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NRL Memorandum Report 1418

**Sonar Transducer Reliability Improvement Program
(STRIP), FY 81 First Quarter Progress Report**

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Transducers Corona Transducer fluids Encapsulation	Cables Connectors Noise & Vibration Pressure Release	Noise Material evaluation Water permeation Environmental tests
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) During the first quarter of FY81, efforts in the various tasks of STRIP have resulted in progress toward the program goals as summarized below:		
- An investigation of the effects of temperature on the performance of K33 ceramic stacks have been initiated. - An evaluation of the TF-122A/B (BQC-1) transducer has revealed an inability to meet performance specifications. A possible solution is indicated.		

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- A report entitled "Twenty-Year Life Hydrophones" has been published.
- Measurements of the relative humidity and water content of a transducer have shown that a large majority (~98%) of the water is absorbed onto surfaces. This casts some doubts on previous calculations of the rate of water permeation into the transducers.
- Composite Unit Accelerated Life Testing (CUALT) continues on the DT-605 hydrophones (fourth-year equivalent) and the TR-316 projectors (second-year equivalent). No new design or aging problems have been found.
- A report entitled "Reliability and Service Life Concepts for Sonar Transducer Applications" has been completed.
- A draft of the "Handbook for Connector and Cable Harness Design" has been completed and is being reviewed.
- New starts for FY81 have been made in the areas of:
 - Specification of Elastomers (Task I-3)
 - Transducer Ceramics (Task D-4)
 - Ceramic Stack Joints (Task F-2)
 - TR-122 FMA and Improvements (Task F-4) and
 - Metal Matrix Composites (Task F-5)

New efforts will be made in the areas of:

- Cable Configuration and Materials (Task C-3)
- Cable Specifications (Task C-4) and
- Improved Hydrophone Analysis (Task D-6)

when contract procedures are completed.

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Sonar Transducer Reliability Improvement Program
NRL Problem 0584
FY81 First Quarter Progress Report

1. INTRODUCTION

1.1. PROGRAM OVERVIEW

The general objective of this program is to perform relevant engineering development which addresses the operational requirements for fleet transducers for active sonar, passive sonar, surveillance, counter-measures and deception devices, navigation, and acoustic communications. The approach is to develop, test, and evaluate improved transducer design, materials, components, and piece-parts that will meet specified requirements in the operational environment during the entire useful life of the transducer. Standards will be prepared to ensure that results obtained during preliminary testing will be obtained consistently in production. This program should result in improved performance and reliability and reduced costs through better utilization and a more comprehensive characterization of materials and design data. The program goals are as follows:

- Reduction in transducer replacement costs
 - Goal - less than 9% of population replaced each year with no automatic replacements at overhaul.
 - Threshold - less than 18% of population replaced each year.
- Improvement in transducer reliability
 - Goal - less than 1% of population failures each year.
 - Threshold - less than 3% of population failures each year.
- Improvement in transducer receiving sensitivity
 - Goal - less than ± 1 dB variation from the specified value over operational frequency band.
 - Threshold - less than ± 2 dB variation from the specified value over operational frequency band.

The Sonar Transducer Reliability Improvement Program (STRIP) is a part of Program Element 64503N. Major task areas with specific objectives to achieve the program goals have been described in the Program Plan and include:

- Task Area A - Encapsulation Methods
- Task Area B - High-Voltage Engineering

- Task Area C - Cables and Connectors
- Task Area D - Transducer Material Standards
- Task Area E - Environmental Test Methods
- Task Area F - Transducer Tests and Evaluation

The FY81 Program Plan for STRIP has been funded at the \$1017K level. The specific tasks and their Principal Investigators for FY81 are listed below:

TASKS		PRINCIPAL INVESTIGATORS	
A	Encapsulation Methods	NRL-USRD	C.M. Thompson
B	High-Voltage Engineering	NRL-USRD	L.P. Browder
C-1	Handbook for Harness Design	EB/GD	R.F. Haworth
C-2	Standard for O-Ring Installation	APL/University of Washington	C.J. Sandwith
C-3	Cable Configuration & Materials	Contractor	
C-4	Cable Specifications	Contractor	
D-1	Alternative Materials: Plastics	NWSC	K. Niemiller
D-2	Pressure Release Materials	NUSC	C.L. LeBlanc
D-3	Specification of Elastomers	NRL-USRD	C.M. Thompson
D-4	Transducer Ceramics	NRL-USRD	A.C. Tims
E-1	CUALT	NOSC	J. Wong
E-2	ALT Verification	NWSC	D.J. Steele
F-1	Failure Modes due to Water	TRI	P.E. Cassidy
F-2	Ceramic Stack Joints	NOSC	C.I. Bohman
F-3	Reliability & Life Prediction Specification	TRI	R.I. Smith
F-4	TR-122 FMA & Improvements	NRL-USRD	R.W. Timme
F-5	Metal Matrix Composites	Honeywell	O.L. Akervold
F-6	Improved Hydrophone Analysis	NWC	D.J. Steele
F-7	Engineering Documentation	NRL-USRD	R.W. Timme

1.2. SUMMARY OF PROGRESS

During the first quarter of FY81, efforts in the various tasks of STRIP have resulted in progress toward the program goals as summarized below:

- An investigation of the effects of temperature on the performance of K₃₃ ceramic stacks has been initiated. See Section 12.

- An evaluation of the TR-122A/B (BQC-1) transducer has revealed an inability to meet performance specifications. A possible solution is indicated. See Section 14.
- A report entitled "Twenty-Year Life Hydrophones" has been published. See Section 15.
- Measurements of the relative humidity and water content of a transducer have shown that a large majority (~98%) of the water is absorbed onto surfaces. This casts some doubts on previous calculations of the rate of water permeation into the transducers. See Section 11.
- Composite Unit Accelerated Life Testing (CUALT) continues on the DT-605 hydrophones (fourth-year equivalent) and the TR-316 projectors (second-year equivalent). No new design or aging problems have been found. See Section 9.
- A report entitled "Reliability and Service Life Concepts for Sonar Transducer Applications" has been completed. See Section 13.
- A draft of the Handbook for Connector and Cable Harness Design has been completed and is being reviewed. See Section 5.
- New starts for FY81 have been made in Tasks D-3, D-4, F-2, F-4, and F-5. New efforts will be made in Tasks C-3, C-4, and F-6 when contract procedures are completed.

1.3. PLANS

The annual review for the STRIP will be held on 12 and 13 March 1981, beginning at 0800, in the Conference Room in Building 226, of the Naval Research Laboratory in Washington, DC. The objectives of the meeting are:

- To inform the NAVSEA managers, the laboratory sonar engineers, and the TRF engineers of R&D being directed toward their problems.
- To inform the present and potential STRIP principal investigators of the transducer problems facing the fleet.
- To initiate planning for the FY82 STRIP.

NAVSEA has issued time guidelines for preparing work planning summaries for FY82. The date of 15 May 1981 has been suggested as the deadline for firm plans for FY82; therefore, an invitation for proposals of work to be included in STRIP FY82 will be extended at the annual review on 13 March 1981. The deadline for proposals will be 17 April 1981. It is planned that the FY82 STRIP plan will be ready by 15 May 1981.

1.4. REPORT ORGANIZATION

The remaining sections of this quarterly report will discuss the objectives, progress, and plans for the specific tasks included in the STRIP.

2. TASK A - ENCAPSULATION METHODS

C.M. Thompson - NRL-USRD

2.1. BACKGROUND

A material to be used for filling a sonar transducer must meet a wide variety of specifications. The requirements imposed by the electrical nature of the device include high resistivity, high dielectric constant, as well as resistance to corona and arc discharges. The water environment of the transducer necessitates low water solubility and other attractive solution properties. In addition, the fluid must maintain its electrical and other properties in the presence of any water which permeates the covering. The acoustic requirements are a close acoustic impedance match with seawater and resistance to cavitation at high drive levels. Other obvious properties include compatibility with other components, stability to degradation, and suitable surface tension and viscosity.

With such a wide variety of requirements, it is not surprising that compromises have to be made. The most commonly used fluid for many years has been castor oil. This use is in spite of its high viscosity. Each of the fluids proposed, so far, as a replacement has serious drawbacks. Silicone oils tend to creep onto and wet all of the surfaces of the transducer. This greatly complicates bonding the components together. Polyalkylene glycol (PAG) has the disadvantages of a high water solubility and low electrical resistivity. The various hydrocarbon liquids have too low an acoustic impedance and are frequently incompatible with the various plastics and rubbers in the transducer. Further research is necessary to find and qualify fill-fluids which represent the best match to all the requirements imposed upon it.

Transducer encapsulants have long presented a source of transducer failure. The necessity that the encapsulants be resistant to water, have a sufficiently long pot-life for de-gassing, bond well to the other components, and have high strength has proved to present a very difficult problem. Many other requirements also apply in special cases. The best choice for a polyurethane encapsulant to date has been a toluene diisocyanate (TDI)-polytetramethylene glycol (PTMG) prepolymer which is chain extended with a 4,4'-methylen-bis(orthochloroaniline) (MOCA). This encapsulant has a long pot-life, good strength, and good water resistance. However, there is serious concern for the health hazards of both the MOCA and the TDI residue in the prepolymers.

2.2. OBJECTIVES

The objectives of this task are:

- To evaluate alternative transducer fill-fluids including fluids specifically for use in towed arrays and to produce specifications for those fluids found suitable.

- To define the relative importance of the properties of transducer encapsulants and to produce a non-hazardous replacement for currently used materials.

2.3. PROGRESS

2.3.1. During this quarter, efforts have been directed at preparing a Request for Proposal (RFP) for designing and producing a hazard-free, non-proprietary encapsulant for sonar transducer use. This RFP will request development of a polyurethane with the following properties specified (ranked in approximate order of importance):

- Low water degradation
- Long pot-life
- Low mix viscosity
- Hazard-free
- High adhesion
- Low water permeation
- High strength (toughness or tear)
- Density near $1,000 \text{ Kg/m}^3$
- Sound speed near 1550 m/s
- Transparent
- Short cure-cycle
- Low acoustic attenuation
- Maintenance of properties at low temperature

Once a non-proprietary formulation has been developed, a compositional specification will be written which may be used by any transducer manufacturer.

In-house work on reduced-hazard curing agents has been stymied because of a lack of supply sources for these materials.

2.3.2. Work has begun under an NRL-funded (1) research problem on modification of commercial polyether fluids. Several of these materials would make very good sonar transducer fill-fluids except for a few unfortunate properties--such as high water solubility and low electrical resistivity. From a chemical standpoint, both of these properties are a result of the terminal alcohol group(s) in these compounds. Therefore, this research project approaches the substitution of hydrogen or alkoxy groups in the polyethers, PAG, and PTMG. As these materials are synthesized, they will transition to the STRIP for testing of their critical transducer-related properties.

2.3.3. Additional data have been taken on transducer and towed-line fill-fluids for inclusion in the "Handbook of Sonar Transducer Passive Materials", which will be published as NRL Memorandum Report 4311 during the second quarter of FY81. This has included density or compatibility determinations on castor oil, several silicone oils, and Nopar 12 (a candidate towed-line fluid). Data sheets of six of the more commonly used fill-fluids have been taken from the handbook and are presented for information in the following. It should be noted that even for these commonly used fluids there are many properties unknown or only partially characterized. This, in itself, produces many of the problems encountered in transducer design.

2.4. PLANS

- Publish a report of transducer fluid properties with a more detailed discussion of fluid selection criteria (2nd Qtr, FY81).
- Perform testing on modified PAG and PTMG. (2nd Qtr, FY81).
- Publish a report on water permeation in sonar transducers and the effect this has on operation and lifetime (cooperative between Tasks A-1 and F-1).
- Publish RFP on encapsulants (27 Feb 1981).
- Award contract on encapsulants (30 Apr 1981).

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MATERIAL: Castor Oil, Ester 13 Grade

CHEMICAL DESCRIPTION: Primarily tri-ester of ricinoleic acid and glycerol; average molecular weight 928 g/mole

REMARKS:

ADVANTAGES: Good compatibility and acoustic properties

DISADVANTAGES: High viscosity, especially at low temperature

PHYSICAL PROPERTIES:

VOLUME ELECTRICAL RESISTIVITY ($\Omega\text{-m}$) 6×10^{10} *[60]

VAPOR PRESSURE (Pa) Very low *[51]

VISCOSITY (CENTIPOISE) 720 at 25°C *[50]

DENSITY (kg/m^3) $\rho = 1000 / (1.02714 + 7.04 \times 10^{-4} T + 9.66 \times 10^{-7} T^2 + 3.0 \times 10^{-9} T^3 - 4.91 \times 10^{-4} P - 2.63 \times 10^{-6} P T - 4.04 \times 10^{-9} P T^2 - 8.8 \times 10^{-11} P T^3 + 1.471 \times 10^{-6} P^2 + 9.2 \times 10^{-9} P^2 T + 3.6 \times 10^{-11} P^2 T^2 - 3.63 \times 10^{-9} P^3 - 1.66 \times 10^{-11} P^3 T)$ where T is in °C and P is in V *[77]

SOUND SPEED (m/s) $1570(1.000 - 2.15 \times 10^{-3} T + 4.0 \times 10^{-6} T^2 + 2.5 \times 10^{-6} P + 2.22 \times 10^{-3} P - 3.0 \times 10^{-6} P^2)$ where T is in °C and P is in MPa *[77]

ACOUSTIC ATTENUATION (dB/cm)

CAVITATION LEVEL (dB/1μPa) 233 *[54]

VOLUME THERMAL EXPANSION ($^{\circ}\text{C}^{-1}$) 7.34×10^{-4} *[51]

ISOTHERMAL COMPRESSIBILITY (Pa^{-1}) 47×10^{-6} *[55]

SURFACE TENSION (N/m) 0.06736 *[51]

WATER SOLUBILITY LIMIT: 1.4% at 25°C *[51]

COMPATIBILITY:

NEOPRENE W - Good *[51]

NEOPRENE 35003 - Excellent *[56]

BUTYL 3252 - Good *[51]

CHLOROBUTYL M852A - Excellent *[56]

SILICONE -

POLYURETHANE -

EPDM -

NATURAL 35007 - Excellent *[56]

NITRILE -

VITON -

CORK-RUBBER COMPOSITES -

DC-100 - Poor

NC-710 - Fair

LC-800 - Excellent

DC-116 - Poor

NC-775 - Poor

*[57]

ADHESIVES -

EPON VI - Excellent *[51]

PLASTICS -

"LEXAN" POLYCARBONATE - Excellent *[51]

SYNACTIC FOAM - Excellent *[51]

METALS -

STABILITY: *[51]

OXIDATION - Reported to polymerize after many years

HYDROLYSIS - Hydrolyzes slowly

OTHERS: *[51]

TOXICITY - Very low

EASE OF CLEANUP - Moderately difficult, soluble in acetone, 1:1 methanol-acetone, trichloroethane

COST: Low

*[] - REFERENCES CONTAINED IN "HANDBOOK OF SOLAR TRANSDUCER PASSIVE MATERIALS"

MATERIAL: Tricresyl Phosphate (TCP)

CHEMICAL DESCRIPTION: $(\text{CH}_3\text{C}_6\text{H}_4\text{O})_3\text{PO}$

REMARKS:

ADVANTAGES - Fair acoustic impedance match, high density for covert operation, low viscosity

DISADVANTAGES - Marginal volume resistivity, compatible with a limited number of elastomers *[51]

PHYSICAL PROPERTIES:

VOLUME ELECTRICAL RESISTIVITY ($\Omega\text{-m}$) 2×10^8 *[60]

VAPOR PRESSURE (Pa)

VISCOSITY (CENTIPOISE) 80 at 20°C

DENSITY (kg/m^3) 1184.21 - 0.83T *[51]

SOUND SPEED (m/s) 1586.1 - 3.50T *[53]

ACOUSTIC ATTENUATION (dB/cm)

CAVITATION LEVEL (dB/1uPa)

VOLUME THERMAL EXPANSION ($^\circ\text{C}^{-1}$) 6.7×10^{-5} *[61]

ISOTHERMAL COMPRESSIBILITY (MPa^{-1})

SURFACE TENSION (N/m) 0.00155 *[62]

WATER SOLUBILITY LIMIT: 0.4% @ 25°C *[51]

COMPATIBILITY:

NEOPRENE W - Poor

NEOPRENE 5112 - Poor

BUTYL B252 - Good

CHLOROBUTYL M962A - Fair

SILICONE - Very Good *[60]

POLYURETHANE PRC 1538 - Poor

EPDM Fair

NATURAL (1155) - Poor

NITRILE - Poor

VITON A - Very Good

CTEN (BFG55075) - Poor

CORK-RUBBER COMPOSITES -

ADHESIVES -

EPON VI - Good *[62]

PLASTICS -

"LEXAN" POLYCARBONATE - Poor

NYLON - Good *[62]

TEFLON - Good

METALS -

STAINLESS STEEL - Very Good

MILD STEEL - Fair

ALUMINUM - Very Good *[51]

COPPER - Very Good

BRASS - Very Good

STABILITY:

OXIDATION - Good *[51]

HYDROLYSIS - Good *[60]

OTHERS:

TOXICITY - (Where ortho isomer has been removed) nontoxic orally not an eye or skin irritant, nonflammable *[61]

EASE OF CLEANUP - Soluble in many organic solvents *[51]

COST: Reasonable *[61]

*[] - REFERENCES CONTAINED IN "HANDBOOK OF SONAR TRANSDUCER PASSIVE MATERIALS"

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MATERIAL: Polyalkylene Glycol (PAG) Union Carbide LB135Y23

CHEMICAL DESCRIPTION: Monobutyl ether of polypropylene oxide; molecular weight, 600 g/mole with small amounts of the antioxidant dodecyl succinic anhydride

REMARKS:

ADVANTAGES - Cheap, well-defined, low thermal expansion *[51]

DISADVANTAGES - High water solubility, incompatible with some common transducer elastomers *[51]

PHYSICAL PROPERTIES:

VOLUME ELECTRICAL RESISTIVITY ($\Omega\text{-m}$) $7.80 \times 10^{11} e^{6.1N}$ (N = mole fraction of water) *[63]

VAPOR PRESSURE (Pa) Very low *[52]

VISCOSITY (CENTIPOISE) $\eta = 190e^{-0.0513T}$ *[52]

DENSITY (kg/m^3) $996.2 - 1.1T + 6.2 \times 10^{-3} T^2$ *[63]

SOUND SPEED (m/s) $1395 - 3.34T$ *[53]

ACOUSTIC ATTENUATION (dB/cm)

CAVITATION LEVEL (dB/ μPa) Threshold at 240; quickly falls to :27 *[54]

VOLUME THERMAL EXPANSION ($^\circ\text{C}^{-1}$)

ISOTHERMAL COMPRESSIBILITY (MPa^{-1}) 2.22×10^{-10} *[63]

SURFACE TENSION (N/m) 0.033 *[51]

WATER SOLUBILITY LIMIT:

COMPATIBILITY:

NEOPRENE W - Fair

NEOPRENE BFG35007 - Poor

BUTYL B252 - Very Good

CHLOROBUTYL H862A - Very Good

SILICONE V121 - Very Good

POLYURETHANE PRC-1538 - Poor *[63]

EPDM NORDEL 1070 - Poor

NATURAL BFG35007 - Poor

NITRILE - Very Good

VITON - Good

CTBN (BFG35075) - Poor

NATURAL (BFG35001) - Poor

RUBBER COMPOSITES -

DC-100 - Poor NC-775 - Fair

NC-710 - Poor LC-800 - Fair *[57]

ADHESIVES -

PLASTICS -

METALS -

STABILITY:

OXIDATION - Good

HYDROLYSIS - Very Good *[63]

OTHERS:

TOXICITY - Nontoxic, no eye or skin irritation. *[63]

EASE OF CLEANUP - Have readily removed from surfaces with acetone, acetone-alcohol, or methyl-ethyl ketone *[63]

COST: Low *[51]

*[] - REFERENCES CONTAINED IN "HANDBOOK OF SONAR TRANSDUCER PASSIVE MATERIALS"

MATERIAL: Dow Corning 200. 00 Silicone

CHEMICAL DESCRIPTION: Polydimethylsiloxane

REMARKS:

ADVANTAGES - Good compatibility

DISADVANTAGES - Low sound speed, troublesome handling properties

PHYSICAL PROPERTIES:

VOLUME ELECTRICAL RESISTIVITY ($\Omega\cdot m$)

VAPOR PRESSURE (Pa) Very Low *[66]

VISCOSITY (CENTIPOISE) 96 @ 25°C *[66]

DENSITY (Kg/m^3) 984.4 - 0.88T *[51]

SOUND SPEED (m/s) 1073 - 2.8T *[53]

ACOUSTIC ATTENUATION (dB/cm) Measurable only at high frequency *[52]

CAVITATION LEVEL (dB/10Pa)

VOLUME THERMAL EXPANSION ($^{\circ}C^{-1}$) 0.00096 *[66]

ISOTHERMAL COMPRESSIBILITY (M^2a^{-1})

SURFACE TENSION (N/m) 0.0209 @ 25°C *[66]

WATER SOLUBILITY LIMIT:

COMPATIBILITY:

NEOPRENE W -

NEOPRENE 35003 -

BUTYL B252 -

CHLOROBUTYL H862A -

SILICONE -

POLYURETHANE -

EPDM -

NATURAL 35007

NITRILE -

VITON -

CORK-RUBBER COMPOSITES -

DC-160 - Fair NC-710 - Fair LC-800 - Fair *[57]

ADHESIVES -

PLASTICS -

METALS -

STABILITY:

OXIDATION - Good *[66]

HYDROLYSIS -

OTHERS:

TOXICITY - Nontoxic eye irritant *[66]

EASE OF CLEANUP - Soluble in methylethylketone, ethyl ether, carbon tetrachloride, toluene, trichloroethane, turpentine, xylene *[66] Some difficulties reported *[51]

COST: Moderate

*[] - REFERENCES CONTAINED IN "HANDBOOK OF SONAR TRANSDUCER PASSIVE MATERIALS"

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MATERIAL: Isopar M (Exxon Company)

CHEMICAL DESCRIPTION: A narrow-boiling fraction of highly branched saturated hydrocarbons, average molecular weight 191 g/mole

REMARKS:

ADVANTAGES - Buoyant *[51]

DISADVANTAGES - Incompatible with many materials *[51]

PHYSICAL PROPERTIES:

VOLUME ELECTRICAL RESISTIVITY ($\Omega\cdot m$)

VAPOR PRESSURE (Pa) 4.1×10^3 *[71]

VISCOSITY (CENTIPOISE) 2.46 @ 25°C *[71]

DENSITY (kg/m^3) 789. - .72T *[62]

SOUND SPEED (m/s) 1359 - 3.9T *[53]

ACOUSTIC ATTENUATION (dB/cm)

CAVITATION LEVEL (dB/1uPa)

VOLUME THERMAL EXPANSION ($^{\circ}C^{-1}$)

ISOTHERMAL COMPRESSIBILITY (MPa^{-1})

SURFACE TENSION (N/m) 0.0248 @ 25°C *[71]

WATER SOLUBILITY LIMIT: 0.01% *[71]

COMPATIBILITY:

NEOPRENE 5109 - Fair *[51]

NEOPRENE 35003 -

BUTYL B252

CHLOROBUTYL H862A - Poor *[51]

SILICONE (V121) - Poor

POLYURETHANE (PRC1538) - Fair *[51]

EPDM NORDEL 1070 - Poor *[51]

NATURAL 1155 - Poor *[51]

NITRILE 6100 - Good *[51]

VITON

CTBN (BF635075) - Poor *[51]

CORK-RUBBER COMPOSITES -

DC-100 - Poor

LC-800 - Poor

NC-775 - Good *[51]

ADHESIVES -

EPON IV - Good *[62]

PLASTICS -

SYNTHETIC FOAM - Good *[62]

TYGON TUBING - Poor *[51]

METALS -

STABILITY:

OXIDATION -

HYDROLYSIS -

OTHERS:

TOXICITY - Possible inhalation toxicity. Skin and eye irritant. *[71]

EASE OF CLEANUP -

COST:

*[] - REFERENCES CONTAINED IN "HANDBOOK OF SONAR TRANSDUCER PASSIVE MATERIALS"

MATERIAL: NORPAR 12

CHEMICAL DESCRIPTION: Narrow-boiling, normal paraffinic petroleum distillate; average molecular weight, 163 g/mole *[72]

REMARKS:

ADVANTAGES - Buoyant *[51]

DISADVANTAGES - Incompatible with many materials

PHYSICAL PROPERTIES:

VOLUME ELECTRICAL RESISTIVITY ($\Omega\cdot m$)

VAPOR PRESSURE (Pa) 5500 @ 38°C *[70]

VISCOSITY (CENTIPOISE) 1.26 @ 15.6°C *[70]

DENSITY (kg/m^3) 758.8 - 0.72T *[51]

SOUND SPEED (m/s) 1264 @ 26°C *[51]

ACOUSTIC ATTENUATION (dB/cm)

CAVITATION LEVEL (dB/1 μ Pa)

VOLUME THERMAL EXPANSION ($^{\circ}C^{-1}$)

ISOTHERMAL COMPRESSIBILITY (MPa^{-1})

SURFACE TENSION (N/m) 0.0248 N/m *[70]

WATER SOLUBILITY LIMIT:

COMPATIBILITY:

NEOPRENE W

NEOPRENE 35003

BUTYL BZ52

CHLOROBUTYL H862A -

SILICONE -

POLYURETHANE -

EPDM -

NATURAL 35007

NITRILE -

VITON -

CORK-RUBBER COMPOSITES -

ADHESIVES -

PLASTICS -

METALS -

STABILITY:

OXIDATION -

HYDROLYSIS -

OTHERS:

TOXICITY - Inhalation TLV: 300 ppm - Acute O₂ 1 LD₅₀ (Rat): > 5 g/kg - Acute Dermal LD₅₀ (Rabbit): > 5 ml/kg. *[72]

EASE OF CLEANUP -

COST:

*[] - REFERENCES CONTAINED IN "HANDBOOK OF SONAR TRANSDUCER PASSIVE MATERIALS"

3. TASK B-1 - CORONA ABATEMENT

L.P. Browder - NRL-USRD

3.1. BACKGROUND

A significant percentage of transducer failures is due to voltage breakdown of insulating materials developing from corona erosion mechanisms. It is not practical to test the completed transducer to measure the effects of corona erosion on lifetime and reliability. To establish reliability factors and quantify protection requirements, corona must be studied as a failure mechanism at the component or piece-part level. Transducer reliability improvement may then be achieved by control of design parameters and construction processes.

3.2. OBJECTIVES

The objectives of this task for FY81 are:

- Study tests, specifications, and procedures that may be used to select coating materials suitable for corona reduction.
- Test various corona reduction coating materials on PZT ceramic to identify the voltage breakdown mechanisms and measure voltage lifetime functions with the coating materials that show improvement.

3.3. PROGRESS

3.3.1. Work is beginning on the approach to use an insulating coat on the PZT ceramic surface to reduce corona and its effects in sonar transducers. There is some reason to expect that this approach may provide more protection than the alternative method of using insulation gases such as sulfur hexafluoride (SF_6), but it is unlikely to be a total cure for corona. Earlier tests of the electrical breakdown of PZT ceramic in castor oil or with the coating material Stycast 2741 [1] indicate that failure with these electrically stronger materials is on the interface between the ceramic and the coating material. It is apparent that the PZT ceramic is the material most susceptible to damage caused by the electrical discharges. This effect is not expected to change substantially regardless of the electrical strength of the coating material.

At the present time, it is unknown if published manufacturers' data for the properties of insulating coatings are applicable to the problem. These data make up the first area to be examined in screening coating materials for corona reduction purposes. The typical properties provided by the manufacturer are:

- Physical - as cured

- Electrical - as cured
- Physical - as supplied

Also, there may be a paragraph describing preparation and curing of the material. There is very little uniformity between manufacturers in the manner of presenting the properties or which of the properties are included in the data. A complicating factor in choosing a coating material is that most manufacturers make no warranty concerning the suitability or fitness of the product for any particular use. It is the user's responsibility to do this.

Screening procedures for selecting the coating materials to be tested are general and simple. They may be summarized as follows:

- Determine that the material is recommended as an electrical insulator and has high dielectric strength and volume resistivity.
- The cured material will be flexible over the temperature range of sonar transducer operation.
- The material will adhere strongly to PZT ceramic, if necessary using a primer to aid adhesion.
- Temperature cycling to -40°C will not affect adhesion to the PZT ceramic.
- The material will be easy to mix and apply, requiring no unusual preparations or equipment to do this.
- Curing of the coating material will occur at a temperature lower than 100°C .
- The cost of the material should be nominal.

These requirements are substantial enough to select good products for testing, yet exclude many materials that are not appropriate. It is the intent to select a few products for testing that will prove the usefulness of the insulator coating approach.

Electrical testing will use the J.C. Biddle Co. System No. 662045-01 to supply the test voltage and detect corona discharges. ASTM Standard Method D1868-73 is used by this machine to measure corona. The same machine will be used for voltage breakdown tests on the test specimens, generally following the procedures of ASTM Standard Method D149-64. A test method described by T.W. Dakin [2] can be used to determine the resistance to high level corona.

Three different test phases will be used to find the most effective corona resistant coating material for PZT ceramic. These are:

- The use of high dielectric strength, self-adhering coatings. Some of these materials are on hand for testing and others will be procured.
- Surface modification of the PZT ceramic to improve insulation coat bonding and exclude moisture.
- The use of a semiconducting coating material such as "Coronox" [3] that has been used successfully to eliminate corona in high-voltage machinery. This test phase will depend on availability of the material from Westinghouse.

3.3.2. Work continued to complete the report on a formulation of the elementary transducer reliability function based on electrical breakdown considerations of untreated PZT ceramic surfaces. A high percentage of the sonar transducers in service use untreated PZT ceramic surfaces as insulators. Empirical formulas are presented that give a numerical rating for the electrical strength of the transducer for most of the factors affecting breakdown. A lifetime formula [4] is used that computes electrical failure rate as a function of drive voltage. From these formulas, the electrical reliability can be computed for any mission duration.

3.4. PLANS

- Tests will begin for evaluating the use of high dielectric strength coatings.
- Study the appropriate application of surface modification techniques for corona reduction, including some testing.
- Continue efforts to obtain Coronox coating material from Westinghouse.
- Complete the report described in paragraph 3.3.2. during the second quarter of FY81.

4. TASK B-2 - CORONA AND VOLTAGE STANDARDS
L.P. Browder - NRL-USRD

4.1. BACKGROUND

An understanding of the basic failure mechanisms due to electrical discharges such as corona is being developed by direct study at the component or piece-part level in transducers. The problem is that previous uses of corona specifications do not seem to be correlated to an expected reliability factor. A corona specification must be composed that will be consistent with good design practice and reflect the things that are known about electrical breakdown mechanisms, yet provide for a positive correlation to expected reliability.

Although it should only be necessary to provide a valid specification to achieve transducer electrical reliability, in practice there should be standard publications that are guides for design procedures and construction procedures. These could be used for an initial evaluation of reliability and a later determination of design and construction flaws.

4.2. OBJECTIVES

The objectives of this task for FY81 are:

- Prepare a preliminary specification for corona.
- Prepare outlines for the standard publications relating to design and construction procedures.

4.3. PROGRESS

Work has begun to assemble and study background material for preparation of the corona specification and the standards. It is intended that the corona specification will follow the general format used for military specifications. It will include the following sections:

1. Scope
2. Referenced Documents
3. Definitions
4. General Requirements
5. Detailed Requirements

6. Notes and Concluding Material

Tables

Figures

Material for the first three sections has been previously developed and appears in existing publications and technical literature but it will require adaptation for the special application to sonar transducers. The last three sections will require careful consideration and development. Services of a contractor may be necessary to complete the work.

The standard for design procedures will promote corona reduction by control of the design parameters of wire size, spacing between electrodes, metal electrode shape, fill-gas purity, gas pressure, ceramic thickness, thin gas films between solid insulation layers, and water vapor content. Special design considerations such as operating frequency and the use of insulating coatings may be included if they are found to be appropriate.

The standard for construction procedures will promote corona reduction by emphasizing items such as cleanliness, moisture removal, PZT ceramic inspection, materials curing, and correct gas-filling methods.

4.4. PLANS

- Continue to assemble and study background material.
- Compose preliminary draft for the first three sections of the corona specification.

5. TASK C-1 - HANDBOOK FOR CONNECTOR AND CABLE HARNESS DESIGN

R.F. Haworth - Electric Boat Division

General Dynamics Corporation

G.D. Hugus - NRL-USRD

5.1. BACKGROUND

The selection of pressure-proof connectors and cable harnesses for hydrophones and transducers is a critical part of Navy shipboard sonar system design; yet, the design of these components for use in this environment is not covered in any one reference publication. Information on this subject is contained in a multitude of military and industry specifications, standards, and publications. The result is that engineers and designers often duplicate work and may overlook relevant information that they need.

5.2. OBJECTIVE

The objective of this task is the preparation of a design handbook covering the technology of pressure-proof underwater connectors and cable harnesses for hydrophones and transducers. The emphasis will be on the application of these components for use in naval surface ships and submarines.

5.3. PROGRESS

Work on this handbook is being done under contract N61339-80-C-0021 by the Electric Boat Division of General Dynamics Corporation. The contents of the handbook were outlined in the last two quarterly report [5, 6]. A first draft of the handbook has been completed and forwarded to 27 potential users for review and comment.

5.4. PLANS

A final draft of the handbook will be produced when review of the first draft has been completed. The handbook will be published during the third quarter of FY81.

6. TASK C-2 - STANDARD FOR O-RING INSTALLATION

C.J. Sanáwith - APL, University of Washington

G.D. Hugus - NRL-USRD

6.1. BACKGROUND

The reliability of sonar transducer arrays can be significantly improved by the adoption of standard procedures for the installation and assembly of O-ring seals. The problem is that no such standard procedure exists. Presently, the installation procedures are determined by the installer and the materials available at the time of installation.

The results of analyzing failures of O-ring seals in connectors used in underwater applications over decades show that roughly eight out of thirteen O-ring failures have resulted from improper installation and assembly or improper quality control and inspection procedures at the time of assembly. Stated another way, the results showed that even though O-ring seal design may be perfected by the proper O-ring type selection (piston, face, or crush) by the maximum crush section thickness, by selecting the proper O-ring size and material, and by using two O-rings in series (double O-rings) a substantial number of the O-ring failures will occur due to improper installation and inspection procedures.

6.2. OBJECTIVE

The objective is to compose, critique (by authorities), edit, and present in final form a standard procedure for the installation of O-ring seals in electrical connectors and undersea static applications. The standard will be composed in the form of similar military standards in handbook form. Once it is approved by NRL and NAVSEA authorities, it will be submitted for approval as a military standard.

6.3. PROGRESS

Work to fulfill this objective is being performed under contract N00024-78-C-6018 by the Applied Physics Laboratory of the University of Washington. The approach to developing this procedure is to use all known proven techniques and procedures of users (military and commercial) and suppliers to develop a unified best procedure. The approach is to collect from the literature, users, and suppliers, all of the data and recommendations concerning each phase of the O-ring seal production.

The following sections of the handbook standard were completed and summarized in two previous STRIP quarterly reports [5, 6].

- SECTION 8 - Packaging
- SECTION 9 - Storage and Aging
- SECTION 10 - Installation

- SECTION 11 - TOOLS
- SECTION 13 - RELIABILITY
- SECTION 14 - LUBRICANTS

The first draft of these sections was sent to three authorities in the field for review and comment.

It was determined, after drafting the above sections, that additional information research is needed to adequately complete the handbook. There is a lack of agreement among authorities and in the literature on requirements for lubricants, lubrication, O-ring seal material selection, installation techniques, sealing surface finish, and shelf life. Additional time is needed to provide answers to the following questions and to incorporate, as necessary, the answers into existing handbook sections.

- What and how should minimum O-ring shelf life be specified?
- What O-ring material provides the best combination of properties (age resistance, dimensional stability in use, lubricant compatibility and cost)? Age resistance and shelf life vary from 2 to 20 years depending on material. Perhaps materials with short shelf life should not be allowed or perhaps only one or two materials should be allowed.
- Which lubricant is the best? How do the lubricants compare on the basis of stability and compatibility?
- What tests of proper seal installation are possible and practical once the transducer or connector is assembled? What procedures and methods could or should be developed to detect improper sealing or seal installation?
- What is the optimum sealing surface finish with respect to machining costs and seal reliability?

6.4. PLANS

The handbook will be completed by March 1981, after review of the section drafts and the additional research.

7. TASK C-3 - CABLES AND CONNECTORS

D.E. Glowe - Texas Research Institute, Inc.

G.D. Hugus - NRL-USRD

7.1. BACKGROUND

The use of cables and connectors is an area of concern for long-term sonar reliability because of a history of failures. Deficiencies can be generally categorized in the four areas of: design of cables and terminations; specification and testing; handling; and repair and maintenance. Specific problems have been identified in a recent failure modes and effects analysis of cables and connectors prepared for NAVSEA by the Electric Boat Division of General Dynamics Corporation. They concluded that, of all the problem areas, the loss of bond of the molded boot to the connector shell or to the cable sheath is the most probable cause of failure. Cable jacket puncture in handling, at installation, or in service is considered to be the second most probable cause of failure.

7.2. OBJECTIVES

The general objective of the task is to provide improved reliability in the cables, connectors, and related hardware for the outboard elements of sonar transducer systems. A specific objective is to complete the investigation of the use of cable/connector boot clamps to determine reliability and failure modes.

7.3. PROGRESS

Work on the investigation of the use of cable/connector boot clamps to determine reliability and failure modes is continuing. The approach is to determine the effect on life, performance, and reliability of applying mechanical clamps to the elastomer boot of Portsmouth connectors (MIL-C-24231). A summary of the scope, configurations of the 64 test connectors, and the Accelerated Life Test (ALT) sequence was given in the preceding STRIP FY80 quarterly report [6].

After 30 weeks of the ALT sequence, four neoprene molded connectors and 13 polyurethane molded connectors have failed (Table 7.1).

7.4. PLANS

An NRL technical report on shielded and unshielded cable strength will be published and distributed during the second quarter of FY81. Also, an interim report will be published on the progress of the investigation of the use of cable/connector boot clamps. This work will continue on the remaining part of the task until a significant number of connector failures occur.

Table 7.1 - ALT connector failure analysis

CONNECTOR NUMBER	TYPE	WEEK FAILED	ANALYSIS
2	Neoprene	1	Manufacturing defect
29	Polyurethane	1	Manufacturing defect
14	Polyurethane	4	Bond failure backshell
24	Polyurethane	8	Cracked during cold cycle due to handling
13	Polyurethane	9	Bond/molding failure at cable
32	Polyurethane	11	Bond failure backshell, molding cracked at cable
26	Polyurethane	18	Bond failure cable, molding cracked at cable
9	Neoprene	21	Cable bond failure
13	Neoprene	21	Backshell bond failure, low reading on cable
7	Neoprene	23	Backshell bond failure
3	Polyurethane	22	Backshell bond failure
5	Polyurethane	22	Molding cracked at cable
19	Polyurethane	22	Backshell bond failure
7	Polyurethane	28	Bond failure at backshell, molding cracked
18	Polyurethane	29	Bond failure at cable and backshell
28	Polyurethane	29	Bond failure at cable and backshell
20	Polyurethane	29	Bond failure at cable and backshell

8. TASK D-1 - ALTERNATIVE MATERIALS: PLASTICS

K. Niemiller - NWSC

8.1. BACKGROUND

Corrosion, cost, and acoustic characteristics are parameters that must be considered when selecting a material for the design of a sonar transducer. In the past decade, plastics have decreased in cost and increased in strength to the point that they are in strong competition with metals for specific applications. Plastics could be used as a design material for sonar transducers in order to lower costs and lengthen service life if they can withstand the ocean environment. An additional advantage is that plastics generally are electrically nonconductive and acoustically transparent.

Specifically, the injection molded thermoplastics are the best materials for consideration as an alternative assembly material since they can be molded to close dimensional tolerances and in many configurations. Metals and electronic connectors can be molded directly into the plastics thus reducing the number of separable parts and insuring in-service reliability.

Naval facilities equipped with the proper molding equipment can fabricate replacement parts for sonar transducers when parts are not in stock or readily available. This would be extremely helpful when emergency repair is necessary and the time for normal procurement procedures is not available. In the event that a shortage of material should occur, thermoplastics can be easily recycled.

Presently there are no general long-term ocean immersion data available for thermoplastics. It would take many years of testing and analysis to determine the long-term life expectancy, but there is an immediate need for information. The only approach for determining this information in a reduced time period is to perform Accelerated Life Testing (ALT), but this must be used with caution. When this method is used, it is always recommended that comparison be made to parts which have been exposed to the actual environment in question.

8.2. OBJECTIVE

The objective is to evaluate the ability of plastics to withstand an ocean environment and the reliability of the ALT method for use in determining long-term material life expectancy.

8.3. PROGRESS

The approach to the objective has been to perform a two-year equivalent ALT on eight types of glass-filled thermoplastics. The choices of material have been described in the STRIP FY80 Second Quarter Progress Report. Parallel to this, the same materials will be exposed

to an ocean environment for two years. Water absorption, volume change, tensile and shear strength, and sound speed will be measured on all samples. A comparison of the results of the ALT and the ocean test will allow a prediction of the life expectancy of these plastics in sonar applications.

The additional test specimens that were ordered to replace the unsatisfactory specimens have been received from the material supplier. All of the specimens have been visually inspected, marked, weighed, and measured.

The ocean test specimens of the eight plastics were placed in an ocean environment on 19 November 1980 at the Naval Research Laboratory's (NRL) Corrosion Testing Laboratory in Key West, FL. Samples withdrawn after one week of exposure were returned to Naval Weapons Support Center (NWSC) in Crane, IN, for tests. Samples withdrawn after three weeks of exposure were tested for sound speed at NRL's Underwater Sound Reference Detachment (USRD) in Orlando, FL, and then returned to NWSC-Crane for tensile and shear strength tests. The unsatisfactory test specimens previously placed in the ocean environment (July 1980) were removed to avoid confusion in subsequent sample withdrawals. Further test samples will be withdrawn according to the established timetable. The laboratory accelerated tests of these same eight materials are well underway. The large amount of data on mass and dimensional change, tensile and shear modulus, and sound speed will be reduced and presented in future STRIP reports.

Information concerning creep measurement procedures, evaluation techniques, and test fixtures were obtained in a meeting on 20 November 1980 with Dr. W.H. Hartt, Associate Professor of Ocean Engineering, Florida Atlantic University. The information will be used in developing procedures for testing creep on these plastics samples.

8.4. PLANS

- Complete ALT in laboratory.
- Continue ocean environment exposure.
- Evaluate data in detail to determine trends in degradation.
- Prepare procedures for evaluating creep, stress degradation, and machined plastics degradation.

9. TASK E-1 - STANDARDIZED TEST PROCEDURE

J. Wong - NOSC

9.1. BACKGROUND

It is, at present, not possible to subject a transducer specimen to a series of environmental stresses over a short time period and prove, if it passes certain operating parameter tests, that the specimen is a reliable transducer with a certain minimum expected life in fleet use. Of course, if we could simply use a set of transducers for the desired fleet life, we could check the failure rates against acceptable replacement or repair rates. But the approach here is to accelerate the environmental stress actions and thereby subject the transducer specimen to seven years of life cycle stresses in a few weeks or months.

9.2. OBJECTIVE

The objective of this task is to develop a set of standardized procedures based on environmental stress requirements to accelerate the aging of transducers.

9.3. PROGRESS

9.3.1. TR-316 Projectors and DT-605 Hydrophones

Composite Unit Accelerated Life Tests (CUALT) on two Ametek/Straza TR-316 projectors (serials A1 and A3) and two Hazeltine Corporation DT-605 hydrophones (serials A1 and A5) continued. The TR-316 projectors A1 and A3 are in the first- and second-year equivalent of CUALT respectively, and both DT-605 hydrophones (A1 and A5) are in the fourth-year equivalent of CUALT.

The construction of two test tanks for the high temperature thermal cycling/shock (71 to 20°C) exposure (Table 9.2 of the STRIP FY80 Fourth Quarter Progress Report) was completed in October 1980. One tank is equipped with a thermostat-controlled heater for raising the temperature of the fresh water to 70°C and a pump circulates the water within the tank to maintain a temperature of 70°C $\pm$ 1°C. The second tank contains fresh water at 24°C $\pm$ 1°C and is circulated within the tank to maintain a near constant temperature. In the high-temperature thermal-shock cycling, the two TR-316 projectors and the two DT-605 hydrophones were alternately submerged in the 70°C and 24°C water for 30 minutes. This time interval was considered to be sufficient for the transducers to stabilize in temperature. The time required to transfer the four transducers from one tank to the other was approximately 15 seconds; therefore, one cycle took approximately one hour. A total of 30 cycles were completed for the four transducers. The hot water tank was also used for the 60 hours of 70°C $\pm$ 1°C fresh water soak exposure.

The two DT-605 hydrophones will have completed the fourth-year equivalent of CUALT after the pressure cycling and pressure dwell exposures and the end of the equivalent year acoustic evaluation checks (beam patterns, receive response and input impedance measurements).

The TR-316 projectors (serials A1 and A3) will have completed the second-year equivalent of CUALT after the pressure cycling and pressure dwell, dry heat and UV exposures, and the acoustic evaluation checks. Projector serial A1 was returned to the CUALT in November 1980 after production assembly defects and other damages were corrected (replaced with five new resonators in the down-beam section and replaced the ruptured rubber window with a new ice shield in the up-beam section as reported in the STRIP FY80 Third Quarter Progress Report.

Table 9.1 summarizes the present CUALT status of the DT-605 and TR-316 transducers. The table gives the approximate stress exposure time, the test and evaluation time, and the total elapsed time to complete one-year equivalent of CUALT. The idle time is calculated by subtracting the stress exposure time and the test and evaluation time from the total elapsed time. The time compression factor for exposure per year is obtained by dividing the number of days in one year by the total number of days required for one-year equivalent of CUALT exposures. This number gives the number of equivalent years of CUALT exposures in one calendar year. Similarly, the overall time compression factor when compared with the exposure time compression factor gives an indication of the efficient use of laboratory test time. The average overall time compression factor for the first three-years equivalent of CUALT on the DT-605 transducers is approximately 2.8. Most of the idle time is waiting time for scheduled stress exposures and acoustical evaluation checks at the Naval Ocean Systems Center (NOSC) test facilities.

9.3.2. AN/SQS-56 Transducer

Hazeltine shipped eight AN/SQS-56 transducer elements (new design) to NOSC's Lake Pend Oreille Test Facility in December 1980. The Hazeltine elements and stave hardwares were designed and built to qualify a second source for an improved AN/SQS-56 transducer. Electrical and acoustical tests on these eight elements, which comprise one stave, will begin in January 1981. Baseline data will be obtained for the stave and each element in the far field. The stave will be mounted in an AN/SQS-56 array with portions of the old array of Raytheon transducer elements. This will provide data taken under identical conditions to compare the new and the old transducers. The data will also be compared with data from previous tests on Raytheon arrays. It is estimated that 150 to 200 hours of ping time will be accumulated on the array during the electroacoustic tests. This will provide a burn-in period and reveal any major design or manufacturing problems. Additional hours of electrical drive at desired drive level and duty cycle may be obtained for an equivalent year of CUALT on the electrical drive exposure.

The recommended CUALT exposures by Texas Research Institute, Inc., based on the service mission profile for the AN/SQS-56 transducer element, are given in Table 9.2.

9.3.3. Report on FY80 CUALT Effort

A preliminary report on the CUALT of the DT-605 hydrophones and the TR-316 projectors during FY80 is being completed.

9.4. PLANS

- Continue with CUALT on the two Hazeltine DT-605 hydrophones and complete as many as possible of the seven-year equivalent CUALT.
- Continue with CUALT on the Ametek/Straza TR-316 projectors (serials A1 and A3) and complete as many as possible of the seven-year equivalent CUALT.
- Initiate CUALT procedure for the new Hazeltine AN/SQS-56 transducers.
- Complete final documentation of FY80 CUALT effort.

Table 9.1 - Progress summary of CUALT on DT-605 and TR-316 transducers

TRANSDUCER	EQUIVALENT-YEAR OF CUALT	STRESS EXPOSURES USED	CUALT DATE		TOTAL ELAPSED TIME PER EQUIVALENT-YEAR (DAYS)	TOTAL EXPOSURE TIME (DAYS)	TEST & EVALUATION TIME (DAYS)	IDLE TIME (DAYS)	EXPOSURE TIME COMPRESSION FACTOR PER YEAR	OVERALL TIME COMPRESSION FACTOR PER YEAR
			STARTED	COMPLETED						
DT-605 Serials A1 & A5 (Hazeltime)	1st	Table 9.1†	4-25-79	9-79	150	35	20	95	$\frac{365}{35} = 10.4$	$\frac{365}{150} = 2.4$
	2nd	Table 9.1*	10-23-79	2-26-80	150*	35	10	105*	10.4	2.4*
	3rd	Table 9.1†	3-12-80	6-09-80	100	35	10	55	10.4	3.7
	4th	Table 9.2††	6-23-80	--	--	(50)	--	--	(7.3)	--
TR-316 Serial A3	1st	Table 9.2††	3-27-80	7-10-80	105	58	10	37	6.3	2.5
	2nd	Table 9.2††	7-14-80	--	**	(58)	--	--	(6.3)	--
TR-316 Serial A1	1st	Table 9.2	11-18-80	--	**	(58)	--	--	(6.3)	--

† Table 9.1 of the SRIP FY80 Fourth Quarter Progress Report

†† Table 9.2 of the SRIP FY80 Fourth Quarter Progress Report

* Three month delay in receiving FY80 funds

** One month delay in receiving FY81 funds

Table 9.2 - Recommended CUALT, exposures, and measurements for AN/SQ3-56 transducers

SEQUENCE	EXPOSURES
1	Saltwater immersion 356 hs at 70°C
2	Pressurize to 700 kPa for 1 h
3	Vibration per MIL-STD-167-1, 1 series
4	High drive, 40% duty cycle for 432 hs*
5	Repeat 1-4 for each "year" of service

MEASUREMENTS

BASELINE MEASUREMENTS (BEFORE CUALT EXPOSURE)

1. Insulation resistance (white lead/water, black lead/water)
2. Visual examination, photographs
3. Free-field acoustic measurements (CIPS references)
 - 4.2.3.9. Transmitting Voltage Response
 - 4.2.4.2. Source Level
 - 4.2.3.1. Input Impedance
 - 4.2.3.10. Open-Circuit Receive Response
 - 4.2.5.1.1. Beam Pattern

AFTER EACH EXPOSURE

1. Insulation resistance
2. Visual examination (record changes photographically)

AFTER 1ST, 2ND, & 4TH COMPLETE "YEAR"***

1. Insulation resistance
2. Visual examination (record changes photographically)
3. Transmitting voltage response or open-circuit receive response

AFTER THE 7TH COMPLETE "YEAR"

Repeat baseline measurements

* High drive will be accomplished using a dumiload setup in a -3°C saltware bath to limit temperature of stack to 53°C.

** NOTE: If significant changes are noted in transmitting voltage response or open-circuit receive response, the baseline measurements should be repeated.

10. TASK E-2 - ACCELERATED LIFE TEST VERIFICATION

A. Phipps, K. McClure, and D. Steele - NWSC

10.1. BACKGROUND

Until recently, sonar transducers that were used in the fleet were fabricated and put into operation with limited life testing. Some units performed quite well throughout the expected service life while others exhibited an early high-failure rate. Costs of transducers have increased dramatically and the life requirements have been increased to fit new over-haul schedules. These and other factors have mandated verifying the reliability of units for the entire service life. In order to determine the reliability of transducers for a given time of service, it was determined that the approach of Composite Unit Accelerated Life Tests (CUALT) should be used. This method not only investigates the physical degradation of the materials used in the transducer assembly, but also the susceptibility of mechanical or electrical failures. Just as Accelerated Life Tests (ALT) for materials need to be verified by using specimens that have been exposed for the full duration to the environment being evaluated, this must also be done for CUALT.

In July 1978, a complete array of 48 DT-1683 hydrophones was removed from the USS STONEWALL JACKSON (SSBN-634) and retained intact for post-service evaluation at the Naval Underwater Systems Center (NUSC) in New London, CT. This array of hydrophones had undergone extensive evaluation at NUSC before being installed in the SSBN-634. It was decided that these hydrophones could be used to verify the acceptability of using CUALT for hydrophones.

The DT-168B is the passive sensor for the AN/BQR-2B sonar system. This set of 48 hydrophones was fabricated by the Naval Weapons Support Center (NWSC), Crane, IN, in 1972. Three sets of five air-backed cylindrical ceramics made of lead-zirconate-titanate (PZT-5A) wired in parallel-series are the main internal electrical components. The ceramics are protected by a steel cage that is covered by a butyl rubber acoustic window. The elements are isolated from the cage by rubber grommets. Shielded DSS-3 cable 38-m-long is used to connect each hydrophone to the system.

By fabricating ten hydrophone units identical to those in the array and performing an established CUALT on these units it will be possible to compare the degradation of these units to the information retrieved from the post-service hydrophones.

10.2. OBJECTIVE

The objective is to verify the accuracy of the CUALT method by comparing results with a known real-time life test.

10.3. PROGRESS

As was stated in the STRIP FY80 Fourth Quarter Progress Report, many problems were encountered with the first ten replicated DT-168B hydrophones. After evaluation of the failures in these hydrophones, the decision was made to build ten new hydrophones for implementation of the CUALT.

After resolving the problems of the first ten units, such as band and clamp width, improper bonding, leaking ceramics and rod bonding, a new set of hydrophones was fabricated. Assembly was started in November 1980 and completed the first week of December 1980. Upon completion of fabrication, production tests such as capacitance and dissipation, null balance, impedance, dc resistance, and hydrostatic pressure were started. Completion date for these tests is 24 December 1980. All ALT equipment has been assembled.

Qualification tests will be conducted during January 1981 with the ALT scheduled to begin 18 February 1981. The test procedure and schedule was described in the last STRIP quarterly progress report [6]. The ALT will run six cycles and is scheduled for completion by mid-June 1981 at which time evaluation will begin to determine the reliability of the CUALT. The only foreseeable problem at this time is the possibility of a scheduling change due to priority testing in the pressure cycling.

10.3. PLANS

- Test and evaluate the hydrophones.
- Begin ALT.
- Test and evaluate the hydrophones for degradation of physical and electrical properties.
- Compare the test data with that of post-service hydrophones for determination of CUALT reliability of effectiveness.

11. TASK F-1 - ENGINEERING ANALYSIS: FAILURE MODES DUE TO WATER
P.E. Cassidy - Texas Research Institute, Inc.

11.1. BACKGROUND

Previous studies have developed some of the techniques of calculating the rate of water ingress into a transducer, but more or less severe assumptions have had to be made for these calculations. In addition to the assumptions about the rate of water ingress, little work has been done on the effects, or the state of the ingressed water. The various failure mechanisms that can be triggered by the presence of water are not well understood and are not quantized.

11.2. OBJECTIVES

The purpose of this task is to investigate the effects of water permeating into a transducer; specifically, to determine the effects on reliability and performance (not related to corona and arcing). The immediate objectives are to determine the effect of the rubber membrane on the permeated water and to measure the electronic changes in a transducer caused by the presence of internal moisture.

11.3. PROGRESS

The work is being done in phases which are designed to determine what happens to water once it gets into a transducer and how it affects the lifetime of the transducer. The first phase will determine the composition of the permeant - the quantity and type of dissolved solids which come through with water, whether they are from seawater or contaminants from the elastomer. The second phase will be to test the effect of water on the lifetime functions of a transducer. An interim report entitled "Failures Due to Water Permeation into Transducers" (TRI Report 7973-3, 20 Nov 1980) by P.E. Cassidy and D.D. Barrett, has been published

11.3.1. Phase 1 - Permeant

Permeation experiments are underway to determine whether species are carried through rubber by permeating water and whether these species originate in the rubber or the water permeant. This should also confirm whether extraction and permeation processes have the same effects on the rubber in question. Two samples have been subjected to salt and fresh water for 103 days at 60°C and have shown water transmissions of 3.74 and 4.48 g, respectively. These will continue and two more samples have been started.

After a sufficiently long time, surface analysis of the G-type neoprene sample will be made.

A literature search conducted has, so far, shown no data which relate to the phenomenon under investigation.

11.3.2. Phase 2 - Effect of Water Vapor on RH in the Transducer

Two TR-208A transducers which had been opened and fitted for earlier work were equilibrated at 89% relative humidity (RH). This high value of RH was chosen because of the expected drop in RH when temperature is raised as part of an accelerated aging. They were placed in a circulating air oven at 70°C.

To monitor degradation, impedance (Z) was measured. However, a temperature effect was discovered by measuring Z of the test fixture, immediately after its removal from the oven and again after one hour at room temperature, a time at which thermal equilibrium still is not reached. In the hot stage, the device has an impedance lower by about one-half from that after one hour cooling. Unfortunately, this masks the effect of the RH on the impedance. Therefore, continuous monitoring of the aging elements will not be possible. Instead, they will be aged for 30 days, and then equilibrated to 20° and the impedance measured.

Another concern was the actual RH when the fixture at 89% RH and 20°C is heated to 70°C. The use of psychrometric tables (either ppm/volume or vapor pressure data) predict 6.4% as the RH at 70°C. This calculation of the change in RH with temperature was invalidated, however, by another series of experiments and calculations. An estimate was desired of the state of the water which is in the element. This work has shown the relationship between RH and total water content in grams (see columns 1 and 2 in Table 11.1). Next, the internal void (gas) volume of the TR-208A was required. This was done by two methods: (1) filling with water and measuring the volume added, and (2) injecting known amount of gaseous contaminant and measuring the diluted concentration after equilibration by diffusion. The former, done through a 1-in.-diameter hold in the side, gave 580 ml. The latter, which used both CO and CH₄ tracer gases gave 630 ml. Errors (too low values) may be introduced in the liquid fill method by trapping of gas pockets. The gas dilution method may give too high values by the absorption or adsorption of the tracer gas. Therefore, a volume of 600 ml was used. Again, psychrometric data show that in 600 ml of air at 20°C and 100% RH, the total weight of water is 0.010 g. From this, the weight of water in air at any RH is found (RH $\times$ 0.010, column 3, Table 11.1). In Table 11.1, the difference between columns 2 and 3 gives the weight of water adsorbed at each RH level (column 4) and column 5 is the percent adsorbed.

The startling result is that nearly all the water at any RH is adsorbed on internal surfaces. This explains the reason for long dehydration times required, when water is removed from the element by a dry air purge.

This phenomenon also may contribute to electrical effects in the element such as surface conductivity, tracking, etc.

Table 11.1

STATE OF WATER IN TR-208A				
(1) RH USED	(2) TOTAL WEIGHT H ₂ O FOUND (g)	(3) WEIGHT H ₂ O 600 ml AIR (g) (RH X 0.010)	(4) WEIGHT H ₂ O ABSORBED ON SURFACES	(5) % H ₂ O ADSORBED ON SURFACES
25	0.2085	0.0025	0.2060	98.8
58	0.3686	0.0058	0.3628	98.4
89	0.5115	0.0089	0.5026	98.3
100	(0.565) calculated	0.010	(0.555)	(98.2)

Because of the equilibrium between surface water and vapor when a TR-208A at 20°C and 89% RH is heated to 70°C the adsorbed water will desorb and contribute to the RH. So actual RH of the element under aging conditions is not known, except that it is between 6.4 and 89%.

An interesting verification was made of the data in Table 11.1 by back-calculating the amount of water vapor in 600 ml at 100% RH (given as 0.010 g from psychrometric tables). At 100% RH the adsorption was assumed to be 98.2%. From the previous work a graphical extrapolation showed that at 100% RH the total water content would be 0.565 g. This means that of the total water, 0.555 g will be adsorbed (98.2% X 0.565 g). Subtraction of the total yields 0.010 g, exactly the value from psychrometric tables.

The conclusions of these observations are that:

- Temperature changes probably do not change the RH drastically.
- A considerable amount of surface adsorbed water is available to affect surface electrical effects.
- All previous estimates of humidity of transducers due to permeation are high because they disregard the surface acting like a desiccant.
- Desiccants may be more important than previously realized, if failure is due to surface conductivity.

11.3.3. Phase 2 - Effect of RH on Transducer Performance

Acoustic measurements are being made on the modified TR-208 transducers as a function of internal RH. Data shown in Fig. 11.1 for the open-circuit free-field voltage sensitivity for the same transducer when dry and at 55% RH. The effects of the water vapor are marked. However, repeatability with other transducers has not been good. Improvements in the statistics are expected in the next phase with the use of DT-308 hydrophones as test vehicles. Modification is in progress on the DT-308 test fixtures to be used in the next phase of this work. Almost all of the switches and associated hardware has been received for wiring the elements of these transducers for independent testing.

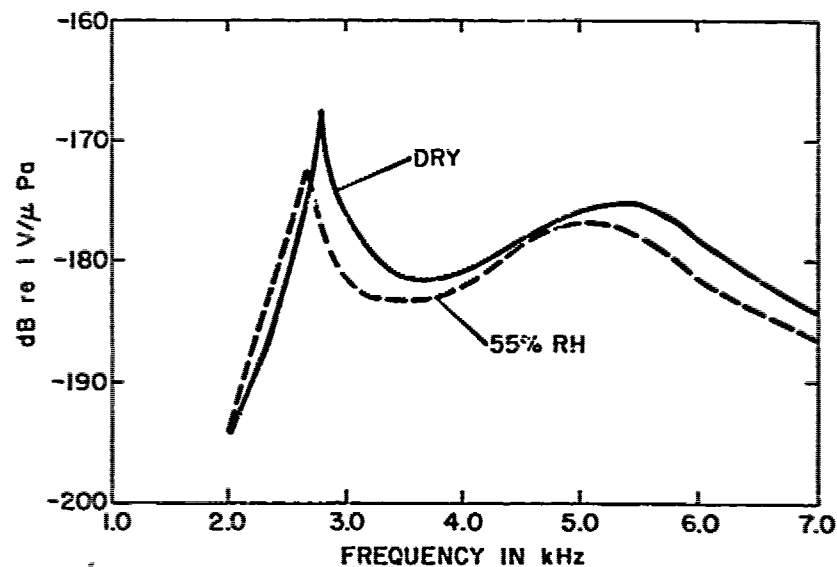


Fig. 11.1 - Open-circuit free-field voltage sensitivity of a modified TR-208 with two different water vapor contents.

11.4. PLANS

- At the end of 30 days at 70°C the two TR-208A transducers will be cooled to ambient and impedance will be measured. The total water content will then be determined by a dry air purge through magnesium perchlorate desiccant. The RH will be re-established at 55%, impedance measured again, and the elements will be sent to NRL-USPD Orlando, for further testing.
- Permeation experiments will continue. Any salts appearing on the rubber surface will be analyzed.

- Modification of the DT-308 transducers into test fixtures will be completed and effects of water vapor on performance will continue.

12. TASK F-2 - ENGINEERING ANALYSIS: CERAMIC STACK JOINTS

C.I. Bohman - NOSC

12.1. BACKGROUND

A severe deterioration in the electroacoustic performance of piezoelectric ceramic stacks that are assembled with epoxy adhesives has been observed at elevated temperatures that are due to either the environment or self-heating. Initial investigation has indicated that this degradation can be attributed partly, if not wholly, to a softening of the cement holding the ceramic stack together when high temperatures are encountered.

12.2. OBJECTIVES

The objectives are to identify and quantify the temperature dependent parameters of cements and ceramic that are used in transducer fabrications, to develop optimum cement joint configurations and fabrication techniques, and to develop math models of cement layers for use in transducer element design that account for the configuration of the cement joint as well as the temperature dependence of the cement.

12.3. PROGRESS

This is a new task which was generated because of temperature related problems first discovered while performing high drive tests on the TR-316 first article projectors [7]. Several units experienced current runaway when they were driven by a constant voltage source. A detailed examination of the faulty transducers indicated that several of the individual piezoelectric ceramic resonators were severely overheated. Subsequent tests on individual resonators showed a definite degradation of electroacoustic performance as the surrounding temperature was raised. While there appeared to be several contributing factors to this phenomenon, two major factors were: insufficient stress on the stress rod, and an increase in the compliance of the cement adhesive at elevated temperatures.

The "in air" impedance of several TR-316 resonators has been measured at different temperatures while driving the resonators with a 10-V rms frequency sweep. An example of an acceptable impedance family of curves as a function of temperature is shown in Fig. 12.1. An example of an unacceptable impedance family of curves as a function of temperature is shown in Fig. 12.2. As can be seen in Fig. 12.2, the losses become so great as the temperature is increased above 200°F that the resonance and anti-resonance disappear. This causes the transducer to experience thermal/current runaway while being driven. As the transducer is being driven for a long period of time at high voltage the individual elements begin to heat up because of internal losses. As the elements heat up the losses become greater and this process accelerates until destruction of the weakest resonator occurs [8].

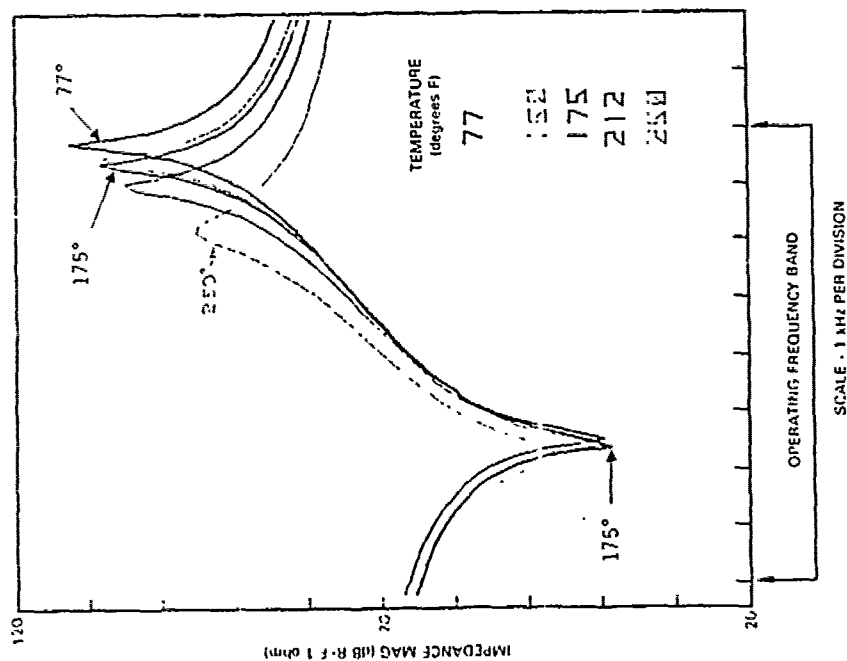


Fig. 1.1 - Impedance magnitude vs frequency for resonator with new Epon VIII cement joints

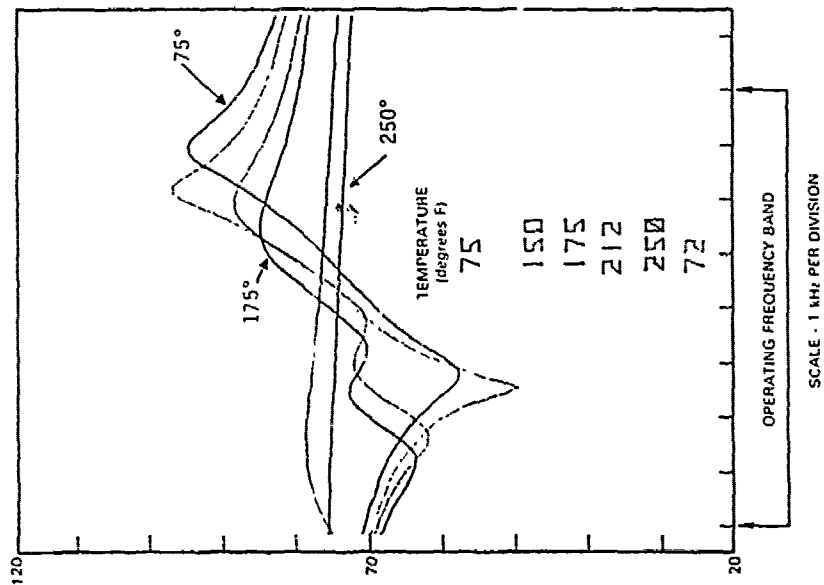


Fig. 1.2 - Impedance magnitude vs frequency for "bad resonator"

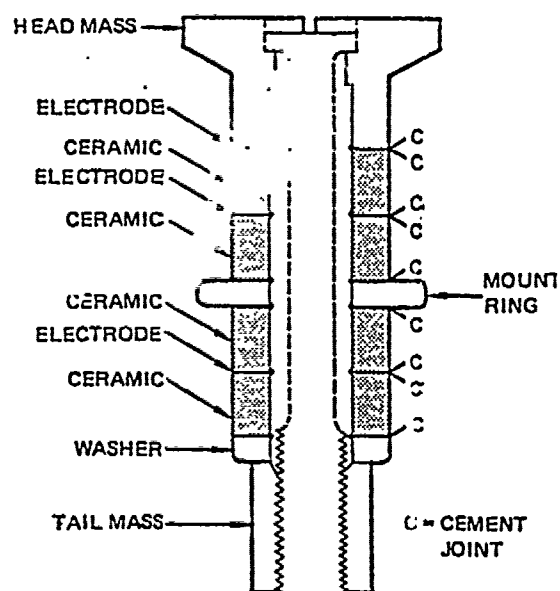


Fig. 12.3 - Makeup of a typical K_{33} ceramic resonator

A cutaway section of a typical TR-316 resonator illustrated in Fig. 12.3 shows the use of cement to provide strength and coupling of the ceramic rings to the electrodes, head, tail washer, mount ring, and to each other. As the cement heats up it becomes more compliant and less effective in providing strength and coupling to the ceramic stack. One solution to this problem is to increase the pre-stress on the ceramic stack while curing the cement; thus forcing more of the cement out of the joints and increasing the coupling. However, this solution may not be feasible with all ceramic stacks.

When measuring the impedance of TR-316 resonators as a function of temperature for the very first time, it has been observed that after the resonator has returned to room temperature the anti-resonance peak has shifted down in frequency as illustrated in Fig. 12.4. This has occurred with almost all of the resonators tested. This seems to indicate that some "settling" has occurred within the ceramic stack. Possibly the cement experiences additional curing during the first temperature cycle. Subsequent measurements of the "in air" impedance at room temperature cycles. The resonance peak has not been as predictable; sometimes shifting down on one resonator, up on another, and perhaps not moving at all on still another.

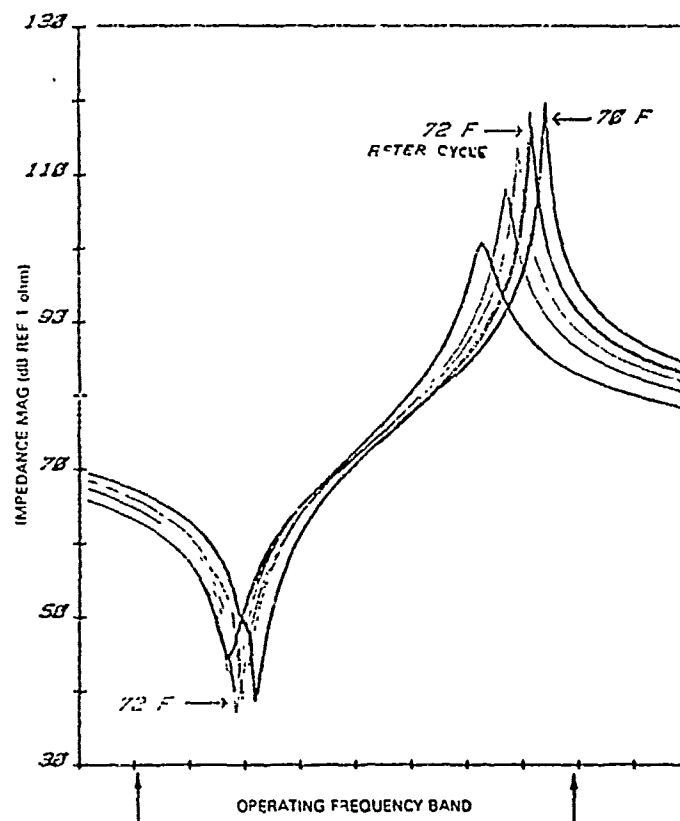


Fig. 12.4 - Impedance magnitude vs frequency

It has also been observed that while driving a resonator in air at 10 V rms and at resonance, the resonance peak will tend to shift to a lower frequency. When measuring the temperature distribution of the resonator with an infrared thermometer under these conditions it was also noted that the ceramic was warmest next to the nodal mount ring and coolest next to the head and tail. In other words, the resonator had heated up a little while being driven and the heat distribution was not uniform across the ceramic. Further investigation is required to determine whether or not the cement joint is a major contributor to these losses.

A temperature dependent model of the TR-16 resonator has been completed by using the NCSC "SEADUCER" computer transducer model program. This model incorporates temperature dependent ceramic and cement parameters at fixed temperatures. Different parameters are entered into the program for each temperature. The next step to making this model totally useful is to compile a table of temperature dependent ceramic and cement parameters. The model is also capable of finding the temperature dependent parameters by an iterative search process if the impedance and

a few key parameters are known at a specific temperature. This process can be repeated for any temperature that parameters are required.

12.4. PLANS

- The data base for temperature measurements of stacked ceramic resonators will be increased by taking additional "in air" impedance measurements of more TR-316 resonators.
- A temperature profile of a TR-316 resonator will be measured while the resonator is under high drive and dumiload conditions. Corresponding impedance measurements will be made at the different temperatures.
- The computer model will be tested by having it estimate some ceramic and cement parameters from resonator impedance calculations. These parameters will, in turn, be used to predict resonator performance.
- Different methods will be investigated to measure ceramic and cement parameters.

13. TASK F-3 - RELIABILITY AND LIFE PREDICTION SPECIFICATION

R.L. Smith and D. Barrett - Texas Research Institute, Inc.

13.1. BACKGROUND

The reliability and life requirements for wet end sonar equipment need to be better defined. Present handbook-style reliability prediction methods do not account for redundancy. There seems to be no unified approach to carrying out a prediction of hardware life in the sonar context. Even to speak of reliability and life as independent concepts ignores their formal duality in reliability theory. Consistent improvements in reliability and life definition and prediction are needed for STRIP objectives to be met. For example, specifying MTBF does not uniquely determine the reliability in the time frame of particular interest--the first few years of service. Other factors, such as the definition of failure, and the use of redundancy in the design dominate the reliability versus time relationships. Specifying service life in years does not embrace degradation during storage nor does it uniquely define wearout reliability.

Reliability is a very strongly statistical concept based on the behavior of a group of nominally identical items. Reliability itself is a distributed quantity, i.e., best represented by a normalized distribution or probability density function. The parameters appearing in reliability models are also distributed. Inferences relating to all such quantities are based on limited sets of observations which yield only estimates of the parameters of interest. However, the methods of statistical inference allow us to make the most definitive statements possible under the circumstances.

The present approach used by the Navy for wet end sonar equipment procurements is to specify numerical reliability and life requirements in the Critical Item Procurement Specification (CIPS) and to ask the contractor to achieve these objectives through a reliability program described in attachment 2 to the contract. Unfortunately, for the reasons given above, a contractor can fulfill all the requirements as currently stated and still deliver hardware that performs less than satisfactorily.

13.2. OBJECTIVES

There are two major wet end sonar reliability objectives:

- Provide the analytical basis for improved hardware reliability.
- Facilitate hardware improvement by developing more satisfactory procurement specifications.

Intermediate subtask objectives in support of the above are:

- Learn how to analyze the superposition of random and wearout reliabilities.
- Learn how to extract wearout failure mechanisms and random failure hazards from an FMEA.
- Learn how to put a time scale on the wearout failure mechanisms vis-a-vis activation energies, stress amplitudes, and cycling, etc.
- Learn how to do a life prediction.
- Improve present (random) reliability prediction methods by correct analysis of redundancy and definitions of failure.
- Learn how to superimpose the results of the last two subtasks above.
- Learn how to handle subjective information (Bayesian inference).
- Determine how the contractor can achieve the predicted overall reliability (random and life) with appropriate contractor-managed reliability achievement programs (critical parts management, piece-part testing, compatibility studies, QC inspection, design reviews, etc.).
- Learn how to tell a contractor how to do all of the above.

13.3. PROGRESS

This is an analytical reliability task initiated in FY80 under contract N00024-79-C-6232. Work is being carried out by Texas Research Institute, Inc. The approach for FY80 was to complete work on intermediate objectives 1 and 5 and to document insights relating to other subtask areas. A comprehensive report, entitled "Reliability and Service Life Concepts for Sonar Transducer Applications," detailing this progress is complete at this writing except for the final editing, assembly, and distribution functions. An outline of the topical contents was presented in the last STRIP quarterly report [6].

At this point one can perhaps see the forest in spite of the trees and try to put the project report in proper perspective. The intended audience is transducer procurement personnel as well as engineers and researchers seeking to improve the product systematically. For the former group, the presentation may be a bit too mathematical for direct application; however, the nature of the reliability problem seems to dictate this kind of description. What the report is intended to do in the procurement setting is to call attention to established methods of

dealing with reliability and to provide a general framework with respect to which the efforts of reliability specialists and technical consultants can be appreciated. For technical personnel, a variety of reliability topics are presented with sufficient rigor to permit use and extension of the methods for treating specific areas of interest. This focus is supported by extensive reference to literature sources.

In retrospect, one can see that two major approaches to the reliability problem are developed; these may be termed the macroscopic and the microscopic views. The macroscopic description of hardware reliability begins with a clear definition of exactly what constitutes acceptable performance. Loss of function is termed failure and often the concept of defining serviceability is referred to simply as "definition of failure." A sharp focus on specific failure definition statements lies at the heart of characterizing any reliability problem. Macroscopically, similar equipments are constructed and exercised until failures are induced. The behavior of such a population may then be described in terms of the rate at which failures occur, the times to failure, or the fraction of the original units surviving. Formally this kind of cataloging is carried out by specifying a hazard rate (instantaneous failure rate), time-to-failure distribution (probability density function), or the reliability (success probability) function. These three quantities are all functions of time and are functionally related to each other (any one implies the other two). The macroscopic measures of reliability are all random variables, meaning that the results of repeated similar observations are not the same but distributed and best represented by normalized probability density functions. In describing such a situation it is common practice to specify the probability that a quantity of interest will lie in a specified range. These descriptors are referred to respectively as the confidence level and confidence limits and are a part of any proper description of reliability attributes.

Not infrequently, the distributional aspects of reliability statements are suppressed. For example, if one sees 10% of the similar units in some population failing in one year, one speaks of 90% reliability for the item involved for that time period. It is important to realize that the upper and lower confidence limits have been allowed to coalesce to some single measure of central tendency in this case. Thus the statement made is one associated with a confidence level of essentially 50%. That is, the true value of the quantity of interest is as likely to be above as below the stated estimate. By how much the two are likely to differ (a dispersion measure) is not specified at this level of treating the problem. Generally, in a statistical situation, dispersion is related to the number of observations made or from which one wishes to draw a conclusion.

Handbook reliability prediction is a special case of a deterministic (dispersion not specified), macroscopic reliability evaluation. It is further specialized in that only the random hazard or exponential reliability model is applied to all situations. There are cases where it is appropriate to do this and other circumstances wherein important

information is suppressed by using this approach. One objective of the project report is to put handbook prediction in proper perspective; another goal is to elucidate and make available alternative methods for use as appropriate.

The microscopic approach to treating reliability problems is an outgrowth of the detailed stress/strength overlap interpretation of reliability. This methodology has been developed in recent years largely under the heading of probabilistic design. Success is defined as component, system, etc., strength exceeding applied stress. The terms "stress" and "strength" are used in a generalized sense here to refer to all kinds of loading and resistance to loading aspects of the situation; stresses may be mechanical, electrical, thermal, chemical, etc. Probabilistic design methods may be applied equally well to distributed statis situations--the random hazard case and dynamic situations where the overlap of stress and strength is time dependent. Infant mortality and wearout fall into the latter category. The dynamic aspects of probabilistic design, what this author refers to as the microscopic view of reliability, represent a particularly appealing way to treat wearout. Wearout is a systematic loss of strength and, ultimately, function associated with any of a variety of degradation processes such as oxidation, abrasion, fatigue, diffusion, sputtering, corrosion, etc. Application of probabilistic design methods to wearout problems allows one to derive (not simply observe directly in collective situations but develop indirectly from fundamental process characterizations) the associated time-to-failure, reliability, and hazard functions. Not only is this situation intellectually appealing but it allows a correlation of cause and effect that facilitates the systematic development of product upgrading strategies.

13.4. PLANS

- Immediate plans in the reliability field call for revising and updating the language of CIPS attachment 2 to make that document a more progressive and useful instrument for eliciting improved product reliability.
- Follow-on reliability work is also expected to include a study addressing the expected quality of the handbook prediction method. This will be an attempt to characterize the dispersion effects normally overlooked in handbook modeling.
- The corrosion modeling example discussed in the project report and the last STRIP quarterly report [6] is felt to provide the basis for a contribution to the open literature. This would be a corrosion or other wearout process study emphasizing the use of probabilistic design methods to facilitate the indirect experimental evaluation of physics-of-failure hypotheses.

- Future work should include the use of analytic methods for characterizing specific failure modes of sonar transducers. This approach should be used for shaping and interpreting coordinated experimental work.

14. TASK F-4 - FAILURE MODES ANALYSIS AND IMPROVEMENTS FOR TR-122
E.W. Thomas and R.W. Timme - NRL-USRD

14.1. BACKGROUND

The TR-122A/B (BQC-1) transducers are two-way communication devices installed aboard all US Navy submarines. In addition to the communication function, there is a built-in homing device for emergency use. This class of transducer was designed and built by the Dyna-Empire Corporation and has been in use on US submarines for many years. They are filled with a solution of dimethyl silicone oil, containing 83% Dow Corning 550 and 17% Dow Corning 200-10, that serves as an acoustic coupler between the seawater and the sensing elements of the transducer. One of the major disadvantages of using silicone oil is that the low surface tension causes it to creep continuously throughout the servicing area of the Transducer Repair Facilities (TRF) in the Naval Shipyards (NSY). This insidious creepage results in a coating of a monomolecular-thick film of oil on all the exposed areas of the transducers, molds, cables, connectors, and associated hardware, which results in weak and unacceptable rubber molds and bonds, cement mixes, and elastomer fabrication.

The Naval Sea Systems Command (NAVSEA) requested the STRIP program to determine the feasibility of replacing dimethyl silicone oil with Baker dB-grade castor oil as the fill-fluid on a class-by-class basis. One class of transducer has already been evaluated and recommended for filling with castor oil. Since the TR-122 transducer is the last class being processed through the TRFs that is filled with dimethyl silicone oil, this investigation will terminate the silicone oil vs castor oil evaluation project.

14.2. OBJECTIVES

The objectives are to analyze the failure modes of the TR-122 (BQC-1) and to develop, test, and evaluate an improved replacement transducer.

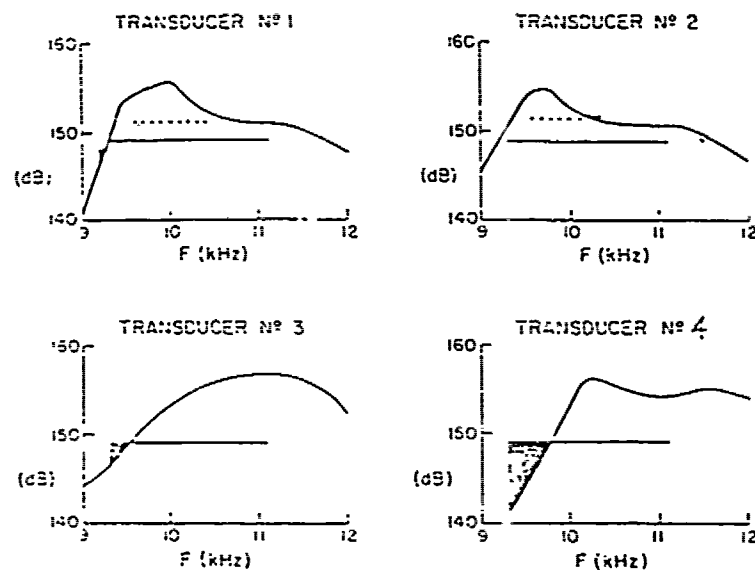
14.3. PROGRESS

Four TR-122 transducers were obtained from the TRFs. Acoustic measurements were made on the transducers first filled with dimethyl silicone oil and then filled with Baker dB-grade castor oil. The types of measurements made and their parameters are shown in Table 14.1. All relevant data were compared to the published specifications and any deviations therefrom were noted.

Table 14.1 - Types of measurements made on TR-122 transducers

PARAMETERS	UNITS
TVR	dB re 1 μ Pa/V/m
Low-level immittance	Ω
DR	dB re 1 μ Pa/V/m

Transmitting Voltage Response (TVR) measurements on the transducers filled with Baker dB-grade castor oil are plotted in Fig. 14.1. A stiffening effect, noted in the response of each transducer, resulted in an upward shift of the resonance frequency of 400 to 800 Hz. This shift causes the specified cardinal points to move out of the acceptable range. An example of the devastating effects of this can be seen in the graph of Fig. 14.1, which shows that all of the transducers fail to meet one or more of the specifications.



The following specification limits have been superimposed on the graphs:

— ≥ 149 dB between 9.3 and 11.1 kHz
 Preference reson. level at 9.6 kHz } ≤ -6 dB between 9.3 and 9.6 kHz
 } ≤ -3 dB between 9.6 and 10.4 kHz

Fig. 14.1 - TVR measurements on TR-122 transducers filled with Baker dB-grade castor oil

Figure 14.2 is plotted to show the major differences between the two coupling fluids. Note that transducers 1, 2, and 4 show the resonance shift very clearly. The character of transducer 3 has changed so radically that it has become unrecognizable.

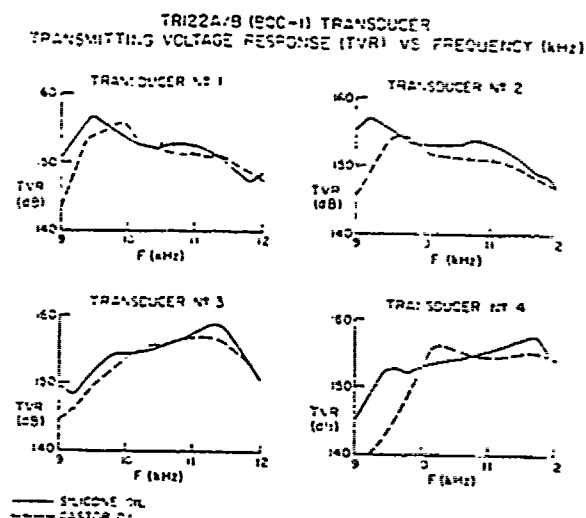


Fig. 14.2 - TVR measurements on TR-122 transducers filled with silicone oil or castor oil

The graph in Fig. 14.3 displays the impact on the TVR due to the substitution of castor oil for silicone oil. The normalized reference line at zero represents the silicone oil and the dashed line represents the variance imposed by the castor oil. This variance is caused by the stiffening effect of the castor oil, which results in the spectrum shift to the higher frequencies and the damping effect which results in lower sound levels.

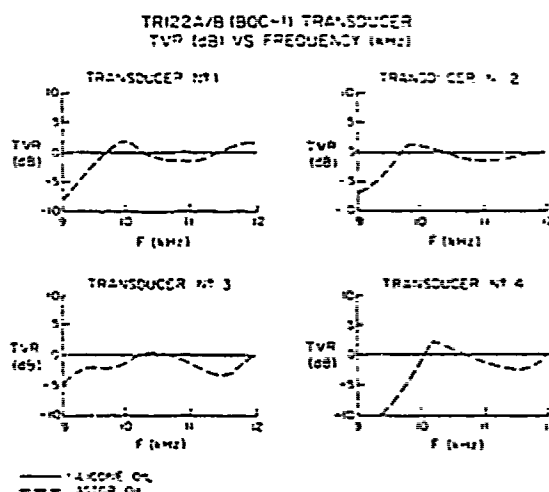


Fig. 14.3 - Impact on TVR due to substitution of coupling fluid

Impedance (Z): Impedance was measured within the bandwidth of 9.3 to 9.9 kHz in the four transducers. Figure 14.4 is plotted to show the Z curves for both the silicone oil and the castor oil. In addition to the spectrum shift observed in the TVR measurements, note the damping action exhibited by the castor oil curve.

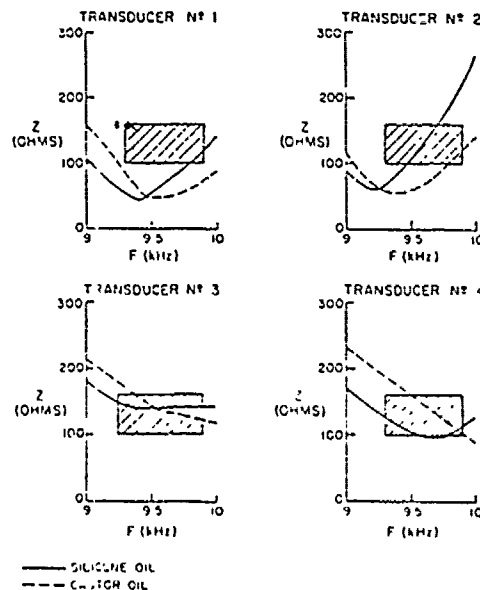


Fig. 14.4 - TR-122A/B (BQC-1) transducer impedance (ohms) vs frequency (kHz). The shaded portions of these graphs represent the specified acceptable parameters of the impedance.

Directional Response (DR): Directional response measurements were made in the XY plane at 9.6 kHz. A comparison of these measurements is shown in Fig. 14.5. Table 14.2 lists the DR measurements and the specification. There seems to be no problem in meeting the requirements.

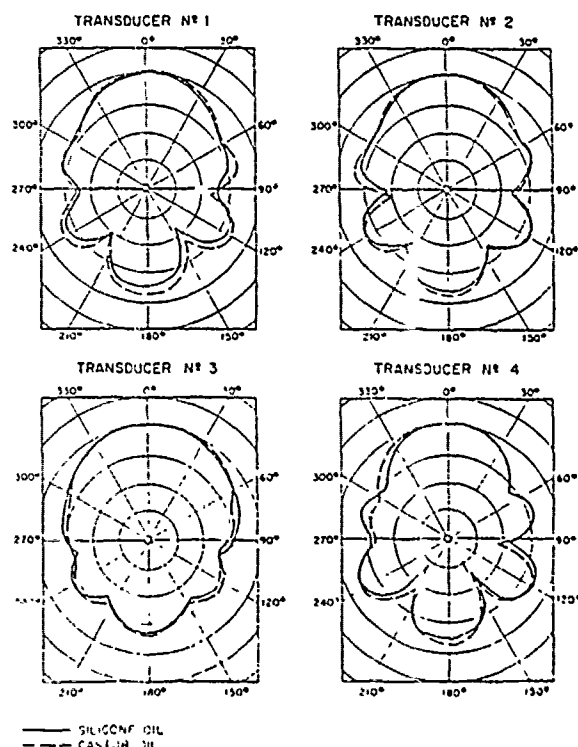


Fig. 14.5 - TR-122A/B (BQC-1) transducer - a comparison of dimethyl silicone oil with castor oil in the XY plane at 9.6 kHz.

Table 14.2 - Directional response measurements and specifications on TR-122 transducers

PARAMETER	SPECIFICATION	TRANSDUCER NO.	SILICONE OIL	CASTOR OIL
DR	>50° at -3 dB point	1	51°	59°
		2	53°	58°
		3	72°	76°
		4	54°	60°

Evaluation of Measurements: A detailed analysis of the failures encountered in this type of transducer when filled with each type of coupling fluid is presented in Table 14.3.

Table 14.3 - Analysis of failures occurring during measurements on TR-122 transducers

PARAMETER	SPECIFICATION	NO. OF TRANSDUCERS FAILING TO MEET SPECS	
		SILICONE OIL	CASTOR OIL
TVR	$\geq 14^{\circ}$ dB between 9.3 and 11.1 kHz	0	2
Reference response level at 9.6 kHz	< -6 dB between 9.2 and 9.6 kHz	0	3
	< -3 dB between 9.6 and 10.4 kHz	1	3
Z	> 100 Ω between 9.3 and 9.9 kHz	3	4
	< 160 Ω between 9.3 and 9.9 kHz		
DR	$\geq 50^{\circ}$ at -3 dB points	0	0

When filled with silicone oil, one transducer failed in the TVR and three transducers failed in the Z tests. When filled with castor oil, all four transducers failed in TVR and Z--there were eight failures in TVR and four in Z. A summary of the failures in regard to the individual transducers is shown in Table 14.4.

Table 14.4 - Summary of failures during TR-122 transducer measurements

PARAMETER	TYPE OF OIL	TRANSDUCER NO.			
		1	2	3	4
TVR	Silicone	X	✓	✓	✓
	Castor	X	X	X	X
Z	Silicone	X	X	✓	X
	Castor	X	X	X	X
DR	Silicone	✓	✓	✓	✓
	Castor	✓	✓	✓	✓

✓ Indicates pass
X Indicates failure

Based on this data and analysis, substitution of Baker dB-grade castor oil for dimethyl silicone oil as the coupling fluid in the TR-122 transducer is not recommended. The study also indicates that in addition to the poor handling characteristics of the coupling fluid, that the operating characteristics of the transducer were borderline. The transducer has a poor record of meeting the published specifications.

An alternative transducer may exist in the form of the Model 55 transducer built for the Trident system by Dyna-Empire Corporation. This transducer appears to be superior in performance and reliability. Investigation at the factory and the TRFs lead to the conclusion that the internal components of the new transducer may be installed into a modified TR-122A/B case assembly and substituted into the existing fleet.

A review of the Critical Item Product Specification (CIPS) for sonar communication set AN/BQC-1 for Trident (Model 55) has been conducted. A comparison of the reported performance of the new transducer (TR-122X) with the performance of the TR-122 is shown in Figs. 14.6, 14.7, 14.8, and 14.9. A report on these comparisons was presented to the TRF conference at Mare Island Naval Shipyard on 27 October 1980. Kits containing the necessary piece-parts to modify four existing TR-122 transducers were purchased from Dyna-Empire and delivered to the TRF at Mare Island.

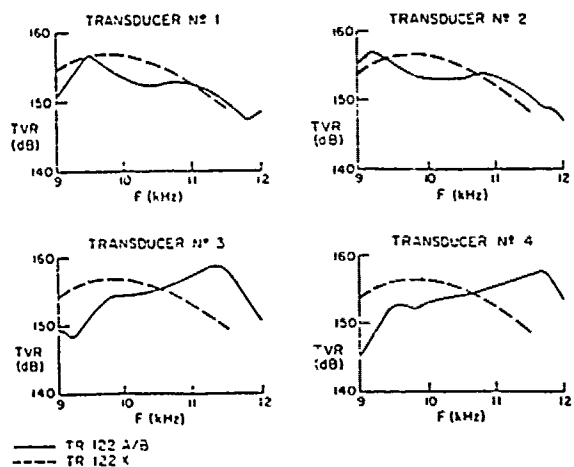


Fig. 14.6 - TVR vs Frequency (kHz).
Note the smooth response curve of the TR-122X.

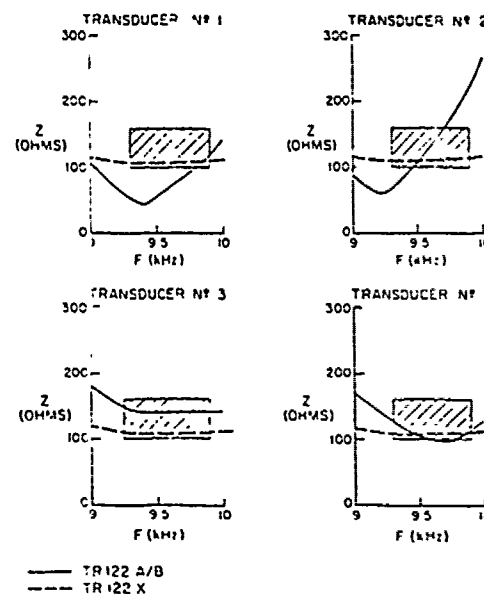


Fig. 14.7 - Impedance (ohms) vs Frequency (kHz). The impedance of the TR-122X remains in specification throughout the entire operating range.

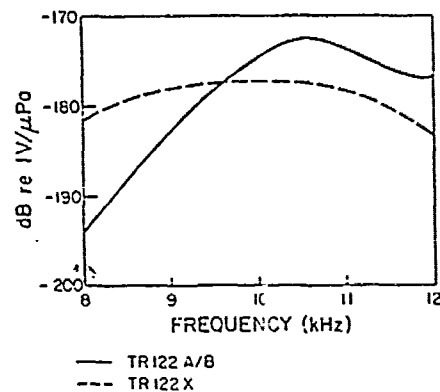


Fig. 14.8 - Free-field Voltage Sensitivity (dB) vs Frequency (kHz). The FFVS curve of the TR-122X is compared to the TR-122A/B.

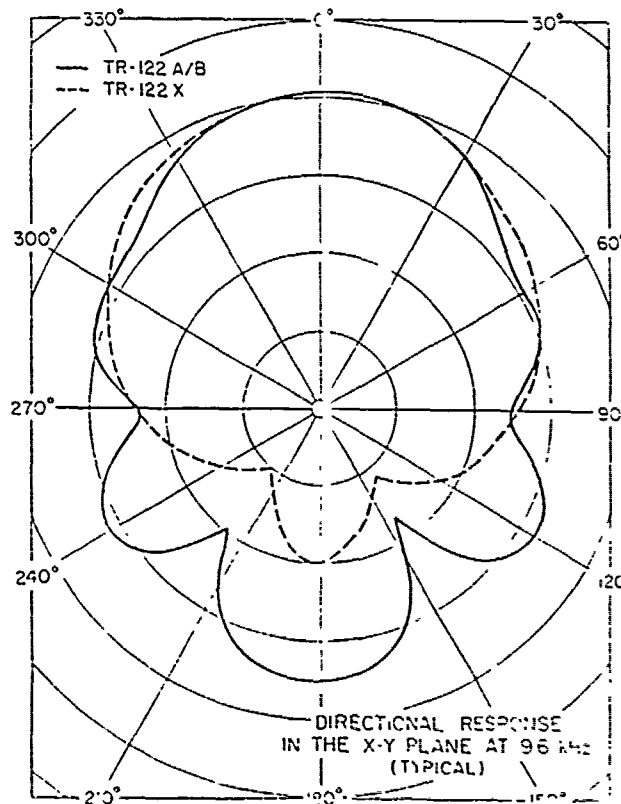


Fig. 14.9 - Directional Response in the XY Plane at 9.6 kHz (typical). Note the reduction of back lobes in the TR-122X.

14.4. PLANS

The TRF at Mare Island will modify the TR-122 transducers in cooperation with NRL-USRD during the second quarter of FY81. Dyna-Empire will loan four Model 55 transducers to NRL-USRD for ALT.

15. TASK F-5 - ENGINEERING DOCUMENTATION

R.W. Timme - NRL-USRD

15.1. BACKGROUND

Each of the other program tasks is expected to be fully documented as an essential part of that particular task. This task will provide an overview. It will link together the various tasks. It will insure that the failures as well as the successes will be discussed. The aim is to help avoid the continued "reinvention-of-the-wheel." All too often in the past, developments and redesigns that have resulted in successful hardware have not been documented in terms of why certain materials and/or construction details are chosen over others. Later, the same decisions must be remade. Based on the results of this program, consideration will be given to procurement via construction specifications rather than performance specifications. The approach here will be to determine and document the proper RDT&E of transducers and hydrophones as required for future acquisition.

15.2. OBJECTIVE

The objective of this task is to provide direction and documentation of the technology of transducer design and engineering that results from this program.

15.3. PROGRESS

Elements of various tasks within the STRIP were applied to the design and development of a hydrophone intended for a 95% probability of operating for 20 years. Development has been completed and the hydrophones have been deployed and are in use. A report entitled "Twenty-Year Life Hydrophones" by A.C. Tims, C.K. Brown, and R.W. Timme was presented on 16 December 1980 at the Institute of Acoustics Conference in Birmingham, England, and has been published in the Proceedings of the Conference: Transducers for Sonar Applications. This report has been reproduced in its entirety on the following pages.

15.4. PLANS

- Progress report on the entire program.
- Annual review of STRIP on 12 and 13 March 1981.

Proceedings of The Institute of Acoustics

TWENTY-YEAR LIFE HYDROPHONES

A. C. Tims, C. K. Brown, R. W. Timme

Naval Research Laboratory, Orlando, Florida

BACKGROUND

Underwater sound transducers are notorious for their poor reliability. It is not uncommon for 25% or more of the transducer elements of a sonar system to be nonfunctional after 1 or 2 years due to a variety of causes. The result, of course, is the increased cost of repair, retrofit, and loss of mission capability. The argument of this paper is that poor reliability need not be the case: transducers, especially hydrophones, can be built with reliability equal to space-age equipment.

A particular application has been chosen to demonstrate that high reliability can be achieved through the use of reliability modeling, an in-depth knowledge of transducer design, careful selection of materials, and good construction techniques. This approach, although applied to a specific type hydrophone, should also be important to other designs as well.

The Underwater Tracking Range of the Atlantic Fleet Weapons Training Facility, located in deep water off the western shore of St. Croix, has utilized a short baseline tracking system for accurate three-dimensional tracking of surface and subsurface targets. An extension to a long baseline tactical tracking capability required the development of hydrophones with extremely high reliability and long service life because of the remoteness and inaccessibility of the hydrophones once deployed in deep water.

OBJECTIVES

Thus, the objectives of this hydrophone development were determined by the requirements of the St. Croix range and are listed below.

- a. A 95% probability that the hydrophone will function 20 years deployed on the ocean bottom at a depth of 1800 m.
- b. A sensor element and preamplifier combination with an output sensitivity of -140 dB re 1 V/ μ Pa at 13 kHz and a bandwidth of 4 kHz to 45 kHz.
- c. A preamplifier with an output impedance of 50 Ω and capable of driving a signal through 20 km of cable.
- d. A directivity pattern to discriminate against bottom reflections.

RELIABILITY ANALYSIS

To develop a reliable hydrophone, the designer must as a first step establish failure criteria. The basis for this determination is to be found in the design objectives. The definition of failure for this hydrophone is the decrease in output sensitivity below -140 dB re 1 V/ μ Pa at 13 kHz and a 3 dB reduction of sensitivity elsewhere in the bandwidth.

Consideration of how this failure might occur leads to the second step which is the development of a simple reliability model. Figure 1 is a block diagram by function of this hydrophone. The sensor element converts sound into

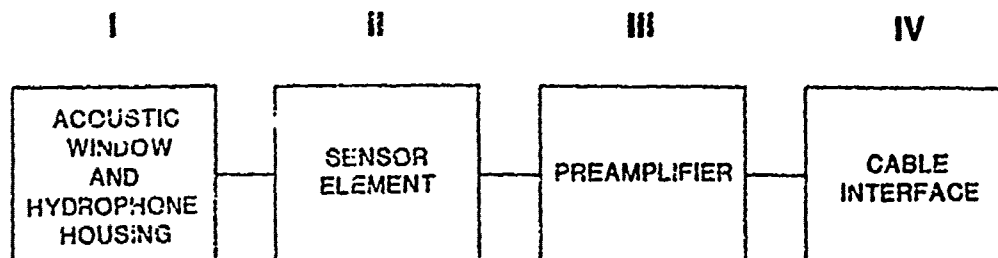


Figure 1. Simplified reliability model of the hydrophone by functional groups.

electrical signal and is usually the most important part of the hydrophone from the acoustical standpoint, but not necessarily so from the reliability standpoint. The acoustic window and housing provide protection to the sensor element and preamplifier from the sea. The preamplifier conditions the signal from the sensor element and provides it to the user via the cable interface. The cable should not necessarily be ignored because it definitely affects reliability, however, in this case, it is defined as outside the area of consideration. It is important to note that the functional groups of Fig. 1 are in reliability series, i.e., a failure in any one results in failure of the hydrophone. This is not to say, however, that the failure, or hazard, rates are equal.

The third step is to determine what the reliability demands mean in terms of failure rates. At this stage it is simplest to assume that infant-mortality is not a factor because of burn-in and acceptance testing. It is so simplest to assume the hazard rate λ is constant with time, and the reliability R , or the probability of successful operation, is

$$R = \int_0^{\infty} \lambda e^{-\lambda t} dt = e^{-\lambda t} \quad (1)$$

Thus, in this hydrophone, the requirement of 95% probability of a 20 year lifetime means the total failure rate λ is equal to or less than 0.3 failures in 10^7 hours. Based upon experience the designer now estimates how the total failure rate can be distributed among the functional blocks. For this hydrophone

$$\begin{aligned} \lambda_{I-} &\leq 0.1f/10^6 \text{ hrs} & \lambda_{I:I-} &\leq 0.1f/10^6 \text{ hrs} \\ \lambda_{II-} &\leq 0.05f/10^6 \text{ hrs} & \lambda_{V-} &\leq 0.05f/10^6 \text{ hrs} \end{aligned} \quad (2)$$

It is important to realize that the assignment of failure rates in Eq(2) is only an estimate and serves as a guide for the design.

HYDROPHONE DEVELOPMENT

To meet the requirements, the hydrophone shown in Fig. 2 was developed. Details of assembly and the reasons for design decisions will be given below.

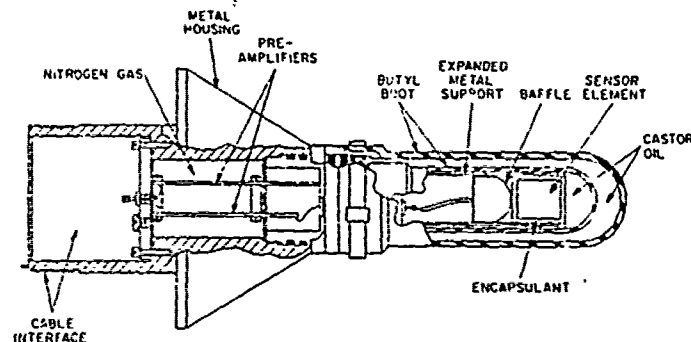


Figure 2. Cutaway view of the long-life hydrophone.

The acoustic sensor element, shown in Fig. 3, was an area ratio unsymmetrical tonpiltz composed of a longitudinally polarized lead-zirconate-titanate cylinder, provided with end caps and sealed by O-rings within an aluminum-oxide, precision-bore cylinder. There are two major advantages to this design. First, it takes full advantage of the high sensitivity given by the g_{33} polarization vector of the ceramic by shielding, and thus eliminating, the g_{31} component. Atmospheric gases sealed within the aluminum oxide housing by the O-rings represent an extreme impedance mismatch to the acoustic wave which eliminates entirely the g_{31} component to the sensitivity. Second, the sensitivity of the ceramic is effectively multiplied by the area ratio of the end caps to the ceramic cylinder. The combination of these two advantages yielded a sensitivity of $-180.8 \text{ dB re } 1 \text{ V}/\mu\text{Pa}$, which is quite high for a small specific volume of ceramic. The metal end caps were bonded with conductive adhesive to the ends of the ceramic cylinder and served as electrodes. Electrical leads were connected to the end caps with screws and insured with

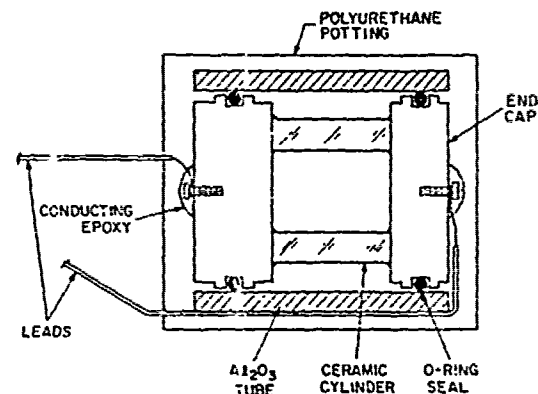


Figure 3. Acoustic sensor element

conductive adhesive. The leads were soldered at their opposite ends to glass-to-metal feed-throughs into the preamp compartment. The aluminum oxide housing with end caps and O-rings and the glass-to-metal feed-throughs were proof-tested to 135 MPa. Thus, the maximum operating pressure allowed a safety factor of 7.5. Reliability was further increased by encapsulating the ceramic sensor in a castor-oil compatible acoustically transparent polyurethane. This greatly reduced the possibility of oil leaking into the aluminum oxide housing and increased the physical integrity of the housing-ceramic cylinder-end cap assembly.

Behind the sensor element was mounted an acoustic baffle of machinable glass which, together with the conical housing, gave the hydrophone the desired cardioid directivity pattern in the forward direction.

The acoustic window, as shown in Fig. 2, consisted of inner and outer boots made of butyl rubber and each sealed to the hydrophone housing with double O-rings. The major reason for the choice of butyl was its low water vapor permeability, because water and water vapor are responsible for most failures in underwater transducers. The water permeability of most butyl compounds is 95 to 98% less than natural rubber, neoprene, polyurethane, Hypalon, or styrene rubbers. Butyl rubber is easy to mold, and bonds readily to metal parts properly prepared with the correct primers. The inner boot was molded of butyl compound 3252, and the outer boot of butyl compound 70821. The major difference in the two is that the latter is an electrical grade. The ingredients and physical characteristics of both of these elastomers are given by Capps [1]. Butyl does not have a good pc match to water, but if the wall section of the boot is uniform and small compared to the acoustic wavelength, it can be used successfully at frequencies below 100 kHz. Both boots were filled with castor oil. The salient characteristics of castor oil are high volume resistivity, close acoustic impedance match with seawater, compatibility with elastomers and other components and chemical stability. It is viscous and difficult to degas but this is a small problem for experienced technicians with proper vacuum systems.

The hydrophone could have been made with the sensor assembly encapsulated which eliminates the use of a fill fluid. But, for many encapsulants there are no general long-term immersion data available. Where data are available, many have a high rate of water vapor permeability; some are prone to bond failure; others leach their plasticizers and become stiff or brittle. Since high reliability was the objective, the proven characteristic of a dB-grade castor oil fluid filled system offered much less risk than an encapsulated system.

A low-noise preamplifier with 40.8 dB gain was designed to fit inside a nitrogen gas filled, sealed compartment within the hydrophone housing. To meet

the requirements for high reliability, the preamp was redundant, consisting of identical channels A and B, as shown in simplified form in Fig. 4. However,

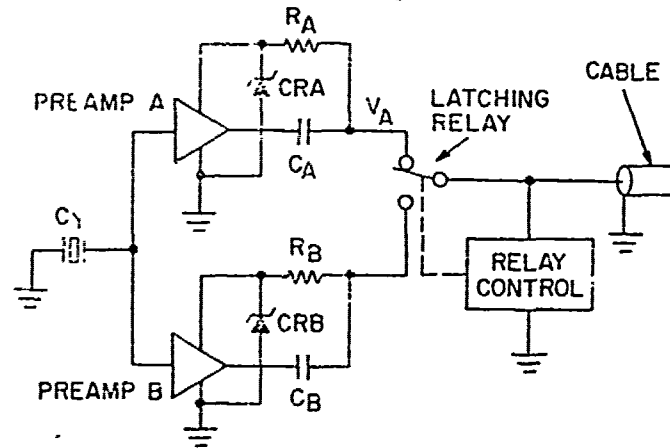


Figure 4. Dual-channel preamplifier design for high reliability.

only one channel is powered at any time with the selection made by the operator via a latching relay. DC power to the preamp and latching relay and ac output signal from the preamp share the common coaxial cable. The position of the latching relay is determined by the relay control network. This network is unenergized as long as the cable voltage is positive, which is the normal situation. In this case, the latching relay remains in its previously set state. To change preamp channels, the user activates the relay control network by momentarily applying a negative dc voltage. When the positive dc voltage is reapplied, the relay control network toggles the latching relay to its alternate position. The negative voltage has no effect on the preamp however. More details of this switching circuit can be found in a patent application [2]. Other features of the preamp included diode switch protection to the input and output from high voltage pulses or charge buildups from the ceramic sensor and to the preamp output from high voltage transients including lightning surges to 100 A.

The Military Standardization Handbook 213, Reliability Prediction of Electronic Equipment was used as a guide in the preamp design. Tried and proven circuits with a minimum of parts, operating under minimal electrical stress, and qualified by adherence to military specifications to the highest levels of established reliability were used in the design. In addition a preamp burn-in at 125°C for 160 hours was conducted to eliminate infant mortality.

The cable interface shown in Fig. 2 accepted a Morrison cable seal. The seal, named after its designer, is a multilevel coaxial submarine cable seal. It has double O-rings at the interface and is designed to seal a coaxial submarine cable for 20 years at depths to 2.1 km (tested to 42 MPa). This seal assembly has been in service in the Navy for 10 years with excellent success.

RELIABILITY PREDICTION

The simple reliability model of Fig. 1 was expanded to the model shown in Fig. 5 during the design phase of the hydrophone. The increase in reliability provided by the redundancy of dual O-rings, dual boots, and dual preamps as shown in Fig. 2 over the reliability of the individual components can be seen with the model. Once the failure rate λ of each component is known the reliability of that component can be calculated from Eq(1). The reliability of the composite can then be calculated with Eq(3) for series components and Eq(4) for parallel components. Failure rates of transducer components are generally

$$R = \prod_{i=1}^n R_i \quad (3)$$

$$R = 1 - \prod_{i=1}^n (1 - R_i) \quad (4)$$

not constant with time as are electronic components. However, it is customary to treat them as constants because of a lack of data. This was done here. Failure rates were assigned to each component as shown in Fig. 5 and were based on records and experience at NRL and references [3-4]. Failure rates depend upon the material, the environment, and the application.

Equations (1), (3), and (4) and the failure rates shown in parentheses in Fig. 5 were used to calculate the reliability and composite failure rate of each of the hydrophone functional groups for a life expectancy of 20 years.

$R_I = .981$	$\lambda_I = 0.1.0 \text{ f}/10^6 \text{ hrs}$	
$R_{II} = .994$	$\lambda_{II} = (.036 \text{ f}/10^6 \text{ hrs}$	(5)
$R_{III} = .980$	$\lambda_{III} = (.115 \text{ f}/10^6 \text{ hrs}$	
$R_{IV} = .991$	$\lambda_{IV} = (.050 \text{ f}/10^6 \text{ hrs}$	

These numbers compare closely with Eqs. (2). The product of the functional group reliabilities shows the probability of the hydrophone operating successfully for 20 years to be 94.7% which is as close to the design goal as one can come with the existing uncertainties in the component failure rates.

This prediction has been based only upon random component failure with the assumption of a constant hazard rate. No consideration has been given to wear-out failure. In this hydrophone, the housing and outer boot, which are exposed to seawater, are likely to encounter wearout first. In recognition of this the housing is made of cadmium plated steel which has a well-documented corrosion rate of 0.07 mm per year. Wearout from this mode would take about 100 years. The outer boot undergoes a very slow chemical reaction with seawater but the choice of butyl ensures a wearout life well in excess of 20 years. Thompson [5] has shown that the chlorobutyl used here will gain only about 3% in weight, about 1% in swell, and about 10 shore hardness points after 20 years contact with seawater. A polyurethane potting or boot would be quite another matter. Both Thompson [5] and Sanewich [4] have shown that certain polyurethanes will

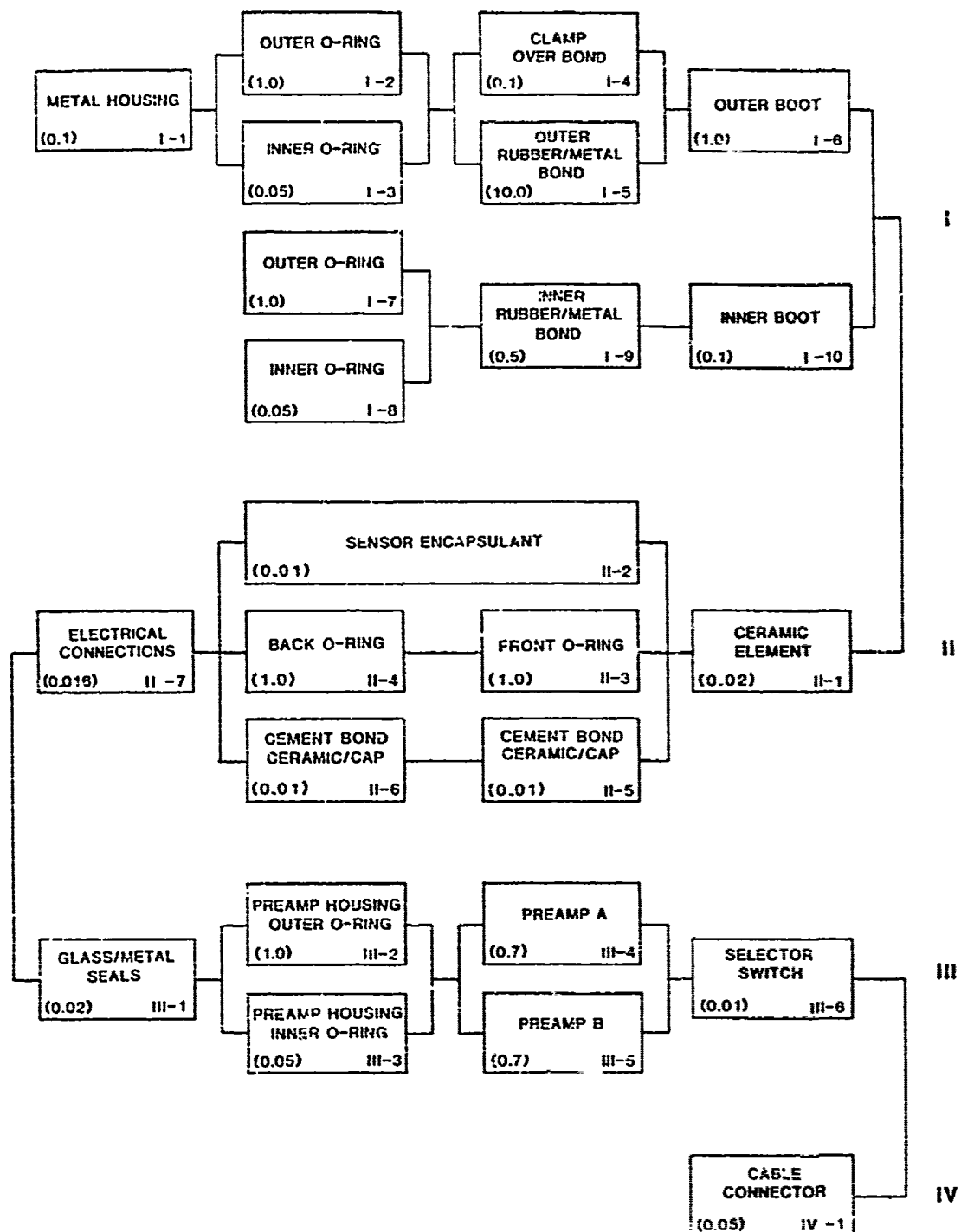


Figure 6. The reliability model of the hydrophone is shown with the components in functional groups I-IV. The failure rate of each component is shown in parentheses in failures per 10^6 hours.

wearout by cracking or complete disintegration in 5 years or less. The inner boot and other internal components have been chosen because of demonstrated compatibility with the castor oil fill fluid. Since there is no pressure or temperature cycling or handling once deployed, no additional stresses are placed upon the hydrophone so wearout within 20 years is not a problem.

An advantage of the reliability model in Fig. 5 is that it shows the value of redundancy. If the hydrophone had been designed with only one boot, single O-rings, and one preamp, the model would consist only of components I-1, I-2, I-5, I-6, II 1-7, III-1, III-2, III-4, and IV-1. The prediction of reliable operation for 20 years would be about 9%. Placing a hose clamp over the boot-metal bond can increase the reliability of 20 year life from 9% to 50%. The addition of double O-rings further increases the reliability to 70%. The double butyl boot construction increases it yet further to 85% and the redundant preamp brings the reliability to the goal. Of course, it is not surprising that the reliability can be improved by reinforcing the weak points, but the reliability model shows very clearly where attention should be placed in what order.

SUMMARY

A hydrophone has been developed with a predicted probability of 95% for a lifetime of 20 years. But, what assurance is there that this is more than an exercise with numbers?

An array of 24 of these hydrophones has been deployed for one year. Another array of 8 hydrophones that are identical except they have only one preamp channel each has been deployed for four years. No failures have occurred. However, the same reliability numbers discussed above predict there is only one chance in four that any failures would have occurred in that population during this time. So, while it is still too soon to be conclusive, there is reason for optimism that a twenty-year life hydrophone has been developed.

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