

AD-A104 314

TEXAS RESEARCH INST INC AUSTIN

INVESTIGATION OF THE STRENGTH OF SHIELDED AND UNSHIELDED UNDERWATER

SEP 81 D E GLOWE, S L ARNETT

N00173-79-C-0129

UNCLASSIFIED

7967-15-DEG

NRL-MR-4468

NL

F/G 9/1

1 OF 1
AD A
104 314

END
DATE
FILMED
10-81
DTIC

AD A104314



12

RECEIVED

SEP 11 1961

DTIC

ELECTRIC

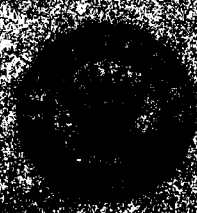
SEP 11 1961

S

D

E

SEP 11 1961



SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
(18) NRL Memorandum Report 4468	AD-A104314	14
4. TITLE (and Subtitle)	5. TYPE OF REPORT & PERIOD COVERED	
(6) INVESTIGATION OF THE STRENGTH OF SHIELDED AND UNSHIELDED UNDERWATER ELECTRICAL CABLES	(9) Final Report on completed contract.	
7. AUTHOR(s)	6. PERFORMING ORG. REPORT NUMBER	
(10) D. E. Glowe and S. L. Arnett	TRI No. 7967-15: DEG	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	8. CONTRACT OR GRANT NUMBER(s)	
Texas Research Institute 5902 W. Bee Caves Road Austin, TX 78746	(15) N00173-79-C-0129	
11. CONTROLLING OFFICE NAME AND ADDRESS	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS	
Naval Research Laboratory Underwater Sound Reference Detachment P.O. Box 8337, Orlando, FL 32856	(11) 64503N; SO219-AS; 0584-05	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	13. REPORT DATE	
Naval Sea Systems Command Washington, DC 20362	(11) 16 September 1981	
	13. NUMBER OF PAGES	
	34	
	15. SECURITY CLASS. (of this report)	
	UNCLASSIFIED	
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	
16. DISTRIBUTION STATEMENT (of this Report)		
Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
1		
18. SUPPLEMENTARY NOTES		
This report is taken from the Texas Research Institute Final Report No. 7967-15 under Contract N00173-79-C-0129, which was sponsored by the Sonar Transducer Reliability Improvement Program.		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)		
Cable	Submarine cable	
Underwater cable	Cable reliability	
Shielded vs. unshielded underwater electrical cable	Sonar cable	
Cable testing	Transducer cable	
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)		
The mechanical properties of shielded and unshielded submarine cables (MIL-C-915/8E) were investigated to determine the effect of shielding on cable life, performance, and reliability. Ten cables (five shielded and five unshielded) were selected for laboratory evaluation. A mission profile was developed to establish the mechanical stress limits that cables must endure in service and a test sequence designed to measure tensile- (Continues)		

DD FORM 1 JAN 73 1473

EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

395436

20. ABSTRACT (Continued)

strength, flexural abrasion endurance, crush resistance, creep under static tension, and performance in a hull-stuffing tube.

The results of this program showed that:

1. DSS-2 cable does not have adequate tensile strength and should have a strength member added. DSS-3 and larger cables have adequate tensile strength with or without the shield.
2. Unshielded DSS-3 type cable does not perform satisfactorily in hull-stuffing tubes.
3. Shielding is not required to meet mission profile specifications for cable crush or flexural abrasion resistance.
4. Construction parameters other than shielding can significantly affect mechanical performance of cable.
5. Unshielded cable construction can result in increased reliability since it permits a thicker single-jacket construction.
6. Unshielded cable construction can reduce the cost of cable by 8 to 20 percent.

Accession For	
NTIS GRA&I	☒
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A	

CONTENTS

BACKGROUND	1
APPROACH	1
Cable Selection	2
Mission Profile	2
Test Selection	5
TEST RESULTS	5
Tensile Properties	5
Flexural Abrasion	7
Bend Tensile Strength	9
Crush Resistance	10
Hull-Stuffing Tube Performance	10
Static Tension	11
DISCUSSION OF RESULTS AND CONCLUSIONS	11
Mission Profile	11
Strength Contribution of Shields	12
Crush Resistance	13
Cable Puncture Resistance	13
Hull-Stuffing Tube Results	14
Cost and Reliability	14
ACKNOWLEDGMENT	15
REFERENCES	15

INVESTIGATION OF THE STRENGTH OF SHIELDED AND UNSHIELDED UNDERWATER ELECTRICAL CABLES

BACKGROUND

This report covers work performed on Phase I of Naval Research Laboratory Contract No. N00173-79-C-0129 on investigation of the strength of shielded and unshielded underwater electrical cables. This contract was awarded to Texas Research Institute, Inc., (TRI) in May 1979 as part of the FY79 Sonar Transducer Reliability Improvement Program (STRIP), managed by the Underwater Sound Reference Detachment (USRD).

The STRIP Program investigates problems of current interest to the fleet. One of its objectives is to provide engineering solutions for problems that improve the life and reliability of sonar hardware. Underwater cables, an essential part of wet-end sonar hardware, have a history of failures that result in premature sonar replacement. Therefore, any improvement to cables that could lessen the frequency of failure could also improve the reliability of any attached sonar hardware.

Puncture of the cable jacket is a known failure mode that has been identified [1] as the most probable cause of cable failure. Jackets on shielded cables are relatively thin and can easily be punctured down to the shield. Such punctures result in flooding of attached connectors, degradation of electrical properties, and loss of the sonar transducer. Therefore, it was theorized that constructing cables without shields could provide thicker and more puncture-resistant cables that would be less susceptible to premature failures.

Arguments for retaining shielded cable construction have been that shielding increases tensile strength, abrasion, and crush resistance. Unshielded cables presently have had only limited use in the fleet, and data confirming their mechanical performance have not been available.

APPROACH

The objective of this investigation was to provide quantitative data to compare the mechanical properties of shielded and unshielded cables, determine how they are used and what mechanical properties are required for use, identify failure modes for the cables under stress, and provide an analysis of the cost and reliability tradeoff of shielded vs. unshielded cable.

To meet these objectives a three-task laboratory program was designed (Fig. 1). Task 1 obtained background information on cables and compiled a detailed mission profile description of cable exposures through all phases of cable life, obtained samples of ten cable types for comparative testing, and developed a test plan consisting of six mechanical tests. Task 2 exercised the test plan using the sample cables. Task 3 analyzed the resulting data and compared test values to service requirements.

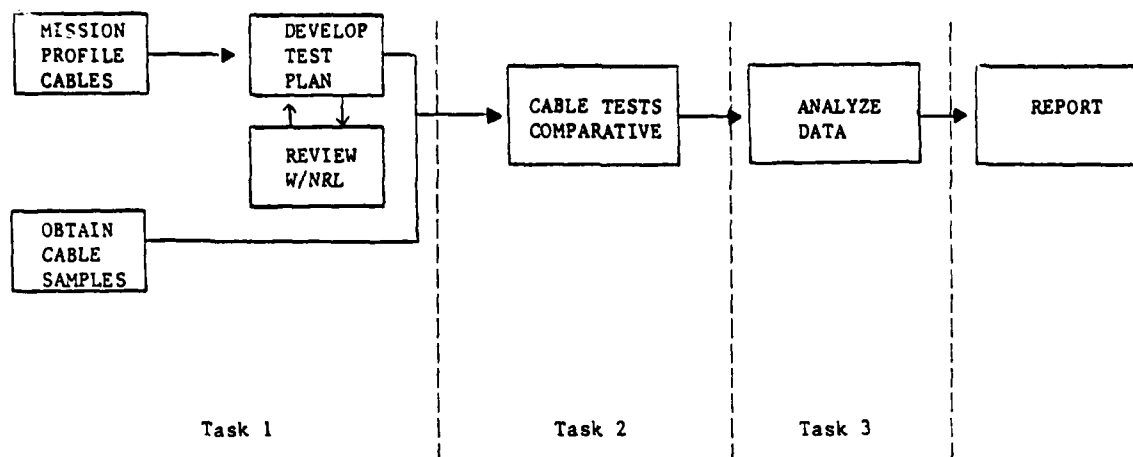


Fig. 1 — Cable evaluation lab program

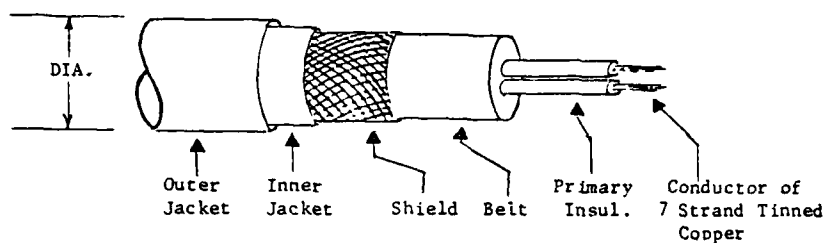
Cable Selection

Ten cable designs were selected for evaluation: five were shielded and five were unshielded. Each was examined, dissected, and had the internal components measured. A list of the cables and physical description of each is given in Table 1.

Cables were selected according to their current or proposed use in the fleet. Shielded cables included types DSS-2, DSS-3 (single and double jacketed), DSS-4, and FSS-2 made to MIL-C-915E. The unshielded cables included TRIDENT specification polyethylene jacketed cable [2], DSU-2 and DSU-3 made to a proposed specification, and DSS-2 and butyl jacketed cable made to in-house descriptions. Figures 2 through 4 are illustrations of the cable samples.

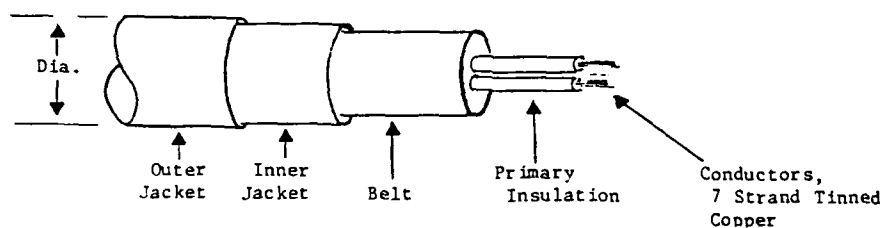
Mission Profile

A mission profile is a description of environmental and mechanical stresses to which hardware are exposed during the lifetime of that hardware. Environmental stresses include temperature extremes, thermal shock, moisture exposure, ultraviolet radiation, pressure excursions, and other exposures that contribute to material degradation or change in properties. Mechanical stresses address physical changes in materials caused by tensile, torsional or compressive loading, fatigue, abrasion, and other similar factors.



Cable Type	Diam (mm)	Outer Jacket Material	Inner Jacket Material	Shield Material	Belt Material	Primary Insul. Material	Strand Diam (mm)
DSS-2/E	10.16	Neoprene	Synthetic Rubber	Tinned Copper	Synthetic Rubber	Synthetic Rubber	0.41
DSS-3/A	12.70	Neoprene	None		Synthetic Rubber	Synthetic Rubber	0.51
DSS-3/E	12.70	Neoprene	Synthetic Rubber		Synthetic Rubber	Synthetic Rubber	0.51
DSS-4/E	12.70	Neoprene	Synthetic Rubber		Synthetic Rubber	Synthetic Rubber	0.61
FSS-2/E	12.70	Neoprene	Synthetic Rubber		Synthetic Rubber	Synthetic Rubber	0.41

Fig. 2 — MIL-C-915/8 cable



Cable Type	Diam (mm)	Outer Jacket Material	Inner Jacket Material	Belt Material	Primary Insul. Material	Diam (mm)
Special DSS-2	8.99	Neoprene	None	Synthetic Rubber	Synthetic Rubber	0.41
DSU-2	9.91	Neoprene	Synthetic	Synthetic	Synthetic	0.38
DSU-3	12.70	Neoprene	None	Synthetic Rubber	Synthetic Rubber	0.46
Butyl-3	12.70	Butyl	None	Synthetic Rubber	Synthetic Rubber	0.51

Fig. 3 — Unshielded DSU cable

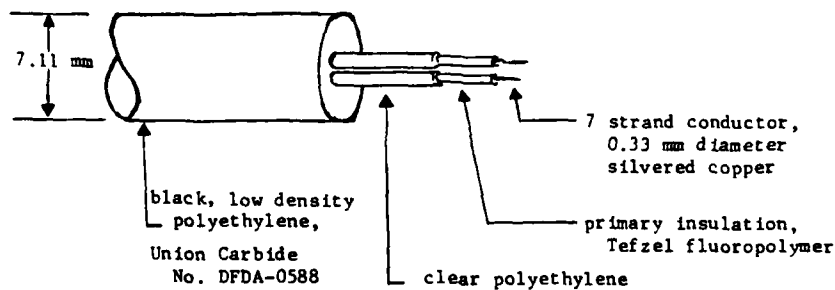


Fig. 4 — TRIDENT polyethylene cable [2]

The information developed is essential input to product design and to verification test design. The maximum and minimum stress exposures called for are used as guidelines to design and to test products for endurance to expected use. As such, the mission profile is a tool for ensuring product reliability and life expectancy.

The mission profile for cables in this program was developed to provide maximum and minimum stress limits for comparison of cable types. Three categories of mission profile were established: Transportation and Storage (Table 2); Installation and Maintenance, Environmental (Table 3) and Installation and Maintenance, Mechanical (Tables 4 through 7); and SSN Service (Table 8), SSBN Service (Table 9) and Surface Ship Service (Table 10). The general format used for describing the mission profile in Tables 2-10 was:

- Column 1 - Exposure number for identification.
- Column 2 - Exposure description.
- Column 3 - Range of exposure, maximum and minimum values that can be experienced. This range covers all ship use.
- Column 4 - Location where the exposure occurs during use.
- Column 5 - Description of extreme exposure given as time average for one year and maximum or minimum exposure values.
- Column 6 - Time average of extreme exposure per year.
- Column 7 - Description of a typical or average exposure given as average for one year.
- Column 8 - Time average of typical exposure per year.
- Column 9 - Companion exposure, if any, that may contribute synergistically to material changes in service.

Information contained in the mission profile was collected from various sources, among which were: product specifications, steaming data or estimates thereof, consensus opinion of naval personnel associated with maintenance and fleet operation, published literature, and manufacturers' opinions. In some instances hard numerical data for an exposure were not available; therefore, the data presented were estimated from data available.

Of the profile categories, the exposures in Transportation and Storage applies to all cable types. Installation and Maintenance was divided into environmental exposures, which apply to all cables, and mechanical exposures, which apply only to specific cable sizes. This division was required because of the difference in weight and use between cables. Service profiles were also divided into SSN, SSBN, and Surface Ship exposures because of the different mission requirements of these ship types. Their maintenance schedules are different, as shown in Table 11, and influence the in-service exposure levels that the hardware will see.

Test Selection

Since the mechanical attributes of shielded and unshielded cables were of primary interest in this program, the mission profiles were reviewed for indications of mechanical stress to the cables. The Installation and Maintenance (Tables 3 through 7) profiles showed that tensile strength, crush and flexure resistance, and static-stress creep were mechanical stresses that influenced cable performance. Cables, DSS-3 in particular, are used in hull-stuffing tubes and must perform satisfactorily in this service.

Standard tests were reviewed to find those applicable to cable performance. The sources reviewed included American Society for Testing and Materials (ASTM), Underwriters Laboratory, military and federal specifications, and other industrial sources. Table 12 lists the tests selected for this program, the measurements to be made, and the test objectives.

TEST RESULTS

Tensile Properties

Tensile properties of complete cables and of the cable components were measured following the testing parameters shown in Table 13. All complete cables, cables less jackets, and cables less jackets and shields were fixtured on a 102-mm-diam capstan grip for testing, as shown in Fig. 5. The individual components removed from the cable were cut into dogbone tensile specimens using ASTM-D-412 Die C. Wedge grips were used to hold elastomer samples and to hold the cut elastomer and conductor samples for tensile testing.

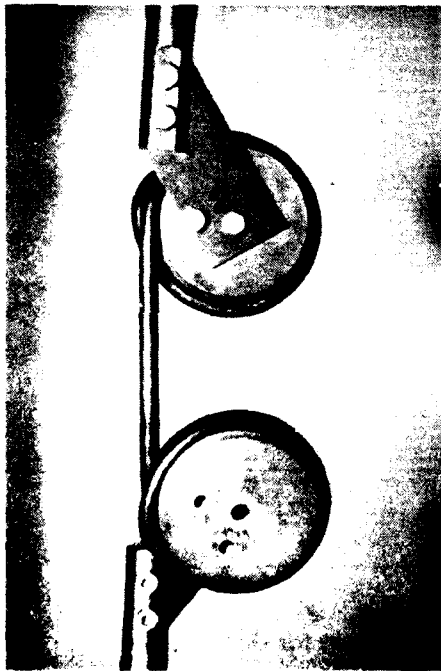


Fig. 5 — Cable tensile test fixture

R-0123

Tensile properties for the cable components are shown in Table 14. Maximum force applied to each sample and the sample elongation at maximum force are reported; maximum force in each cable sample was obtained at that point where a conductor broke. Stress for the elastomer dogbone samples was calculated on the basis of the unstressed cross-sectional area of the sample. The jackets on the unshielded DSS-2 and on the shielded DSU-2 did not separate from the belt; therefore, strength of cable less jacket was not measured. Also, the TRIDENT polyethylene cable does not have a separate jacket; therefore, jacket data are not reported.

Cable tensile properties are given in Table 15. Three samples of each cable type were tested; the maximum force of each cable was obtained when a conductor broke. The elongation at maximum force is also reported. The yield strength was calculated for each cable and is included in the data. Fig. 6 shows a recorded force-elongation plot for DSS-3 cable and Fig. 7 the recorded data for DSU-3 cable. These curves were typical of those obtained for other cable sizes.

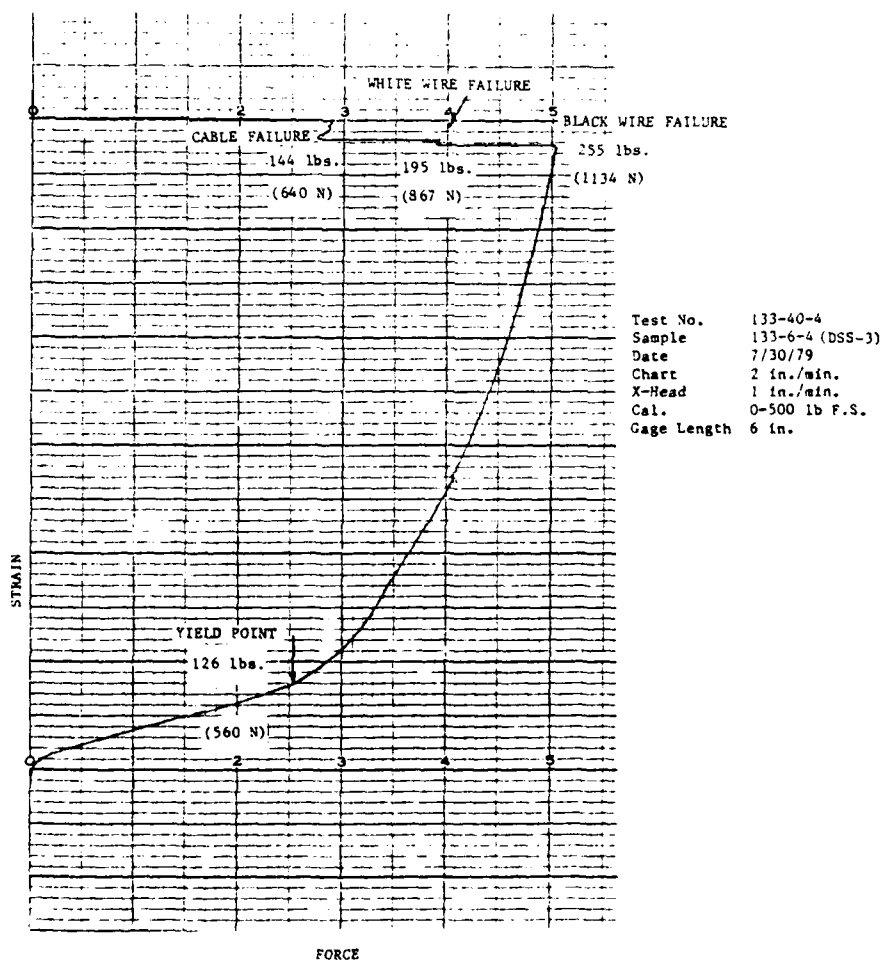


Fig. 6 — Tensile load chart for DSS-3 cable

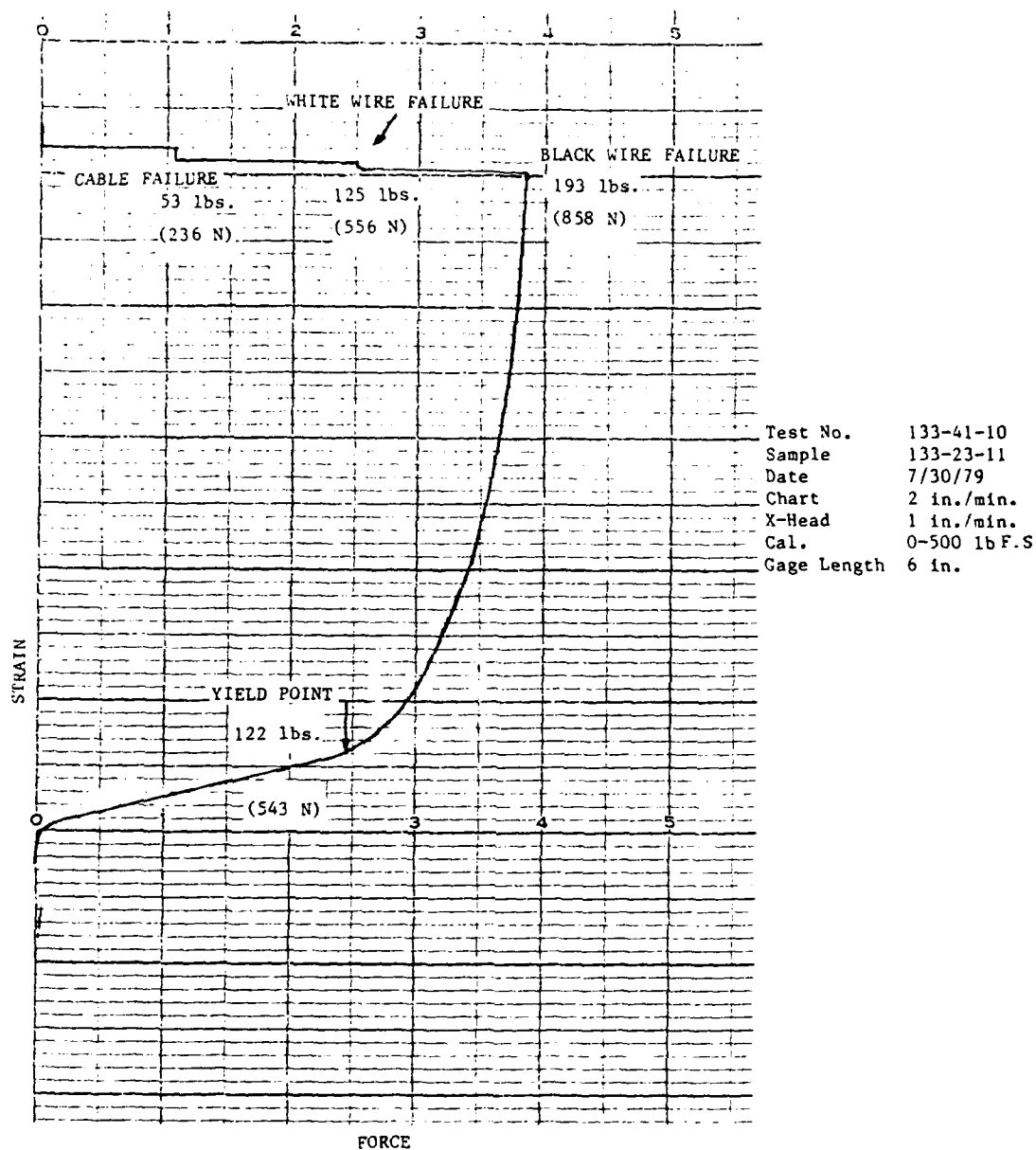


Fig. 7 — Tensile load chart for DSU-3 cable

Flexural Abrasion

A flexural abrasion test was designed to fatigue the metal components of the cables while under stress. The objective was to induce failure of the shield wires and measure any penetration of the jacket or primary insulation by broken wires through monitoring electrical continuity of the wires to ground.

The apparatus used for this test was based on a design developed by DuPont Corp. for evaluating internal abrasion of Kevlar® electromechanical cables. The test and fixture were presented by DuPont at the February 1979

Marine Technology Society's Cables and Connectors Workshop in San Diego, and no formal specification is known to exist. The equipment is schematically shown in Fig. 8 and consists of a 51-mm-diam octagonal mandrel submerged in a water bath, a drive system to move test cables over the mandrel, and a tensioning system to stress the cables while in motion. Fig. 9 shows cables attached to the apparatus.

In operation, the cables were individually tensioned using dead weights, bent 180° around the octagonal bar, and oscillated at 30 cycles/min with a 127-mm stroke length. The tensions selected were in excess of those identified in the service mission profiles for static tensile load. They were chosen so as not to result in tensile failure of the conductors due to tension alone. The continuity of the conductors was monitored during the test. Insulation resistances between the conductors and shielding and between the conductors, shield, and water were also monitored to detect possible penetration of the insulation by broken wires. Failure was defined as shield or conductor discontinuity or a short indicating penetration of the insulation.

Table 16 shows the results of this test. The number of cycles at failure is noted along with the increase in cable length. The failure mode in each failed cable was an open conductor. Shorts to ground or degradation of insulation resistance was not found, indicating that insulation was not punctured by broken wires. Two cable samples, FSS-2 and TRIDENT polyethylene, did not fail and were removed from the test after 20,000 cycles. All test cables were dissected at conclusion of the test to confirm failure modes; the observations made are summarized in Table 17.

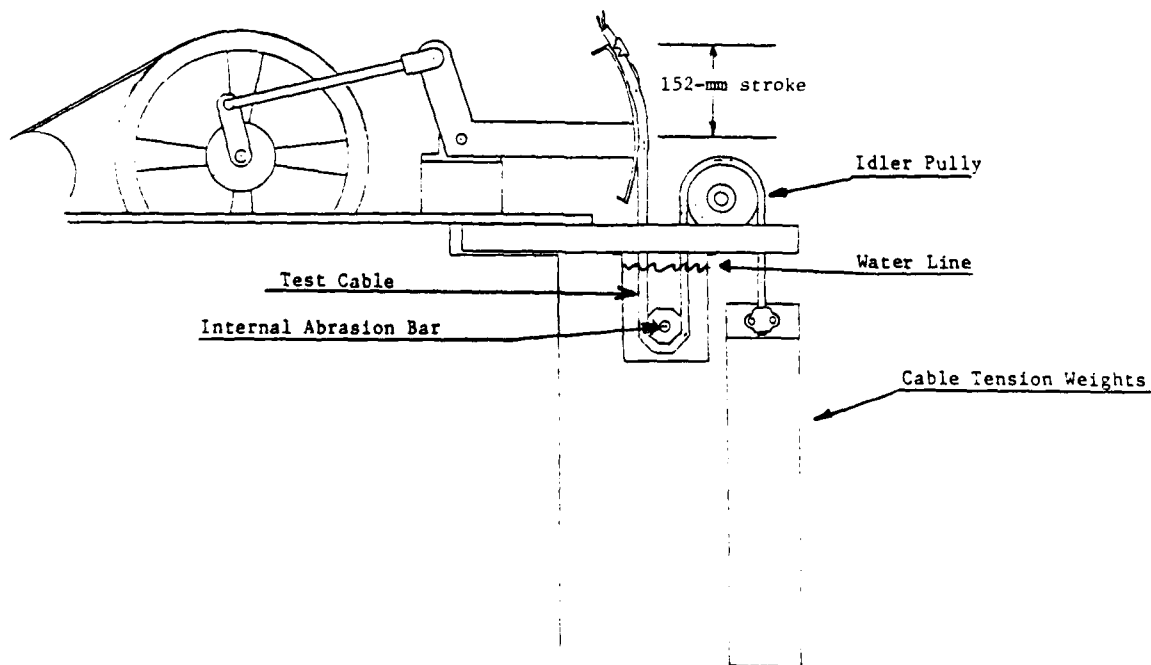
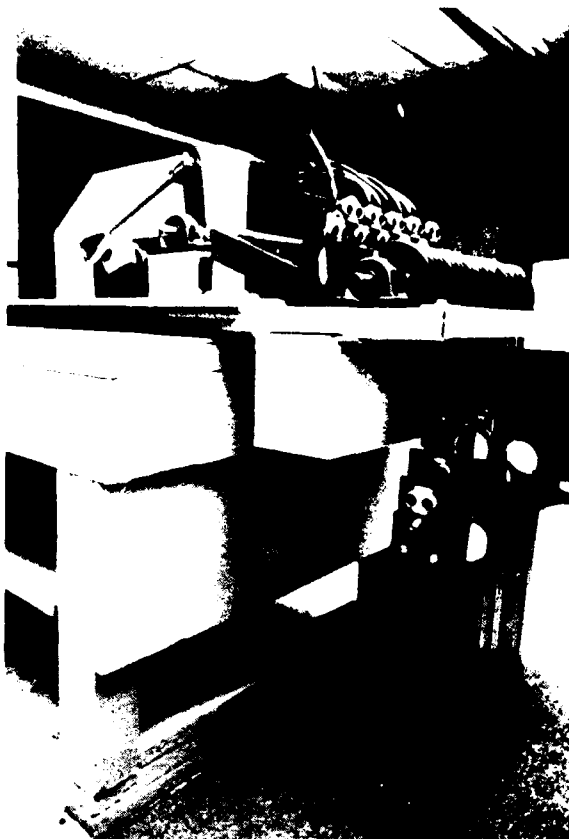


Fig. 8 — Flexural abrasion test fixture schematic



R-0124

Fig. 9 — Flexural abrasion test fixture

Bend Tensile Strength

Samples of DSS-3 and DSU-3 cables were tested in tension around a 51-mm-diam mandrel to determine the effect of compressive force in conjunction with a tensile force on cable failure characteristics. Both ends of the sample were fixtured to a 102-mm-diam capstan grip with the center supported by the mandrel. The samples were tensioned at a rate of 51 mm/min while the electrical continuity of the conductors and the resistance between conductors and shield was monitored. Applied force was continuously recorded during the test.

Three samples of both cable types were tested; the results are summarized in Table 18. The location of conductor failure was between the mandrel and the grip, and no damage was observed in the cables in contact with the mandrel. A separate sample of DSU-3 was tested in the same fixture, and mutual capacitance of the conductors was monitored. Capacitance as a function of applied force is plotted in Fig. 10.

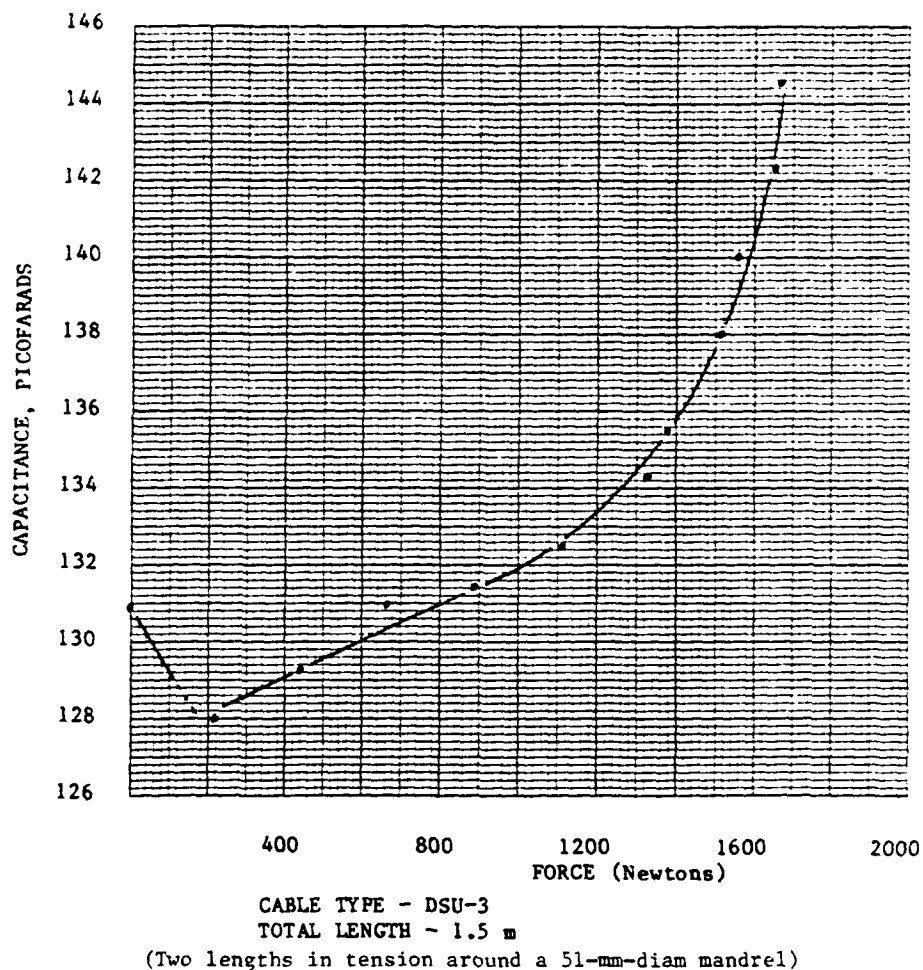


Fig. 10 — Capacitance change with tensile force

Crush Resistance

Crush resistance of cables was measured following the test procedures outlined in Reference 3. This test required that a cable sample be placed between two 51-mm-wide, parallel steel plates and then a force be applied to the plates at a rate of 13-mm/min. The compressive force was continuously recorded, and electrical continuity between conductors and steel plates monitored. Tests results are given in Table 19. Dissection of samples after testing confirmed the indicated failure modes. In no instance did a conductor or shield short to the compression plates before the conductors shorted to each other. In case of the TRIDENT polyethylene cable, the conductors parted and did not short.

Hull-Stuffing Tube Performance

Performance of the DSS-3 and DSU-3 cables was evaluated in a hull-stuffing tube [4]. This assembly was a compression grommet seal device used as a cable feedthrough in ship hulls. The test cables were assembled in the stuffing tube according to Naval Sea Systems Command procedures and subjected to three series of hydrostatic pressure sequences as shown in

Table 20. Criteria for evaluation were measurement of cable movement during or between test sequences, water leakage through the stuffing tube, and electrical characteristics of the conductors and shields.

Three samples of DSS-3 cable and four samples of DSU-3 cable were tested. Table 21 summarizes test results throughout the three complete test sequences. Insulation resistance of the conductors and shield was measured at the end of each complete sequence, as was cable movement through the fitting. Sample Numbers 4 and 5 of DSU-3 cable were removed after the first test sequence because they slipped too far in the stuffing tube during the first pressure-test sequence. None of the cables showed electrical failure. All cable samples were dissected at the conclusion of test. The shielded cables showed permanent deformation of the shield and partial shield breakage. Defects or permanent set were not observed in the nonshielded cables.

Static Tension

All cable samples were subjected to a static tensile stress simulating conditions that might exist when a vertical length of cable is hung unsecured. The load used for this test was the same as the load used for flexural abrasion testing and were in excess of those values identified in the mission profile. A sample length was 305 mm and was monitored for elongation during the test. The test was terminated after 30 days, and the test results are shown in Table 22.

DISCUSSION OF RESULTS AND CONCLUSIONS

Four specific questions have been addressed in this project:

- 1) What forces do cables experience during installation, ship operations, and maintenance?
- 2) Does the shield provide additional tensile or crush strength and resistance to cable failure?
- 3) Does a shield provide any protection from puncture, or does it contribute to failure by abrading and puncturing the insulation?
- 4) What is the cost and reliability tradeoff of shielded vs. unshielded cables?

The following discussion addresses these questions and proposes solutions to identified problems.

Mission Profile

Two divisions of the mission profile identify mechanical stresses to cables. The most strenuous exposure occurred during Installation and Maintenance of Cables (Tables 3 through 7) and less-strenuous but longer-term exposure occurred in Service.

Tensile stress occurred in both areas. Examination of installation and maintenance requirements showed that developed stress was dependent on cable type because of the difference in weights of the cables and of an attached transducer. Independent of cable type was the possibility of a cable used as a handhold by maintenance personnel and thereby supporting the full weight of a person, approximately 880 N. Although the DSS-3 profile showed a maximum weight of 1960 N when attached to TR-232 transducers, cable exposure to this value was unlikely since the conductors would break and detection would be obvious. Reports from the fleet have not been made of this excessive stress. More typically attached weight is approximately 240 N, and hand-hold occurrence of 880 N is the most probable maximum tensile stress cables will see.

Long-term static tensile stress is the result of an unsecured, vertically suspended length of cable. Shipboard cable installations are designed to be secured in cable trays, and an unsupported cable run is not likely to occur. In the event an unsupported condition would exist, the resulting tensile load for 30 m of DSS-3 cable would be 70 N less than the overriding maintenance hand-hold exposure.

Impact, crush, flexural abrasion, and compression squeeze are the remaining mechanical cable stresses that occur during installation and maintenance. Impact and crush values are identical among cable types, resulting from dropped tools, pinching in cable trays, foot traffic, and similar abuse. Stress levels for impact and crush were extracted from Underwriter's Laboratory Standard 44, since it has been accepted by industry as describing the practical endurance limits. Flexural-abrasion exposure and the accompanying flexural stress occur during installation, and the stated values are an approximation of maximum forces encountered due to cable installation in or over conduits. The reported exposures were determined by combining maximum tensile stress with a typical bend radius of 25 mm.

Table 23 summarizes the maximum mechanical stresses as identified in the mission profile for cables during installation, ship operations, and maintenance.

Strength Contribution of Shields

The tensile results of whole cables show that shielding contributes 15-18% of the strength of DSS-2 cable and 24% of the strength of DSS-3 cable. Comparing Butyl Size 3 cable to DSS-3 cable shows the shielding contributes 32% to overall strength. However, shielding does not increase the yield strength of cables.

Table 24 lists the required and measured strengths of the test cables. Neither shielded nor unshielded Size 2 cable meets the strength requirements for the 880-N hand-hold maintenance requirements and would break under this load. DSS-3 exceeds the 880-N requirement, and DSU-3 is within 20 N of meeting it. The 880-N hand-hold requirement is a high estimate of the weight of maintenance personnel; average exposure would most likely be less than this value. Therefore, both DSS-3 and DSU-3 cables can be expected to survive such exposure.

Full loading by heavy transducers (1960 N for DSS-3) although possible, is not likely to occur. Use of cable as a handle to lift transducers does frequently occur, but because of human lifting limitations, the lifted load is generally less than 240 N. Cables used as a handhold during maintenance are likely to result in an 880-N load, which should be considered in cable design and as a valid exposure limit.

Table 25 itemizes the strength contribution of the cable components. In all cables the conductors were a major strength component. However, for the TRIDENT cable the polyethylene insulation contributed 29% of the cable strength, which exceeds the 25% strength contribution of shielding for DSS-3 and FSS-2 cables. Also, the butyl cables showed 9% strength contributed by the insulation materials. DSU-3 cable, a similar construction to that of the butyl cable, has 17% strength contributed by the belt and jacket.

It is concluded that shielding can act as a strength member; and for small-diam cable, such as DSS-2, a strength member is required. However, shielding alone does not provide sufficient strength for Size 2 cable, and improved strength members should be considered. For DSS-3 and larger cables, shielding or other strength members are not required to prevent cable breakage. Insulation materials can add to tensile strength as exhibited by the TRIDENT polyethylene cable, or lessen the strength, as in the Butyl Size 3 cable compared to DSU-3.

Crush Resistance

Data obtained for cable crush characteristics (Table 19) show that shielded cables DSS-2 and DSS-3 are 7-15% more resistant to crush failure than a DSU type cable. However, all measured cables, with the exception of the DSS-2 Special Unshielded and the Unshielded Butyl Size 3, survived crushing forces in excess of the mission profile limit of 5300-N/50-mm length. The unshielded TRIDENT polyethylene cable was approximately four times more resistant to crush than the elastomeric shielded cables and ultimately failed with an open circuit rather than by shorted conductors. This again indicates that properties of the cable insulating materials can add to or detract from the crush resistance of cables more than shielding can.

It is concluded that shielding is not required for protection from crush damage. Also, increased crush resistance can be obtained, if required, by selecting tougher materials for insulation, such as that used for the TRIDENT polyethylene cables.

Cable Puncture Resistance

Cable puncture was not found to be a result of conductor-wire or shield-wire breakage. The flexural-abrasion test did fatigue shield and conductor wires to failure, but electrical measurements made during the test showed no degradation of insulation resistance or shorting to ground or between conductors. The failure mode identified during the crush test was conductor-to-conductor shorting. Jacket or primary insulation puncture by the shield was not found to be a failure mode.

Puncture of the cable by external forces was not investigated in this program. Shielding can be expected to inhibit cable puncture to the conductors by external forces; however, once the jacket is punctured down to the shield, water ingress along the shield will occur causing the cable to fail at the connector.

It is concluded that shielding does not contribute to internal puncture-related failures and can only delay and not prevent failure from external puncture.

Hull-Stuffing Tube Results

As shown in Table 21, three of the four samples of unshielded cable (DSU-3) moved over 6 mm during the pressure cycling, and all four of them continued moving at each cycle. The shielded cables moved less than 2-1/2 mm in the test series, appeared to become set after two pressure cycles, and thereafter moved little or none.

Cost and Reliability

Complete cost figures for unshielded cables are not available from manufacturers since DSU cable is not routinely made. Removing the shield results in a considerable manufacturing time savings in cable assembly and could also delete the requirement for double jackets. Estimates of 8-20% cost savings by shield removal have been made by cable manufacturers.

Impact of shield removal on the reliability of cable varies with failure mode and cable size. The most likely failure mode identified in Reference 1 was puncture of the cable jacket. Since internal puncture was not found in the test program, puncture from external causes is the failure mechanism of concern. Shield removal would allow an elastomer-puncture barrier in DSS-3 cable that is as much as 150% thicker than is presently available. The probability of external puncture to unshielded conductors would be less than the probability of puncture through the jacket only. Shield removal would appear, therefore, to increase cable reliability.

Considering the small Size 2 cables, shield removal would increase the probability of failure due to tensile stress. Size 3 cables are not as affected in a tensile failure mode, and the reliability impact of shield removal would not be significant.

The TRIDENT cable demonstrated superior performance in tests of flexural abrasion and crush and typical performance in the other areas tested. Therefore, it appears to be a highly reliable cable, and the reliability of cable assemblies using it would most likely depend on the reliability of the terminations.

ACKNOWLEDGMENT

This report is basically the final report by Messrs. D. E. Glowe and S. L. Arnett of Texas Research Institute, Inc., submitted on Phase I of NRL-USRD Contract N00173-79-C-0129. All figures and tables were compiled by TRI.

REFERENCES

- 1 - General Dynamics Corp./Electric Boat Division Report No. U443-78-036, "Electrical Cable and Connector Design for the Amatek/Straza TR-215 () Sonar Projector", Dec. 1978, Contract N66001-77-C-0220.
- 2 - Naval Sea Systems Command Specification, "Cable, Electrical, One Twisted Pair, AWG-20, for TRIDENT Submarine Outboard Use (not for inboard use) - Type IPR-20E."
- 3 - American National Standard Institute ANSI/UL Standard 44-1977, PAR 81, date unknown.
- 4 - Naval Sea Systems Command Dwg. 900-56202-F-1197101, Stuffing Tube PP for SS and TSP Types Cable, date unknown.

Table 1 — Cable description

CABLE	TYPE	MASS (kg/km)	CABLE DIAM (mm)	JACKET THICKNESS (mm)	NO. OF LAYERS	BELT		NO.	INSULATION		COLOR	STRAND DIAM (mm)*	COMMENTS
						DIAM (mm)	THICKNESS (mm)		TYPE	THICKNESS (mm)			
DSS-2 Spec. 1a1	unshielded	3.3	8.80	2.16-3.68	1	---	---	2	Single Rubber	0.63	BLW	0.41	Conductors loose in belt, will slide under tension.
DSS-2	shielded	4.2	10.18	1.52	2	6.72	0.76-1.65	2	Single Rubber	0.63	BLW	0.41	Double jacket separates easily, shield is tightly adhered to inner jacket. Conductors separate easily.
DSS-2	unshielded	3.5	9.91	1.90-4.10	2	---	---	2	Rubber w/ plastic sheath	0.63	BLW	0.38	Double jacket separates easily, jacket separates from belt easily. Conductors loose in belt.
DSS-3 Beach, Jacket	shielded	7.2	12.70	2.16	2	8.25	0.63-3.30	2	Single Rubber	0.99	BLW	0.51	Double jacket separates easily, shield removed easily. Con- ductors separate easily.
DSS-3 Single Jacket	shielded	7.2	12.70	2.16	1	8.25	0.80-3.42	2	Single Rubber	0.39-1.14	BLW	0.51	Jacket tightly adhered to belt, conductors loose in belt.
DSS-3	unshielded	5.4	12.70	2.41	1	8.00	1.78-3.43	2	Single Rubber	0.76	BLW	0.46	Jacket tightly adhered to belt, conductors loose in belt.
DSS-3	shielded	8.1	12.70	1.78	2	8.25	0.76-3.26	2	Rubber w/ plastic sheath	0.91	BLW	0.61	Double jacket separates easily, shield separates easily. Con- ductors separate easily.
DSS-2	shielded	8.4	12.70	2.29	2	8.25	0.80-2.42	4	Single Rubber	0.63	BLW	0.41	Double jacket separates easily, shield separates easily. Con- ductors adhered to belt.
BUTYL	unshielded	5.3	12.70	2.29	1	8.25	0.63-1.00	2	Single Rubber	0.63-1.27	BLW	0.51	Jacket separates from belt easily. Conductors loose in belt.
PHILKNT Polyethylene	unshielded	1.5	7.11	1.65-2.05	1	---	---	2	Double Plastic	0.28	Clear over BLW	0.20	Jacket hard and tight over conductors

* Seven strands per conductor.

Table 2 - Cable mission profile: transportation and storage

DURATION (Time or Cycles)						
NO.	EXPOSURE	EXPOSURE RANGE	OCCURRENCE	EXTREME	PER 1 YR.	CONTINUING LONG TERM PER 1 YR.
1	Temperature in air	-30° to +70°C	Storage Outside	70°C for 5 hrs/day x 180 days	900 hrs	
2				-30°C 12 hrs/day x 360 days	360 hrs	Humidity Ultraviolet Air Pollution
3			Covered Storage			-6° to +38°C 8640 hrs
4	Pressure in Air	12 to 100 kPa	Air Transportation	12 kPa 2 flights x 8 hrs	16 hrs	
5			Storage			100 kPa 8640 hrs
6	Humidity	-30° to +38°C Dew Point	Storage	-30°C Dew Point 30 days	720 hrs	
7				+38°C Dew Point 120 days	2880 hrs	Humidity Temperature Air Pollution
8						+10 to 32°C Dew Point 8640 hrs
9	Ultraviolet Radiation	0-2625 μ w/cm ² @ 290-400 nm	Storage Outside Uncovered	2625 μ w/cm ² 1.5 hrs/day 270 days	410 hrs	
10						770 μ w/cm ² 8 hrs/day x 360 days 2880 hrs
11	Air Pollution	0-500 psi ^a	Storage	500 psi 8 hrs/day for 3 days ^b	24 hrs	
12						200 + 50 psi 8 hrs/day for 180 days 1440 hrs
13	Rough Handling	Per MIL-STD-167-1c	Transportation	Per MIL-STD-167-1	1 series	

^a - psi - Pollution Standard Index per Fed. Reg. Vol. 44 #219

^b - Based on Los Angeles Experience, 1975. Ozone is major contaminant.

^c - Rough handling as defined by specification due to lack of service data.

Table 3 — Cable mission profile installation and maintenance, environmental

NO	EXPOSURE	EXPOSURE RANGE	OCCURANCE	DURATION (Time or Cycles)				COMPANION EXPOSURES
				EXTREME	PER 1 YR.	CONTINUING LONG TERM	PER 1 YR.	
1	Temperature in Air	-30° to +60°C	Dry Dock ^c Winter	-30°C for 30 Days	720 Hrs			Humidity Air Pollution
2						-11° to +11°C for 180 Days	4320 Hrs	
3			Dry Dock ^c Summer	+60°C for 8 Hrs/Day 90 Days	720 Hrs			
4						+11° to +39°C for 180 Days	4320 Hrs	
5	Temperature in Water	-2° to +32°C	Dockside Winter	-2°C for 90 Days	2160 Hrs			
6						-1° to +15°C for 180 Days	4320 Hrs	
7			Dockside Summer	+32°C for 90 Days	2160 Hrs			
8						+10° to +32°C for 180 Days	4320 Hrs	
9	Thermal Cycling	$\Delta T < 50^\circ C$	Dry Dock ^c	$\Delta T = 50^\circ C$ 1 Cycle/Day 90 Days	90 Cycles			Humidity Air Pollution
10						$\Delta T = 30^\circ C$ 1 Cycle/Day for 180 Days	180 Cycle	
11	Humidity	-30° to +38°C Dew Point	Dry Dock ^c Dockside	-30°C Dew Point 30 Days	720 Hrs			Temperature Air Pollution
12				+38° Dew Point 120 Days	2880 Hrs			
13						+10° to +32°C Dew Point	8640 Hrs	
14	Air Pollution	0 -500 psi ^a	Dockside and Dry Dock ^c	500 psi 8 hrs/day for 3 days ^b	24 Hrs			Temperature Humidity
15						200 ± 50 psi 8 hrs/day for 180 days	1440 Hrs	

a - psi - Pollution Standard Index per Fed. Reg. Vol. 44 #219

b - Based on Los Angeles experience, 1975. Ozone is the major contaminant.

c - Drydock frequency varies with ship type.

Table 4 — Mission profile: installation and maintenance, mechanical, DSS-2 cable

NO	EXPOSURES LOAD	EXPOSURE RANGE	OCCURANCE	DURATION (Time or Cycles)			
				EXTREME	PER 1 YR.	CONTINUAL LONG TERM	PER 1 YR.
1	Tensile Load, Dynamic	<250 N ^a	Installation	250 N	1 Cycle		
2		<880 N ^b	Maintenance	880 N	1 Cycle		
3						240 N	1 min.
4	Impact	<2 N·m	Maintenance Installation	2 N·m	1 Cycle ^c		
5	Crush	5300 N/51 mm Length	Maintenance Installation	5300 N/51 mm Length	1 Cycle ^d		
6	Internal Abrasion	250 N Tension on 51-mm diam mandrel	Installation	250 N on 51-mm diam mandrel	5 Cycles		

a - Weight of maximum cable length plus maximum attached transducer weight

b - Hand hold support.

c - Specified in Underwriter Lab STD 44 (Par 82).

d - Specified in Underwriter Lab STD 44 (Par 81).

Table 5 — Mission profile: installation and maintenance, mechanical, DSS-3 cable

NO	EXPOSURE LOAD	EXPOSURE RANGE	OCCURANCE	DURATION (Time or Cycles)			
				EXTREME	PER 1 YR.	CONTINUAL LONG TERM	PER 1 YR.
1	Tensile Load, Dynamic	<2000 N ^a	Installation	2000 N	1 Cycle		
2		<880 N ^b	Maintenance	880 N	1 Cycle		
3						240 N	1 min.
4	Impact	< 2 N·m	Maintenance Installation	2 N·m	1 Cycle ^c		
5	Crush	5300 N/51-mm Length	Maintenance Installation	5300 N/51-mm length	1 Cycle ^d		
6	Internal Abrasion	2000 N Tension 51-mm-diam mandrel	Installation	2000 N on 51-mm-diam mandrel	5 Cycle		

a - Weight of maximum cable length plus maximum attached transducer weight.

b - Hand hold support.

c - Specified in Underwriters Lab STD 44 (Par. 82).

d - Specified in Underwriters Lab STD 44 (Par. 81).

Table 6 — Mission profile: installation and maintenance, mechanical, DSS-4 cable

NO	EXPOSURE LOAD	EXPOSURE RANGE	OCCURANCE	DURATION (Time or Cycles)			
				EXTREME	PER 1 YR	CONTINUAL LONG TERM	PER 1 YR
1	Tensile Load, Dynamic	<490 N ^a	Installation	490 N	1 Cycle		
2		<880 N ^b	Maintenance	880 N	1 Cycle		
3						240 N	1 Min.
4	Impact	≤ 2 N·m	Maintenance Installation	2 N·m	1 Cycle ^c		
5	Crush	5300 N/51-mm Length	Maintenance Installation	5300 N/51-mm length	1 Cycled		
6	Internal Abrasion	490 N Tension on 51-mm-diam mandrel	Installation	490 N on 51-mm-diam mandrel	5 Cycles		

a - Weight of maximum cable length plus maximum attached transducer weight.

b - Hand hold support.

c - Specified in Underwriters Lab STD 44 (Par.82).

d - Specified in Underwriters Lab STD 44 (Par.81).

Table 7 — Mission profile: installation and maintenance, mechanical, FSS-2 cable

NO	EXPOSURE LOAD	EXPOSURE RANGE	OCCURANCE	DURATION (Time or Cycles)			
				EXTREME	PER 1 YR.	CONTINUAL LONG TERM	PER 1 YR.
1	Tensile Load, Dynamic	<860 N ^a	Installation	860 N	1 Cycle		
2		<880 N ^b	Maintenance	880 N	1 Cycle		
3						240 N	1 min.
4	Impact	≤ 2 N·m	Maintenance Installation	2N·m	1 Cycle ^c		
5	Crush	5300 N/51-mm Length	Maintenance Installation	5300 N/51-mm length	1 Cycled		
6	Internal Abrasion	860 N Tension on 51-mm-diam mandrel	Installation	860 N on 51-mm-diam mandrel	5 Cycles		

a - Weight of maximum cable length plus maximum attached transducer weight

b - Hand hold support

c - Specified in Underwriters Lab STD 44 (Par 82).

d - Specified in Underwriters Lab STD 44 (Par 81).

Table 8 - Cable mission profile: SSN service

NO.	EXPOSURE	RANGE OF EXPOSURE	OCCURANCE	DURATION OF EXPOSURE (hrs or cycles)				COMPANION EXPOSURE
				EXTREME	PER 1 YR.	CONTINUING LONG TERM	PER 1 YR.	
1	Temperature in Air	-55° to +60°C	Dockside	+60°C, 1.5 hr/day-270 days	405 hr			Humidity Air Pollution
2				-30°C 12 hr/day - 30 days	360 hr			
3						+3° to +37°C for 270 days	6480 hr	
4			Arctic Surface	-55°C for 21 days	504 hr			
5	Temperature in Sea Water	-2° to +32°C	Tropical Ser.	+32°C for 90 days	2160 hr			Pressure Vibration
6			Arctic Service	-2°C for 90 days	2160 hr			
7						-1° to 11°C for 90 days	2160 hr	
8	Thermal Cycling	$\Delta T \leq 50^\circ C$	Dockside	$\Delta T = 50^\circ C$	270 cycles			Humidity Air Pollution
9						$\Delta T \leq 30^\circ C$	365 cycles	
10	Thermal shock	$\Delta T \leq 53^\circ C$	Diving-Tropic	$\Delta T \leq 28^\circ C$	30 cycles			
11			Diving-Arctic	$\Delta T \leq 53^\circ C$	3 cycles			
12	Pressure	100 to 4100 kPa	At Sea	4100 kPa day - 90 days	180 hr			Temperature Vibration
13						700 to 2100 kPa for 90 days	2160 hrs	
14	Pressure Cycling	100 < P < 4100 kPa	At Sea	100 to 4100 kPa 2/day - 90 days	180 cycles			
15						700 to 2100 kPa 90 days	180 cycles	
16	Humidity	-55° to +38°C Dew	Surface	38°C D.P. 24 hr/day -	6480 hr			Temperature Air
17						10° to 32°C D.P. - 270 days	6480 hrs	
18	Air Pollution	0-500 psi ^a	Dockside	500 psi 18 hrs/day for 3 days ^c	24 hr			Temperature Humidity
19						200 + 50 psi 18 hrs/day 180 days	1440 hrs	
20	Vibration	Per MIL-STD-167-1 ^b	At Sea	Per MIL-STD-167-1	1 series			Temperature Pressure
21	Explosive Shock	Per CIPS ^b		Per CIPS	1 series			Pressure
22	Tensile Load, Static	Note d	All Service			Continuous Load per Note d	8640 hrs	Humidity Temperature Vibration Air Pollution

NOTES: a psi - Pollution Standard Index per Fed. Reg. Vol. 44 #219
b Vibration and explosive shock as defined by specification due to lack of service data.
c Based on Los Angeles experience, 1975. Ozone is the major contaminant.
d Static stress based on 10 meters of unsupported cable. DSS-2 = 13 N, DSS-3 = 23 N, DSS-4 = 26 N, FSS-2 = 26 N.

Table 9 — Cable mission profile: SSBN service

NO.	EXPOSURE	RANGE OF EXPOSURE	OCCURANCE	DURATION OF EXPOSURE (hrs or cycles)				COMPANION EXPOSURE
				EXTREME	PER 1 YR.	CONTINUING LONG TERM	PER 1 YR.	
1	Temperature Air	-55° to +60°C	Dockside	+60°C, 1.5 hr/day-40days	60 hrs			Humidity Pollution Air Pollution
2				-30°C 12 hr/day - 20 days	240 hrs			
3						+3° to 37°C for 60 days	1440 hr	
4			Arctic Surface	-55°C for 21 days	504 hrs			
5	Temperature Sea Water	-2° to +32°C	Tropical Service	+32°C for 270 days	6480 hrs	-1° to 11°C		Pressure
6			Arctic Service	-2°C for 270 days	6480 hrs			
7						1°C 11°C for 270 days	6480 hr	
8	Thermal Cycling	$\Delta T \leq 50^\circ C$	Dockside	$\Delta T = 50^\circ C$	60 cycles			Humidity Air Pollution
9						$\Delta T \leq 30^\circ C$	60 cycles	
10	Thermal Shock	$\Delta T \leq 53^\circ C$	Diving-Tropic	$\Delta T \leq 28^\circ C$	300 cycles			
11			Diving-Arctic	$\Delta T \leq 53^\circ C$	300 cycles			
12	Pressure	100 to 4100 kPa	At Sea	4100 kPa day - 300 days	7200 hrs			Temperature Vibration
13						700 to 2100kPa for 300 days	7200 hrs	
14	Pressure Cycling	100<P<4100 kPa	At Sea	100 to 4100kPa 2/day-300days	600 cycles			
15						700 to 2100kPa	600 cycles	
16	Humidity	-55° to +38°C Dew Point	Surface	38°C D.P. 24 hr/day - 60 days	1440 hr			Temperature Air Pollution
17						+10° to +32°C D.P. - 60days	1440 hr	
18	Air Pollution	0-500 psi ^a	Dockside	500 psi 8 hrs/day for 3 days ^c	24 hr			Temperature Humidity
19						200 + 50 psi 8 hrs/day for 60 days	48 hr	
20	Vibration	Per MIL-STD-167-1 ^b	At Sea	Per MIL-STD - 167-1	1 series			Temperature Pressure
21	Explosive Shock	Per CIPS ^b		Per CIPS	1 series			Pressure
22	Tensile Load, Static	Note d	All Service			Continuous Load per Note d	8640 hr	Humidity Temperature Vibration Air Pollution

NOTES: a psi - Pollution Standard Index per Fed. Reg. Vol. 44, #219
 b Vibration and explosive shock as defined by specification due to lack of service data.
 c Based on Los Angeles experience, 1975. Ozone is the major contaminant.
 d Static stress based on 10 meters of unsupported cable. DSS-2 = 59 N, DSS-3 = 98 N, DSS-4 = 120 N, FSS-2 = 120 N.

Table 10 — Cable mission profile: surface ship service

NO.	EXPOSURE	RANGE OF EXPOSURE	OCCURANCE	DURATION OF EXPOSURE (hrs or cycles)				COMPANION EXPOSURE
				EXTREME	PER 1 YR.	CONTINUING LONG TERM	PER 1 YR.	
1	Temperature in Air	0° to +38°C	Dockside	0° C	4320 hr			Humidity Pollution
2				180 days				
3				+38°C	8640 hr			
4	Temperature in Sea Water	-2° to 32°C	Arctic	-2° C for 180 days	4320 hr			Pressure Vibration
5			Tropical	+32°C for 360 days	8640 hr			
6						0° to +30°C for 360 days	8640 hr	
7	Pressure	100 to 250 kPa	Service	250 kPa day 360 days	8640 hr			Temperature Vibration
8						100 to 250 kPa for 360 days	8640 hrs	
9	Humidity	0° to +38°C Dew Point	Service	38°C D.P. 360 days	8640 hr			Temperature Pollution
10						10° to +32°C D.P. - 360days	8640 hr	
11	Air Pollution	0-500 psi ^a	Dockside	500 psi, 8 hrs/day for 3 days	24 hr			Temperature Humidity
12						200 + 50 psi 360 days	8640 hr	
13	Vibration	Per MIL-STD-167-1 ^b	At Sea	Per MIL-STD - 167-1	1 series			Temperature Pressure
14	Explosive Shock	Per CIPSP ^c	At Sea	Per CIPS	1 series			Pressure
15	Tensile Load, Static	Note d	All Service			Continuous Load per Note d	8640 hr	Humidity

NOTES: a psi - Pollution Standard Index per Fed. Reg. Vol. 44 #219
b Vibration and explosive shock as defined by specification due to lack of service data.
c Based on Los Angeles experience, 1975. Ozone is the major contaminant.
d Static stress based on 10 meters of unsupported cable. DSS-2 = 6 Kg, DSS-3 = 10 Kg, DSS-4 = 12 Kg, FSS-2 = 12 Kg.

Table 11 — Hypothetical maintenance schedule

SHIP TYPE	DRYDOCK - RESTRICTED AVAILABILITY		DRYDOCK - OVERHAUL	
	INTERVAL	TIME IN DRYDOCK	INTERVAL	TIME IN DRYDOCK
SSN	22 - 24 Months	45 Days	5 1/2 - 7 Years	6 - 10 Months
SSBN	22 - 24 Months	45 Days	5 1/2 - 7 Years	6 - 10 Months
SURFACE	-----	-----	3 - 4 Years	28 - 45 Days

Table 12 — Cable test plan

TEST	PROCEDURE	MISSION PROFILE REFERENCE	TEST SAMPLES	MEASUREMENTS, OBSERVATIONS	OBJECTIVE
Tensile Breaking Strength	ASTM-D-412 ASTM-D-470	Installation & Maintenance	Cable & Components, All Samples	Ultimate Strength, Elongation, Order of Component Break, Electrical Continuity	Ultimate Strength, Resistance to Maintenance and Installation Abuse
Flexural Abrasion	DuPont Design	Installation & Maintenance	Cables, All Samples	Stress, Cycles, Elongation, Continuity Resistance Breakdown (Megohm) Electrical Insulation	Fatigue Endurance, Insulation Degradation Due to Internal Conductor or Shield Break
Breaking Bend Strength	----	Installation & Maintenance	Cables, All Samples	Ultimate Strength, Elongation, Mode of Electrical Failure (Open or Short)	Mode of Electrical Failure Ultimate Strength Due to Tension over a Radius
Crush Resistance	ANSI/UL STD.44-1977	Installation & Maintenance	Cables, All Samples	Force to Failure Mode of Electrical Failure (Open or Short)	Resistance to Crushing Force, Mode of Failure
Performance Hull Stuffing Tube	----	Service	Cables, (DSS-3, DSU-3)	Electrical Characteristics Physical Dimensions, Grommet Compression, Leakage, Cable Movement Permanent Set in Cables	Movement, Leakage, Electrical characteristics in stuffing tube
Creep in Static	----	Installation & Maintenance,	Cables, All Samples	Stress, Time, Elongation Electrical Characteristics	Failure due to creep

Table 13 — Tensile test parameters of cables and cable components

Test No.	Test Description	Sample	Strain Rate (mm/min)	Gage Length (mm)
1	Tensile strength, cable, 102 mm diameter Capstan grips	Cable and components, 1.83m sample	51	102
2	Tensile strength, wire, wedge grips	Wire sample 152 mm sample	51	51
3	Tensile strength, insulation, wedge grips	Elastomer insulation cut to ASTM-D-412, Die C	51	51

Table 14 — Cable component tensile properties

CABLE TYPE	COMPLETE CABLE		LESS JACKET		LESS JACKET & SHIELD		CONDUCTOR W/INSULATION		COMPONENT STRENGTH MPa	
	Max Force N	Elong. %	Max Force N	Elong. %	Max Force N	Elong. %	Max Force N	Elong. %	Jacket	Belt
DSS-2 Unshielded	520	46	---	---	---	---	230	7	11.0	---
DSS-2	600	76	570	47	460	56	210	7	9.0	5.9
DSU-2	500	50	---	---	---	---	210	7	13.1	6.0
DSS-3 Double Jacket	1140	70	990	48	710	46	340	19	8.3	6.1
DSS-3 Single Jacket	1120	77	1010	68	720	38	340	19	9.0	6.7
DSU-3	860	56	680	30	---	---	370	16	12.4	16.5
DSS-4	1560	84	1490	56	1200	54	590	16	7.6	8.3
FSS-2	1320	57	1230	51	900	36	230	15	6.3	9.0
BUTYL Size 3	760	73	730	64	---	---	340	13	11.0	10.3
TRIDENT Polyethylene [2]	800	49	---	---	---	---	280	12	---	---

Table 15 — Cable tensile properties

SAMPLE TYPE	Maximum Force (N)				ELONGATION	YIELD STRENGTH (N) 1% OFFSET
	1	2	3	AVERAGE		
DSS-2 Unshielded	510	510	530	520	46%	400
DSS-2	610	650	550	600	76%	390
DSU-2	520	490	500	500	50%	390
DSS-3 Double Jacket	1130	1110	1170	1140	70%	660
DSS-3 Single Jacket	1130	1130	1110	1120	77%	660
DSU-3	860	840	870	860	56%	640
DSS-4	1540	1570	1570	1560	84%	1040
FSS-2	1320	1330	1310	1320	57%	840
BUTYL Size 3	750	740	790	760	73%	550
TRIDENT Polyethylene [2]	870	770	750	800	49%	620

Table 16 — Flexural abrasion test results

Sample Number	Type	Cable Load (N)	Cycles to Failure	Elongation at Failure (%)	Failure Mode
1	DSS-2 Unshielded	38	1900	2.8	Open Conductor
2	DSS-2	38	13000	2.8	Open Conductor
3	DSU-2	38	10000	1.4	Open Conductor
4	DSS-3 Double Jacket	57	15000	2.1	Open Conductor
5	DSS-3 Single Jacket	57	11000	1.4	Open Conductor
6	DSU-3	57	8800	0.7	Open Conductor
7	DSS-4	57	11000	1.4	Open Conductor
8	FSS-2	57	>20000	1.4	No Failure
9	BUTYL Size 3	57	6700	3.5	Open Conductor
10	TRIDENT Polyethylene [2]	22	>20000	<0.7	No Failure

Table 17 — Flexural abrasion test observations

Sample Number	Type	Observation
1	DSS-2 Unshielded	Both conductors separated.
2	DSS-2	Shield intact, both conductors separated.
3	DSU-2	Both conductors separated.
4	DSS-3 Double Jacket	Shield separated 50%, no shield penetration of insulation. Both conductors separated.
5	DSS-3 Single Jacket	Shield intact, both conductors separated.
6	DSU-3	Both conductors separated.
7	DSS-4	Shield intact, both conductors separated.
8	FSS-2	Cable intact, no conductor or shield breakage.
9	BUTYL Size 3	Both conductors separated.
10	TRIDENT Polyethylene [2]	Cable exterior roughened, no internal damage observed.

Table 18 — Tensile bend-test results

CABLE TYPE	AVERAGE FORCE TO FAILURE (N)	FORCE PER CABLE (N)	FAILURE ANALYSIS
DSS-3 Double Jacket	2222	1111	Conductor broken between mandrel and grip, no damage observed over mandrel, 40-50% shield broken, separation of 1st and 2nd jacket observed.
DSU-3	1713	857	Conductor broken between mandrel and grip, no damage observed over mandrel, separation of jacket and belt observed.

Table 19 — Cable crush-test results

CABLE TYPE	CABLE DIAMETER (mm)	COMPRESSION AT FAILURE (mm)	Z COMPRES- SION	LOAD TO FAILURE (N)				FAILURE MODE
				1	2	3	AVG	
DSS-2 Unshielded	8.89	4.1	50	1660	2260	2660	2200	Conductor-conductor short
DSS-2	10.16	5.2	51	6060	6070	5250	5790	Conductor-conductor short
DSU-2	9.91	5.6	56	4440	5340	5340	5040	Conductor-conductor short
DSS-3 Double Jacket	12.70	6.9	54	6110	7110	7110	6770	Conductor-conductor short
DSS-3 Single Jacket	12.70	6.9	55	6220	6670	6670	6520	Conductor-conductor short
DSU-3	12.70	6.9	54	6220	6670	5340	6070	Conductor-conductor short
DSS-4	12.70	6.7	53	6330	5550	5440	5780	Conductor-conductor short
FSS-2	12.70	7.5	59	9780	8890	11110	9930	Conductor-conductor short
BUTYL Size 3	12.70	5.4	43	1770	1770	1770	1770	Conductor-conductor short
TRIDENT Polyethylene [2]	7.11	5.7	78	26600	25400	28900	27000	Open conductor

Table 20 — Stuffing-tube-test sequence

Cycle	Operation
1	Pressurize 0-1.82 MPa - repeat for 20 cycles
2	Pressurize 0-3.55 MPa - repeat for 20 cycles
3	Pressurize 0-6.99 MPa - repeat for 20 cycles
4	Pressurize 0-10.44 MPa - repeat for 20 cycles
5	Pressurize 0-13.89 MPa - repeat for 20 cycles
6	Pressurize 0-1.82 MPa - hold at 1.72 MPa for 8 hrs.
7	Reduce pressure to 0.1 MPa - hold at 0.1 MPa for 8 hrs.

Table 21 — Hull-stuffing-tube performance results

SAMPLE NUMBER	CABLE TYPE	INITIAL		SEQUENCE 1			SEQUENCE 2			SEQUENCE 3		
		IR Ohms	CONDUCTORS	IR Ohms	CONDUCTORS	MOVEMENT (mm)	IR Ohms	CONDUCTORS	ACCUMUL. MOVEMENT (mm)	IR Ohms	CONDUCTORS	ACCUMUL. MOVEMENT (mm)
1	DSS-3	>100G	Good	>20G	Good	1.78	>20G	Good	2.41	>20G	Good	2.41
2	DSS-3	>100G	Good	>1G	Good	1.14	>1G	Good	1.40	>1G	Good	1.40
3	DSS-3	>100G	Good	>100G	Good	1.45	>30G	Good	1.85	>30G	Good	1.91
4	DSU-3	>100G	Good	>100G	Good	22.48	>100G	--	--	--	--	--
5	DSU-3	>100G	Good	>100G	Good	6.68	>100G	--	--	--	--	--
6	DSU-3	>200G	Good	>100G	Good	1.78	>100G	Good	3.56	>100G	Good	3.81
7	DSU-3	>200G	Good	>100G	Good	1.47	>100G	Good	17.14	>100G	Good	18.03

Table 22 — Cable elongation in static tension

SAMPLE NO.	CABLE	LOAD (N)	TIME	ELONGATION % *
1	DSS-2 Unshielded	38	30 Days	<1.0
2	DSS-2	38	30 Days	<1.0
3	DSU-2	38	30 Days	<1.0
4	DSS-3 Double Jacket	57	30 Days	<1.0
5	DSS-3 Single Jacket	57	30 Days	<1.0
6	DSU-3	57	30 Days	<1.0
7	DSS-4	57	30 Days	<1.0
8	FSS-2	57	30 Days	<1.0
9	BUTYL Size 3	57	30 Days	<1.0
10	TRIDENT Polyethylene [2]	22	30 Days	<1.0

*All samples elongated 3.17 mm per 305 mm gage length.

Table 23 — Cable strength limits

EXPOSURE	CABLE TYPE			
	DSS-2	DSS-3	DSS-4	FSS-2
Tensile N	880	1960*	880	880
Crush N/50 mm	5290	5290	5290	5290
Impact N•m	2	2	2	2
Flexural Abrasion Load (N) Over 50 mm Mandrel	255	1960*	490	862

*Load for TR-232 system only.

Table 24 — Cable tensile load performance

Cable	Tensile (N)		Yield (N)
	M.P. ¹	Test	Test
DSS-2	880	600	390
DSU-2	880	520	390
DSS-3 ³	1960 ²	1140	660
DSU-3	1960 ²	860	640
Butyl-3	880	760	550
DSS-4	880	1560	1040
FSS-2	880	1320	840
TRIDENT	880	800	620

1 - M.P. = Mission Profile requirements.

2 - Stress Requirement for TR-232 only; other systems require 880 N.

3 - Double jacket.

Table 25 — Strength contribution of cable components

Cable Type	Strength Contribution (%)		
	Insulated Conductors	Belt and Jacket	Shield
DSS-2 Unshielded	89	11	none
DSS-2	67	16	17
DSU-2	88	12	none
DSS-3 Double Jacket	61	15	24
DSS-3 Single Jacket	62	13	25
DSU-3	83	17	none
DSS-4	77	5	18
FSS-2	68	7	25
Butyl Size 3	91	9	none
TRIDENT Polyethylene	71	29	none

DATE
ILME