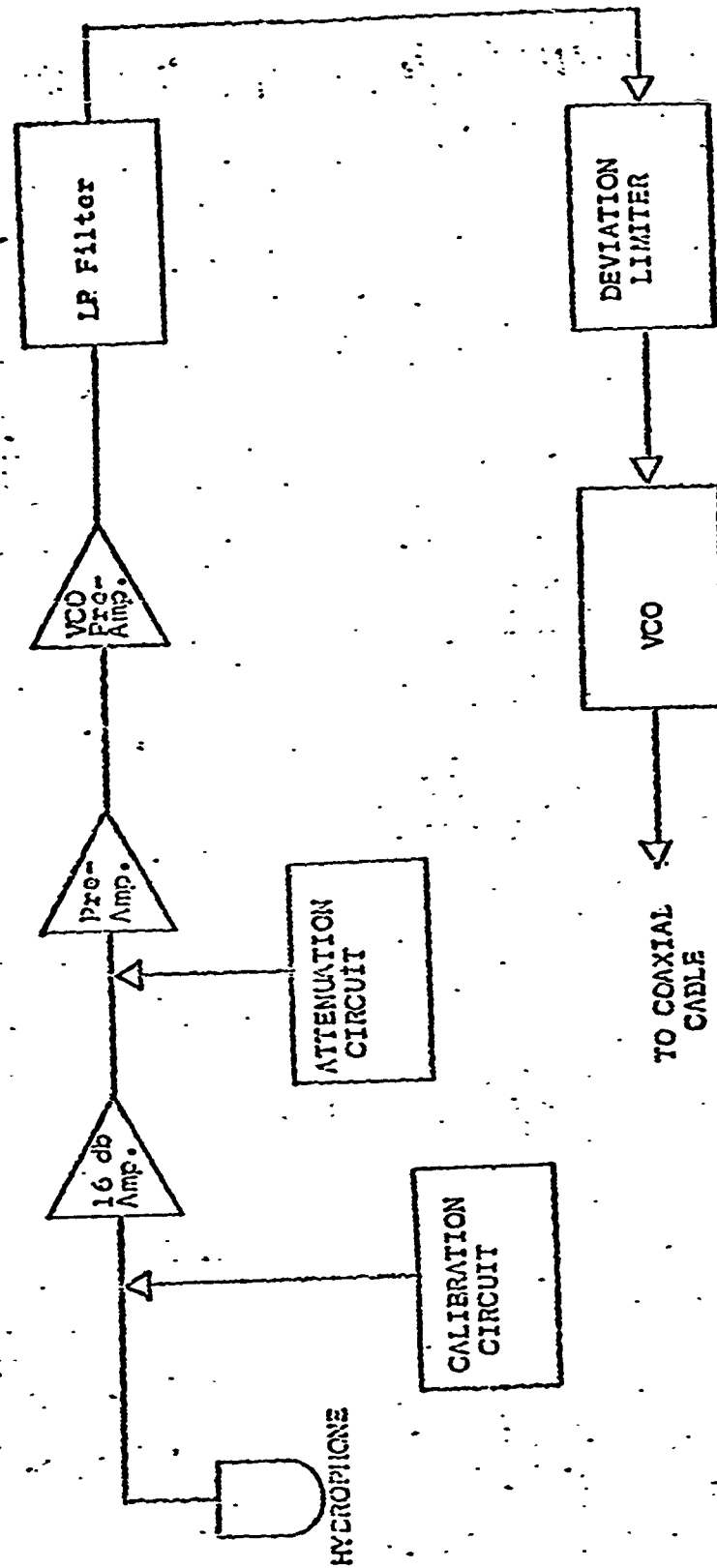


FIGURE 3. SIMPLIFIED HYD SIGNAL BLOCK DIAGRAM

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about the center frequency of the VCO carrier. The VCO carriers are frequency multiplexed and transmitted to the terminal end.

(U) The telemetry electronics were competitively selected from reputable firms, all adequately experienced in developing and delivering reliable electronics. However, the delivery dates that were experienced caused the assembly of the packages to become a critical element in the timing of implantment and thus contributed significantly to the inadequacy of the testing performed on the Array prior to implantment.

3.5.5 Command Control Unit

(U) The command control unit, which is part of the shore electronics, contains address and command tones that are frequency multiplied and telemetered to the hydrophone packages to actuate relays. The address tone composed of two individual frequencies allows for the selection of a particular package to be commanded. The command tones also composed of two frequencies allows for the selection of the various operational modes. Referring to Figure 4 (Reference 27), the received tones are filtered and amplified and then sent to the decoder circuitry. The AGC amplifier has a dynamic range of 10 db so that the command and address tone levels should not have to be critically set. The decoder board contains a shift register and relay drivers for operation of the relays. All modes of operation are selected through relay control.

(U) The command control units are one of the major weak points in the engineering design of the packages. In actual operation of the Array (Reference 37), these units became critical in the selection for signal return, and also in the selection of redundant components that are built into the system for overall system

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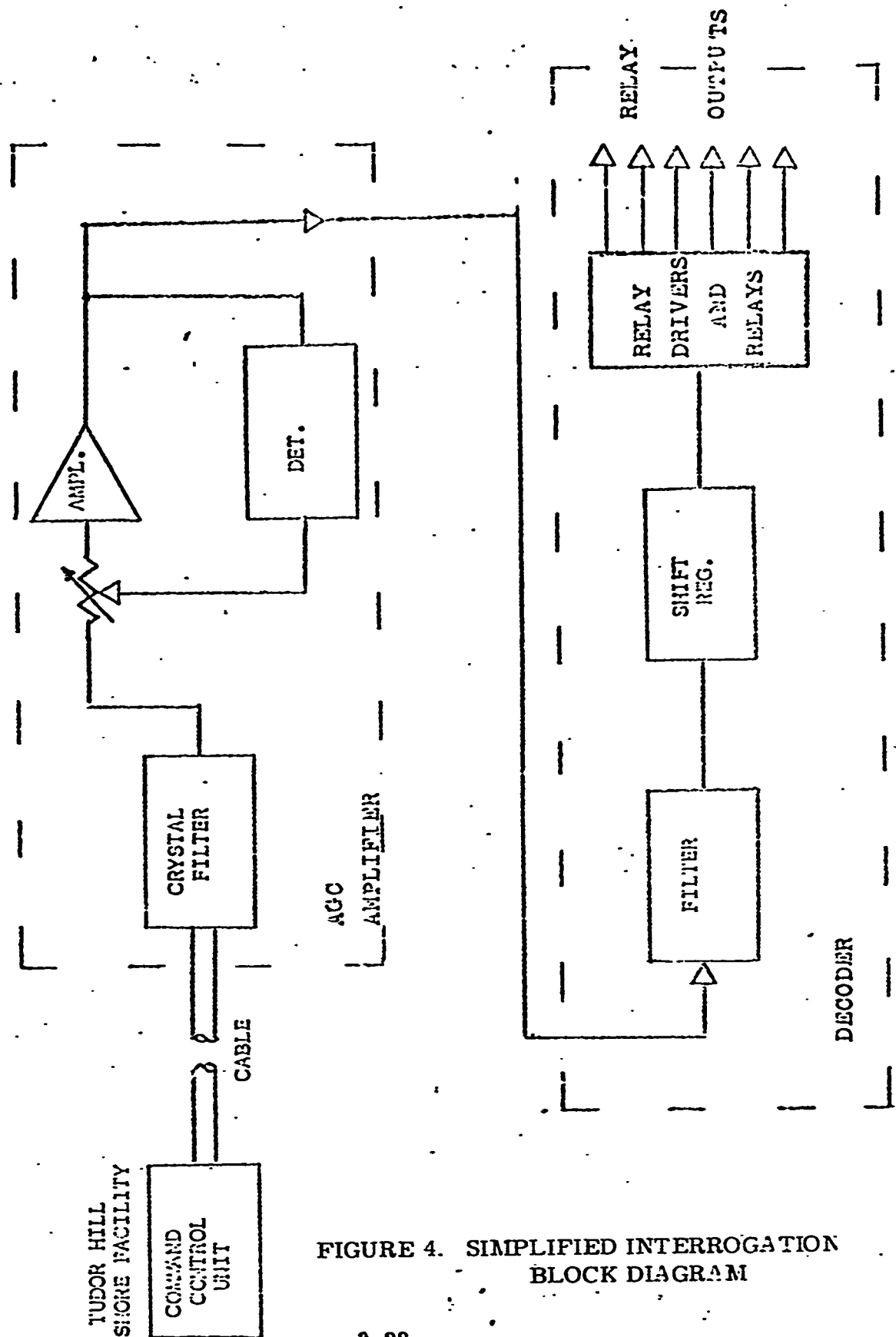


FIGURE 4. SIMPLIFIED INTERROGATION BLOCK DIAGRAM

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reliability. Two major weak points exist within this unit. First, the relays that were used required high current, were selected from on-hand relays at NUSC, and were not of sufficient reliability or quality to be used in a system with a projected 3-5 year life. The second weak area was the selection of the ceramic filters for command tone detection. These filters are extremely critical to shock and vibration which causes mechanical failure, have very broad bandwidth skirts in their frequency response which require a very delicate control of the amplitude of the command tone, and are not as selective to frequency as they should be for adequate command response. NUSC, forced by critical implantment timing, did not elect to replace these ceramic filters with more reliable products that are on the market. Since the implantment, NUSC has investigated a tuning fork driven reed relay that both replaces the ceramic filter for tone detection and the heavy current relays with a highly reliable, very accurate and sensitive decode capability. In future implantments, these new relays should be considered for use over the filters and relays used for the TEST BED.

3.5.6 Power Supply

(U) The hydrophone packages are powered from the shore end and require a voltage of 42 to 60V DC to operate. Voltage regulators in the hydrophone packages reduce this voltage to + 20 and -15 V DC. The current drain on each package is in the order of 35 ma.

(U) The power supplies were adequately designed and built to meet the overall requirements of the hydrophone packages. The only apparent problem reverts back to the command and control circuit relays in that surge currents can translate from the relays with a large supporting capacitor through the power supply to the

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source voltage on the coax line, which can destroy the fuses, which decouples the package. This, in fact, was experienced while the packages were being assembled and NUSC issued a memorandum on 10 November 1970 to use caution in applying line voltage. The replacement of the aforementioned relays would solve this problem and, therefore, no modification of the power supplies is recommended.

3.5.7 Testing

(U) According to the addendum to the NUSC Report, Section XXIV, "Test Procedures for Array Electronics Components", the planned test procedures were fully adequate to insure both operation and long-term reliability. Unfortunately, the time frame allotted for the test was almost completely utilized by the construction, shipment and implantment phases of the effort. Therefore, the testing of the Array was never properly completed. In fact, on September 16, 1970, even the engineering review of the electronics portion of the TEST BED was foregone. However, in reviewing the instrumentation log, the testing that was performed uncovered numerous problems. During the actual construction of the Array, many of the epoxy coated fuses that were designed into the system for overall Array safety experienced mechanical breakage and circuit disconnect. By the time of implantment, many of these fuses had been shorted, thus leaving, in the high voltage side of the cable, only the fuse in the T-connectors which was also designed for system safety. However, all packages were adequately fused in both the high and ground lines and were capable of operation.

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3.5.8 Reliability

(U) The reliability design for the hydrophone packages was good. The selection of the components and the requirement for maximum use of the SEA SPIDER equipment combined into what could be considered to be an unreliable system. The dual VCO for redundant operation was adequate for the life span of the hydrophones and the internal electronics, but the poor decode capability along with potentially unreliable relay switching could very well eliminate the capability to select the redundant component. The thought put into Array protection from possible flooding of packages by fusing both the high and low connections to the coax was good. As proven in the Array construction, the epoxy covering for the fuses was mechanically inadequate; this technique should be replaced in future programs. The T-connector, itself, was designed to fully protect the high side of the coax cable. Again, the thinking behind its operation was good; although extensive pressure tests of this device were conducted by NUSC, insufficient data presently exists on the capability of the polyethylene to adhere to the bare copper and resist sea water hosing for long periods of time. DeBell & Richardson, Inc., proposed to study the effects of oxidizing the copper prior to the polyethylene coating to increase their bonding capabilities and thus attain a five-year life protection. This study should be conducted prior to any new deep water implantment.

3.6 Engineering Packages

(U) A single electronics package can contain up to four engineering sensor voltage controlled oscillators (VCOs). The information rate of most sensors is in the range of 0 Hz to 10 Hz; therefore, a frequency modulation (FM) deviation of $\pm 62\frac{1}{2}$ Hz is

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used which allows a modulation index of greater than five for high quality signal reproduction. These narrow band channels are fitted into the telemetry band from 859 Hz through 6.13 kHz. Carrier frequency drift becomes a problem if the peak deviation (62.5 Hz) is less than 1% of the carrier frequency, and a reasonable guard band is necessary between channels. There are also four wide band (± 500 Hz deviation) channels between the upper control frequency of 14.75 kHz and the lowest hydrophone VCO at 40 kHz. These channels are used for the high resolution depth sensors and the wide band vibration sensors located inside package 18E5.

(U) Attenuation of the engineering package VCO signals as they pass along the Array is a problem at frequencies below approximately 5kHz. The PACIFIC SEA SPIDER system did not use this frequency band, so no attempt had been made to keep hydrophone package shunting impedance high in this band. These new low frequency VCO signals encountered mis-match losses as they passed each hydrophone package on the line. Approximate losses varied from 0.2 db at 10 kHz to 2.7 db at 1 kHz per package. Therefore, the lowest frequency channels are positioned at the shore end of the Array to minimize signal loss.

(U) The individual packages vary in the number of sensors and VCO used and in the vibration packages, an amplifier is substituted for the calibrator board. Connection to the coaxial Array cable is made through two fuses which are potted inside the pressure housing head to isolate the cable from the package in the event of either an electrical failure or a sea water leak into the housing. Normally, the smaller 1/8 ampere shield fuse would blow first, and if a high current path remained, the larger 1/4 ampere center lead fuse would also blow. This pair of wires carries DC power and address tones from shore to the package and also carries up to four

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FM channels of data back to shore. The Automatic Gain Controlled Preamplifier (AGC) board is the same as that used in the hydrophone packages and was purchased from IEC. The other boards were designed and constructed at the New London Laboratory with an attempt to use the same components as used in the hydrophone packages to minimize spare parts required. The VCOs are potted plug-in modules purchased from Sonex.

(U) The engineering sensor documentation was examined along with the supporting electronic diagrams to determine the adequacy of the engineering, the range of measurements and their usefulness to the Array implantment to determine, as in the acoustical packages, the reliability of the actual circuits. The sensors are divided into two groups, internal and external of the pressure housing.

3.6.1 Internal Sensors

(U) The internal sensors are placed within the pressure housing along with their required electronics and are not designed to resist breakdown of the hydromechanical housings, except through the fusing network that was discussed earlier.

3.6.1.1 Voltage

(U) The internal voltage monitors located at each end of the Array allow the operator to monitor and thus supply correct voltage to the Array. Expected Array line current varies between one and two amperes, supplied through the shore cable having a distributed resistance of 125 ohms. The minimum operating voltage for all sensors is + 42 volts while the maximum operating voltage is limited to + 60 volts at the outboard end and + 90 volts at the shore end of the Array. The shore end voltage monitor has a linear range of 50 volts

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around a center voltage of + 65 volts while the outboard end has the same linear range around + 45 volts. This unit was adequately designed and implemented and did operate well within the reliability requirements of the system. A suggestion due to the problems experienced within the implantment phase for further deep water implantment would be an increased number of the electrical sensors throughout the Array to insure complete protection.

3.6.1.2 Inclinometers

(U) Three internal 2 degree of freedom pendulum type inclinometers (Humphrey AV01-0101-1) measured tilt of the Array up to 60 degrees from vertical and azimuth rotation of the cable in the range of 0 to 355 degrees. These monitors have proven performance in deep ocean operation and are adequate for their intended operation in the Array. They were monitored during implantment to insure proper Array configuration. It may be helpful in future implantments to have this data displayed on the bridge.

3.6.1.3 Pressure Sensors

(U) Two internal pressure sensors (Bourns Model 2309) were inserted in the Array to determine the depth of the horizontal section ends and were designed to measure depths from 0 to 11,000 ft. These units are standard, have proven reliability in deep ocean water and are adequate to the requirements of the system. A suggested improvement for further implantments would be to install pressure measurement devices near the anchored ends of the Array also. Although these additional measuring devices would consume more of the bandwidth of the telemetry, they could, under the command

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and control techniques, be used only during the implantment procedure and then never reactivated; therefore, they could use identical frequency bands with the hydrophones or other engineering sensors. This would allow better engineering knowledge of the Array's structure during the implantment phase.

3.6.1.4 Accelerometers

(U) The vibration sensing packages are different from others in that voltage gain amplifiers are substituted for the usual calibration boards. The sensors are accelerometers of a piezoelectric type having a sensitivity of 275. millivolts/g from a 2000 pf capacitive source. A low frequency response to 0.1 Hz requires an accelerometer preamplifier input impedance of at least 1000 megohms. This is accomplished by using an integrated circuit (monolithic silicon-field effect transistor) and bipolar transistor in a bootstrapped source follower circuit to couple the accelerometer signal to the voltage gain amplifier. This second amplifier has a non-inverting gain of 15 db to produce full scale sensitivity of 3. g peak to peak for package 18E5 and 30 db for 0.2g peak to peak sensitivity for the other two packages.

(U) The accelerometers were included to measure the internal quadrature components of the Array cable vibration caused by ocean currents and vortex shedding. A frequency response from 0.1 Hz to 10 Hz and full scale acceleration of 0.2g peak to peak was chosen to sense the low level vibrations expected. One unit package 18E5 has reduced sensitivity to 3g peak to peak and an increased frequency response to 100 Hz, in case higher levels of vibrations and frequency occur. These sensors have sufficient reliability and are deemed adequate for the system operation. These accelerations should be monitored during the implantment phase. This would enable

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the crew to monitor during implantment the characteristic vibrations being experienced through this phase and may very well aid any analysis in future implantment problems.

3.6.2 External Sensors

(U) External sensors are mounted outside of the main pressure housing because of their size or because of the requirement of external physical coupling.

3.6.2.1 Tension Monitors

(U) The tension monitors, with a range of 0 to 12,500 lbs., were used to detect static as well as time varying tensions in the Array legs. The units are model WS 1000 (Oceanic Industries) and are deemed adequate for the system operation. During the implantment phase, these units were periodically monitored to determine the tension being experienced in the cable. However, this information was not displayed on the bridge to help control the tension that was being applied during implantment. It is suggested that for future implantments the tensiometer outputs be displayed on the bridge so that the Implant Director can directly and more accurately monitor the tension in the cable, rather than entirely relying on the dynamometers of the cable laying equipment.

3.6.2.2 Inclinometers

(U) Single axis inclinometers (Humphrey CP17-0624-1) at each end of the horizontal span were used to monitor the tilt in a range of ± 70 degrees from the horizontal. These units are proven deep water instruments, and are adequate for the system. They

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were monitored while deploying the SDC cable to determine that the Array was implanted in the proper configuration. Here, again, this information was not displayed on the bridge during the implantment phase and should, for future implantments, be used to aid the operation.

3.6.2.3 Current Meters

(U) Water current speed and direction was measured using a Q12 Vane (Marine Advisors) which senses the current direction and a synchronous rotor (Bendix) using the rotation of a rotor to determine the current speed. The resulting electrical signals from both sensors are summed to drive a single telemetry channel. Again, these units are proven deep water sensors and are adequate for the system. They have a specific operational problem in the implantment phase because they require external mounting after passing out of the cable handling equipment and before being deployed over the side. The experience in the TEST BED implantment dictates the application of these current meters only to cable not being held in highly varying tensions. In other words, from this experience, the current meters should be in the last leg to be implanted. Current meter technology should be advanced to include in-line solid state current meters that would not require the separate stop and attachment procedures.

3.6.3 Calibration Circuit

(U) Calibration of the first two sensor channels is provided in most engineering packages as shown in Figure 5, and in USL Dwg. E-01318C16. Relay contacts are shown in the normal position connecting sensor signals to the VCO. Normal VCO input voltages range between 0. and + 5. volts to provide respectively minus and

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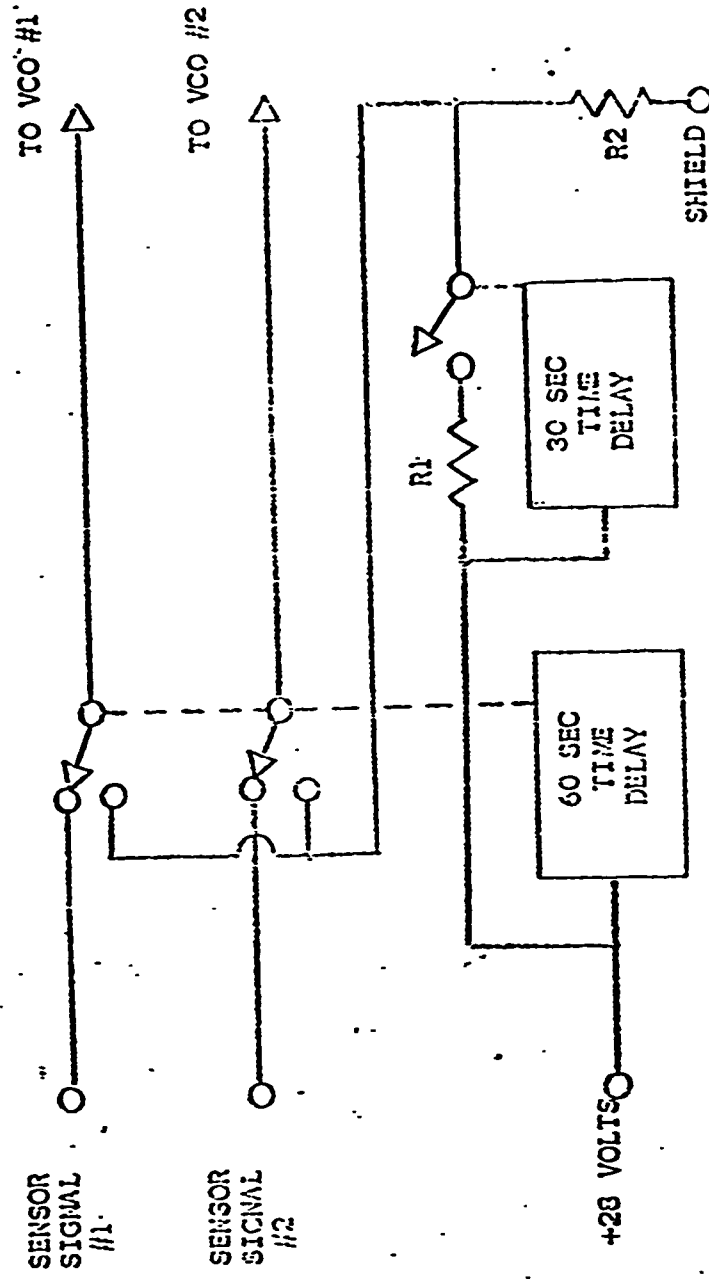


FIGURE 5. CALIBRATION BOARD AND RELAYS

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plus full scale deviation from the nominal center frequency. If Array power is momentarily interrupted or initially turned on, the time delay circuits energize both relays to provide a full scale calibration level of + 5 volts as developed across a voltage divider to both VCO. After thirty seconds, the calibration voltage drops to zero volts and after another thirty second delay the normal sensor signals are returned to the VCO inputs.

(U) The calibration circuits as in the acoustic packages (not used with the vibration packages) required the use of two time-delayed relays. The basic circuit giving a single step voltage calibration (0V and + 5V) to each of the first two VCOs follows standard engineering practice for this type of measurement. There is insufficient data to determine the reliability of the two time-delay relays so that further use of this circuit requires some reliability and life-cycle analysis and testing.

3.6.4 Telemetry Electronics

(U) The telemetry electronics as in the acoustic packages was competitively selected from reputable firms, all adequately experienced in developing and delivering reliable electronics. However, the delivery dates that were experienced caused the assembly of the packages to become a critical element in the time of implantment and thus contributed significantly to the inadequacy of the testing performed on the Array prior to implantment. In all other aspects, the basic electronics could be used in future implantments.

3.6.5 Command Control Unit

(U) The AGC Command control tone preamplifier board is used in all Array packages as shown in Figure 6, and IEC Dgw. No.

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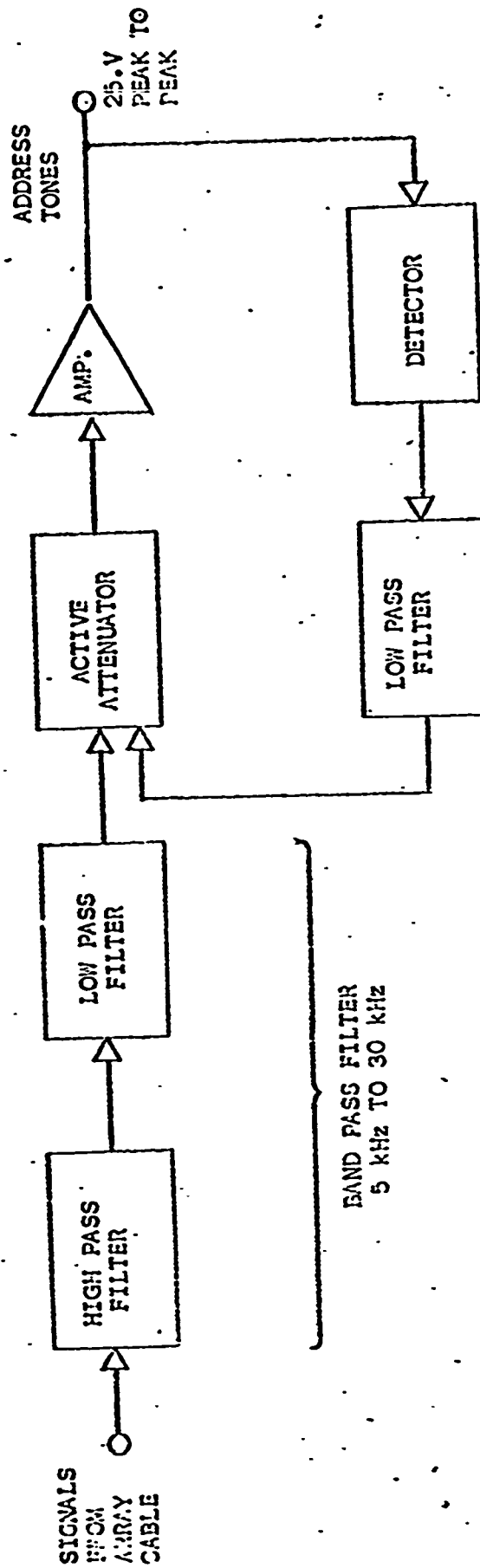


FIGURE 6. AGC COMMAND CONTROL TONE PREAMPLIFIER.

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0-1000425D. These boards have two RC stages each of high pass and low pass filters to pass and amplify the command control tones near 10 kHz. The control tones then pass an active attenuator stage before being amplified. The amplified output signal is detected, low pass filtered and fed back to the active attenuator stage. The overall circuit provides gain of 37 db or less as needed to maintain an output control tone level of 25. volts peak to peak.

(U) Actually the useful active gain control range of the amplifier is limited by interference picked up from engineering VCO frequencies near 6 kHz and 20 kHz. The amplifier input RC filter is quite broad and has a rejection of less than 2 db at these frequencies. The normal command tone level on the Array cable at shore end packages is 1. volt peak to peak, decreasing to .33 V peak to peak at the far end of the Array. Worst case VCO signal interference levels are approximately 140 mV peak to peak at the far end of the Array. In this case the interfering VCO signals are only about 10 db below the individual control tone levels, so the AGC preamplifiers do not cure all of the control tone level problems, although they certainly do help. The original SEA SPIDER fixed gain system required control tone level adjustments to within 1. db for operation of individual packages.

(U) The decoder card causes the + 28 volt power relay contacts to open or close when the card's particular pair of address tones are present at 25 volts peak to peak. Figure 7 shows the address signal flow through this board and USL Dwg. E-01318C6 shows schematic detail. There are 12 possible address frequencies between 11. kHz and 13.75 kHz, spaced 250 Hz apart. Each decoder board has two ceramic narrow band filters installed to only pass a particular pair of address tones to the detectors. If both tones are simultaneously present, the AND gate causes a constant current to flow into a storage capacitor. The address tones normally have a duration of 1.0 seconds

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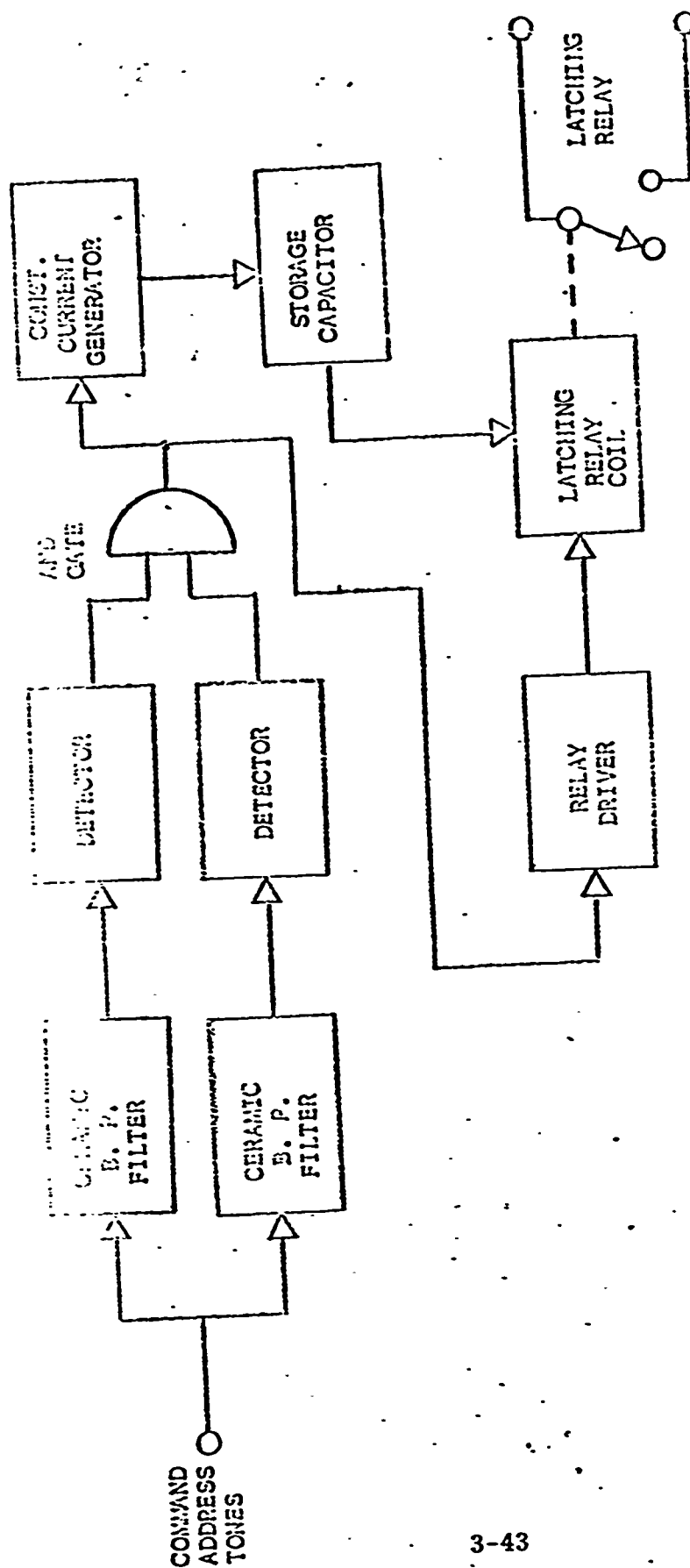


FIGURE 7. COMMAND ADDRESS TONE DECODER BOARD

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which is sufficient to fully charge the capacitor from the constant current source. At the conclusion of the tone pair, the relay driver discharges the storage capacitor through one of the relay coils, causing the relay contacts to toggle into the other position. The relay uses an internal permanent magnet to hold the contacts in this new position until the conclusion of the next accepted address tones. If the Array DC power is removed and then restored, the relay contacts remain in their previous position. Any data pulses accompanying the address tones are ignored by the engineering packages.

(U) The command control units as in the acoustic packages are one of the major weak spots in the engineering design of the packages. In actual operation of the Array, these units became critical in the selection for signal return, and also in the selection of redundant components that are built into the system for overall reliability. Two major weak points exist within this unit. First, the relays that were used required high current to energize, were selected from on-hand relays at NUSC and are not of sufficient reliability or quality to be used in a system with a projected 3-5 year life. The second weak area was the selection of the ceramic filters for command tone detection. These filters are extremely susceptible to mechanical failure from shock and vibration, have very broad bandwidth skirts requiring precise control of the amplitude of the command tone, and are not as selective to frequency as they should be for adequate command response.

3.6.6 Power Supply

(U) The power supply regulator and output amplifier board is shown in Figure 8, and in full detail in USL Dwg. E-01318C11. DC power from the Array cable is decoupled from signals and limited in level to ± 42 V by the first regulator, to supply circuits that must

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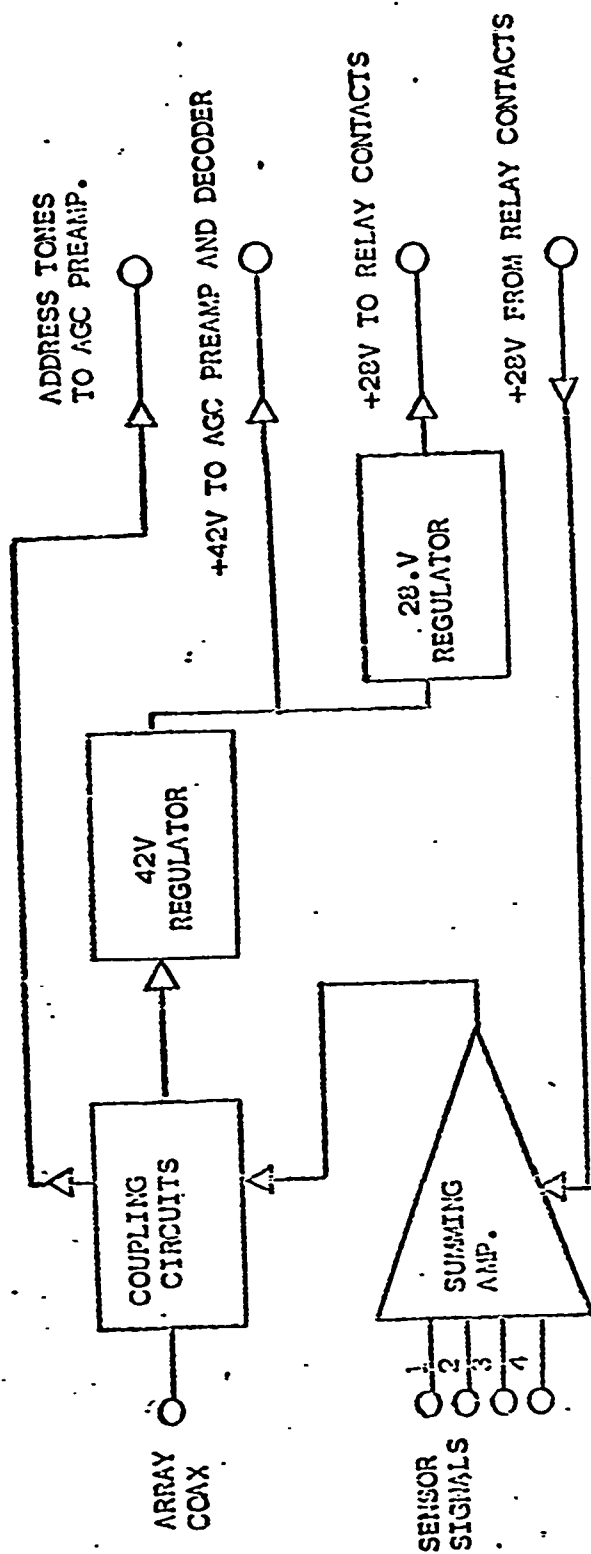


FIGURE 8. POWER SUPPLY REGULATORS AND OUTPUT STAGE

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always remain on. The second regulator controls the ± 28 volt line which is switched on or off by the power latching relay contacts. When switched on, ± 28 volts is available for the output summing amplifier and other internal circuits which include VCO, calibrator, and some sensor circuits.

(U) The power supplies as in the acoustic packages were adequately designed and built to meet the overall requirements of the engineering packages. The only real problem reverts back to the command and control circuit relays in that surge currents can translate from the relays with a large supporting capacitor through the power supply to the source voltage on the coax line, which can destroy the fuses and decouple the package.

3.6.7 Testing

(U) According to the addendum to Section XXIV, "Test Procedures for Array Electronics Components", the planned test procedures were fully adequate to insure both operation and long-term reliability. Unfortunately, the time frame available for the test was almost completely utilized by the construction, shipment and implantment phases of the effort. Therefore, the testing of the Array was never properly completed. The testing that was performed uncovered numerous problems, as recorded in the NUSC instrumentation log (Reference 37). During the actual construction of the Array, many of the epoxy coated fuses that were designed into the system for overall Array safety experienced mechanical breakage and circuit disconnect. By the time of implantment, many of these had been eliminated, thus using only the fuse in the T-connectors which was also designed for system safety. But all packages were adequately fused in both the high and ground lines and were capable of operation.

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3.6.8 Reliability

(U) The reliability design for the engineering packages was good. The selection of the components and the requirement for maximum use of the SEA SPIDER equipment combined into what could be considered to be an unreliable system. The redundant operation of multiple engineering sensors seems adequate for the life span of the Array but, as in the acoustic packages, the decode capability along with the relay switching could very well eliminate the capability to select the proper operation.

3.7 Line Driver

(U) At the shore receiving point, it is desired to receive all telemetry signals at nearly the same level to minimize interference from other channels and local noise. A shore received level of -75 dbv per channel was considered to be sufficient to provide hydrophone data signal to noise (S/N) ratios of at least 50 db. The 47 Nautical Mile length of SD cable attenuates the telemetry signals from 13 to 63 db depending on frequency. The Array cable and shunting effect of Array packages cause additional signal attenuation also depending on carrier frequency and on package position on the Array cable. The variation in total attenuation is 55 db over the telemetry spectrum. Individual package output levels can be adjusted to compensate for a 20 db range although hydrophone package outputs can be about 5 db higher in level than engineering packages. If these output adjustments were made, received signals would still vary over a 30 db range. In addition, the lowest signal level (250 kHz) would be -90 dbv (-22 dbv output level and 68 db cable loss) at the receiving point, which is 15 db below the desired signal level.

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(U) A line driver (Figure 9) having increasing gain with frequency and located at the base of the Array was included in the system to alleviate this situation. The problem of trying to pass DC power and control tones from shore to the Array while at the same time sending equalized and amplified Array signals both above and below the control frequencies in the opposite direction was overcome by accepting the limitation of a single direction signal flow at any one time (except for DC power). A reasonably simple and compact unit resulted.

(U) The line driver is one of the most essential parts of the Array in that all signals and DC power must pass through its circuits, thus catastrophic failure or loss of this unit would disable the entire Array. The engineering on the line driver is good. Complete redundancy of active elements are selectable through the command and control networks and in the event of failure of all active elements, the line driver is still capable of passing low gain signals back to shore. Although decoupling fuses could not be used to protect the Array from flooding of the line driver, internal fusing in series with each of the 42 volt regulator inputs was used to isolate the high current paths that could develop within the driver.

3.7.1 Low Pass Filter

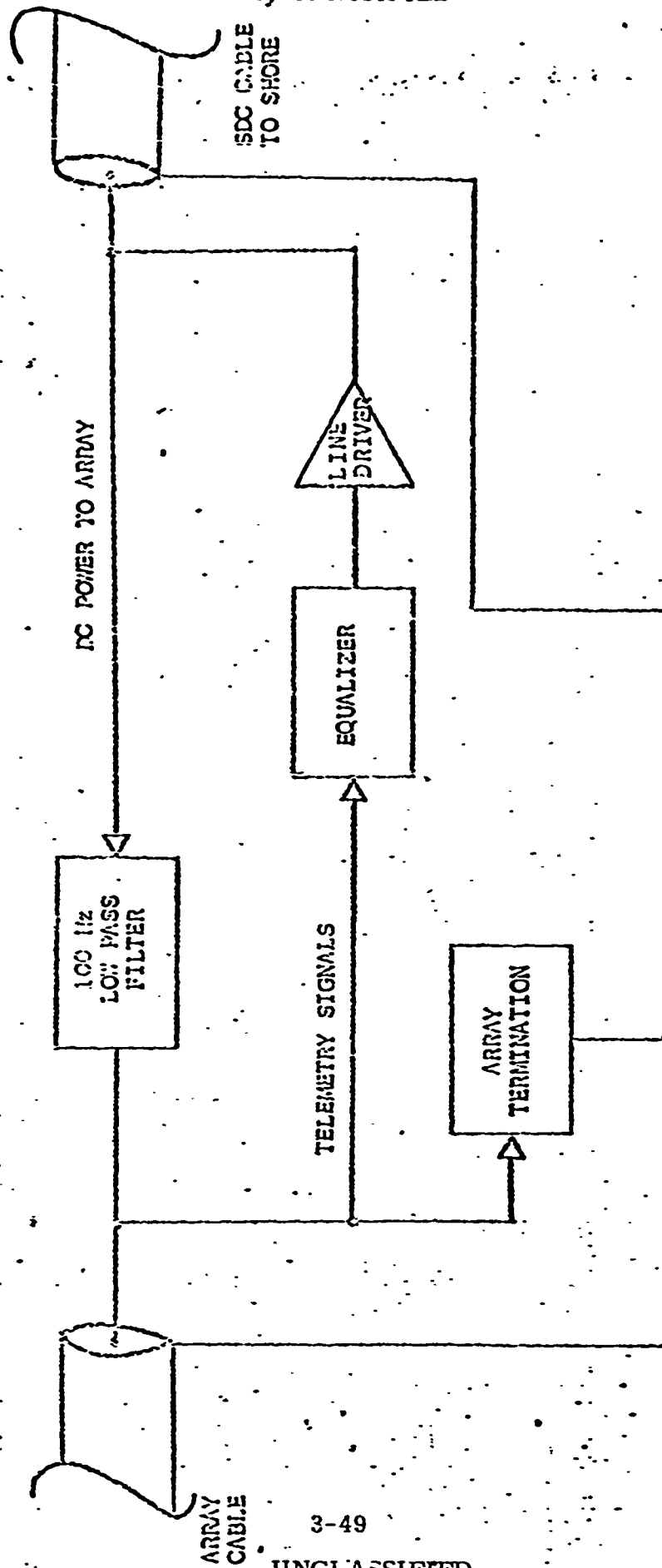
(U) The 100 Hz low pass filter is adequately designed to meet the operational and reliability requirements of the Array and can be used in the same fashion for any further implantment.

3.7.2 Inverting Amplifiers

(U) Operational amplifier techniques were used to provide continuous DC power to the Array through the 100 Hz low pass filter while the inverting amplifier provided signal gain in the opposite

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FIGURE 9. SIMPLIFIED LINE DRIVER

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direction. The gain was tailored by use of feedback and a passive equalizer network to provide a reasonably flat low gain response for the engineering sensor telemetry band, and gain increasing at 6 db per octave in the hydrophone telemetry band. Maximum gain was set for 18 db which provided minimum carrier levels of -75 dbv at the shore receiving station.

(U) The line driver amplifiers are redundant with the main driver having higher gain than its backup and are selectable by the command and control circuits. The Model S-29 (Sonex, Inc.) amplifier which was selected has proven operation and reliability, which matches the requirements of the Array. These devices are adequate for the operation and could be used in any future implantment.

3.7.3 Power Supplies

(U) Two separate 42 volt pre-regulators are provided so either one can operate circuits in the amplifier section to increase reliability. These regulators are constructed using a modified engineering sensor power regulator and output driver board (NUSC Dwg. No. E-01318C). The modifications allow use of two separate 42 volt supplies, each with increased supply current capability to properly supply the line driver. The remaining portion of the board supplies 28 volts as required by the voltage monitor VCO and its output driver stage. Both 42 volt supplies are made available to the amplifier section through bulkhead connectors and inter-package wiring.

(U) A standard hydrophone package dual power supply regular board (IEC Dwg. No. 0-1000073D) was modified to provide two entirely separate ± 17 volt power sources for the two line drivers. Modifications include substituting a previously common stage in the space formerly

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occupied by signal decoupling inductors, and re-adjusting the output voltages to ± 17 volts. The line drivers are permanently attached to their respective supplies, but only one of the regulators is turned on at a time through the latching relays.

(U) The power supplies are standard throughout the Array, and are an extension of the SEA SPIDER electronics utilization. As in the acoustic and engineering packages, the power supplies were adequately designed and built to meet the overall requirements of the Array. In the case of the line drivers, redundant power supplies were furnished. Either power supply can be used under command and control to power either of the line driver amplifiers. The basic redundancy built into the line driver was well engineered for overall operation of the Array throughout the proposed life cycle.

3.7.4 Command Control Unit

(U) A standard decoder board (IEC Dwg. No. 0-10000094D) is used with address code of 8 and 3 to drive a standard shift register and latching relay board (IEC Dwg. No. 0-1000123H). Only three of the twelve control relays are needed to allow selection of either line driver or to bypass the line driver for remote control of other Array packages from shore. Line driver (LD) #1 amplifies the Array telemetry signals for use at shore. In case of difficulty with LD #1, backup LD #2 can be activated by turning on control bits 9 and 4, which respectively transfer DC power from LD #1 to #2 and connects LD #2 into the signal path. Line driver #2 has one to two db less gain over the whole telemetry band than LD #1. This feature allows the operator to check for proper relay operation by comparing received carrier levels as the amplifiers are switched. When either line driver is being used, the Array cable is terminated by its characteristic impedance for all signal frequencies.

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This termination reduces signal reflection back down the Array which could cause interference due to standing waves.

(U) If the operator wishes to change the control functions of any Array package, the line driver must first be addressed with bit 11 on. This causes the 100 Hz low pass filter to be bypassed, allowing address and control tones to reach the Array packages. In this bypassed condition, Array signals do reach shore, but the high frequency hydrophone signal levels are very low in level, since neither line driver is operating. Even though the line drivers are not active, the bit 9 relay always connects power to one of the amplifiers, maintaining fairly constant power dissipation in the line driver package. This feature eliminates the need to readjust shore power supply voltage when addressing the line driver package. After Array control changes are completed, the line driver should be addressed with all control bits at zero to restore operation of line driver #1 and allow reception of normal Array signals.

(U) The command and control unit is the major weak point in the entire Array. Bound by the requirement for maximum use of the SEA SPIDER equipment, plus the time frame for selection of components, implementation of the command and control circuits for the line drivers leaves much to be desired. During construction, tests, and implantment, the line driver command and control networks were a major source of problems. For future implantment, this network must be changed. Both the decode networks and the relay operation have to be improved in their operational reliability before any reliable Array operation could be anticipated.

3.7.5 Overvoltage Circuits

(U) Array damage can occur if the supply voltage exceeds 93 volts at the line driver. This high voltage condition is possible if the

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full Array is powered with 85 volts at the line driver and the operator turns off individual Array packages without reducing the shore power supply voltage. In this case, as soon as the SD cable IR voltage drop decreases by 5 volts (a reduction in line current of only 40 ma), the DC line voltage at the line driver will approach the dangerous level; therefore, a circuit to absorb power when line voltage reaches 90 volts is included. Relays were discarded for this application because they have a slow response, followed by abrupt switching which could either miss high voltage transients or introduce additional ones. Therefore, a DC switching amplifier driving a high power passive resistor is used as shown in the block diagram of Figure 10. This circuit draws essentially no current below 89 volts, but gradually starts to conduct current through the 200 watt, 100 ohm load resistor as the line voltage exceeds 90 volts. The plot in Figure 10 shows how the total line driver package current varies with line voltage. Power dissipation is also plotted, showing that dissipation in the transistor switch is limited to 22 watts, while the load resistor handles the major dissipation for high voltages. An alternate solution would be to use a bank of series zener diodes, but in this case the major power dissipation would have to be handled by the semiconductor zeners, leading to reduced reliability over a passive load resistor.

(U) Because of the nature of the Array operation, DC voltage being supplied from the shore and telemetry signals being sent back through the common coax cable and because of the high voltage loss due to the current drain of the Array through the long coax cable, protection had to be built into the line drivers so that operator control through the command and control networks could not damage or destroy the overall Array. Again, good basic engineering was used. The use of a switching amplifier, a load resistor and a zener reference diode is considered the best protection that could have been given to the

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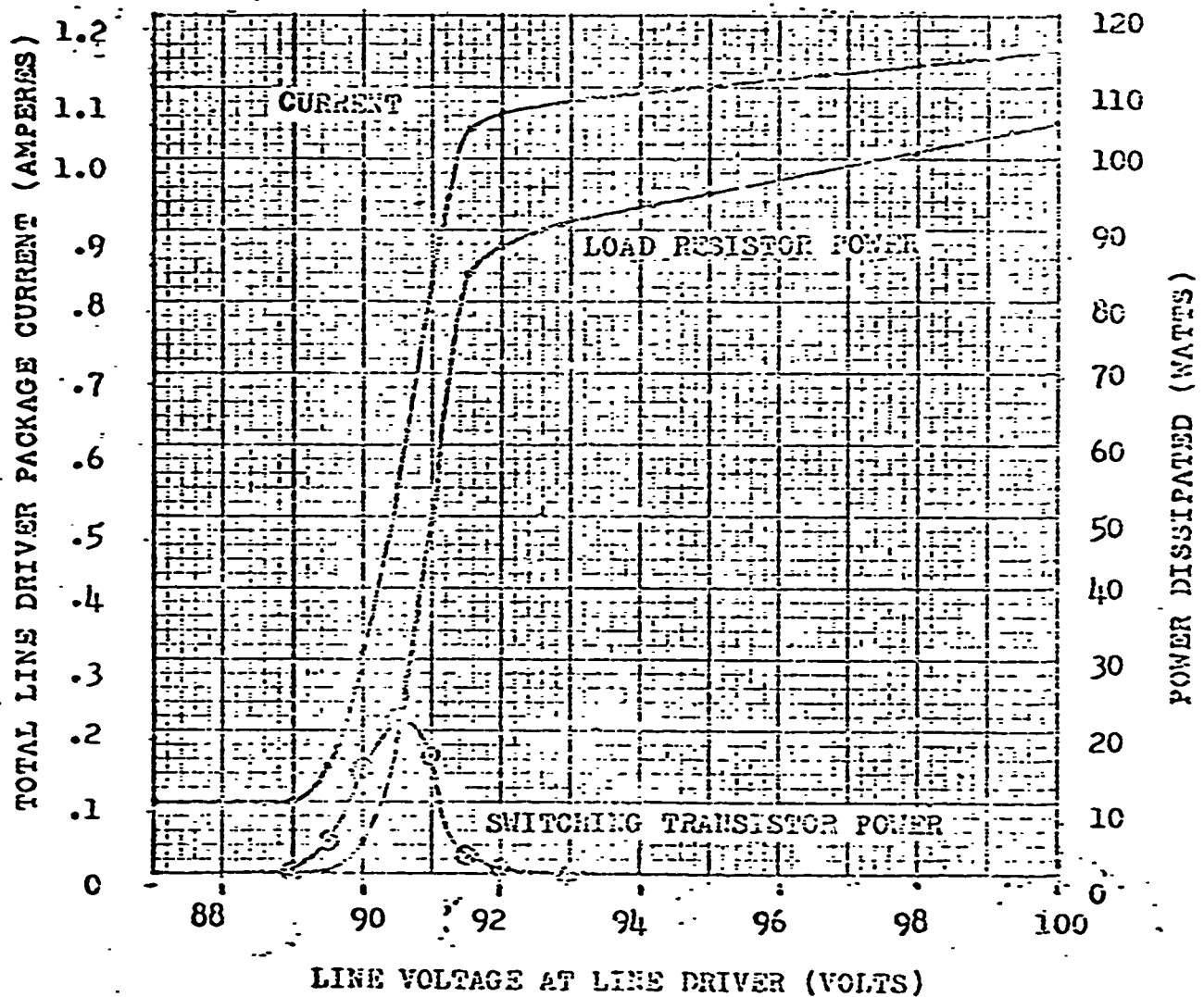
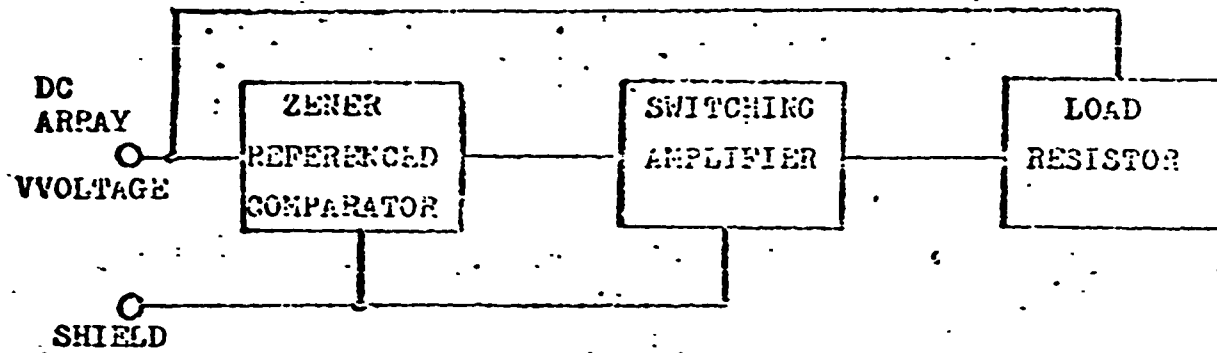


FIGURE 10. OVERVOLTAGE PROTECTOR BLOCK DIAGRAM AND LINE VOLTAGE VS POWER DISSIPATION IN THE LINE DRIVER

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Array. This circuit could be used in any future implantment and is well within the reliability and the operational requirements of deep ocean operation.

3.7.6 Voltage Monitor

(U) A voltage monitor telemetry channel inside the line driver package provides DC line voltage information for the operator at the shore end of the SD cable. The voltage monitor operates within a 50 volt linear range from 40 to 90 volts with an accuracy of ± 1 volt. Since no control switching contacts are available in the filter section, the line voltage monitor remains on and does not include a calibration circuit. Line voltage monitor operation can be checked by calculating line voltage at this point since shore line resistance is known (125 ohms) and shore supplied current and voltage can be measured.

(U) The internal voltage monitor within the Array, and its individual VCO are identical with the voltage monitor placed in the outboard engineering package and is used for operator control of power to the Array. As stated in the engineering package analysis, this circuit is adequate for the operation of deep ocean arrays, could be used in any future implantment and it is recommended that more of the voltage monitors be applied to the total Array as components of the other packages in the Array.

3.7.7 Testing

(U) As stated earlier, the test procedures originally planned for the Array were not conducted due to the time element. However, the line driver was completely tested prior to insertion in the Array and after inadvertently experiencing high shock while loading the

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Array onto the ship, was again totally tested and was operational. During the implantment, the line driver was adequately checked out but due to the problems in the command and control circuit, the line driver was held in a bypass condition throughout the implantment of the SDC cable. The testing and test procedures applied to the line driver were certainly adequate. However, during the implantment phase, the command and control circuit proved to have questionable operation. This was mainly caused by the fact that part of the voltage control system was in Package 30E10 and in severing the Array at package 21, this voltage control and current control electrically was decoupled from the Array and therefore all new voltages and currents had to be used. This leads further to the conclusion that the ceramic filters and high current relays should be changed for any future operation.

3.7.8 Reliability

(U) The basic design of the line driver was certainly adequate for the reliability needed. Only the selection of components to implement the design can be questioned in terms of reliability. Future implantments should certainly use the basic design concepts and lesson from the TEST BED implementation that component selection should be made as judiciously as the original engineering design.

3.8 Telemetry

(U) Instrumentation for the shore terminal consists of a transmitter for interrogating the individual stations and receivers for separating the multiplexed signals into their original constituent parts. A voltage and current limiting power supply to power the Array is included. Associated with the power supply is an isolation network

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which prevents the power supply from attenuating the interrogating and multiplex signals. Figure 11 is a block diagram of the receiving system.

3.8.1 Interrogator

(U) High frequency audio (8-13 kHz) signals are transmitted down the coaxial cable for interrogation purposes. Each station on the Array is equipped with a wave filter and code demodulator. The filter is unique for each station; however, the codes for a specific function are identical at each station. Each station may be addressed and certain functions executed without regard to or affecting other units. The engineering sensors are powered "on" and "off"; however, a multiplicity of additional functions may be performed at the hydrophone stations. The application of power to many of the engineering sensors provides an automatic calibration interval. Circuits provide DC potentials equivalent to the sensors extreme $\pm$ ranges for a short interval prior to the operational mode. In this manner, a calibration is obtained each time power is applied.

(U) The shore equipment which performs this interrogation is constructed from integrated circuits and a bank of tuning fork oscillators. Two horizontal rows of panel-mounted switches may be manipulated to provide the tones and codes necessary to interrogate 30 separate stations. Two address tones and two command tones provide the information necessary to select a specific function. The two address tones determine which Array unit is to be changed and the command tones determine the change to be made. Each tonal pair is selected by means of a digital 12 bit word. Two and one-half volts RMS needs to be impressed across the coaxial line for interrogation purposes. A power amplifier is inserted between the command

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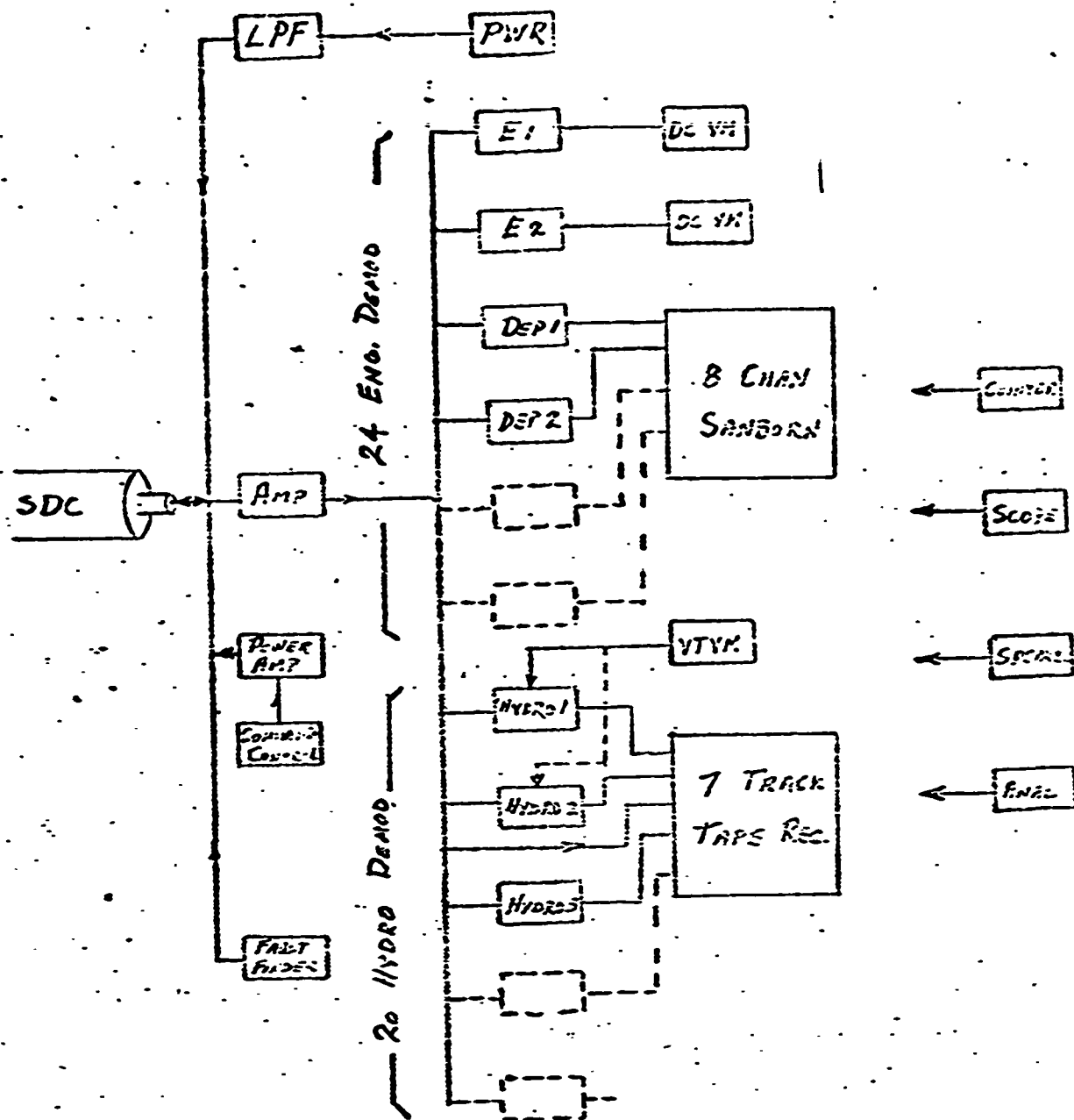


FIGURE 11. SHORE FACILITY RECEIVING SYSTEM

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equipment and the cable to provide the necessary power. A coded signal of one-second duration, one-half of which is address, is needed to activate a specific function.

3.8.2 Receiver

(U) Bridged across the coaxial line are 44 single-channel FM demodulators. Twenty are used to recover hydrophone information while the remainder demodulate the information from the engineering sensors.

(U) Twenty constant bandwidth FM multiplexed carriers convey the hydrophone information. These carriers are centered at 15 kHz to 325 kHz. The hydrophone voltage-controlled oscillators are band limited to ± 4 kHz. The hydrophone demodulators are Defense Electronics Industries Mod SCD-5 phase locked discriminators with a dynamic range of 0.005 to 5.0 volts. The intelligence band is limited to 1.2 kHz by an incorporated low pass filter.

(U) Two banks of 10 each demodulators tuned from 40 kHz to 175 kHz make up this system. Incoming signals from 190 kHz to 325 kHz are translated to 40 kHz to 175 kHz by an included crystal oscillator and translator. For example, a 325 kHz carrier signal is mixed with a 365 kHz crystal oscillator signal yielding a difference frequency of 40 kHz (365 kHz - 325 kHz) and is processed by a 40 kHz demodulator. The translated system was necessary to comply with stability specifications. Adjustments were made on the translated units to preserve the phase and coherence of received acoustic signals.

(U) Inserted between the coaxial cable and the demodulators is a variable gain preamplifier. This is adjusted to assure saturation of the limiters of all demodulators. A cable driver amplifier located on the shore side of the Array may be commanded into the circuit to enhance the high frequency portion of the multiplex. This amplifier

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is equalized to yield 18 db of gain at 300 kHz and unity gain at 3 kHz. This response is essentially the reciprocal of the 47 miles of SD cable attenuation.

3.8.3 Power Supply

(U) A DC power supply capable of delivering 600 watts is used to power the Array. Voltage output is continuously variable from 0 to 300 volts and current output may be limited from 0 to 2 amperes. A low pass filter is inserted between the supply and the line to effectively isolate the supply from the high frequency multiplex and interrogation signals. Power requirement for the entire Array is 240V DC at 1.4 amperes. The construction of the command and control circuits, high current relays with attendant capacitors, make it possible to destroy the Array protective fuses by switching the power on and off. In operation, the voltage control must be turned to minimum before the power supply may be turned on or off. This is a manual precaution.

(U) The shore-based equipment is adequate for this operation and can be used to support any future implantment if the high current problem is eliminated. If not, then an automatic slow power on-off capability should be added.

4. OPERATIONS EVALUATION

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4. OPERATIONS EVALUATION

4.1 Introduction

(U) BKD conducted extensive investigations into the studies, designs, plans and operational records of the LRAPP TEST BED Program. These efforts included interviews with key personnel.

(U) The purpose of this section is to present a concise record of the advantages and disadvantages of the major elements of the designs, planning, Array system, supporting systems and equipments. Also, when relevant, to cite those decisions that lead to significant or far reaching changes in the program.

4.2 Implantation

(C) The following criteria were established by NUSC in February 1970 in connection with implanting the LRAPP TEST BED Array:

1. The Array must be installed in calendar year 1970, as established by ONR Code 102-OS.
2. Every attempt should be made to schedule the at-sea implantment for the most suitable weather in the Bermuda area; i. e., the month of August and no later than the month of September 1970.
3. The selection of the components was to be based on availability and delivery schedule necessary to meet the installation date.
4. That equal importance between the ocean engineering (proving the capability to install and achieve the proposed Array configuration), and the environmental data to be gathered were to be the prime considerations for proceeding with the most expedient time schedule, and that the ocean engineering was equally or more important than the environmental data that would be obtained from the Array after installation.

(U) It is believed that the above criteria had a significant influence on many of the following decisions:

1. To select an Array cable having little historical behavior data.
2. To design a trainer Array using a different type of cable than that used in the implantment.
3. To use only one sensor housing in the trainer Array.
4. To conduct minimum testing of the Array cable behavior under simulated or actual sea conditions.
5. To proceed to Bermuda with the vessel under tow before loading and testing the Array as per the installation plan.
6. To not require cable manufacturer representatives to come to Bermuda during the loading of the cable after discovering the cable had a tendency to twist when being loaded or board the ship from the flat-bed trailer.
7. Not to determine the exact cause of the cable or fault noise that developed during loading the Array aboard the vessel, and why the fault disappeared without any corrective action being taken.
8. To continue deployment of the Array into the sea after the first twist, hockle, and electronic fault had occurred.

4.2.1 Implantation Plan

(U) The NUSC plan covered the basic preparation needed for at-sea tasks, together with a description of the Array mechanics, the cable laying machinery, the vessel's dynamic positioning system, and main machinery details. It also provided detailed procedures and personnel task responsibilities in depth. The primary content dealt with the preparation activities prior to the SDC installation, the sequence of events on a day-to-day basis, geological data of the implantment area, and an analysis of the Array and cable configuration as related to tension versus depth and vessel position.

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4.2.2 Site Selection

(U) The Bermuda area was selected by the Chief Scientist of NUSC and concurred to by ONR for the implantation of the LRAPP TEST BED Array for several reasons: the proximity to the New London, Connecticut Laboratory of NUSC, the deep water near shore at Bermuda, the general bottom configuration, facilities and personnel already existing at the shore base station and the historical acoustical data gathered by previous experiments in the Bermuda area over several years. It is felt that the Bermuda site was a good choice.

4.2.2.1 Bathymetric Surveys

(U) During March and April of 1970, the USNS SANS conducted a detailed site survey to determine depth, magnitude and direction of deep ocean currents and obtained bottom cores in the general Array area of the proposed site for soil analyses. This survey was very thorough, including the establishment of shore locations for navigational aids and requirements for the equipments' reliability, measurements repeatability and range.

4.2.2.2 Soil Mechanics Analyses

(U) In late May of 1970, the University of Rhode Island prepared a report which provided sufficient data to design the Array anchorage. The data provided by the University of Rhode Island proved adequate during the deployment of the Array and indicated that the soil analyses and anchor design correlated, and anchor dragging did not occur. The bottom was soft silt and/or clay overlying a carbonate sand. The silt and/or clay layer was 0-30" thick; the carbonate sand was sufficiently stiff to prevent penetration of the gravity corers to less than a few feet.

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4.2.2.3 Charts

(U) The Naval Oceanographic Office prepared the basic plotting charts including navigational grids and water depths. These charts, which were very detailed, proved adequate for the implantation.

4.2.3 Implantation (Reference 27)

4.2.3.1 Mushroom Anchor and Grapnel Line

(U) The basic design of the LRAPP TEST BED Array included a mushroom anchor and 34,000 ft. of grapnel line seaward of the Array. The grapnel line was installed for retrieval and reconfiguration of the Array, after obtaining sufficient data in the initial configuration. The mushroom anchor was to serve as an additional weight and properly tensioned, together with the grapnel line, to help place the outboard anchor in its preselected location. However, through an error during the installation (actually due to an error in the length of the grapnel line), the outboard Array ball anchor was placed 2,000 ft. inshore of its preselected location. It would have been necessary to recover and re-implant the grapnel line and the mushroom anchor had the bottom configuration been unsuitable to accommodate this error. As it turned out, the bottom configuration was satisfactory and the grapnel line and mushroom anchor were left in place and the entire Array was placed 2,000 ft. shoreward.

(U) It is recommended in the future that accurate measurements be made of all components including the grapnel line, and that accurate length counters on the portable cable transfer machine and the main cable machine drum counters should be used to determine the actual length of the grapnel line. There were no problems encountered in the deployment of the mushroom anchor and the grapnel line, with the exception that the extremely large shackles and thimbles had to be accommodated with teak shoes to prevent them from going on the drum in

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a flat condition, as there was insufficient width between the fleeting knives and the cable drum to accommodate the thimbles and shackles of this size.

4.2.3.2 Seaward Riser Leg

(U) The units themselves came out of the tank, passed through the cable machinery and over the stern chute with no problems. The crew did not experience difficulty in attaching the 10" floats, however, the 16" floats were considerably harder to attach to the cable and required additional personnel in handling. During the deployment of the seaward riser leg, the instrumentation room detected a fault in the cable. Payout was stopped and the unit was opened for testing. However, stopping the cable payout before the seaward Array ball anchor had been lowered to the bottom caused the recorded tensions to exceed 14,000 lbs. Mr. Cummings recommended and ONR Codes 485 and 102-OS concurred that since this leg had originally been planned as a completely uninstrumented portion of the Array, and because heavy weather was expected within the next 24-36 hours, that the unit be sealed and payout continued. This was accomplished and payout was allowed to continue until the seaward Array ball anchor was on the bottom, resulting in the tension decreasing as expected.

(U) One major problem was encountered in the deployment of the seaward riser leg. A hockle developed just prior to instrument package 28E9. This hockle was straightened and splice rods added and deployed overboard as there was no indication of electrical failure. As instrument package 22E7 was being deployed, a short circuit was detected in the seaward riser leg. Testing seaward showed that there was an electrical short approximately in the area of 28E9. This short was proven to be a center conductor to shield short, in a sea cell.

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4.2.3.3 Flotation Units

(U) The main flotation units were 8' x 4' elliptical floats for minimum drag characteristics. There was no significant problem in putting them overboard. However, considerable time was required for the crew to attach the flotation bellmouths to the cable enabling the cable to bend around the flotation unit without excessive bending. Before future implantments, the bellmouth arrangement with flotation unit should be redesigned to make the attachment either simpler or more easily used.

4.2.3.4 Horizontal Leg Implantment

(U) During the deployment of the horizontal leg, twists were again developed in the tank just ahead of the unit that was to come out next. Up to 2-1/2 twists were observed building up in the cable tank and the crew continued to pull these twists up out of the tank onto the deck by hand and pass them through the machinery.

4.2.3.5 Shoreward Riser Leg

(U) Problems were experienced in the deployment of the TEST BED shoreward riser leg. The cable developed a tendency to twist just ahead of the sensor unit that was lying in the cable tank. Several methods were tried to remove these twists. One method was to rotate the unit past the twist into the next following section. Secondly, an attempt was made to pull the cable up on deck, relieve the twist by hand, release the hold back machinery tension and slowly pay the cable twists onto the drum. This last method seemed to be the only solution that worked consistently to correct twists developed in the cable leaving the tank.

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(U) During the deployment of this shoreward leg, a twist was passed into the machinery unnoticed, and as it came out on deck, visual examination indicated that the cable would need to be stopped off, cut, and respliced at this point. The splice was accomplished aboard the vessel, the cable was tested and payout resumed.

4.2.3.6 Shoreward Ground Tackle

(U) The anchor and chain were attached to the cable during deployment and paid out without difficulty. As the anchor was nearing the bottom, tensions to 15,000 lbs. were noted. To achieve proper depth of the two sub-surface syntactic floats, the payout was slowed to drag the ball anchor along the bottom toward shore until verification that both floats were within tolerance. What occurred was that the inshore ball anchor was placed too close to the offshore ball anchor, allowing the inshore syntactic float to rise some 300 ft. above its predetermined position. Because the entire Array was oscillating or moving up and down with a periodicity of about 15 minutes, it was possible to correct the position by pulling the shoreward ball anchor shoreward and allowing the Array to come down into its original precalculated configuration. Once the position of the two syntactic floats and the horizontal portion of the Array was determined, the SDC cable was payed out as planned. However, at this time the sea state was so great that the decision was made not to add the anchor chain to the cable but to change the routine slightly and lay the cable so that the SDC cable would serve by itself as the anchor. Numerous checks with the instrumentation room determined that the Array was remaining within tolerances and the angle indicators indicated proper configuration.

4.2.3.7 SDC Cable and Splice

(U) Upon arrival at the splice area, the weather was so poor that the auxiliary vessel, ATF NIPMUC, was unable to go into a four

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point moor. The cable was buoyed off and dropped to the ocean floor. Several days later, on December 10, the NAUBUC proceeded into the previous implant area, brought the two ends of the cable together, and after the instrumentation room verified that the cable was testing good in both directions, the final splice was made. Upon completion of the final splice, it was lowered in the water and tests from shore indicated that the splice was properly made and sealed and that the Array was in actual working condition. However, approximately two hours after finishing the final splice, word was received on the vessel that a short had developed in the Array during the powering of the Array from the shoreboard laboratory and that the Array was dead.

4.2.3.8 Summary of Implantation Faults

(U) There were no significant Array cable mishaps at any time from its manufacture, through Array fabrication and assembly, up until the loading aboard the NAUBUC. In fact, preliminary training runs appeared to indicate that the actual implantment would be achieved with little difficulty. Only two cases of cable twisting were observed in over ten cycles of payout and haul-in during the training period, and the twists straightened themselves out in both cases. There were significant differences between the training runs and the actual implantment:

(1) no tests of the cable's electrical integrity were made during training, (2) only 11,000 ft. of cable were used, (3) the practice cable was not the same as the Array cable, and (4) tensions in the training cable never approached the actual implantment tensions (Reference 33), and (5) water depths were radically different in the training area versus the implantment area.

(U) The first operational irregularity occurred during loading of the Array cable onto the NAUBUC. After approximately 11,000 ft. had been loaded, a twist in the cable started building up on deck. The

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twist was relieved by unfastening a joint at the nearest instrument cage. Further loading of cable was accompanied by additional twisting, and on each occasion the twists were relieved as they were starting to build up. A total of 29 turns were relieved during the last 23,816 ft. of cable loading onto the NAUBUC, and it is assumed that in addition there were several revolutions of the bitter end of the cable made as it went aboard the NAUBUC.

(U) A large number of mishaps took place during actual cable payout. The points along the Array where they occurred are shown in Figure 12, together with those of the identified electrical shorts. The nature of these irregularities may be described as follows (Reference 34):

1. 2,000 ft. up the offshore leg the cable went into the payout machinery as a hockle. It came out of the machinery looking a little better than it did going in, as the outer armor tended to realign itself. There was no measurable change in the cable's electrical resistance, so preformed 24" splice rods were installed over the hockle and payout was resumed.
2. Between instrument packages located 4,600 ft. and 7,800 ft. above the offshore anchor, exact location not recorded, an electrical short developed. There is no further mention of this problem in any of the logs.
3. Between instrument packages located 11,000 ft. and 13,200 ft. above the offshore anchor, cable was observed twisting in the tank. No further mention of this problem is made so it can be assumed that the twist distributed itself satisfactorily.
4. 12,000 ft. up from the offshore anchor, a hockle formed in the tank and the cable came out of the machinery as a kink. There was no change in the cable's electrical resistance so it was merely stress-relieved at the kink by means of 3/8" wire rope and preformed grips.

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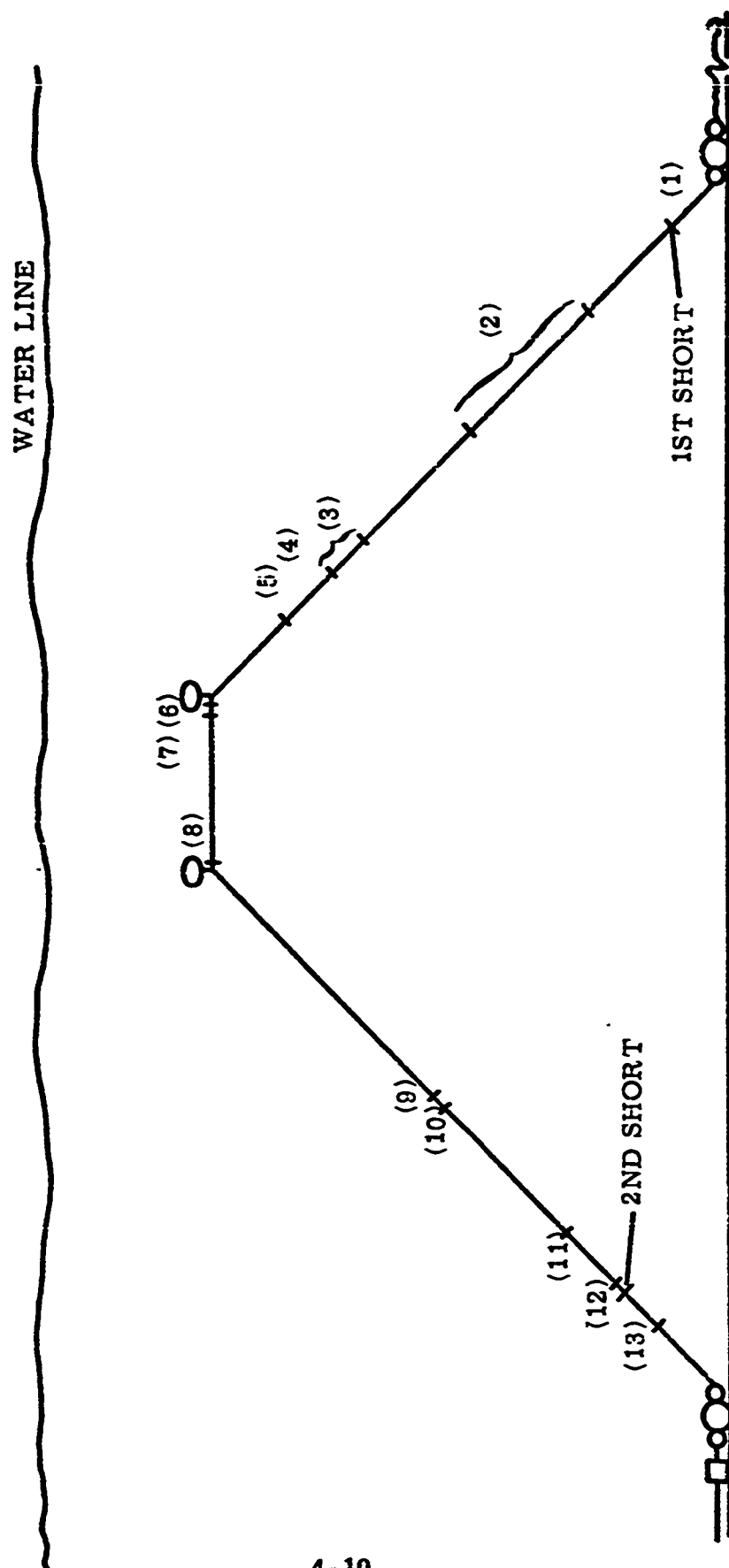


FIGURE 12. LOCATION OF IMPLANT IRREGULARITIES AND ELECTRICAL SHORTS

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5. 13,230 ft. up the offshore leg at instrument package 22E7, the Array went dead electrically as this instrument package went over the drum. The electrical wire was purposely cut within the package and tested in both directions. There were no electrical faults looking shoreward. Looking seaward, a shield-to-outer-conductor short was detected, and its location was determined to be in the vicinity of the first hockle. At this point the choices were to (a) attempt to haul back cable for repair, (b) electrically terminate the Array at the cut and then proceed to lay cable, (c) proceed laying cable and electrically terminate the Array inboard of the seaward riser corner float. The first possibility was ruled out because of the impending rough weather, the length of time it would take (including time to remove the glass spheres) and the lack of confidence in performing this tricky recovery procedure successfully. The second remedy was discarded in favor of the third because the ship was heaving, cable tensions were quite high and it was only a short distance to the point where the offshore anchor would touch down and thereby relieve tension in the cable. Consequently, payout was resumed.
6. 50 ft. inward from the offshore buoy, the Array cable was opened electrically at this point.
7. 350 ft. inward from the offshore buoy, a kink developed in the cable. There was no measurable electrical damage so the kink was stress-relieved with 3/8" wire rope using preformed grips and turnbuckles.
8. Between instrument packages located 100 ft. and 70 ft. outward before the inshore buoy, there was very little length of flexible cable between splice rods. This fact is noted with no additional information. Apparently there was no noteworthy damage in this segment.
9. Before the instrument package located halfway down the inshore leg, exact location not specified, the payout process was halted in order to distribute twists along the cable. Payout was then resumed.

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10. 7,900 ft. up the inshore leg, a very bad kink occurred. In addition to the structural damage, the cable's electrical conductivity was broken. The entire segment of kinked cable was cut and the remaining cable ends were respliced electrically. The connecting segment was then overmolded to the armor outside diameter and taped. Steel wire together with deadeye stoppers and preformed grips provided a tension bypass for that segment. Payout was then resumed.
11. 5,200 ft. up the inshore leg, twists were developing in the tank. They were allowed to distribute themselves sufficiently and no hockles were formed coming out of the machinery.
12. Just below the instrument located 4,200 ft. up the inshore leg a severe twist was developing just before the DOHB was reached. Payout was halted and the twist was distributed down into the tank. The cable looked good coming out of the machinery, so no splice rods were used.
13. Just below the instrument package located 2,700 ft. up the inshore leg the cable started twisting in the tank. The twist was redistributed by hand and the cable looked good coming out of the machinery. Again, no splice rods were used.
14. At the SDC cable payout point calculated to correspond to the inshore anchor touching bottom there was no corresponding reduction in tension. Moreover, the depth gage showed the inshore buoy to be at 3,600 ft. depth - in its final geometry it should have been at 4,100 ft. depth. Upon additional payout of SDC cable, the inshore buoy rose to 3,570 ft. depth. Consequently the ship started paying out SDC cable with negative slack until the inshore corner location stabilized at 3,800 ft. By this time the storm was so violent that tensions at payout never did drop to the range corresponding merely to the weight of the suspended SDC cable in water - which would have indicated that the anchor had definitely touched down. Payout tensions during the next day of cable laying varied between 0 to 10,000 lbs. The final weighted chain attachment was not

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made because of the rough seas. The inshore Array corner eventually held at 3,800 ft. depth as additional cable was laid.

15. Within two hours after the shore cable splice, the entire Array went dead electrically.

4.2.4 Positioning

4.2.4.1 Navigational Aids

(U) Primary navigational aids system used on board the vessel NAUBUC was the Decca Hi-Fix System. Secondarily, navigational assistance was obtained from Bermuda, NASA Radar. During the deployment, five minute comparison checks for verification between the two systems were conducted. During the laying of the SDC cable to the beach, half-hour verification checks were made. At no time during the LRAPP TEST BED deployment were any major discrepancies found between the two systems involved. Each Decca Hi-Fix shore station was in duplication to insure continuous fixing for the NAUBUC automatic control system.

4.2.4.2 Implantation Configuration

(U) The Decca Hi-Fix and the NASA Radar were used continuously. The vessel conducted a manual plot in addition to the automatic system to verify the ship's position. At the anchor point, transponders were attached and the auxiliary vessel conducted location exercises and confirmed the mushroom anchor location and the inboard Array anchor location. The outboard Array anchor transponder failed and that position was not possible to confirm by transponder from the auxiliary vessel. In addition to the positioning of the vessel by Decca Hi-Fix, a mathematical model had previously been prepared indicating where the ship should be with a given amount of cable having already been deployed.

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A vertical plot board was constructed, based on this mathematical model and was updated continually during deployment to give a graphic review of the entire Array during implantment.

4.2.5 Array Position Configuration Confirmation

(U) As discussed above, it was necessary to move the inshore ball anchor shoreward to bring the horizontal Array down into its prescribed position. This maneuver allowed the Array to come into the configuration as precalculated, with the exception that the entire Array was set 2,000 ft. shoreward from its calculated position. A final configuration confirmation was made independently by Mr. Martin on USS NIPMUC, and Mr. Smith in the instrumentation room on board the USNS NAUBUC, and their agreement was that the outer and inner syntactic buoys were within tolerance of their precalculated depths, that the inshore anchor was in its position, and it was then permissible to commence laying the SDC cable to shore.

4.2.6 Casualty Plans

(U) Casualty guidelines were prepared that considered three major elements. First, weather, second, equipment failure aboard ship and third, failure of individual units or faults developed in the cable itself. Extreme precautions were taken to provide two weather forecasters at Bermuda continuously updating Navy Fleet Weather Forecasts. No unexpected storms could be encountered during the deployment of the Array and for the cable laying toward the beach.

(U) It was clearly defined in all the planning stages that the sea conditions at the start of the implantment would be no more than a Beaufort Scale 3 wind, a 3 to 5 foot sea running at the time of commencement and that a minimum of 40 hours of good weather would follow (Reference 33). However, during the deployment of the Array, due to troubles

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experienced with twists in the cable and stopping to perform one splice in the Array cable, more time was required for deployment than the vessel had anticipated and notification that a storm was approaching caused consideration. The decision on board the vessel at that time was that the storm would not reach the area until after the SDC cable was being deployed and since that SDC cable could be deployed under adverse conditions, the decision was made to continue to lay the Array.

(U) The casualty guidelines also called for sufficiently good weather to install the Array itself and lay at least 10 miles of SDC cable and then in the event it became necessary, the ship could attach a stopper at the end of the cable, a payout grapneling line, and a buoy at the bitter end of the cable, and it could come back when the weather was abated and retrieve the other cable, make a splice and continue on to the beach. The guidelines further specified that in the event of ship-board equipment failure, spare parts were to be provided and a manufacturer's representative be available in the event of a breakdown. The guidelines covered the possibility of individual unit failure and the decision criteria as to the number and location of hydrophone failures that could be tolerated and the location of the individual environmental sensor failures that could occur and still allow deployment of the Array. These are discussed in detail in Table 4, Casualty Guidelines (Reference 19).

(U) During planning, it was recognized and the criteria established that in the event of a cable fault on the horizontal or inboard leg, requirements would dictate retrieval of the fault and a splice made. In the event that the SDC cable faulted, it would be required that the NAUBUC and the auxiliary vessel return to port and that the hydraulic press be transferred to the auxiliary vessel which was to conduct the SDC splice to the shoreward cable. These guidelines were considered adequate.

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TABLE 4
CASUALTY GUIDELINES (Reference 19)

The following criteria as to the type, number, corrective action or implantment attenuations for possible equipment casualties in the LRAPP Array and its implantment is promulgated as a guide. Due to the number of interrelated variables and their effects, the final decisions and responsibility will and must be that of the NUSC Program Manager.

At no time will the Array continuity nor its primary acoustic mission be jeopardized. Therefore, no electronics cans will be opened at sea to take any corrective actions. The only corrective actions taken at sea will be from the fuse seaward on the Array. Any corrective action requiring opening of the electronics cans will constitute an abort of the operations.

During the implantment, the only significant checks that can be made of the Array are for electrical continuity. Most of the sensor elements will not be functioning due to their limited depth and orientation until the Array is down and in place. Therefore, the following assumes proper operation once in place and tests can only be run for continuity of the Array and sensor.

ARRAY CABLE FAILURE

In the event of an Array cable failure.

Electric

The Array will be recovered to the point of electrical failure and dependent on weather will be spliced on scene or the Array will be recovered to the stable braid grapnel line. The stable braid will be buoyed off using an Array buoy and the Array will be taken into port for repair. The ATF will stand by the buoy to assure it remains intact. Extra stoppers and Dyna Grips are carried on NAUBUC for this purpose.

Mechanical

Should a gross mechanical failure occur, the remainder of the payed out Array will be recovered and the Array will be taken into port for repair and replacement. In the event of a partial mechanical failure and no electrical failure, repairs will be made on scene if the weather and other variables allow; otherwise array recovery will be undertaken.

TENSIOMETERS

There are five (5) tensiometers in the Array with one (1) spare. In the event of a malfunction on overboarding, only one can be replaced.

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TABLE 4
CASUALTY GUIDELINES (Continued)

After these sensors are in the water and continuity assures no malfunction, the electronics cannot be corrected.

INCLINOMETERS

There are three (3) inclinometers in the array and no spares. These instruments are integrally housed with their electronics and in the event of failure cannot be repaired.

DEPTH METERS

There are two (2) depth meters in the Array and no spares. These instruments are integral to the horizontal leg inclinometers and, other than continuity, cannot be repaired at sea.

CURRENT METERS

There are four (4) current meters in the Array and one spare. These are plug-in units to the Array and can easily be replaced if malfunction occurs prior to overboarding. They must be protected by a special cover device, therefore, their operational performance will not be known for several hours until the corrosive link holding the cover on has deteriorated and the cover fallen away. Only continuity check can therefore be made.

ACCELEROMETERS

There are three (3) accelerometers in the Array with no spares and they are integrally sealed with their electronics and cannot be repaired at sea.

HYDROPHONES

There are only two spare hydrophones for the Array and they can replace others if failure occurs. The cages would have to be partially disassembled. There are no spares of the hydrophone electronics, therefore, no replacement is available. Complete electronics failures of the hydrophones is highly unlikely due to the redundancy built into each package.

Generally, hydrophone or associated electronics failures, though not expected, could occur. The number and position of failed elements would require on-the-spot decisions. However, the maximum number of failures tolerable before complete Array recovery and mission abortion is eleven (11). This assumes seven oddly spaced on the horizontal leg and two (2) each on the riser legs fail. This

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TABLE 4

CASUALTY GUIDELINES (Continued)

assumes that the four (4) on the riser legs would all be at different depths.

In any case, if more than two (2) hydrophones are inoperative on any riser leg, the operation would be aborted and the array recovered, taken in to port for repair. The same would hold if more than seven hydrophones on the horizontal leg failed.

LINE DRIVERS

There are two (2) line drivers in series on the Array inshore of the last Array anchor. One spare line driver is available. In the event of complete failure of the line driver, replacement would have to be accomplished. Failure of a line driver is highly improbable due to the redundancy of the electronics in the line drivers. The details of line driver replacement are subject to a great number of variables and will be dictated by on-scene circumstances.

SEA CABLE SDC

There are two possible failures of the SDC Sea Cable, mechanical and electrical.

Mechanical

If the SDC Cable fails mechanically, it will occur between the Draw Off and Hold Back machine (DOHB) and the stern chute, in which case grapneling operations will be necessary to retrieve the lost end. It will then be necessary to bring NAUBUC into port and place the SDC Splicing equipment aboard and outfit the vessel for grapneling operations to recover the lost end of the SDC Cable. Once the ends have been recovered, a splice will be made and the cable laying continued. In the event of a hockle which would weaken the center strength member but not damage the electrical properties of the cable, LIST 1 stoppers will be applied to take the strain of the laying operation from the weakened section and transfer it to the intact sections.

Electrical

If the electrical continuity of the SDC Cable is broken, a complete splice will be required because a mechanical failure has likewise occurred. The center conductor cannot be parted without parting the center strength member.

The outer jacket and the return tape can be damaged from a number of causes. In this case sufficient spare jacket and copper

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TABLE 4
CASUALTY GUIDELINES (Continued)

return tape is being carried on NAUBUC to make emergency repairs. A cut of the return tape and jacket would not be a disaster to the implant as the entire system is grounded to sea, however, repairs will be made by cutting out the damaged outer jacket and return tape and then soldering in new return tape and welding on replacement polyethylene jacket.

NAVIGATION

The primary navigational system to be used is the Decca Hi-Fix system consisting of two completely independent systems. Failure, therefore, is highly unlikely. However, in the event of failure the NASA Bermuda Tracking Station will provide ranges and bearings (mashed) for navigation. It is intended to repair DECCA immediately and then proceed in the automatic mode. If the DECCA Systems are completely irreparable, a decision to continue using NASA Radar or recover the Array will be made as circumstances on the scene dictate. the loss of Decca Hi-Fix System means the loss of computer automatic control. Manual Mode operations must therefore be used.

In the unlikely event of both DECCA and NASA Radar failures, LORAN "C" will be used to provide station keeping navigation for NAUBUC. Implantment will not proceed using LORAN "C" as its accuracies are not sufficient.

A computer failure would affect the operation in the same manner as a DECCA failure and the same procedure would be followed.

THRUSTER FAILURE

The failure of any one thruster has no effect on the implantment nor the automatic control system of the vessel. The automatic control system can handle thruster failures until either both forward or after thrusters fail. Then manual operations must commence. However, the computer strip chart and plotting system would still function. Therefore, in the event of both forward thrusters or after become disabled, manual ship operation will be used.

PERSONNEL CASUALTY

In the event of serious personnel casualty requiring MEDEVAC, a helicopter from Kindley Naval Air Station will be dispatched to NAUBUC and the casualty air lifted to the Naval Hospital at Kindley Naval Air Station, Bermuda. There will be no doctor aboard either the NAUBUC or NIPMUC.

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TABLE 4
CASUALTY GUIDELINES (Continued)

DYNAMOMETER FAILURE

The installed Dynamometer has two load cells one covering the range 0 - 6,000 pounds tension and the other 0 - 25,000 pounds.

In the event of failure of the lower range load cell and associated equipment, there is no problem. However, if the 0 - 25,000 pound load cell and equipment fail, the knowledge of tensions will be minimal. The implantment will go forth using the precision navigation information and the known payout of cable. This increases the work load on the plotters and calculators, but can be done without detrimental effect on the Array or its positioning.

LOCATION FAILURE

The failure to precisely locate the Array, SNAPS, NAUBUC or ATF are so remote as to not warrant consideration, and have been fully explored elsewhere under different heading in the Technical Plan.

Possible multiple failures occurring at the same time will be dealt with as circumstances at the scene dictate and the interaction of the failures effect the implantment plan.

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4.3 Cable Lay Analysis

(U) The decision to implant the Array, laying the cable from sea to shore, was based on the following. First and foremost, during the deployment of the Array itself, which was anticipated to take approximately 24 hours, good weather conditions had to exist prior to starting the lay and continue for a minimum of 36 hours. Starting in the reverse direction and laying from shore to sea, some 36 to 40 hours would have been used up in laying the SDC cable prior to arriving at the Array site location. Also during the 36 to 40 hours while laying the cable, the weather could have turned bad; therefore, this was the primary reasoning behind the direction in which the implantment started. Another reason was that the Array would have to have been loaded into the ship's cable tank first if the direction of lay had been from the beach to the shore. This would have made the Array inaccessible for tests on board before the implantment.

4.3.1 Selection of the Array Cable

(U) One of the advantages of the selected Array cable was the delivery date versus that of another cable type. Also, the manufacturer's cable specifications of the electrical and mechanical characteristics were deemed a good choice along with being double armored and torque balanced.

(U) The major disadvantage in the selection of the Array cable was insufficient data available on cable of this type to be used on a program of this magnitude. Additionally, there was insufficient history of testing under actual at-sea conditions on this cable. The selection was influenced by the overall time schedule, which led to the selection of a cable without prior history and proper testing.

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4.3.2 Selection of the SDC Cable

(U) Again, the rationale in selecting this cable was its reported availability for the program, within the established time frame. The history of this type cable was available and had been used by the government and commercial industry for several years. Another favorable point was the electrical and mechanical strength characteristics of the cable.

(U) The following disadvantages developed or existed with the SDC cable:

1. The cable later developed a delivery schedule slippage.
2. The cable finally selected was out of specification, both physically and electrically.
3. The cable was in three separate lengths.

4.3.3 Array Instrumentation Package Design

(U) The advantages of the design were as follows:

1. Provided the capability to splice each instrumentation package in line prior to the implantment of the Array.
2. Rugged design to protect the electronics while passing through the cable handling machinery.
3. Ease of being able to open the package and remove any electronic equipment prior to the deployment of this Array, in the event of failure to a component.

(U) The disadvantages of the package design were:

1. Excessive weight.
2. Space restrictions inside the package for electronics and cable leads. (The size and length of the package design was predicted on cable handling machinery capability).

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3. Instrumentation packages that had to be attached on deck after having the main unit passed through the cable machinery.

4.3.4 Flotation

(U) A good feature of the flotation design was the syntactic foam, 8 ft. diameter corner floats. Major disadvantages were the efforts required to mount 1,623 flotation glass spheres on the Array and the number of personnel required to handle and attach these floats.

4.3.5 Selection of Anchors

(U) The only good point of these anchors is that the mass (weight) is concentrated. However, there was a marginal amount of anchor weight in relation to the buoyancy that was added to the cable. Another undesirable feature was the time that was required to attach these anchors to the cable.

4.3.6 Cable Laying Vessel

(U) The arrangement of the ship and machinery is shown in Figure 13. The following major criteria were used in justifying of the cable ship:

1. Positioning control capability that the vessel had.
2. Sufficient length on deck was provided between the dynamometer and the stern chute to attach the glass balls and bellmouths for the flotation gear.
3. The size of the cable machine drum and the pay-out control enabled the machine to pay out one ft. of cable per minute.
4. The fleeting knife arrangement on this particular cable machine permitted the units to be paid out without problem. The lack of fleeting knives on another cable ship drum would have presented a considerable problem with overriding turns.

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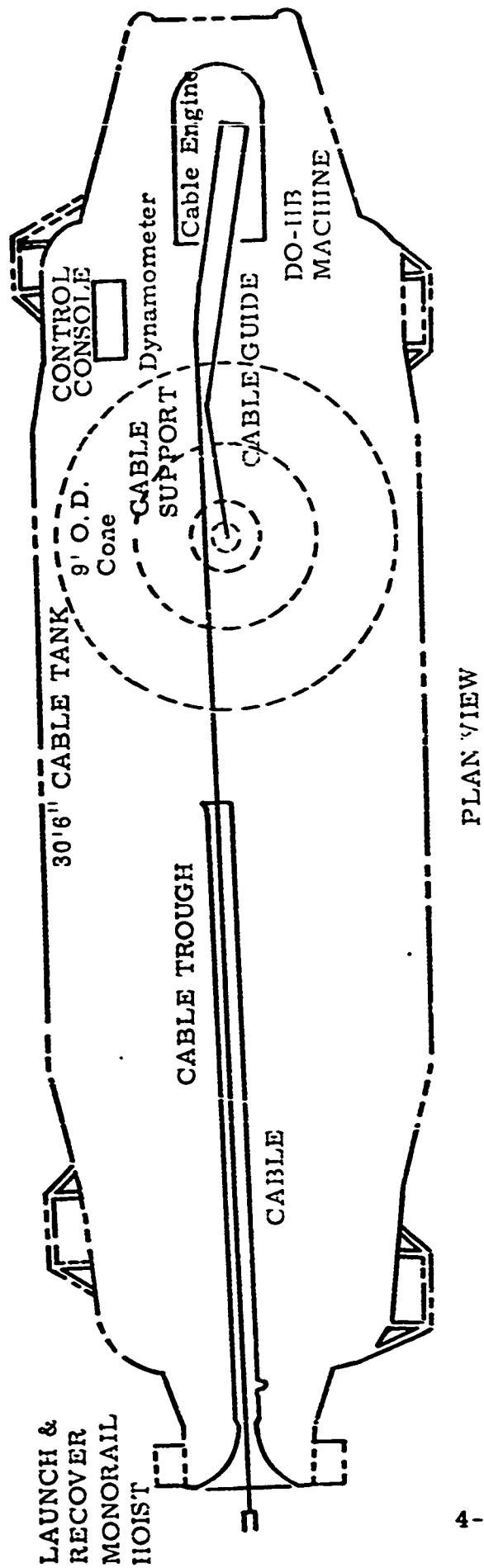


FIGURE 13 - USNS NAUBUC Cable Handling Facilities

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(U) Disadvantages in the selection of this vessel were:

1. Limited facilities on board for messing and berthing of the crew.
2. The space available for an instrumentation room.

4.3.7 Cable Behavior Tests

(U) This being a new cable design, it is believed that insufficient field testing was conducted on the cable. It could have been passed through the NAUBUC cable machine with sensory units intermittently attached to the cable and with weight equal to the mass anchors to determine cable behavior. During the shallow water training period, this new Array cable was not used. Instead, approximately two nautical miles of SEA SPIDER cable was substituted. During the training period there was insufficient tension applied to the cable due to the shallow water.

(U) The above, plus the difference in design of the two cables, permitted the training cable to be layed and retrieved repeatedly without developing substantial defects. Secondly, insufficient units were spliced into this training cable or possibly the twisting action would have developed. Hindsight indicates that this type Array cable, including a number of instrumentation packages, should have been field tested in deep water, simulating actual conditions that would be encountered in the final Array deployment. Table 5 summarizes the types of stresses imposed on the cable at each stage of handling and deployment.

(U) The on-site decision to continue with the program even with the intermittent fault that had developed in the Array, and after the first fault occurred during deployment, was undoubtedly influenced by statements made during the regular monthly meetings held at New London, Connecticut. A large percentage of emphasis of the deployment of this Array was based on the capabilities to deploy and achieve this Array configuration with a much lesser percentage of emphasis on the environmental data.

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TABLE 5
STRESSES AT ALL STAGES OF CABLE HANDLING
(Reference 34)

<u>CABLE HANDLING PROCEDURE</u>	<u>STRESS</u>
Manufacture	Tension and release
Cable wound onto reels	Tension plus bending
Cable transferred onto smaller reels	Maintain tension - remove & reapply bending
Array fabrication	Remove tension and bending - no provision for untwisting
Coil into tank for leakage test	Combined bending and torsion
Uncoil from tank	Remove bending and tension
Coil into truck flatbed	Combined bending and tension
Uncoil from truck flatbed	Remove bending and tension
Test instrument cages aboard ship	Tension and release
Through drum and fleeting knives	Combined tension and bending, and possibly torsion
Through DOHB	Traction and lateral compression
Coil into tank of ship	Combined bending and torsion
Uncoil from tank of ship	Remove bending and torsion
Through DOHB	Traction
Through drum and fleeting knives	Tension and bending (and torsion?)
Over dynamometer	Combined tension and bending
Over stern plate	Combined tension and bending
Implantment	Tension - possibly torquing
In-situ	Tension, possibly torsion also

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4.3.8 Mathematical Model

(U) This model was developed at NUSC to approximate the Array tensions and configuration during deployment. It was very close to what was actually experienced at sea and was helpful during the deployment in determining where the ship should be, versus the amount of cable out at all times.

4.3.9 Cause of Twists that Developed (See Section 4.4, Cable Handling Analysis).

(U) Table 6 contains a summary of the twists removed from the cable while being loaded into NAUBUC.

(U) Several possibilities of the cause of these twists exist as follows:

1. Unbalanced torque of the external wires for short distances during the manufacturing on either inner or outer armor wires.
2. Slight change in helix on the inner or outer wires during manufacture over short periods.
3. Repeated handling of cable at the DeBell and Richardson plant during Array fabrication while cutting it into correct lengths for splicing in the electronics units.
4. Lack of external jacket over outer armor wires permitting the wires to shift during handling.
5. Induced twists during the loading into the ship's cable tank.

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TABLE 6

SUMMARY OF TURNS REMOVED FROM .68 TEST BED CABLE
WHILE LOADING INTO NAUBUC'S TANK
(Reference 34)

<u>NO. OF TURNS REMOVED</u>	<u>LOCATION ON ARRAY</u>	<u>SENSOR STATION</u>	<u>METHOD OF REMOVAL</u>	<u>ACCUMULATED TURNS</u>
2½	Inboard Leg	6	Rotate Ball Joint	2½
2	Horizontal Span	8 & 9	"	4½
2½	Horizontal Span	20	"	7
1	Outboard Leg	22	"	8
21	Outboard Leg	Distributed Below Sta 22	Rotate Truck	29

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(U) The cable handling system on board the USNS NAUBUC was manufactured by the Western Gear Corporation (Everett, Washington), a leading American manufacturer of cable machinery. The total system is comprised of one main cable drum 12' in diameter, having a maximum lift capacity of 25,000 lbs., with a 3-knot speed for either payout or pick-up. It has four fleeting knives that engaged to the drum face, permitting packages such as those in the LRAPP Array to be fledged around the drum without causing cable to pile up, as would be experienced on the fleeting ring or a single fleeting knife. Each wrap of cable on the drum was fledged independently.

(U) Another major piece of machinery was the linear draw-off hold back machine (DOHB), which normally is operated with about 1,000 lbs. tension or compression on the cable to prevent slack building upon the main cable drum. A cable dynamometer measured tension on the cable, a stern payout chute with a 12' diameter radius, a cable tank 36' in diameter, cable fairleads and bellmouths where the cable comes out of the tank and as it passes along the deck, cable measuring counters and cable payout speed counters. This particular machine aboard the NAUBUC has paid out and retrieved in excess of 100 miles of submarine cable and grapnel line.

(U) The control on this machine is electro-hydraulic and operates very well. It is possible for the cable engine operator to pay out just a few inches of cable, stop, or pay it out at under one foot per minute if that becomes a requirement. Basically, the entire path that the cable takes from the cable tank to the stern is so designed so that the cable cannot be bent around anything less than a 12' diameter. This machine to date has caused no known problems during previous operations. A complete description of the entire vessel and all of its equipment, including the cable handling machinery, is available aboard the vessel and is also detailed in the technical plan prepared by NUSC.

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4.4 Cable Handling Analysis

(U) During the deployment of the TEST BED Array, a number of hockles, kinks and other defects in the cable occurred in the Array cable while being payed out of the vessel's cable tank, and prior to this, several twists in the cable, which were relieved, were experienced while attempting to load the tank from the flatbed truck. There are numerous possibilities that would allow for the cause of this hocking or kinking in a cable. Due to the lack of engineering data at the present time, there is no simple, single solution that can be put forward to describe the twists that were encountered in the cable, both in loading aboard the NAUBUC and in the deployment of the Array.

(U) It is quite possible that the twists which developed into hockles, and in some cases kinks, were responsible for the cable failure and, in turn, for the Array failure. There are other feasible causes with less probability for the Array failure which might be considered such as failure of the electronic packages, etc., but the basic design of the system was to guard against this type of failure. The damage that was induced into the cable itself by excessive twisting, i. e., the severe mechanical damage at numerous points, and in one case electrical damage, must be explained in a diagnostic analysis of the LRAPP TEST BED Failure.

(U) The LRAPP TEST BED cable was a cable that had not been used before in a similar array implantment. Its torsional and tensional properties were essentially unknown, empirical data were absolutely lacking and implantment had never before been attempted. The only data that were available was that under tension this cable would not rotate more than 1.85 rotations per thousand feet under 50% breaking strength. The LRAPP TEST BED Array cable is coaxial double armored cable consisting of copper core and copper braided shield separated by polyethylene insulation and surrounded by a polyethylene jacket encased in left-handed twist armor and right-handed twist armor of plow steel.

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(U) To get the Array to lie dead, the TEST BED cable was coiled counterclockwise at the DeBell and Richardson Plant, on the flatbed truck, and in the cable tank aboard the NAUBUC. The righthand twist imparted by the counterclockwise coiling loosens the righthand outer cable lay and tightens the left-hand inner cable lay. In forming a flake, the cable, in essence, is twisted 360° and must be capable of absorbing this amount of twist; otherwise, the cable will not lie dead.

(U) The basic nature of the double armored cable is to resist twisting; consequently, when the outer lay was twisted each full 360° , the inner lay most probably resisted the full turn due to tightening and thus a residual torque was developed. It is believed, but not empirically verified, that this residual torque is not fully relieved when the cable is uncoiled because of the frictional resistance between the inner and outer armor. Thus, each time the cable was uncoiled and then recoiled in the same counterclockwise direction more and more of the unrelieved residual torque was developed.

(U) When the cable was passed from the flat-bed truck to the cable tank it passed against the fleeting knives, over the cable drum, and through the Draw-Off Hold-Back machine. These devices prevented rotation of the cable which forced the residual torque to move back through the cable toward the cable storage on the truck. The movement of this torque eventually built up to the point where hockles began to develop. The hockles and residual torque buildup were relieved by breaking the ball joints and rotating the cable, by rotating the truck, and by allowing the bitter end of the cable to rotate.

(U) Latent torque or residual torque can, therefore, build up within the cable to a point where the cable must kink or hockle or a free end must rotate. The process of transferring this torque from one part of the cable to another is described as stripping. This action occurs as the cable is moved from one location to another and is passed over

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sheaves, chutes, bellmouths, fleeting knives or any other positive surface that prevents the cable from rotating.

(U) This tendency to rotate will be passed along the cable as it butts against any obstruction against which the cable moves. As this is happening, there is a dynamic action taking place within the structure of the cable. The residual torque builds a twisting force that structurally appears in the form of a helix that moves down the cable much the same as a standing wave. With continued unrelieved cable movement, the helix compresses until cable damage or twist relief is experienced.

(U) During Array deployment, the cable handling equipment forced the residual torque back into the cable tank. This phenomenon, where the cable was becoming alive several turns ahead of pull-out, was observed by Mr. Cummings, the Project Manager. It is noteworthy to observe that the hockles and kinks developed just in front of the sensor packages as they were being drawn out of the tank. This reflects the resistance of the heavy electronic packages to rotate and thus pass the helix on into the storage tank. Experiments were conducted by Mr. T. Cummings, Project Manager, by placing a white strip on the cable and observing its behavior as it passed around the cable drum and through the DOHB machine. Mr. Cummings, Captain Wyeth and others concerned with these experiments attest that absolutely no rotation of the cable took place as it passed through the DOHB machine or over the cable drum. However, these observations were restricted to a hundred or so feet of cable and there exists the possibility that the cable drum would allow cable twisting at some fraction of a revolution per thousands of feet.

(U) It is quite probable that the hockles and kinks experienced during the implantment of the TEST BED Array were due to the induced residual torque that was stored in the cable by the multiple coiling prior to loading and the twists that were made as the Array was flaked into the

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cable tank. The fact that the Array was spliced to the SDC cable prior to loading on the NAUBUC removed any capability of the bitter end (at the line driver) rotating, and compounded the hockle problem in deployment over and above that experienced at the time of loading.

(U) The twisting built up to a point where the cable could no longer absorb it because of its inherent torsion resistant characteristics and had only one of two options, either to revolve one end, which was impossible since both ends were fixed, or to throw itself into a series of loops and kinks. The latter occurred some thousands of feet after initial deployment and continued to occur at increasing frequency until the end of the Array. The SDC cable, on the other hand, was not torsion resistant and was deployed without mishaps.

(U) The above is a pragmatic analysis of what may have occurred aboard the NAUBUC during the deployment of the TEST BED Array. Analytical data are completely lacking as can be discerned in the recommendations that testing be done with the 500 ft. section and the 2,000 ft. section of TEST BED cable still remaining unused. These tests should be conducted to determine the cable's torsion resistant characteristics and its behavior under coiling so that a complete analysis can be made of the TEST BED failure.

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5. TRAINING

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5. TRAINING

5.1 Introduction

(U) The Master of the NAUBUC (the Implant Director) and the Project Manager, NUSC, were responsible for planning the training exercise. It was well planned and well executed. The training array consisted of 11,000 ft. of SEA SPIDER cable, Rochester No. 20675, an actual instrument cage, glass spheres to give the cable neutral buoyancy, grapnel line and a 1,000 pound mushroom anchor (Reference 33). The first ten trips consisted of laying the Array and recovering it two cycles per trip. The first six of these excursions were from NUSC to a point southeast of Block Island Sound. The last four of these excursions were from NUSC to Gardner's Bay off Long Island Sound. During the field trips, the crews encountered variable weather, ranging from complete calm to sea states approaching State 3. After the first ten trips which consisted of laying and recovering the Array, there were four more trips for the training of the bridge crews and plot teams. The next training trip was to Long Island Sound for the recovery of an old array cable lying on the bottom of the Sound. The NAUBUC was successful in retrieving the cable with the help of divers. Subsequently, two other field excursions followed which consisted of launching and recovering the 8 ft. diameter syntactic foam buoys to make sure they would slip off the radius plate at the stern.

5.2 Equipment

(U) The equipment that was used for training the personnel aboard the NAUBUC in laying and recovering the above described training array, was the same equipment that was actually used in the implantment. Therefore, the crew had the advantage of using exactly

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the same cable handling equipment that was used for the implantment and had a chance to be accustomed to the peculiarities of the NAUBUC herself. As stated above, the training cable was 11,000 ft. of PACIFIC SEA SPIDER cable, carried by the Rochester Corporation under the Stock No. 20675. This cable has slightly different characteristics from the cable that was used for the final TEST BED implantment, which was a cable originally designed for Scripps Institution of Oceanography and carried under the Rochester Stock No. 20680. There are several differences in the physical properties of these two cables, but the one that is most applicable to the present analysis of the TEST BED Failure has to do with the twist under tension that each of these cables undergoes; e.g., the 20680 cable makes only 1.85 turns per thousand feet when loaded to fifty percent of its breaking strength, compared to 51 turns per thousand feet for the 20675 cable (Reference 34). Therefore, the training program, although carried out with identical equipment used for the implantment, used a cable with somewhat different physical properties. Consequently, the crew of the NAUBUC had no opportunity to handle a highly torsional resistant cable such as the actual TEST BED cable.

(U) The test array, when passed through the NAUBUC's cable handling equipment, showed few problem areas through ten cycles of implantment and retrieval. Consequently, it was assumed that the actual TEST BED cable would be compatible with the NAUBUC and her handling equipment and could be implanted without any problems.

5.3 Personnel

(U) One of the reasons that the NAUBUC was chosen for the implantation ship was that it was possible to recover most of the people that had originally been trained on the NAUBUC for a similar program.

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This included not only the ship's officers, but cable machine operators and the key deck personnel. The TEST BED Program was successful in obtaining the services of more than 50 percent of these trained personnel. This was very fortunate since under the earlier program an extensive training period of over a year and a half had taken place and this training combined with the training program off of Connecticut just prior to the TEST BED Implantment insured a very well trained crew.

(U) An extensive training document was prepared for the personnel that were to work on the TEST BED Implantment. In addition, there were training sessions with these personnel in the classroom, as well as aboard ship. Because of the great complexity of the implantment, it was not possible to familiarize every man with every single operation on the ship, but each man was very well trained by the time he went to sea for his own particular job. The personnel aboard the NAUBUC were of exceptionally high quality and were very well trained prior to the implantment.

5.4 Training Routine

(U) There were some very great differences in the training routine that took place off Connecticut and the actual implantment that took place off of Bermuda (Reference 33). Mainly, the differences lay in the fact that the training program was carried out in shallow water with a short length of cable, whereas the actual implantment was carried out in very deep water with a very long length of cable. As was stated above, ten times the training cable was passed through the NAUBUC's cable handling equipment, was coiled and uncoiled, without any problem arising. However, when the same technique was applied to the TEST BED cable, tensions developed in the cable far in excess of those that had been observed during training. The crew of the NAUBUC were not prepared for the high tensions that developed in the actual implantation

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cable, nor were they prepared for the highly torsion resistant characteristics of that cable.

(U) With the exception of the cable, the other training routines were directly applicable to the implantation. They included such things as how to attach the buoys to the cable, how to release the buoys into the water, how to lay the ground tackle, how to handle the sensor units, how to attach the floats to the cable, etc. All of these training exercises were of great assistance in the actual implantment.

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6. SEAMANSHIP

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6. SEAMANSHIP

6.1 Introduction

(U) The seamanship displayed during the implantment of the LRAPP TEST BED Program was adequate. This quality of seamanship was primarily due to the very well executed training programs that had taken place prior to implantment, to the excellent positioning equipment that was available for use aboard the NAUBUC, and to the design of the Array itself which allowed the master to know at all times the position of the various components of the Array. In addition, implantment predictions had been made beforehand which specified in detail the shipboard procedures during the implantment. These procedures included the prediction of cable payed out, the ship's position, the cable's payout speed versus the ship's speed, shipboard cable tensions, etc. All these data were of great assistance to the master in achieving a high level of seamanship.

(U) The general plan of the implantment called for the NAUBUC to lay-to in port or lay-to at sea until excellent weather conditions existed before attempting to lay the Array. Consequently, during the laying of the Array, almost ideal conditions existed regarding sea state and no problems were experienced in handling the ship or equipment because of sea conditions. On the fourth and fifth of December, while deploying the SDC cable, the sea picked up with wind speeds approaching 60 knots and 15 to 18 ft. swells (Reference 33). It was during this time that Captain Wyeth displayed excellent seamanship in not losing the Array or damaging any equipment or injuring any personnel. The implantment continued during this period of high sea states until they moderated on the afternoon of the fifth. The NAUBUC has a very short period, uncomfortable roll and this was bothersome to some of the

personnel but was not dangerous to the operation. Captain Wyeth was concerned at several points during the fourth and fifth of December for the safety of his men on the foredeck. These men were in very exposed positions and with heavy swells and seas breaking over the deck; there was some danger. Nevertheless, the NAUBUC was able to proceed with the Array implantment to its successful conclusion.

(U) Although good seamanship was displayed by the master and the ship's crew, technical people aboard the ship who were not familiar with shipboard procedures were, in some instances, somewhat of a hindrance to the master's successful completion of the laying of the Array. During an implantment of this complexity, the ship's bridge must be kept in a very quiet and organized condition. Excess personnel had to be excluded from the bridge, as well as all excess noise including radio transmissions, voice conversations between people on the bridge and any other sorts of confused activities.

6.2 Ship Loading

6.2.1 Synopsis of Ship Loading

(U) The LRAPP TEST BED Array was delivered to the NAUBUC in Bermuda aboard a flatbed truck onto which it had been coiled at the DeBell and Richardson plant by coiling counterclockwise around two stumps on the bed of the truck. The cable had laid exceptionally well in the truck with the exception of a few instances in which a cage segment had to make the sharp turn around the bullnose. Unable to bend the cage segment readily, DeBell and Richardson broke the counterclockwise pattern by looping the cable just before the bullnose, stretching the instrument package across the truck and back to the prior bullnose, and then continuing in a counterclockwise direction. The Array thus loaded on the truck was airlifted to Bermuda and brought dockside

along the NAUBUC. Because the cable had laid nicely in the truck, there was no indication of any dynamic bending or residual torque.

(U) The cable was uncoiled clockwise from the truck, led onto the stern of the NAUBUC 90 degrees around a fairlead sheave, across the deck, over a dynamometer to the 12 ft. diameter drum where it made four and a half turns between the fleeting knives, then across the Draw-Off-Hold-Back Machine (DOHB), 90 degrees over a 12 ft. diameter radius plate, and through a hole in the deck to the storage tank. As before, the cable was coiled counterclockwise in the tank of the ship (Reference 33).

(U) The drum and fleeting knife arrangement provided at least several hundred pounds of tension on the cable at all times, while the DOHB machine provided a traction force estimated by NUSC to be several hundreds of pounds.

(U) As each instrument package approached the middle of the deck, the cable was stopped off near the stern with a preform line grip. With the drum and fleeting knives providing a driving force, and the DOHB exerting an additional backup traction, the cable was tensioned at each package to values ranging from 14,000 to 20,500 lbs. Each package was dipped in a salt water trough and tested electrically after tension was applied, while in other cases the test was administered both before and after application of tension (Reference 27).

(U) Although the cable was free to rotate at the preform line grip, no rotation was evident either as a result of tensioning the instrument packages or of relieving these tensions, nor were any twisting tendencies discerned during nominal stressing of the Array by the drum (References 31 and 33).

(U) After 11,000 ft. of Array cable had been loaded, a twist was built up at instrument package 6H5. The twist was righthanded and

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tended to tighten the outer righthand wound armor. The twist was relieved by unfastening the ball joint at 6H5 and allowing it to rotate two and a half turns.

(U) The following day another socket was relieved one and a half turns in the same direction. Later on that day, still another turn had to be relieved, also in the same direction. However, this time rather than relieving the socket, the truckbed was lifted with a crane and allowed to rotate one turn clockwise, looking down on the truck.

(U) On the third day four more turns were made by rotating the truckbed. On the fourth day, twenty more turns were made. No turns were made on the fifth and last day of loading, but there is no record of how many times, if any, the end of the Array was rotated.

6.2.2 Ship Loading Analysis

(U) After all of the Array cable had been stored in the cable storage tank, it lay flat and without life, indicating that there was no residual torque built up in it or that there was no tendency for it to twist in the tank (Reference 33). At this point in time, it is probably true that the cable lay in the cable tank in near satisfactory condition with no exceptionally prominent built-in problems. However, the extreme difficulty encountered in passing the Array cable through the cable handling machinery to the cable tank, as just delineated above in the synopsis, should have indicated a major incompatibility between the Array cable and the cable handling machinery. This incompatibility could have been envisioned to also occur on paying out of the cable during implantation.

(U) It was at this point that a serious error was made in handling the cable. No attempt should have been made to pay the cable out again through the cable handling machinery without discerning carefully the reasons for the rotations of the truckbed and the socket joints upon

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loading. The fact that the cable was severely twisting upon passing through the cable handling machinery should have been indication enough to warrant a complete engineering analysis before proceeding further.

6.3 Positioning

(U) Excellent navigation and positioning was carried out throughout the entire operation. Decca Hi-Fix equipment was installed aboard the NAUBUC and that, together with the use of the NASA Radar, allowed very accurate ship positioning. A constant plot was being kept in the plotting room of the position of the ship and the position of each component of the Array. Even during the bad weather that developed on the fourth and fifth of December, the navigational aids aboard the ship functioned perfectly and the ship's master knew exactly where he was at all times and could continue on with the operation. The navigational seamanship displayed during the implantment of the TEST BED Array was of exceptionally high quality.

6.4 Deployment (Reference 27)

6.4.1 Mushroom Anchor and Grapnel Line

(C) Deployment of the Array, commencing with the mushroom anchor, commenced at 1735 Z hours on 2 December, after having waited in the area about one and a half days for the seas to moderate. The anchor reached the bottom in four hours. The remainder of the grapnel line was payed out in five hours while the ship moved ahead along the track 24,000 ft.

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6.4.2 Seaward Riser Leg

(C) The offshore anchor was deployed in about one-half hour, after which it was lowered as the ship proceeded along the track and payed out the offshore vertical Array cable. After 2,178 ft. of cable had been payed out, a kink formed just below 28E-9. Action was taken to protect the weakened area. A short near the kink was observed after about 7,500 ft. of cable had been payed out. Initially, while lowering the anchor, high tension peaks, 15,000 lb. maximum, were observed due to ship motion in the seaway. These dynamic tension peaks moderated after one and a half miles of Array cable had been payed out. The offshore Array ball anchor touched down at 1337 Z hours on 3 December 1970, about ten and a half hours after it was deployed. Indicated Array cable payed out was 14,541 ft. The remainder of the offshore vertical Array cable was payed out in about another one and a half hours.

(U) Deployment of the offshore buoy and electrical modifications to the Array because of a short consumed about four and a half hours. It was during this time that the position of the offshore anchor was determined by means of an acoustic transponder and independently from cable payed out and ship position data available on ship, and found to be 2,000 ft. shoreward from its precalculated position.

6.4.3 Horizontal Leg and Shoreward Riser Leg

(C) The horizontal and inshore legs were deployed along the surface after the offshore buoy had been deployed. Sufficient tension was maintained to keep the offshore buoy submerged during this operation. The horizontal leg was deployed in about four hours, during which time additional problems with kinks were encountered. Deployment of the inshore buoy consumed about one-half hour. As the inshore vertical leg

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was payed out, a severe kink developed which required that a splice be made. The splice was completed in ten and a half hours at 1348 Z hours on 4 December 1970. Deployment of the remainder of the inshore vertical leg was then completed, but several additional twists in the cable were encountered. Deployment of the inshore leg was completed at 1810 Z hours on 4 December 1970, about eighteen hours after deployment of the inshore buoy. During this period, seas had moderated to a near calm and then had begun to pick up again.

6.4.4 Deployment of Inshore Anchor, Line Driver and Final Positioning of the Array

(U) The inshore anchor and line driver were deployed with the assistance of hack lines until about 50 ft. of sea cable had been payed out. The ship then moved ahead, paying out sea cable, to a position from which touchdown of the inshore anchor was to be affected. At this point, cable payout and ship movement were stopped for about 25 minutes to allow the Array to approach a static configuration. Payout was resumed to complete touchdown. Touchdown was difficult to observe because by this time the seas had picked up considerably. When it was thought that the anchor had touched down and when depth measurements had shown the inshore Array corner to be within tolerances, at 3,600 ft. depth, the ship proceeded ahead, paying out cable. The Array corner was then observed to be rising. Cable was laid with negative slack until the Array corner came down to 3,800 ft. depth where it remained thereafter. The time from deployment of the anchor to achievement of the final Array position was about seven and one-half hours.

(U) When the final Array had been achieved, the seas had built up to the point where deployment of the final anchor chain was not possible so it was decided to rely on the sea cable to supplement the holding power of the inshore Array anchor. This was done by laying cable at

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zero slack for the first four miles of SDC cable and then turning to the west, laying slack cable toward the inshore splice point.

6.4.5 Laying the SDC Cable

(C) Throughout the night of 4-5 December 1970, cable was laid in a severe storm. During this time, it was necessary to be concerned only with the safety of the men on the ship and with losing the cable. As stated above in another section, the ship's master was mainly concerned with the safety of the men on the foredeck. During the day of 5 December 1970, the seas gradually moderated, cable payed out and ship position data were analyzed and adjustments to payout were made to assure that the inshore splice point would be reached. On the morning of 6 December, the ship turned north and made the run to the splice position. The cable was cut and dropped a few hundred feet inshore of the splice position at 1339 Z hours on 6 December 1970. Approximately 1,700 ft. of cable were left on the ship.

6.4.6 Summary

(C) The above exercises in laying the Array, especially the behavior of the crew, master and associated personnel during the storm of the night 4-5 December 1970, all indicate an adequate degree of seamanship. Implantment predictions were made beforehand to specify in some detail the shipboard procedures during the implantment. These procedures included prediction of cable payed out, ship position, cable payout speeds versus ship speeds, and shipboard cable tensions to be expected. Predictions also were to serve as a design aid since maximum cable tensions were predicted. The usefulness of these predictions was somewhat negated by the misplacement of the offshore ball anchor 2,000 ft. inshore from its precalculated position. Nevertheless, the implant predictions provided an essential guide throughout the entire

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operation. Supplementing these predictions, the vertical plot board provided up-to-date visual information on the progress of the implantment.

(U) Through the cooperation of the vertical plot board personnel, the navigational personnel on the bridge and ashore and the skill of the master of the ship, the deployment of the Array even under storm conditions was carried out in the most seaman-like manner possible. Several instances of zero cable tension occurred, specifically during the laying of the offshore anchor for touchdown, and several instances of very high cable tension occurred, specifically during the laying of the SDC cable. Nevertheless, no equipment was lost, no personnel were injured, and the engineering aspect of the entire task was carried off in a very seamanlike and in an expeditious manner.

6.5 Confirmation of Array Position and Configuration

(U) In the laying of the Array, the mushroom anchor was put into its precalculated position and a grapnel line was payed out toward shore. However, it was found out that rather than having somewhat over 31,000 ft. of grapnel line, the actual length of the grapnel line was something like 34,000 ft. This resulted apparently from stretching and mis-measurement of the nylon grapnel line and ultimately reflects back on the lack of meeting the specifications for stretch and length as specified under the TEST BED Project by the manufacturer of the grapnel line. The result of this over-length of line was that the offshore ball anchor was placed some 2,000 ft. inshore from its precalculated position. This circumstance disrupted the precalculated positions of all other entities in the Array and consequently there was some concern as to the exact Array configuration as it was being laid. At the time the shoreward ball anchor touched bottom, the shoreward float on the upper end of the shoreward riser leg was some 100 ft. or so higher in the water column than intended. To correct this, as the entire Array was oscillating or

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bouncing with about a 15 minute periodicity, the shoreward ball anchor was pulled shoreward several hundreds of feet. This maneuver allowed the horizontal Array component to come into its precalculated alignment with the bottom and essentially produced the Array configuration as precalculated, the exception being that the entire Array was set 2,000 ft. shoreward from its precalculated position.

(U) The final configuration confirmation was made independently by Mr. Martin on USS NIPMUC and Mr. Smith in the instrumentation room on board the NAUBUC, and their agreement was that the outer and inner buoys were at the precalculated depths, that the inshore anchor was in its position and that it was permissible to commence laying the SDC cable to shore. The confirmation of the Array position and configuration was the confirmation of the successful engineering of a very difficult ocean engineering problem, i. e., the laying of a midwater Array of this magnitude in over 14,000 ft. of water.

6.6 Sea State Effects and Contingencies

(U) The successful laying of the TEST BED Array depended upon excellent weather during the implantation of the Array itself. Consequently, the NAUBUC stood by at sea for one and one-half days waiting for a period of excellent weather to occur. When that period did occur, she began to lay the Array. Therefore, during the actual implantment of the Array, good to excellent weather was present the entire time. During the laying of the shoreward anchor and as the SDC cable was beginning to be laid shoreward, the weather deteriorated rapidly until 15-18 ft. seas and 60 knot winds developed. However, during the laying of the actual Array, itself, there were ideal sea conditions, and sea states probably had no effect upon the final failure of the LRAPP TEST BED Array.

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(U) When the weather did begin to deteriorate, and it deteriorated very rapidly, the shoreward anchor was being lowered to the bottom by the SDC cable. During this period the SDC cable at some time went through changes of tension from zero to about 15,000 lbs. It was during this period, the 4th and 5th of December, that Capt. Wyeth became concerned about the safety of the cable machine operator (Reference 33).

(U) During the laying of the offshore riser leg, an electrical short had occurred in the lower part of the leg. The question then arose whether that part of the offshore leg should be retrieved, the cable repaired and put back in the water, or whether the lay should continue. Weather conditions were one of the considerations that led to the decision to leave the leg intact and not try to retrieve it, but to go on and lay the rest of the Array, because at that time the NAUBUC had already begun to receive weather reports from the eastern United States indicating the approach of bad weather. If they had retrieved the seaward riser leg and tried to lay it again, they may well have been caught in the bad weather that followed soon after.

(U) Another major consideration that dictated that the seaward riser leg be left in place rather than be retrieved and repaired was the fact that during the planning of the TEST BED Implantment at one stage it was considered that the seaward riser leg would not be instrumented at all but would be an uninstrumented cable. Consequently, since this had been one of the plans at the beginning of the program, and since weather was impinging upon the successful laying of the rest of the Array, it was decided to proceed with laying the Array and to block off electrically the lower part of the offshore riser leg (Reference 33).

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7. LOGISTICS

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7. LOGISTICS

7.1 Headquarters Operation

7.1.1 Functional

(U) The logistics function within the project was in the main performed by the Project Manager and each of the several leading engineers and scientists. A review of the project's trip reports, meetings and correspondence file reveals that a major percentage of the time of management and senior technical staff was expended on logistic activities. A logistics staff would have allowed project personnel more time resolving the technical tasks of design, fabrication and systems testing. The project would have had a "one point" contact for all logistics information flow, allowing close scheduling and coordination among project groups, thereby resulting in better utilization of valuable management and technical labor time. A logistics coordinator could have assisted and relieved the Project Manager and key technical personnel of most of the details associated with the following operations:

1. Planning and scheduling of logistics operations and interaction with others.
2. Selection of procurement channels and coordination within the offices of each agency.
3. Liaison, monitoring, expediting, inspection and follow-up work associated with each procurement.
4. Selection of transportation and coordination of government bills of lading.
5. Selection, coordination and arrangement for warehousing, staging and handling operations.
6. Coordination of fabrication and machine shop services within NUSC and surrounding areas.

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7. Coordination of local purchases.
8. Arranging for loaned, rental, or leased test equipments and other equipments similarly attained.
9. Provision of a daily, weekly and monthly input to the project's schedule for updating and spotlighting problems, real or potential.
10. Assistance to the Project Manager and others in seeking out and planning solutions for contingencies and problems that arise.

7.2 Operations

7.2.1 Coordination

(U) The NUSC Project Manager was responsible for all project coordination within the Continental United States and Bermuda. NUSC was fully responsible for implementing the Bermuda operation. This included all negotiations and liaisons with Tudor Hill, the Bermuda government, Naval Station support and Navy Weather support. The setting up of the Bermuda operation involved many trips to Bermuda to coordinate with the several agencies involved in supporting the implement operation.

7.2.2 Monitoring and Expediting

(U) In addition to the technical responsibilities within the program and the above stated coordination requirements, the Project Manager and his key personnel were responsible for monitoring the progress and performance of each of the many participating agencies and offices. This included expediting, inspection and acceptance of the various components. Often, this would involve a visit to the procurement source for inspection and acceptance testing.

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7.2.3 Staging and Handling

(U) The first major staging operation occurred in the United States when the NAUBUC and the support ship NIPMUC were loaded with the project materials for transport to Bermuda. The Project Manager was assisted with the loading phase and the staging operations, both on shore and aboard ships. Upon arrival in Bermuda and offloading of excess gear, the ships were outfitted for the sea installation phase. Again, prior arrangements with the agencies in Bermuda had been conducted by the Project Manager. The Project Manager performed the bulk of the liaison between the LRAPP operation and the local agencies and other support facilities while at Bermuda.

7.3 Field Site Operations

7.3.1 Shore Operations

7.3.1.1 Offices, Warehousing and Staging Areas

(U) The field site operations in Bermuda required little in the way of offices; however, certain special pieces of equipment were required to be warehoused and safeguarded. Additionally, a sizable staging area was needed for the various support systems required for the installation.

7.3.1.2 Communication Facilities

(U) The NUSC project office was fully supported by Navy communications facilities on Bermuda and also utilized the shipboard communications supplemented with portable radio transceivers. No known problems occurred regarding communications.

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7.3.1.3 Transportation and Handling

(U) Very little was required in the way of transportation while at Bermuda. The one major transportation requirement was for moving the cable Array on the flat bed trailer to dockside for unloading onto the NAUBUC. The cable Array on the flat bed trailer was moved from the Air Base to the ship dock via barge. Additionally, this required a crane and tractor truck.

7.3.1.4 Personnel Housing, Messing and Transport

(U) Upon arrival in Bermuda, and prior to the at-sea implantment, personnel were required to live ashore. Personnel housing was difficult to obtain in Bermuda and prices for motels and hotels were high due to the tourist season. All personnel housing, messing and transport was arranged for prior to arrival in Bermuda of the main group by the NUSC Project Manager.

7.3.1.5 Liaison with Local Support Groups

(U) The NUSC Project Manager performed the majority of the liaison functions between the LRAPP TEST BED operation in Bermuda and the local support groups such as U.S. Navy facilities, NASA Radar facilities, Bermuda government, and local contractors.

7.4 Shipboard Operations

7.4.1 Cable Ship Mobilization

(U) Following the selection of the NAUBUC as the cable support ship to be utilized for the implantment, there was a vast amount of logistic activity associated with the outfitting and refurbishing of the vessel for this specific operation. The major portion of this logistic responsibility was conducted by the operator, Ocean Systems, Inc., who

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was subcontractor to the Supervisor of Salvage. The vessel's mobilization required refurbishing of some of the ship's systems, refurbishing and modification of the cable handling machinery on board, and the addition of berths to accommodate the large number of people that were going to actually be present at the implantment. During the early days of the vessel operation, and while conducting the training exercise, one of the four main propulsion units of the vessel became inoperative and necessitated dry docking of the vessel for repairs. It appears that the mobilization of the NAUBUC was well executed by OSI.

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8. RECOMMENDATIONS

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8. RECOMMENDATIONS

8.1 Existing LRAPP TEST BED Options

(U) There are several major options that exist in regard to the presently installed LRAPP TEST BED Array. The option that is recommended by BKD is to retrieve the array and examine all electronic components and the Array cable itself to better determine the cause of the failure and to better determine future methods of handling suspended arrays. It is recommended that the SDC cable be left in place for future use in subsequent engineering programs.

(U) There are several other options that exist:

1. Completely abandon the project, leaving the Array and the SDC cable in place. This option has no cost involved and little risk except the possibility of damage to passing vessels or to submarines by entanglement in the Array. However, international law may require the removal of at least part of the Array above the sea floor. Furthermore, this option is not desirable from the standpoint that it does nothing to advance the United States Navy's technology in the area of suspended arrays, and it would involve the loss of valuable engineering technology that could be obtained from the recovery and analysis of the Array.
2. Total recovery of the LRAPP TEST BED Array and its 47 miles of SDC cable.
3. Total retrieval of the LRAPP TEST BED Array with repair and refurbishment on the scene.
4. Partial retrieval of the Array components. For example, moving the seaward ball anchor shoreward a distance sufficient to allow the center horizontal span to rise to the surface; retrieve the center span only, leaving the riser legs attached to the syntactic foam buoys.

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5. Construction of a totally new array, and while recovering the present Array, implant the new array.
6. Contruction of new leg or legs for the TEST BED and while recovering the present Array, replace, as needed, those legs that are damaged.

(U) BKD does not recommend any of the six major auxiliary options as stated above, but recommends that only the Array itself be retrieved, leaving the SDC cable in place. The purpose of this retrieval would be to advance the United States Navy's engineering technology by constructing a diagnostic analysis of the actual components and cable itself in several steps.

1. Preliminary examination and testing aboard the cable retrieval ship as the Array is being retrieved.
2. Secondary examination and testing ashore in Bermuda prior to packaging and shipping.
3. Complete component analysis of the Array components and possibly sections of the cable upon return to the Continental United States.

(U) The detailed methods of retrieving the Array are outlined in the following subsection.

8.2 Retrieval Procedure for the Recovery of the LRAPP TEST BED Array

(U) It is recommended that since the SDC cable can have a multiple of uses, that it should be left in the site area and the LRAPP TEST BED Array be retrieved. Several methods of retrieval have been examined and the best method outlined below. Prime consideration has been given to minimize damage or parting of the Array cable during the recovery.

(U) The retrieval of the LRAPP TEST BED Array can be accomplished with minimum damage to the cable in the following steps:

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1. Grapnel for the stable braid, nylon grapneling line near the offshore end.
2. Retrieve the 34,000 feet of grapnel line, maintaining the minimum angle between the recovering grapnel line and the offshore riser leg by moving the cable retrieving ship toward the Array under controlled speed.
3. When the cable ship is nearly over the offshore Array ball anchor and the weight of this anchor is starting to be lifted off the bottom, it will be necessary for the cable ship to be moved astern under controlled speed to maintain tension throughout the entire Array. This is absolutely necessary to prevent loops and kinks from forming in the Array cable. To carry out this maneuver, accurate vessel position plots at the rate of one fix per minute will be required. Further, a vertical plot board of the array configuration and the vessel position in relation to the Array will also be required to be maintained.
4. The stable braid grapneling line, having approximately a 72,000 pounds breaking strength, will lift the offshore Array anchor. As this anchor is raised, the entire Array will move upward because of the action of the two corner subsurface floats. It is necessary for the cable ship to keep moving astern under controlled speed as the lower end of the riser leg is being lifted. Constant tension must be maintained on the entire Array to control the rate of the rising of the subsurface floats and to keep the Array from going into loops.
5. When the offshore anchor has been retrieved, the cable ship will continue retrieval of the offshore riser leg, maintaining 1,000 to 2,000 pound tension on the total Array.
6. Retrieval of the array cable will continue with the offshore riser leg, the offshore subsurface syntactic float and the horizontal leg. In the meantime, the cable ship will maintain a constant tension by controlled speed on the inshore riser leg and on the inshore anchor.
7. An auxiliary vessel, i.e., a small vessel 65 feet or less in length, will be required to attach a tow line

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to the top of the shoreward syntactic foam buoy and tow the inshore buoy seaward, maintaining 500-1,000 pound tension on the inshore riser leg and anchor. Station keeping can be accomplished by the NASA Radar Bearings and Range.

8. The horizontal Array cable will be cut just seaward of the inshore syntactic foam float. At this time, the float will be attached to the auxiliary vessel and the inshore riser leg will be under tension to prevent looping.
9. The cable ship will now proceed to a point approximately 6 to 8 nautical miles shoreward of the inshore Array anchor and grapnel for the SDC cable.
10. When the bight of the SDC cable is aboard and stoppered off, the cable will be cut.
11. Two shots of one and one-half inch chain, recovered from the offshore Array anchor, will be attached to the sea end of the SDC cable and to that will be attached the one and five eighths inch recovered stable braid nylon grapneling line.
12. The cable ship will then proceed seaward toward the auxiliary vessel, paying out the stable braid grapnel line and picking up the SDC cable.
13. When the total length of the stable braid grapneling line has been payed out, an anchor will be attached to the bitter end of the grapnel line and allowed to free fall to the ocean floor.
14. The cable ship will continue retrieval of the SDC cable. When nearing the riser leg, the auxiliary vessel must increase tension to approximately 1,500 pounds to insure that entanglement does not occur. The inshore ball anchor at the base of the inshore riser leg will be lifted to the surface by the SDC cable. As soon as the inshore ball anchor is aboard the cable ship, the inshore riser leg will be retrieved aboard the cable ship.

(U) The above method of retrieval of the LRAPP TEST BED Array can be accomplished starting at either end of the Array, based upon the

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wind and current direction. During the recovery of the offshore and horizontal leg of the Array, the offshore anchor and the main weight will be borne by the stable braid grapneling line; except for maintaining predetermined positions and Array tensions, no unexpected problems should be encountered. While recovering the inshore anchor with the SDC cable, tensions up to 15,000 pounds may occur, and since there is some question of damage to the SDC cable during implantment in that particular area of the cable, there is a possibility that the SDC cable will part upon retrieval of the inshore ball anchor. Should this happen, the cable ship can proceed to the auxiliary vessel and attempt recovery of the inshore riser leg from the shoreward syntactic foam buoy that is being held by the auxiliary vessel. However, this section of cable, that is the inshore riser leg, during deployment was hockled and may not be able to bear the strain of lifting the inshore ball anchor. It is because of the inferred defects and weaknesses of this inshore leg and the desire to prevent further damage so that a diagnostic analysis can be made, that it is suggested that the inshore ball anchor be retrieved by the SDC cable.

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9. CANDIDATE REPAIR-RETRIEVAL SHIPS

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9 CANDIDATE REPAIR-RETRIEVAL SHIPS

9.1 Desired Characteristics

(U) The cable laying or retrieval ship used for the LRAPP TEST BED Array Retrieval, must have the capability to handle the sensor units through the cable machinery. This capability must include sufficient clearance in connection with the following pieces of equipment:

1. Between the cable drum and its base.
2. At the dynamometer.
3. At the cable fairleads and bellmouths along the deck and down into the cable tank.
4. At the bow sheave.

(U) Special clearance problems of handling the sensor units on the cable will be encountered at the cable drum where the fleeting knives engage the sensor packages. A single fleeting knife on the drum will present the problem of the cable riding over the unit on the drum. Consequently, a multiple knife arrangement is almost a requirement.

(U) Other capabilities that a candidate cable retrieval ship suitable for the LRAPP TEST BED Array retrieval should have include:

1. Excellent positive positioning control (bow thrusters or bow jets).
2. Sufficient deck clearance to remove glass floats and store them.
3. Sufficient storage tanks for the LRAPP TEST BED Array cable which will probably be in very poor condition for easy storage.
4. Lifting capabilities to handle the weights and the sub-surface floats during retrieval.
5. A cable drum at least 6 feet or larger in diameter.
6. Superior navigational aids being able to provide two minute fixes having less than ± 300 foot error.

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7. Speed capabilities that will allow forward speed of the ship to be reduced to less than one knot.
8. Course holding capabilities to ± 10 degrees.

9.2 Recommended Retrieval Vessel

(U) BKD has surveyed the available commercial cable ships and recommends that the C. S. SENTINEL owned by Cable and Wireless Limited and based in Bermuda be selected as the retrieval vessel. The SENTINEL is 480'-0" overall length, breadth 55'-8", draft 27'-10", gross tonnage 3,537, and is registered in Great Britain. The SENTINEL has four cable storage tanks, each 41'-0" in diameter. The tanks are located forward of the machinery spaces, they are accessible from sheltered deck hatches, and are suitable for coiling the retrieved cable which is expected to be in poor condition.

(U) The cable drums are 6'-10" in diameter with a drawoff gear fitted with 7'-0" diameter sheaves. They are equipped with dynamometers with recorders. The SENTINEL has spacious, well-equipped electronic test areas that will enable testing to be performed while recovering the Array. There are comfortable quarters available for a scientific party of nine. The Master informed BKD that the ship will be able to operate comfortably in Beaufort scale wind force 6, and if required to force 8. The SENTINEL is equipped with two diesel powered work boats. The Master, Captain Reynolds, is an experienced officer and our review party was impressed with his staff of officers. The SENTINEL is very well equipped to perform the recovery and its equipment appeared to be in fine shape.

9.3 Estimated Recovery Costs

(U) It is estimated that barring any unforeseen difficulties the retrieval costs will be approximately \$190,000.

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BREAKDOWN OF RETRIEVAL COSTS

Mobilization

Vessel 3 days @ 7500/day	\$ 22,500
Modifications	20,000
Labor, Engineering and Consultants	10,000
Travel and Misc. Expenditures	7,500
Decca Hi-Fix and Technician	<u>10,000</u>
	\$ 70,000
General and Administrative @ 30%	<u>21,000</u>
	\$ 91,000
Fee @ 10%	<u>9,100</u>
Total	\$100,100

Retrieval and Preliminary Analysis in Bermuda

Vessel 5 days @ 8500/day	\$42,500
Labor, Engineering and Consultants	15,000
Travel and Misc. Expenditures	<u>5,000</u>
	\$62,500
General and Administrative @ 30%	<u>18,750</u>
	\$81,250
Fee @ 10%	<u>8,125</u>
Total Cost	\$89,375

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The above costs include the following assumptions:

1. Availability of the SENTINEL.
2. No escalation in the quoted rates for the SENTINEL.
3. Shipments via GBL.
4. ONR will supply photographers to record the recovery.
5. ONR will supply suitable ATF as an assist vessel.
6. Final electronics testing to be performed by ONR in CONUS.
7. ONR will provide storage and handling capability in Bermuda.

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11. APPENDICES

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APPENDIX A
Comments of The Rochester Corporation on
the TEST BED Cable

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APPENDIX A

**Comments of The Rochester Corporation on
the TEST BED Cable**

(U) Mr. Al Crane, Product Manager for The Rochester Corporation of Culpepper, Virginia, contacted BKD early in the Diagnostic Analysis program and requested to know if Rochester could be of assistance to BKD in the diagnostic and that they were willing to liaison with BKD at no cost. The Rochester Corporation expressed a sincere interest in participation in the analysis of the cable handling problems and other problems that may have contributed to the failure of the cable used in TEST BED. During the course of this diagnostic, several conferences were held with Rochester personnel. These meetings resulted in the disclosure or surfacing of several aspects of the TEST BED Program heretofore unknown to BKD, also some important findings and comments relating to the deformations caused to the TEST BED cable during handling and implantment.

COMMENTS:

(U) During all manufacturing operations, effort is made to avoid twist or to counterbalance induced twist. The armor wires are laid in a planetary system so that there is no individual twist in the wire. After the cable is closed, there is no operation in which twist would be induced in the cable, and it should come off of the shipping drum without a tendency to twist. Nearly all steel shipping reels used with armored cable, will contract or double deform at the drum as a means of relief of the compounding compressive tension imposed by each wrap of the cable. Wooden shipping reels also yield, but spring back and the deformation is not so apparent in the wooden reels. Shipping drums, be they wooden or

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steel, are not constructed to take high spooling tensions. In fact, care must be used to minimize the spooling tension in order to remain within the structural limits of the reel.

(U) With regard to cable handling during manufacturing operations, the cable is handled by reels and is kept under modest tension during any and all handling operations. Where higher tensions are needed for prestressing, double capstans are used. It is recommended that the reels that contain the cable be rolled in such a direction as to continually tighten the cable as if it were being spooled on the reel. During manufacture, each wire is under several pounds tension due to the breaking action of spools of wire and this is overcome by using a double capstan traction system. The cable is then fed onto the shipping reel, and the tension between the double capstan and the shipping reel is modest, only a fraction of one hundred pounds or so, as necessary to obtain a uniform lay of the cable.

(U) A caterpuller system, consisting of parallel moving treads, applies a general, well distributed pressure on the cable and sufficient longitudinal friction to move the cable along during the handling operation. This system is used primarily in large non-armored cable factories because of the delicate nature of the jacketing or in-process insulating material. This caterpuller is also used on some cable laying vessels for laying of cable.

(U) The system described above and as used in the manufacturing of cable by The Rochester Corporation and others, prevents any rolling or slipping forces from being applied to the rope or cable as it is being manufactured, and the grooves in the capstans help to support the cable so there is the minimum of flattening of the cable. In summary, great care is taken in the manufacturing process to minimize and avoid induction of twists into a cable. This same care was exercised in the manufacture of the TEST BED cable and it is believed that the cable as shipped

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from The Rochester Corporation on storage reels was devoid of any twist or residual torque in the cable.

(U) The amount of twist that can be induced in a torque balanced cable before damage takes place, has not been established. The industry has had considerable experience in handling and laying uni-directional cables such as single armored submarine cables on the ocean floor, where the cable is not under tension during its performance and the strength characteristics were required only during the laying operation. Double armored cables such as the TEST BED cable have been used without difficulty whenever they were used on tension bearing drums and reels and operated under tension.

(U) It is only when the cable handling systems began to envision either coiling operations or tension relieved drums that difficulties have been encountered with counter wound cables. There appears to be an indication of difficulty even with torque balanced cables of competitive manufacture when they are reeled under tension by a single capstan and stored under no tension conditions, either by low tension drums or by coiling.

(U) Having been shown representative photographs of actual hockles, kinks and other deformations sustained by the cable during implantment, it is believed that most of these were of a severity to cause damage to the insulation and thereby, electrical failures. Even though a hockle may have appeared to straighten itself out under tensioning, the core and/or insulation could easily have been broken or damaged so as to create a sea cell or to have caused loss of continuity in the coax center conductor.

(U) These deformations could have a delayed affect upon the electrical operation, theorized as follows: while these hockles or other deformations tested good electrically aboard ship under a short period of voltage application, then, when the system had been implanted and power was

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applied for a considerable time, there was a failure. The failure could be due to a hydrolysis effect which generated gas and lead to the deterioration of the system.

(U) The above theory is one very good reason for continuously monitoring the voltage while there is a variable cyclic test of the cable under varying tensions, and while rolling back and forth in seawater for a period of time long enough to permit hydrolysis, if any, to occur. This test would be conducted with known deformations and known tensions in the cable with definite applied signals being continuously monitored.

(U) Briefly stated, torque balancing of the armors has merely solved one problem; that is, tension induced twisting or torquing. There is a need to study the handling systems for this particular type of cable. Previous handling systems have been with uni-directional items such as single armored submarine cable or rope and over the past 120 years, much experience has been gained in this area using techniques developed by the "cut and try" principle. The same learning or study techniques cannot be applied to double armored cable, since time and the complexity of the analysis of double armored cable does not permit. Some of the questions for which answers are needed immediately are as follows:

1. How many turns can a cable take without damaging insulation or core?
2. What is the relationship between ultimate tensile strength and twist as related to electrical integrity of the cable?
3. What is the relationship between degrees of twist per foot and breaking strength?
4. What is the relationship of the bending radius versus breaking strength for a given cable?

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(U) The answers to these questions are not readily available by casual observation or from a library.

(U) In summary, The Rochester Corporation's primary recommendation is that counter wound cables including torque balanced cables be handled under conditions of positive tension and by reeling. It is recognized that array cables are not conveniently handled by reeling systems and; therefore, an engineering compromise is necessary. In view of the experience on the TEST BED Project, it is suggested that if reels are impractical, that a modified figure eight system be used to avoid inducing twists into the cable. At the same time, compensation for twists induced for unknown or unexpected factors should be built into a system and we would suggest that the cable storage tank be mounted on a central axis such as the entire cable mass could be rotated in such a direction as to compensate for the twist induced by unknown factors. Caterpuller or double capstan systems are recommended over single capstan systems.

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APPENDIX B

**Captain H. Wyeth's Comments on the TEST BED
Cable Handling and Implantment Procedures**

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APPENDIX B

**Captain H. Wyeth's Comments on the TEST BED
Cable Handling and Implantment Procedures**

Captain H. Wyeth was contracted by the Office of Naval Research, Code 469, to assist BKD in the TEST BED Diagnostic Analysis. This enabled BKD to obtain valuable information not to be found in project records. Captain Wyeth, is employed by the General Electric Corporation, and was contracted by Ocean Systems, Inc. to serve as the NAUBUC master and Cable Laying Manager during the TEST BED Program.

COMMENTS:

During the deployment of the Array, a number of hockles occurred in the Array cable while being payed out of the vessel's cable tank. Several possibilities exist as to the cause of this hocking, as follows:

1. Unbalanced residual torque stored in the cable.
2. Twists induced into the cable while being loaded into the vessel's tank. The cable as it is coiled into a shipboard cable tank must be capable of "swallowing" or accepting one rotation per turn in the tank, or it will become unruly and will not lay "dead". Although the cable laid "dead" in the vessel's tank, it was not torque free. The torque was in the cable and it exhibited itself when it was paid out during implantment.
3. Torque induced by repeated handling of the cables in various lengths during the array fabrication and subsequent payout from the vessel's cable tank. The cable was subjected to repeated handling from reels to various size coils and configurations and being passed around sheaves and curved chutes. Each time this cable was handled until payout from the vessel's cable tank, the cable was freed of

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torque and the resultant hockles by rotation, by rotation of the sensor cages, and by rotation of the trailer which removed the hockles before they were allowed to be formed. However, when the Array cable was being deployed, no method was readily available to remove the latent torque from the cable and therefore, hockles were formed as a result of this inability to remove the torque. Cable having no latent torque characteristics and neutrally buoyant should be considered if future arrays of this configuration are planned.

(U) There were four major ground rules established during the first meeting with NUSC personnel early in February of 1970. These ground rules were as follows:

1. That these arrays must be installed in the calendar year 1970.
2. That every attempt should be made to schedule for the most suitable weather in the Bermuda area as being during the month of August and no later than the month of September.
3. That the selection of the components was based on their availability and delivery schedule to meet the installation dates.
4. The repeated statement that equal importance between the ocean engineering (proving the capability to install and achieve the proposed array configuration) and the environmental data were to be the prime consideration for proceeding with the most expedient time schedule and that the ocean engineering was equal of more important than the environmental data that would be resulting from the Array after installation.

It is believed that the above ground rules had a great deal of influence on the following decisions made during the implementation of the program.

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1. Selection of an array cable having little historical data and its availability for DeBell and Richardson to start fabricating the sensor units.
2. To design a training array using a different type of cable than the final array cable.
3. The decision to use only one sensor housing in the training array.
4. A minimum testing program of the Array cable behavior under simulated or actual sea conditions.
5. Not requiring the cable manufacturer's representative to come to Bermuda during the loading of the cable after discovering the cable having a tendency to twist while being loaded onboard ship from the trailer.
6. By not determining the exact cause of the fault noise in the cable that developed during loading of the Array aboard the vessel and why this fault disappeared without any work being done on it.
7. The continuing of the at sea deployment of the Array after the first twist, hockle and a fault had occurred.
8. The decision to proceed with a vessel under tow to Bermuda before loading and testing the entire Array per installation plan.

(U) It is believed that the five fleeting knives, the curved plate going out of the tank, and the linear cable machine all contributed towards stripping the torque back into the cable tank. The torque that was stripped back into the tank developed from high loads imposed during deployment. The torque was increased and stripped back toward the cable tank until finally, the cable hockled.

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APPENDIX C
Synopsis of LRAPP TEST BED
Advisory Committee Meetings Minutes

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APPENDIX C

**Synopsis of LRAPP TEST BED
Advisory Committee Meetings Minutes**

(U) A contract was let to BKD to complete a diagnostic review and evaluation of the LRAPP TEST BED which was implanted off Bermuda in December 1970. The investigation will be complete with the submission of a series of reports.

(U) ONR-469 authorized and formed an Advisory Committee to provide guidance "and review from the duration of the Diagnostic Study." The first meeting of the Advisory Committee was held on 4 May 1971 and the second meeting was held on 29 June 1971.

(U) ONR-469 invited ten persons to participate in the Advisory Committee. Those invited were as follows:

1. Mr. S. Kulek, BKD (Chairman)
2. Mr. L. M. Treitel, ASW-240
3. Mr. G. O. Pickens, NUC
4. Dr. M. M. Balaban, TRW (Rand)
5. Capt. J. P. Kelly, NAVELESYSCOM, EPO-3
6. Mr. C. H. Holm, Global Oceanics, Inc.
7. Mr. J. B. Gregory, ONR-485
8. Cdr. W. J. Eager, NAVFAC-PC-2
9. Mr. A. E. White, ONR-102-OS
10. Mr. T. R. Cummings, NUSC

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FIRST MEETING:

TIME: 1:30 P.M.
DATE: 4 May 1971
PLACE: BKD, Rockville, Maryland

COMMITTEE MEMBERS WHO ATTENDED:

1. Dr. M. M. Balaban, TRW, Inc.
2. Mr. T. R. Cummings, NUSC
3. Cdr. W. J. Eager, NAVFAC-PC-2
4. Mr. S. Kulek, BKD
5. Mr. G. O. Pickens, NUC
6. Mr. A. E. White, ONR-102-OS

COMMITTEE MEMBERS WHO DID NOT ATTEND:

1. Mr. J. B. Gregory, ONR-485
2. Capt. J. P. Kelly, NAVELESYSCOM, EPO-3
3. Mr. L. M. Treitel, ASW-240

ALSO PRESENT WERE:

1. Dr. T. C. Chamberlain, BKD
2. Dr. R. D. Gaul, ONR-469
3. Mr. R. Hovey, BKD
4. Mr. J. A. Kelly, BKD
5. Mr. I. F. Kuhn, BKD
6. Mr. D. Taylor, Global Oceanics

(U) The purpose of the meeting was to allow TRW, NUC, Global Oceanics, and BKD to present their preliminary findings on the TEST BED failure to the other members of the Committee, to solicit comments and suggestions and, in general, to allow an exchange of information and ideas concerning the failure that would assist the contributing members of the committee and the furtherance of their analyses.

(U) Dr. Balaban stated that after careful analysis of the two identifiable electrical failures, he concluded that they were definitely linked to cable twisting. The causes of these twists he has traced to loops that developed in the cable during loading. Dr. Balaban stated that he had traced every possible cause of these turns that had to be taken out, such as the

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coiling and uncoiling, possible twisting at the Array fabrication site, and he concludes that the only thing that could have caused these turns was the ship's pay-out machinery.

(U) Dr. Balaban stated that he had traced the cause to an unwanted component of the fleeting knife force on the cable, mainly a frictional component that induced torsion on the cable. Dr. Balaban further commented that a static calculation would have shown that the inshore anchor would have difficulty touching down. The horizontal component force that the inshore anchor was required to take was really much greater than could have been expected of it. The net downward force on the anchor was actually less than the horizontal component, so, subsequently a lot of SDC cable had to be laid before that corner of the Array stabilized itself. Dr. Balaban felt that in the lowering of this corner of the Array, the Array cable and the SDC cable may have entangled.

(U) Dr. Balaban made the following recommendations for future array implantments:

1. A more streamline pay-out process, possibly incorporating buoyancy elements into the cable.
2. Miniaturization of all instrument packages.
3. Plug-in electronics.
4. Handling the cable as little as possible.
5. No coiling of the cable at any stage, the use of reels.
6. Never allow the cable to go to zero tension.
7. Situations where two lengths of cable can twist around each other should be avoided.
8. The response of the cable to every phase of the handling should be completely determined beforehand.

(U) Mr. George Pickens, NUC, expressed his feeling that he was very impressed with what he considered the good engineering that NUSC

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had done with the Array. The sensor cable assembly seemed to him to be a very good design and it was consistent so that it did not have to change designs from cage to cage. The pressure housings, were very good. He further stated that everyone would like to have much smaller pressure housings and perhaps even clip them on as the but, at the moment he thought it was impractical to improve on these housings.

(U) Mr. Pickens commented at great length on the bulkhead cable penetrators which were made out of corrosion resistant steel, series 316, and were seated against zinc plated steel housings. Even though these metals are separated by O rings and nylon washers, crevice corrosion and galvanic deterioration of the hardware is an important consideration.

(U) Mr. Pickens felt that the Ellipsoid syntactic floats are possibly adequate. However, the glass spheres were of great concern to him because they took so long to be placed onto the cable, consequently slowing down the operation and wearing people out. Mr. Pickens suggested that the possibility of using self buoyant cable be investigated.

(U) Mr. Pickens expressed concern over the NAUBUC's machinery's inability to effectively retrieve the cable once paid out. Mr. Pickens pointed out that if the cable can be recovered during deployment, that more control and flexibility in the process of laying the cable is assured, and provides a means of stopping the cable off or retracting the cable back aboard should a contingency arise.

(U) Mr. Pickens made the following recommendations:

1. It would have been preferable to have utilized seven different reels, three for each of the slanted riser sections and one for the horizontal section. This would have facilitated handling of the Array during staging and shipping and possibly prevented some of the problems that occurred during implantation.

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2. A contingency plan which would have allowed stopping off the cable in case of severe weather.
3. While the NAUBUC was available and inviting, this necessitated utilizing the cable tank on the NAULUC and pay-out machinery which apparently put twists in the cable. Even so, it is believed that a roller plate would have been preferable in reducing friction on the cable should the cable have been retrieved.
4. Constant tension must be provided on the cable at all times and there were no constant tension provisions on the NAUBUC.

(U) Mr. Taylor, Global Oceanics, commented that the most significant observation that he could make was that the cable was mishandled and this may have been the result of misunderstanding of how to handle this type of cable.

(U) Mr. Taylor also commented that the plus or minus 5 fathom accuracy of the bathymetric surveys may have caused a fair amount of bridging and with bottom currents and bridging, a certain amount of oscillation of the cable could result in eventual failure.

(U) Mr. Taylor questioned the use of the 3500 pound ball anchors, why a geometry was not selected that could allow bottom penetration. Mr. Taylor had questions concerning the ground tackle used on the Array.

(U) Mr. Taylor's final comments were concerned with the late Carl Holms, general statement that he, Carl Holms, was not particularly impressed with the operation and that he felt with the kind of program that was at stake and the expenditures at stake, that it possibly could have been planned a little bit better from the field operations aspect.

(U) Mr. Hovey, BKD, commented on the engineering data and instrumentation. His main comment was that the engineers at NUSC accomplished excellent engineering in the design of the Array considering the time constraint of the program schedule. He felt that the original

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constraint of utilizing SEA SPIDER equipment was very detrimental to the Program. This time constraint resulted in NUSC engineers utilizing relays whos reliability is questionable. Also, Mr. Hovey felt that the schedule did not give NUSC engineers sufficient time to completely check out the Array.

(U) Mr. Hovey was further concerned about the single series component hook-up of the cable and line drivers which would cause the cable to go dead if anything should happen to either component. His concern for the line drivers centered about the use of the unreliable relays.

(U) Mr. Hovey commented that there is some question in his mind as to whether the electrical failures were actually in the cable or in the sensor packages. Additionally, he felt that the line drivers were mishandled during the loading operation of the cable aboard ship. Mr. Hovey was also concerned that the Array was not properly grounded and it is possible for the Array to act as an antenna.

(U) Dr. Chamberlain felt that the training program was exceptionally well planned, however, the Scripps' cable that was actually planted in the Array was not used by the training team. The Array cable and the training cable have vastly different handling properties and the well planned training exercises were somewhat negated by the use of a different cable.

(U) Dr. Chamberlain believes that many of the problems that occurred resulted from the fact: (1) that there was a certain amount of conflict among the key people onboard, and (2) the exercise was planned for good weather and that the latter part of the implantment was executed in bad weather.

(U) Mr. Kelly, BKD, stated that the logistics problems only added to the already burdened management and engineering team.

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Further, that the lack of adequate logistics staff support may have contributed to the escalation of costs for the total program.

(U) Dr. Gaul, ONR-469, summarized the meeting by stating that there appeared to be a unanimous opinion that the general engineering of the TEST BED was good to excellent and that the most likely cause of the TEST BED failure was the cable twist problem in one form or another and that this twist problem appeared to be induced somewhere within the cable handling system of the NAUBUC.

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SECOND MEETING:

TIME: 1:30 P.M.
DATE: 29 June 1971
PLACE: BKD, Rockville, Maryland

COMMITTEE MEMBERS WHO ATTENDED:

1. Dr. M. M. Balaban, TRW, Inc. (Rand)
2. Cdr. R. Hadspeth, NAVFAC-PC-2
3. Mr. S. Kulek, BKD
4. Mr. A. E. White, ONR-102-OS
5. Mr. G. O. Pickens, NUC
6. Mr. R. Pierce, NUSC

COMMITTEE MEMBERS WHO DID NOT ATTEND:

1. Mr. J. B. Gregory, ONR-485
2. Capt. J. P. Kelly, NAVELESYSCOM, EPO-3
3. Mr. L. M. Treitel, ASW-240

ALSO PRESENT WERE:

1. Dr. T. C. Chamberlain, BKD
2. Dr. R. D. Gaul, ONR-469
3. Mr. T. Tarantino, TRW, Inc.
4. Mr. R. Hovey, BKD
5. Mr. J. Kelly, BKD

(U) The purpose of this meeting is to go through the draft of the diagnostic analysis report prepared by BKD. This report integrates the results from several other efforts that have been commissioned. One of these is the effort by TRW which was prepared by Dr. M. M. Balaban, who has now left the employ of TRW and is currently employed by the Rand Corporation. Dr. Balaban is in attendance today on his own initiative, to assist us with this review.

(U) The intent of the original contract was to bring in an independent party who had not been involved in the TEST BED Program and who could organize the diagnostic review and apply efforts in areas where no attention was being given, together with incorporating the

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separately funded efforts that have been contracted for with TRW and NUSC. Mr. Pickens effort, from NUC, has been under direct coordination with BKD, and ONR has funded NUC separately. In this review meeting, we will be able to review the technical volume, both in general and in as much detail as required.

(U) Mr. Kulek, BKD, stated that no one has had copies of the technical volume for sufficient time to be able to respond with written comment. A specific topic to start off the meeting will be the review of the TRW report prepared by Dr. Balaban.

(U) Mr. Robert Pierce, substituting for Mr. T. Cummings of NUSC, stated that there were a great many areas in which NUSC disagreed with Dr. Balaban's report. Specifically, NUSC found no evidence that the fleeting knives on the drum produced twists in the cable. He further stated that the ship had the capability of recovering the Array at all points during the implantment. However, there were circumstances which made it seem unwise to do so at the time. Mr. Pierce stated that it was determined that in the event the outboard leg should be damaged or suffer catastrophic failure, the Array implantment would continue as the outboard leg was largely redundant. He believes that the primary acoustic mission of the Array was not compromised by this decision.

(U) Mr. Pierce stated that with regard to continuing the implantment following the occurrence of the first hockle in the riser leg, that the decision was made following a detailed and involved discussion both aboard ship and with personnel ashore.

(U) Dr. Chamberlain stated that Capt. Wyeth had expressed the belief that the cable could well have parted had an attempt been made to recover the portion of the Array already deployed. Capt. Wyeth's concern over recovering the cable was based on his belief

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that the cable would have parted due to the friction against that cable in the stern plate.

(U) Mr. Kulek stated that Capt. Wyeth had stated the three possibilities that existed at the time the fault occurred in the out-board riser leg. The three possibilities were to haul back the cable for repair, electrically terminate the Array at the cut, and proceed with the laying. The first possibility was ruled out because of the impending rough weather, the length of time it would have taken to retrieve the Array including removing the glass spheres, and the lack of confidence in performing this tricky recovery procedure successfully. For these reasons, Capt. Wyeth did not believe that the NAUBUC had the capability to recover the deployed array.

(U) Dr. Gaul stated that the reason for investigating this point in great detail is that the implantment, recovery and casualty response considerations are as much a part of the design as the transducer and line driver.

(U) Mr. Pierce stated that the primary considerations, as discussed with personnel ashore and on board ship, was the weather window and whether or not the Array could be utilized with a dead leg. There was concern that the cable was weakened in the area of the fault and it was believed generally that there was a good chance that the Array would be lost if an attempt was made to recover it. In summary, the decision concerning the Array was based upon the operations of the Array and not upon the capability or lack of capability on the part of NAUBUC to recover the cable.

(U) Mr. Kulek stated that the Rochester Corporation apparently was aware of some of the problems that NUSC was having in Bermuda and were extremely surprised that they were not asked to render an opinion or to go down and observe. Also, when the loading

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problem occurred, Rochester personnel were in New London and were not invited to review the problems in the field.

(U) Mr. Pickens, NUC, stated that in his belief there are three major problems fundamental to this diagnostic. These three problem areas are: (1) the decision to completely assemble the Array on shore and keep it in one piece, (2) the decision to minimize recovery facilities, and (3) the decision to use the NAUBUC and its associated machinery without major modification.

(U) Dr. Gaul stated that any discussion of the machinery aboard the NAUBUC and the use of the NAUBUC must be placed in the context of management decisions that were made and that they are two separate items. Therefore, the technical analysis starts with the NAUBUC having already been selected and then investigates the adequacy of the NAUBUC as a whole and the cable handling machinery aboard. Dr. Gaul further stated that the basic problem is that we do not have a conventional cable problem. As a matter of fact, the conventional cable laying part of this TEST BED program went extremely well and that no problems were found with it insofar as is known. The part that was not conventional can be summarized in four areas as follows:

1. It was not laid on the bottom. That is, the suspended Array comes up off the bottom and that is unusual.
2. It had things on it besides just cable, significant things, not just a repeater now and then, but glass spheres and other housings.
3. It was not an SDC type cable, not a conventional cable. It was a special double armored kind of cable with which there is very little experience.
4. Whether or not the NAUBUC as it was configured, was suitable for both laying of the system and recovery of the system? That is the germane question.

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(U) Dr. Gaul stated that problem area number 4 as listed above is the one that should receive attention in this analysis and it is the one that should resolve whether or not the NAUBUC is suitable for utilization in laying cable systems of this sort in the future, or whether some other vessel should be considered.

(U) Dr. Chamberlain summarized the investigations of BKD personnel and The Rochester Corporation. This cable was a very special cable. It was a torque balanced cable which gave it a torsion resistant characteristic. Part of the reason for the problems with this cable was the fact that it was a double armored cable, however, this is only a small part of the reason. The other part is that the construction of each armor wire was of special plow steel wire which is different from the double armored coaxial cable that is normally laid in the ocean. These plow steel wires would not deform, whereas the normal kind of cable that is laid will deform under torque. This is a very special cable and it has only been used once before by the Scripps Institute of Oceanography and its properties are not known.

(U) Dr. Gaul stated that he would like to summarize any other comments relating to the NAUBUC's capability or incapability. These comments are summarized as follows:

1. The inconveniences of people working a long time at sea in what amounted to a day-boat atmosphere.
2. The length of the vessel restricted what you could do with machinery. The cable had to be doubled back over the length of the hull and other similar items.
3. The size of the vessel also caused accelerations which put undue strains on the cable.

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(U) Dr. Gaul stated that the meeting should put aside further discussion of the NAUBUC and begin discussion of the TRW Report which is a major portion of the agenda for this meeting.

(U) Mr. Pickens of NUC was asked to present his review of the TRW Report. Mr. Pickens stated that the streamlining of the pay-out process by making the electronics packages smaller would cost a great deal of money. Also, that the incorporation of buoyancy into the cable is pushing the state of the art and there is no practical way of accomplishing this at this time. He further stated that the use of power reels is not necessarily the proper way of recovering a cable. Additionally, Mr. Pickens questioned the reliability of utilizing slip joints every few hundred feet along the cable as a means of relieving the cable from its torsion. With this many interfaces in the cable, there is an excellent chance that the cable would flood out. Mr. Pickens did not favor the recommendation in the report that the riser legs be shortened in an effort to maintain continuous tension on the riser leg and prevent slack in the cable that might cause twists. Mr. Pickens stated that with regards to the recommendation of using two cables to lower a weight to the ocean floor, that there are ways to keep cables from twisting or entwining. Mr. Pickens further stated that during tests where measurements of a cable properties are being made, that the use of a Miller swivel is not necessarily recommended.

(U) Mr. Robert Pierce, NUSC, substituting for Mr. Tom Cummings made the following comments regarding the TRW Report. With regard to the cable twisting on the cable drum because of action of the fleeting knives, observations made by NUSC and others show no evidence that there were any twists in the cable from one end to the other, entering the drum versus leaving the drum. Dr. Chamberlain was asked to state

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alternate hypotheses relating to possible causes of twists being induced into the cable. Dr. Chamberlain stated that other hypotheses have to do with residual torque in the cable and stripping of the residual torque down the cable as the cable length entered the cable laying machinery. The fact that 29 turns were relieved in the cable during the loading of the cable from the truck bed trailer onto NAUBUC, and the fact that these 29 turns could not be relieved during deployment of the cable should have been recognized at the time of the loading of the cable.

(U) Another hypothesis stated by Dr. Chamberlain was as follows. In twisting a torsion resistant cable, there will be a movement between the inner and outer wire. During this twisting, there is a possibility that these wires will not come back into the same alignment as they had previously. These two hypotheses are in addition to what Dr. Balaban has proposed in the TRW Report.

(U) Mr. Kulek asked all members of the Advisory Committee on TEST BED to write their comments and submit them to BKD as soon as possible so that they may be incorporated in the final draft of the Diagnostic Analysis Report.

(U) Dr. Gaul expressed his deepest appreciation for the involvement of the members of the Advisory Committee and for the time that was put into this diagnostic analysis.

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Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body, of abstract and indexing annotation must be entered when the overall report is classified)

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		2b. GROUP 3	
3. REPORT TITLE Technical Diagnostic Analysis of LRAPP Test Bed Program Failure (U)			
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Final Report			
5. AUTHOR(S) (First name, middle initial, last name) Philip G. Bernard, Sidney Kulek, Richard K. Hovey, Theodore Chamberlain			
6. REPORT DATE 2 August 1971		7a. TOTAL NO. OF PAGES 177	7b. NO. OF REFS 36
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10. DISTRIBUTION STATEMENT			
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY Office of Naval Research, Code 469	
13. ABSTRACT A diagnostic analysis of the LRAPP TEST BED Failure was made by B-K Dynamics, Inc. at the request of ONR Code 469. The engineering, operational, training, seamanship, and logistical aspects of the implant were discussed in detail. Conclusions were drawn as to the probable cause of the failure and recommendations made as to what future action should be taken by the U.S. Navy in regard to the LRAPP TEST BED.			

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Ref: (a) SECNAVINST 5510.36

Encl: (1) List of DECLASSIFIED LRAPP Documents

1. In accordance with reference (a), a declassification review has been conducted on a number of classified LRAPP documents.
2. The LRAPP documents listed in enclosure (1) have been downgraded to UNCLASSIFIED and have been approved for public release. These documents should be remarked as follows:

Classification changed to UNCLASSIFIED by authority of the Chief of Naval Operations (N772) letter N772A/6U875630, 20 January 2006.

DISTRIBUTION STATEMENT A: Approved for Public Release; Distribution is unlimited.

3. Questions may be directed to the undersigned on (703) 696-4619, DSN 426-4619.

A handwritten signature in black ink, appearing to read "B. F. Link", is positioned above the typed name.

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Current availability key: NS - NRL Stennis; ND - NRL D.C.; AU - ARLUT; ADXXXXXXX-DTIC						
Report Number	Personal Author	Title	Publication Source (Originator)	Pub. Date	Current Availability	Class.
HLR167; CU-195-69-ONR-266-PHYS	Hardy, W. A.	PROJECT APTERYX: FINAL REPORT (U) (HUDSON LABORATORIES OPERATION 245)	Columbia Univ / Hudson Labs	690301	NS; ND	C
MCR002	Unavailable	MEDITERRANEAN SEA ENVIRONMENTAL ATLAS FOR ITASS (U)	Maury Center for Ocean Science	691001	NS; ND	C
NUSCNL3018	Unavailable	TECHNICAL PLAN FOR IMPLANTMENT OF THE TEST BED ARRAY FOR THE LONG RANGE ACOUSTIC PROPAGATION PROGRAM (LRAPP) (U)	Naval Underwater Systems Center	700810	NS; ND	C
Project469 149429855R700	Balaban, M. M.	LRAPP TEST BED ARRAY CABLE FAILURE ANALYSIS (U)	TRW Systems Group	710730	AD0516710; NS; ND	C
BKDCN667	Bernard, P. G., et al.	TECHNICAL DIAGNOSTIC ANALYSIS OF LRAPP TEST BED PROGRAM FAILURE (U)	B-K Dynamics, Inc.	710802	AD0516656; NS; ND	C
NUSCPUB6002	Unavailable	IOMED EXPERIMENT. PRELIMINARY DATA REPORT (U)	Naval Underwater Systems Center	711206	NS; ND	C
ADL ED 15316; ADL 116-672	Unavailable	SQUARE DEAL EXERCISE PLAN (U)	Arthur D. Little, Inc.	720301	ND	C
ADLR4560372	Sullivan, D. L., et al.	PRELIMINARY ANALYSIS OF ACODAC MEASUREMENTS NEAR MADEIRA ON 13-16 OCTOBER 1971 (U)	Arthur D. Little, Inc.	720331	AD0595812; NS; ND	C
MCR07	Gaul, R. D., et al.	IOMEDEX SYNOPSIS ON ENVIRONMENTAL ACOUSTIC EXERCISE IN THE IONIAN BASIN OF THE MEDITERRANEAN SEA NOVEMBER 1971.	Maury Center for Ocean Science	720401	NS; ND	C
P1243	Unavailable	FINAL REPORT ACOUSTIC TEST ARRAY (U)	Raytheon Co.	720831	AD0522104; NS; ND	C
Unavailable	Unavailable	CHART-BATHYMETRIC-SQUARE DEAL EXERCISE (U)	Naval Oceanographic Office	730601	AU	C
TM SA23-C275-73	Wilcox, J. D.	A DESCRIPTION OF THE LRAPP ATLANTIC TEST BED ARRAY FOR MOTION PREDICTION STUDIES (U)	Naval Underwater Systems Center	731212	ND	C
Unavailable	Unavailable	CHURCH ANCHOR AMBIENT NOISE REPORT (U)	Texas Instruments, Inc.	740501	AU	C
Unavailable	Hoffman, J., et al.	CHURCH ANCHOR CW PROPAGATION LOSS AND SIGNAL EXCESS REPORT(U)	Texas Instruments, Inc.	740701	AU; ND	C
MCR104	Unavailable	MEDITERRANEAN ENVIRONMENTAL ACOUSTIC SUMMARY (U)	Maury Center for Ocean Science	740701	NS; ND	C
OSTP-39	Romain, N. E.	OSTP-39 NER: ANALYSIS OF DATA FROM A FIELD TRIAL OF THE LAMBDA ARRAY (U)	Westinghouse Electric Corp. and Bell Laboratories	740930	ND	C
MC-103	Unavailable	MEDITERRANEAN ENVIRONMENTAL ACOUSTIC DATA CATALOG (U)	Office of Naval Research	750501	ND	C
Unavailable	Unavailable	SQUARE DEAL SUS TRANSMISSION LOSS (U)	Arthur D. Little, Inc.	750725	AU	C