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NOSC

NOSC TR 516

C Technical Report 516

COMPOSITE-UNIT ACCELERATED LIFE TESTING (CUALT) OF SONAR TRANSDUCERS

DL Carson et al

September 1979

Final Report for Period March 1978 – September 1979

Prepared for
Naval Research Laboratory/Underwater
Sound Reference Division (NRL/USRD)
Orlando, FL 32856

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AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

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ADMINISTRATIVE INFORMATION

Work was performed under Sensors and Spatial Processing Division (Code 712) by members of the Transducer Lab Branch (7121) for the US Navy. It was sponsored by the Naval Research Laboratory/Underwater Sound Reference Division (NRL/USRD).

Released by
DL Carson, Head
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Processing Division

Under authority of
HA Schenck, Head
Undersea Surveillance
Department

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
NOSC Technical Report 516 (TR 516)

2. GOVT ACCESSION NO.
AD-A085393

3. RECIPIENT'S CATALOG NUMBER
9 Final rept.

4. TITLE (and Subtitle)
6 Composite-Unit Accelerated Life Testing (CUALT) of Sonar Transducers

5. TYPE OF REPORT & PERIOD COVERED
Mar 78 - Sep 79

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
10 DL Carson

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Naval Ocean Systems Center
San Diego, California 92152

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
NAVSEA

12. REPORT DATE
11 Sep[redacted]979

13. NUMBER OF PAGES
186

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
12 162

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

14 NOSC/TR-516

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Sonar transducers
Accelerated life testing — transducers
Transducers — reliability

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

NOSC was assigned to develop standardized methods to accelerate the aging of transducers to provide experimental methods for early discovery of problems that would detrimentally affect their reliability and useful life cycle. A secondary accomplishment was directed to aid in the development of selected transducers currently being procured. Both projector and receiver types were included in the effort to perfect the accelerated life testing (ALT) methods.

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S/N 0102-LF-014-6601

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

OBJECTIVE

Develop and demonstrate experimental accelerated life testing (ALT) methods for early discovery of problems which would detrimentally affect the reliability and useful life cycle of fleet sonar transducers.

RESULTS

1. Using composite-unit accelerated life testing (CUALT) methods, existent and potential design and quality control problems which would not have been discovered using piece-part testing were identified and corrected.

2. Resolution of the current-runaway problem on the TR-316 was largely based on the CUALT experimental and analytical data presented.

3. The first-year equivalent of CUALT was completed on both the TR-316 and DT-605 transducers.

RECOMMENDATIONS

1. To develop and implement a qualification test series which will demonstrate that the test units can survive each of the more severe exposures at least once prior to introducing the CUALT sequence.

2. To modify shipment, storage and installation procedures for transducers.

3. To implement an improved CUALT exposure plan for the TR-316 and DT-605 transducers in terms of heat and atmospheric contamination, thermal cycling, water soak, pressure cycling, pressure dwell, low-temperature shock, vibration and impact/penetration.

ACRONYM DEFINITIONS

Acronym	Definition	First Page Encountered
ALT	Accelerated Life Testing	1-1
CFMA	Critical Failure Mode Analysis	3-7
CIPS	Critical Item Product Specification	5-2
CUALT	Composite-Unit Accelerated Life Testing	2-1
CW	Continuous Wave	6-15
FMEA	Failure Modes and Effects Analyses	2-3
IFMEA	Iterative Failure Modes and Effects Analysis	3-1
NOSC	Naval Ocean Systems Center	1-1
NRL/USRD	Naval Research Laboratory/ Underwater Sound Reference Division	1-1
SE	Stress Exposure	6-1
TRI	Texas Research Institute	3-7
TVR	Transmit Voltage Response	6-3
UV	Ultraviolet	5-20

ACKNOWLEDGEMENTS

Charles Clark - NAVSEA	Originally sponsored the precursor of this effort and insisted that improved reliability requirements for sonar transducers be specified and their realization be experimentally verified.
Robert W. Timme NRL/USRD	Sponsor - see page 1-1.
David L. Carson - NOSC	Directed the overall effort, devised the approach, participated in the interpretation of test results and corresponding development of corrective-action recommendations, and prepared the FY 79 documentation.
Jack Wong - NOSC	Carried out the CUALT plan and participated in and contributed to all phases of the technical effort, including interpretation of test results, automation of the in-air impedance experiments and development of corrective-action recommendations.
Dr. Gerald L. Kinnison - NOSC	Suggested the use of in-air impedance experiments on individual resonators to understand the current-runaway problem.
Homer Ding - Jack Wong NOSC	Automated the in-air impedance experiments, making it possible to obtain extensive data in the available time.
Don Huckle - Leonard Reavis - John Fransdal - NOSC	Interpreted test results, suggested diagnostic tests, and developed corrective-action recommendations.
Scott Thornton - Texas Research Institute	Developed and technically defended the CUALT plan. Helped prepare sections 5 and 7.
Edward Hobaica and Ray Haworth - General Dynamics/E.B. Div.	Developed Failure Modes and Effects Analyses (FMEAs) for transducers. Developed FMEAs for cables and connectors.

Composite-Unit Accelerated Life Testing (CUALT)
for Sonar Transducers - Part 1

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (Cont'd)

LIST OF FIGURES

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF TABLES

COMPOSITE-UNIT ACCELERATED LIFE TESTING (CUALT) FOR SONAR TRANSDUCERS - PART 1

SECTION 1

1.0 Introduction

This program was initiated in FY 1978 with sponsorship consolidated in NAVSEA 63XT and block-funded to Naval Research Laboratory/Underwater Sound Reference Division (NRL/USRD) (see reference 1 for Program Plan). Under the block funding, Naval Ocean Systems Center (NOSC), San Diego, was assigned the task of developing a set of standardized methods to accelerate the aging of transducers based upon environmental stress requirements. For brevity, such methods are referred to herein as accelerated life testing (ALT).

The work on this task began in March, 1978. This report documents the results as of September, 1979 with regard to the ALT of transducers and their subcomponents. The reader desiring a short overview of the results should read Section 1 (Introduction), Section 2 (Guidelines Adopted), Section 3 (Approach Evolved), and Section 8 (Summary).

1.1 Objectives

The primary objective of this effort is to develop and demonstrate experimental ALT methods for early discovery of problems which would detrimentally affect the reliability and useful life cycle of fleet sonar transducers. To be successful, the ALT would have to lead to early discovery and correction of problems or potential problems before they occur in actual fleet operations.

A secondary objective is to aid directly in the development of selected transducers currently being procured.

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[1] Dr. Robert W. Timme, Program Plans for Sonar Transducer Reliability Improvement, NRL, September, 1977.

1.2 Justification

The detrimental effects on life-cycle costs and fleet readiness when sonar transducer problems are first discovered during fleet operation are potentially disastrous. Discovery of problems early in the design, development and/or production stages permits timely corrective action at reasonable cost and with some flexibility in the possible solution. Discovery of problems later in the life cycle creates production delivery problems and possible shipyard delay claims, emergency fix actions at higher cost, and strict limitations on which technical solutions, if any, can be implemented. The effort herein described was justified on the following basis: the state of the art has advanced such that ALT methods could probably be improved to the point where most transducer problems or potential problems could be discovered (and corrective action taken) before such problems occur in the fleet.

SECTION 2

2.0 Guidelines Adopted

During the initial planning of this task there was considerable debate concerning the selection of an approach which would have a high probability of yielding practical, usable results. The role of piece-part testing versus tests on the composite transducer unit received particular attention. As a result, the following key guidelines were adopted as requirements for the performance of the accelerated life testing.

2.1 Emphasis of Composite-Unit ALT (CUALT)

The emphasis on composite-unit accelerated life testing (CUALT), as opposed to piece-part testing, for example, resulted partly from the conviction that it is not reasonable to anticipate the many ways problems can result from interactions in the composite production transducer units. Design and quality-control deficiencies combine in a complex fashion with fleet operationally-induced physical and chemical interactions of the piece parts. Only composite-unit stress exposure is likely to reveal the resulting problems prior to fleet operations.

In general, all along the line from the designer/manufacturer to the user (Navy personnel) and transducer repair facilities, it appears that only when a problem is discovered on composite units is a given problem accepted as real and commensurate action taken. The CUALT should capture this motivational feeling of urgency and applicability by simulating conditions, on a composite transducer, approaching those encountered in fleet use of the hardware.

The emphasis on CUALT also resulted partly from the historical fact that piece-part testing in general has proven most useful after problems have been encountered in the composite transducer unit. Piece-part testing by physical chemists and material specialists has subsequently contributed greatly to solving many such composite-unit problems. After a design has been proven reliable, piece-part testing may also be important for maintaining the inherent reliability of the design during production.

After a thorough investigation of the potential and limitations of CUALT, additional processes can be considered to remove any limitations. For example, such augmentation might include pre-aging of certain parts or subassemblies and using those parts in a reassembled transducer, which would then be subjected to CUALT.

2.2 Use of Current-Buy Transducers

It was decided that added benefits could be obtained by perfecting the ALT methods using transducers of current interest and, specifically, transducers currently being purchased. Aside from the fact that the method would be developed, one would obtain the benefits of analyzing realistic cases of interest and possibly discovering potential problems in a timely fashion. If successful, this effort could contribute directly to the improvement in fleet transducers before the problems occur during operation.

2.3 Use of Both Projector and Receiver Transducers

Since projectors and receivers are subjected to different operational stress conditions, both types of transducers must be included in the approach to perfecting the ALT methods. The most obvious difference in the two is that the projectors are subjected to high-drive levels, whereas the receiver hydrophones are not. Other differences, such as subtleties due to construction, size, and required sensitivity, would be highlighted in systematic CUALT.

2.4 Hands-on ALT Experience by Government Technical Monitors

Hands-on experience is needed by the government technical personnel responsible for writing specifications, judging proposals, monitoring contractor efforts, and helping the fleet use the transducers which result from such efforts. The personnel would not long be competent to perform the government role unless they have continuing hands-on experience in all phases of design, construction, evaluation, and operation of the product. Because of this, the requirement was established that a significant part of the development of ALT methods be performed by government technical monitors associated with whichever transducers were selected for use in the development. On the other hand, for the sake of efficiency (both in time and money), special talents from other organizations were to be used to implement certain tasks.

2.5 Systematic Application of Prior Experience

Experience has shown that some of the most valuable insights into potential problem areas for a given transducer design are articulated at some point in the process of developing specifications and writing and evaluating proposals. Many of these observations are only qualitative since they represent, in some cases, years of accumulated experience on similar transducer designs. It was desired that this and similar experiences, including state-of-the-art analysis and test results, be systematically documented and applied to planning the CUALT. The format and technique used in failure mode and effects analysis (FMEA) were used in a modified iterative manner for this purpose.

SECTION 3

3.0 Approach Evolved

It is appropriate at this point to discuss the evolution of the approach and the details of its implementation for the composite-unit accelerated life testing. The guidelines presented in section 2 were complied with during the evolution of the approach. An early initiation of CUALT which affected the evolution of the approach (see section 3.6) was demanded and performed. The approach evolved is presented below.

3.1 Use of AN/BQS-8B/10A/14A/20 Projectors and Hydrophones

New TR-316 projectors (formerly TR 215) and DT-605 (formerly DT-308) receiver hydrophones were being purchased for use in the under-ice sonar system (AN/BQS-8B/10A/14A/20). These transducers were used in this exploratory development effort and met the criteria of the guidelines presented above. Figure 3-1 indicates the location of these transducers on a submarine. The TR-316 appears as three separate, vertically mounted staves, and the DT-605, as a cylindrical array of thirty housings containing two vertical lines of hydrophones per housing. Figures 3-2 and 3-3 illustrate the TR-316 configurations; figures 3-4 and 3-5, the DT-605 configurations. The extra benefit of developing and validating the CUALT method on current production units has been realized. Utilization of current-buy transducers led to the early identification, verification, and correction of problems and potential problems, in this instance, prior to production runs.

3.2 Iterative Failure Modes and Effects Analysis (IFMEA)

The technique selected for the systematic identification and documentation of potential transducer problem areas and incorporation of practical experience is a modified FMEA described below as an iterative FMEA (IFMEA). General Dynamics/Electric Boat was tasked to assemble and augment available

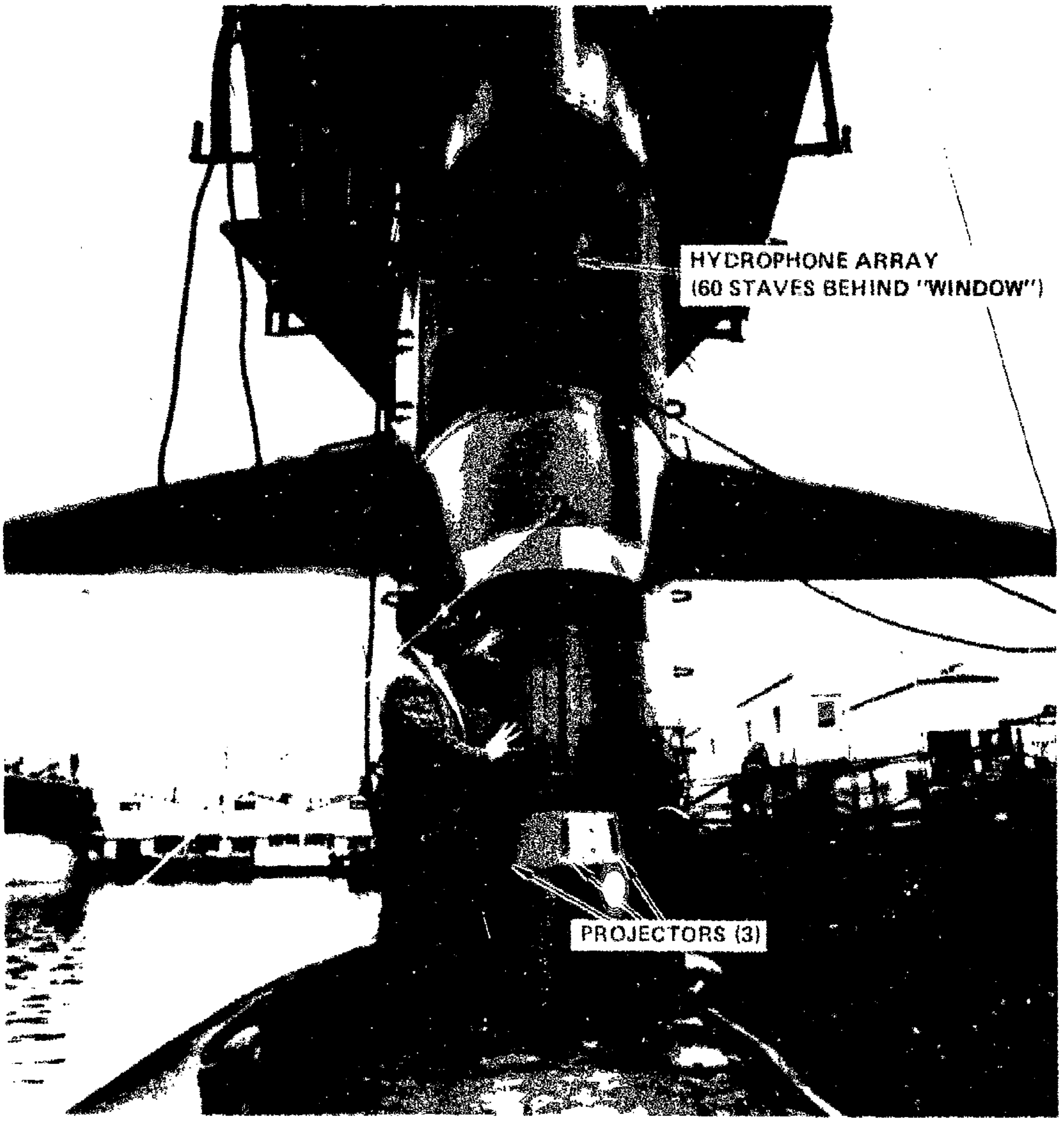


Figure 3-1. Typical Location of [illegible]QS-[illegible]/10A/14A/20
Hydrophone Array and Projectors

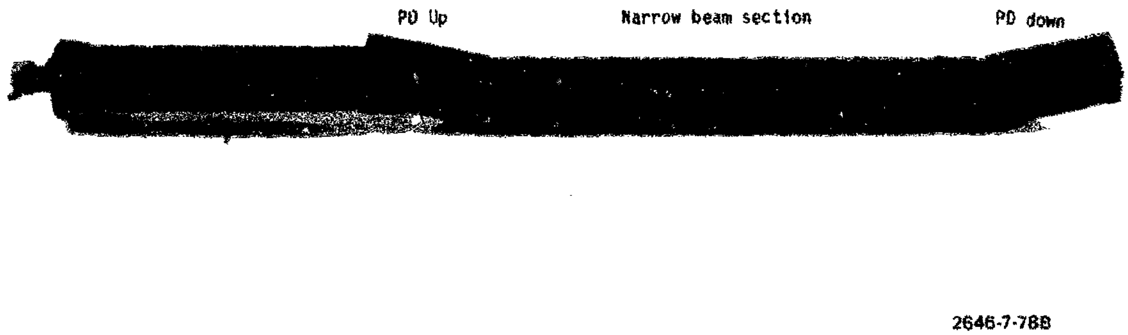


Figure 3-2. TR-316 Projector

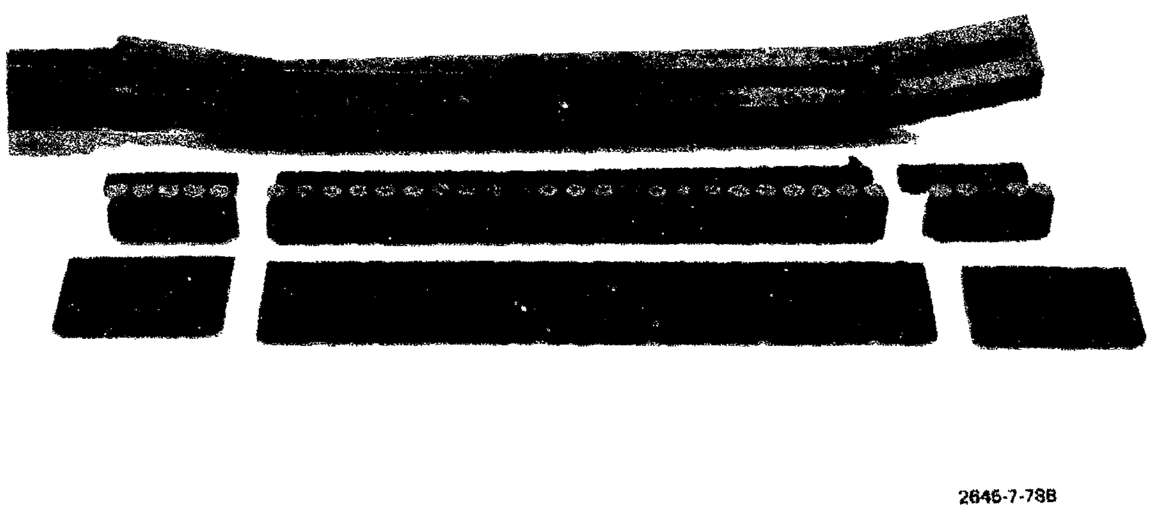


Figure 3-3. TR-316 Projector Disassembled

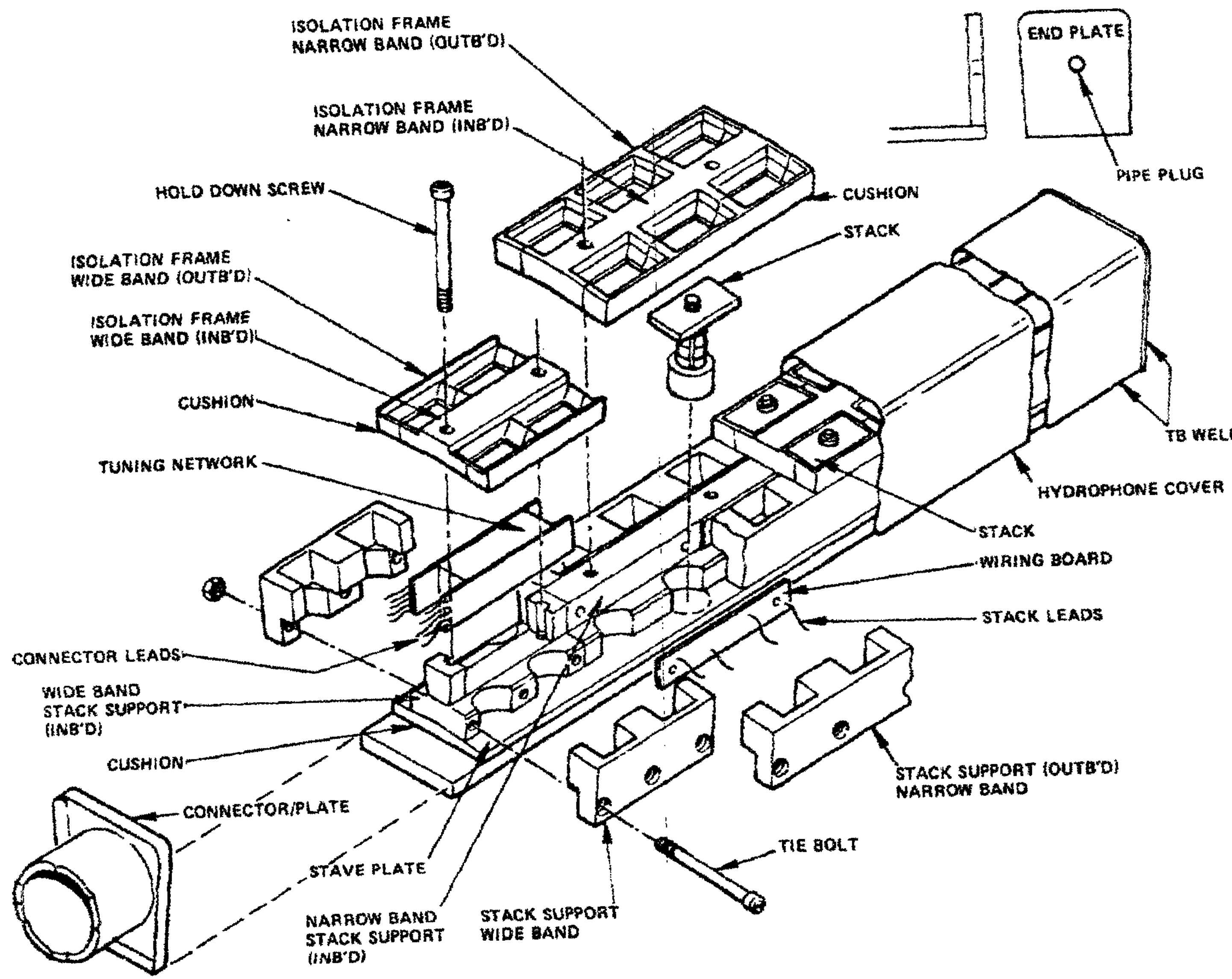
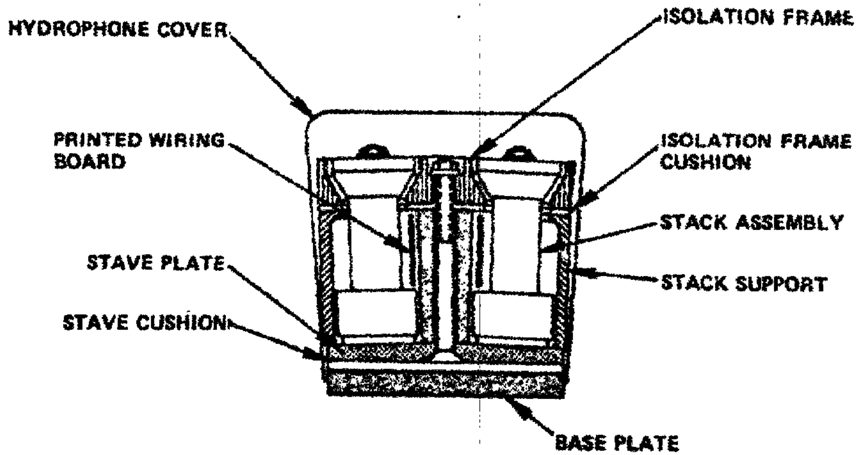


Figure 3-4. DT-605 Hydrophone Breakdown



NARROW BAND CROSS SECTION, DT-605 HYDROPHONE

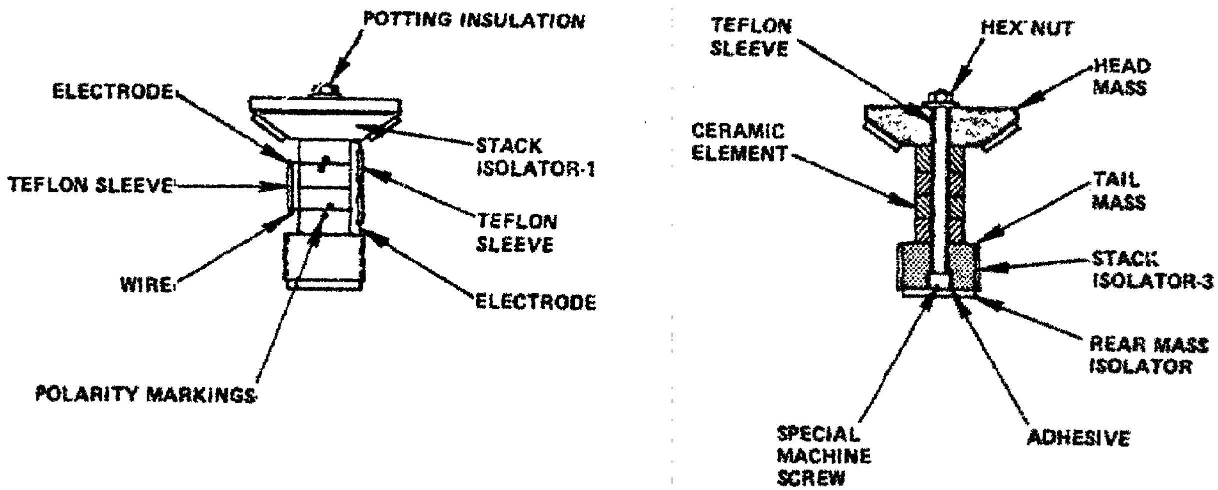


Figure 3-5. DT-605 Hydrophone Stack Assembly

data in the form of a first iteration FMEA for both the TR-316 projector and the DT-605 hydrophone transducers considered.

The conventional FMEA is a standard technique used to perform a systematic design review aimed at identifying potential failures at various levels of subassembly and analyzing the effects of these failures at higher levels, such as the component or system level, (or even at the level of accomplishment of a mission). MIL-STD-1629, often applied to sonar transducers, requires that each output function be examined for typical failure modes, such as premature operation, failure to operate or cease operating at a prescribed time, failure during operation, and degraded operational capability.

As used in the transducer CUALT program, it is necessary to use the FMEA technique iteratively at various stages of development of a transducer. For example, as early as the development of a specification (and corresponding initial design) for a transducer procurement, valuable considerations from past experience will be applied. These early observations should be systematically documented. Later in the proposal evaluation stage the contractor may submit only preliminary drawings or sketches and yet many additional observations by the evaluation team should be documented at this point. Still later, as the transducer is readied for manufacture, detailed plans should become available, at which point the critical-component list may become the focus of an IFMEA such as in the standard FMEA.

In future iterations of the IFMEA it is intended that as suggested by Texas Research Institute (TRI), a critical failure mode analysis (CFMA), become a part of the IFMEA. Because of deviations from a standard FMEA, such as those indicated above, the corresponding process in this task has been called an IFMEA.

3.3 CUALT Plan Proposed and Technically Justified by Specialists

Although hands-on experience for the government contract monitors is required by the guidelines adopted for the ALT task, it was decided that personnel already experienced and qualified in theoretical and experimental analysis and correction of failures in similar transducers should be tasked to propose and technically defend the CUALT plan for each specific transducer considered. The IFMEA was used as a starting point, at first informally and later formally, in this procedure of generating and defending the CUALT plan.

Texas Research Institute (TRI) was contracted to lead this effort with instructions to utilize all known applicable material, including that from the sponsor, NRL, Orlando, Florida.

3.4 NOSC Technical Monitors Apply CUALT

Since NOSC, San Diego, was responsible for the procurement of the selected projector and hydrophone, NOSC was tasked to implement, perfect, and apply the CUALT plan and to take the initial step to institute corrective action for any potential problems discovered. This task assignment was made in compliance with the desire to obtain hands-on experience for the government technical personnel (see section 2.4). NOSC worked with TRI and others in generating the CUALT plan. However, TRI was primarily responsible for the technical defense of the CUALT plan as a meaningful method of detecting reliability problems and operational-life limitations.

3.5 In-Depth Failure Analysis Tasked to Specialists

Although the development of the ALT method was exploratory in nature, problems in the design for these transducers were discovered early enough that the manufacturer could consider and rectify the problems. After initial consideration of corrective action by NOSC working with the contractor, it was decided (just as in the historical case where transducer problems were discovered during fleet operations) that certain selected in-depth analyses of the failures revealed by CUALT should be tasked to specialists, as required.

3.6 Early CUALT

A general but pervasive feature of the iterative approach had a productive influence on the results and is therefore worthy of mention at this point. It was demanded that CUALT be initiated early in the program even if this meant using makeshift testing apparatus or following a CUALT plan which would inevitably be changed. Thus, a quick informal iteration of the IFMEA and CUALT plan was produced and applied.

Early CUALT not only provided feedback, influencing subsequent iterations of the IFMEA and CUALT plan, but produced early positive test results. For this overall task, success represented discovery through CUALT of problems or potential problems (and of course subsequent correction) before they had affected the fleet operations. In this task some important problems were discovered early enough to affect the first production run.

The early hands-on experience by the technical monitors and directors of the production contract also produced the hoped-for results. It enabled them to perform their function from a position of strength and conviction.

SECTION 4

4.0 Iterative Failure Modes And Effects Analysis (IFMEA)

General Dynamics/Electric Boat completed and documented a first iteration failure modes and effects analysis for the Ametek/Straza TR-316 sonar projector[2] and the DT-605 hydrophone.[3] As stated previously in discussing the IFMEA, its purpose was to aid in the systematic identification and documentation of the potential transducer problems and to incorporate practical experience. The results were used directly to recommend design changes and as a starting point in developing the CUALT plan. It was recognized that the cables and connectors could be the weak link in the sonar system, and therefore General Dynamics/Electric Boat was also tasked to prepare a cable and connector FMEA for the TR-316, DT-605 and SQS-56 transducers.

4.1 TR-316 IFMEA

The approach used by General Dynamics/Electric Boat Division for the first iteration TR-316 FMEA was the conventional approach described in MIL-STD-1629. First a detailed listing of the parts by subassemblies making up the transducer (material indenture listing) was generated (see table 4-1 as typical of the complete listing in reference 2). The listing included the part nomenclature, drawing number, drawing item number and the number (quantity) of a given part used. The parts listing was grouped according to subassembly membership. Second, the functional purpose of each part was given (see table 4-2 as typical of the rest of the data in reference 2).

[2] E. C. Hobaica, R. A. Larmi, R. F. Haworth, Failure Modes and Effects Analysis for the Ametek/Straza TR-215 ( ) (now called the TR-316) Sonar Projector, EB Div Report No.: U 443-78-053, Revision "A", December, 1978.

[3] R. A. Larmi, E. C. Hobaica, Failure Modes & Effects Analysis for the DT-308' ( ) (now called the DT-605) Hydrophone, EB Div Report No.: U 443-78-095, December, 1978.

Table 4-1. Sonar Projector TR-316 Material Indenture Listing

Index	Nomenclature	Dwg. No.	Dwg. Item No.	Qty.
	SONAR PROJECTOR TR-316	Ametek (Straza) 8-6A018460		1
1	MACHINED HOUSING	8-6A018460	1	1
	Housing, Weldment	8-6A018463		1
1-A	Formed Plate	8-6A018462	1	1
1-B	Channel (2-1/2 wide)	8-6A018462	2	1
1-C	Top Cap	8-6A018462	3	1
1-D	Blank Weldment Plug	8-6A018462	6	3
1-E	Coil Housing Weldment/Machined Casting	8-6A018462	4	1
1-F	Coil Housing Investment Casting	8-6A018432	1	1
1-G	Bulkhead Plug	8-6A018432	2	1
1-H	Weld Rod (316L)	8-6A018432	3	AR
1-J	Wedge	8-6A018462	5	1
1-K	Weld Rod (316L SST)	8-6A018462	11	AR
1-L	Bulkhead	8-6A018462	8,9	1,1
2	WIRE ASSEMBLY (BLACK)	8-6A018460	3	1
2-A	Wire	8-6A017120-1	1	30"
2-B	Threaded Bushing Terminal	8-6A017120-1	4	1
3	WIRE ASSEMBLY (RED)	8-6A018460	4	1
3-A	Wire	8-6A017120-2	1	30"
3-B	Threaded Bushing Terminal	8-6A017120-2	4	1

The third step resulted in a listing of the possible failure modes, possible failure causes, test suggestions, level-of-severity estimates, probability-of-occurrence (of the failure) estimate, and remarks and recommendations (see table 4-3 as typical of the rest of the table in reference 2). The failure modes for the parts were listed in column one without regard to the probability of occurrence. The expected failure cause was listed in column two, and some tests which might reveal this failure prior to its occurrence were listed in column three.

MIL-STD-1629 requires that a level-of-severity estimate be classified from level one to level four as minor, major, critical or catastrophic. These vary from no effect on the ship's mission capability or functional output to the other extreme of severe reduction in ship's mission capability or functional output of the item. These level-of-severity estimates are shown in column four.

The standard also requires failure-probability index numbers by qualitative or quantitative classifications with levels from one to four, again increasing in severity from failure-mode probabilities of very low to very high (in the case of qualitative estimates).

Qualitatively, level 1 is described as a negligible chance of occurrence, level 2 as an unlikely chance of occurrence, level 3 as a 50/50 chance, and level 4 as a likely chance of occurrence during the time-operating interval.

In the case of quantitative estimates the probability index is related to the percentage of total failures of a part (such as a ceramic ring) or operation (such as soldered joints) being evaluated, relative to the total number of failures for the composite unit. This ratio will be termed a single-failure-mode probability. The relationship between probability index and single-mode probability is as follows:

Table 4-2. Functional Description for TR-316 Components

Index	Nomenclature	Function
	SONAR PROJECTOR TR-316	An electroacoustic transducer projector element consisting of three acoustic sources: a wide down beam section, a narrow beam section, and a wide up beam section. Specific performance information can be found in "Critical Item Product Specification for Sonar Projector TR-316," Naval Sea Systems Command Code 63XT.
1	MACHINED HOUSING	Encloses, supports and protects the transducer components from the sea environment.
1-A	Formed Plate	Mount for providing seal and support for acoustic window and ice shield.
1-B	Channel	Encloses and supports transducer components.
1-C	Top Cap	Seals one end of channel.
1-D	Blank Weldment Plug	After machining becomes fill hole for transducer fluid.
1-E	Coil Housing Weldment/ Machined Casting	A sealed,air-filled compartment which protects inductors and transformers.

Table 4-3. Summary of Failure Mode and Effects Analysis for Sonar Projector TR-316

Index	Failure Mode Item (a) Failure/ Function Loss / Effect	Possible Failure Causes	Level of Severity: Test Suggestions	1-2-3-4	Probability of Failure	Remarks & Recommendations
	SONAR PROJECTOR TR-316					
	(a) Poorly fitting assemblies/may not meet performance specs/leaking (oil or water) may lead to shorting and/or collapse of acoustic window and unit failure. Poor fit may, in itself, affect performance.	(a) Tolerances too large on drawing Parts not manufactured to tolerances specified.	(a) None	4	2	This failure mode can be corrected by reducing tolerances and implementing a good quality-control program. See "Recommended Design Changes, item 5, figures 5, 6, 7 and 8".
	(b) Water permeation/ unit fails to isolate components from sea water/ changes resistivity of oil, may cause shorting of oil-protected units, humidity increase in coil housing may cause arc-over; in either case unit fails.	(b) Inherent whereever polymeric barriers are used.	(b) Operate in high temperature saltwater bath. This will increase equilibrium concentration and rate of diffusion. Hydrostatic pressure test.	4	2	Actual diffusion rates are slow and depend upon operating temperature, barrier material characteristics and how often transducer is operated (mixing of transducer fluid).

Probability Index	Single-Failure-Mode Probability piece-part failures / total failures
1	<.01
2	.01 to .10
3	.10 to .20
4	>.20

If, for example, 22% of the failures of a transducer were due to ceramic failures, this item's failure-mode probability would be .22. It would have a probability index of 4 since its failure-mode probability is greater than .20. These estimates are included in column five.

By itself the failure-probability index only indicates the one component in the composite unit which is most likely to fail. To completely assess reliability one would also have to have a measure of the number of units which fail over an operating-time interval (usually in number of failures per 1 million hours of testing).

The quantitative estimates of failure probability due to random failures of specific components can best be obtained by performing a reliability prediction of the device. Hazard rates are assigned to each component and by proper consideration of redundancy a composite hazard rate is derived for the unit. Column six contains a summary statement of recommendations concerning a given possible failure mode.

Finally, the major problem areas were summarized for easy review in a separate table. This summary of major component and failure mechanisms is included in its entirety as table 4-4.

Other items of interest in the FMEA report were drawings which illustrated potential failure points. These are included as figures 4-1, 4-2, and 4-3. GD/EB stated that the most obvious failure site in the TR-316 was along the gasket seal between the formed plate and acoustic window. This was due to excessive compression set of the rubber, poor dimensional control of the rubber and compression stop washer, scratches in the flange face, dirt, etc.

Table 4-4. Major Components and Potential Failure Mechanism

Components	Failures	Failure Cause	Effects On System	Probability Of Failure	Accelerated Test
1. Machined Housing	Water intrusion	Improper welding; breakdown of seals	Could be catastropic over a long period of time	Low	Vibration Pressure and temperature cycling of structure in sea water
2. Wire Assemblies	Shorting, breakage, overheating	Poor manufacturing; intrusion of water	Could be catastropic over a long period of time	Low	Vibration Pressure and temperature cycling of structure in sea water
3. Pressure Release Pad	Bond failure Breakage of Sonite	Poor bonding techniques; rough handling	Reduction in performance of transducer	Mod	Vibration Pressure and temperature cycling of transducer
4. Resonator Arrays	Breakdown of ceramic assembly	Breakage and shorting of wires; poor assembly techniques; aging of ceramic	Loss in performance of array	Low	Vibration Pressure and temperature cycling of transducer
5. Molded Clamp Ring	Water intrusion	Loss in seal between ring and diaphram; porosity of diaphram	Catastropic	Mod	Pressure and temperature cycling of transducer

Table 4-4. Major Components and Potential Failure Mechanism (Cont.)

Components	Failures	Failure Cause	Effects On System	Probability Of Failure	Accelerated Test
6. Connectors, Receptacles	Water intrusion	Loss of seal weld between receptacle and transducer cover; poor weld techniques	Catastropic	Low	Pressure cycling of transducer
7. Connector Plug	Water intrusion	Loss of bond between molded boot and plug	Catastropic	Mod	Pressure and temperature cycling of transducer
	Water intrusion	Loss of seal between plug and receptacle; seal surface damage	Catastrophic	Low	None
8. Transformers, Inductors	Water intrusion	Loss of seal	Catastropic	Low	Pressure and temperature cycling of transducers

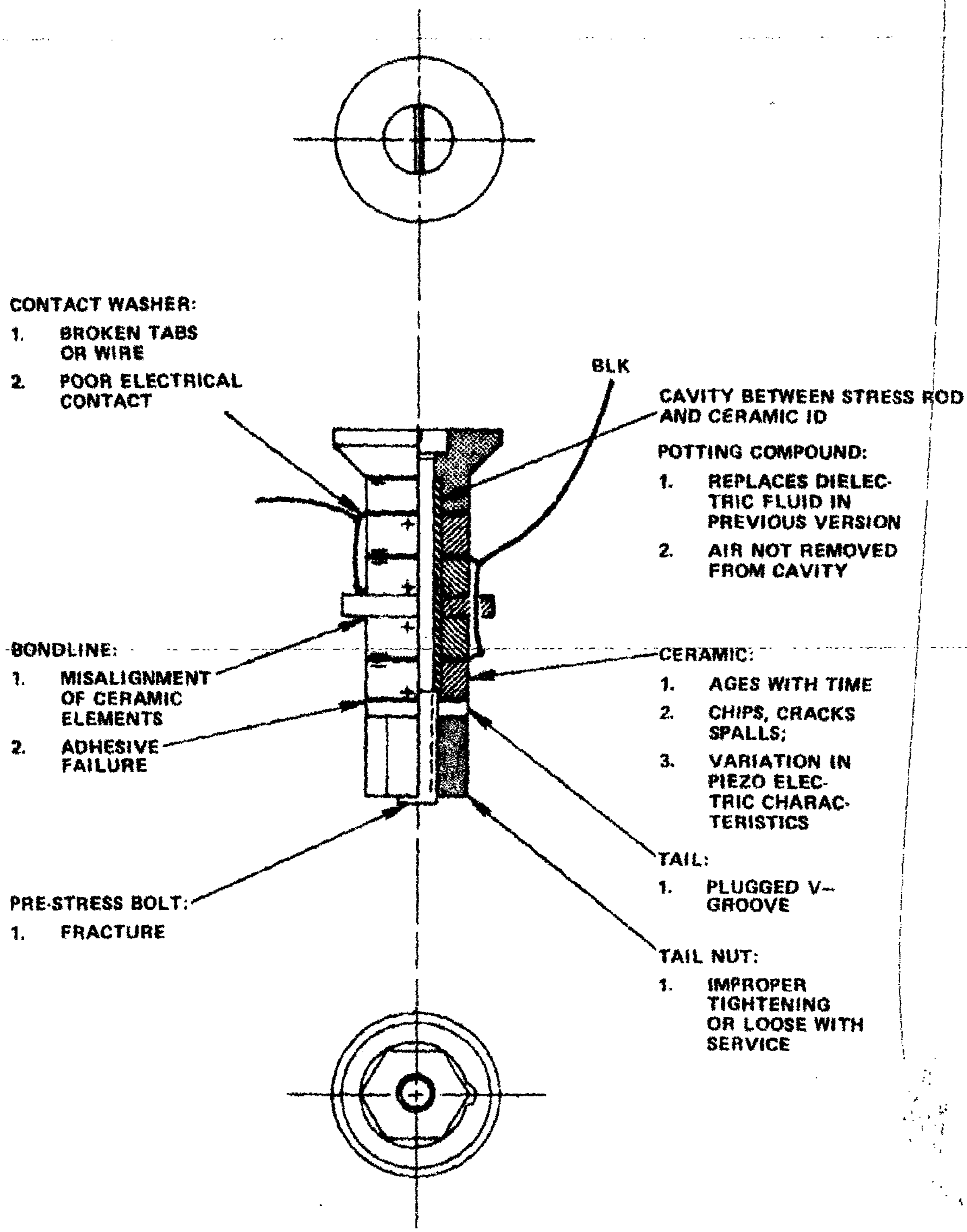


Figure 4-1. Resonator-Array Failure Sites

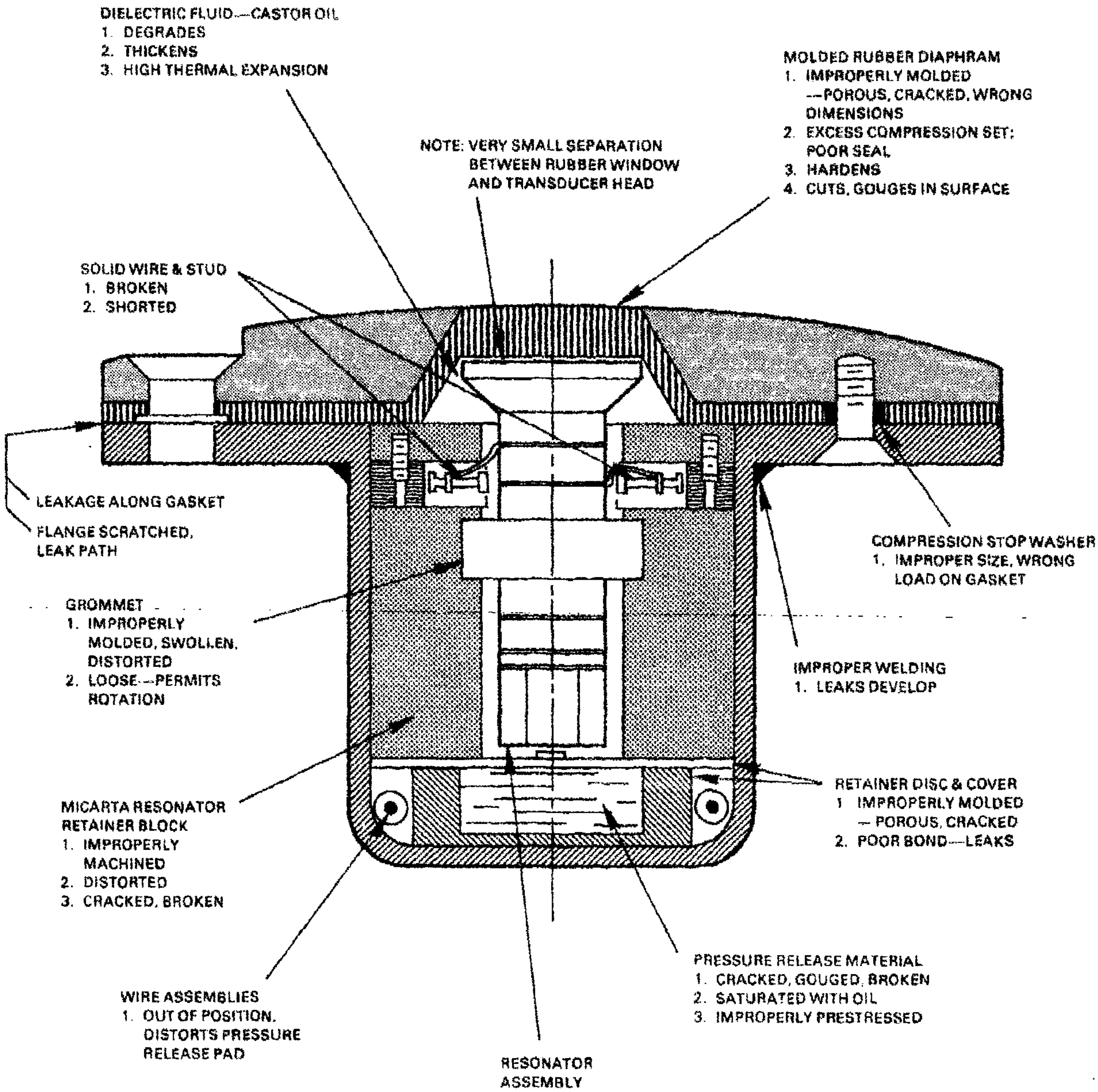


Figure 4-2. Cross Section of Transducer Failure Sites

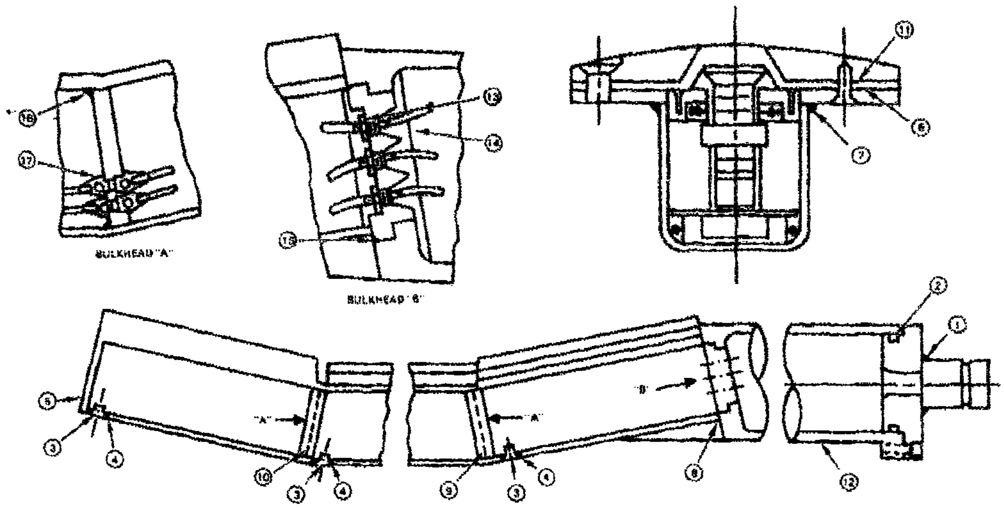


Figure 4-3. Failure Sites in TR-316 Transducer Envelope

1.	Weld	Receptacle to transducer cover.
2.	O-Ring Seal	Transducer cover to housing.
3.	O-Ring Seal	Oil fill hole screw.
4.	Weld	Oil fill hole boss.
5.	Weld	Housing end piece.
6.	Flat Gasket Seal	Rubber window.
7.	Weld	Housing to housing flange.
8.	Weld	Cylindrical housing casting to housing.
9.	Weld	Housing to housing.
10.	Weld	Housing to housing.
11.	Bond	Clamping to rubber windows.
12.	Casting	Cylindrical housing.
13.	O-Ring	Hermetically sealed header to bulkhead.
14.	Connector	Hermetically sealed contact.
15.	Weld	Bulkhead to housing.
16.	Bonded Rubber Seal	Bulkhead to housing.
17.	Potted Seal	Conductor to bulkhead.

A significant change proposed by NOSC personnel was the use of a metal spacer to limit the compression on the rubber gasket (see figure 4.2). This gasket, already properly tightened during assembly of the transducer, would be distorted during tightening of the bolts attaching the transducer to the ship. An extensive list of potential failures was included, one item of which was the susceptibility of the pressure release pad due to possible improper bonding. This later was verified to be a failure on one of the transducers tested.

Electric Boat proposed testing for vibration to simulate shipboard vibrations, temperature cycling, especially for the polymeric materials, a shock test to simulate the unit being hit by floating debris or ice, hydrostatic pressure tests, and electrical tests. A series of tests and their sequence was proposed along with suggestions for "basis" and "post" test examinations. This set of recommendations was considered by TRI and NOSC in formulating an improved CUALT plan.

Finally, the document recommended a series of design changes, some of which have already been implemented by Ametek/Straza.

4.2 DT-605 IFMEA

The DT-605 IFMEA is essentially the same as that for the TR-316 except that some of the tables were organized along the functional lines of protection function, performance function, and positioning function (identified by 100-, 200-, and 300-series numbers) (see figure 4-4). Table 4-5 is the indenture listing with a functional description of the hydrophone components. Table 4-6 is the detailed failure mode and effects analysis, as was done for the TR-316. Severity levels were assigned from levels 1 to 4, varying from minor to catastrophic as explained previously.

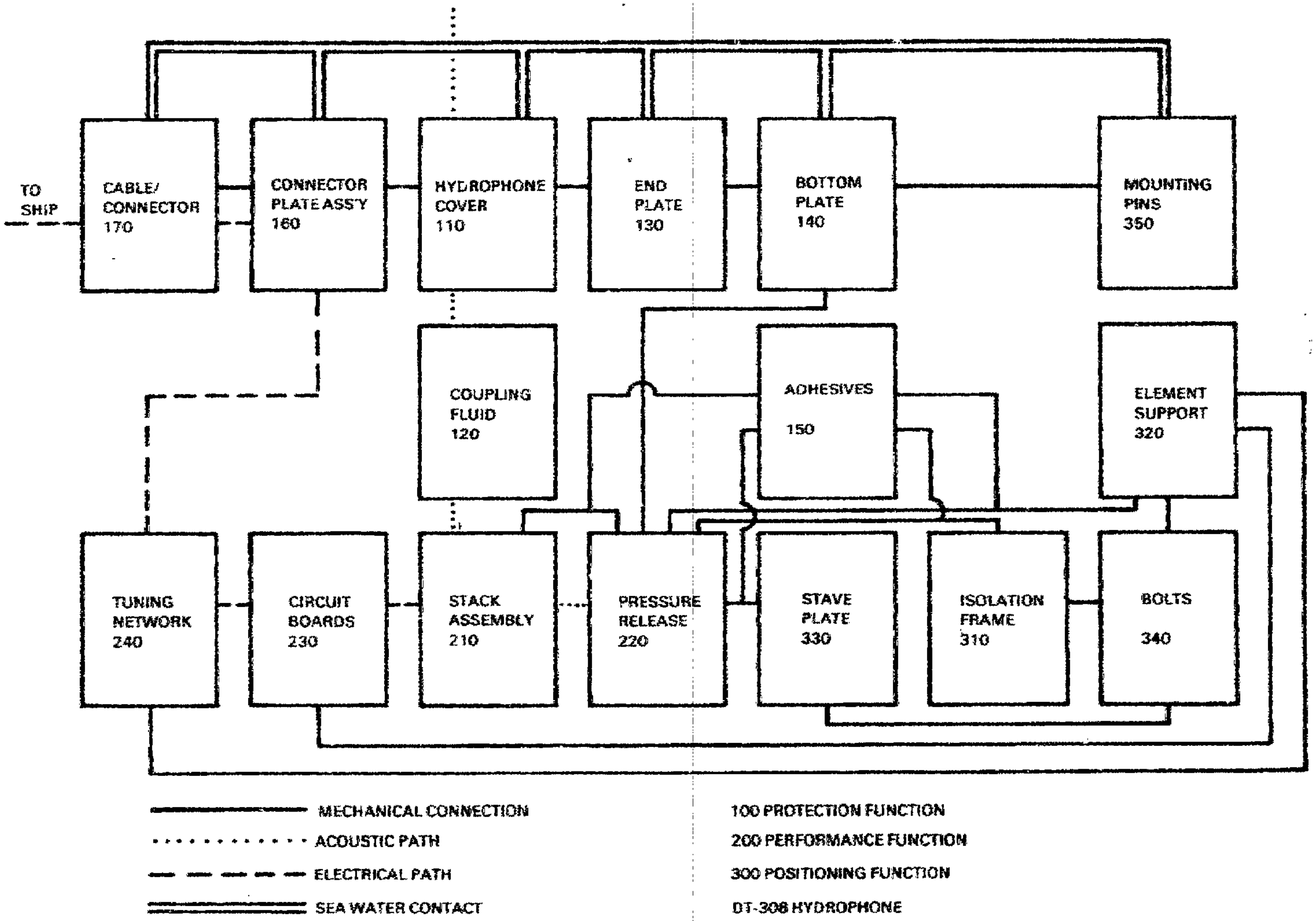


Figure 4-4. Third-Indenture-Level Functional Block Diagram

Table 4-5. Functional-Description Indenture Listing for DT-605 Hydrophone

Index	Nomenclature	Description	Drawing	Item Drawing Number
100	PROTECTION FUNCTION	All components that secure and protect the operating components from the environment		
110	Hydrophone Cover	Provides a seawater barrier while permitting acoustic transfer into the unit	120164	540263
120	Electrical Oil Coupling Fluid	Insulates exposed wiring, provides for acoustic transfer between cover and stack assemblies, and provides pressure compensation	120164	260771
130	End Plate	Seals one end of frame assembly and provides fill hole for coupling fluid	200925	
140	Bottom Plate	Backbone to which every component is attached	200925	
150	Adhesives Potting Compound	Attach and secure various components		

Table 4-6. Failure Mode and Effects Analysis for DT-605 Hydrophone

1st INDENTURE LEVEL

System/Component Identification	Failure Mode	Possible Causes	Effect	S	P	Remarks Recommendations
#000 DT-605 HYDROPHONE	Fails to operate completely or partially	Incomplete assembly Shorting Open circuit Faulty or damaged stack element Air in transducer Shock Vibration Careless assembly				
	Operates improperly					
	Beam pattern misdirected	Misaligned mounting pins	May promote misinterpretation of data	2	1	
	Low sensitivity	Fouled frame assembly Corroded frame assembly Improper prestress Defective ceramics Poor solder joints (weak contacts) Increased impedance	May promote misinterpretation of data	2	2	

S = Severity
1 = Lowest

P = Probability
4 = Highest

4.3 Cable and Connector FMEA's

The cable and connector FMEA prepared by General Dynamics/Electric Boat* follows the approach used in the TR-316 transducer FMEA, i.e., a listing of parts and their function/purpose followed by consideration of indirectly or inherently caused failures and an action/risk analysis (see tables 4-1 through 4-3 as typical of the data presented).

The transducer connector and the hull connector are presented as figures 4-5 and 4-6. The GD/EB recommendations for change were:

Immediate

1. Revise the cable/plug assembly to increase the cable-length tolerance from six inches to one foot.

2. Mold the plug assemblies at each end of the cable with MIL-M-24041 polyurethane instead of neoprene rubber.

3. Show plug protective caps on the cable/plug assemblies drawing.

4. Revise the cable/plug assembly drawing to list all quality-conformance tests and packaging and shipping instructions to be conducted on the cable assembly.

5. Provide a note on the cable/plug assembly drawing which identifies the fabricator's U.S. Navy-approved plug wiring and molding procedures. These procedures should also include a manufacturer's check-off list.

*R.F. Haworth, Electrical Cable and Connector Design for the Ametek Straza TR 215 (now called the TR-316) Sonar Projector, Dec. 1978.

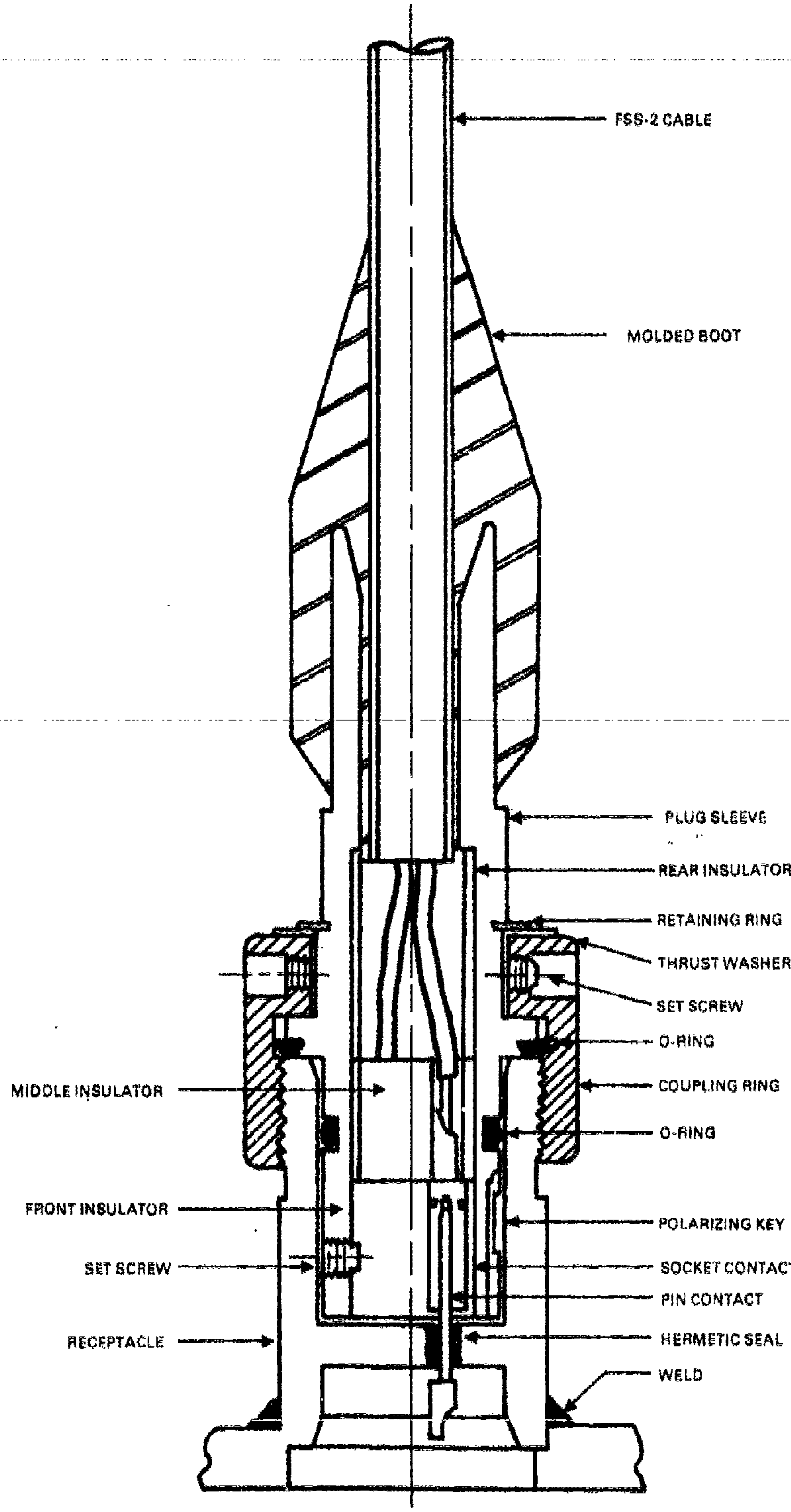


Figure 4-5. BUSHIPS DWG 815-1197170 Hermetically Sealed Connector

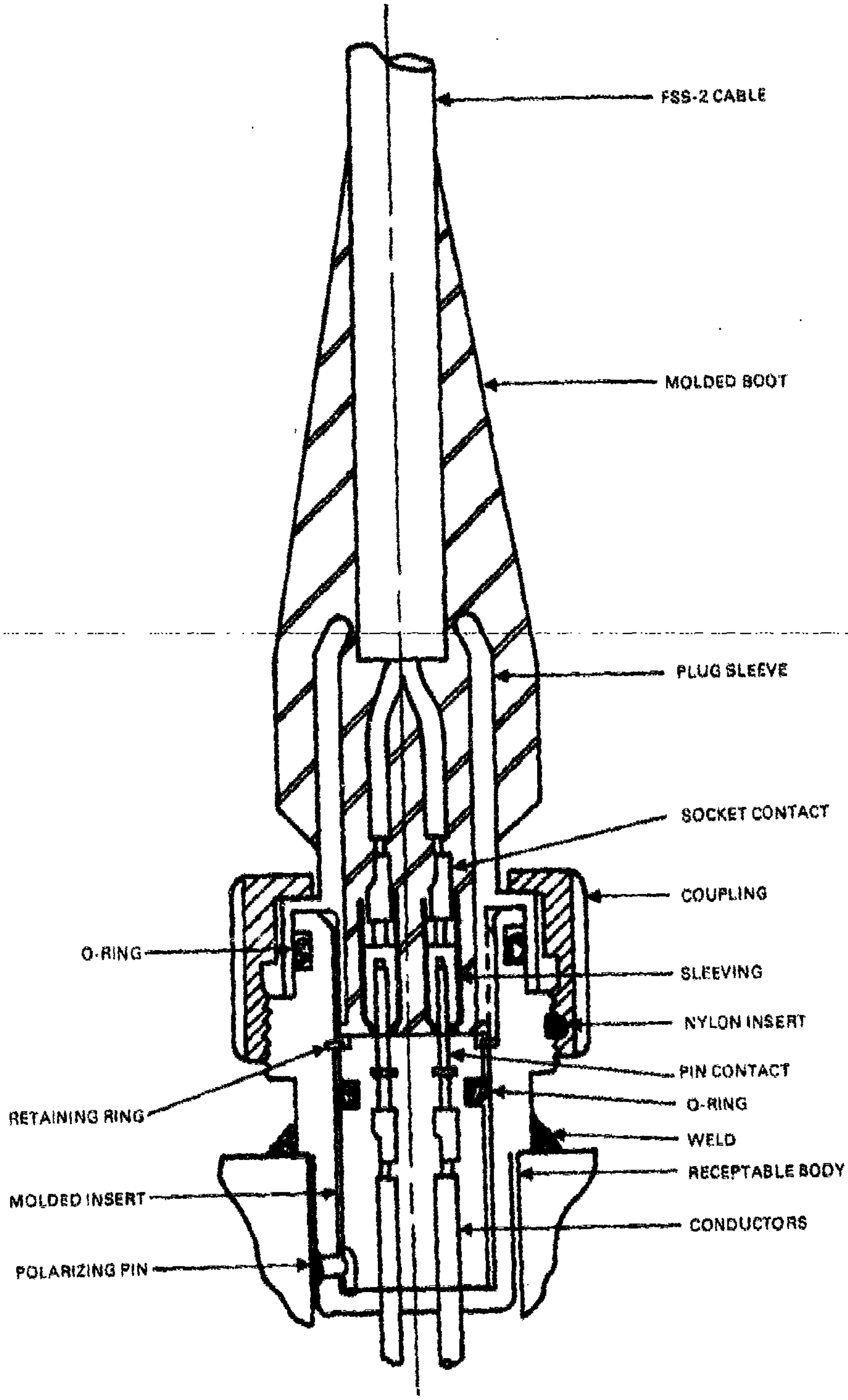


Figure 4-6. MIL-C-24231 Plug and Connector

6. Add a note to require the manufacturer's identification and serial number on each cable assembly.

7. Should the plugs be molded with neoprene, revise and update the BUSHIPS Drawing 815-1197170 wiring and molding procedures. A substitution must be made for the KNR neoprene polymer, which is no longer available from DuPont.

8. In shipping, package the cable/plug assembly separate from the transducer assembly. The two plug assemblies and transducer receptacle should be fitted with protective caps.

9. Delete the use of the coupling-ring set screws on the Drawing 815-1197170 plug assembly.

Long Range - (Next Procurement)

1. Delete the requirement for the use of BUSHIPS Drawing 815-1197170 connectors. These connectors have been replaced by a new naval design. As these transducers are primarily for submarine applications, MIL-C-24231 connectors should be used, as most of the pressure-proof connectors used topside on submarines are of this type.

2. Specify connector/cable wiring and molding procedures in accordance with the latest revision of reference 20 of reference 4 for assembling the MIL-C-24231 plug assemblies.

3. Replace the MIL-C-915 FSS-2 type cable with a new unshielded design.

4. Remove the procurement of cable/plug assemblies from the transducer specification. The pressure-proof connector at the transducer provides a natural interface. As the shipyard normally wires and molds a plug to the cable assembly just prior to installation, it would appear preferable to have them do the complete assembly at one time. Cost savings could then result from reduced needs for handling, shipping-testing and additional vendor middlemen.

5. Add a secondary plug-to-receptacle gasket to the MIL-C-24231 plug design.

6. Require that the MIL-C-24231 plug insert be bonded to the socket contacts.

It was noted that of all the problem areas listed in reference 4, the loss of bond of the molded boot to the plug shell was the most probable cause of connector failure.

The DT-308 connectors presented in the GD/EB FMEA report[5] are the same used for the TR-316. Therefore, the analysis was not repeated; however, differences were addressed and separate recommendations included. The differences in the assemblies are due to the cables (FSS-2 for TR-316 and 2SWF-4 for DT-308).

For the SQS-56 cable and connector, the FMEA report[6] presented a complete analysis like that for the TR-316 transducer. All the above cable and connector work should be followed up in FY 80 with ALT. Testing could possibly be accomplished in conjunction with the corresponding transducer tests.

[5] R. F. Haworth, Electrical Cable and Connector Design for the Hazeltine Corporation DT 308 ( ) (now called DT-605) Hydrophone, Dec. 1978.

[6] R. F. Haworth, Design Analysis of the Pressure-Proof Connector for the AN/SQS-56 Transducer, Dec. 1978.

SECTION 5

5.0 CUALT Plan Development and Technical Defense

The transducer reliability program has as a prime objective the development of ALT methods which would simulate via laboratory conditions a series of exposures which approximate those which the transducers will see under operational conditions. The implication is obviously that the units being tested will be artificially aged or the environmental exposures otherwise compressed in time so that the evaluation of the laboratory units can be accomplished in a reasonable time period. Thus, the results of CUALT are intended to impact the production or design of the transducers.

5.1 Failure Classification

In order to assess failures resulting from accelerated life testing it is convenient to classify failures according to:

1. Congenital defects which lead to infant mortality,
2. Failures due to random events or random defects,
3. Failures due to wearout, and
4. Failures due to abuse.

A convenient way to convey the concept of the different classifications of failure is through an idealized description of the distributions of stress and strength of the various components. For the purpose of this idealization the strength and stress distributions can be taken as a composite of all electrical, chemical, and mechanical strengths and stresses of all the components and subassemblies that make up the total population of a particular transducer series. If, for example, the strength distribution was centered about 3,000 psi and stress about 1,000 psi, the conventionally calculated safety factor would be 3. Despite this apparently comfortable margin, the safety factor is in actuality a random variable and there is still a small probability of failure proportional to the area under the two distribution curves (see the shaded area of figure 5-1). Random failures are the inevitable result of this overlap of stress and strength distributions. Failures grouped into the congenital classification result when the strength distribution is skewed to the left as a consequence of underdesign of one or more components or by lax quality control, which permits defective components to be assembled in the unit. This situation leads to a large number of early failures and a failure rate that decreases with time as the defective units are removed from the population. Wearout failures occur when the strength distribution shifts to the left as a function of time and results in an increasing failure rate (see figure 5-2). Failures due to abuse can result when a stress which is considered outside the mission profile is applied.

5.2 Test-Exposure Limits

An accelerated life test will include periods of time at elevated environmental stresses as described in detail later. In order to assure that the result is a measurement related to service life and not a form of abuse due to excess stress, some limits must be established for those stresses. Limits are extracted from the Critical Item Product Specification (CIPS) and from the mission profile.

5.2.1 Mission Profile

A mission profile is a summary of the environmental exposures an item may be expected to encounter. For any particular environmental stress the mission profile will list the range of exposure (-30° to +70°C), the duration or number of cycles of the extremes (70°C for 4 hours per day or 1460 hours per year), the duration or number of cycles of typically expected exposures (-10° to 22°C for 24 hours per day or 8760 hours per year), and the companion exposures (simultaneous exposure to humidity). This document is prepared from ship steaming data and dry dock schedules as well as discussions with personnel familiar with the item and the missions it experiences.

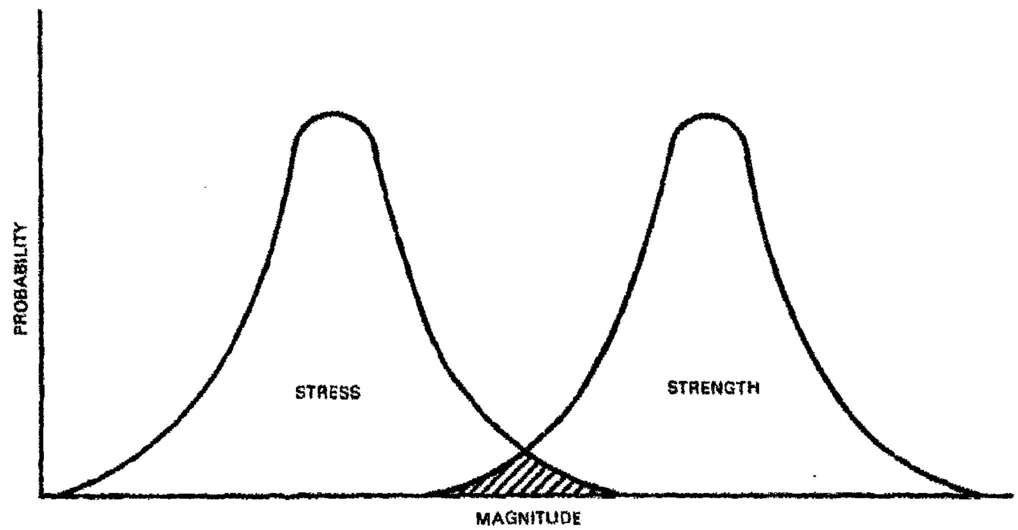


Figure 5-1. Strength and Stress Distributions

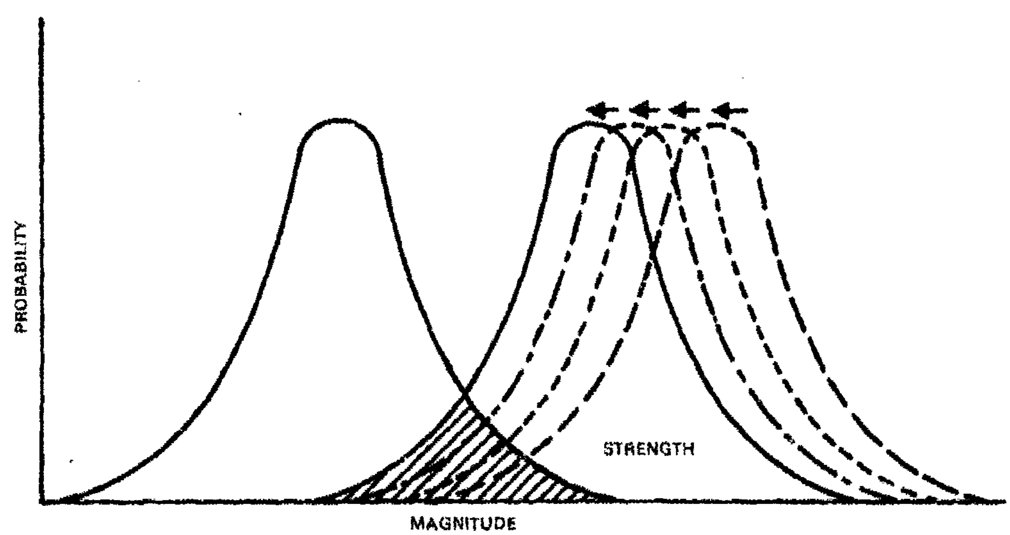


Figure 5-2. Strength and Stress Distributions After Time

5.2.2 Critical Item Product Specification

The CIPS includes the ranges of environmental stresses which the item must tolerate to be acceptable for Navy use and may therefore include safety factors. As discussed in the guidelines below, ALT stresses should not be called for which are outside those ranges, including temperature, humidity, pressure, shock, vibration, etc.

5.3 Time-Compression-Techniques Development Considerations

5.3.1 Processes Used in Time Compression

Various aging processes (also called rate processes) result in rearrangement of atoms and molecules, which can decrease or improve material strength. Sometimes aging increases strength, as in the case of precipitation hardening of aluminum alloys. Sometimes the application of stress helps the strengthening process during aging, such as the strain aging of carbon steels. However, aging, with or without the application of stress, often results in a time-dependent reduction and spreading of the strength distribution.

There are other processes which are not time-dependent (at least not to a first approximation), but that are frequency-dependent or stress-intensity-dependent and which can cause a rearrangement of atoms and molecules. The fatigue damage of metals when tested in an inert atmosphere at low temperature is an example of a frequency- and stress-intensity-dependent process. Stress intensity alone is sometimes the most important factor in causing a strength change, such as in the yielding of metals under tensile stress.

5.3.2 Techniques

Time-compression techniques have been developed to reduce the duration of exposures in the laboratory required to simulate predicted service exposures. The most common are accelerated aging, increased duty cycle or frequency, and increased stress.

5.3.2.1 Accelerated Aging

Accelerated aging is the acceleration of rate processes and can be accomplished by increasing the temperature. The transformation of a long-term service exposure to a short-term laboratory exposure can be calculated using the Arrhenius equation (see figure 5-3). The Arrhenius equation was first applied in 1889 to describe the temperature dependence of the rate of inversion of sucrose.[1] It is now generally accepted that this kind of relationship describes the temperature dependence of reaction rates of most chemical reactions and certain physical processes, such as viscous flow, diffusion, permeation, and ionic mobility in solution, and various electrochemical processes.[2] Underwriters Laboratories uses the Arrhenius approach in evaluating the uses of materials for elevated-temperature electrical applications and has published a specification describing one accceptable procedure.[3]

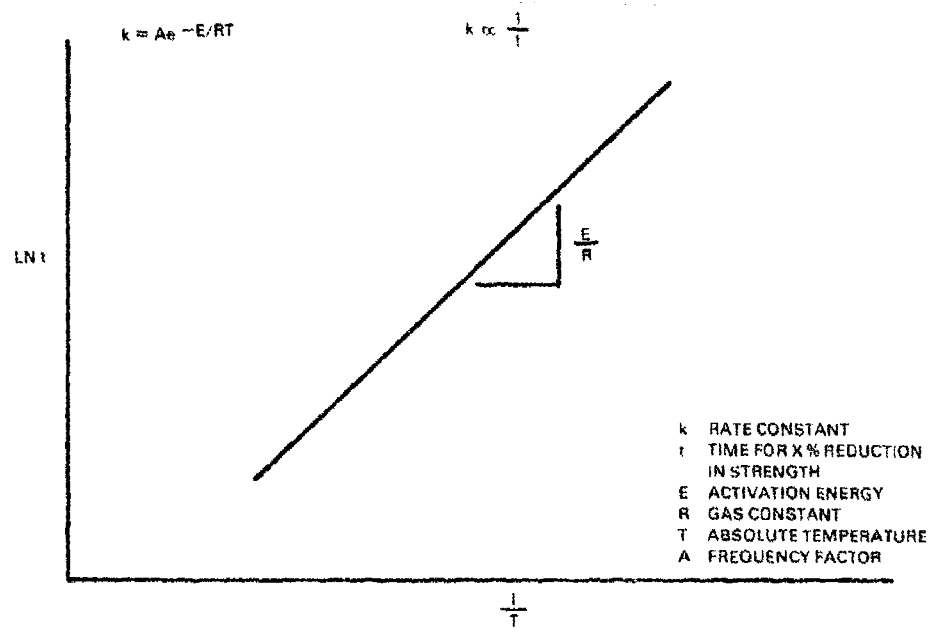


Figure 5-3. Arrhenius Equation

1. S. Arrhenius Z. Physik Chem, 4, 226 (1889)
2. S. Glasstone, K. J. Laidler, and H. Eyring, Theory of Rate Processes, McGraw Hill, 1941
3. UL746B, "Polymeric Materials-Long Term Property Evaluation" Underwriters Laboratories Inc., (1975)

The concept of activation energy which appears in the Arrhenius equation is illustrated in figures 5-4 and 5-5. Figure 5-4 depicts the activation energy for a physical process such as diffusion, where an atom or molecule has no net change in energy in changing positions along the reaction coordinate. As a simplified example of this concept, consider the diffusion of carbon in iron. In order to change its position from one site to another, the carbon must acquire the activation energy E in order to squeeze between the neighboring iron atoms. Figure 5-5 shows an activation energy for a process involving a chemical reaction such as oxidation of neoprene rubber, where the energy of the reacting species is lowered by the heat of reaction ΔH. Obviously the rate of reaction in the right-hand direction is much higher than the rate of reaction in the reverse direction because the energy required for the reverse reaction is E plus ΔH.

The activation energies for the various degradation processes differ for the different materials/components in a composite unit (see figure 5-6). When increasing the temperature to accelerate aging, some processes will be accelerated more than others. Thus, in addition to a shift in the mean of a strength distribution, we expect to see a widening of the strength distribution. An apparent problem is created because one year of accelerated aging on component X may represent several years of accelerated aging for component Y. This may be more of an academic than a practical problem, however. If the temperature limits described by the mission profile are not exceeded in the laboratory, then any resulting failures could justifiably be considered life-limiting. Furthermore, as wearout failures are experienced, a thorough analysis will reveal the mechanism, and an appropriate adjustment in the time scaling can be made.

5.3.2.2 Increased Duty Cycle

Increasing the duty cycle is another time-compression tool which can be used when interaction effects can be reasonably neglected. This simply amounts to taking the space out of the service environmental profile (see figure 5-7) and has the result of increasing the duty cycle of the stress. Space could be defined as that portion of time which does not contribute significantly to the deterioration of the sample. For example, the stress for a

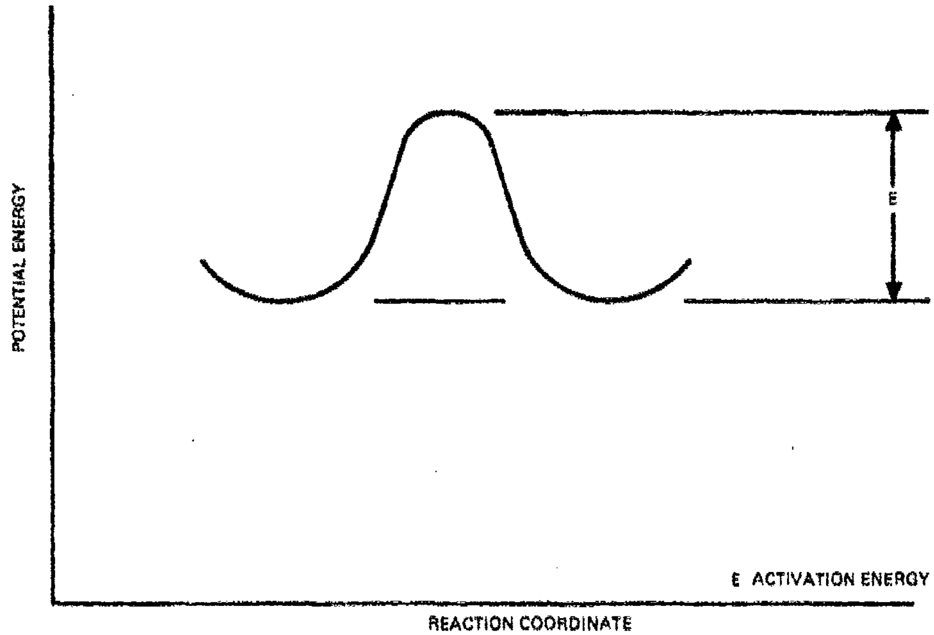


Figure 5-4. Activation Energy for Physical Processes

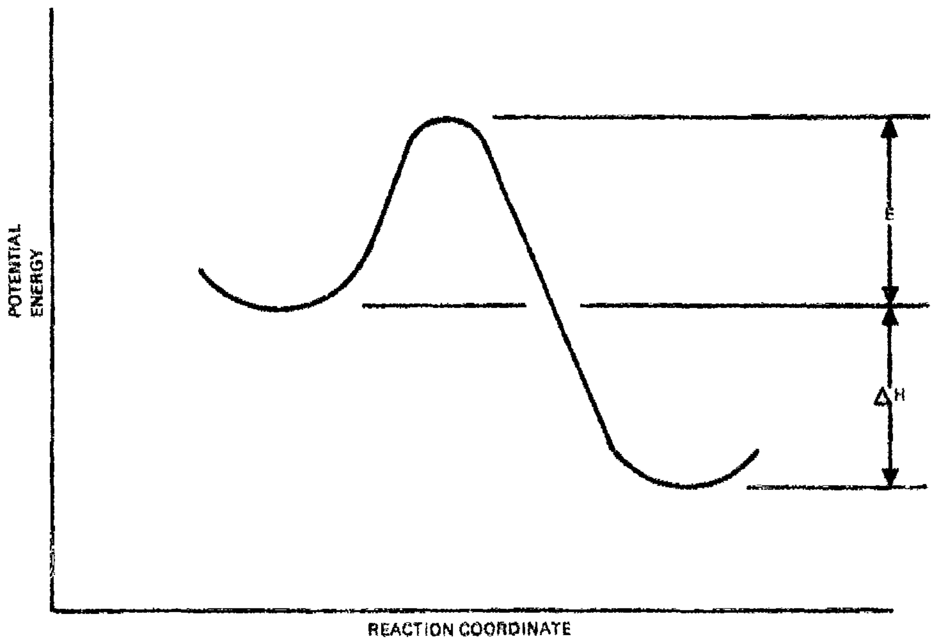


Figure 5-5. Activation Energy for Chemical Processes

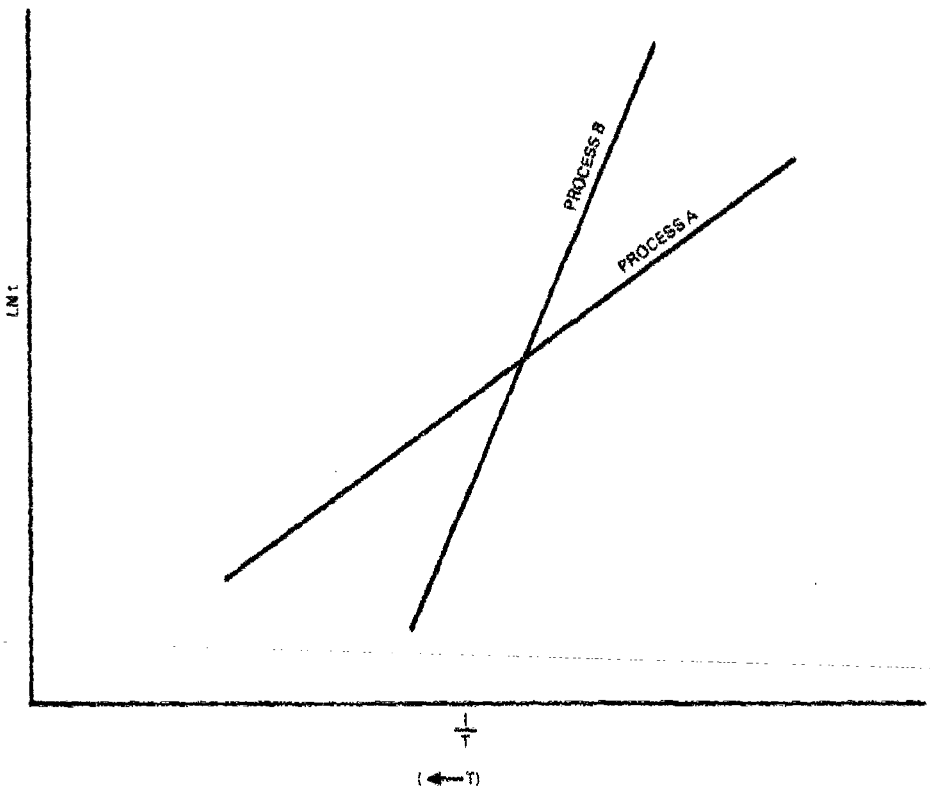


Figure 5-6. Effect of Temperature (T) on Time (t) for Process A and Process B

large portion of the operational time may be of a very low magnitude or the temperature may reside at favorable levels for long periods of time in between very high or very low temperatures. Increasing the frequency or duty cycle may not have a linear inverse relationship to time compression because of interaction effects that are not anticipated or unavoidable in practice. For example, operating a power device at high duty cycle may cause excess temperature in the device, which could result in a failure that otherwise would not occur. To minimize the incidence of bad calls, test units can be instrumented to detect interaction effects. Countermeasures, such as supplementary cooling for the example of the power device, can be employed, and a careful analysis of all failures can be used as a basis to determine the classification of the failure. Failures of abuse, of course, do not count.

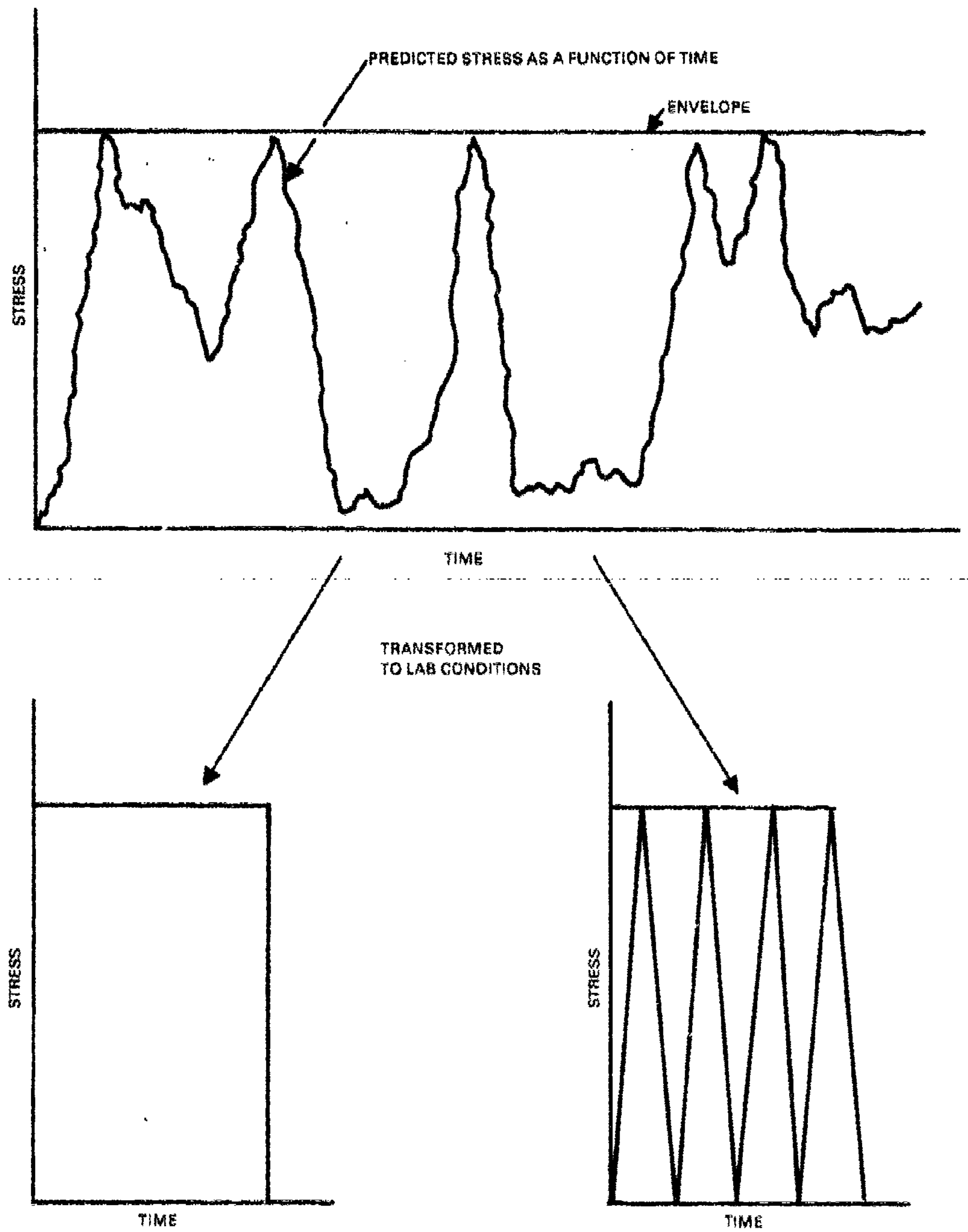


Figure 5-7. Mission Profile/Lab Exposure

5.3.2.3 Increased Stress

Increasing environmental stresses other than temperature can lead to accelerated aging by reducing the activation energy for rate processes, as in the ionic diffusion in an electric field. Also, increasing one type of stress can cause a decrease in resistance to other stresses, as in increasing the concentration of corrosive liquid to increase corrosion rate. In practice this is the most controversial of the tools available because of the difficulty in achieving a correlatable reduction in a strength distribution instead of a failure due to overstressing by itself. Keeping stresses within the bounds of the mission profile to the extent practical minimizes this problem.

5.3.2.4 Principle of Superposition

Often it is impractical to apply different types of laboratory exposures simultaneously. For example, exposure to salt water plus elevated temperature plus pressure cycling is not easy to obtain in a single environmental cell. In decomposing the mission profile into different laboratory exposures and applying them sequentially, we are tacitly relying on the principle of superposition, which does not always apply. To mitigate the complete absence of environmental interaction effects, we can design the sequence of exposures with attention to the types of degradation processes that are expected to occur. An example of this would be a water soak prior to low-temperature thermal-shock exposure in order to maximize the hazard to rubber components which absorb water. Also performing the laboratory exposures in one-year increments will recompose the exposures to some extent. However, the extent of recomposure is not known.

In general the approach in sequencing the exposures has been to apply the accelerated-aging stresses (temperature, humidity, etc.) in the early part of the sequence and the mechanical-duty stresses (pressure, thermal cycling, high drive) in the latter part of the sequence. This maximizes the hazard to materials which are susceptible to physio-chemical degradation processes.

5.3.2.5 Guidelines

One must exercise caution in effecting a time compression. Some good general rules to follow are: the closer laboratory conditions duplicate service conditions, the better the correlation between laboratory results and service experience; and the more one attempts to compress time with laboratory exposures, the less the laboratory results will correlate with service experience.

While problems exist with time-compression techniques, measures can be taken to retain the reasonability of this approach. The following is a list of the problems encountered with time compression:

1. Activation energies differ for different processes.

2. Increasing the duty cycle may have side effects.

3. Increasing stress may cause premature failure.

4. Principle of superposition may not apply.

The approaches to assure reasonability of time compression are:

1. Do not exceed temperature and stress limits of mission profile without caution.

2. Instrument the test unit to detect interaction effects within the unit with sensors such as thermocouples.

3. Sequence exposures to obtain reasonable environmental interaction.

4. Perform careful failure analysis to eliminate failure of abuse.

5.4 CUALT Plan Development

Based upon the above discussion of problems associated with accelerated life testing and given the desirability of a systematic approach, the following rationale is proposed for the CUALT program.

5.4.1 Analyze Mission Profile

The analysis of the mission profile will be accomplished by decomposing it into stress amplitudes, temperatures, times, and cycles.

5.4.2 Identify Critical Components/Materials and Failure Mechanisms

Identification of critical components and materials and failure mechanisms will be facilitated by a vulnerability analysis provided by the critical failure modes analysis, reliability prediction, classifications of failures, and identification of failure mechanisms.

5.4.3 Transform Service Exposures to Equivalent Laboratory Exposures

The service exposures will be transformed to laboratory exposures by means of time-compression techniques:

1. Calculate laboratory temperatures and times using the Arrhenius equation and activation energies appropriate for the expected degradation mechanisms.

2. Increase duty cycle or frequency for stress cycling.

3. Limit increase in stress to CIPS requirement.

4. Sequence exposures based on analysis.

It will be necessary to postulate activation energies from degradation mechanisms where these data are not available and to sequence exposures based on analysis. Therefore, in tailoring the laboratory exposures to service exposures, a fair degree of experience and judgment is required.

5.4.4 Tests and Instrumentation

The instrumentation and tests will be based on the resolution desired (for example, when did failure occur?) and will depend on the definition of failure adopted (for example, beam patterns or impedance levels specified).

5.5 First Iteration CUALT Plan

5.5.1 Preliminary Analysis

The first CUALT plan for the TR-316 was developed at a meeting between NOSC and TRI at San Diego in March, 1978. In preparation for the CUALT plan, a preliminary mission profile, an interim definition of failure and a CFMA were accomplished on a simplified version of the transducer. Since drawings of the transducer were not available at that early date, analysis of the complete transducer could not be made.

The mission profile for a one-year service period was taken to be:

1. Exposure to maximum solar intensity 1 1/2 hr/day for 9 months at dockside and exposure to moderate temperatures in service and dockside for the balance of the service year;

2. Salt spray and seawater exposure for the year;

3. A total of 400 dives to 600 psi with an accumulation of 16 hours at 600 psi; and

4. One Arctic mission including 3 exposures to -54°C (-65°F) ambient temperature at the surface and 2 weeks of continuous, high-power operation under ice.

The definition of failure was taken to be any performance deviation from the requirements of the CIPS. The advantage of this definition is that it is the basis of agreement between the transducer manufacturer and the Navy. However, it has the disadvantage of not being practical, since it cannot be easily applied in the field.

The CFMA yielded a number of expected degradation mechanisms. Those for which accelerated aging was the appropriate time-compression tool were:

1. Oxidation of the rubber window due to heat and air, which could lead to hardening, embrittlement and cracking;

2. Moisture permeation into rubber window, which would aggravate cracking upon exposure to low-temperature shock, and possible water ingression into transducer;

3. Fill-fluid permeation into the face rubber, the pressure release pad and the nodal ring grommet, causing softening, loss of soluble material from the rubber and possible contamination of the fill fluid;

4. Loss of adhesive bonds in the ceramic stacks and the pressure release pad due to permeation of fill fluid;

5. Aging of ceramics due to thermally activated, domain-boundary motion; and

6. Saltwater corrosion at fill-fluid fill ports.

Exposure to pressure, pressure cycling and thermal shock were expected to lead to mechanical-degradation mechanisms which could be compressed in time by duty-cycle increase. The mechanical effects considered were:

1. Low-cycle fatigue of components due to differential thermal expansion;

2. Failure of seals and bonds previously weakened by accelerated aging;

3. Cracking of ceramics by thermal shock and uneven internal pressure distribution; and

4. Cracking of welds due to thermal shock and pressure cycling.

The high-power-drive exposure was considered to be amenable to time compression via stress increase. The idea was to run the transducer at low frequency, which requires maximum input power, instead of scanning the frequency range, which is the normal mode of operation. The primary effect expected was fatigue of the stress rod.

5.5.2 TR-316 CUALT Plan and Rationale

Table 5-1 shows the CUALT as planned on the transducers and section 6 discusses the CUALT as actually performed on the transducers. The specific tests and exposures that were planned for, their underlying rationales, and the results of the first year of compressed time are presented in the following paragraphs.

Table 5-1. Accelerated Life Test Performed on TR-316 Prototype Units

Exposure	Time(cycles)	Purpose	Time Compression	Equivalent Service
Dry Heat 81°C	119 hrs	Accelerate rubber degradation, reaction between fill fluid and components, mechanical stress on boot due to expansion; simulate dockside storage.	Accelerated Aging	5438 hrs at 20°C(E=13,000)
	TEST:	RUBBER EXPANSION, DUROMETER		
Dry Heat 75.5°C with UV Irradiation	478 hrs	Accelerate rubber degradation, reaction between fill fluid and components, mechanical stress on boot due to expansion, degradation of rubber; simulate dockside storage.	Accelerated Aging Duty-Cycle Increase (UV)	16,395 hrs at 20°C (E=13,000) 1-2 hrs per day in sunlight for 9 mo.
	TEST:	BEAM PATTERNS, TVR, RUBBER EXPANSION, DUROMETER		
Salt Water 60°C	8 hrs	Corrosion of seal plug, case, screws; water permeation; simulate wet operations.	Accelerated Aging	115 hrs at 20°C (E=13,000) 3750 hrs at 20°C (E=30,000)
Pressure Cycling	400 cycles	Mechanical stress, water intrusion, water permeation; simulate diving conditions.	Duty-Cycle Increase	1-2 years of diving
Pressure Dwell 600	16 hrs	Mechanical stress, water intrusion, water permeation; simulate diving conditions.	Duty-Cycle Increase	16 hrs at pressure
Thermal Shock	3 cycles	Mechanical stress due to contraction; elastomer and adhesive integrity; water intrusion; simulate Arctic conditions.	Duty-Cycle Increase	One Arctic mission
	TEST:	BEAM PATTERNS, TVR, RUBBER EXPANSION, DUROMETER		
High-Power Drive	168 hrs	Simulate continuous operation.	Duty-Cycle Increase, Stress Increase, (low freq.)	One Arctic mission
	TEST:	BEAM PATTERNS,TVR, ACOUSTIC PROBE		

NOTE: VISUAL OBSERVATIONS AFTER EACH EXPOSURE, UNITS DISASSEMBLED AND REPAIRED BEFORE HIGH-POWER DRIVE, UNITS DISASSEMBLED AFTER HIGH-POWER DRIVE.

5.5.2.1 Stress Exposure 1 (SE1) - Dry Heat: 81°C for 119 Hours

The intent of the first stress exposure was to accelerate the aging of internal components/materials in contact with the fill fluid. The permeation of the elastomers, plastics and adhesives by castor oil (fill fluid) was considered to be the rate-controlling mechanism. Based on an activation energy of 13,000 calories/mole, the 119 hour exposure at 81°C corresponds to 9400 hours of combined service and dockside exposure at 13°C (55°F). The balance of the compressed year (450 hrs) is discussed in the next section. Other effects expected from this exposure included oxidation of the face rubber and connector seals, which would be manifested as a hardness (durometer) increase, and stressing of the face rubber and seal due to expansion of the castor oil (fill fluid). Thus rubber expansion and hardness were to be monitored. The selection of 81°C for this exposure was made to obtain fast results. Since 71°C is the CIPS limit, future ALT planners should carefully consider this limit.

5.5.2.2 Stress Exposure 2 (SE2) - Dry Heat plus UV Light: 75.5°C for 450 Hours

It was estimated that an extreme service condition could result during a nine-month dockside period in an equatorial location. The face rubber could be exposed to intense midday sunlight, achieving a surface temperature of 75.5°C (160°F) for 1-2 hours per day for 300 days. Since simultaneous heat and UV exposure is deleterious to rubber properties and because the mechanism is complex, it was decided to increase the duty cycle of the exposure but not to attempt to accelerate the aging that would take place. An exposure was to be devised to apply the equivalent UV intensity as found in natural sunlight for the total time of 450 hours. The expected mechanisms operating during the rubber degradation were oxidation, bond cleavage and further crosslinking, resulting in a hardening and embrittlement of the rubber. It was planned to do acoustic measurements as well as rubber expansion and durometer measurements after this exposure.

5.5.2.3 Stress Exposure 3 (SE3) - Seawater Soak: 60°C for 8 Hours

A hot seawater soak was specified to simulate the corrosive effect of a one-year service exposure to salt spray and sea water. Using the Arrhenius equation and an activation energy of 30,000 calories/mole, an average service temperature of 15°C (60°F) for one year is equivalent to 60°C (140°F) for 8 hours. As indicated earlier, subsequent analysis revealed that the water permeation of the rubber window occurs with a lower activation energy than that assumed for corrosion. Therefore a seawater soak for 8 hours at 60°C does not result in an appreciable amount of moisture in the rubber. Also, since the resistance of hull-grounded 316L stainless steel to seawater corrosion is well established, this exposure was dropped in favor of a longer soak in fresh water. Visual inspection only of the transducer was to be made after this exposure.

5.5.2.4 Stress Exposure 4 (SE4) - Water Pressure: 9-600 psi

A total of 400 pressure cycles between 9 and 600 psi with an intermediate dwell of 16 hours at 600 psi was specified for this exposure sequence. The time compression was achieved by increasing the duty cycle. Any internal components weakened in mechanical strength by previous exposures might be expected to break after pressure testing or the low-temperature thermal-shock exposure to follow. Thus, other than visual observation, no tests were specified.

5.5.2.5 Stress Exposure 5 (SE5) - Low-Temperature Thermal Shock: -54°C to 0°C

The three cycles of thermal shock were expected to occur in an Arctic mission. Again this exposure was mechanical and time compression was achieved by performing it in test chambers as rapidly as possible. Stressing of components previously exposed to temperature and water was achieved. Weakening of the face rubber by the freezing (and expansion) of permeated water was one concern. The tests called for after this exposure were acoustic (beam patterns and transmit voltage response) and mechanical (rubber expansion and durometer).

5.5.2.6 Stress Exposure 6 (SE6) - High-Power Drive

One week of high-power, continuous operation at one frequency at the low end of the band was considered to be equivalent to several weeks of operation under ice while scanning over the frequency range. The transducer operates at a higher power level when driven at that single frequency and this therefore represents a stress-increase time compression. This exposure is within the CIPS requirement envelope. Since temperatures will change during high-power operation of the transducer, this exposure is physio-chemical as well as mechanical and electrical in nature. The measurements planned were to monitor voltage and current during the exposure and to repeat the acoustic tests at the completion of the exposure.

5.5.3 DT-605 CUALT Exposure Plan

Any CUALT plan for the DT-605 will be essentially identical to that for the TR-316 with the following exceptions:

1. UV exposure will not affect the unit because the DT-605 does not have a rubber window and the unit is behind a dome;

2. Impact/penetration is unnecessary because the unit is behind a dome which shields it from ice; and

3. High electrical drive is inappropriate for a hydrophone.

5.5.4 Time-Compression Objective

The minimum laboratory time required to accomplish the first iteration CUALT for each compressed year of simulated service is about 9 weeks of normal 5-day operation of a laboratory. Obviously some of the exposures and tests can take place on a 24-hour-a-day basis, but others must be attended, and therefore cannot. The time breakdown is as follows:

Item	Elapsed Time: Exposure	Test and Evaluation	Idle (weekends)
Initial Evaluation		5 days	
Dry heat (SE1)	5 days		2 days
Evaluation		1 day	2 days
UV and heat (SE2)	20 days		
Evaluation		2 days	2 days
Saltwater (SE3)	1 day		
Evaluation		1/2 day	
Pressure (SE4)	2 days		
Evaluation		1/2 day	2 days
Thermal Shock (SE5)	2 days		
Evaluation		3 days	
Power Drive (SE6)	7 days		2 days
Evaluation		5 days	
	37 days	17 days	10 days

Time-compression factor for exposure 365 ÷ 37 = 10X

Time-compression factor overall 365 ÷ 64 = 5.7X

SECTION 6

6.0 CUALT First-Year-Equivalent Implementation

6.1 CUALT of Prototype TR-316 Projectors

The CUALT plan calls for application of a simulated seven-year-equivalent of operational stress exposure conditions. Success of CUALT in discovering problems and potential problems slowed the testing in FY 79 and thus only the first-year-equivalent testing was completed. These results for the TR-316's are described in this section.

Four prototype TR-316 projectors (not first article transducers) of a new design manufactured by Ametek/Straza were used in the initial development of the IFMEA and CUALT. The four projectors are designated T1, T2, T3 and T4 (standing for transducers 1 through 4, respectively). Each projector has three sections (PD down, narrow beam, and PD up) as shown in figures 3-2 and 3-3. The projector is mounted vertically on the submarine with the connector receptacle pointing down. For brevity (e.g., in the case of T1) the PD down section will be designated T1D, the narrow beam section T1N, and the PD up section T1U. Similar designators are used for T2, T3 and T4. Only T2, T3, and T4 were subjected to the accelerated life tests. T1 was retained as a control.

Table 6-1 presents the six stress exposures which were used in the initial CUALT to approximate one-year-equivalent of storage and operational conditions to be experienced by the transducer. Heat, seawater immersion, pressure cycle, thermal shock, and high-power-drive conditions were imposed on the transducer as indicated in stress exposures 1 through 6 (SE1-SE6).

Table 6-1. Accelerated Life Test Performed on Straza Prototype TR-316 Projectors, Equivalent to 1 Year of Stress

Test Sequence	Test Duration in Hours Planned	Test Duration in Hours Actual	Stress	Rationale	Measurements	Unit Tested	Test Date
1	113	119	Dry heat at 81° C (178°F)	Accelerate rubber degradation, reaction w/fill fluid & components, mechanical stress due to expansion, simulate dockside storage	Rubber durometer before stress, monitored	T2 & T3	4-27-78 to 5-2-78
2	450	478 on T2 & T3 & 454 on T4	Dry heat w/ultraviolet (UV) exposure at 75.5°C (168°F)	Same as T.S.1 w/UV degradation of rubber based on 450 hrs/yr exposure	Monitored rubber expansions; rubber durometer, beam patterns & transmit response after stress	T2, T3 & T4	5-2-78 to 5-22-78
3	8	8	Immerse in sea water at 60°C (140°F)	Corrosion of seal plugs, case, screws	Observations	T2 & T3	6-6, 7-78
4	*	*	Pressure cycle 9-600 psig at rate of 1.5 min/cycle for 400 cycles plus 16 hr dwell at 600 psig in fresh water	Mechanical stress, water intrusion, simulate diving conditions.	Observations	T2 and T3	6-14, 15-78
5	*	*	Thermal shock, 16 Hrs @ -65°F, immerse in ice water for 30 min, 2 hrs @ -65°F, ice water for 30 min, 2 hrs @-65°F, ice for 30 min, 7 hrs @ -65°F, ice water for 30 min, room temp water for 64 hrs.	Mechanical stress due to contraction, elastomer & adhesive integrity, water intrusion, simulate Arctic conditions	Rubber durometer rubber expansions before and after stress	T2 & T3	6-21-78 to 6-23-78
6	170	171	High power drive at low freq., 60 ft. ocean water	Electrical integrity, water intrusion	Beam patterns, transmit response & impedance before & after stress; monitor voltage & current during stress	T2,T3,&T4	11-9-78 to 11-20-78

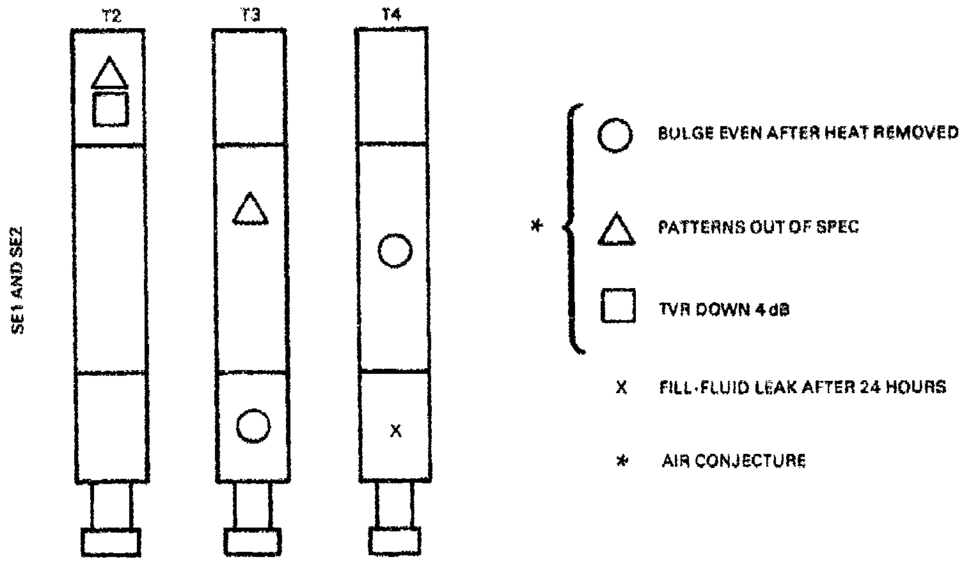
*Test duration or cycles as noted in "stress" column

Because of the many TR-316 problems or potential problems uncovered during the testing, it would be difficult to put the findings in perspective without a pictorial summary. Figures 6-1a and 6-1b present such a pictorial summary of findings of significance during and after each of the six stress-exposure tests. The three transducers T2, T3, and T4 subjected to CUALT are pictured with symbols indicating the findings inserted in the three sections (up, down, and narrow beam section). The following pertinent results are indicated in figures 6-1a and 6-1b.

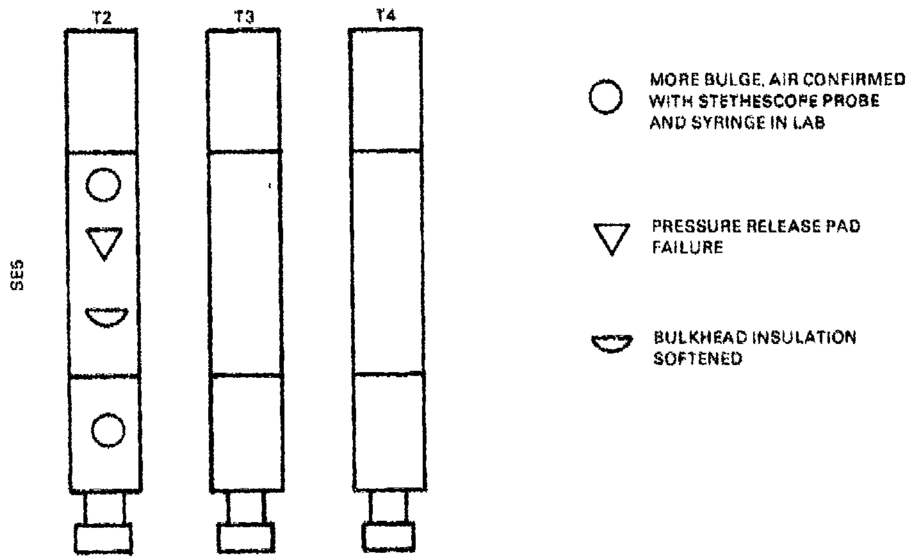
After SE1 and SE2 (stress exposures 1 and 2, dry heat and ultraviolet exposure) it will be noted from figure 6-1a that T4N and T3U retained a bulge even after the heat was removed (marked ○). It was conjectured that this permanent bulge was caused by air forced from the ceramic cavity into the fill fluid by the heat stress (the cavity should have been filled with fill fluid during assembly). However, the beam patterns were satisfactory. Thus, it was further conjectured that the air moved to non-critical regions in the unit when the beam patterns were taken. On the other hand, the patterns for T2D and T3N (which had no permanent bulges) were out of specification (marked Δ) and the transmit voltage response (TVR) for T2D was down 4 dB (marked □). Thus, for these sections (T2D and T3N), it was conjectured that although not enough air entered the fill-fluid to cause a permanent bulge, there was enough air to cause the faulty patterns and TVR. In this case, the air presumably moved to a critical position in the vicinity between the transducer radiating faces and the acoustic window. These patterns were taken at the TRANSDEC facility immediately after SE2 was completed. T4U experienced a fill-fluid leak after 24 hours of testing (marked X) and thus was not subjected to acoustic tests.

During SE3 and SE4 (immersion in salt water and pressure cycling) no additional problems were observed.

During stress exposure 5 (thermal shock) it was found that more bulges remained in the rubber windows of T2N and T2U (marked with ○). Immediately after SE5, air was confirmed as described later with stethoscope probes and an air removal syringe. It was also found upon disassembly that the pressure

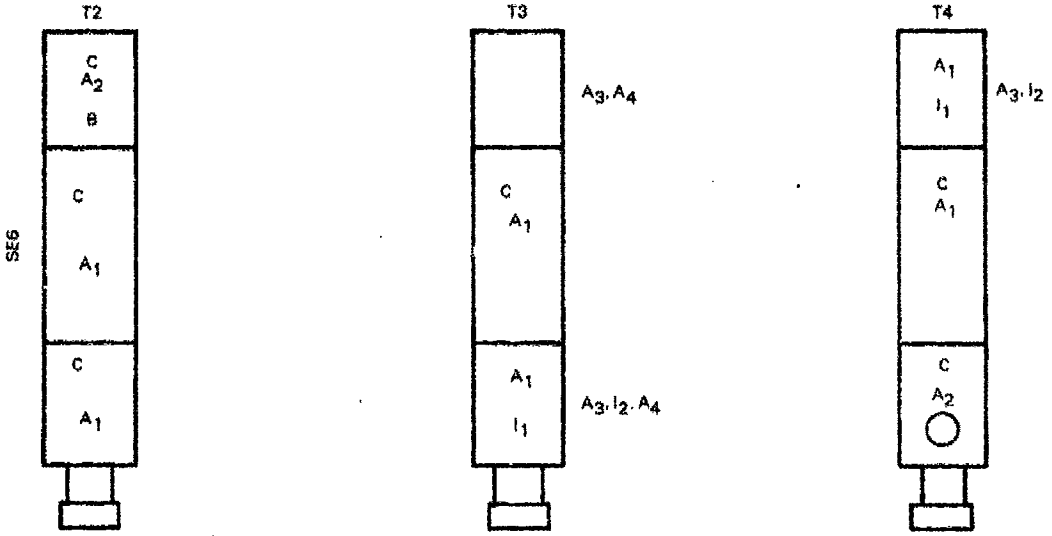


SE3 and SE4 - No additional problems observed



Units modified and repaired at Straza-meet CIPS

Figure 6-1a. CAULT Problem Summary for SE 1 through SE5



Tests at ocean tower

A_1 - Initial, activated (6 sections)

I_1 - Current runaway (< 1 hr) (air conjecture)

A_2 - Activated to replace I_1's

C - 171 hrs. completed at full power

A_3 - Activated for $\leq$ 1 hr

I_2 - Current runaway (< 1 hr)

Tests at TRANSDEC or lab

o - Window bulge, short circuit (impedance inductive); all other sections OK at low level

A_4 - Activated and current runaway in $\leq$ 1 hr; air conjecture weakened, thin fill-fluid-film conjecture, sections fail

B Small bump in window

Figure 6-1b. CAULT Problem Summary for SE6 release pad of T2N had experienced a failure (marked ., and for this section of the transducer the bulkhead insulation had softened (marked).

The three units (T2, T3, and T4) were returned to Straza for corrective action. Straza chose to inject Sylgard in the ceramic cavities instead of improving the fill-fluid entry ports. After repair, all units were recalibrated at TRANSDEC and found to meet all the requirements of the CIPS.

SE6 (high-power drive) was performed at an ocean tower at 56-foot depth. Sections marked A_1 in figure 6-1b were those initially activated (T2N, T2U, T3N, T3U, T4D and T4N). Sections marked I_1 experienced current runaway after less than one hour of high-level drive. At this point it was again conjectured that air had moved in front of some resonator radiating faces, leading to heating of these resonators and thus the current runaway. Since T3U and T4D experienced current runaway, sections T2D and T4U (marked A_2) were substituted for them in the testing. One hundred and seventy-one hours of testing were completed on all sections marked C, that is, all sections of T2 and T3N, T4N, and T4U. Sections marked A_3 were then activated for approximately one more hour. Section T3D showed no problem, but sections marked I_2 (T3U and T4D) again experienced current runaway.

After the tests at the ocean tower, low-level tests were conducted at TRANSDEC on units T2, T3, and T4 and high-level tests on T3. Sections T4 and T2 were dismantled at the laboratory. It was found that T4U experienced a permanent window bulge (marked ○ in figure 6-1b) and was discovered to be short-circuited. All other sections functioned as per specification at low-level drives. Sections marked A_4 (T3D and T3U) were activated and experienced current runaway in less than one hour. Satisfactory low-level performance and accompanying circumstances greatly weakened the conjecture that air bubbles between the radiating face and the window led to current runaway. Therefore it was conjectured that an excessively thin fill-fluid film (see figure 4-2) between the rubber window and transducer radiating face resulted in vaporization and subsequent failure, due to a change in radiation impedance seen by the head. It was also noticed that T2D (marked B) had a small bump in the window caused by epoxy attached to the rubber window (probably due to faulty fabrication). The major implications of these findings are presented in the following, more detailed discussion.

6.1.1 Calibration in the TRANSDEC Facility

Immediately prior to the CUALT, T2, T3, and T4 were tested at the TRANSDEC calibration facility for compliance with the CIPS. All units met the CIPS requirements. After calibration, the sequence of stress exposures, (SE1-SE6), outlined and described in table 6-1, was performed, and the following discussion augments the information in table 6-1.

6.1.2 SE1 Application

SE1 consisted of applying dry heat at 81°C (178°F) to the transducers. The purpose of the test was to accelerate rubber degradation and reactions with the fill fluid and components to simulate both dockside storage and mechanical stress due to expansion. Transducers T2 and T3 were tested in SE1. Transducer T4 was not ready in time for its inclusion in SE1.

6.1.3 SE2 Application

SE2 was similar to SE1 in that dry heat was applied but this time augmented with ultraviolet light to simulate exposure of the rubber acoustic window to sunlight during the periods when the submarine is surfaced. The temperature was reduced from 81°C (178°F) to 75.5°C (168°F). This reduction in temperature was due to difficulties associated with establishing the temperature specification value in SE1. SE1 was conducted at a temperature above the specification value while SE2 was conducted at a temperature almost that required by the CIPS.

Initially only T2 and T3 were available for the first 24 hours of testing, and then T4 was included. Thus a total time of 478 hours was applied to T2 and T3 and 454 hours to T4.

After 24 hours of testing T4 in SE2, a fill-fluid leak developed in the T4U section (marked X in figure 6-1a). It should be noted that subsequent dismantling and inspection of T4 showed that the leak in the acoustic window was due to a nonrecurring temporary modification by NOSC of that one window. This modification was made to allow for the slightly longer resonators used in T4. Thus the leak was not counted as an important problem. T4 was not included in any further tests until it was repaired. After repair, it was incorporated in SE6 (the high-drive test). Thus, transducer T4 was never subjected to stress exposures 1, 3, 4 and 5.

All sections of transducers T2, T3 and T4 had bulges in the rubber windows due to heating during SE1 or 2 (see figure 6-2). Even after the heat was removed, the bulges remained in T3U and T4N (marked O in figure 6-1a).

6.1.4 Measurements After SE1 and SE2

Measurements of the durometer of the rubber windows indicated a small, but definite, increase in rubber durometer, which was indicative of rubber aging due to SE1 and SE2.

After SE2, transducers T2 and T3 were checked again at TRANSDEC. Section T2D had beam patterns which were out of specification (marked as Δ in figure 6-1a) and the transmit voltage response was down approximately 4 dB (marked as □ in figure 6-1a). In T3N, the beam patterns were out of specification (also marked as Δ in figure 6-1a).

It was conjectured that the air was never successfully removed from the cavity in the resonators between the stress rod and the inside of the ceramic rings (see figure 4-1) during the fill-fluid fill operation. This was believed due to the extremely small size of the ports (a tiny groove in the tail mass) intended for fill-fluid entrance into the cavity. It was further conjectured

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Figure 6-2. Rubber Window Bulges Due to Heat that heating during SE1 and SE2 forced some of this air out into the fill fluid, but that the small vent ports did not allow the fill fluid to reenter the ceramic stack cavity in the resonators. It would then follow that this air trapped in the fill fluid accounted for the permanent bulge after the heat was removed.

One possible reason why the sections showing the permanent bulge did not show problems at TRANSDEC is that as the element was placed in various positions during handling, transportation, etc., air may have moved to positions within the cavity where it did not affect the performance. On the other hand, the sections which did show problems could have had air move from one region in the cavity to a region between the radiating face and the rubber window. This would account for the defective patterns and lowered TVR.

6.1.5 SE3 Application

Next, T2 and T3 were subjected to SE3, which was the immersion in sea water at 60°C (140°F). The purpose of this test was to investigate corrosion of seal plugs, case, and screws. No visual changes (such as fill-fluid leakage) were noted as a result of SE3. It was subsequently determined that SE3 was ineffective in creating corrosion due to the type of stainless steel used in these transducers, namely, type 316L.

6.1.6 SE4 Application

Next, transducers T2 and T3 were subjected to SE4 (pressure cycling). The purpose of this test was to simulate diving conditions by applying a varying pressure. No visual changes were noted as a result of this test.

6.1.7 SE5 Application

Next, T2 and T3 were subjected to SE5 (thermal-shock exposure - see figure 6-3 with transducers being hosed down to remove ice). The purpose of this test was to simulate thermal-shock conditions which might be encountered in the Arctic. Additional bulging of the rubber windows remained at the finish of SE5 in transducer T2 in the narrow beam center section and in the PD up section (marked ○ in figure 6-1a in SE5). It was conjectured that the cold temperature of the thermal-shock cycle contracted the fill fluid and thus forced additional air out of the cavity between the piezoelectric rings and the stress rod in the resonators. Transducer T2 was activated in-air and probed using a small microphone (hydrophone pressed against the rubber and used like a stethoscope), which indicated that there was air in all three sections, but not everywhere in all three sections. As before, there were indications that moving the transducer around changed the location of the air bubbles.

A special syringe was used to extract air from the center section of transducer T2 (see figure 6-4). The transducer was positioned so that air, if present, would be in a certain location in the center section, and the syringe then was used to begin the extraction process. As expected, a quantity of air was removed before fill fluid began to appear in the device. A subsequent check showed that the amount of air removed (1.6 in^3) was almost exactly equal to the volume occupied by the cavities between the piezoelectric rings and the stress rod.

6.1.8 Observations and Corrections After SE5

At this point transducer T2 was disassembled (see figure 3-3). It was discovered that the rubber protection for the pressure release Min-K pucks had separated (marked as ∇ in figure 6-1a), allowing fill fluid to saturate some of the pucks (see figure 6-5). It was also discovered that an insulation material used at the bulkheads to electrically insulate the wires had softened (marked ▽ in figure 6-1a). The purpose of this insulation is to prevent shorting of wires passing from a given section into other sections should the given section be flooded with water.

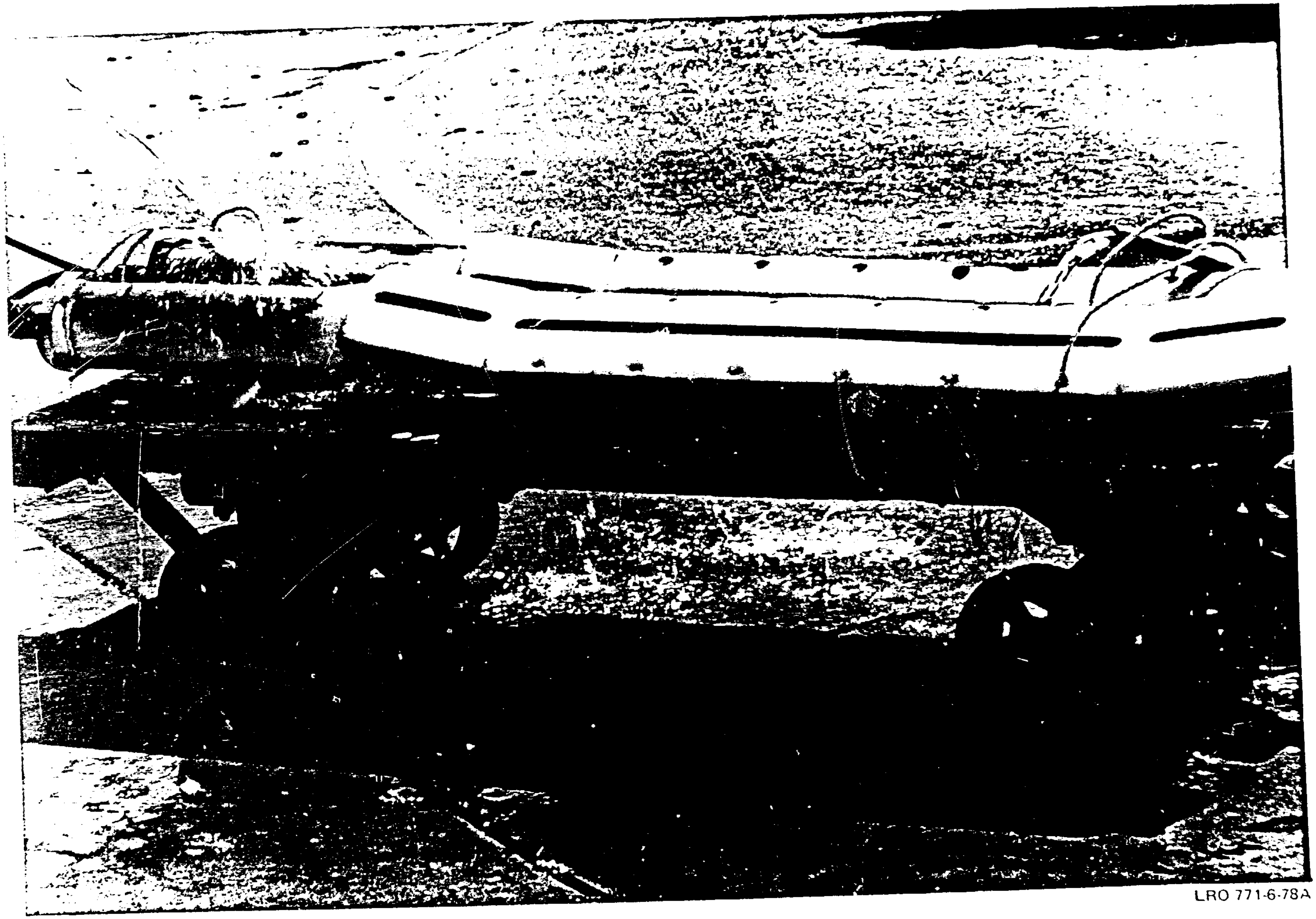
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Figure 6-3. Transducers After Thermal-Shock Exposure

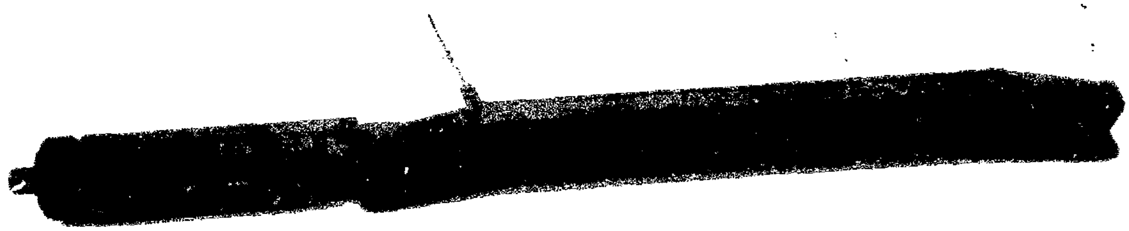


Figure 6-4. Device Used to Detect Air in Transducer

Figure 6-5. Separation of Rubber Cover for Min-K Isolation

Corrective actions were suggested and pursued as follows:

1. It was suggested that the ports intended to allow fill fluid to enter and leave the cavity between the rings and the stress rod be made sufficiently large so that there would be no problems in removing the air and filling these cavities with fill fluid. Apparently, since the resonators used in the TR-316 are the same ones as used in the production TR-242, Straza did not wish to change the design but instead chose to fill the cavity with Sylgard 184 (a silicon compound).

2. Relative to the pressure release pad, Straza chose to simply replace the pads with new pads but indicated that in the future the rubber material would be vulcanized instead of cemented.

3. The acoustic window on T4, which had resulted in the fill-fluid leak, was also replaced. It should be recalled that the leak in the acoustic window was not attributed to life testing, but due instead to a nonrecurring modification by NOSC of that particular rubber window.

6.1.9 Calibration of Repaired Units

All three units (T2, T3, and T4) were modified and repaired by Straza and returned to NOSC. All three units were tested at TRANSDEC and found to meet the CIPS. In fact, the repaired units appeared to be more uniform than they had previously.

6.1.10 SE6 Application

Next, SE6, the high-power-drive sequence was initiated on all three TR-316's. The tests were performed in the ocean tower in approximately 56 feet of water. The transducers were operated in a horizontal position as shown in figure 6-6. There was only sufficient power at the test site to drive six of the total of nine sections in the three TR-316's. Each section was driven with 126 volts RMS at the lowest operating frequency (CW), which is the frequency producing the highest volts per mil on the piezoelectric rings.

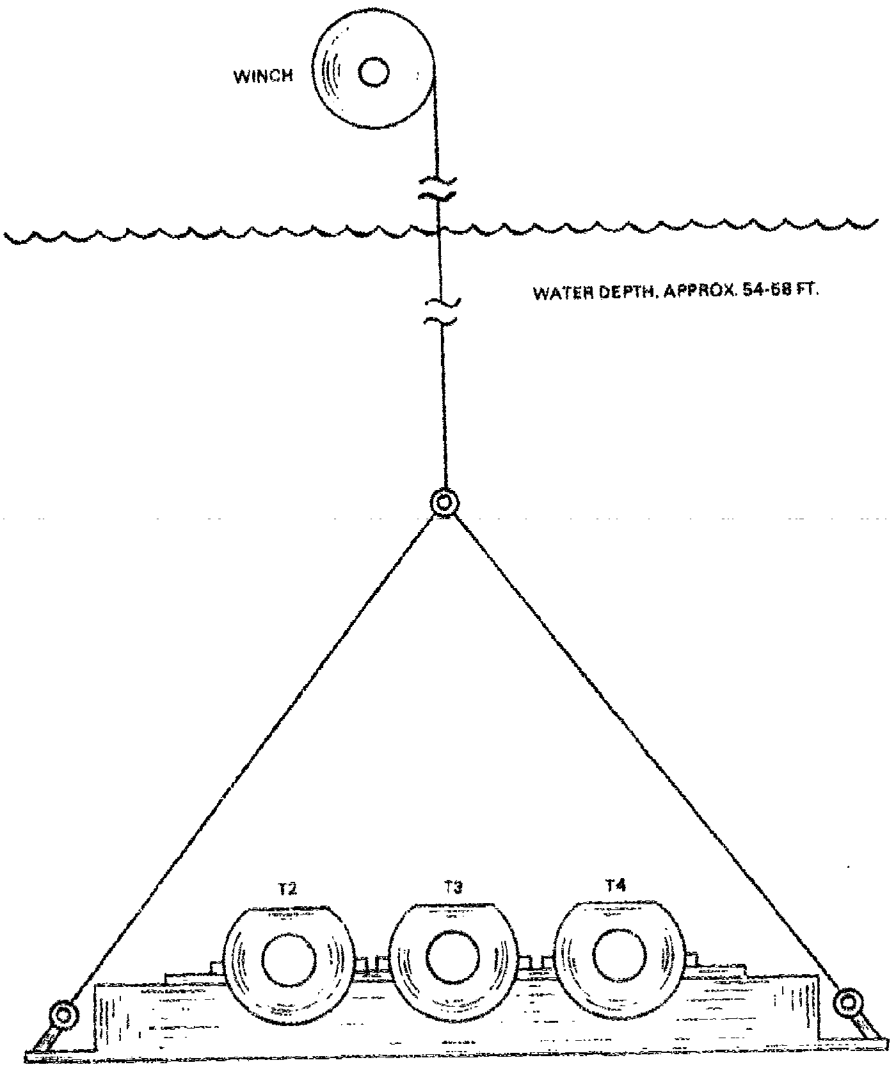


Figure 6-6. Positions of Three TR-316 Projectors Moun[illegible] on a Platform in the Hig[illegible]-Power Drive Test

Sections T2N, T2U, T3N, T3U, T4N, and T4D were initially driven (marked A_1 in figure 6-1b). After approximately 15 to 60 minutes T3U and T4D had begun to experience current runaway (marked I_1 in figure 6-1b). The current had risen from approximately 2.5 amps to over 3 amps. These two sections were disconnected from the power-drive amplifier and in their place T2D and T4U were activated (marked A_2 in figure 6-1b). The tests were continued to complete the 171 hours of high-level drive required. No further problems were noted and thus the first-year-equivalent life testing was completed.

Note that certain sections survived the full 171 hours (one-year-equivalent) of high-level drive. Specifically, the sections receiving the 171 hours of high-level drive were all sections of T2, and T3N, T4N, and T4U (marked C in figure 6-1b).

After completion of the 171 hours, two sections which had previously exhibited current runaway were again tested at the ocean tower (marked A_3 in figure 6-1b). The units initially had recovered and appeared to be normal but the problem was repeated: within approximately 15 to 60 minutes T3U and T4D had again commenced current runaway (marked I_2 in figure 6-1b). That part of the test was again discontinued. During the same time period T3D, which had never been tested, was also activated (also marked A_3 in figure 6-1b) and received approximately 1 hour of high-level drive. No indications of problems were observed on T3D during this 1 hour of high-level drive.

6.1.11 Observations at Lab and TRANSDEC After SE6

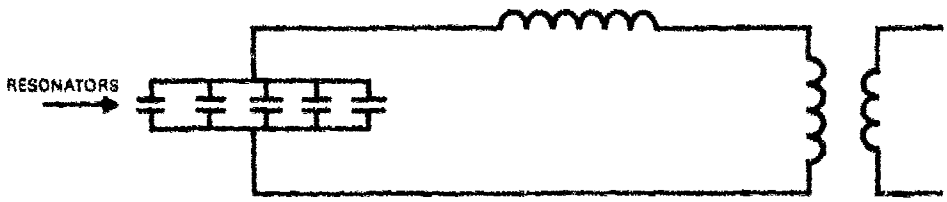
The three units, T2, T3, and T4, were returned to the laboratory and checked for window bulge and rubber hardness. There was essentially no further change (beyond the aging noted after SE1 and SE2) in the rubber hardness; however, the acoustic window on T4U had bulged (marked ○ in figure 6-1b). Note that this section was not one of the sections which had indicated trouble during the high-drive tests. The units were then tested at TRANSDEC at low-level drive and the same section (T4U) was inoperative. The impedance measured at this time on T4U appeared to be that of the inductor (also marked ○ in figure 6-1b). This led to the suspicion (later confirmed) that one or more of the resonators of this section were shorted. Recall that before the high-level-drive tests all units were satisfactory as indicated by the previous TRANSDEC testing. Therefore, the short had to have occurred sometime during the high-drive testing.

T4U was dismantled and the suspected short circuit across the resonator was confirmed. Why did T4U appear normal during the high-drive test? The answer is indicated in figure 6-7. At the test frequency, the magnitude of the current drawn by the normal transducer is nearly the same as that drawn by an inductor only.

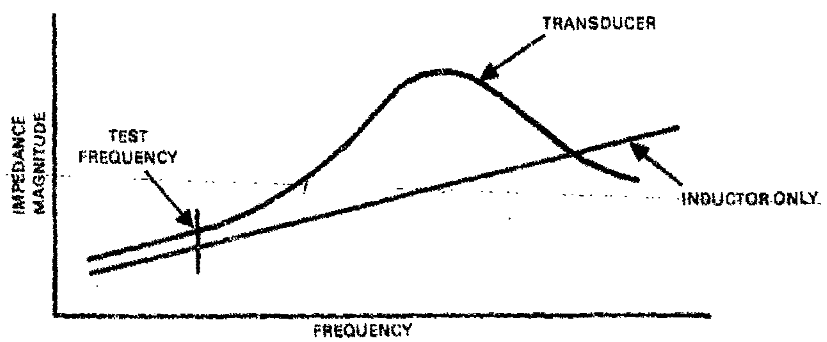
The misaligned and distorted nodal mount grommet shown in figure 6-8 appears to have been a contributing factor in causing the short circuit. The short circuit in T4U was caused by failure of the insulation, resulting in the electrical connection of the wire to the metal portion of the nodal mount as shown in figure 6-9.

It was shown at TRANSDEC that all sections which had current-runaway problems at the tower proved to be satisfactory at low levels as indicated by all of the TRANSDEC testing (recall these sections are T3U and T4D).

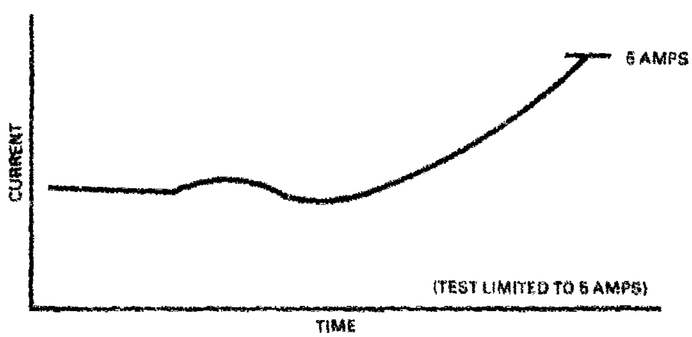
Transducer T3 was returned to TRANSDEC and mounted horizontally just as it had been mounted at the tower during high-drive testing. All low-level tests (patterns, TVR, etc.) were satisfactory, indicating among other things that no air bubbles were present between the resonator radiating faces and the window. Nonetheless, when operated at high-drive levels (marked A_4 in figure 6-1b) without repositioning the unit (and thus possibly moving air bubbles into detrimental positions between the radiating faces and the window), T3U behaved as it had at the tower during high drive. Specifically, after less than one hour of high drive, T3U had experienced current runaway (a 5-amp limit was placed in the circuit). After allowing sufficient time for cooling, T3U again checked out normal at low levels.



a. Series-tuned circuit with five transducers in parallel



b. Comparison of Normal Transducer Impedance vs Impedance When One or More Resonators Is Shorted



c. Current Runaway Response

Figure 6-7. Transducer Circuitry and High-Drive Response

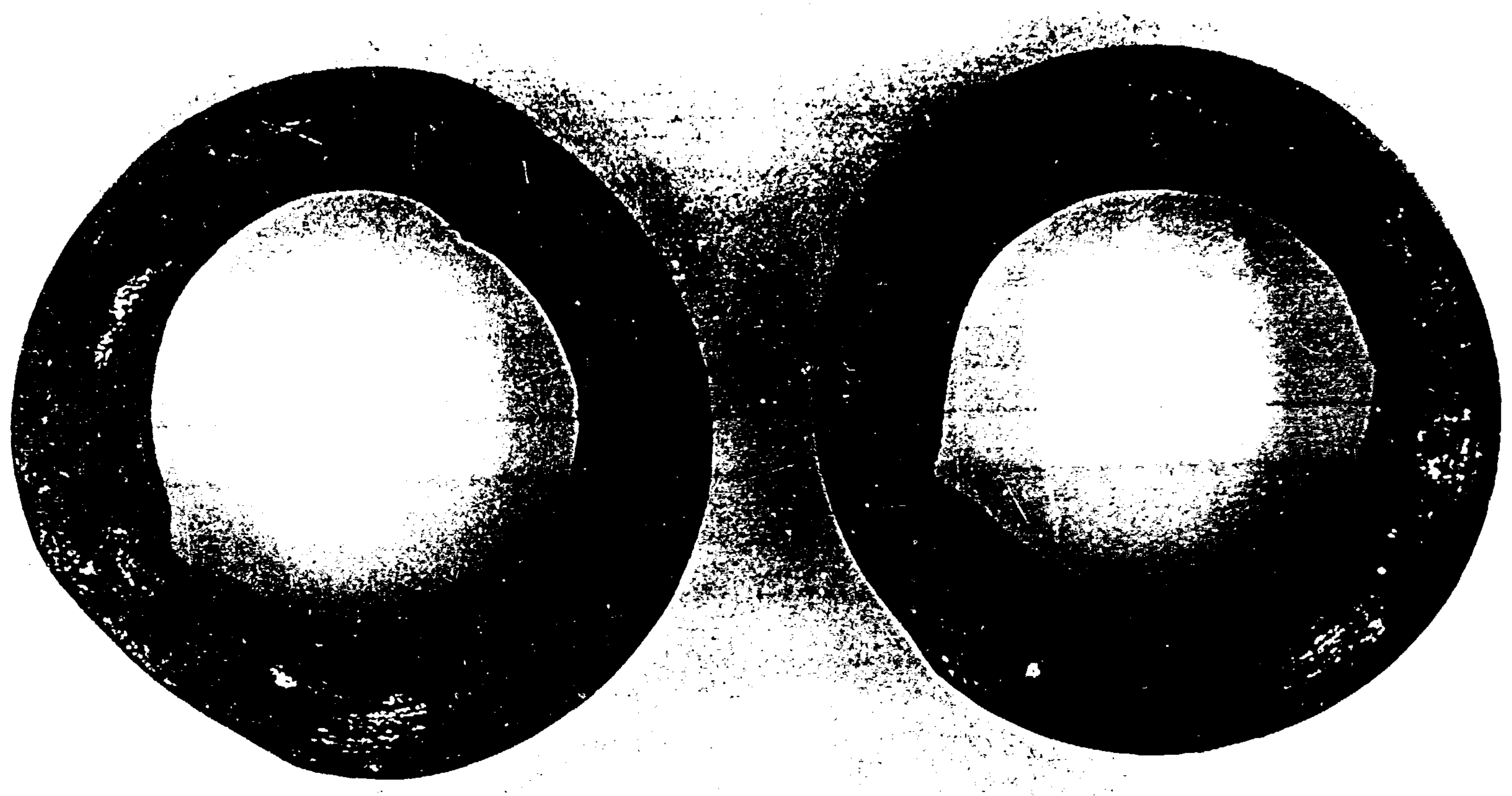


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Figure 6-8. Evidence of Incorrect Assembly of Nodal Mount

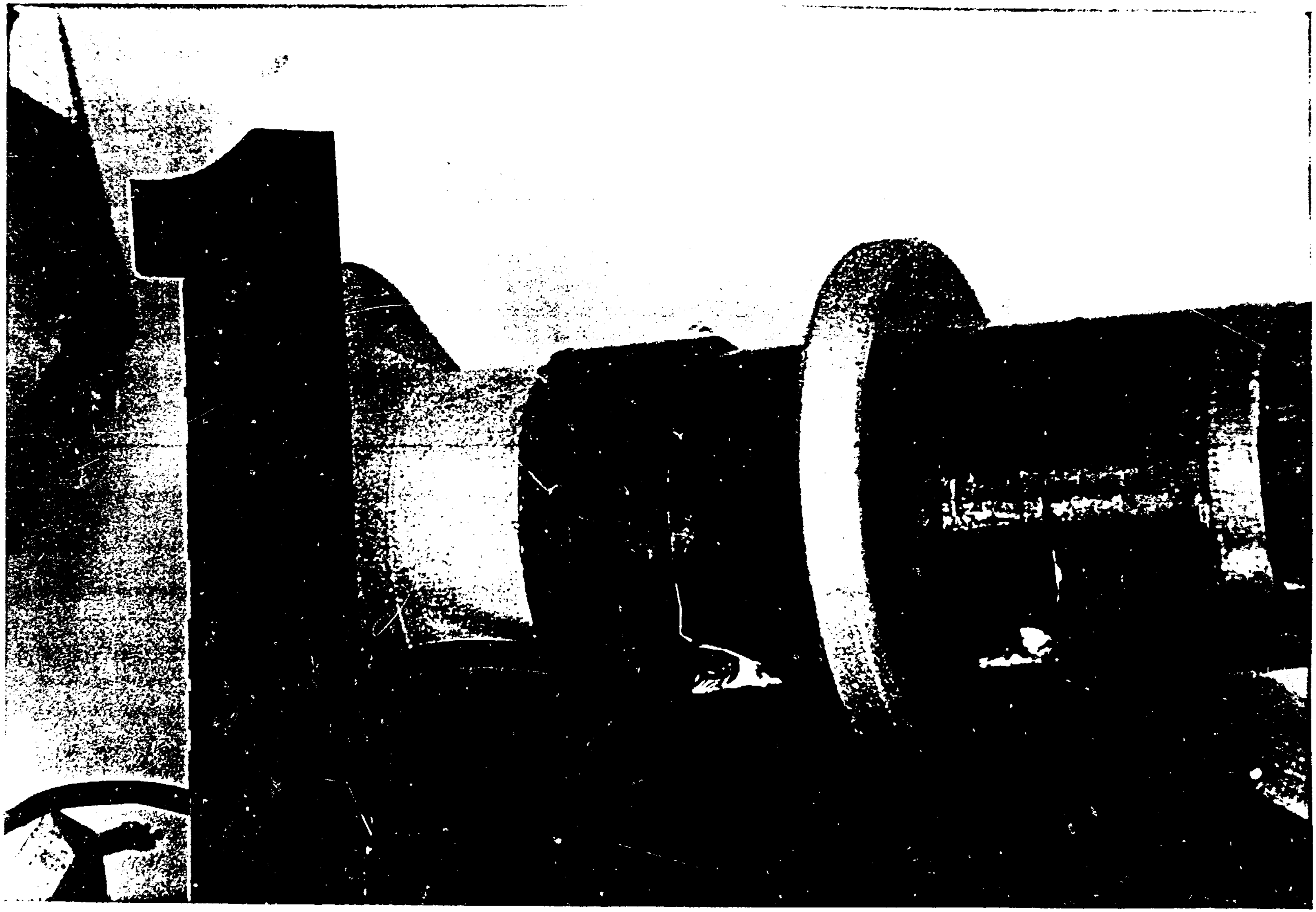

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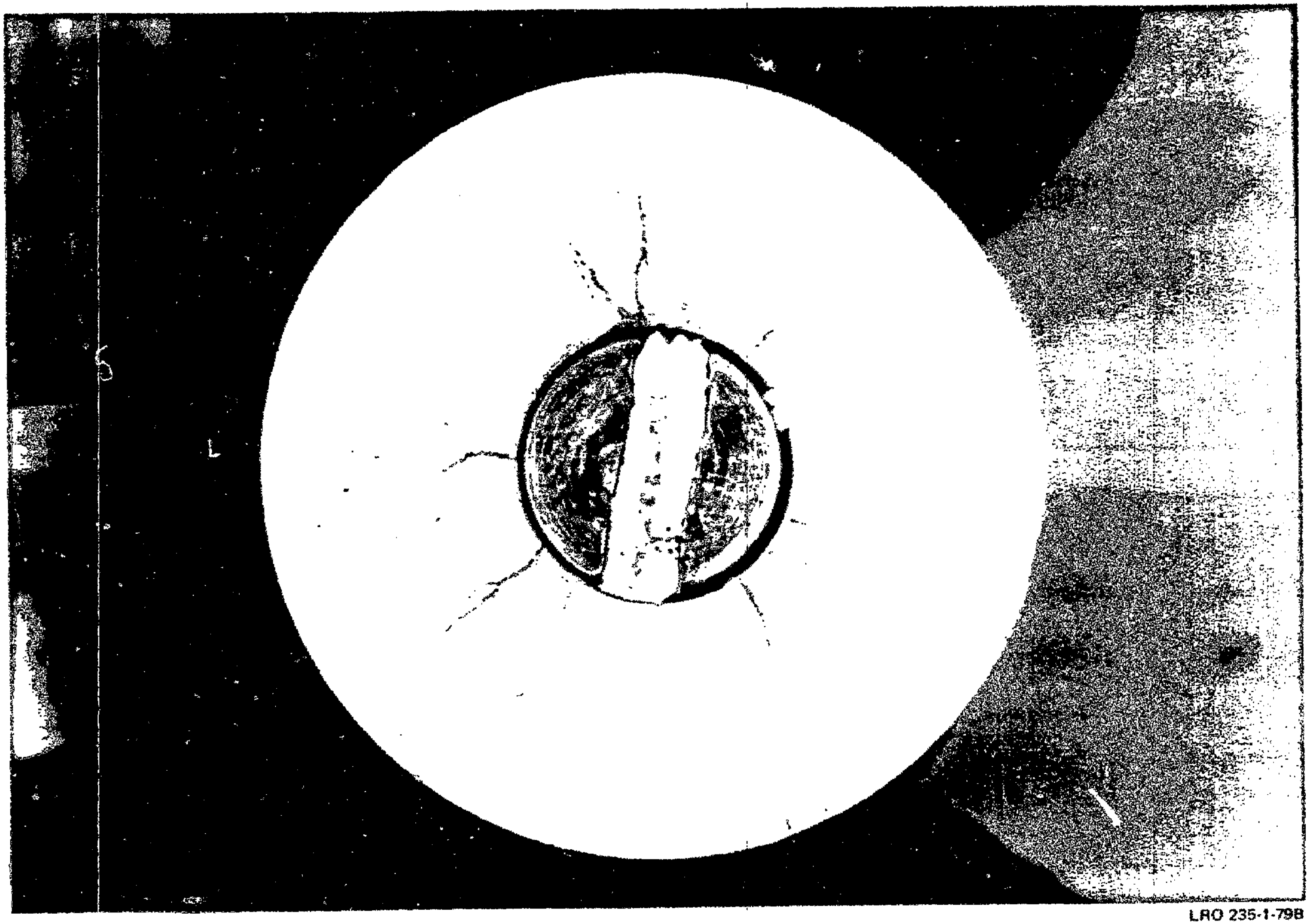
Figure 6-9. Cracked Ceramic Stack and Bent Electrodes

The above behavior of T3U tended to discredit the conjecture that air bubbles in front of the radiating faces had caused the problem associated with rising current versus time for high-drive levels. However, to save this conjecture, it was pointed out that perhaps the depth of operation had been insufficient for this particular TRANSDEC test and that cavitation had caused the problem in this one instance. There had been no direct evidence of cavitation however.

A simple solution for the cavitation problem (if it in fact existed) would have been to lower T3 to the bottom of TRANSDEC and repeat the high-drive tests. Unfortunately, there were insufficient pipes to lower the unit to the bottom and maintain T3 in the horizontal position. Therefore a chain was used, resulting in T3 now being mounted vertically. This repositioning reopened the possibility of air bubbles moving into exactly the right places to account for the current-runaway problem. T3 was suspended vertically, but with the PD up section at the highest point on the vertical transducer (the position is important in the detective work that follows).

High-drive testing was resumed, the current quickly rose to high levels, and this time the 5-amp limit was removed. A current-runaway condition occurred, and at 10 amps the unit suddenly became inductive, the current dropped back to "normal," and the section was then acoustically inoperative.

The unit was returned to the shop and dismantled, where it was discovered that the resonator which would have been at the lowest point of the PD up section (T3U) during the vertical-suspension high-drive tests (at which time the unit failed) was the resonator that broke. One would have thought that if air bubbles were the cause of current runaway, they would have moved (if they moved at all) to the <u>highest</u> point in T3U, not the lowest point. Thus the air-bubble conjecture concerning the current-runaway problem was further weakened. The piezoelectric material had cracked, apparently due to excessive heating of the Sylgard and the subsequent expansion (figure 6-9). The resonator in the uppermost position also showed signs of problems, namely, the aluminum head mass had apparently developed stress cracks (figure 6-10). Subsequent dye tests by Straza showed the cracks to be superficial and probably the result of cavitation on the element face.



LRO 235-1-79B

Figure 6-10. Cracked Head of Resonator

Review of the previous statements tended to discredit the theory that air bubbles in front of the radiating heads were the cause of problems associated with current runaway versus time. It was next conjectured that the current-runaway problem might be due to the rubber window not being sufficiently separated from the head. The fact that in some cases only a thin fill-fluid film exists between the radiating face and the rubber window suggested a non-linear explanation of the problem. Specifically, it was suggested that at low levels the thin fill-fluid film operates satisfactorily as a coupler between the head and the rubber window. However, as the drive level is increased, a non-linear condition might occur where heating of the thin film of fill fluid could convert it into a vapor. This could result in a decoupling of the head from the rubber acoustic window. The consequent heating of the piezoelectric material might change the impedance in such a way as to make the current rise and ultimately destroy the resonator.

Simultaneously while testing T3U (while the unit was suspended vertically on a chain) the PD down section was operated at high-drive levels (also marked A4 in figure 6-1b). However, recall that the PD down section in this vertical position had actually been positioned at the low point on the transducer. For the first 30 minutes or so the current level seemed normal, just as had been experienced during the one (and only) hour in which T3D had been driven at the tower. By the time 40 minutes had passed, the current had risen from a more or less normal value of 2.2 amps to 3 amps. In the next approximately 10 seconds the current rose from 3 amps to 6 amps and then the element went inductive. Going inductive was recognized as a symptom of a short circuit of one or more resonators.

The unit was dismantled in the laboratory. It was found that in the position at which the unit had physically been mounted the uppermost two resonators in the PD down section had been broken. The piezoelectric ring had broken, the same as in T3U. The photograph with the number 1 is for T3D (figure 6-9), the photograph with the number 2 is for T3U. The photograph showing head cracking (figure 6-10) is for a transducer from the T3U section.

Some of the resonators with cracked ceramic showed that the Sylgard had extruded through the tiny port or groove originally intended for fill-fluid filling of the cavity in the resonator. This and other indications led to the strong conjecture that heat expansion of the Sylgard ultimately led to the cracking of the piezoelectric rings. The extruded Sylgard is not shown on any photograph due to the extremely small size of the hair-like extrusion, corresponding to the small size of the fill-port groove.

No further results or problems directly attributable to high drive at TRANSDEC were noted. However, T2D presented a special case in that it did not display current runaway, but during the inspection after the TRANSDEC testing it was noticed that there was a small bump (marked B in figure 6-1b) on the rubber window of T2D (figure 6-11). It was thought that perhaps the stress rod (which physically is a bolt with the screw head side-mounted in the radiating face) had broken and was pushing out against the rubber window. However, when the unit was dismantled, as shown in the photo, it was noted that some of the Armstrong adhesive A2 used to cover the slot in the screw head of the stress bolt had attached to the back side of the rubber window. There was also evidence of burning in the same general area (figure 6-11). It was further noted that the radiating face of this resonator was higher than the others (it protruded approximately 1/32" further in the direction of the rubber window than the other resonators).

It was conjectured that the Armstrong adhesive A2 had become accidentally bonded to the rubber window during the high-drive test when heating softened the Armstrong material and allowed it to adhere to the rubber window. It was also conjectured that there may have been a flaw in the rubber window. A considerable amount of the rubber in that vicinity had been carbonized due to heating. Thus, although this particular section (T2D) apparently did not unload itself in such a way as to cause the heating problem (with increasing current, consequent heating, and ultimate destruction), there were some local heating effects.

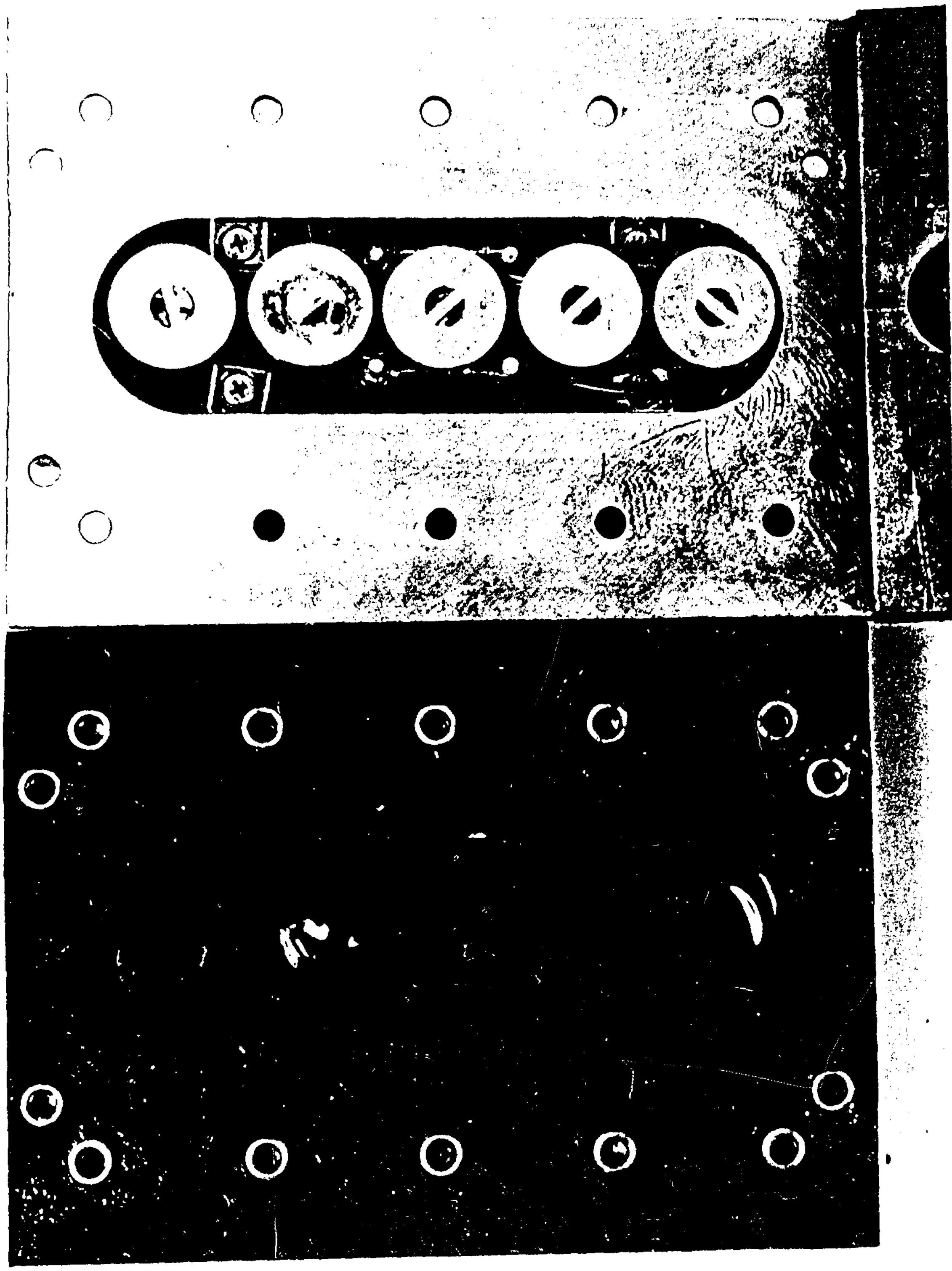


Figure 6-11. Bump on Rubber Window on T2D

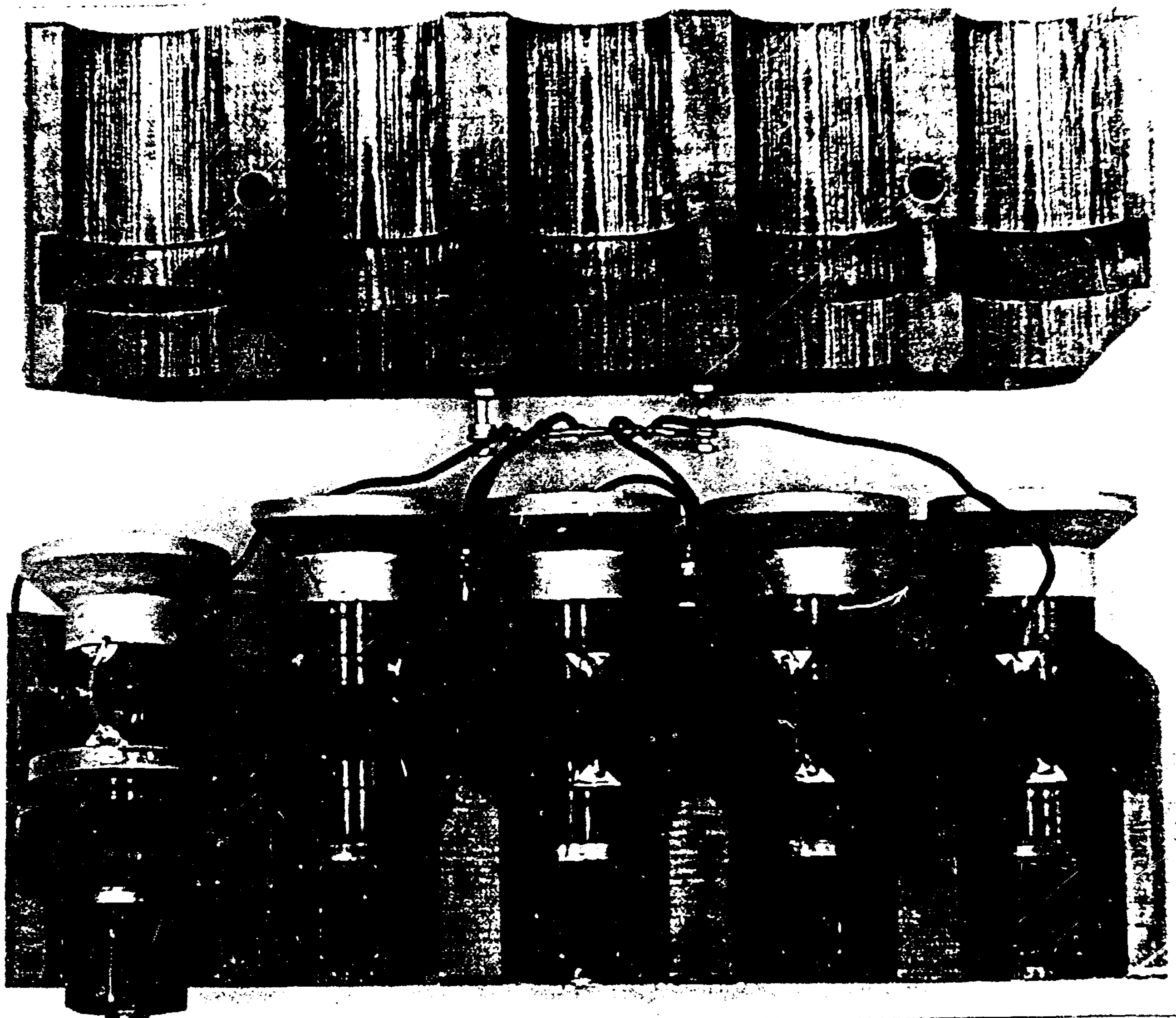
Figure 6-12 indicates the onset of a possible problem in T3U, namely, two discolored places where the rubber nodal mounts fit into the mounting block. It is noted that the pitting, etc., of the rubber is reminiscent of other conditions known to have been caused by cavitation. It is also noted that there are no electrical wires or terminals anywhere near this vicinity. Therefore the problem could not be associated with electrical phenomena.

Some general indications of poor quality control were noted. Failure of a soldered joint and wire insulation cut too short is shown in figure 6-13. Also, the electrode tabs are shown to be bent down, thus reducing the effective distance between positive and negative foils. This defeats the goal of having a low electric field (less than 5.0 volts/mil). Bent tabs have been a direct cause of drastic failures in other transducers.

6.1.12 Summary of Current-Runaway Problem

This section summarizes the status of the current-runaway problem as of the end of the first-year-equivalent CUALT of the TR-316. Most of the short sections, (PD up and PD down sections, also known as wide beam sections) failed the high-drive test. Recall that the problem manifested itself during high-level-drive testing as a current runaway versus time, culminating in failure of certain resonators (probably due to excessive heating). None of the long sections (known as the narrow beam sections) had high-drive problems. The explanation for this is as follows: the transformer/electrical impedance characteristics of the long sections are such that the 23 resonators of the narrow beam sections draw the same power as the 5 elements in the wide beam sections. There were no high-drive failures in the narrow beam section simply because the resonators in these sections operate at a much lower drive level (i.e. power level) than the wide beam (short) sections.

2



LBO 2311 798

Figure 6-12. Discoloration of Mounting Block at Nodal Mount Location

LRO 233'798

Figure 6-13. Insulation of Wires Cut Short and Cold Soldered Connection Failure

It is significant that the short sections of T2 (T2U and T2D) survived for a full 171 hours of high-level drive, whereas the other short sections failed in usually less than one hour. This fact suggested that the basic design was capable of accommodating high drive in the short sections. Therefore, although no satisfactory explanation for the current-runaway problem had yet been proven at this point in the program, there was reason to believe that the problem could be understood and corrected without major design changes.

6.1.13 Solution of the Current-Runaway Problem

This section describes the work leading to an understanding and solution of the current-runaway problem summarized in the previous section. As explained in section 6.1.11, it was conjectured that the current-runaway problem might be due to the rubber window not being sufficiently separated from the radiating head of some of the resonators. This conjecture was tested using two different procedures at the TRANSDEC facility. First, the rubber window was moved further away from the resonator faces by inserting an additional spacer at the position where the rubber window serves as a gasket. The rubber window was also moved further away from the resonator faces by putting the fill fluid under sufficient pressure to bulge the rubber window. Neither of these changes solved or even changed the effects associated with the current-runaway problem.

During some of the initial experimentation directed toward understanding the current-runaway problem, the short sections of T2 (that is, T2U and T2D), which had previously passed the high-drive tests, were retested with disappointing results in TRANSDEC. The T2U section began exhibiting current runaway almost immediately and T2D showed signs, although very slowly as time progressed, of having a current-runaway problem. It was conjectured that the slightly warmer water of the TRANSDEC facility (as compared to the water temperature in the ocean-tower test facility) was accounting for the fact that T2 had passed the high-drive test in the ocean but was failing at the TRANSDEC test facility. This disturbing result added an even greater sense of urgency to understanding and solving the current-runaway problem.

6.1.13.1 First Article High-Drive-Test Failure

At this point in the program, Straza reported that the first article TR-316 transducers required by the contract had passed the high-drive test. This contradicted the above described high-level-drive testing experience of the government technical monitors performing CUALT on the prototype units T_2, T_3 and T_4. Because of the confidence and competence developed through hands-on experience by the government technical monitors, these monitors were able to successfully challenge Straza's claim that the first article transducers had passed the high-level-drive test.

Initial examination of the Straza data did indeed indicate that the first article transducers had been driven at high level for the required 170 operating hours, and had subsequently passed the low-level calibration tests. However, a more detailed investigation resulted in the discovery that the power amplifiers used in the Straza high-drive tests were current-control amplifiers as opposed to voltage-control amplifiers. The TR-316, when used in actual applications in the sonar system, is driven with a voltage-control amplifier. It was for this reason that the specification required that the high-level drive test be conducted by applying 126 volts RMS to the input terminal of the TR-316. Thus, the explanation for the apparently, but not actually, successful Straza high-drive tests was that the incorrect voltage was applied, and the incorrect use of current-control amplifiers prevented the current-runaway condition from occurring.

Testing by the government technical monitors showed that the first article transducers, when driven with a voltage-control amplifier, exhibited the current-runaway problem almost immediately upon implementation of the high-drive tests. Straza objected to the fact that the government tests were performed at one frequency, whereas the specification only required that the transducers pass the high-drive tests when driven with the frequency-sweep-type input signal. This objection was resolved by having the technical monitors repeat the tests using the frequency-sweep rather than the single-frequency drive. The current-runaway problem was encountered immediately.

The technical evidence at this point was overwhelming in indicating that a serious problem existed in both the TR-316 prototypes and the first article transducers. It cannot be emphasized too strongly that the hands-on experience gained in the CUALT program by the government contract technical monitors played a key role in the successful challenge to the claim by Straza that the first article transducer had passed the high-level-drive test and the subsequent discovery of the error in the Straza test procedure. The end result was that the initial first article transducers had to be rejected.

6.1.13.2 <u>In-Air Impedance Measurements Versus Temperature</u>

At this point in the program, the current-runaway problem had become critical. An intensive government brainstorming session was initiated by an expanded government technical team in an effort to understand and develop possible solutions to the problem. Straza's excellent cooperation contributed to the successful effort to understand and correct the problem.

One of the most fruitful results of the brainstorming session was the suggestion of applying an in-air impedance test versus temperature to the individual resonators in an effort to help understand the problem. This in-air impedance testing versus temperature of individual resonators provided the insight necessary to understand and solve the problem. Subsequent temperature monitoring of the stabilization temperature of the resonators in the composite unit was needed to finally characterize the nature of the problem and verify the suggested solutions.

In order to examine enough cases to be definitive in a short enough time period, it was necessary to automate the in-air impedance versus temperature test procedure for the individual resonators. This automation was accomplished, including automatic data graphing. In a matter of hours, a resonator incorporating a given design feature could be experimentally evaluated.

Dozens of plots of experimental data on individual resonators tested for in-air impedance (magnitude and phase) versus temperature were produced. Representative results are contained in figures 6-14 through 6-21. The experimental data for in-air impedance magnitude and phase versus temperature shown in these figures presents representative results for the principal evidence leading to an understanding and solution of the current-runaway problem. In outline form, the in-air impedance experimental results address the following resonator configurations:

1. Production resonators from units that failed the high-drive tests - "bad resonators" (see figures 6-14a and 6-14b);

2. Resonators from units which passed (in the cold ocean water) the high-drive tests - "alledgedly good resonators" (see figures 6-15a and 6-15b);

3. Production resonator but with reduced-diameter stress rod and proper prestress (see figures 6-16a and 6-16b);

4. Resonator with no cement joints, production stress rod but extra high prestress (see figures 6-17a and 6-17b);

5. Same resonator as in 4, except with normal prestress (see figures 6-18a and 6-18b);

6. Same resonator as item 4, except a reduced-diameter stress rod and normal prestress (see figures 6-19a and 6-19b);

7. Resonator using 914 cement, instead of Epon 8 (constructed at Ametek/Straza) (see figures 6-20a_1, 6-20b_2, 6-20b_1 and 6-20b_2);

8. Resonator with properly constructed Epon 8 cement joints, the production stress rod but with extra high stress (see figures 6-21a_1, 6-21a_2, 6-21b_1 and 6-21b_2).

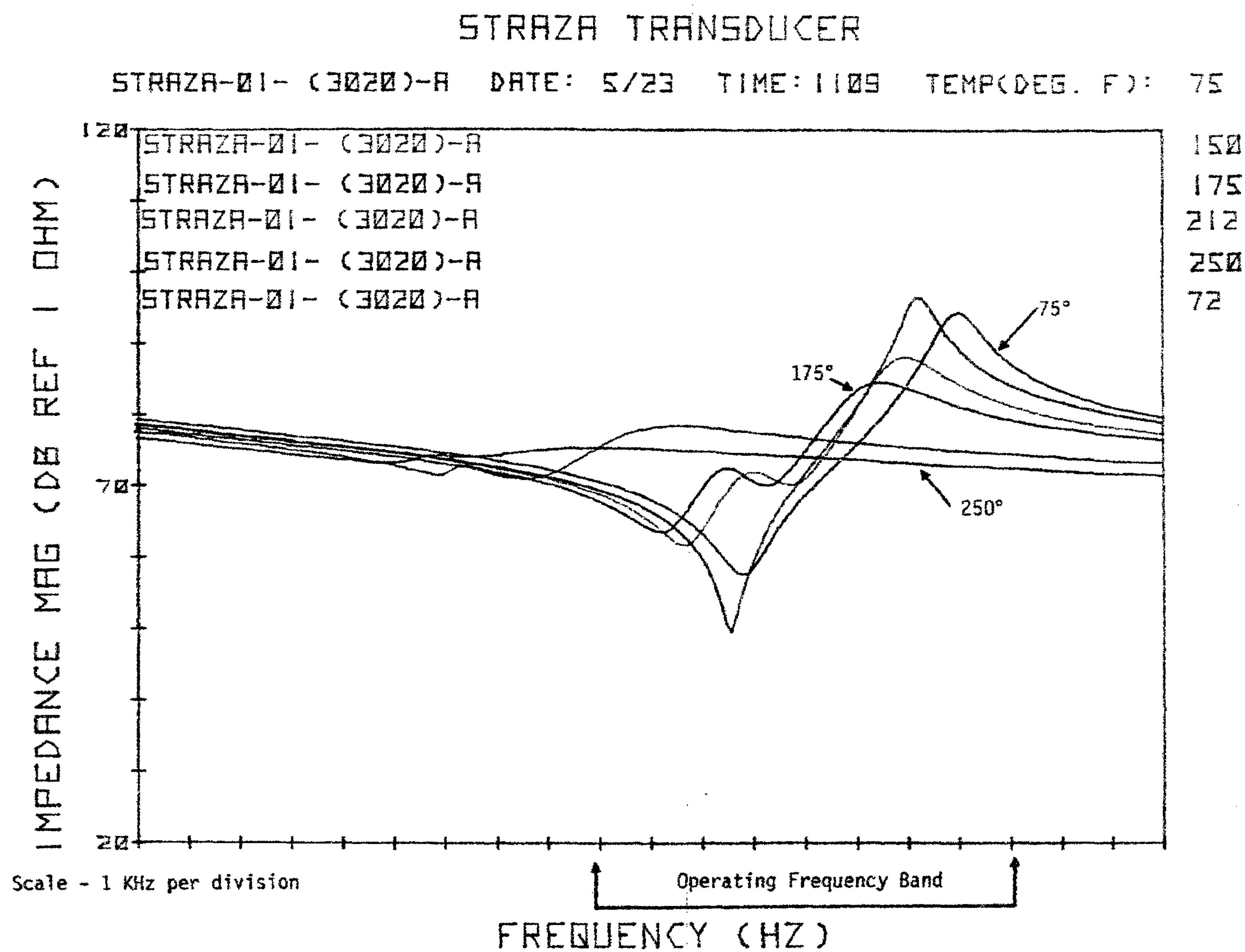


Figure 6-14a. Magnitude of In-Air Impedance Vs. Temperature for a "Bad Resonator"

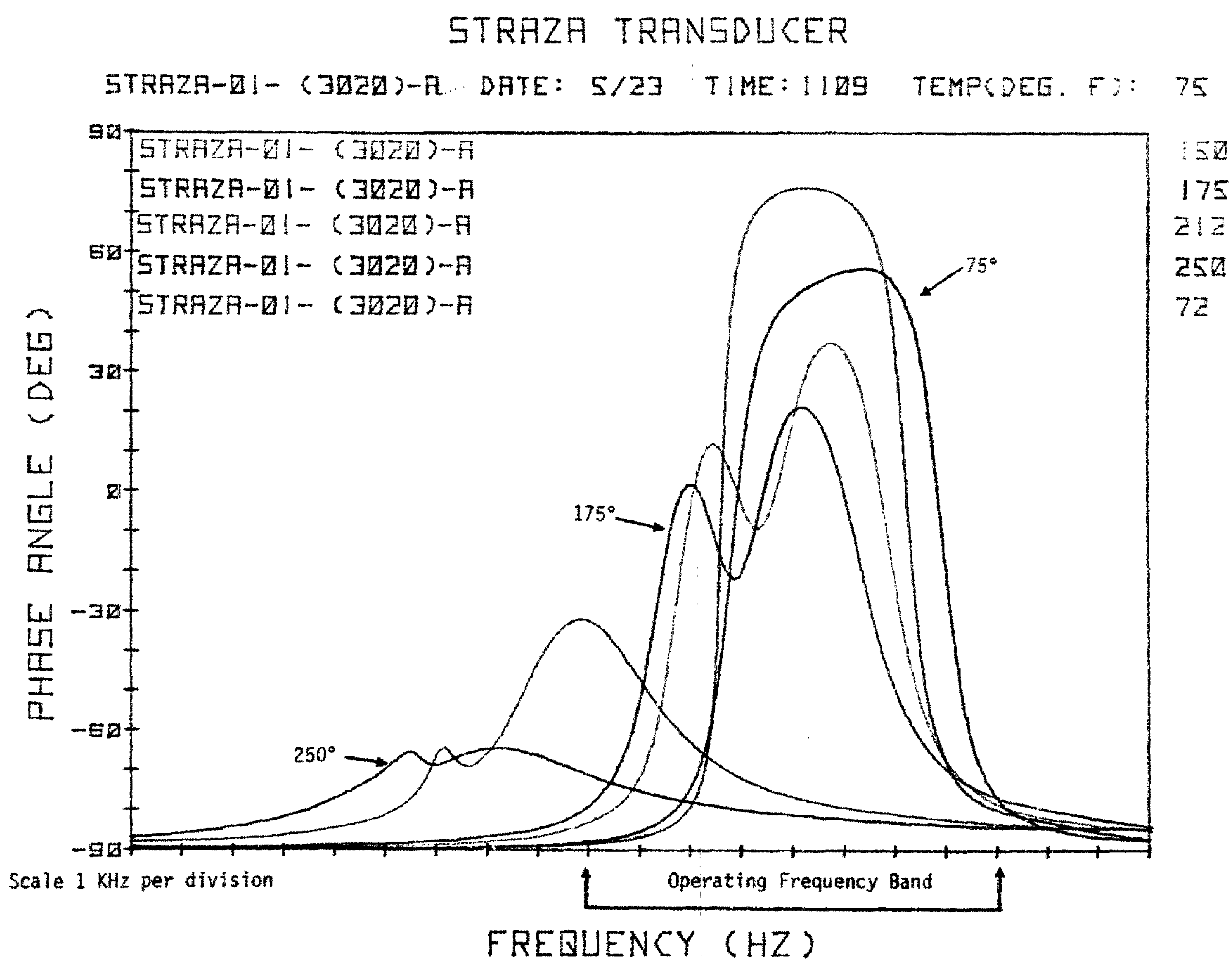


Figure 6-14b. Phase Angle of In-Air Impedance Vs. Temperature for a "Bad Resonator"

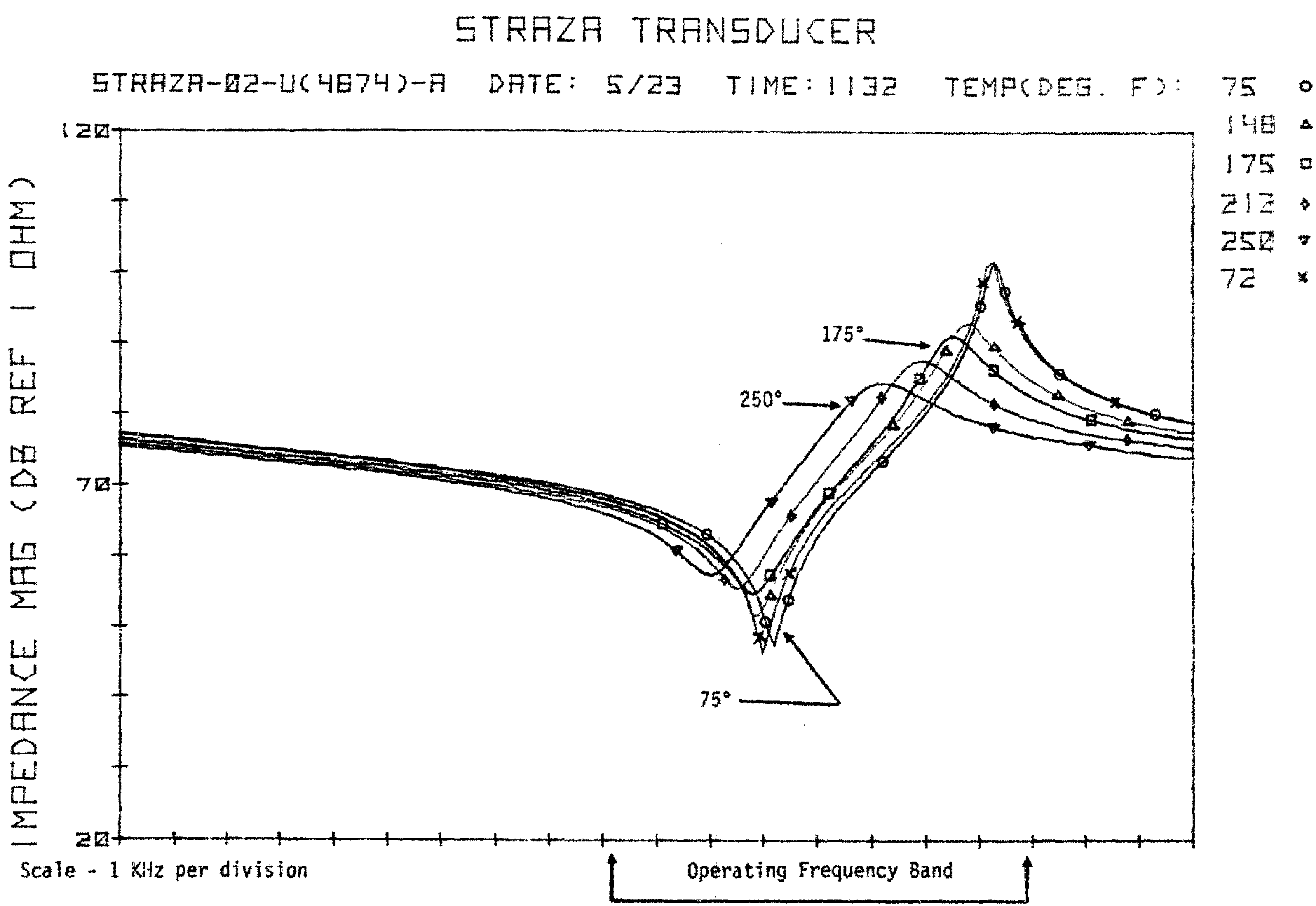


Figure 6-15a. Magnitude of In-Air Impedance Vs. Temperature for "Allegedly Good Resonator"

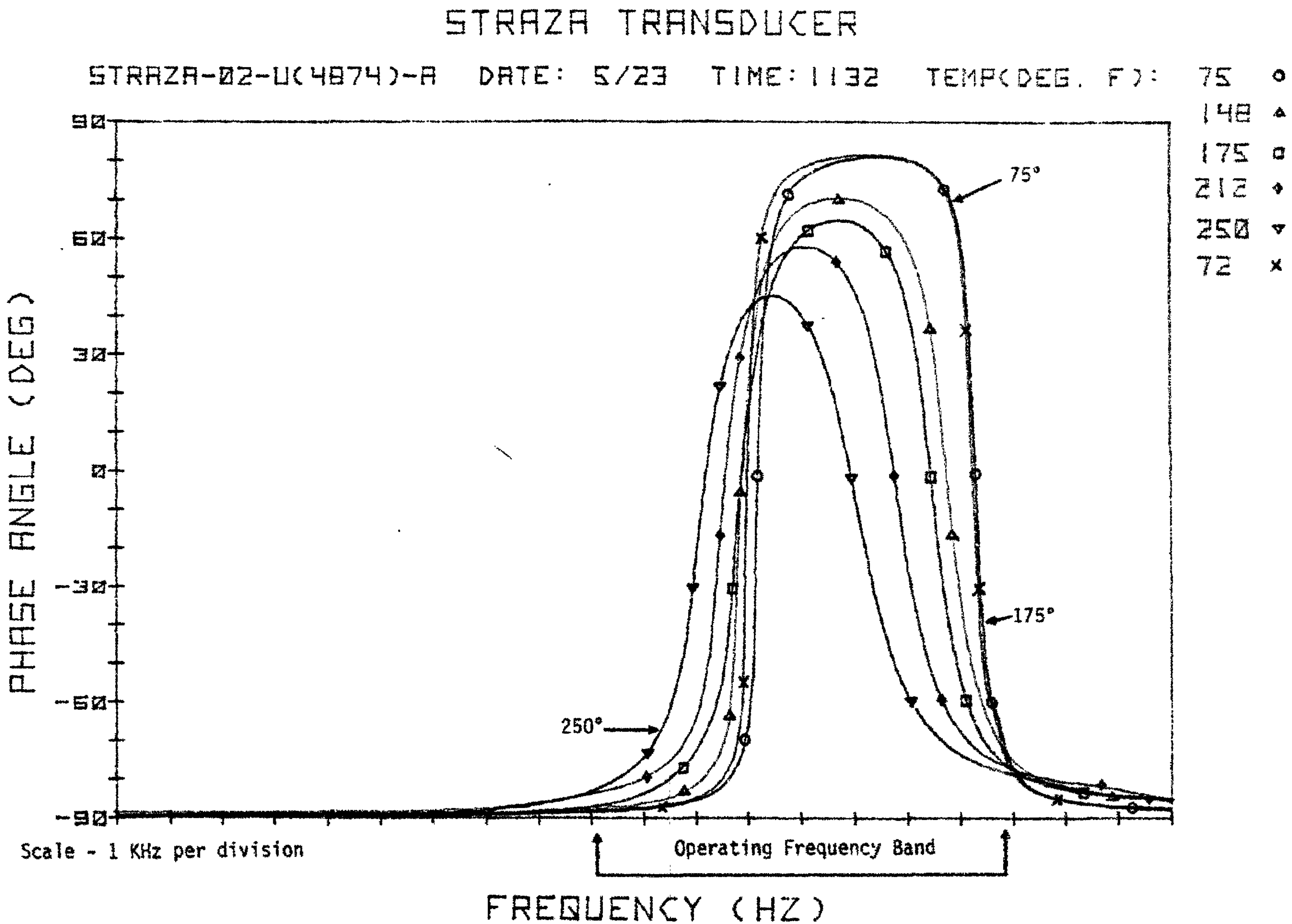


Figure 6-15b. Phase Angle of In-Air Impedance Vs. Temperature for "Allegedly Good Resonator"

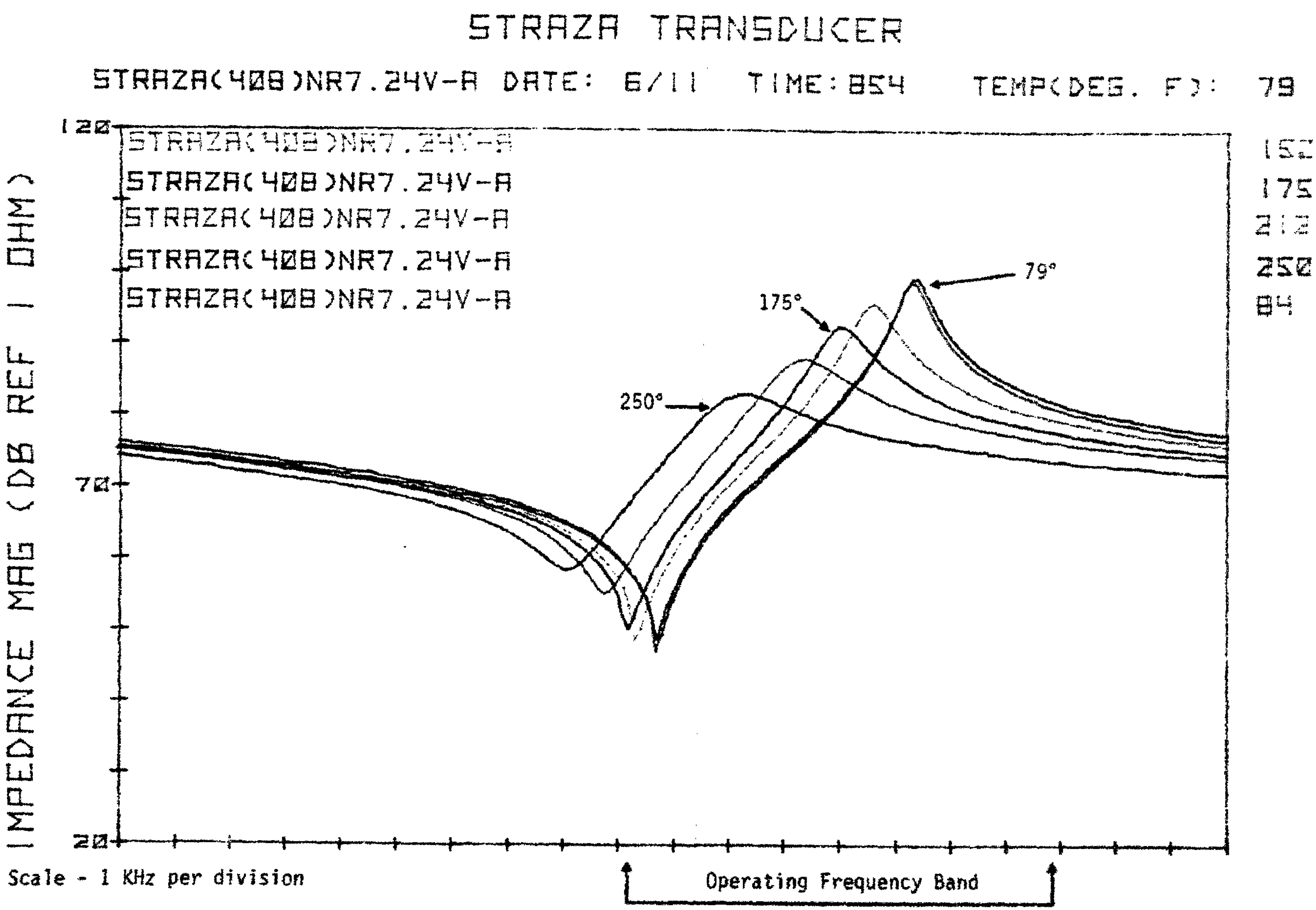


Figure 6-16a. Magnitude of In-Air Impedance Vs. Temperature with a Reduced Diameter Stress Rod

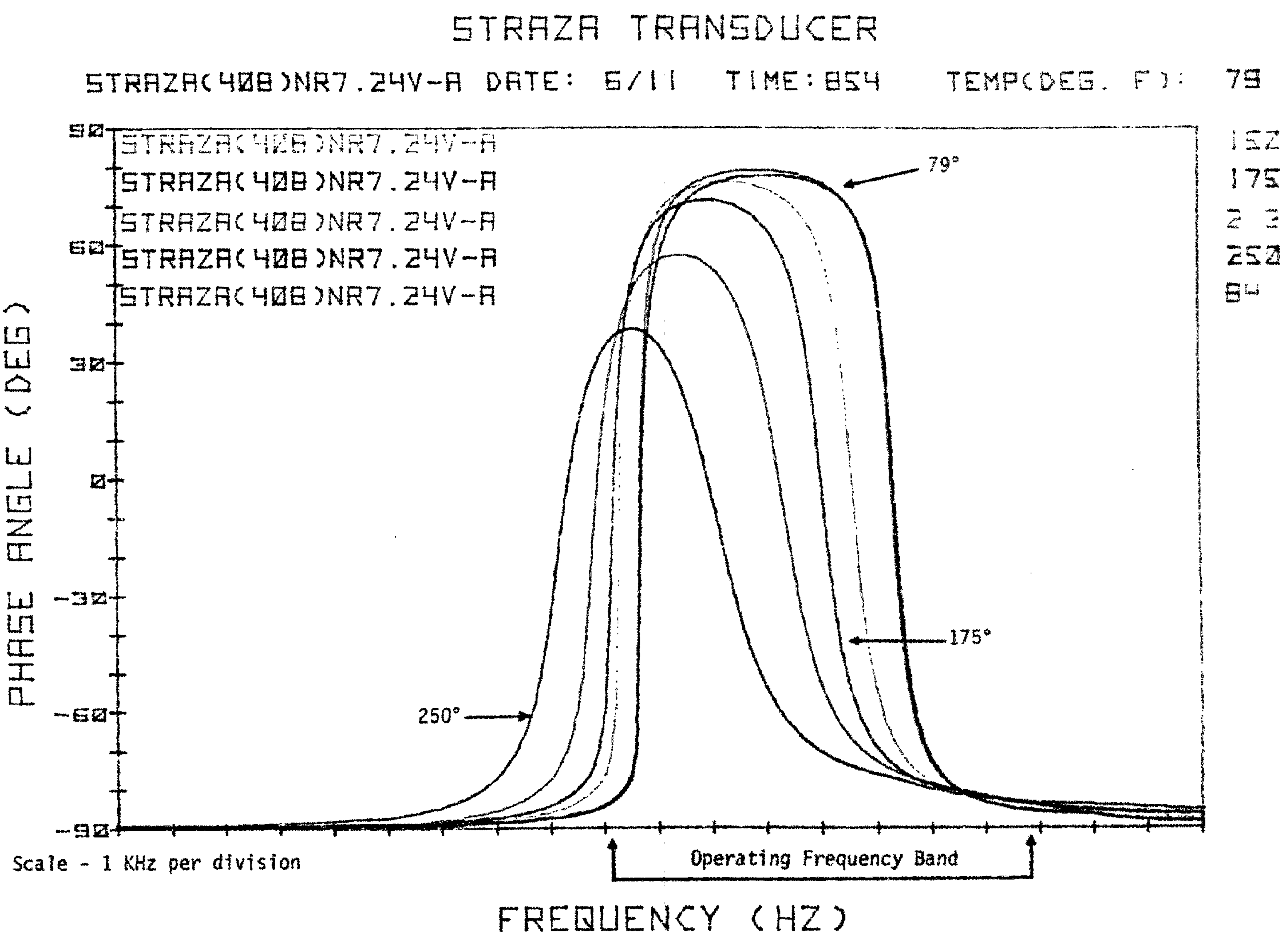


Figure 6-16b. Phase Angle of In-Air Impedance Vs. Temperature with a Reduced Diameter Stress Rod

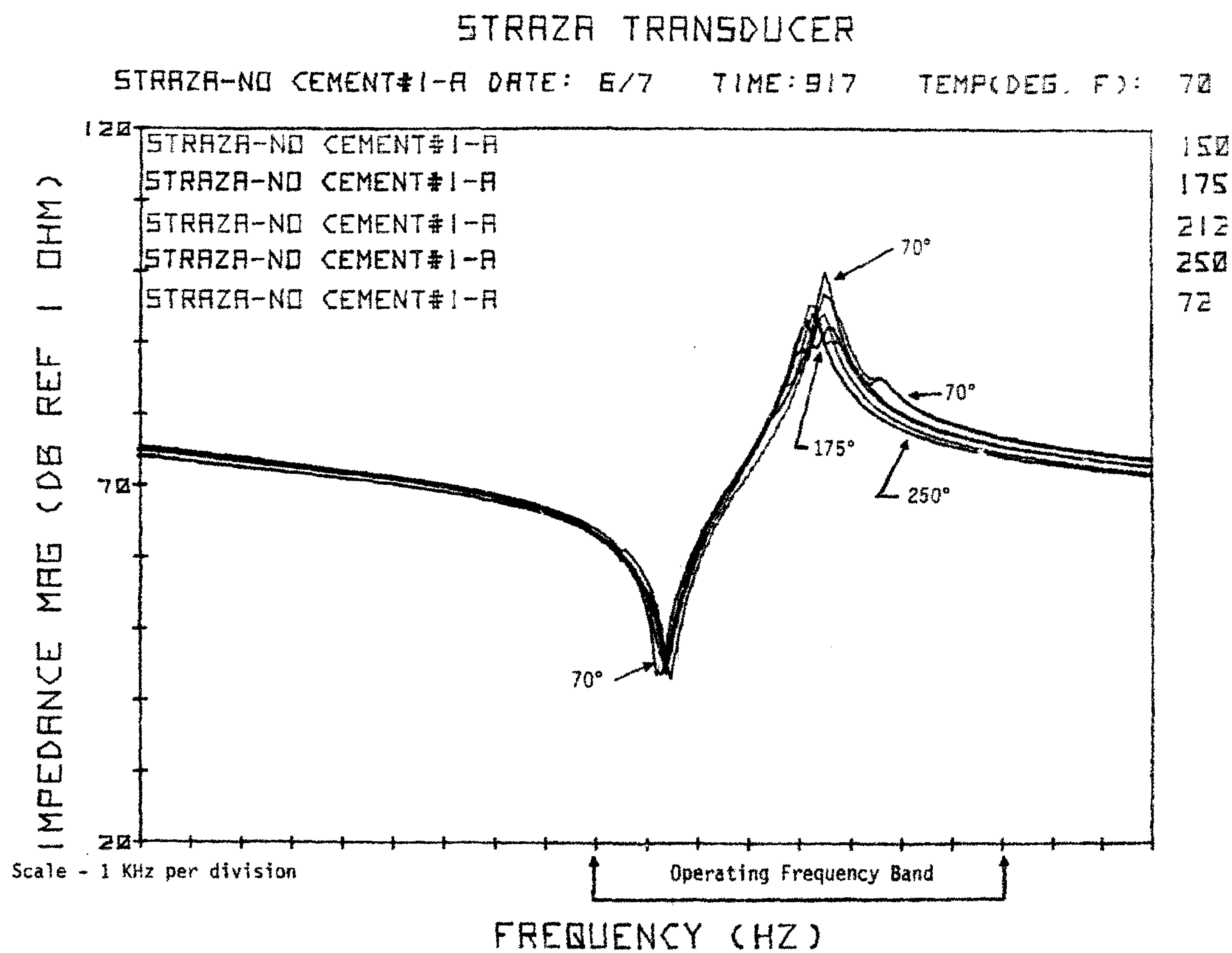


Figure 6-17a. Magnitude of In-Air Impedance Vs. Temperature with No Cement and High Prestress

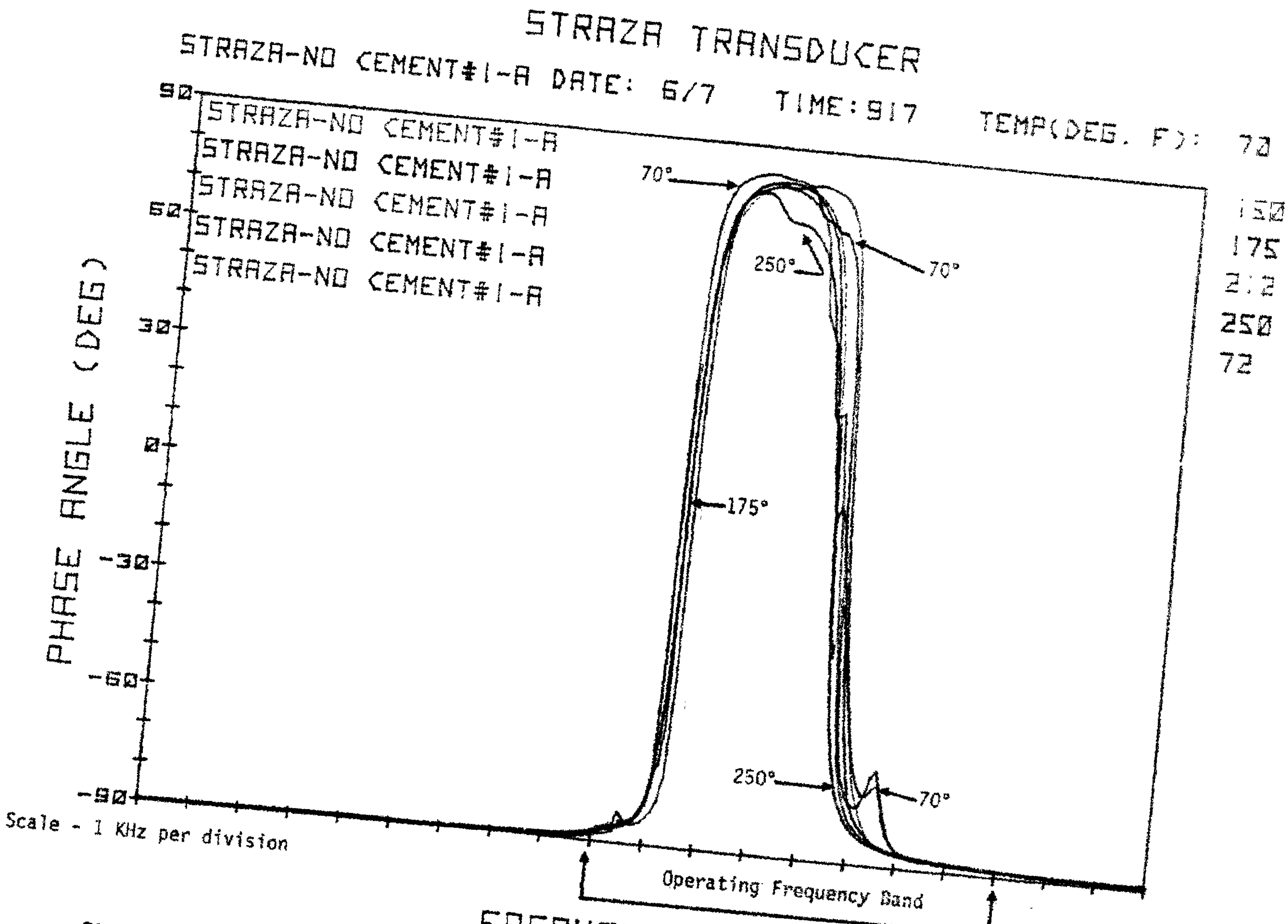


Figure 6-17b. Phase Angle of In-Air Impedance Vs. Temperature with No Cement and High Prestress

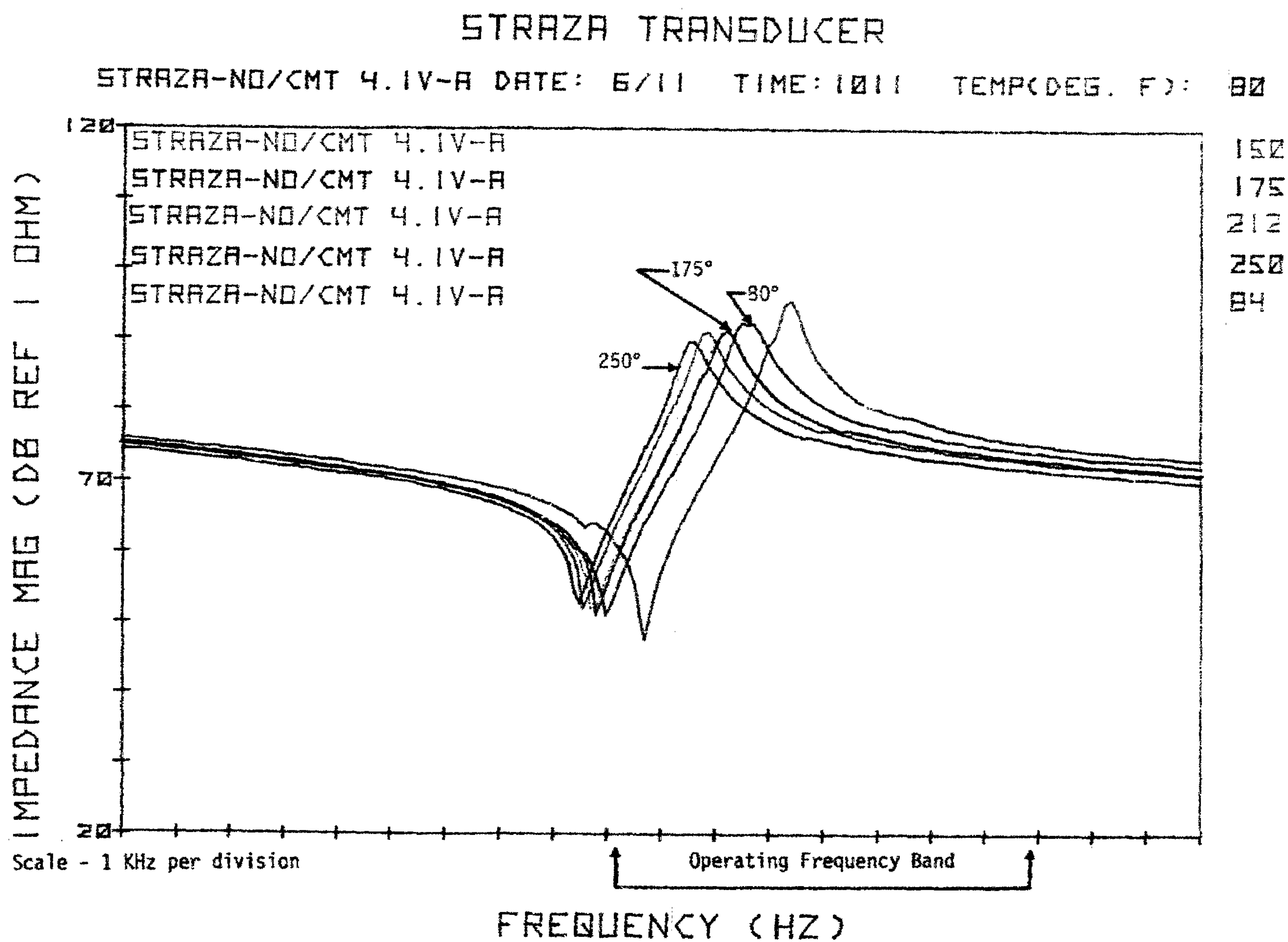


Figure 6-18a. Magnitude of In-Air Impedance Vs. Temperature with No Cement and Normal Prestress

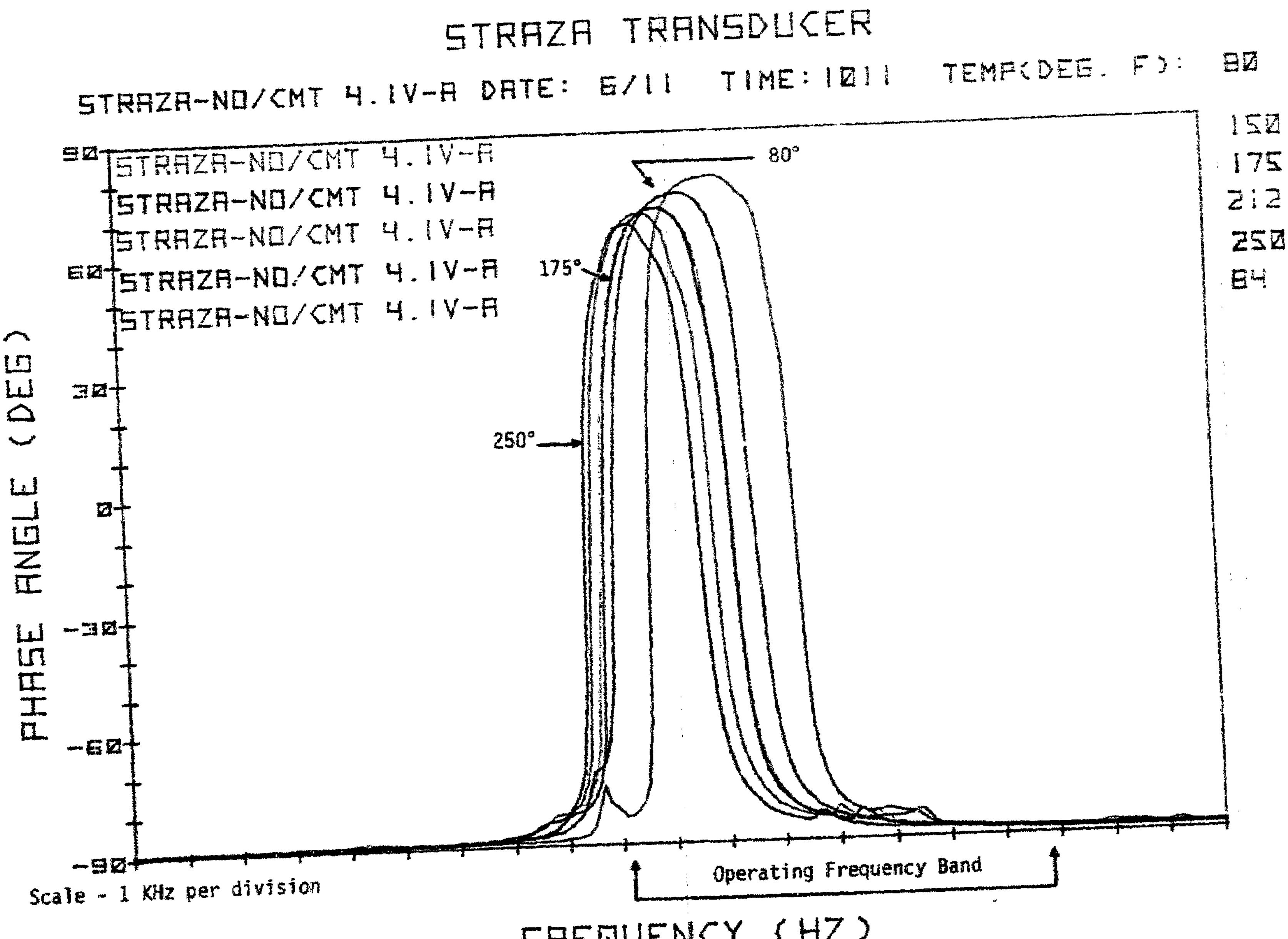


Figure 6-18b. Phase Angle of In-Air Impedance Vs. Temperature with No Cement and Normal Prestress

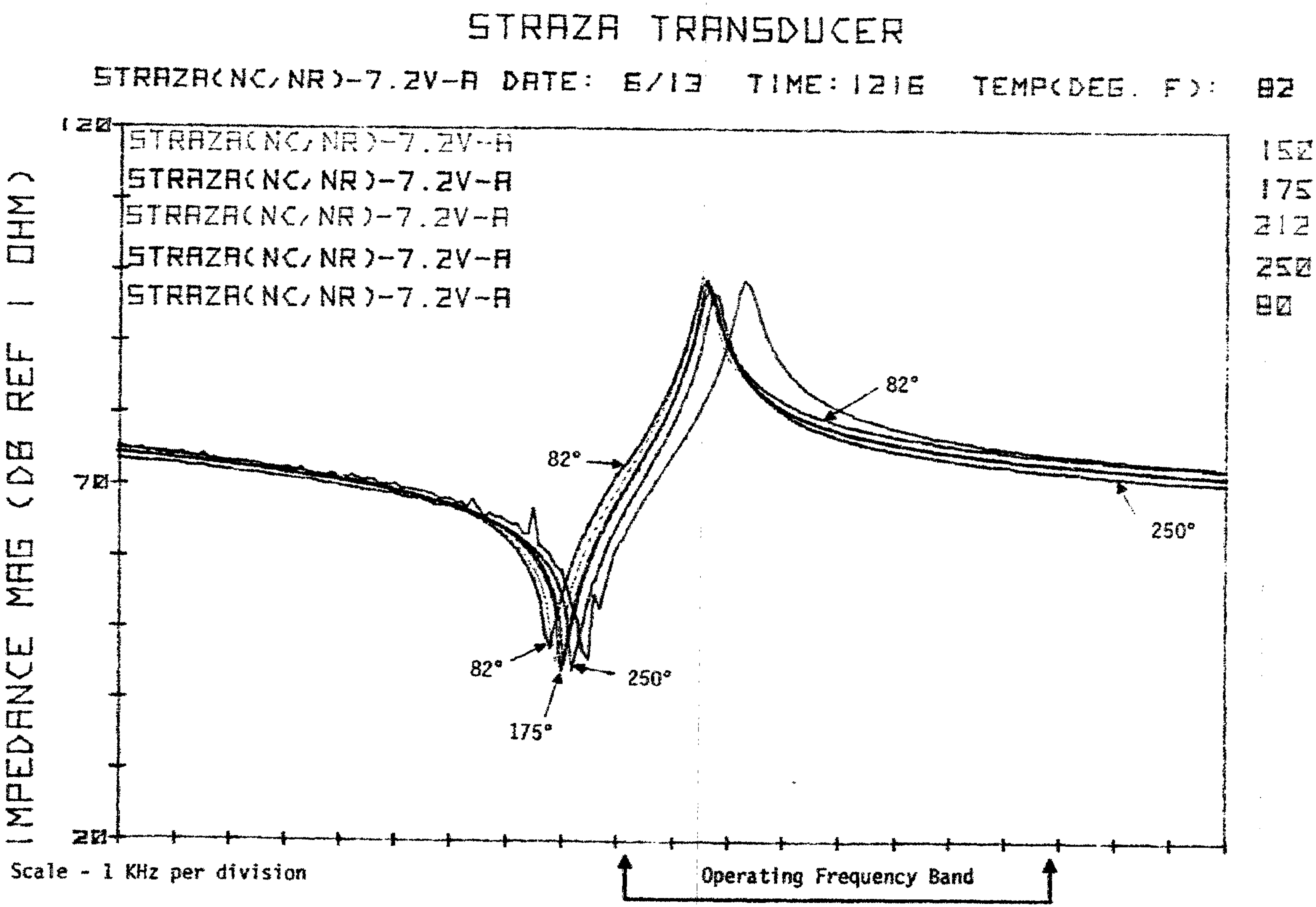


Figure 6-19a. Magnitude of In-Air Impedance Vs. Temperature with No Cement, Reduced Diameter Stress Rod, and Normal Prestress

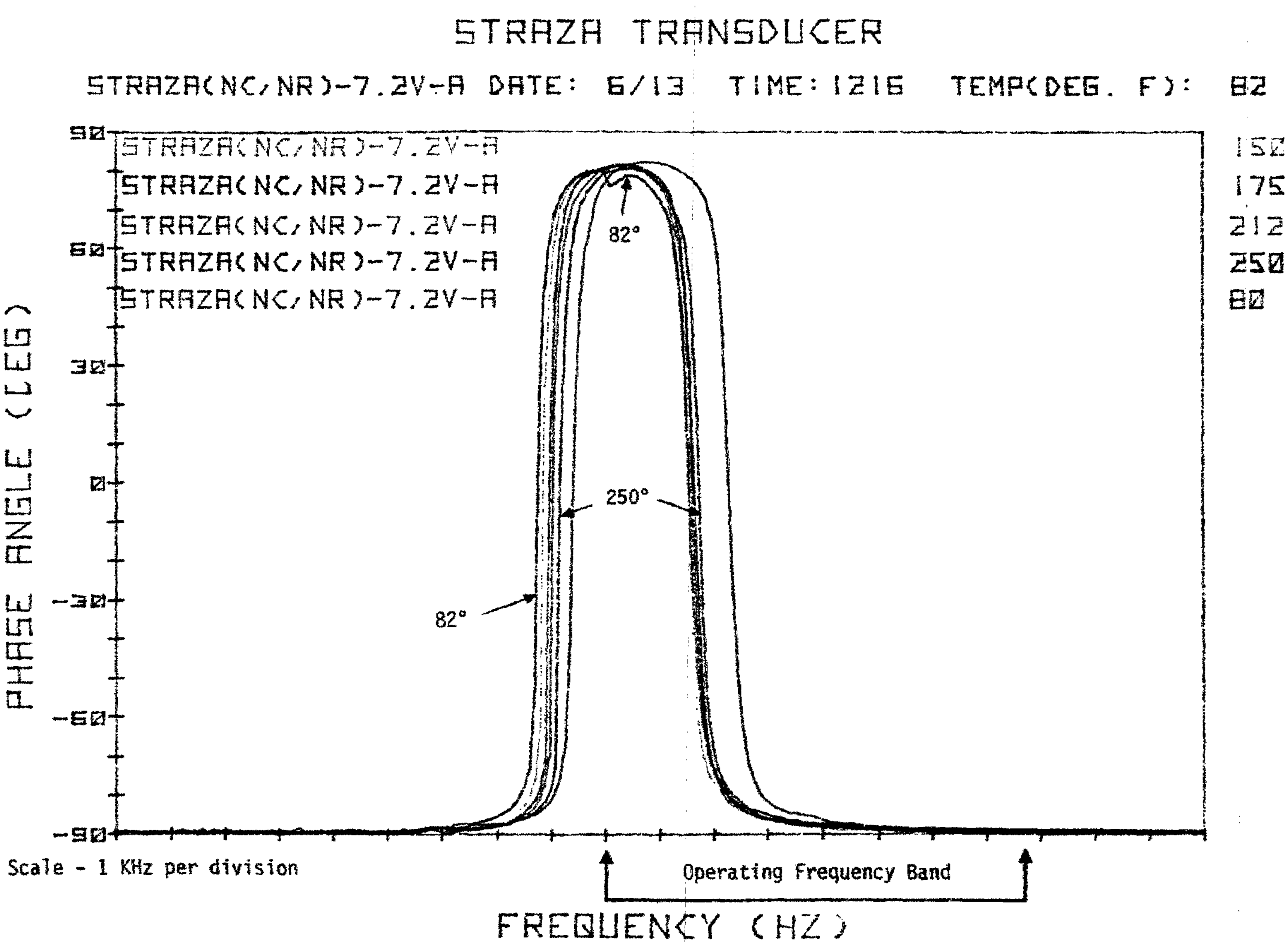


Figure 6-19b. Phase Angle of In-Air Impedance Vs. Temperature with No Cement, Reduced Diameter Stress Rod, and Normal Prestress

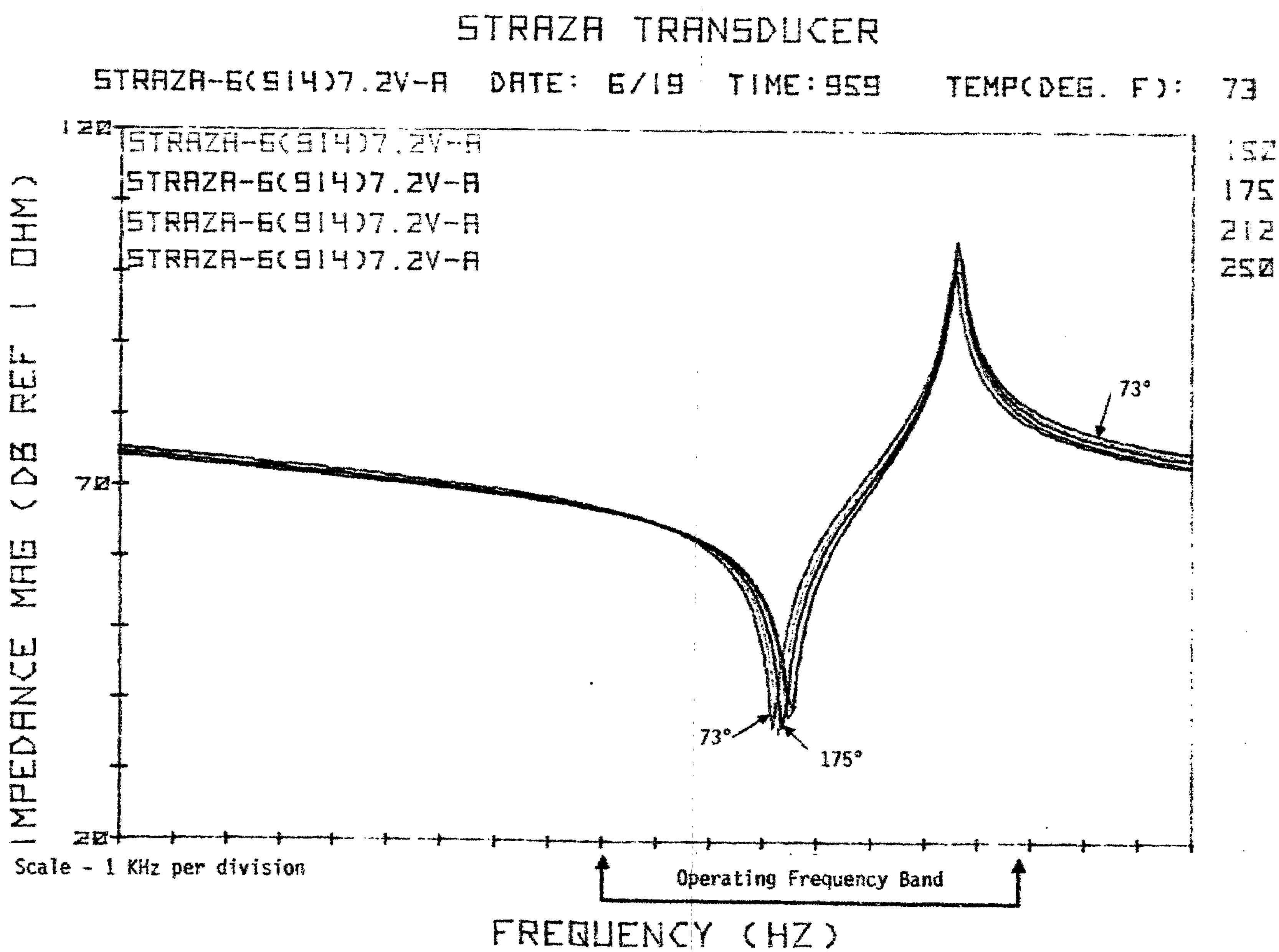


Figure 6-20a$_1$. Magnitude of In-Air Impedance Vs. Temperature with 914 Cement Joints

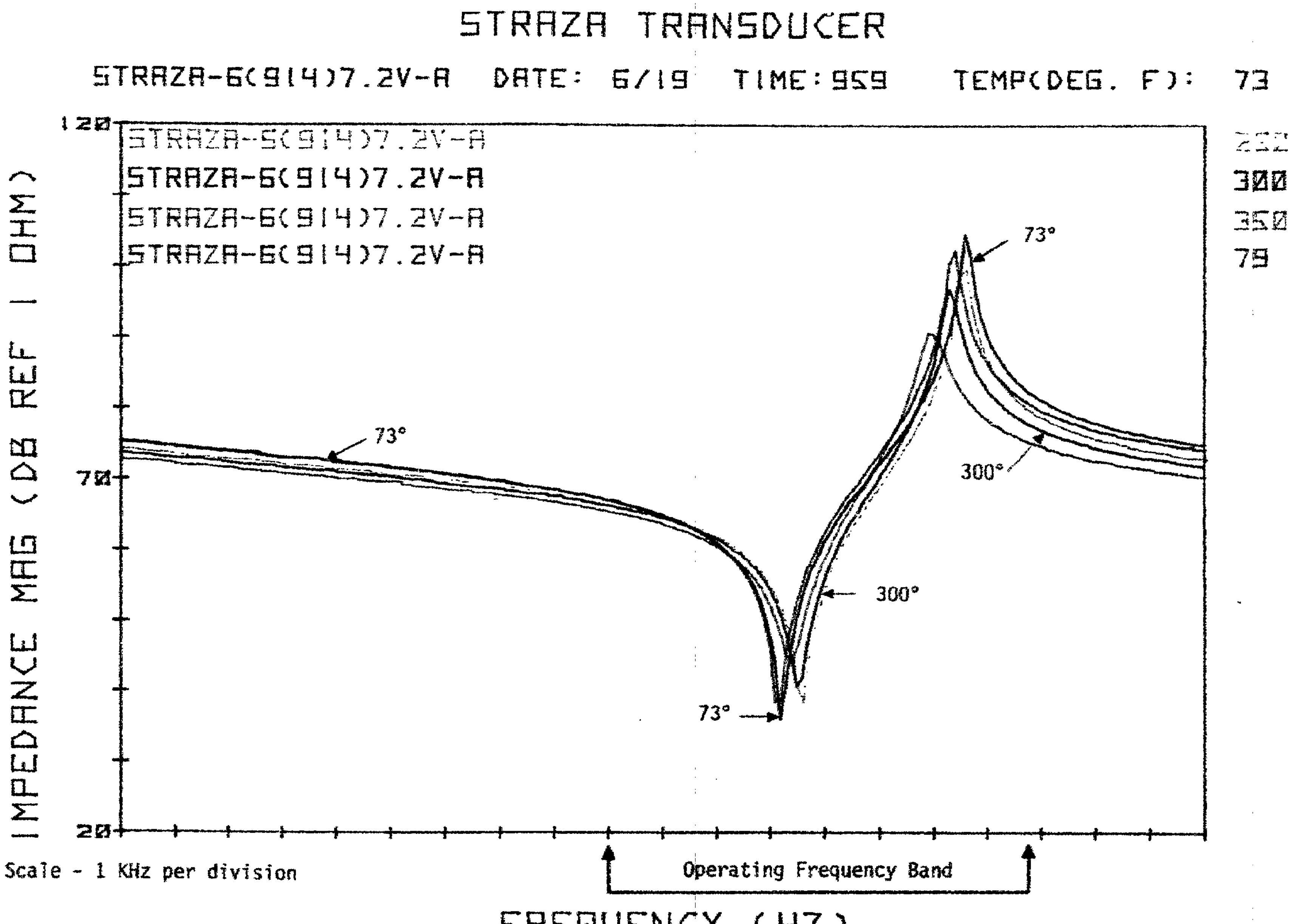


Figure 6-20a$_2$. Magnitude of In-Air Impedance Vs. Temperature with 914 Cement Joints (cont'd)

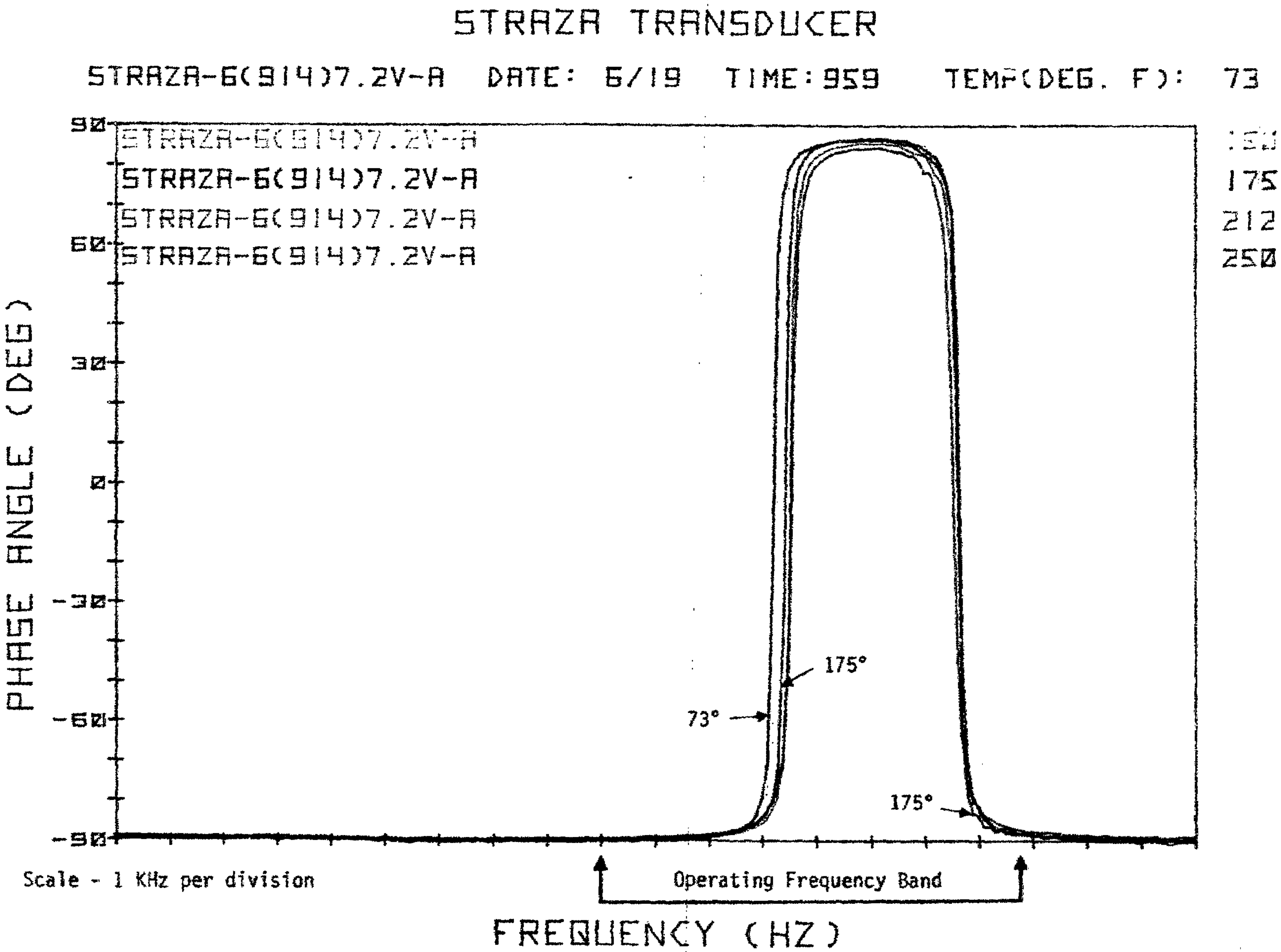


Figure 6-20b$_1$. Phase Angle of In-Air Impedance Vs. Temperature with 914 Cement Joints

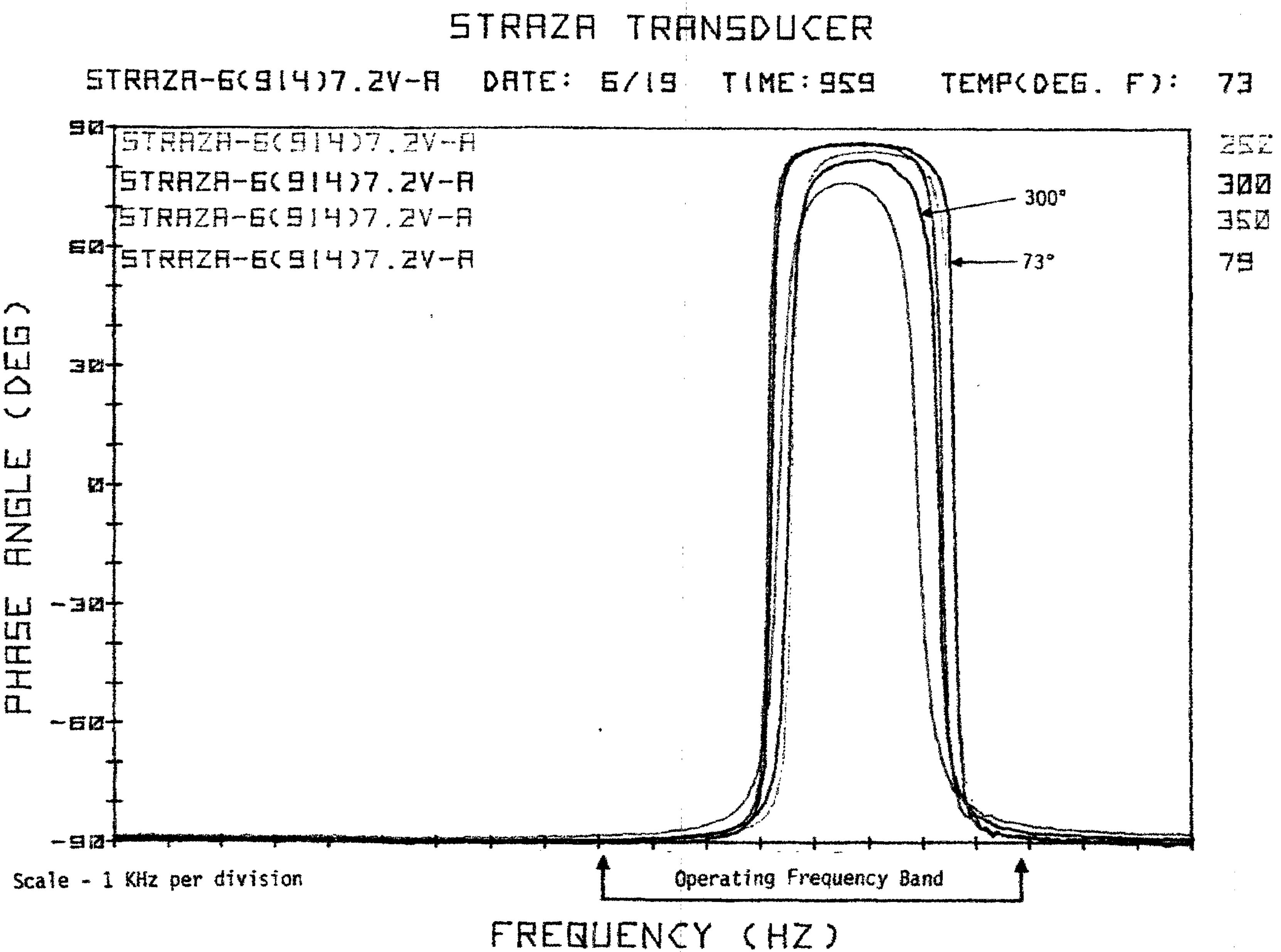


Figure 6-20b$_2$. Phase Angle of In-Air Impedance Vs. Temperature with 914 Cement Joints (con't)

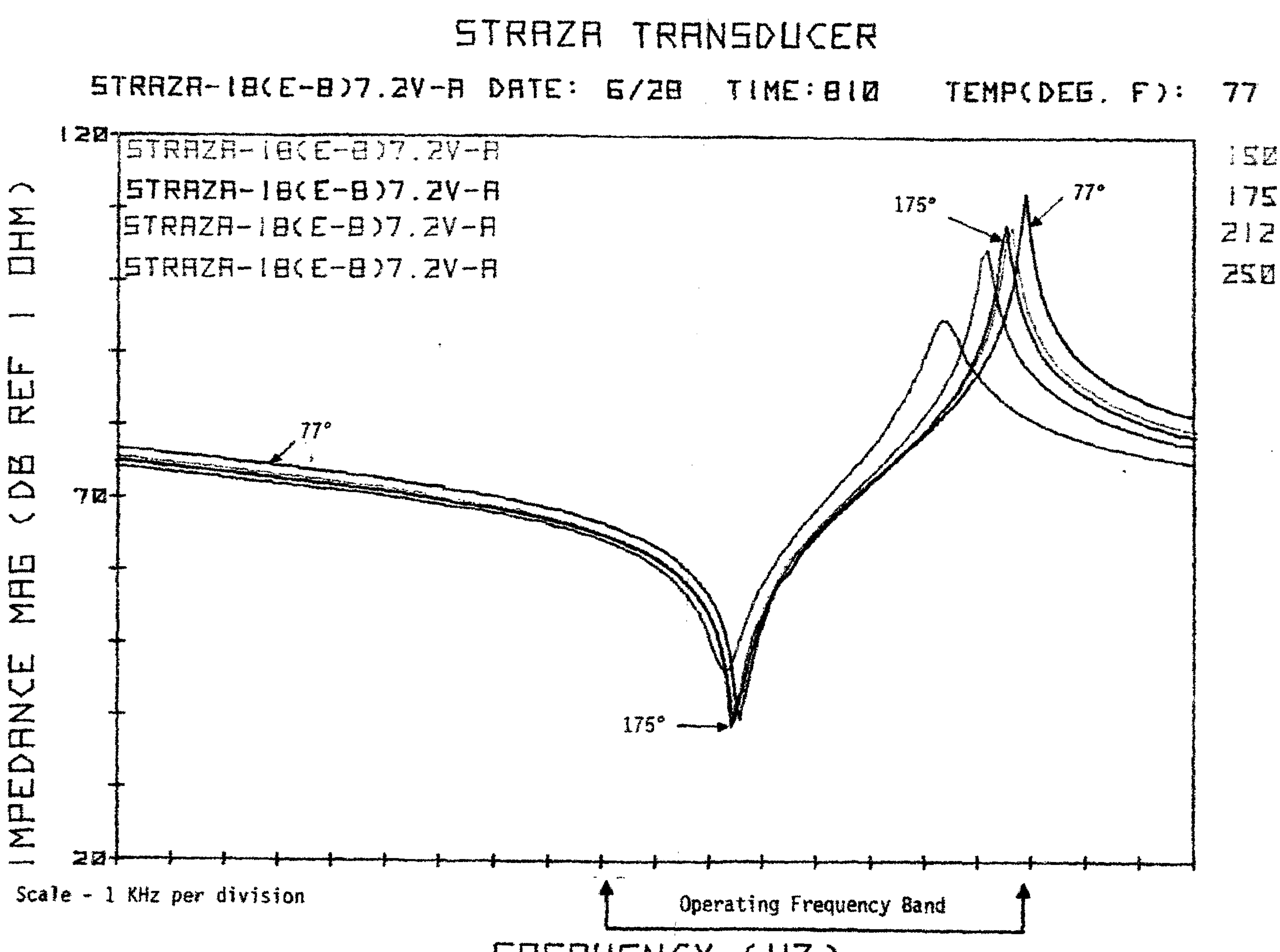


Figure 6-21a$_1$. Magnitude of In-Air Impedance Vs. Temperature with New Epon 8 Cement Joints and High Prestress

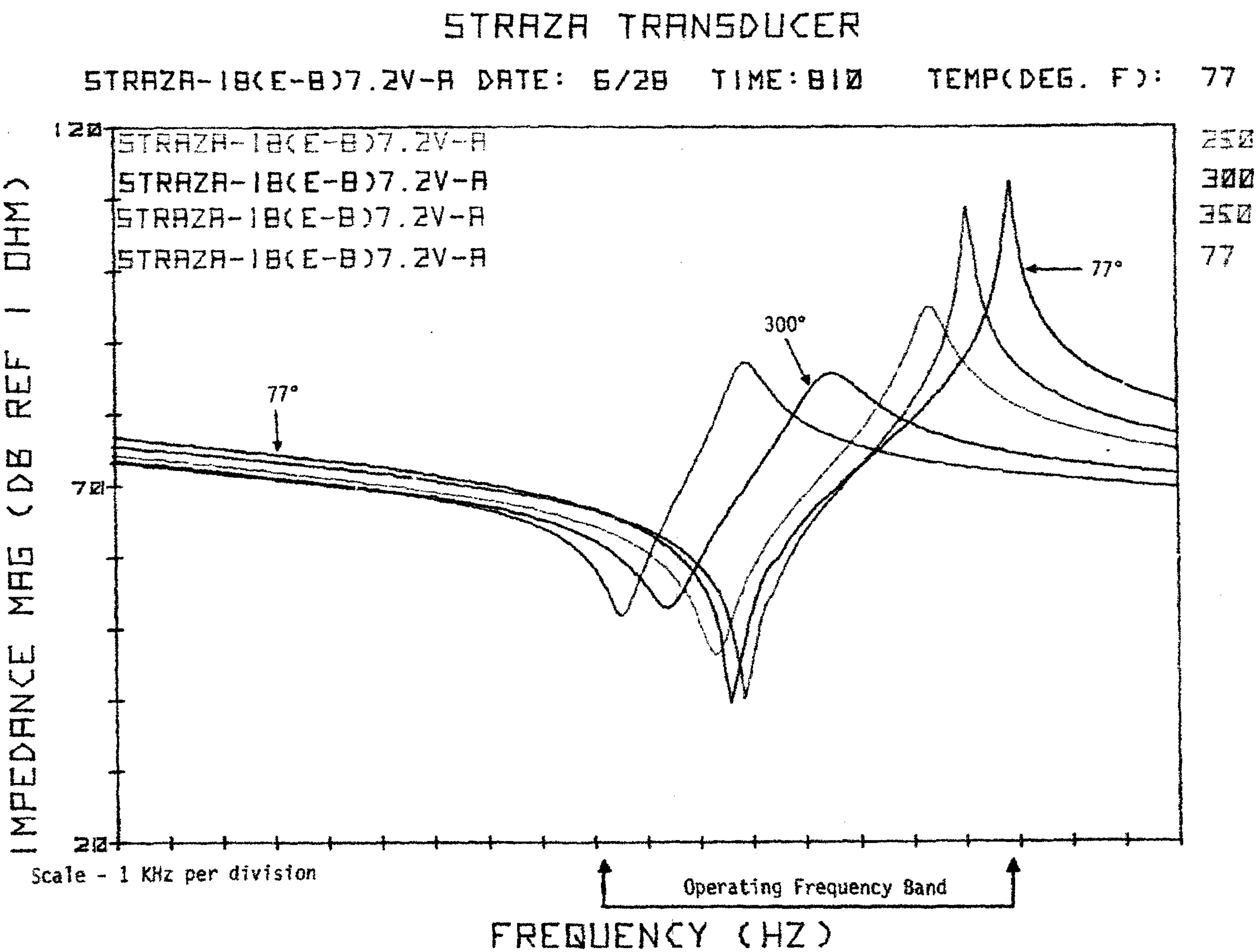


Figure 6-21a_2. Magnitude of In-Air Impedance Vs. Temperature with New Epon 8 Cement Joints and High Prestress

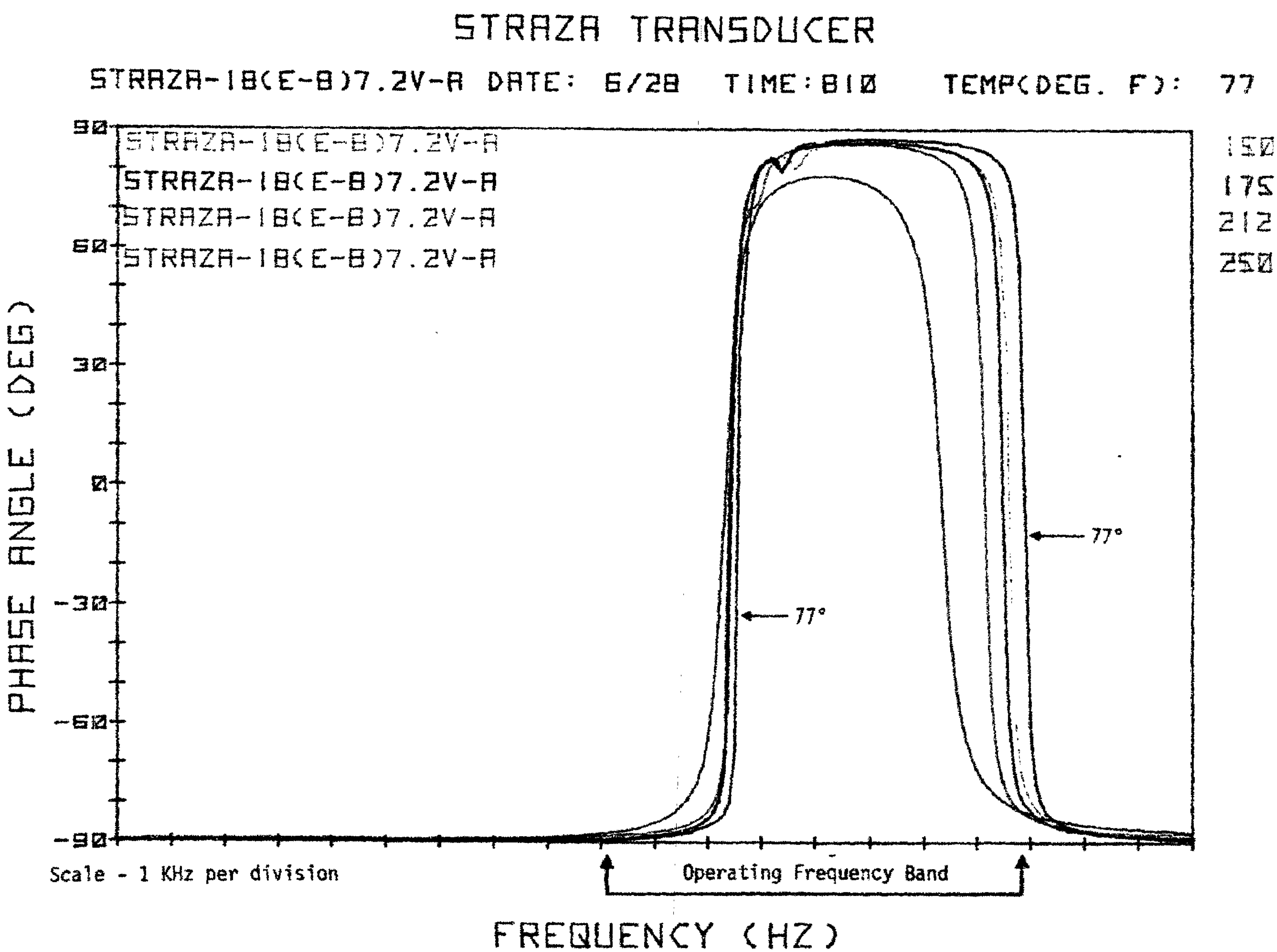


Figure 6-21b$_1$. Phase Angle of In-Air Impedance Vs. Temperature with New Epon 8 Cement Joints and High Prestress

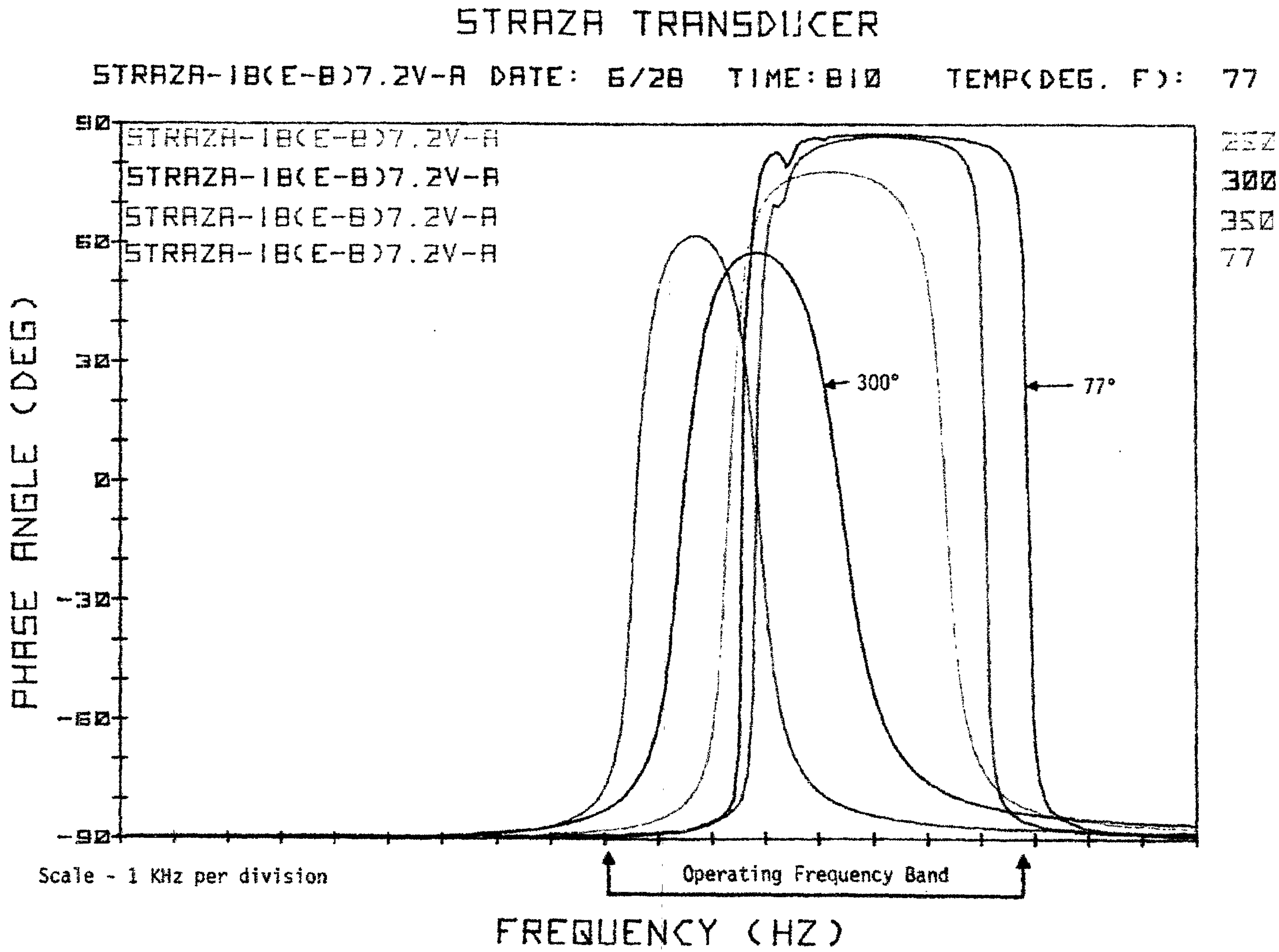


Figure 6-21b$_2$. Phase Angle of In-Air Impedance Vs. Temperature with New Epon 8 Cement Joints and High Prestress (cont'd)

For figures 6-14 to 6-21 the room temperature curves (in red) are the impedance and phase angle of the resonator after the heat tests (cooled for 16 hours or more after the highest temperature to which the resonator had been subjected). This provides a comparison with the initial room temperature before the heat test (in black).

In figures 6-14a (In-Air Impedance Magnitude) and figure 6-14b (In-Air Impedance Phase Angle), typical in-air impedance results versus temperature are presented for "bad resonators" from production transducer resonators used in the prototype TR-316s and similar to those from sections which failed the high-drive CUALT. This original Straza resonator, STRAZA-01-(3020)-A, was a PD wide beam section from S/N 1 Unit without Sylgard 184. Notice that results are presented for temperature measured in degrees Fahrenheit and appropriately color-coded for temperatures of 75°F (23.9°C), 150°F (65.6°C), 175°F (79.4°C), 212°F (100°C), 250°F (121.1°C), and 72°F (22.2°C). Even the highest of these temperatures, 250°F (121.1°C), is still well below the temperature for which the piezoelectric material normally encounters temperature problems. None-theless, even at 150°F (65.6°C), one observes in figures 6-14a and 6-14b a serious deterioration for the bad resonators. As the temperature is increased to what should still be a safe value of 250°F (121.1°C), one observes from the curves that all indications of the normal transducer resonance have dis-appeared, and indications of extreme losses have become evident. Note that just as in the composite TR316's, after the temperature is allowed to return to normal, even the "bad resonators" recover. Of course in the case of the composite TR316's, when the current was allowed to increase without limit, resonators were finally destroyed.

In figures 6-15a and 6-15b, typical in-air impedance results are presented for "allegedly good resonators" from T2 which passed the ocean portion of the high-drive tests. This original Straza resonator, STRAZA-02-U(4874)-A, was a PD up beam section from S/N 2 Unit with Sylgard 184.

Although the deterioration versus temperature is not nearly as devastating as in the case of the "bad resonators," nonetheless, serious deterioration of the resonator's performance is indicated. Specifically, in figure 6-15a, for the magnitude of the in-air impedance, one notices a drastic shift downward in the resonance frequency versus temperature, as well as a drastic deterioration in the dB spread between F_n and F_m -- once again indicating unacceptable increases in losses versus resonator temperature. The bandwidth, as indicated by the difference in frequency between F_n and F_m, is also deteriorating with increasing temperature. The corresponding results for the in-air impedance phase angle shown in figure 6-15b present an alternate indication of the same deterioration in resonator performance versus increasing temperature. Notice, as in the case of the "bad resonators," the "good resonators" recover when the temperature is allowed to return to low values, namely, approximately 75°F.

In figures 6-16a and 6-16b, the in-air impedance versus temperature results are presented for a resonator using a reduced-diameter stress rod. Straza resonator STRAZA (408)NR7.24V-A was constructed with Epon 8 adhesive (stressed with 2.8 N-m (25 in-lb) torque before adhesive cure) and a thinned-down stress rod (OD range from 0.47 to 0.30 cm or 0.186" to 0.120"). This resonator was considered to assure that the correct prestress was being applied to the piezoelectric stack via the stress rod. In order to maintain consistency prior to testing configurations 3, 6, 7 and 8 (as designated on page 6-33), a stress was applied by NOSC which developed 7.2 volts on a 0.97 microfarad capacitor. This voltage corresponds to approximately 30 kPa (4500 psi) prestress in the ceramic.

Consideration of a resonator incorporating a reduced-diameter stress rod came about as follows. First, it was noticed that the stress-rod area of the TR-316 was quite large compared to the piezoelectric ceramic area, when compared to other typical longitudinal vibrators. Furthermore, investigation at the factory uncovered the fact that Straza used stress-rod tension to fine tune the resonators. In addition to not being considered a valid fine-tuning approach (the change in ceramic parameters is only temporarily altered since with time the ceramic stack parameters will return to almost the prestress condition), this technique was leading to erratic prestress values in the different resonators. In addition, Straza used the torque-wrench method (5.7 N_m - 50 in-lb) in determining what tensions they had applied in the stress rod. It is known from experience that the torque-wrench method is notoriously inaccurate and can result in almost any value of torque on the different resonators. For example, the ceramic stack might not be stressed at all if the nut siezed upon the threads of the stress rod. Measurement of the charge generated during prestressing is one acceptable technique.

Based on this knowledge, it was speculated that in some transducers with the lower stress values, when accompanied by the extra-large diameter of the stress rod, one might encounter a condition where the stress rod released most or all of the prestress versus increasing temperature. It was further speculated that this could lead to a chain reaction that might account for the increase in current, and ultimately, the current-runaway condition. However, examination of figures 6-16a and 6-16b shows that the resonator incorporating a reduced-diameter stress rod and the proper stress still exhibited drastic detrimental changes versus increasing temperature. In particular, this resonator incorporating the reduced-diameter stress rod with the known recommended normal stress (nominally used in the Straza production) was no better than the "allegedly good resonators," whose results are indicated in figures 6-15a and 6-15b.

With the reduced-diameter stress-rod-resonator results in hand, it seemed obvious that the problem leading to current runaway must either be associated with the piezoelectric material or the cement joints. Experienced transducer specialists did not believe that the cement joints could account for the problem, but as it turns out, they were wrong.

In figures 6-17a and 6-17b, the in-air impedance versus temperature results are presented for a resonator, STRAZA-NO CEMENT #1-A, with no cement joints and a high prestress in the production-line stress rod (the larger-diameter stress rod) equivalent to 11.3 N-m (100 in-lb) instead of 5.7 N-m (50 in-lb). Notice that there are practically no changes in resonant frequency or dB spread with increasing temperature for this non-cement joint radiator as compared to the previous resonators considered.

In passing, it is noted than the frequency spread between F_n and F_m is less than for some of the previous resonators examined at low operating temperatures. It is also noted there is some evidence that joints without cement do not have good mechanical couplings. However, these results are considered incidental to the study and were not pursued further.

Since an extra-high prestress was applied to the resonator used to derive the data shown in figures 6-17a and 6-17b, it was decided that the resonators should be restressed to normal prestress values to determine the role of the prestress in the satisfactory results accompanying the non-cemented resonators. Figures 6-18a and 6-18b, STRAZA-NO/CMT 4.1V-A, present the results for the no-cement joint, normal prestress 5.7 N-m(50 in-lb torque) resonator using the production stress rod. In this case, one finds a drastic shift in resonant frequency with increasing temperature but not the drastic indication of high losses versus increasing temperature. It was speculated that this effect was due to the large-diameter stress rod relieving the prestress as the temperature was increased. This conjecture was confirmed (as described in the next paragraph) by replacing the large stress rod with the reduced-diameter stress rod in the non-cement joint resonator.

Figures 6-19a and 6-19b present the results for a resonator with no-cement joints and reduced-diameter stress rod, 0.30 cm (0.120" OD), under normal initial prestress. Examination of these results shows that the shift in resonant frequency versus temperature even with normal prestress has been eliminated by replacing the large stress rod with the reduced-diameter stress rod. These results are later used to argue that either a reduced-diameter stress rod or higher prestress in the larger-diameter stress rod must be used (to stretch them sufficiently).

Figures 6-20a_1 and 6-20a_2 (presenting magnitude of impedance) and figures 6-20b_1 and 6-20b_2 (presenting phase angles of impedance) present the in-air impedance results versus temperature for a resonator, STRAZA-6 (914) 7.2 V-A, constructed with a different cement, namely, 914 cement joints instead of the previously used Epon 8 cement. The stress rod was prestressed to 11.3 cm (100 in-lb) before adhesive cure. Two graphs are presented where previously one sufficed, because additional extra-high temperature values were required before any sign of detrimental results occurred. The 914 cement cured at approximately 56°C (100°F) higher than Epon 8, and consequently could withstand the higher temperature before showing deterioration. These results confirm this expectation that essentially no deterioration is noted up to 121°C (250°F). It should be noted, however, that 914 cement has a recommended cure temperature of 204°C (400°F). This temperature is above that which would cause deterioration of ceramic electro-mechanical properties and therefore is not recommended for production transducers.

In Figures 6-21a_1, 6-21a_2, 6-21b_1, and 6-21b_2, in-air impedance versus temperature measurements are presented for a resonator, STRAZA-13 (E-8) 7.2 V-A, using Epon 8 as in the production resonators, but with a new construction technique to produce improved Epon 8 cement joints. Specifically, during the curing of the Epon 8 cement, a much higher prestress, 11.3 N-m (100 in-lb) torque, is applied so that the joints will be more uniform and thinner than before, thus having less Epon 8. It was reasoned that the previous low and probably erratic prestress applied by Straza had resulted in correspondingly erratic cement joints of varying and excessive thickness. Even if the previously selected lower prestress used both for curing and simultaneous assembly had been achieved, it was speculated that the cement joints might have been excessively thick.

The results indicate that the new Epon 8 cement joints are satisfactory up to and including a temperature of at least 100°C (212°F). It should also be noted that in going to the improved Epon 8 cement joint construction and higher stress-rod prestress, as opposed to the old construction, an increase in delta F between resonance and anti-resonance and an increase in the amplitude between anti-resonance and resonance points were measured. Attention is also called to the fact that these resonators also incorporated the large stress rod but used the new high-prestress value in order to stretch these large stress rods sufficiently to eliminate relaxing of prestress versus temperature.

A comparison of the resonator results using the new Epon 8 cement joints with those using the 914 cement joints (figure 6-20) indicates that resonators with the former cement joints have a larger bandwidth than the latter cement joints. An explanation of this result was never pursued; however, it was conjectured that the higher curing temperature of the 914 cement had contributed to some slight depolarization of the piezoelectric material. These results plus concern about possible thermal-shock problems using 914 cement were considered in recommending use of the properly constructed Epon 8 cement joints to help solve the current-runaway problem.

6.1.13.3 Temperature and Sound-Pressure-Level Monitoring in the Composite TR-316

Section 6.1.13.2 described definitive results for the resonators versus artificially induced increasing temperature. The question of what temperatures actually resulted during operation of the composite TR-316 transducers under high-drive-level conditions still had to be answered. These stabilization temperatures for the resonators in the composite transducer were required not only for the old resonators but for resonators incorporating the new improved Epon 8 cement joint construction technique and the higher stress-rod prestress.

While reviewing the current-runaway problem relative to temperature, it was noted that the thermal conduction path for cooling of the resonators was poor in both the prototype and first article TR-316s. The resonators were surrounded on the sides by the micarta resonator retainer block (see figure 4-2), in the back by the pressure release pads and in the front by the rubber window. Thus, there was no direct contact of the fill fluid to the metal case. As a result, a very poor thermal cooling path to the outside water heat sink existed. The government technical team, therefore, decided to investigate a design which replaced the poor thermal-conducting micarta resonator retainer blocks with an aluminum resonator retainer block. This design puts the fill fluid in contact with the good thermal-conducting aluminum block, which is in turn in contact with the outside steel case interfacing with the water.

A number of combinations of transducers were tested to determine the temperatures at which stability occurred. This testing was performed both by Straza and NOSC. In the case of Straza, the tests were performed using a frequency sweep, Δf, which is all that is required by the specifications. At NOSC, a single-frequency test, f_o, was performed for more uniformity between combinations of transducers, such as those with aluminum blocks, micarta blocks, and those with Epon 8. NOSC also performed a frequency-sweep test on the combinations of most interest, namely, the units with the micarta block and the aluminum block using the new assembly technique and Epon 8. For the NOSC new Epon 8 resonator composite TR-316 configurations, the same set of resonators was used in all experiments (i.e. both in the micarta and aluminum blocks). Temperature monitoring was accomplished in the wide beam sections by bonding a thermister to the nodal ring of the center resonator.

For all of the combinations of trial designs tested, the sound-pressure level was monitored as well as the temperature of the resonators. The voltage to achieve the required sound-pressure level varied in general from 120-130 Vrms. It is important to note that at Straza the beam patterns were recorded for the various PD sections tested (old and new assembly techniques in micarta and aluminum blocks) and were essentially the same. Except for the case involving the old Epon 8 cement joints with the normal prestress in the resonators, the sound-pressure level at the stabilization temperatures did not vary significantly from that measured at the beginning of the experiment, namely, with the resonators at the same temperature as the water. For the case using the old Epon 8 cement joints (that is, the old resonators), as before, a current-runaway condition was encountered and, in fact, the current-runaway condition occurred so rapidly that no measurements of the sound-pressure level at high temperatures were obtained (since stabilization of temperature was not achieved).

Table 6-2 summarizes the steady-state stabilization temperatures for some of the more interesting experimental design configurations performed at NOSC. These are the temperatures which were finally reached during high drive of TR-316 experimental PD up and PD down sections as indicated in figures 6-22 through 6-26. In some of the tests there were minor interruptions in testing which caused a discontinuity in the curves.

Column 1 of table 6-2 indicates which set of resonators was considered, namely, the set using the old Epon 8 cement joints or a set using the new Epon 8 cement joints, which were cured using a higher prestress. For the cement joint curing process the new cement joints were stressed by applying 11.3 N-m (100 in-lb) torque to the nut on the stress rod as versus 2.8 N-m (25 in-lb) for the old joints (referred to as normal prestress). The second column contains the results using the micarta resonator retainer block. This column is further divided to present results for single-frequency (labeled f_0) and frequency-sweep testing (labeled Δf). Column 3 contains the results for the aluminum resonator retainer block configuration. The last column, column 4, indicates the outside water temperature. Only two temperatures were considered, the normal TRANSDEC calibration facility temperature at the time of 22°C (72°F) and the higher temperature required by the specification, namely, 32°C (90°F). As indicated in table 6-2 by an asterisk, some combinations of experimental designs and drive conditions were not considered, due to a lack of time and priority requirements. Details of the results presented in table 6-2 plus additional data are presented below for completeness of documentation.

At NOSC, the following results were obtained: for Epon 8 using the new assembly technique, aluminum block, and single frequency drive, the temperature stabilized at 65°C (150°F) (figure 6-22). The same set of resonators used in the previous experiment was then placed in a micarta block at single-frequency drive and the temperature stabilized at 85°C (185°F) (figure 6-23). It should be noted that the source level between those two experiments was maintained within 1 dB. The temperature difference of 20°C (36°F) is probably a useful number to represent the difference between the aluminum block and micarta block configurations.

Table 6-2. Resonator Stabilization Temperatures in the TR-316

1 Transducer Set	2 Micarta Block		3 Aluminum Block		4 Water Temp.
	f_o	Δf	f_o	Δf	
Old Epon 8	Current runaway	*	*	*	22°C (71.6°F)
New Epon 8	85°C (185°F)	85°C (185°F)	65°C (149°F)	65°C** (149°F)	22°C (71.6°F)
New Epon 8	*	92°C (197.6°F)	*	72°C** (161.6°F)	32.2°C (90°F)

*not tested

**an anticipated value

For the combination of Epon 8, new assembly technique, micarta block, and frequency sweep, the temperatures stabilized at 85°C (185°F) and 92°C (197.6°F) for initial water temperatures of 22°C and 32.2°C, respectively (figures 6-24 and 6-25).

For the combination of Epon 8 using the old assembly technique and a micarta block and single-frequency drive, the temperature reached 137.8°C (280°F) (figure 6-26) and was still rising with no apparent inclination to stabilize when the experiment was terminated. The temperature-rise experiment on the complete transducer in conjunction with the in-air impedance measurements explains why a runaway condition exists on the old transducers. The improperly formed cement joints were the cause of the problem. No other combinations using the old Epon 8 cement joints were considered because utilization of this construction had been definitely ruled out for the future.

Some combinations using the Epon 914 epoxy cement and the aluminum block and the micarta block with thin joints were tested. These tests, however, were not controlled like those for the Epon 8 cement joint resonators in that the same resonators were not tested in both the micarta and aluminum blocks. In general, the results were the same as for the Epon 8, since the aluminum block PD configuration stabilized at a significantly lower temperature than that of the micarta block PD configuration.

The results at Straza were as follows: for the resonators using Epon 8, the new assembly technique, a micarta block and frequency-sweep drive, the temperature stabilized at 78°C (173°F). For the new assembly technique, Epon 8 and the aluminum block, the temperature stabilized at approximately 65°C (150°F) (no figure presented). Recall that at Straza, the frequency is swept, which is all that is required according to the specifications. For the micarta block and new Epon 8 resonators the difference between the NOSC value of 85°C and the Straza value of 78°C can be easily explained by the fact that different resonators were used as well as possibly different measurement techniques.

Conclusions were arrived at from the above temperature stabilization testing. Trends for the new Epon 8 composite TR-316 results are particularly significant, since the same resonators were used in the aluminum and micarta retainer blocks. The pertinent trends to be noted are:

1. There are no significant differences in temperature rise between single-frequency and frequency-sweep drives;

2. There is about a 20°C (36°F) stabilization temperature differential between the micarta and aluminum block configurations (this gives a decided advantage to the aluminum block composite TR-316 with regard to the reduction of both temperature and the tendency for current runaway);

3. An increase of 10°C in ambient from 22° to 32°C results in a corresponding increase of 7°C in the maximum temperature of the composite TR-316.

6.1.14 Changes and Modifications Incorporated by Straza

As a result of CUALT as documented above, Ametek/Straza undertook a program of TR-316 change and modification. A summary of the changes and modifications follows:.

1. The transducer housing has been modified to incorporate two fill ports for each cavity section of the projector (PD up, PD down, and narrow beam).

2. The oil-fill procedure has been modified to incorporate the technique of circulating warm, evacuated oil.

3. The Sylgard has been removed and the fill-fluid slot in the tail washer enlarged to provide improved oil filling within each resonator cavity (i.e. between the piezoelectric stack and the stress rod).

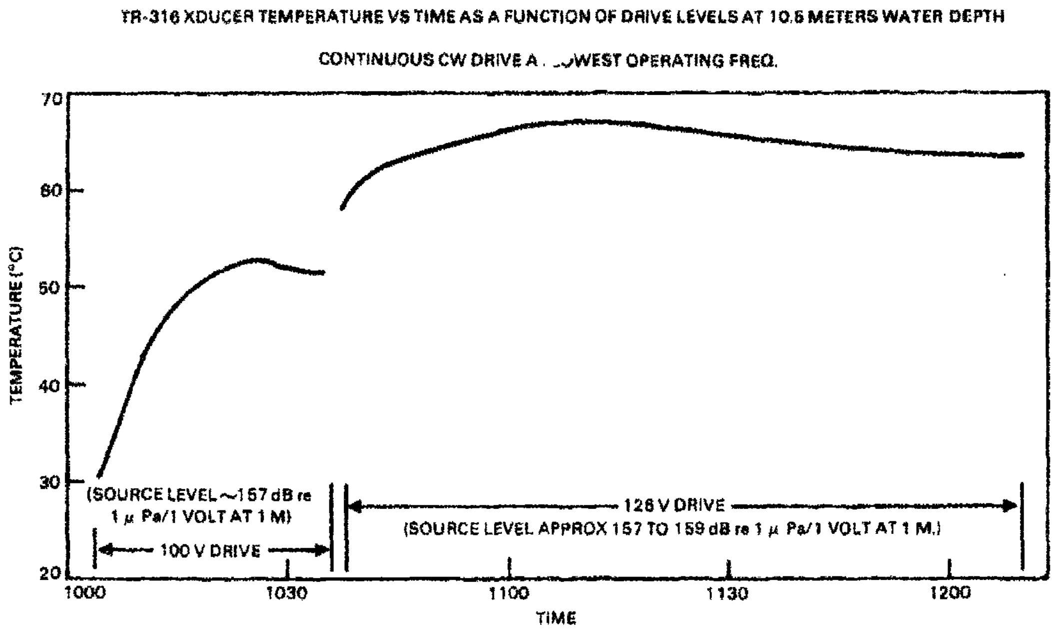


Figure 6-22. Transducer Stabilization Curve for Aluminum Block, f_o, Epon 8, and New Assembly Technique Tested at 22°C

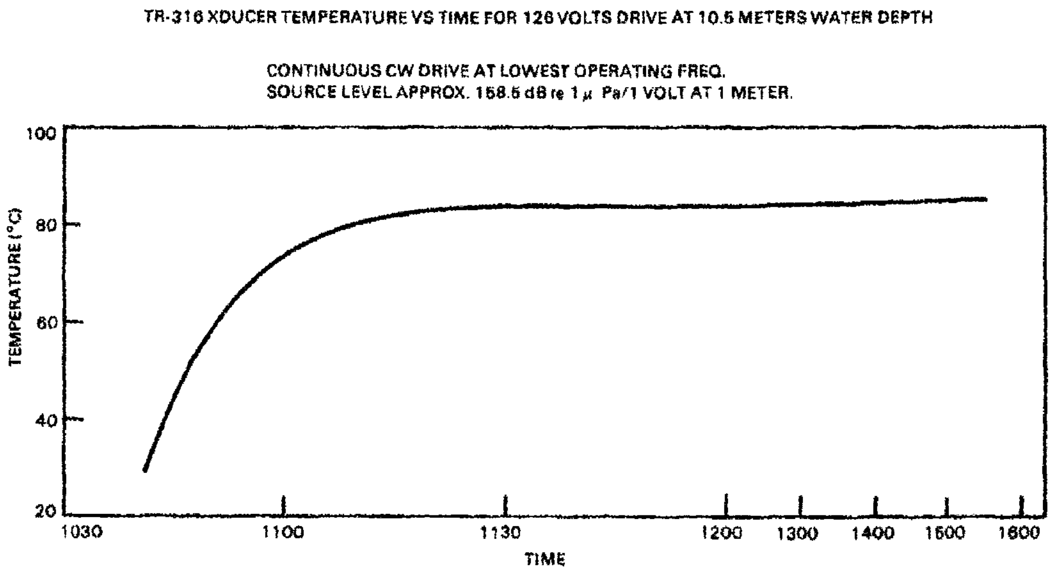


Figure 6-23. Transducer Stabilization Curve for Micarta Block, f_o, Epon 8 and New Assembly Technique Tested at 22°C

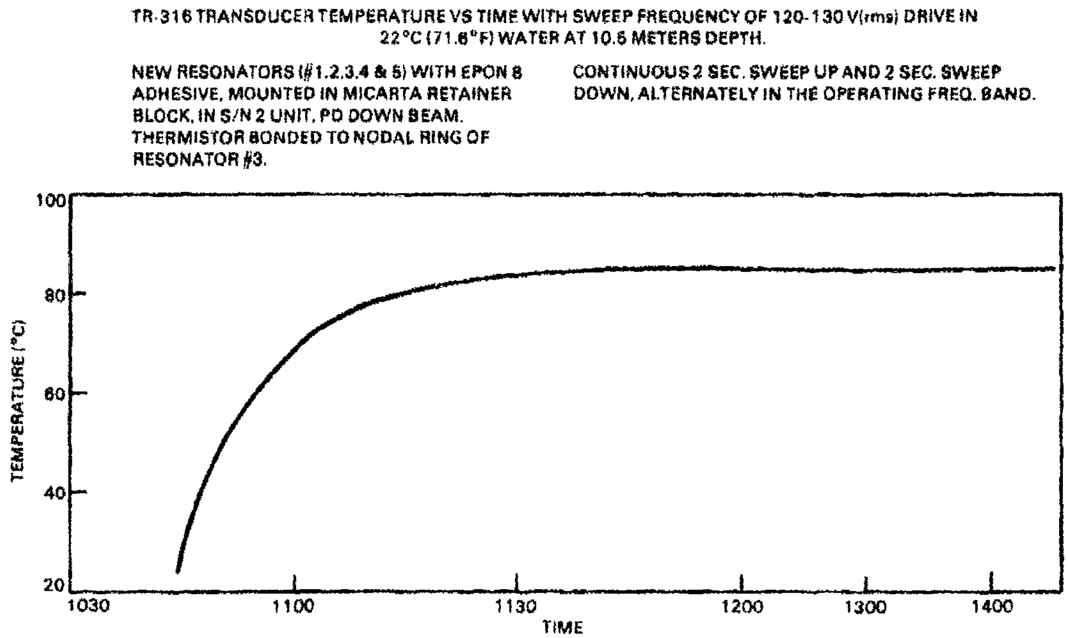


Figure 6-24. Transducer Stabilization Curve for Micarta Block, Δf, Epon 8, and New Assembly Technique Tested at 22°C

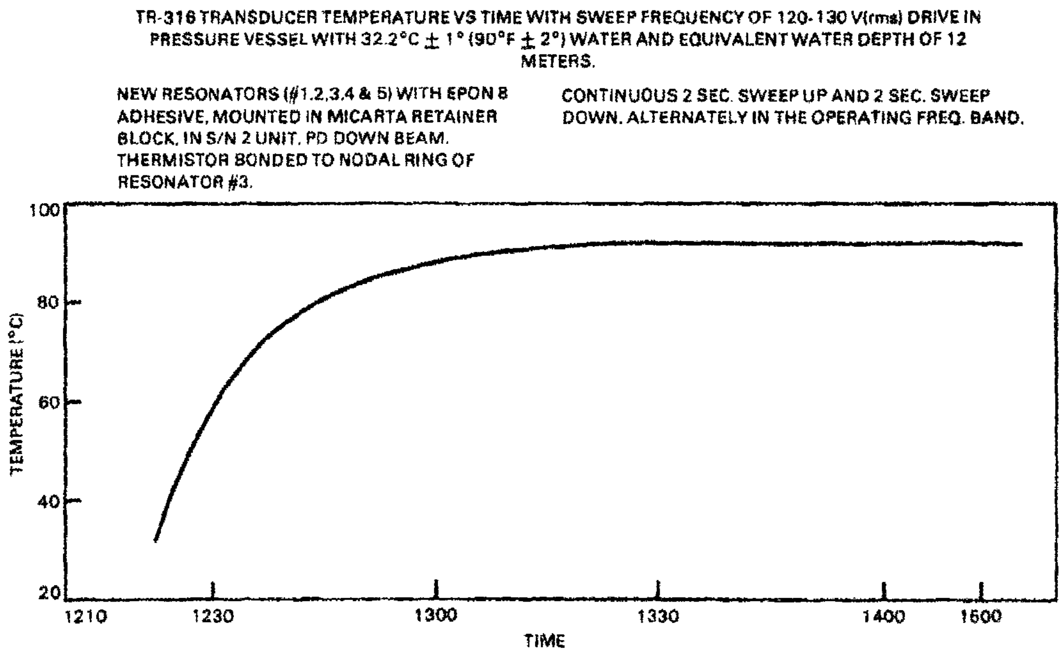


Figure 6-25. Transducer Stabilization Curve for Micarta Block, Δf, Epon 8, and New Assembly Technique Tested at 32.2°C

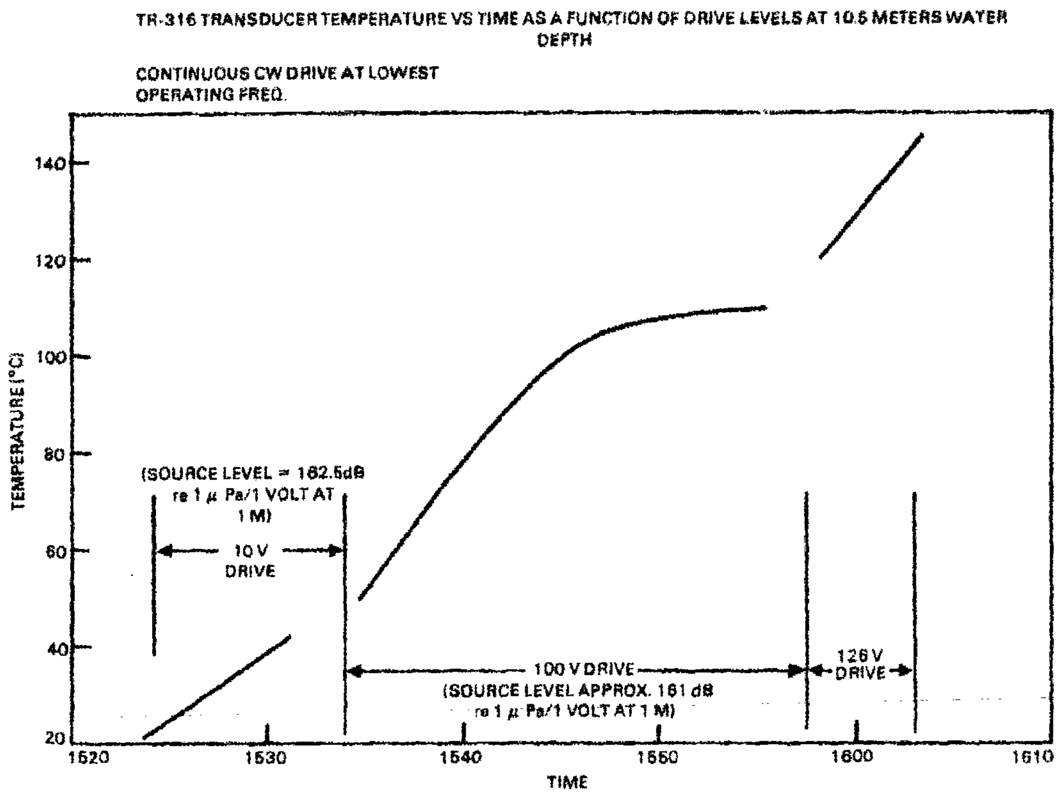


Figure 6-26. Transducer Stabilization Curve for Micarta Block, f_0, Epon 8, and Old Assembly Technique Tested at 22°C

4. A revised resonator-prestress procedure including the use of a digital multimeter to measure the charge has been incorporated to measure the prestress in lieu of the torque method.

5. The resonator-assembly procedure was modified to provide a high stress on the stack while the cement cured. This produced an improved Epon 8 cement joint with lower losses, eliminating the major cause of the current-runaway problem.

6. An anodized aluminum resonator retainer block has been fabricated and tested to improve the thermal dissipation and thus provide a safety factor with regard to the current-runaway problem. This aluminum resonator retainer block will replace the micarta resonator retainer block (see figure 4-2) in the short sections (PD up and PD down sections). The micarta block will still be permitted in the long section (narrow beam sections).

7. A revised tuning procedure has been incorporated whereby the reactive component is maintained inductive over the lower 5/8 of the operating band.

6.2 CUALT of Prototype DT-605 Hydrophones

The CUALT plan calls for application of a simulated 7-year-equivalent of operational stress conditions. Two prototype DT-605 hydrophones of a new design manufactured by Hazeltine were used in the initial development of the IFMEA. These hydrophones, S/N A1 and S/N A5, were subjected to CUALT after the techniques were improved by experience obtained from testing the TR-316 prototypes.

Since the DT-605 hydrophone testing was performed considerably later than that for the TR-316 projectors, the revised accelerated life tests proposed for both the TR-316 and DT-605, table 6-3, were used as the basis for the DT-605 stress exposures. This interim plan, however, was never used for TR-316 stress exposures and is superseded by table 7-4 (see section 7.1), which is proposed for all future testing of both the TR-316 and the DT-605 configurations.

Of the seven stress exposures given in table 6-3, only five are applicable to the DT-605 hydrophone. These are heat, pressure cycling, and thermal shock. The freshwater exposures for water permeation were not included since this stress exposure applies only to rubber components which are exposed to water. The DT-605 contains no such external components. The high-power-drive tests are not applicable to a hydrophone.

6.2.1 Calibration in the TRANSDEC Facility

Immediately prior to the CUALT the two DT-605 hydrophones were tested at the TRANSDEC calibration facility for compliance with CIPS. All units met the CIPS requirements. After calibration, the sequence of stress exposures outlined and described in table 6-3 was performed and the following discussion augments the information in table 6-3.

6.2.2 SE1 Application

SE1 consisted of applying dry heat at 75°C (167°F) to the hydrophones. The purpose of this test was to accelerate reactions with the fill fluid and components to simulate mechanical stress due to expansion and to simulate dockside storage. Both hydrophones were tested for a total of 477 hours. This is more than the 475 hours required in table 6-3. Acoustic and megger tests were performed after completion of this test and these were satisfactory. There was no visual damage observed.

Table [illegible]-3. Revised Accelerated Life Test Proposed (July 78) for TR-316 or DT-605*

Exposure	Time	Purpose	Time Compression	Equivalent Service
Dry Heat 75°C UV Exposure	475 hrs	Accelerate rubber degradation, reaction between fill fluid and components, mechanical stress on boot due to expansion, degradation of rubber, simulate dockside storage.	Accelerated Aging Duty-Cycle Increase	16,300 hrs at 20°C (E=13,000) 1-2 hrs/day of sunlight for 9 mo.
	TEST:	BEAM PATTERN, TVR, OIL PRESSURE, IMPEDANCE, RUBBER CHANGES, MEGGER		
Fresh Water 60°C**	40 hrs	Water permeation, simulate wet operation	Accelerated Aging	575 hrs at 20°C (E=13,000) 18,750 hrs at 20°C (E=30,000)
	TEST:	MEGGER		
Pressure Cycling	250 cycles	Mechanical stress, water intrusion, water permeation, simulate diving conditions.	Duty-Cycle Increase	1 year diving
Pressure Dwell, 4100 Pa (600 psi)	2 X 16 hrs ea	Mechanical stress, water intrusion, water permeation, simulate diving conditions.	Duty-Cycle Increase	32 hrs at pressure
	TEST:	MEGGER, ACOUSTIC PROBE		
Thermal Shock -54° to 0°C	3 cycles	Mechanical stress due to contraction, elastomer and adhesive integrity, water intrusion, simulate Arctic conditions.	Duty-Cycle Increase	One Arctic mission
Repeat Pressure Cycling and Dwells	--	--	--	--
	TEST:	BEAM PATTERNS, TVR, IMPEDANCE		
High-Power Drive**	168 hrs	Simulate continuous operation	Duty-Cycle Increase, Stress Increase	One Arctic mission
	TEST:	BEAM PATTERNS, TVR, IMPEDANCE		

*UV exposure is eliminated for the DT-605 hydrophone
**Not applicable to DT-605 hydrophone

6.2.3 SE2 Application

As stated above, SE2 of table 6-3 was not performed, since it is not applicable to hydrophones with construction like that of the DT-605 (no external rubber components).

6.2.4 SE3 Application

Next, the hydrophones were subjected to SE3 (pressure cycling). The purpose of this test was to simulate diving conditions by applying varying pressure. Two hundred and fifty cycles were performed as per the requirements of table 6-3. No visual changes were observed as a result of this test.

6.2.5 SE4 Application

Transducers S/N A1, and S/N A5 were subjected to SE4 (pressure dwells at 4100 Pa (600 psi). Two dwells of 16 hours each at 4100 Pa (600 psi) as per table 6-3 were performed. The purpose of this test was to further simulate diving conditions and complement the previous pressure-cycling test.

6.2.6 SE5 Application

Next, the hydrophones were subjected to SE5 (thermal shock). Three cycles were performed going from -54°C (-65°F) to 0°C (32°F) as per table 6-3.

6.2.7 SE6 Application

Next, the hydrophones were resubjected to SE3 and SE4 (pressure cycling and pressure dwell). Although table 6-3 calls for 250 pressure cycles, only 200 were performed. After completion of these tests, there was no visual evidence of damage, and megger tests performed at completion gave satisfactory readings.

6.2.8 SE7 Application

The high-power-drive test was not performed, as stated above, since it is not applicable to hydrophones.

6.2.9 Observations at TRANSDEC After Stress Exposures Above

The two units were returned to TRANSDEC to check on the acoustic performance required by the CIPS.

Testing was completed on one of the units as of September, 1979. However, time did not permit an in-depth evaluation of the results before the publishing of this report. A cursory inspection of the TRANSDEC data for the first unit did not reveal any substantial changes in performance. Therefore it does not appear there will be any holdup in completing the testing of the second unit followed by an in-depth analysis of the effects of the CUALT on the DT-605 in early FY 80. The encouraging preliminary results will probably permit initiation of the second-year CUALT on schedule.

Section 7

7.0 Recommendations for Future CUALT Plans

7.1 Progress in Testing and Analysis

The preliminary analysis and the planning for the first iteration CUALT was accomplished in March, 1978 (see table 6-3). The CUALT plan was revised once (table 7-1) in July, 1978, and as more information became available, it was appropriate to consider further improvements in the test plans based on what had been learned. Some of the important learning experiences are summarized below:

1. Major failures resulting from CUALT efforts were due to congenital defects appearing early in the life cycle;

2. The CUALT exposures which appeared to produce failures were high temperature and high-power drive;

3. Locating the origin of failures was facilitated by auxiliary measurements, some of which can be easily incorporated into the CUALT program (internal pressure and temperature, acoustic probe and/or near-field receivers);

4. A first article DT-605 hydrophone passed explosive-shock requirements and yet failed a vibration test subsequent to the shock test. Analysis by TRI showed that the failure (a wire separation from a solder joint) had actually occurred in explosive shock but did not manifest itself until after the vibration test;

5. The GD/EB IFMEA's discussed in section 4 produced recommendations that thermal cycling, vibration, additional water soaking, and impact exposures be considered for the CUALT sequence;

6. TRI has assembled formal mission profiles (tables 7-1, 7-2, 7-3 and 7-4) for transportation and storage and service exposures for the transducers and these suggest additional CUALT exposures (agreeing with GD/EB recommendations) and preliminary qualification exposures as discussed below;

7. Examination of the implications of redundant features of the transducers, such as their ability to operate with several resonators nonfunctional, indicates that reliability-improvement efforts should focus on nonredundant components, such as fill-fluid vent ports, face rubber, connectors, housing compartments, and O-rings.

7.2 Proposed Qualification Tests

The TR-316 prototypes were assumed to be totally qualified for the CUALT program because they had passed the explosive-shock test, which is obviously the most aggressive of all the environmental exposures for wet-end sonar hardware. Yet serious congenital defects in the prototype units were discovered early in certain of the compressed-time environmental exposures. From the standpoint of the technical team members, this program has been highly successful in uncovering problems that would not otherwise have been detected in the standard approach to first article testing. From a management point of view, however, it took almost a year of real time to complete the first year of compressed time because of the analysis and rework efforts required to fix the problems as they were discovered. Whereas it was not possible to anticipate the problems uncovered, it is not unreasonable to ask how we can identify earlier in the process the more serious problems, which are relatively independent of compressed-time exposure. A qualification-test series which goes beyond the explosive-shock test is the proposed approach. The purpose of qualification tests is to demonstrate that the test units can survive each of the most severe exposures at least once prior to introducing the units to the CUALT sequence. The qualification tests should include at least the following:

TABLE 7-1
MISSION PROFILE - TRANSPORTATION AND STORAGE
FOR TR-316 AND DT-605

				DURATION OF EXPOSURE (hrs or cycles)					CIPS REFERENCES		
NO.	EXPOSURE	RANGE OF EXPOSURE	OCCURANCE	EXTREME	PER 1 YR.	CONTINUING LONG TERM	PER 1 YR.	COMPANION EXPOSURE	REQUIREMENT	QA INSPECTION	EXPOSURE SPECIFIED
1	Temperature/ Air[a]	-30° to +71°C	Transportation & Storage	+71°C, 4 Hr/ Day x 360 Days	1460 hr			Humidity	3.2.5.1	3.2.5.1	-54° to +71°C Extended Time
2						-13° to +29°C	8640 hr				
3	Pressure in Air	12 to 100 kPa	Air Transportation	12 kPa 2 Flights x 8 Hrs	16 hr				3.2.5.1	3.2.5.1	12 kPa
4	Humidity	-30° to +38°C Dew Point	Storage and Installation	27° to 38°C Dew Point 90 days	2190 hr			Temperature			
5						21°C Dew Point	8640 hr				
6	Rough Handling[b]	Per MIL-P-116	Transportation	Per MIL-P-116	1 test series				5.1	5.1	MIL-P-116

NOTES: a Environmental effects on equipment minimized by container.
b Rough Handling profile defined in terms of MIL-P-116 due to lack of data.

TABLE 7-2
HYPOTHETICAL SERVICE PROFILE FOR TR-316

				DURATION OF EXPOSURE (hrs or cycles)					CIPS REFERENCES		
NO.	EXPOSURE	RANGE OF EXPOSURE	OCCURANCE	EXTREME	PER 1 YR.	CONTINUING LONG TERM	PER 1 YR.	COMPANION EXPOSURE	REQUIREMENT	QA INSPECTION	EXPOSURE SPECIFIED
1	Temperature/ Air	-55° to +71°C	Dockside	+71°C, 1.5 hr/day-270days	410 hr			Humidity Pollution Ultraviolet	3.2.5.1		-54° to +71°C Extended Time
2				-30°C 24 hr/ day - 30 days	720 hr						
3						+3° to 37°C for 270 days	6570 hr				
4			Arctic Surface	-55°C for 21 days	504 hr						
5	Temperature/ Sea Water	-2° to +32°C	At Sea	+32°C for 90 days	2190 hr			Pressure	3.2.5.2.2	4.2.3.1	Conditioning 168 hr at 32°C
6						1° to +10°C for 90 days	2190 hr				
7	Thermal Cycling	ΔT ≤125C°	Dockside	-55° to +71°C	5 cycles			Humidity Pollution	3.2.5.1		-54° to +71°C
8						ΔT ≤ 16C°	365 cycles				
9	Thermal Shock	ΔT ≤ 54C°	Diving-Tropic	71° to 21°C	30 cycles				3.2.5.2.1	4.2.3.5	3 cycles 60° → 0°C 4 cycles -54° → 0°C
10			Diving-Arctic	-55 to -1°C	3 cycles						
11	Pressure/ Sea Water	100 to 4100 kPa	At Sea	4100 kPa 2 hr/ day - 90 days	180 hr			Sea Water Temp. Vibration Impact/ Penetration	3.2.5.2.3	4.2.2.3	6800 kPa 24 hrs (over 5 cycles) Note a
12						770 to 2100kPa for 90 days	2190 hrs			4.2.3.3	
13	Pressure Cycling/Sea Water	100<P<4100 kPa	At Sea	100 to 4100kPa 2/day-90 days	180 cycles					4.2.3.2.1 4.2.3.4	Note b Note c
14						770 to 2100kPa	360 cycles				
15	Humidity	-29° to +38°C Dew Point	Surface	38°C D.P. 8 hr/day- 270 days	2190 hr			Air Temp. Pollution Ultraviolet			
16						+10° to +32°C D.P. - 270days	6570 hr				
17	Air Pollution	0-500 AQL[d]	Dockside	500 AQL 8 days[e]	192 hr			Air Temp. Humidity Ultraviolet			
18						150 to 250 AQL 270 days	6570 hr				
19	Ultraviolet	0-5500[f] $\mu w/cm^2$	Dockside	5500 $\mu w/cm^2$ 1 1/2 hr/day 270 days	410 hr			Air Temp. Humidity Pollution			
20	Vibration	Per MIL-STD-167-1	At Sea	Per MIL-STD - 167-1	1 series			Sea Water Temp. Pressure	3.2.5.2.5	4.2.3.2.3	MIL-STD-167-1 Type I

	Penetration										
22	Explosive Shock	Per CIPS g	At Sea	Per CIPS	1 series				3.2.5.2.4	4.2.3.6	27 kg [illegible] Depth at 18.5,13.8, 9.2,6.2 m distance
23	Electrical Drive	0-Max Pwr Low to High Freq	At Sea	Max Power Low Frequency Continuous	336 hr			Sea Water Temp. Pressure	3.2.1	4.2.3.2.2	170 hr Cont. Drive at 126V, Frequency Sweep
24						Max Power Low Frequency Intermittent (10%) 90 days	219 hr				
25			In Air	Max Power Low Frequency Continuous	168 hr			Air Temp.	3.2.2.3	4.2.3.2.4	10 min Cont. Drive at 126V, Frequency Sweep

NOTES:

a 100 kPa (at 3°, 18° and 32°C) and 2100 kPa and 4100 kPa (at 3° and 18°C).
b 60 to 4100 kPa for 5000 cycles.
c 60 to 4100 kPa, 50 cycles each at 67 and 670 kPa/minute.
d AQL = Air Quality Level as defined by EPA.
e Based on Los Angeles experience, 1975. Ozone is the major contaminant.
f Wavelength range 240-400 nm.
g Vibration and explosive shock as defined by specification due to lack of service data.
h Impact of 6 kg ice block having rounded edges at 10 m/sec (20 kt).

2

TABLE 7-3
HYPOTHETICAL SERVICE PROFILE FOR DT-605

NO.	EXPOSURE	RANGE OF EXPOSURE	OCCURANCE	DURATION OF EXPOSURE (hrs or cycles): EXTREME	PER 1 YR.	CONTINUING LONG TERM	PER 1 YR.	COMPANION EXPOSURE	CIPS REFERENCES: REQUIREMENT	QA INSPECTION	EXPOSURE SPECIFIED
1	Temperature/ Air	-29° to +71°C	Dockside	+71°C, 1.5 hr/day-270days	410 hr			Humidity Pollution	3.2.5.1		-54° to +71°C
2				-29°C 24 hr/ day - 30 days	720 hr						
3						+3° to 37°C for 270 days	6570 hr				
4			Arctic Surface	-55°C for 21 days	504 hr						
5	Temperature/ Sea Water	-2° to +32°C	At Sea	+32°C for 90 days	2190 hr			Pressure	3.2.5.2.2	4.2.3.1	Conditioning 168 hr at 32°C
6						1° to +10°C for 90 days	2190 hr				
7	Thermal Cycling	ΔT ≤ 125C°	All Service	-55° to +71°C	5 cycles						
8						ΔT ≤ 16C°	365 cycles				
9	Thermal Shock	ΔT ≤ 54C°	Diving-Tropic	60° to 21°C	30 cycles		-		3.2.5.2.1		3 cycles 60°→ 0°C 4 cycles -54°→ 0°C
10			Diving-Arctic	-55 to -1°C	3 cycles						
11	Pressure/ Sea Water	100 to 4100 kPa	At Sea	4100 kPa 2 hr/ day - 90 days	180 hr			Sea Water Temp. Vibration	3.2.5.2.3	4.2.2.3	6800 kPa 24 hrs (over 5 cycles)
12						770 to 2100kPa for 90 days	2190 hrs			4.2.3.3	Note a
13	Pressure Cycling/Sea Water	100<P<4100 kPa	At Sea	100 to 4100kpa 2/day-90 days	180 cycles					4.2.3.2.1 4.2.3.4	Note b Note c
14						770 to 2100kPa	360 cycles				
15	Humidity	-29° to +38°C Dew Point	Surface	38°C D.P. 8 hr/day-270 days	2190 hr			Air Temp. Pollution			
16						+10° to +32°C D.P. - 270days	6570 hr				
17	Air Pollution	0-500 AQL[d]	Dockside	500 AQL 8 days[e]	192 hr			Air Temp. Humidity Ultraviolet			
18						150 to 250 AQL 270 days	6570 hr				
19	Vibration	Per MIL-STD-167-1[f]	At Sea	Per MIL-STD - 167-1	1 series			Sea Water Temp. Pressure	3.2.5.2.5	4.2.3.2.3	MIL-STD-167-1 Type I 27 kg HBX-1; 7.4m

20	Explosive Shock	Per CIPS[f]	At Sea	Per CIPS	I series				3.2.5.2.4	4.2.5.6	Depth at [illegible], 9.2,6.2 m distance

NOTES:

a 100 kPa (at 3°, 18° and 32°C) and 2100 kPa and 4100 kPa (at 3° and 18°C).
b 60 to 4100 kPa for 5000 cycles.
c 60 to 4100 kPa, 50 cycles each at 67 and 670 kPa/minute.
d AQL = Air Quality Level as defined by EPA.
e Based on Los Angeles experience, 1975. Ozone is the major contaminant.
f Vibration and explosive shock as defined by specification due to lack of service data.

TABLE 7-4. ACCELERATED LIFE EXPOSURE PER MISSION PROFILE FOR TR-316 OR DT-605*

Exposure	Time	Time Compression	Equivalent Service
Temperature 71°C (81°C) Humidity (40°C Dew Point) Air Pollution (300 AQL) UV Irrad (max solar)*	653 hrs (385 hours)	Duty-Cycle Increase & Accelerated Aging	71°C, 1 1/2 hr/day, 9 mo. plus 21°C, 22 1/2 hr/day, 9 mo. (E=13,000)
Thermal Cycling/Shock** (High Temp) 71°C to 20°C	30 cycles	Duty-Cycle Increase	30 dives from hot surface
Fresh Water 71°C**	30 hours	Accelerated Aging	3 mo. mission at average temp of 21°C
Thermal Cycling/Shock (Low Temp) -54°C to 20°C	3 cycles	Duty-Cycle Increase	One Arctic mission
Pressure Cycling 60-4100 kPa**	180 cycles	Duty-Cycle Increase	180 dives
Pressure Dwell 4100 kPa**	180 hours	Duty-Cycle Increase	Deep operation
Vibration (MIL-STD-167-I)	1 series	Unknown	Operation
Impact/Penetration* (to be specified)	180 impacts	Unknown	180 dives
Electrical Drive*	168 hours	Duty-Cycle Increase Stress Increase (low frequency)	One Arctic mission

NOTE: Tests to be specified.

* UV exposure, Impact/Penetration and Electrical Drive are not required for the DT-605 hydrophone.

** Fresh water and Thermal Cycling/Shock exposures can be combined as can Pressure Cycling and Pressure Dwell exposures.

1. Explosive shock

2. Transportation and storage
   (1) High temperature and humidity
   (2) Vacuum
   (3) Rough handling

3. High-power drive (for projectors)

To this list could be added any other short-time exposure to which the equipment might be considered sensitive.

7.3 Improved CUALT Exposure Plan

In October, 1978, TRI was tasked to produce formal mission profiles for the transducers. Tables 7-1 through 7-3 are the result of conversations with personnel from several organizations. Table 7-1 is the mission profile for shipment, storage and installation of both transducers. Table 7-2 is the service mission profile for the TR-316, and table 7-3 is the service mission profile for the DT-605.

From those formal mission profiles, a recommended improved CUALT Exposure Plan (table 7-4) was developed for the TR-316. This plan will work for the DT-605 with the exceptions noted in section 5.5.3. This plan differs from the first CUALT Plan (table 6-1) and the revised plan (table 6-3) in several ways as described below.

7.3.1 Heat and Atmospheric Contamination

Previous exposures to dry heat and UV are replaced by a combined exposure to heat, humidity, UV and air pollution due to carbon monoxide and photo-oxidents (mainly ozone), which are real, companion exposures for submarines docked in metropolitan areas. The lack of an appropriate specification for the TR-316 face rubber gives some concern about resistance to this environment. The temperature is reduced to the CIPS limit of 71°C (160°F) at the expense of an additional 178 hours of exposure time because the need for good data is greater than the need for fast results. The time of 655 hours is arrived at by a combination of duty-cycle increase and accelerated aging. Extreme service per the mission profile is 71°C (160°F) for 1-1/2 hours/day (noon day sun, black body) for a dockside period of 9 months. Increasing the duty cycle yields 1.5 hrs/day x 274 days = 411 hours of continuous exposure. The balance of the dockside hours are 22.5 hours/day x 274 days = 6165 hours. It is postulated that diffusion of water and fluid controls the rate of degradation of elastomers, plastics, and adhesives. A composite activation energy of 13,000 calories/mole is chosen based on various considerations including permeation studies on various elastomers at TRI laboratories.[4] The equivalent laboratory exposure time at 71°C (160°F) for the dockside time of 6165 hours at an assumed mean temperature of 20°C (68°F) is calculated using the Arrhenius equation as shown below:

For 20°C (68°F)

$$\frac{1}{t_{20}} = Ae^{-E/RT_{20}}$$

also for 71°C (160°F)

$$\frac{1}{t_{71}} = Ae^{-E/RT_{71}}$$

combining these equations and rearranging

$$t_{71} = t_{20}\, e^{\frac{-E}{R}\left(\frac{1}{T_{20}} - \frac{1}{T_{71}}\right)}$$

substituting 293°K for $T_{20^\circ C}$, 343°K for $T_{71^\circ C}$,

and 6165 for t_{20}

$$t_{71} = 6165\, e^{\frac{-13,000}{2}\left(\frac{1}{293} - \frac{1}{343}\right)}$$

$$= 244 \text{ hours .}$$

4. D. E. Glowe and J. S. Thornton, "Preliminary Aging Results", Report 7631-2, Contract No. N66001-77-C-0085, May 20, 1977.

The total laboratory exposure time thus becomes

Duty-cycle increase	411
Accelerated aging	244
Total	655 Hours.

7.3.2 Thermal Cycling

Thermal cycling between 71°C (160°F) and 20°C (68°F) is added to the list of exposures. This exposure simulates dockside thermal cycling (noon-night) for 270 days plus 30 dives from a hot surface, per the mission profile. The effect of the cycling is internal mechanical stresses because of differential thermal expansion of the various materials. This is second in the sequence of exposures primarily for convenience, since the test units would come from the oven at 71°C (160°F).

7.3.3 Water Soak

Freshwater exposure for 60 hours at 71°C (160°F) replaces the previous sea water and freshwater exposures. This exposure is the equivalent of 3 months of active service at an average water temperature of 15°C as calculated by the Arrhenius equation using E = 13,000 calories/mole. Additional accelerated aging of internal components will be accomplished because of the elevated temperatures, and additional water will be driven into the external rubber parts by this exposure. As indicated earlier, fresh water permeates elastomers more rapidly than salt water, so that some increase in environmental stress as well as accelerated aging are the time-compression tools used here. In order to conserve laboratory time, it is suggested that the high-temperature thermal cycling and freshwater exposure be combined. By transferring the test unit between warm and cold water tanks, the temperature change can be accomplished quickly, and the time at 71°C (160°F) can be accumulated in small increments.

7.3.4 Pressure Cycling

Pressure cycling between 60 and 4100 Pascals (9 and 600 psi) for 180 cycles is a reduction from the 400 or 250 cycles called for in the previous plans. This change is due to the expectation that 2 dives to 4100 Pa (600 psi) per day for 3 months is an extreme exposure and is so shown in the mission profile. This exposure is primarily mechanical and the time-compression factor is duty cycle. Since this exposure and the one to follow are in water, additional water permeation might be expected in the rubber. However, this depends heavily on the permeability of water in neoprene at 71°C (168°F) vs. the temperature of the test tank. A more likely result than additional permeation is that there will be little total change in water content and a modest reduction of the water concentration gradient in the rubber over the course of the exposure. Some thought was given to reversing the sequence of exposures to have the low-temperature cycling shock precede the pressure cycling. Either way is acceptable.

7.3.5 Pressure Dwell

The pressure dwell at 4100 Pa (600 psi) for an accumulated 180 hours replaces the 32 hours of the revised plan for 16 hours in the first plan. This follows the mission profile extreme service exposure, which anticipates a one-hour dwell at 4100 Pa (600 psi) for each of the 180 dives to this pressure. It is totally acceptable to accumulate the 180 hours in short segments of time. This exposure is primarily mechanical and the time-compression tool is increased duty cycle.

7.3.6 Low-Temperature Shock

The various exposures to water precede the low-temperature cycling shock exposure to allow water to permeate the rubber window. The effect of the resulting small water pockets in the rubber will be deleterious when going through the freeze-thaw cycle. There is no change in this exposure from the previous CUALT plans. The effect of these low-tempcratrure cycles is primarily mechanical because of the differential thermal expansion between various components and between materials and permeated water and fill fluid contained in them. The time-compression tool is increased duty cycle.

7.3.7 Vibration

A vibration series per MIL-STD-167-I was not included in the previous CUALT exposure sequences because shipboard vibration was not previously considered a problem. GD/EB has strongly recommended that vibration be included, and therefore it is in the present sequence. Further investigation into the vibration spectra of surface and subsurface operation is needed before it will be known what this exposure means in terms of equivalent service.

7.3.8 Impact/Penetration

An impact/penetration test needs to be developed to simulate repeated collisions with floating debris, especially ice, during an operational dive. Three of the 180 impacts should be done at low temperature (-54°C) because of Arctic mission requirements. This is partly a stress of the rubber windows to determine their resistance to penetration by sharp objects. The impacts can be applied directly over transducer elements to provide a level of shock to the ceramic stacks. The three cold impacts would be the most severe on the rubber because the rubber would be near the temperature where it exhibits lossy behavior.

7.3.9 Electrical Drive

Electrical-drive exposure is unchanged from the previous exposure sequences. The mission profile anticipates a two-week, under-ice, maximum-power operation with frequency sweep. One-week exposure at low frequency is outside the mission profile and therefore considered a stress-increase time compression. The transducer draws more current at low frequency, as shown in figure 6-7. This exposure is not outside the CIPS requirement.

7.4 Improved Tests and Instrumentation

The exposures described above are not tests in themselves. They become tests when accompanied by measurements designed to determine changes in the test article caused by the exposures. As mentioned previously, the appropriate measurements and number to be made depend on the definition of failure and the desired degree of temporal resolution. In the present case unit failure is defined as failure to meet the acoustic performance requirements of the CIPS. If, for example, all one needed to know was in which compressed year the unit failed, then performance measurements could be limited to a minimum of one per year. However, in this program, more resolution is desired than a complete compressed year of simulated operations, especially in the early "years" of testing, because there is particular interest in identifying congenital defects in order to affect the design of the transducers. On the other hand, acoustic performance tests are expensive, so they should be minimized. A suggested compromise approach for future CUALT efforts on the TR-316 and DT-605 transducers is to make more use of quantitative acoustic probe techniques and reserve the beam pattern and TVR measurements for the times when changes in probe readings suggest a problem. Near-field measurements of acoustic performance during the high-drive sequence should be incorporated.

Continued use of measurements of rubber durometer, dimensional changes, internal fill-fluid pressure, and insulation resistance is encouraged. Provision for internal temperature measurements using thermocouples or thermisters inserted through fill-fluid fill ports is recommended. These measurements are inexpensive and should be made during and between each exposure in the sequence.

7.5 Time Compression

The estimated minimum laboratory time required to accomplish the proposed improved CUALT is about 11 weeks of normal 5-day operation of a laboratory as shown below:

Elapsed Time

Item	Exposure	Test and Evaluation	Idle (weekends)
Initial Evaluation		5 days	2 days
Heat and Atmosphere	28 days		
Evaluation		1 day	2 days
Thermal Cycling/Soak	7 days		
Evaluation		1 day	
Pressure Cycling/Dwell	10 days		
Evaluation		1 day	
Thermal Cycling/Soak	2 days		2 days
Evaluation		1 day	
Vibration	1 day		
Evaluation		1 day	
Impact/Penetration	1 day		
Evaluation		1 day	2 days
Power Drive	7 days		
Evaluation		5 days	
	56 days	16 days	8 days

Time-compression factor for exposure 365 ÷ 56 = 6.5X

Time-compression factor overall 365 ÷ 80 = 4.6X

It is not known how well the compressed-time years will correlate to service years but further time compression for CUALT will reduce the confidence in our predictions. If the pressure for reducing the laboratory exposure time is great, the recommended approach is to eliminate idle time (weekend operation of the laboratory), reduce test and evaluation time (expand use of automatic monitoring and recording equipment), and increase exposure efficiencies (automatic environmental chambers). Only as a last resort should levels of exposure be increased to effect further time compression for composite units.

SECTION 8

8.0 Summary

8.1 Tasks Completed

The following is a list of tasks completed by September, 1979:

1. First iteration IFMEA completed for TR-316 and DT-605 transducers.

2. First iteration IFMEA completed for TR-316, DT-605, and SQS-56 cables and connectors.

3. First iteration CUALT plan developed for TR-316 and DT-605.

4. First-year-equivalent CUALT completed for TR-316.

5. Problems and potential problems for the TR-316 discovered and corrected in a timely manner, including the critical current-runaway problem.

6. First-year-equivalent CUALT completed on DT-605's.

8.2 Summary of Pertinent Findings Uncovered During the Exercise of the IFMEA/CUALT FY 1979 Effort

Perhaps the most significant finding of the IFMEA/CUALT effort was that the procedure developed was capable of early identification of transducer problems and potential problems. This was accomplished using the modified failure modes and effects analysis technique in an iterative fashion (IFMEA) and then demonstrating numerous failures in the composite-unit accelerated life testing (CUALT). Since the technique was developed on transducers of current interest, such as the TR-316, the CUALT contributed directly to the improvement in fleet transducers in a timely fashion (before the problems occurred during operation). The following is a summary of specific findings uncovered during the exercise of the IFMEA/CUALT during the FY 79 effort.

The high-drive problem, also known herein as the current-runaway problem, was the most serious problem discovered and subsequently characterized, understood, and solved. Its resolution was largely based on the experimental and analytical data presented by the technical monitors. The competency which the technical monitors developed via the hands-on experience herein described made their contributions possible.

As an example, the hardware contractor reported that the prototype units had passed the 170 hours of high-drive testing required by the specification. However, the technical monitors' hands-on experience in testing this transducer led them to claim and subsequently verify that the high-drive tests performed by the contractor were invalid. Specifically, the contractor's high-drive test setup incorporated an electronic power amplifier which controlled the current instead of the voltage. Obviously, no current runaway resulted since the amplifier held the current constant versus load.

An intensive effort by the government technical monitors with excellent cooperation by Straza led to the understanding and correction of the high-drive current-runaway problem. Using in-air impedance tests on the individual resonators versus temperature, various hypotheses were tested, resulting in the final conclusion that faulty cement joints were the primary cause of the current-runaway problem. A new cement joint assembly and curing procedure corrected the cement joint problem.

It remained to be shown in the composite units what temperatures were resulting in conjunction with the high-drive problem. These temperature measurements, plus the in-air impedance measurements, completely confirmed the cause of the problem. Similar measurements validated the solution to the problem by testing units incorporating the improved Epon 8 cement joints.

One further change to the transducer design was required to provide a safety factor, namely, improvement of the thermal cooling path from the resonators to the outside sea water. This improvement was accomplished by replacing the micarta resonator retainer blocks (see figure 4-2) with aluminum resonator retainer blocks.

Originally, Straza indicated that they not only wanted to use the micarta blocks already purchased but expected to use micarta blocks in all future contracts. Subsequently, Straza informed the government that their subcontractor was reluctant to make more micarta blocks because machining micarta causes rapid wear of cutting tools. Thus it was found that the subcontractor would supply aluminum blocks at a lower price than the micarta blocks.

Straza then wanted to use those micarta blocks already fabricated and later switch to the aluminum blocks to provide the NOSC-desired further factor of safety. It was decided as a compromise to allow the micarta blocks on hand to be used only in the narrowbeam sections because they do not experience current-runaway problems (recall that the power levels experienced in these sections are low). All PD up and down sections were required to use aluminum blocks exclusively. In summary, it was concluded that the micarta blocks are marginal in the PD up and down sections but that the aluminum blocks provide a good safety factor.

Using CUALT, combination design and quality-control problems were discovered which would not have been discovered and/or taken seriously using only piece-part testing. A prime example is the high-drive problem. The fact that all sections of the transducers functioned as per the critical item production specification at low-level drives but at high drive experienced current runaway, leading to the sequence of events outlined above, illustrates the need for the CUALT-type testing. Another example of this was the presence of air in the transducer fill fluid. This became apparent only after the temperature stress exposures. It appears the air was trapped inside the transducer cavity between the ceramic ID and stress rod due to an insufficiently sized venting port. The presence of air manifested itself as a bulging of the acoustic windows. These examples demonstrate that CUALT uncovered real problems with all their ramifications, which would have been almost impossible to conclusively identify without CUALT.

A number of other inadequacies which led to partial failure or which presented potential problems for mass-produced elements were uncovered. For example:

1. Inadequate quality assurance had led to the failure of the pressure release pad. The bond on the rubber covering of the Min-K pressure release material failed, allowing the transducer fill fluid to enter the area occupied by the Min-K, destroying its decoupling properties. Better bonding procedures or vulcanization of this rubber cover was recommended to rectify this situation.

2. Improper assembly techniques led to the distortion of the rubber nodal mount, precipating an electrical failure due to squashing of the insulation wire. Better quality control could prevent this.

3. Improper design (the selection of bulkhead insulation material) caused an incompatibility of the bulkhead insulation and the dielectric fluid. Thus, the function of this bulkhead was compromised. It was recommended that a new material be utilized.

4. Faulty workmanship or lack of attention to details in the design caused a potential failure situation in that the electrodes were bent from a vertical to a longitudinal position, defeating the intent of having a piezoelectric field of less than 5 volts per mil.

5. The insulation on the wires connecting electrodes was cut short so as not to derive the full benefit of the distance between the electrodes.

Changes and modifications incorporated by Straza as a result of CUALT findings are summarized in section 6.1.14.

8.3 Projected Benefits to the Navy from CUALT of TR-316

The TR-316 CUALT has both monetary and calendar impact. It is difficult to estimate the benefits derived because of its multifaceted impact on the fleet. It is estimated that the savings achieved because this CUALT was applied early in the game are on the order of four million dollars in directly accountable costs. The four-million-dollar figure is predicated on the assumption that the high-drive failure would not have been caught during first article testing. Therefore the units supplied to the fleet under current production-assembly methods would have failed. Since the number of TR-215 units produced each year has been about 70 and the cost per unit $18,000, the total cost of a reprocurement would be about two million dollars over a two-year period. The cost of replacing unreliable units over the same two years is estimated to be another two million dollars.

It is difficult to estimate the value of avoiding a failure in a fleet operational mode which is critical. The BQS-14 and -15 sonars are used not only to navigate under the ice but as a traffic navigation and a surface check sonar. For example, the PD up section is used to ensonify the surface when a submarine wishes to check for traffic to avoid collisions upon surfacing. It is used at full power and for long periods of time. Therefore, a failure in this mode would result in reduced operational capabilities and threaten the safety of the submarine.

The same resonator is used for both the TR-316 and the TR-242 units. The change will be made in both resonators and therefore the ballistic submarine navigation suit also benefits. There are other substantial benefits derived which are difficult to quantify. Even though the production of TR-316 units was delayed by the problems documented in this report, detecting faults early in the production program has had a beneficial impact on overall production schedules and costs. Part of the directly accountable cost savings are in production yield, which is anticipated to be much greater. The contractor points out that with the new uniform stress his matching procedures are much easier.

SECTION 9

9.0 FY 80 Plans

The basic approach for performing Accelerated Life Testing on transducers similar to the TR-316 and the DT-605 has been formulated as documented herein. For these specific two transducers the FY 80 goal in general is to improve the efficiency of applying the method and achieve the full seven-year-equivalent testing on both units. A new transducer type, namely, a lower-frequency array of new design transducers for the SQS-56 sonar system, will be considered. Full consideration of the lessons already learned will be applied to planning the CUALT for the new SQS-56 transducer design. In outline form the tasks to be accomplished are as follows:

1. Improve the efficiency of the methods of applying the CUALT to the TR-316 and DT-605 transducers. For example, consider simultaneous application of the stress exposures where practical to both the TR-316 projector and the DT-605 hydrophone.

2. Complete as much as possible of the seven-year-equivalent CUALT of the TR-316 and DT-605-type transducer.

3. Perform IFMEA and develop a CUALT plan for the new SQS-56 design. Incorporate the results of the source-selection process (contractor-proposal evaluations). Begin application of the CUALT plan as the hardware becomes available.

9.1 Continued CUALT Method Development and Application to TR-316 and DT-605

Innovations will be sought to make the process of applying the CUALT to the TR-316 and DT-605 more efficient and cost-effective. One example indicated above is the simultaneous application of the stress exposures in the same apparatus when practical to both the TR-316 and the DT-605. Another example might be the use of dockside facilities for the high-drive test as opposed to the costly and time-consuming use of the ocean-tower facility previously utilized. In general a formal review and appraisal of all results will be made in brainstorming sessions to propose new innovations for the method and then the more promising innovations will be tried.

The second-year-equivalent CUALT of the TR-316 projector will be initiated when revised projectors incorporating the agreed-to changes and modifications are received. In particular the units will have changes to cure the high-drive current-runaway problem. The high-drive stress exposure (previously SE6) will be the first stress exposure in the second-year-equivalent series of testing. In general the order of the stress exposures in the CUALT plan is important and should not be changed arbitrarily. However, since the first-year-equivalent CUALT has been completed and since failure of the PD up and PD down sections (the short sections) during high-drive testing was the most serious problem discovered, it is reasonable to address this problem first. After it has been confirmed that the high-drive problem has been corrected in the revised projectors, the stress-exposure sequence from the CUALT plan will again be followed.

Of course, if, as in the first equivalent year of testing, serious problems are discovered in the transducer units (such as the current-runaway problem discussed above), CUALT application will be suspended in favor of understanding and correcting the problem in a timely fashion, since this is the real goal of ALT. If no further major problems are encountered in the units, then the goal will be to achieve the full seven-year-equivalent testing and thereby age the piece-part components.

9.2 SQS-56 New Transducer Design CUALT

A new design of a more inherently reliable SQS-56 transducer is in the process of being developed and procured. There are many differences between this transducer and the previously considered TR-316 and DT-605. Therefore this unit has been selected as the next transducer type to be considered in the further development of the general CUALT and ALT methods. Full consideration will be given to the lessons already learned in producing IFMEA's and the CUALT plan when applying them to this new transducer. Observations from the source-selection process will be considered in the IFMEA's. Also the lessons learned in testing the present SQS-56 transducer arrays will be incorporated.

Theoretical predictions as well as previous experimental results will be used to help develop the IFMEAs and the CUALT plan. For example, the degree to which array interactions must be considered in the CUALT plan will be assessed. Development and application of a critical failure mode analysis technique is also planned.

The earliest delivery of a partial array of the new SQS-56 transducers appears to be approximately 1 June, 1980. Therefore it is anticipated that CUALT for the new SQS-56 transducer design will only be initiated in FY 80 and must continue into FY 81.