NRC Research and Technical Assistance Report

INTERIM REPORT

Accession No. ____________

Contract Program or Project Title: ACOUSTIC EMISSION/FLAW RELATIONSHIPS FOR INSERVICE MONITORING OF NUCLEAR PRESSURE VESSELS

Subject of this Document: MONTHLY PROGRESS - APRIL 1981

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Author(s): PH HUTTON, RJ KURTZ

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Responsible NRC Individual and NRC Office or Division:
Dr. Joe Muscara
Materials Engineering Branch
Engineering Technology Division

This document was prepared primarily for preliminary or internal use. It has not received full review and approval. Since there may be substantive changes, this document should not be considered final.

BATTELLE
Pacific Northwest Laboratory
P. O. Box 999
Richland, WA 99352

Prepared for
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

INTERIM REPORT

NRC Research and Technical Assistance Report

Battelle
Pacific Northwest Laboratories
P.O. Box 999
Richland, Washington U.S.A. 99352
Telephone (509) 375-2157
Telex 15-2874

May 18, 1981

Dr. Joe Muscara
Materials Engineering Branch
Engineering Technology Division
Nuclear Regulatory Commission
Mail Stop 5650NL
Washington, D.C. 20555

NRC Research and Technical Assistance Report

Dear Joe:

MONTHLY LETTER REPORT - APRIL, 1981
ACOUSTIC EMISSION CHARACTERIZATION OF
FLAW GROWTH IN A533B PRESSURE VESSEL STEEL
FIN. NO. B2088

ACCOMPLISHMENTS

- Fabrication of the A533B insert for the ZB-1 vessel test continued.
- The test plan for the ZB-1 vessel test was revised and updated.
- Prepared a draft installation/test plan and schedule for Watts Bar reactor AE system installation.
- Met with TVA to discuss details of AE system installation.
- Fabricating sensors and preamplifiers for Watts Bar reactor and ZB-1 vessel tests.
- Repaired D/E computer system to permit continued testing of the AE monitor system.

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Vessel Test

The test plan for the ZB-1 vessel test has been revised (see Appendix A) in preparation for a planning meeting to be held in Stuttgart, Germany on June 2, 1981. The thrust of the third revision of the test plan is to fully define all details of the test. The plan in its present form represents our most desired set of test conditions. Based on information obtained by R. J. Kurtz during a recent visit to Stuttgart, some areas of the matrix (test temperature, slag inclusion, thermal shock of weld cladding, and test pressure) are controversial. It is anticipated that compromise positions may need to be adopted to obtain final approval for the matrix.

Approval has been granted by BMFT to begin fabrication of the test vessel. Plans call for shipping the vessel to the manufacturer in mid-May. The fabrication time will be approximately six months. This means the earliest startup time for the test is about January 1982.

Thirty-five waveguide sensors have been fabricated for use on the ZB-1 vessel test. They have been calibrated using a helium jet excitation to assure proper fabrication. The sensors have been assigned serial numbers and a fabrication and calibration record book has been established to completely document the fabrication history of each sensor and to record its calibration data with it. One of the sensors has been subjected to temperature tests at temperatures as high as 225°, and this has had no adverse effect on the sensor's performance. The differential preamps for use with the waveguide sensors are nearly completed. These are laid out on a printed circuit board and fabrication is in process.

A request has been made to Jack McElroy at Philadelphia Electric for information on the design of the mechanical impacter used for reproducibility checks on AE instrumentation at Peachbottom reactor. This device has performed satisfactorily in the reactor environment for over a year. We plan to incorporate the mechanical impacter as part of our calibration procedure for the AE systems on the ZB-1 vessel and on Watts Bar reactor.

Reactor Monitoring

Details of the AE system installation were reviewed with TVA staff on May 4 and 5 at Knoxville, Tennessee and the plant site. The schedule shown in Figure 1 was acceptable to TVA. The current plant schedule shows:

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- Cold hydro test - 10/9/81
- Hot functional - 2/11/82
- Fuel load - 6/1/82

Approval of documentation for AE system installation appears to be the critical path item. There are three separate documents needed. These are:

1. Installation and test plan.
2. A "Letter of Agreement" contract between PNL and TVA.
3. Seismic qualification documentation.

A draft installation and test plan has been reviewed with TVA and was generally acceptable. Finalizing this involves primarily the recognized need for drawings to document system installation.

Drafting a "Letter of Agreement" contract requires PNL submittal of a summary of the intended work, time schedule, and benefits to TVA. This will be done within the month of May.

The first step in seismic qualification determination is to identify precisely the location of all sensor installations and location of the monitor instrument. Given this, TVA will then supply PNL with the criteria for seismic qualification. The visit to the Watts Bar plant May 5 provided the details necessary for us to proceed with these determinations.

Fabrication of sensors and preamplifiers for the Watts Bar installation is in progress. The material for fabrication of the sensors has been obtained and fabrication of these sensors has begun. The stainless steel boxes that will house the sensor and preamplifier are being made at PNL metal shops. These sensors will be of the differential design, also on stainless steel waveguides. Waveguide design is being reviewed to ensure that the optimum choice will be made in selecting the diameter and shape of the waveguides to be used.

AE Monitor System

Repair of the disc drive unit on the Dunegan/Endevco system has been completed and the system is in transit back to PNL. This will allow resumption of full AE monitor system testing. The waveform tagging between DART and the waveform acquisition has been accomplished and is in the debug stage. Also updated DART software has been incorporated into the NRC DART system.

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HSST Irradiated Fracture Specimens

In concurrence with NRL, plans are to monitor testing of one irradiated 4T specimen and the companion unirradiated specimen the week of May 25. A two to three week interval will be allowed for evaluation of the resulting data and then another pair of specimens will be monitored. One irradiated specimen will be high toughness and one will be low toughness. Present plans are to monitor only the two specimen sets. This will be reviewed following the second set of tests.

SCHEDULE AND FUNDING

Figure 2 shows the overall program schedule. The critical path item (fabrication of the ZB-1 test vessel) is now progressing with final authorization having been received by MPA. It appears that January 1982 is the earliest that vessel testing could start. Following the June 2 meeting in Germany, information should be available for updating the schedule.

Funding status is summarized in Table 1.

PLANS FOR MAY

- Complete fabrication of A533B insert for the ZB-1 vessel.
- Finalize the ZB-1 vessel test matrix.
- Finalize sensor locations for Watts Bar reactor installation.
- Continue instrument system testing.
- Monitor fracture testing of one irradiated HSST specimen and its companion unirradiated specimen.
- Obtain a report on results from AE weld monitor demonstration performed in Germany
- Prepare for ZB-1 vessel test planning meeting in Germany.

Yours very truly,

P. H. Hutton

P. H. HUTTON
Project Manager

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PHH:kw

Attachments

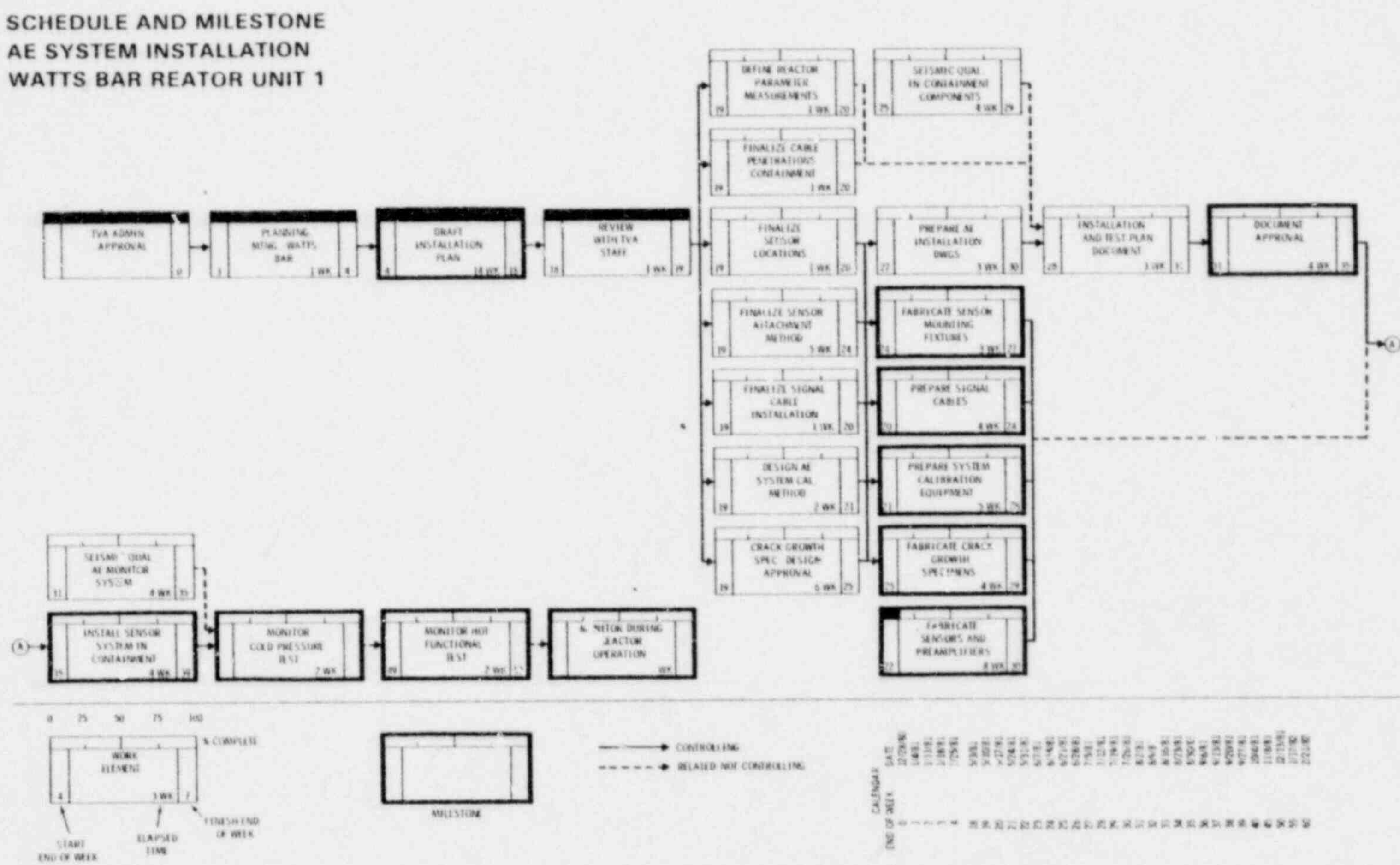


Figure 1. Schedule and Milestones-AE Testing at Watts Bar Reactor

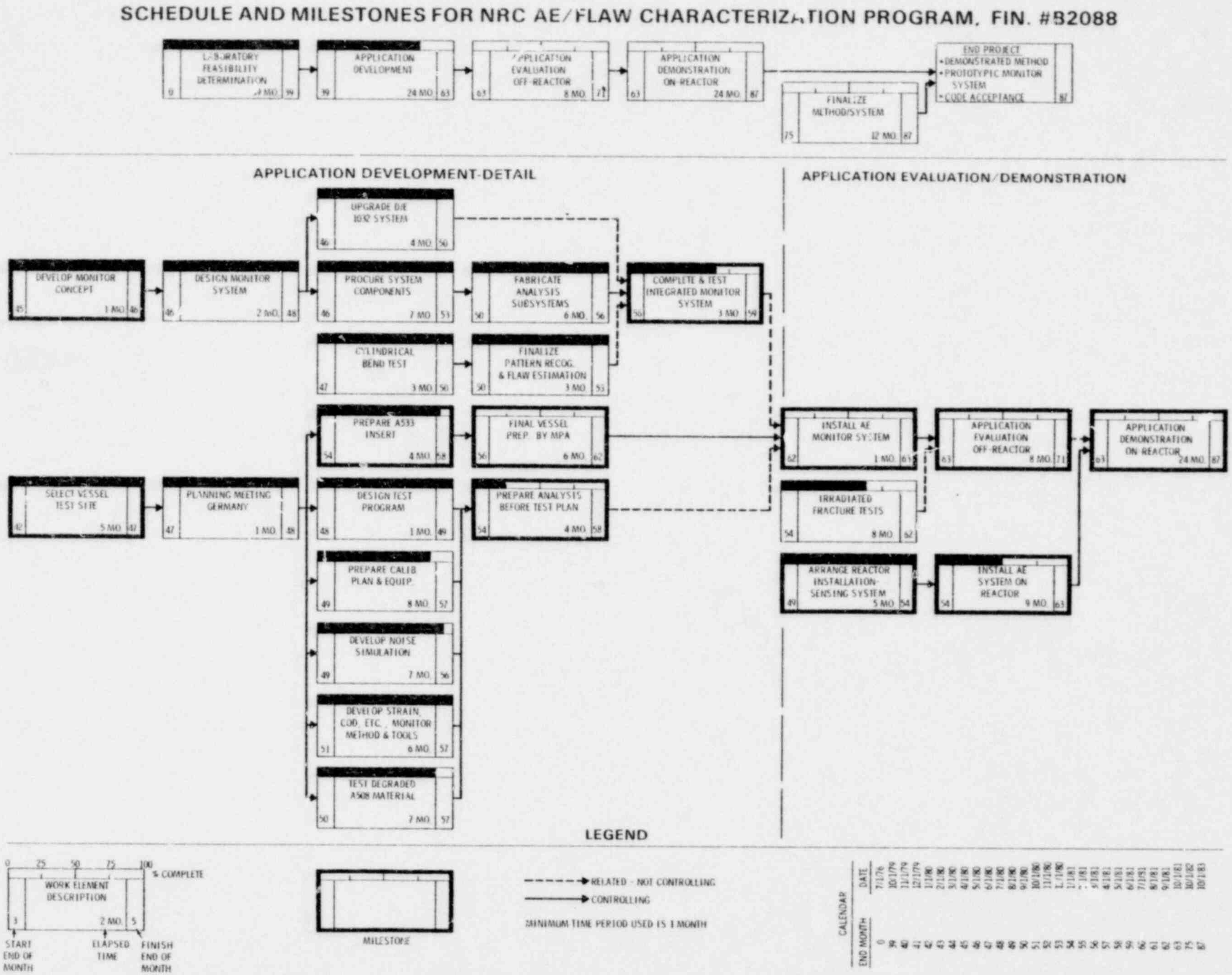


Figure 2. Program Schedule and Milestones

IMAGE EVALUATION TEST TARGET (MT-3)

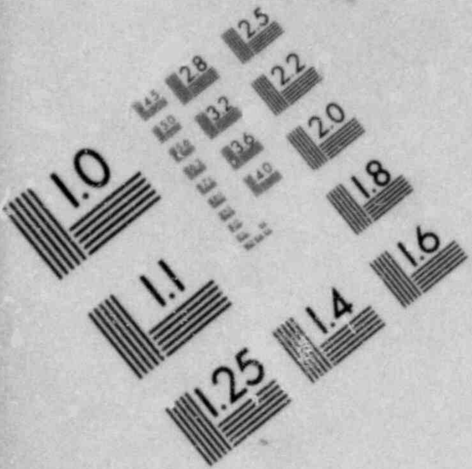
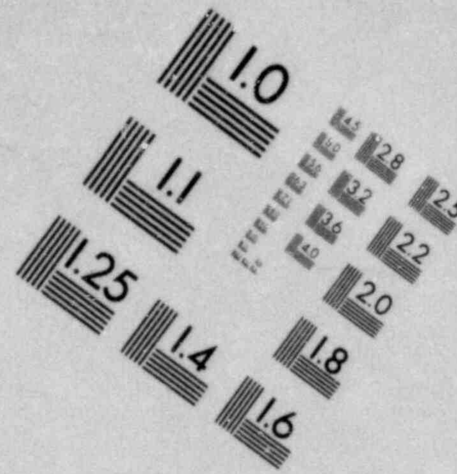
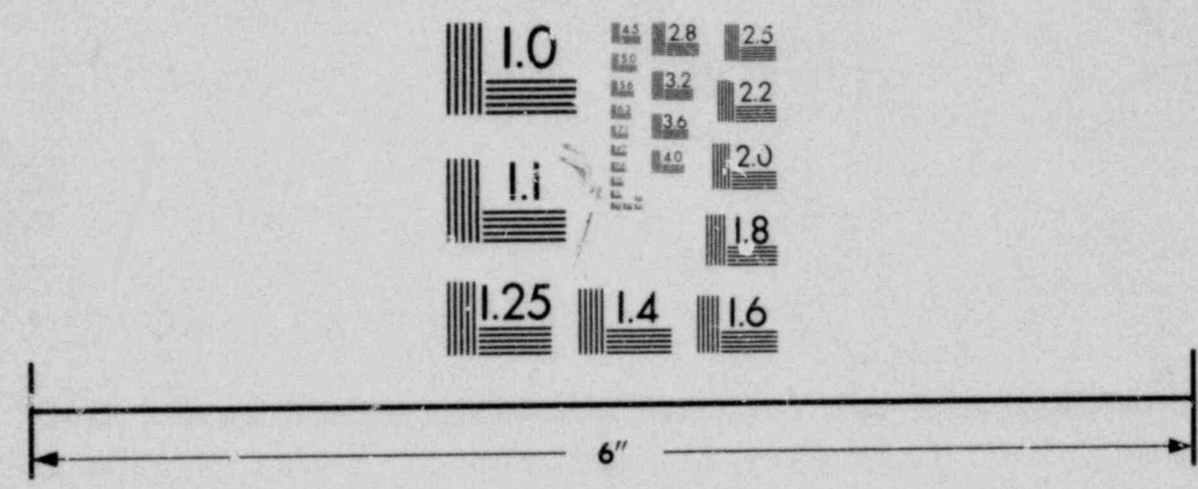
6"

IMAGE EVALUATION
TEST TARGET (MT-3)

6″

IMAGE EVALUATION
TEST TARGET (MT-3)

IMAGE EVALUATION
TEST TARGET (MT-3)

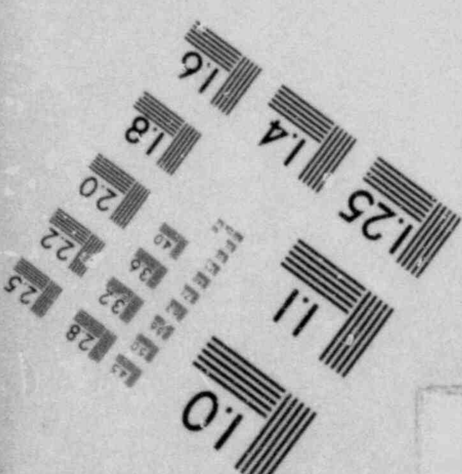
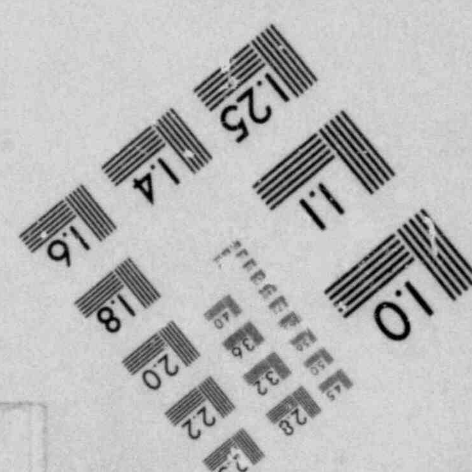



Table 1

AE/FLAW CHARACTERIZATION PROGRAM

SUMMARY OF FY81 COSTS

Total Funding:	Expense - FY81		$500.0K
	- FY80 carryover		122.0K
		Total	$622.0K
	Capital - FY81		$ 31.0K
	- FY80 carryover		14.4K
		Total	$ 45.4K
Cost to 5/1/81:	Expense - Spent*		$402.0K
	- Balance		220.0K
	Capital - Spent*		$ 42.1K
	- Balance		3.3K

*Includes outstanding commitments

Major FY81 Cost Elements to Date

Irradiated Specimen Tests	$ 21.0K
Vessel Test Preparation including Fabricate A533 Insert	98.0K
AE Monitor System	84.0K
Sensor System Improvements	23.0K
Reactor Installation	13.0K
Pattern Recognition	42.0K
AE Weld Monitor Demonstration	45.0K
General - Reporting, Travel, Program Management	76.0K
Total	$402.0K

Projected Remaining FY81 Costs

Expense

Vessel Test Preparation	$ 30.0K
Vessel Test and Analysis	40.0K
Irradiated Fracture Specimen Monitoring	20.0K
AE Monitor System Fabrication and Testing	10.0K

Table 1

(cont'd)

Projected Remaining FY81 Costs - cont'd

Expense - cont'd

Reactor Installation of AE Sensing System		\$ 30.0K
Weld Monitor Demonstration		5.0K
Pattern Recognition Refinement		15.0K
Laboratory Tests to be Defined		40.0K
Reporting, Program Management, Travel		30.0K
	Total	\$220.0K

Capital

Signal Conditioning Equipment		\$ 4.4K
	Total	\$ 4.4K

APPENDIX A

DRAFT - REVISED ZB-1 VESSEL

TEST PLAN

Revision 3
4/81

TEST PLAN

for

U.S. - GERMAN

COOPERATIVE RESEARCH TO ACOUSTIC EMISSION MONITOR

PRESSURE VESSEL TEST ZB-1

AT MPA STUTTGART LABORATORY

TEST PLAN
for
COOPERATIVE RESEARCH TO ACOUSTIC EMISSION MONITOR PRESSURE VESSEL TEST ZB-1 AT MPA STUTTGART LABORATORY

1.0 INTRODUCTION

The U.S. NRC, Reactor Safety Research Division has been conducting an extensive research program through one of their contractors (Battelle, Pacific Northwest Laboratories) to develop the application of acoustic emission (AE) to continuously monitor reactor pressure vessels for detection and evaluation of growing flaws. The initial work has been done primarily on laboratory specimens of Type A533-B Class 1 pressure vessel steel. The program has reached a point where it is recognized that further work must be conducted on heavy section vessels under simulated reactor conditions to adequately evaluate AE signal identification and flaw interpretation techniques developed. The forthcoming ZB-1 vessel test, to be performed at MPA Stuttgart, can meet the technical needs of the NRC program. Cooperative participation by the U.S. and Germany on this test also appears to offer mutually beneficial technical information exchange.

This test plan is intended to establish a technical and administrative understanding of the basis for U.S. NRC participation in the ZB-1 vessel test. Work in behalf of the U.S. NRC will be performed by its contractor, Battelle Pacific Northwest Laboratories (PNL).

2.0 TEST PLAN

2.1 PURPOSE

The purpose of this test is to measure and analyze acoustic emission (AE) data from fatigue crack growth in a heavy section (120 mm thick) steel pressure vessel. The conditions of the test will attempt to simulate reactor pressure vessel (RPV) operation within practical limits. In the ZB-1 test, the primary AE data will be derived from fatigue crack growth in an insert of ASTM A533 Grade B, Class 1 steel in the vessel wall.

2.2 TEST VESSEL DESCRIPTION

Intermediate pressure vessel ZB-1 is a 120 mm thick, 1715 mm O.D. cylindrical vessel with hemispherical closure heads. The cylindrical section of the vessel is 2280 mm long. The vessel material is A508 steel. Two part cylindrical inserts shall be welded into the test vessel. One of the inserts shall be composed of KS07C (A508) degraded material 1500 mm long by 700 mm circumferential width (as measured on the outside surface of the vessel). This insert shall be supplied by MPA. The level of material degradation will be determined by MPA. The second insert shall consist of A533B, Class 1 steel 1500 mm long by 750 mm circumferential width, and will be provided by PNL. This insert will contain three part-circular surface flaws which will be fatigue presharpened by internal notch pressurization. Two of the flaws will be machined on the inside surface of the insert and one flaw will be on the outside surface. The longitudinal axes of the flaws shall be perpendicular to the circumferential stress in the vessel. Figure 1 shows the cylindrical portion of the vessel and gives the relative location of the two inserts. Figures 2 and 3 show the geometry of the A533B insert and the location and geometry of the three part-circular cracks.

2.3 VESSEL LOADING CONDITIONS

In order to simulate RPV loading conditions, the test vessel shall be internally pressurized with water at temperatures of 90 and 288°C. About one-half of the planned test matrix shall be conducted at each test temperature. The water pressurization system will provide sinusoidal or sawtooth cyclic mechanical stressing of the vessel at a frequency near one cycle per minute. In addition, pressure cycling at R-ratios (R = minimum pressure/

maximum pressure) between 0.1 and 0.6 shall be performed. At the higher R-ratios the cyclic frequency shall be increased to the limit of the pressurizing system (approximately two cycles/minute). The planned test sequence is shown in Table I. High and low R-ratio load cycling shall be alternated to promote crack front marking at various stages of the test. Simulated hydrotests shall also be performed periodically during the test sequence. The first vessel loading shall be a simulated hydrotest to a pressure of 280 bar at a rate of 1 bar/minute. Additional hydrotests, identical to the first, shall be performed following each crack marking. The final hydrotest shall be conducted after all fatigue cycling is completed and pressurization shall be continued to vessel failure.

TABLE I

TEST SEQUENCE FOR VESSEL TEST ZB-1 (Rev. 2)

PRESSURE, BAR		TEMP., °C	NUMBER OF CYCLES	COMMENTS
MAX.	MIN.			
320	32	90	2,000	--
320	192	90	20,000	Crack Mark
320	32	90	2,000	--
320	192	90	20,000	Crack Mark
320	80	288	1,500	--
320	192	288	17,000	Crack Mark
320	80	288	1,500	--
320	192	288	13,000	Crack Mark
320	80	288	1,500	--

2.4 INNOCUOUS NOISE SOURCE SIMULATIONS

One of the important objectives of AE monitoring the vessel test is to evaluate the effect of various reactor background noise elements on AE monitoring. This relates to both basic detection of the AE signal and to identification of crack growth AE signals in the presence of similar noise signals.

One major source of noise is the reactor coolant circulation system. Measurements of this noise taken on operating reactors shows it to be very high relative to AE signal levels at low frequencies (< 100 kHz). However, with increasing frequency, it diminishes until at about 400-500 kHz, it is down near the electronic noise level of the measurement system. To evaluate flow noise effects on AE monitoring requires a noise field similar to reactor noise and a growing crack producing AE in that noise field. The planned approach to simulating reactor flow noise at a localized area is to drive transducers (3) located on the inside surface of the vessel with a shaped electrical input.

Mechanical rubbing of thermal insulation on the exterior of the vessel is a potential noise source to be simulated. To produce this noise, the vessel should be covered with blanket-type glass fiber insulation except for a 450 mm wide band of mirror insulation around the vessel cylinder.

Mechanical stressing of a weld slag inclusion may produce noise similar to acoustic emission. To investigate this, a slag inclusion is to be incorporated into one of the A533B insert-to-vessel welds. The slag should be about 5 to 10 mm in diameter and near mid-thickness of the vessel wall. The tentative location and size of the slag inclusion is to be determined prior to pressure cycling of the vessel by nondestructive means (e.g., X-ray and UT) for verification. Following the test, the slag inclusion and any associated crack growth will be characterized by destructive sectioning for correlation with AE results.

Potential base metal-to-weld cladding interface noise must also be investigated. It is proposed to simulate this by depositing a patch of stainless steel weld cladding approximately 5 mm thick over an area of the inside surface of the vessel of about 0.3 m^2 near the A533B insert. Thermal stressing of the cladding-to-vessel interface is needed to investigate potential resulting

AE sources. The method of producing the desired thermal stress will be by injecting cold water on the inner clad surface through a sparger pipe during the 288°C portion of the test. Thermocouples will be installed on each side of the interface to measure the thermal gradient.

Electrical transients represent the last noise source to be introduced. These transients may be produced simply by methods such as spark discharge, or turning electric motors on and off. These noises will be inserted at random locations on the test sequence.

2.5 AE MONITORING

A fundamental requirement in AE monitoring is that it be performed by methods which can be directly applied on an operating reactor. This requires the use of sensors capable of monitoring a 288°C surface. Other requirements are to obtain good quality data t- be processed for source location, pattern recognition chara[illegible] and crack grow[illegible] estimation. In addition, digitized sig[illegible] [illegible]eforms, plus conventional AE signal parameters such as signal peak time, amplitude, energy and duration must be recorded in a fashion which allows identification with test conditions and sequence.

To achieve the above requirements, the planned monitoring arrays include:

1. A sensor array located entirely on the A533B insert and encompassing the flaws. This will provide optimized AE data from the growing flaws.
2. One sensor array located to monitor the cylindrical portion of the vessel. These will provide a circumstance more directly related to monitoring a reactor pressure vessel wherein attenuation and geometry effects can be evaluated and relate[illegible] to information from the optimized array in 1 above.

Desired sensor locations are shown in Figure 4.

2.6 CRACK GROWTH MONITORING REQUIREMENTS

Methods for monitoring the crack propagation other than AE are required during the test. Crack opening displacement (COD) and ultrasonic (UT) inspection measurements will be used for this purpose. In order to perform COD measurements for the I.D. flaws, high temperature, water immersible MTS COD gages will be installed on the inside surface of the vessel. Thus, access to the interior of the vessel is required, as well as feedthroughs for leadwires. Technique and installation details will be jointly established by MPA and PNL.

High temperature, water immersible Ailtech type strain gages shall be spot welded to the A533B insert at locations specified in Figure 5.

After the test is completed, the COD and UT inspection results will be confirmed by destructive examination of each flaw. It will, therefore, be necessary to remove the A533B insert after the test is completed. Subsequent detailed sectioning of the flaws shall be performed at PNL.

2.7 BLIND TESTS

Blind tests of the AE monitoring system shall be performed at randomly selected times during the test sequence. In addition to monitoring crack growth in the presence and absence of various innocuous sources (see Section 2.4), it is also necessary to AE monitor the vessel in the presence of background noise when no crack growth is occurring. To produce this situation requires activating the various noise source mechanisms while cycling the vessel pressure between 25 bar and 126 bar. This pressure cycle should produce little, if any, crack growth and should be applied for only a limited number of cycles (a few hundred) at randomly selected points in the test sequence.

3.0 RESPONSIBILITIES

U.S. and German responsibilities in this cooperative test are:

U.S. (PNL)

1. Provide a finished insert of A533B material in accordance with dimensional specification and schedule requirements set forth by MPA. Flaws will be machined into the insert and precracked ready for testing. Insert is to be delivered to the vessel fabrication site.
2. Perform laboratory tests of samples of the degraded A508 material with microcracks prior to vessel testing to evaluate AE characteristics.
3. Provide complete AE monitor/analysis and physical measurements systems at the test site (MPA Stuttgart), install AE sensors and prepare the system for testing in accordance with the schedule set forth by MPA.
4. Provide physical measurement devices (strain gauges, COD gauges) and signal recording instruments required in support of the AE monitoring as agreed by MPA and PNL.
5. Provide the necessary qualified personnel to conduct AE monitoring and analysis during the course of the test.
6. Record and provide to MPA any AE data from the A508 insert to the extent practical without compromising AE monitoring of the A533 insert.
7. After removal of the A533 insert following the test, transport the insert to PNL, perform destructive examination of the flaws to confirm crack growth characteristics.
8. Prepare a report describing AE monitoring results, physical measurement data, destructive examination results relevant to the AE monitoring and the correlations among these. This

complete report, plus any supporting data is to be available to MPA Stuttgart.

GERMANY (MPA STUTTGART)

1. Provide samples of degraded A508 material for laboratory testing by PNL to evaluate AE characteristics prior to the vessel test. The material is to be representative of that being inserted into the ZB-1 vessel.
2. Install the A533B insert provided by PNL in the ZB-1 vessel including necessary post weld stress relief and slag inclusion.
3. Install stainless steel cladding on section of vessel inner surface.
4. Keep PNL informed on test preparation and testing schedule.
5. Install physical measurement devices (strain gauges, COD gauges, thermocouples) as agreed by MPA and PNL.
6. Provide vessel test facilities and perform a test sequence in accordance with the test plan described herein. NOTE: In the event of problems with excessive crack growth rate or lack of growth in either insert, this test plan may be modified by mutual consent of PNL and MPA.
7. Remove the A533B insert from the ZB-1 vessel following test completion.
8. Document physical test results and AE results by others in a report to be made available to PNL.

JOINT RESPONSIBILITIES

1. In the event of premature failure of either insert, the party responsible for that insert shall arrange for repair to facilitate completion of the test. Premature failure is defined as any throughwall penetration occurring prior to completion of the loading conditions specified in Table I.

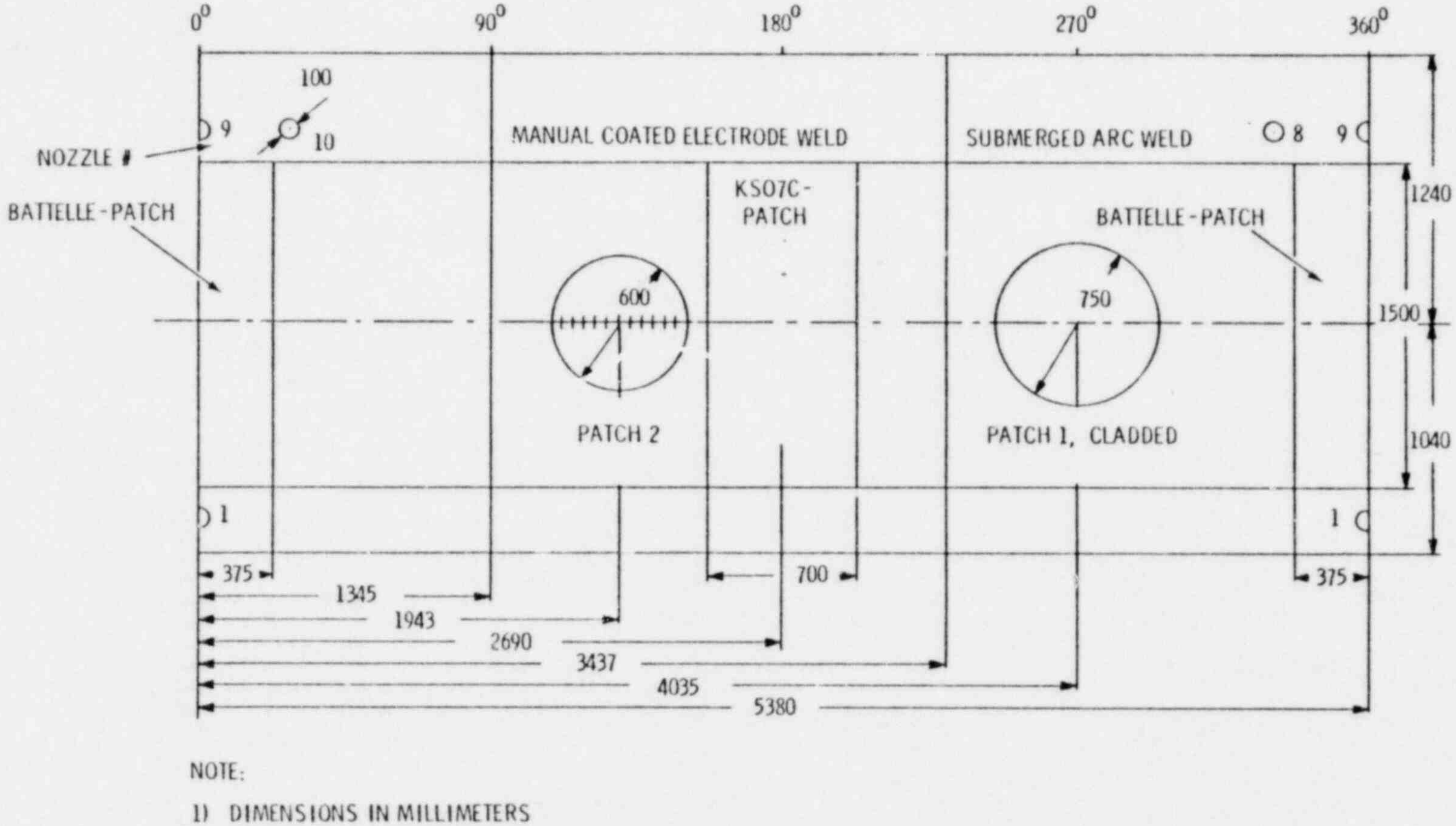


Figure 1. Cylindrical Portion of ZB-1 Vessel

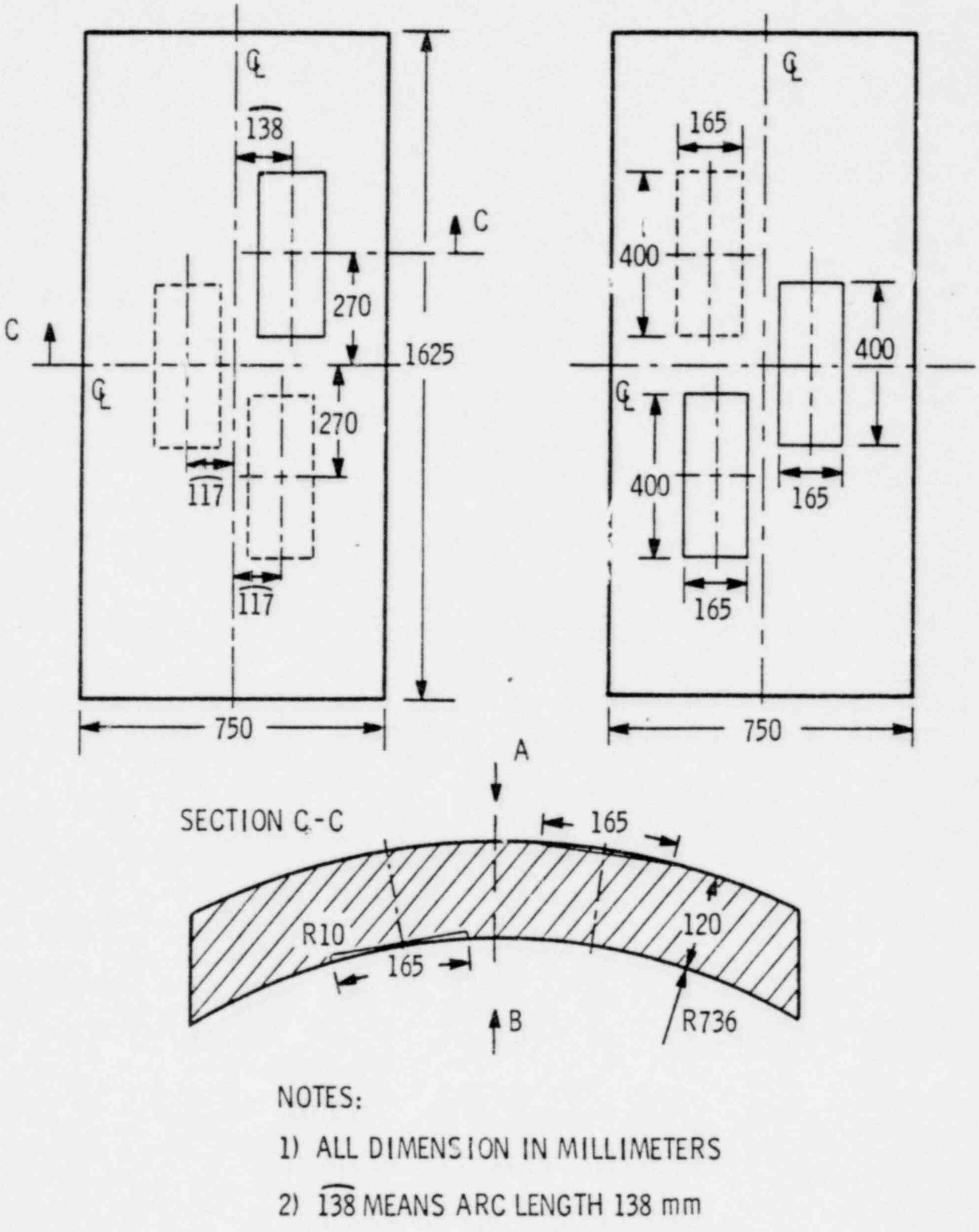
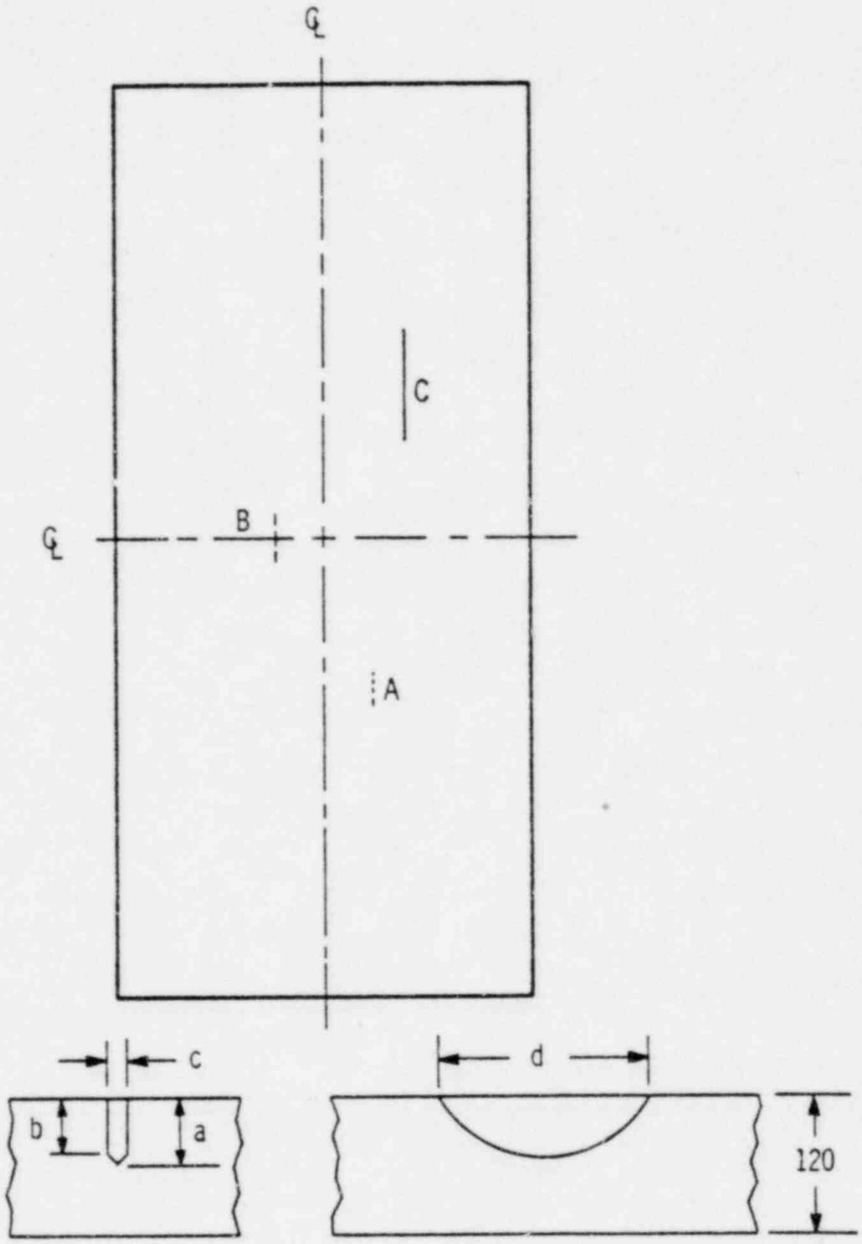


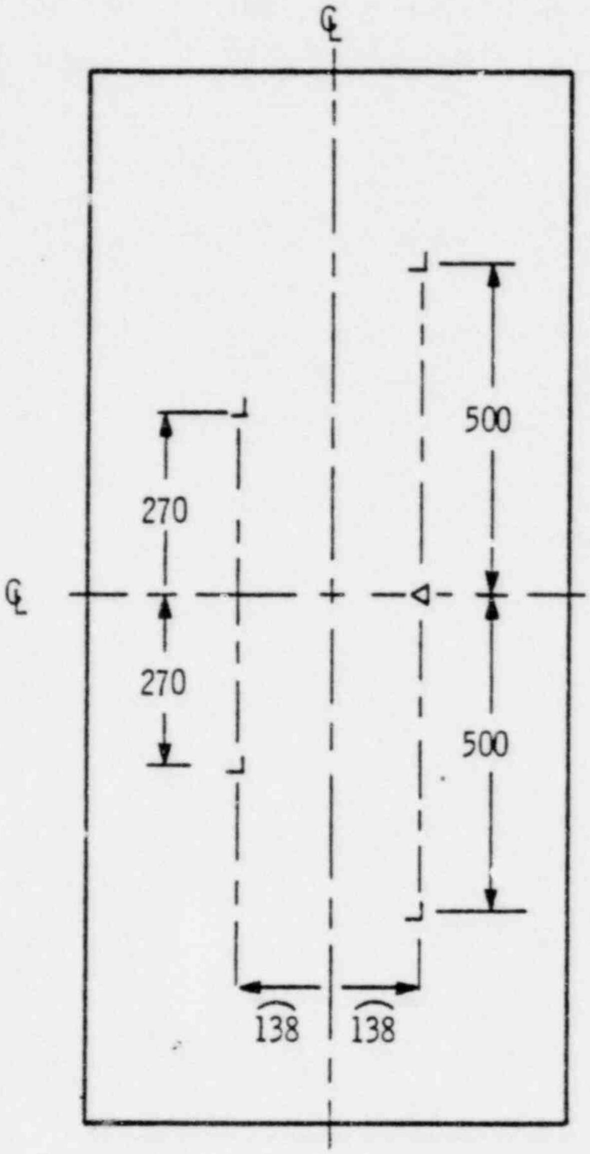
Figure 2. Geometry of A533B Insert



NOTCH	LOCATION	a	b	c	d	a/w
A	I.D.	22	16	3	54	0.18
B	I.D.	32	26	3	81	0.27
C	O.D.	48	36	6	190	0.40

NOTE: ALL DIMENSIONS IN MILLIMETERS

Figure 3. Geometry of Notches in A533B Insert



NOTES:

1) Δ = DELTA ROSETTE

2) L = BIAXIAL GAGES

3) OUTSIDE SURFACE OF PATCH, IDENTICAL SERIES OF GAGES ON INSIDE SURFACE

4) DIMENSIONS IN MILLIMETERS

Figure 5. Strain Gage Plan for A533B Insert