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INTERIM REPORT

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Author(s): P.H. HUTTON

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Responsible NRC Individual and NRC Office or Division:
DR. JOE MUSCARA
METALLURGY AND MATERIALS RESEARCH BRANCH, RSR

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BATTELLE
PACIFIC NORTHWEST LABORATORIES
P.O. BOX 999
RICHLAND, WA 99352

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

INTERIM REPORT

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

July 7, 1980

Dr. Joe Muscara
Metallurgy and Materials Research Branch
Reactor Safety Research Division
Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Joe:

MONTHLY LETTER REPORT - MAY AND JUNE, 1980
ACOUSTIC EMISSION CHARACTERIATION OF
FLAW GROWTH IN A533B PRESSURE VESSEL STEEL
FIN. NO. B2088

ACCOMPLISHMENTS

- Participated in meetings in Saarbrucken and Stuttgart, West Germany to resolve details of AE monitoring forthcoming vessel tests at MPA, Stuttgart.
- Developed an initial test matrix for German ZB1 vessel test and revised to meet requirements established in meetings with German technical personnel.
- Prepared a final fabrication drawing for A533 steel insert for ZB1 vessel.
- Bids for fabrication of the A533 steel insert have been requrested.
- Contacted ORNL staff to establish firm details for precracking flaws in the A533 insert.
- Started evaluation of thermal stressing of weld clad in the ZB1 vessel by external heating.
- Continued fabrication of the AE monitor system for the ZB1 vessel test.
- Evaluated application of pattern recognition techniques to identify AE signals detected with waveguides.
- Met with Philadelphia Electric staff members to discuss installation of AE system on Peachbottom reactor.
- Presented a review of the AE/Flaw Characterization Program to ACRS.

Dr. J. Muscara, NRC, and R.J. Kurtz and P.H. Hutton, PNL, traveled to West Germany for meetings on June 2-4, with IZFP staff, Saarbrucken and MPA staff, Stuttgart to resolve technical details of AE monitoring forthcoming vessel tests at MPA, Stuttgart. A copy of the subsequent trip report is appended (Appendix A) to this report for further details.

An initial test plan was developed for AE monitoring the fatigue testing of pressure vessel ZB1 at the MPA, Stuttgart laboratory (see Appendix B for a copy of the plan). This plan was used in discussions with IZFP and MPA staff to establish technical details of the test and associated preparation activities. The results of the meetings conducted on June 3-4, 1980, in Stuttgart, indicated that some revisions to the proposed matrix were necessary in order to complete the test within the desired three to four month time period. The major revisions consisted of: (1) reducing the total number of pressure cycles by about 33 percent, (2) decreasing the cyclic frequency to 1.0 cycle/min., (3) increasing the test pressure by about 27 percent, and (4) adjusting the flaw geometries to accomodate the reduced cycles and increased stress. Tables I and II summarize the changes which have been made to the matrix.

A revised drawing of the A533B insert and machined flaws was made based upon the design input obtained from MPA and ORNL staff. Bids for fabricating the A533 insert for the ZB1 vessel have been requested from several machine shops with a bid due date of July 9, 1980.

The ORNL staff provided the necessary design requirements for precracking of the machined flaws in the A533 insert for the ZB1 vessel. Time and cost estimates were also obtained which indicated that precracking should cost about $15K and require about four weeks to complete.

Since the ZB1 vessel test at MPA will be run at 200°F, we are faced with a problem in devising a method for simulating thermal stressing of stainless steel cladding to vessel interface in an operating reactor vessel. One method suggested is by external local heating of the section of the vessel having inside cladding. The validity of this suggestion is being evaluated by PNL heat transfer specialists.

The AE monitor system to be used in the German ZB1 vessel test will consist of three distinct packages: (1) Dunegan/Endevco (D/E) AE detection and source location system, (2) digitized waveform recorder, and (3) pattern recognition analyzer. All major equipment items for the waveform recorder and pattern recognition analyzer have been placed on order. The longest lead time item is the 9-track tape recorders (common to both systems) at four months. The recorders, however, are not critical path items and will not prevent system fabrication from progressing. The existing NRC-owned D/E 1032 system is presently at Dunegan/Endevco undergoing system upgrading to include a newly designed frontend and data acquisition system (DART).

The waveform recorder system will utilize an existing NRC-owned 8-bit Biomation 8100 transient recorder for signal digitization. The digital data will be transferred to 9-track digital tape via a microprocessor controller. Each waveform will have associated with it an identifier code extracted from the D/E system. The code is necessary for matching waveforms with vessel source location in the pattern recognition analyzer. Design of the microprocessor controller is approximately 60% complete.

The pattern recognition system is centered around a Digital Equipment Corporation (DEC) PDP 11/03 minicomputer. Data tapes from the waveform recorder will be played back and matched with data input from the D/E system. Specific analysis features will act upon the two data sets for noise versus AE discrimination. The net output expected is a delineation of AE signals verified by pattern recognition and identified by source location. Data tapes will also be shipped back to PNL for detailed pattern recognition analysis. If the presently selected features need to be changed, new features can be sent back to Germany and loaded onto the PDP 11/03 system via floppy disk. Consideration is being given to the possibility of using a large minicomputer at Battelle-Frankfurt in Germany for the detailed pattern recognition analysis. Flaw significance evaluation using AE data will also be performed on the PDP 11/03 system. The PDP 11/03 system is a component system with minimal assembly time once all the separate component items are received. All items have been placed on order.

AE systems will be housed in shock mounted metal traveling containers. The front and back of the containers are removeable for system usage. The systems will not have to be removed from the containers for operation.

Earlier analysis of AE waveforms recorded by waveguide sensors indicated insufficient information was available for pattern recognition analysis. The reason for this was that the preamps associated with the waveguides were tuned to a very narrow range of frequencies. The effect of this tuning was to filter out much of the discrimination information needed for the pattern recognition analysis. Figure 1 compares the spectrum of surface-mounted sensors used in the experiment documented in PNL-3052, with initial data from a waveguide sensor. The effect of the preamp tuning on the shape of the waveguide spectrum is very apparent.

Since it would be valuable to use waveguides in the hostile environment of a reactor vessel, data was collected during the cylindrical bend specimen test using a preamp that had been modified to pass a broader band of frequencies. Figure 2 shows a typical spectrum. The noise source in this case is background noise.

The broadband waveguide sensor data set consisted of a total of 83 waveforms. This data was divided as follows:

Valid AE	31
C-Clamp	16
Background	20
Rubbing	16
	83

The feature generation and reduction techniques documented in "Acoustic Emission Analysis Using Pattern Recognition", PNL-3052, were used to analyze this data. Eleven features were generated for the analysis:

Standard Deviation
Skewness
Kurtosis
Autocorrelation at Lag 13
Autocorrelation at Lag 37
Maximum frequency response
Frequency of maximum response
Total power (0 Hz - 1 MHz)
First moment of the power spectrum
Second moment of the power spectrum

Comparing this list of features with the list used in PNL-3052 shows that one of the features, the mean, was not included. The mean was not used in this analysis because during the experiment the input offset of the transient analyzer was adjusted several times. Adjusting the input offset changes the mean.

The 10 features were autoscaled and a correlation-to-property feature reduction algorithm was used. Six features were selected as having the best discrimination capability. The six features listed in order of importance are:

Kurtosis
Autocorrelation at Lag 37
Standard Deviation
Second moment of the power spectrum
First moment of the power spectrum
Total power

This list can be compared to the following set of features that were found to contain the best separation information for AE data gathered during the same experiment but with surface-mounted sensors (see Monthly Report for January, 1980).

Kurtosis
Autocorrelation at Lag 37
Mean
Total power
First moment of the power spectrum

Four of the five features selected for this set of data were also selected for data collected with the waveguides. In addition, the two features Kurtosis and Autocorrelation at Lag 37 were selected as the most valuable in both cases.

The first five features selected by the feature reduction algorithm for the waveguide data were input to a least squares fitting algorithm to produce a decision function. The output of this decision function is plotted in Figure 3. The waveform number is listed on the abscissa and is arbitrary. The horizontal line represents the value of the decision rule; all points above this line are classified as noise and all those below the line as valid AE. As shown in Figure 3, seven of the 83 waveforms were misclassified giving a 92% correct classification.

If all six selected features are input to the least squares fitting algorithm, the correct classification rate increases to 99%. The decision function is plotted in Figure 4.

The results of this work with waveguide data indicates that sufficient information can be obtained for pattern recognition analysis if the preamp used has a sufficiently broad frequency response.

Installation of an AE system to test continuous monitoring on an operating reactor was discussed with Dr. C.F. Mengers, Director, and J. McElroy, Research and Testing Division, Philadelphia Electric Company on May 29, 1980. Desired monitoring locations are: (1) a vessel nozzle, (2) a section of vessel weld, and (3) a section of primary piping. Obtaining permission to monitor primary piping does not appear to be a problem. Investigation of any significant AE indications would only require about two to three days of reactor down-time. Obtaining permission to monitor a nozzle and/or a section of vessel weld definitely is a problem. Investigation of any AE indications in these locations would require a minimum of about 35 days reactor down-time. NRC waiver of responsibility to investigate AE indications would do little to aleviate the problem because utility policy requires that any indications of a flaw or fault be investigated. This appears to be a common circumstance among the utilities. The outlook for arranging to install the desired AE sensor arrays on an operating reactor in FY-80 appears very discouraging at this time. We are, however, continuing to search for such an arrangement which will ultimately fulfill the need to test the results of this program on an operating reactor.

A review of the AE/Flaw Characterization Progam was presented to the ACRS Subcommittee on Metal Components on June 17, 1980. The review appears to have been favorably received. A copy of the summary is attached as Appendix C of this report.

WORK PLANS FOR JULY

- Obtain time and cost estimates for fabricating the patch, and initiate the work.
- Obtain A508 test material from MPA and initiate specimen fabrication.
- Complete evaluation of cladding thermal stressing by heating from the outside of the vessel.

- Design and procure the necessary components to measure crack opening displacements for the I.D. notches on the A533 insert for the ZB1 vessel.
- Evaluate application of pattern recognition techniques for crack growth AE identification to a composite of waveform data collected to date.
- Complete the cylindrical bend specimen test.
- Follow-up on action items for the MPA vessel test.

Yours very truly,

P. H. Hutton

P.H. HUTTON
Project Manager

PHH:dd

Attachments

TABLE I

REVISED TEST SEQUENCE FOR VESSEL ZB1

PRESSURE, BAR		NUMBER OF CYCLES	COMMENTS
MAX.	MIN.		
320	32	2,000	---
320	192	20,000	Crack Mark
320	32	2,000	---
320	192	20,000	Crack Mark
320	32	1,500	---
320	192	17,000	Crack Mark
320	32	1,500	---
320	192	13,000	Crack Mark
320	32	1,500	---

NOTE

1. The cyclic frequency shall be at least 1.0 cycles/min. and possibly greater during crack marking.

2. 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/min. 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 II

REVISED FLAW GEOMETRIES - ZB1
A533B INSERT

FLAW LOCATION	FLAW DEPTH, mm	FLAW LENGTH, mm
I.D.	21	53
I.D.	33	85
O.D.	50	200

NOTE

The dimensions in the table represent the machined notch dimensions.

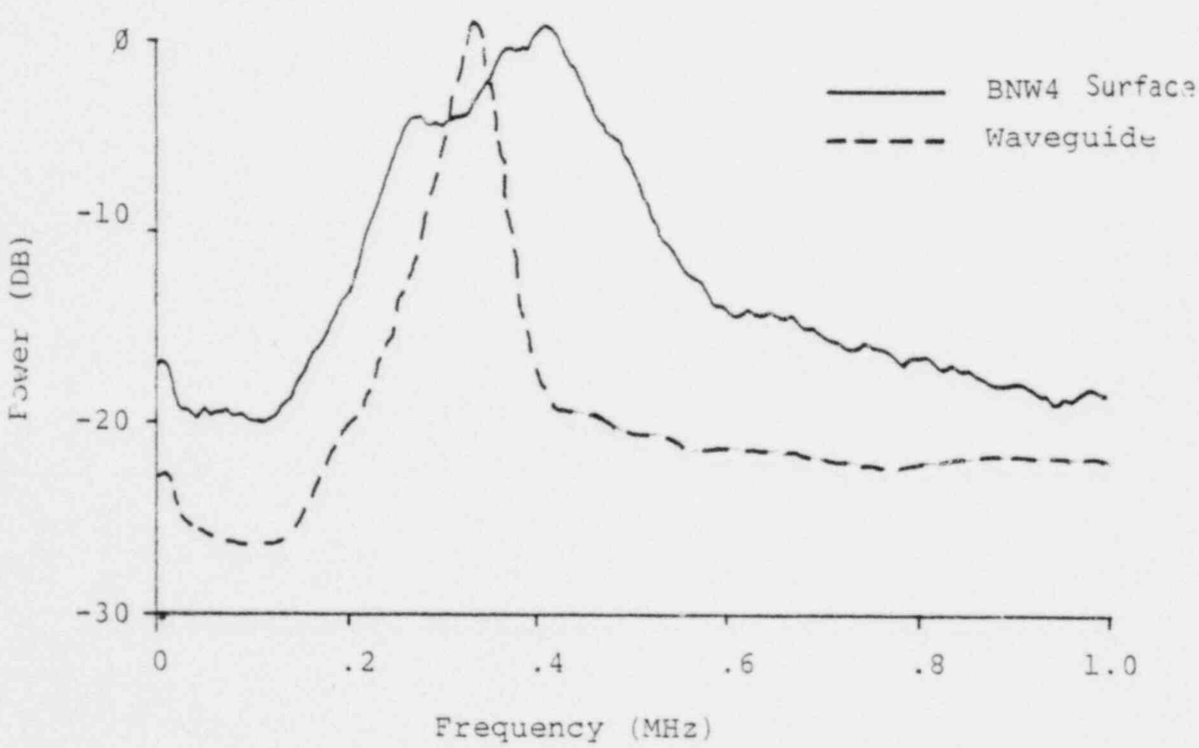

FIGURE 1. Comparison of Two AE Sensors.

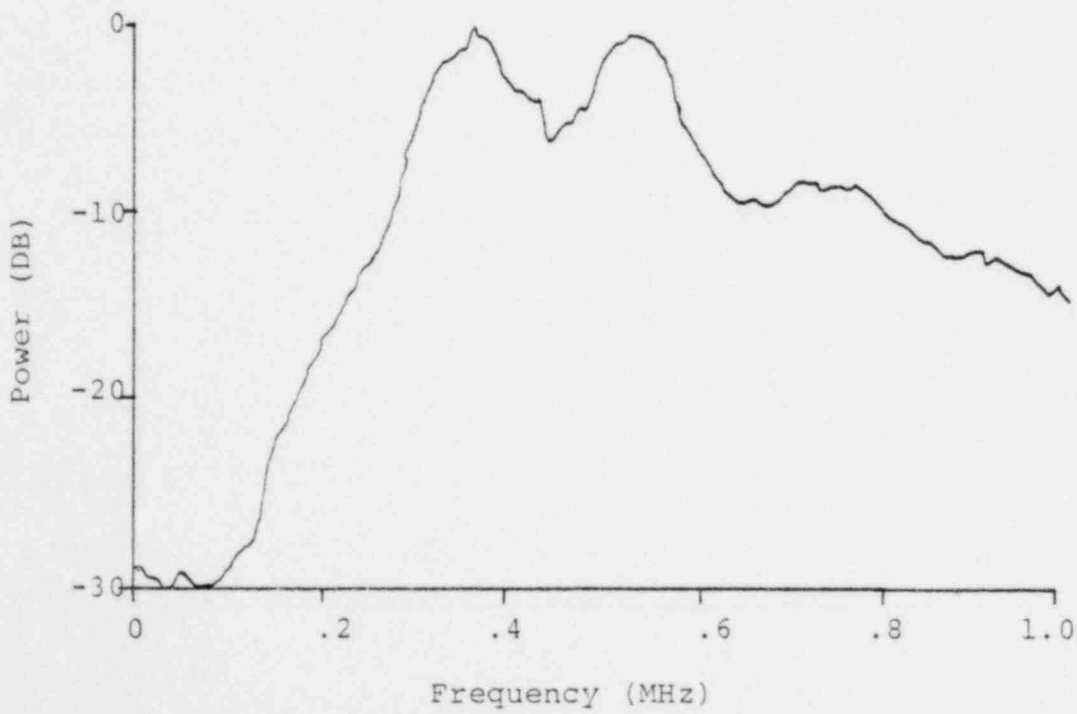

FIGURE 2. Typical Response of Broadband Waveguide to Background Noise.

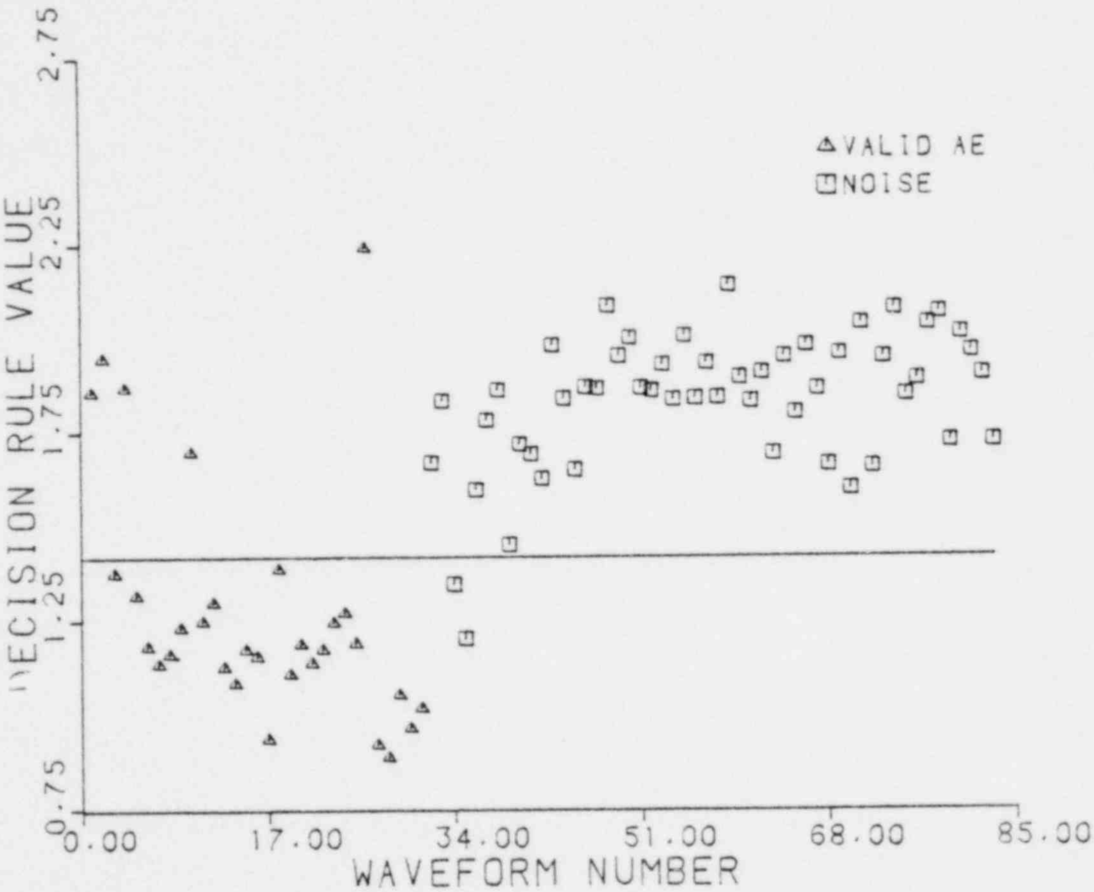

FIGURE 3. Least Squares Decision Rule with Five Features.

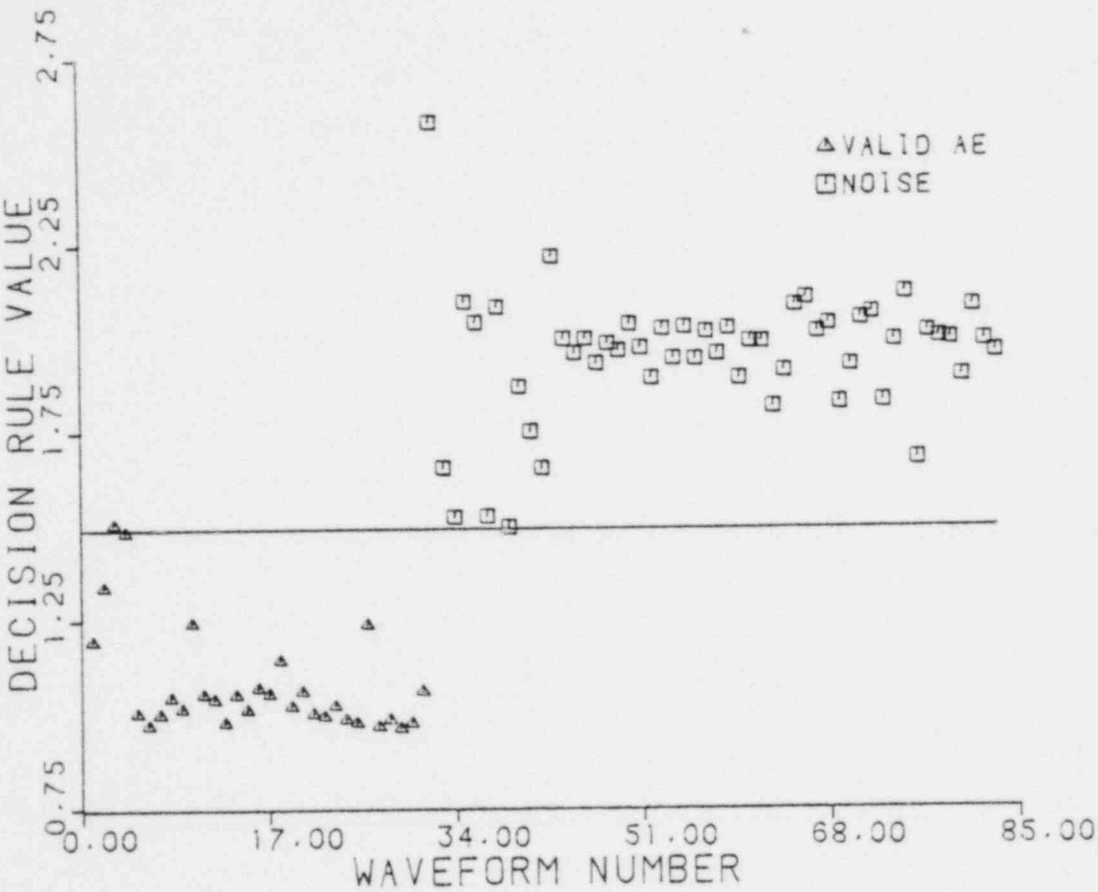

FIGURE 4. Least Squares Decision Rule with Six Features.

APPENDIX A

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

June 25, 1980

Dr. Joe Muscara
Metallurgy and Materials Research Branch
Reactor Safety Research Division
Nuclear Regulatory Commission
Mail Stop 1130-SS
Washington, D.C. 20555

Dear Joe:

TRIP REPORT: SAARBRUCKEN AND STUTTGART, GERMANY, JUNE 2-4, 1980

T is trip report summarizes meetings with IZFP staff at Saarbrucken, and with MPA staff at Stuttgart, West Germany concerning acoustic emission monitoring of forthcoming vessel tests at MPA Stuttgart.

Attendance

Saarbrucken (6/2/80):

Mr. Harbecke	FRG
Dr. Holler	IZFP
Dr. Deuster	IZFP
Mr. Lottermoser	IZFP
Mr. Waschkies	IZFP
Dr. Jax	Battelle-Frankfurt
Mr. Arendts	EG&G - NRC
Dr Muscara	NRC
Mr. Kurtz	PNL
Mr. Hutton	PNL

Stuttgart (6/3-4/80):

Dr. Kussmaul	MPA
Mr. Sturm	MPA
Dr. Gillot	MPA
Mr. Julisch	MPA
Dr. Issler	MPA
Dr. Eisenblatter	Battelle-Frankfurt
Mr. Lottermoser	IZFP
Dr. Deuster	IZFP
Mr. Arendts	EG&G - NRC
Dr. Muscara	NRC
Mr. Kurtz	PNL
Mr. Hutton	PNL

Purpose

Participation in the ZB-1 and ZB-2 vessel tests at MPA, Stuttgart, West Germany was selected earlier as a means of testing the results of the AE/Flaw Relationship Program (Fin. No. B2088) under simulated reactor conditions. This grew out of an invitation for such participation from Dr. Issler, MPA. The objective of this visit was to resolve technical details of the test and associated preparation activities. It was also intended to coordinate the activities of three participants in AE monitoring - PNL, Battelle-Frankfurt and IZFP. The meetings were very productive toward achieving the objectives.

Action Items

PNL:

1. Start preparation of the A533 insert for the ZB-1 vessel. This needs to be completed and delivered to MPA by September 1, 1980. Drill and tap holes for mounting sensors on insert before it is shipped to MPA.

2. Revise the test matrix to achieve desired results within three to four months at a slower cycle rate (1/min.) than originally anticipated. Also, to incorporate four to five hydrotest steps, with the last one being a burst test.

3. Evaluate a) flow noise generation with a hydraulic loop using an autoclave as a simulated vessel, and b) flow noise simulation electronically. Completion required by September 1, 1980. Following this, prepare specifications for a hydraulic noise loop for ZB-1 vessel.

4. Send IZPF and Battelle-Frankfurt reactor noise measurement data.

5. Send an NBS calibrated sensor to Battelle-Frankfurt for comparative calibration by their reciprocity method.

6. Submit a written calibration procedure (sensors and instrument system) for all stages of monitoring to Lottermoser. He is to coordinate this phase of monitoring procedure. Due date of August 1, 1980.

7. Determine the time required to obtain NBS calibration of 10 AE sensors (3 BF, 2 IZPF, 5 PNL).

8. Advise Dr. Issler whether or not we can reasonably monitor both -1 and ZB-2 simultaneously.

9. Determine what measures are necessary to accomodate 50 cycle power supply.

10. Determine status of PNL staff insurance under the conditions of the planned test.

11. Evaluate thermal stressing of cladding by heating from the outside.

MPA:

1. Provide PNL with a piece of degraded A508 material for ZB-1 and segregated A508 material for ZB-2 by the end of July, 1980 for AE characterization testing.

2. Send PNL a drawing showing MPA physical measurement plan by the end of July, 1980. PNL will then show any additions/modifications needed.

3. Provide a slag inclusion in a longitudinal A533 insert weld.

4. Put stainless cladding on a disk to be inserted in an existing hole in the side of the vessel (about 2 feet in diameter).

General

The present schedule calls for installation of instrument systems on the vessel in December, 1980. Testing to start in January, 1981.

2. Plan on another review meeting with MPA and IZPF personnel at the Water Reactor Safety Review meeting in Washington, D.C. in late October, 1980.

3. There is some consideration of a two phase test; 200°F testing at Stuttgart and 550°F testing at Manheim. Dr. Issler is to provide further clarification.

4. If the A508 insert fails prematurely, MPA will repair the vessel and continue to test A533 insert.

5. A533 insert will be separated from the A508 insert by about 30 inches circumferentially.

6. Both IZPF and Battelle-Frankfurt are focusing their work on hydro testing.

The German participants in these meetings showed an outstanding attitude of cooperation on all phases of the test plan.

Yours very truly,

P.H. Hutton/dd

P.H. HUTTON
Nondestructive Testing Section

R.J. Kurtz

R.J. KURTZ
Metallurgy Research Section

PHH:dd

TEST PLAN
FOR
U.S. - GERMAN
COOPERATIVE RESEARCH TO ACOUSTIC EMISSION MONITOR
PRESSURE VESSEL TESTS ZB1 AND ZB2
AT MPA STUTTGART LABORATORY

TEST PLAN
FOR
U.S. - GERMAN
COOPERATIVE RESEARCH TO ACOUSTIC EMISSION MONITOR
PRESSURE VESSEL TESTS ZB1 AND ZB2
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 vessel tests, ZB1 and ZB2, to be performed at MPA Stuttgart, can meet the technical needs of the NRC program. Cooperative participation by the U.S. and Germany in these tests also appears to offer mutually beneficial technical information exchange.

This test plan is intended to establish a technical and administrative understanding of the bases for U.S. NRC participation in the ZB1 and ZB2 vessel tests. Work in behalf of the U.S. NRC will be performed by its contractor, Battelle, Pacific Northwest Laboratories (BPNL).

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 (100-150 mm thick) steel pressure vessel. The conditions of the test will attempt to simulate reactor pressure vessel (RPV) operation within practical limits. In the ZB1 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. In the ZB2 test, attention will focus on fatigue crack growth in a nozzle fabricated from degraded A508 material, as planned by MPA.

The following test requirements relate to test ZB1 only. A test plan for ZB2 will be developed separately.

2.2 TEST VESSEL DESCRIPTION - ZB1

Intermediate pressure vessel ZB1 is a 120 mm thick, 1715 mm O.D. cylindrical vessel with hemispherical closure heads. The cylindrical section of the vessel is 2700 mm long. The vessel material is A508 steel. An insert of A533B Class 1 steel to be welded into the vessel shell will be provided by BPNL. Figure 1 shows the tenative configuration of the insert. The largest insert BPNL can provide from A533B material on hand is 1550 mm long by 800 mm in the circumferential direction. The insert will contain three part-circular surface flaws which have been 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 axis of the flaws shall be oriented perpendicular to the circumferential stress in the vessel. Final dimensions of the insert will be in accordance with drawings to be provided by MPA.

2.3 VESSEL LOADING CONDITIONS - ZB1

In order to simulate RPV loading conditions, the test vessel should be internally pressurized with water at a temperature of about 90°C. The water pressurization system should be capable of providing sinusoidal cyclic mechanical stressing of the vessel at frequencies ranging between 0.5 and 5 cycles per minute. In addition, pressure cycling at R-ratios (R = minimum pressure/maximum pressure) of between 0.1 and 0.6 should be possible. It is desired to cycle at rates up to 10 cycles per minute during much of the 0.6 R-ratio testing. The proposed test sequence (see Table I) is designed to produce measureable crack growth from each of the three flaws but none of the flaws are expected to propagate through wall during the loading sequence (see Table II).

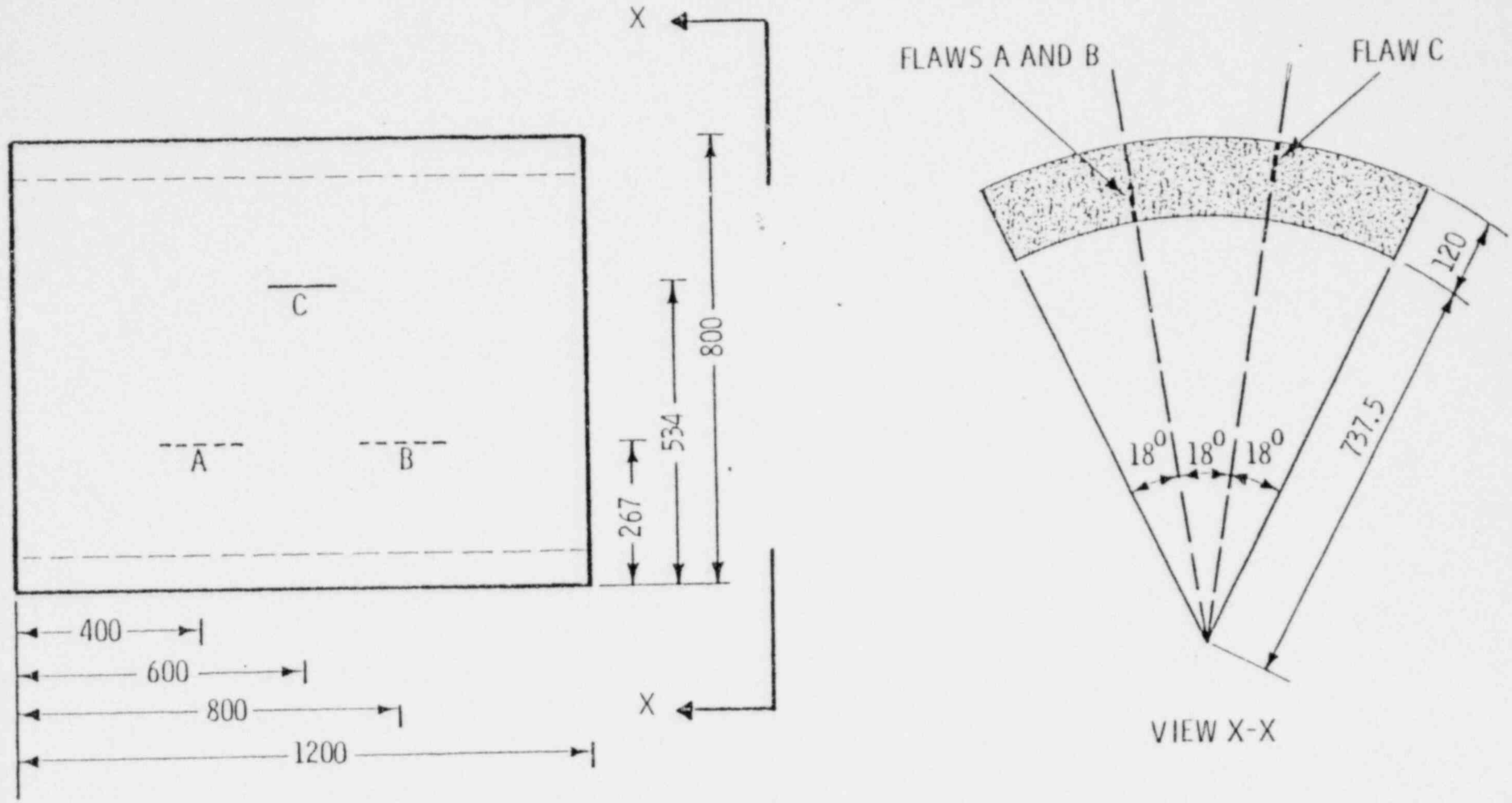

FIGURE 1 FLAW LOCATIONS IN A533B INSERT
(ALL DIMENSIONS IN mm)

TABLE I

PROPOSED TEST SEQUENCE FOR VESSEL ZB1

PRESSURE, BAR		CYCLIC FREQUENCY CPM	NUMBER OF CYCLES	COMMENTS
MAX.	MIN.			
252	25	5.0	3,000	
252	150	10.0	30,000	Crack Mark
252	25	5.0	3,000	
252	150	10.0	30,000	Crack Mark
252	25	5.0	2,500	
252	150	0.5/5.0	25,000	Mark, 2 K cycles @ 0.5
252	25	5.0	2,500	
252	150	0.5/5.0	20,000	Mark, 2 K cycles @ 0.5
252	25	5.0	2,000	

NOTE: This test matrix will require approximately 400 hours of cycling time, as well as at least 200 hours of preparation, repair and analysis. Operating on the basis of a 40 hour week, this represents 15 weeks total. If two shift operation were used, the overall test time could be reduced.

TABLE II

PROPOSED FLAW GEOMETRIES - ZB1
A533B MATERIAL INSERT

FLAW LOCATION	INITIAL FLAW DEPTH, MM	INITIAL FLAW LENGTH, MM	MAX. FINAL FLAW DEPTH, MM*
I.D.	24.0	58.9	34
I.D.	47.75	127.0	71.0
O.D.	59.7	221.0	89

*These numbers represent a conservative estimate of the potential crack growth

2.4 INNOCUOUS NOISE SOURCE SIMULATIONS - ZBI

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 both to 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. An approach to simulating reactor flow noise at a localized area requires the water system for pressurizing the vessel to be capable of about 6 m/sec. flow rate in the vessel feedwater piping. A throttling valve is necessary in the feedwater line to increase flow noise to a level comparable with reactor conditions by restricting flow at randomly selected intervals. In conjunction with flow noise generation, a growing crack in a pipe wall near the noise source is needed to produce AE. This could consist of a spool piece inserted adjacent to the valve with a lateral leg containing a crack which can be grown by cyclic bending of the lateral leg. BPNL would provide the test spool piece, plus a straight pipe replacement for long term operation. The approach to be used and the final details are to be jointly developed by BPNL and MPA.

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, which will either naturally or by manipulation have some movement relative to the vessel surface.

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 10 to 20 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 clad 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 on 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 jointly determined by MPA and BPNL. Thermocouples will be installed on each side of the interface to measure actual 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 - ZB1

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 290°C surface even though the test temperature will be only about 90°C. Other requirements are to obtain good quality data to be processed for source location, pattern recognition characteristics, and crack growth estimation. In addition, digitized signal waveforms, 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 or two sensor arrays 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 related to information from the optimized array in 1 above.

Each array will involve five high temperature sensors and each sensor will require about 13 cm square for a mounting fixture.

2.6 CRACK GROWTH MONITORING REQUIREMENTS - ZB1

Methods for monitoring the crack propagation other than AE are required during the test. Crack opening displacement (COD) and ultrasonic (UT) inspection measurements should be used for this purpose. In order to perform COD measurements for the I.D. flaws, COD gages will be required 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 BPNL.

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 BP"..

2.7 BLIND TESTS - ZB1

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 noise 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. (BPNL)

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 BPNL.

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 BPNL, 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.

TEST PLAN

GERMANY (MPA STUTTGART)

1. Provide samples of degraded A508 material for laboratory testing by BPNL to evaluate AE characteristics prior to the vessel test. The material is to be representative of that being inserted into the ZB1 vessel.

2. Install the A533B insert provided by BPNL in the ZB1 vessel including necessary post weld stress relief and slag inclusion.

3. Install stainless steel cladding on section of vessel inner surface.

4. Keep BPNL informed on test preparation and testing schedule.

5. Install physical measurement devices (strain gauges, COD gauges, thermocouples) as agreed by MPA and BPNL.

6. Provide fixtures and loading apparatus as required by plan jointly agreed on for growing a crack in vessel feedwater pipe (ref. paragraph two, Section 2.4).

7. 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 BPNL and MPA.

8. Remove the A533B insert from the ZB1 vessel following test completion.

9. Document physical test results and AE results by others in a report to be made available to BPNL.

ACOUSTIC EMISSION - FLAW RELATIONSHIP FOR IN-SERVICE MONITORING OF NUCLEAR PRESSURE VESSELS

P. H. Hutton, Project Manager
R.J. Kurtz
Pacific Northwest Laboratory

OBJECTIVE

The objective of the acoustic emission (AE)/flaw characterization program is to provide an experimental feasibility evaluation of using the AE method on a continuous basis to detect and analyze flaw growth in reactor pressure boundaries. This effort is based on the philosophy that AE offers the potential of being a valuable addition to current NDI methods with unique capability for continuous monitoring, high sensitivity, and remote flaw location. It is not viewed as a replacement for current methods, at least in the foreseeable future.

LICENSING AND SAFETY ISSUE

This program addresses the following areas of significance:

- Older reactors where effective inspection of the vessel by conventional methods is extremely difficult. AE can potentially be used to monitor these vessels to detect and locate active flaws, facilitate an estimate of severity based on AE, and localize shielding penetration location(s) for flaw inspection by conventional methods.

- Monitor vessel areas such as nozzles where conventional NDI is difficult and expensive. AE could detect the presence of an active flaw and maintain surveillance of flaw growth to minimize the need for conventional NDI.

- As a secondary benefit, AE systems provide a sensitive detector of leaks as well as cracking in piping. They can also be adapted to sensing flow - no flow in critical valves.

SCOPE

The program scope is described by three primary areas of effort:

- Develop a method to identify crack growth AE signals as unique from other innocuous but similar acoustic signals.

- Develop a relationship between measured AE and crack growth which will enable an estimate of flaw severity based on measured AE information.

- Demonstrate the total concept through off-reactor vessel tests and finally, on-reactor monitoring. This includes developing the necessary instrumentation system.

The program is structured to start with testing laboratory specimens to determine fundamental feasibility. Since theoretical transfer of these results to a full size structure is very questionable in this case, the next phase calls for testing on a heavy section (> 4 inch wall) vessel to establish criteria more directly relateable to a reactor vesel. Vessel testing is to include a simulation of pertinent reactor environment conditions (background noise, flaws exposed to pressurized and heated water, etc.) excluding nuclear radiation. The final phase requires installation and operation of a prototypic AE monitor sytem on an operating reactor on a test basis.

One of the important sub-phases in the general program calls for measuring and analyzing AE from HSST program tests - vessel fracture and irradiated fracture specimen tests.

All test work has by intent focused on ASTM A533 Grade B, Class 1 steel.

RESULTS

Major accomplishments to date include:

Completion of laboratory testing from which we:

(a) showed the feasibility of separating crack growth AE signals from other transient signals using pattern recognition methods
(b) developed an AE/fracture mechanics relationship for flaw interpretation
(c) measured and analyzed AE data from HSST vessel tests with positive results

- Established a location and facilities for performing simulated reactor vessel monitoring.

- Are negotiating for installation of an AE sensing system on a reactor.

Expanding on the accomplishments:

Identification of Crack Growth AE

Pattern recognition was tested as a means of identifying crack growth AE using a sample of about 225 AE signals from a growing crack in a laboratory test specimen and assorted noise signals. Figure 1 shows an example of the overt similarity between many of these signal types. Ten pattern recognition features were examined. Out of these, auto-correlation produced the most definitive result (Figure 2). Applying this as a decision rule to sort the data resulted in a 96% correct classification as shown in Figure 3. This same technique was subsequently tested on a data sample from a 3 inch wall cylindircal bend specimen with equally definitive results.

AE/Fracture Mechanics Relationship - Flaw Interpretation

In Figure 4, a composite of AE/crack growth data measured from laboratory specimens is presented. The two diagonal lines are "worst case" slope lines for room temperature and 550°F test conditions. Figure 5 shows the concept for using the experimental data as a base for estimating flaw significance using AE measured on a reactor. As can be noted, the laboratory data is in terms AE and crack growth per cycle. We are presently evaluating whether a "per cycle" or a time base represents the most realistic approach to applying the concept to a reactor circumstance. The format selected will be evaluated on a vessel test to be performed at MPA, Stuttgart, Germany in the first quarter of FY-81. The vessel test will attempt to simulate reactor environment with the exception of nuclear radiation.

HSST Test Results

Two intermediate vessel tests at ORNL under the HSST program have been monitored for AE and the results analyzed. Figure 6 gives a composite of the results in terms of AE versus stress intensity factor "K". Considering the differences in test conditions for the two cases (200°F versus -5°F and different flaw sizes), these results are viewed as being very encouraging. Both of these tests

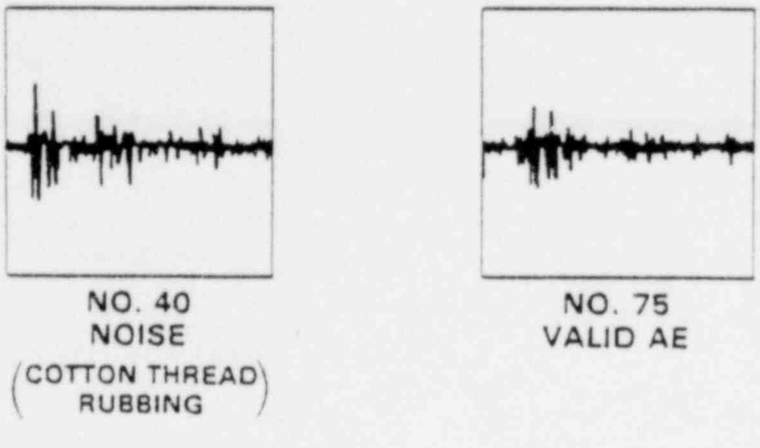

Figure 1. Sample Digitized Waveforms from Pattern Recognition Study.

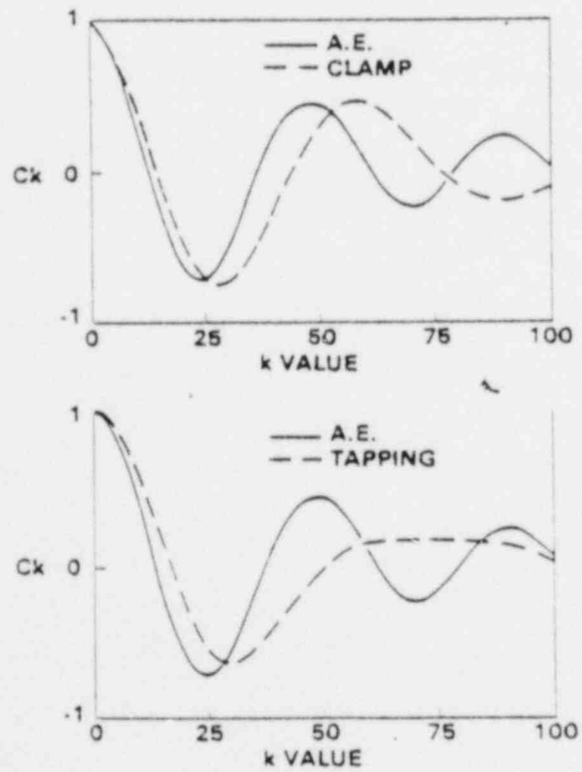

Figure 2. Autocorrelations for AE and Noise Waveforms.

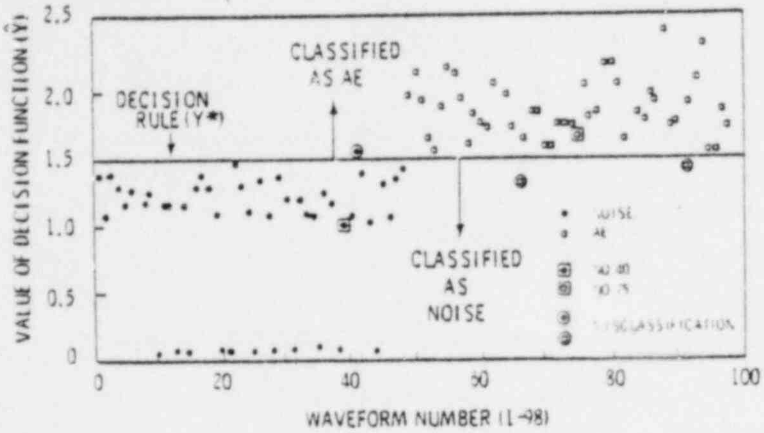

Figure 3. Results of Pattern Recognition Analysis of Valid AE and Noise (96% Successful Classification).

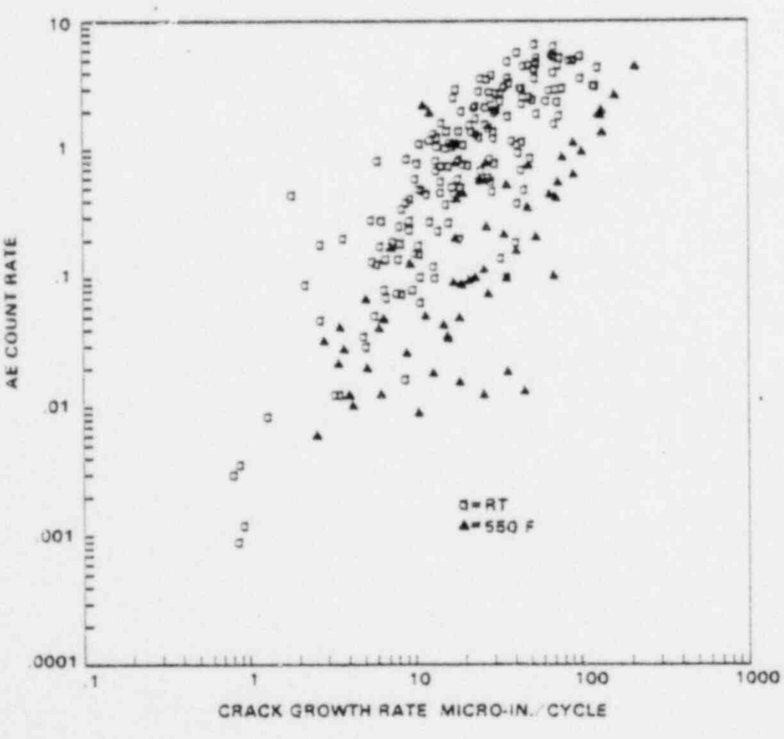

Figure 4. Experimental AE Rate Versus Fatigue Crack Growth Rate.

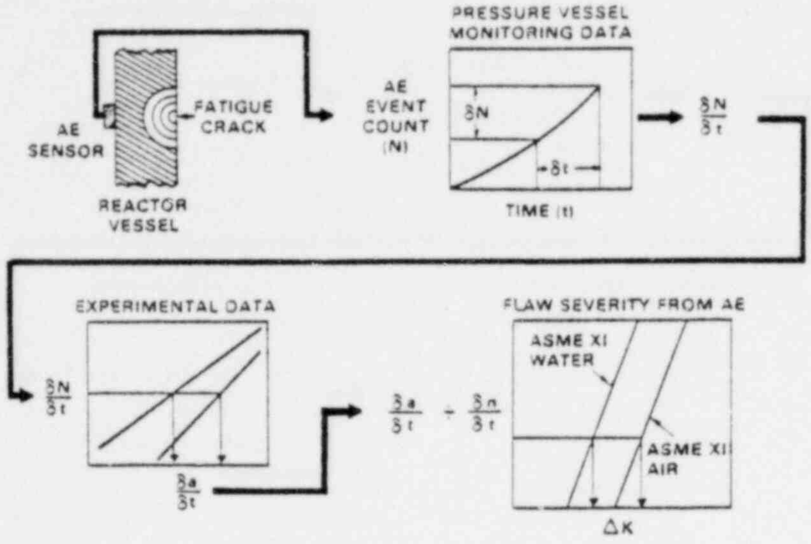

Figure 5. Schematic Procedure: Determination of Flaw Severity During Operation.

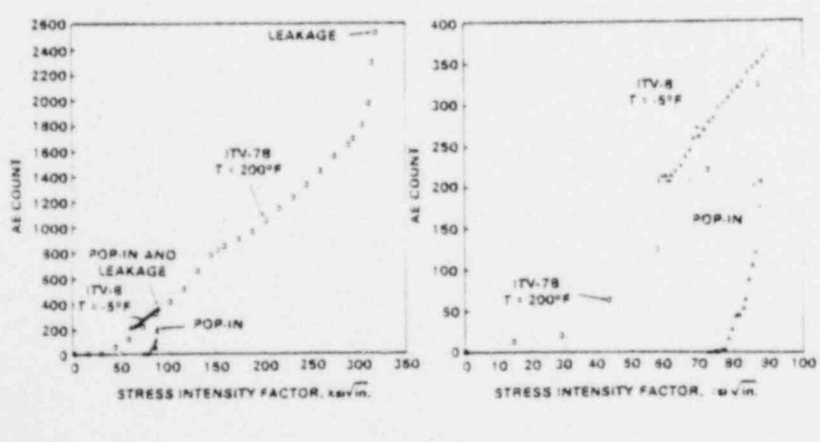

Figure 6. AE Results - HSST Vessel Tests.

involved montonic loading to failure at a machined flaw. A concept for applying these results to evaluate flaws using AE data from a hydrotest circumstance is shown in Figure 7.

Simulated Reactor Vessel Test

After comparing three options for a vessel test (two in the U.S. and one in Germany), vessel testing at MPA, Stuttgart, West Germany was selected as the site for this work. There are advantages from the standpoint of both cost and time schedule. An additional incentive is the opportunity to monitor two vessel tests at MPA. The vessels are about 5 inch wall, 70 inch O.D. and 110 inches long. Present plans call for the testing to start in October, 1980.

Reactor Installation

Potential for installing an AE monitoring system on an operating reactor is currently being discussed with Philadelphia Electric and Commonwealth Edison. The objective is to install three AE sensing arrays on a reactor by the end of FY-80.

KEY MILESTONES

FY-80

- Complete Lab Testing
- Develop Application Relationships
- Prepare Demonstration Instrument System
- Arrange for Off-Reactor Vessel Test
- Install Sensing System on a Reactor

FY-81

- Complete Off-Reactor Vessel Test
- Refine Relationships
- Install Demonstration AE Instrument System on Reactor

FY-82

- Complete First Year Reactor Monitoring
- Fabricate Prototypic AE Monitor System
- Install Prototype on a Reactor

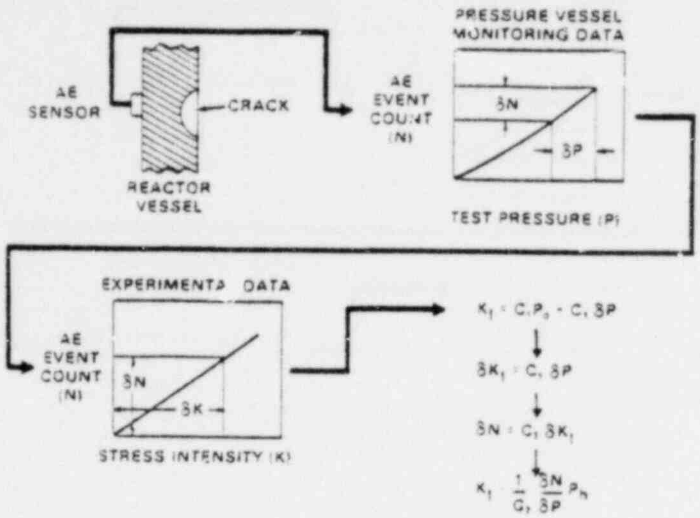

Figure 7. Schematic Procedure: Determination of Flaw Severity During Hydrotest.

<u>KEY MILESTONES</u> - Continued

<u>FY-82</u> - Continued

- Prepare Code Case
- Characterize Piping Material

<u>FY-83</u>

- Complete System Modification
- Complete Technology Transfer
- Obtain Code Acceptance