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Acoustic Emission/Flaw Relationship for In-Service Monitoring of Nuclear Pressure Vessels

Quarterly Report
October 1983 - March 1984

Prepared by P. H. Hutton, R. J. Kurtz

Pacific Northwest Laboratory
Operated by
Battelle Memorial Institute

Prepared for
U.S. Nuclear Regulatory Commission

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ABSTRACT

This report describes technical progress on a program to apply acoustic emission for continuous integrity surveillance of nuclear reactor pressure boundaries. The period is October 1983-March 1984. Test data from the completed intermediate scale vessel (ZB-1) test is being analyzed to isolate AE from crack growth for the purpose of refining AE signal identification and AE interpretation methods. Fatigue crack growth in the ZB-1 vessel is being characterized by destructive examination. Acoustic data obtained from the No. 2 inlet nozzle during hot functional testing at Watts Bar Unit 1 reactor showed a source concentration. A cooperative effort between TVA and PNL is planned to evaluate the significance of the data. Identification of crack growth AE by pattern recognition is showing much improved results. Fatigue testing of A106B ferritic pipe material is showing mixed AE results related to previous relationships developed for A533B steel. Development of an ASTM Standard Practice for continuous AE monitoring of pressure boundaries has been initiated. A NUREG document on results from AE monitoring at Watts Bar, Unit 1 reactor during hot functional testing has been completed.

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FIGURES

FIGURES

(cont'd)

ACOUSTIC EMISSION/FLAW RELATIONSHIP FOR IN-SERVICE MONITORING OF NUCLEAR PRESSURE VESSELS[a]

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SUMMARY

Test data from the completed intermediate scale vessel (ZB-1) test is being analyzed to isolate AE from crack growth for the purpose of refining AE signal identification and AE interpretation methods. Filtering by peak load and signal amplitude parameters has proven effective in isolating crack growth AE from the low temperature (65°C) portion of the test. High temperature (250°C) test data analysis is in progress. The load and amplitude parameters are less effective on this data. A pressure coupled sensor array monitoring the entire vessel was particularly effective in detecting AE from a natural crack in a fabrication weld. An A533B steel implant containing machined flaws and several trepan specimens have been retrieved from the ZB-1 vessel in order to characterize fatigue crack growth by destructive examination.

Acoustic data obtained from the No. 2 inlet nozzle during hot functional testing at Watts Bar Unit 1 reactor showed a source concentration. A cooperative effort between TVA and PNL is planned to evaluate the significance of the data.

A supplementary approach to identification of crack growth AE by pattern recognition is showing much improved results over the earlier approach.

Fatigue testing of A106B ferritic pipe material is showing mixed AE results related to previous relationships developed for A533B pressure vessel material in the laboratory.

Development of an ASTM Standard Practice for continuous AE monitoring of pressure boundaries has been initiated.

A NUREG document on results from AE monitoring at Watts Bar, Unit 1 reactor during hot functional testing has been completed.

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[a] Work supported by the U.S. Nuclear Regulatory Commission under Contract DC-AC06-76RLO 1830; FIN. B2088; NRC Contact: Dr. J. Muscara.

INTRODUCTION

The purpose of this Pacific Northwest Laboratory (PNL) program is to provide an experimental evaluation of the feasibility of detecting and analyzing flaw growth in reactor pressure boundaries on a continuous basis using acoustic emission (AE). Type A533B, Class 1 pressure vessel steel, and SA351-CF-8A cast stainless, Type 304 wrought, and A106 ferritic piping steels are being considered. Objectives of this program are to:

- develop a method to identify crack growth AE signals in the presence of other acoustic signals
- develop a relationship to estimate flaw significance from AE data
- develop an instrument system to implement these techniques
- demonstrate the total concept off-reactor and on-reactor.

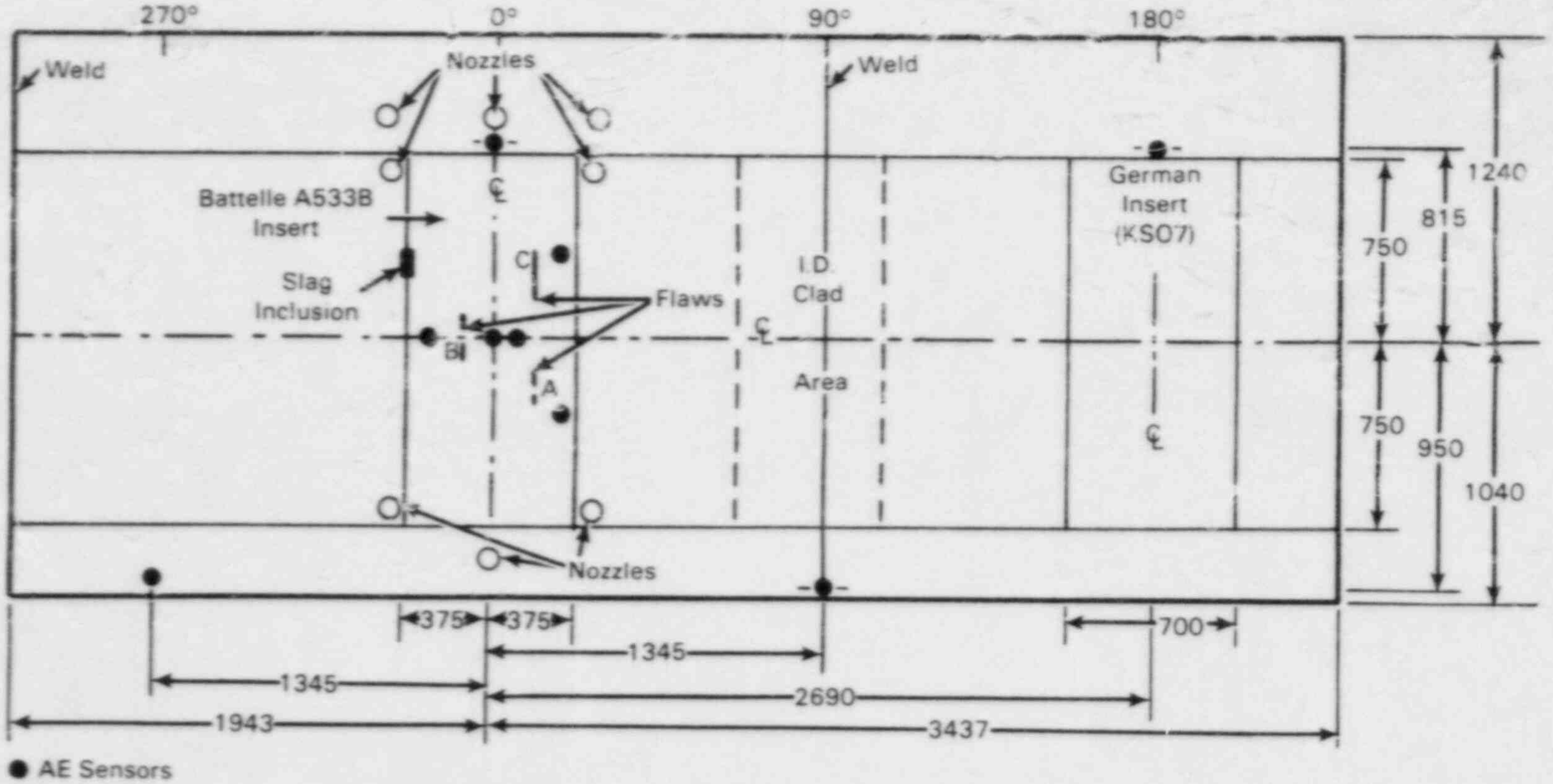
TECHNICAL PROGRESS

Technical progress over the report period is discussed under five topics:

- Off-Reactor Vessel Test
- Reactor Monitoring
- AE Signal Pattern Recognition
- Pipe Material Testing
- Standards and Codes

OFF-REACTOR VESSEL TEST

The off-reactor vessel test, designated ZB-1, was performed in Mannheim, West Germany in cooperation with the Materialpruefungsanstalt (MPA) laboratory and Grosskraftwerk Mannheim (GKM) utility company. The test was completed in late September 1983 after one year total duration. To aid the reader in keeping the discussion in context, Figure 1 summarizes the test vessel arrangement. This shows the various features (A533B insert with machined precracked flaws, slag inclusion, ID clad areas, and the insert of degraded German steel) of the test vessel which are of primary importance.



NOTE:

1) Illustration is a Roll-Out of Vessel Cylinder. 120 mm Wall Thickness.
2) Dimensions in Millimeters
3) All Battelle AE Sensors Will be Metal Wave Guides
4) AE Sensors on the Battelle Insert Mounted in Drilled and Tapped Holes. Other Sensors Pressure Coupled.

Figure 1. Test Features of the ZB-1 Vessel.

The intial objective of analysis of the massive amount of data developed during this test is to isolate by any means the AE associated with crack growth. This then provides the basis for two key further steps - i.e., 1) test and adjust the AE/flaw severity relationship and 2) development of pattern recognition improvements to be able to achieve the same level of signal isolation by processing waveforms. Another key aspect is the fact that the data was derived from a structure under simulated reactor environment.

Data from the first half of the test performed at 65°C (150°F) showed that the signal amplitude and the location on the load cycle curve where the signal occurred (load position) were effective parameters for isolating crack growth AE. Load position is obviously not a suitable parameter for use on reactor; however, it is legitimate in the analytical sequence described above.

The initial analysis of acoustic data from the first two cyclic load steps (8 and 9) of the high temperature portion of the ZB-1 test has been completed. Although it is not as clear cut as in the cold data, the combination of peak load position and high amplitude still appears to be a reasonably effective filter to identify data from the growing flaws. Noise data covering a wide range of characteristics is much more evident in the high temperature testing compared to the previous low temperature testing. Figures 2, 3, and 4 provide an example of this. Figure 2, where the data for Step 9 is filtered around peak load, shows a wide scatter of data. In Figure 3, where the data is now filtered by an amplitude range of 8-10 volts, the scatter is reduced but still present. It requires both filters (Figure 4) to focus on data in the flaw region. This is showing the effects of acoustic data distributed over a range of amplitudes and load positions so that neither parameter alone is very effective in isolating crack related signals. In referring to Figures 2-4, it needs to be noted that this array is skewing the source location indications to the left and up for reasons not fully understood. This was verified with artificial signals introduced at known locations. The data concentrations are related to Flaw B and perhaps the No. 1 nozzle on the vessel.

There does, however, remain an association of high amplitude AE signals with crack growth. Figures 5-10 illustrate this point. These show the amplitude distribution of all data sources located within a 1-T area around each of the flaws for Steps 8 and 9. Flaws A and B, both of which grew substantially, also show a definite population of signals in the 9-10 volt range. Flaw C which grew a very limited amount shows few high amplitude signals.

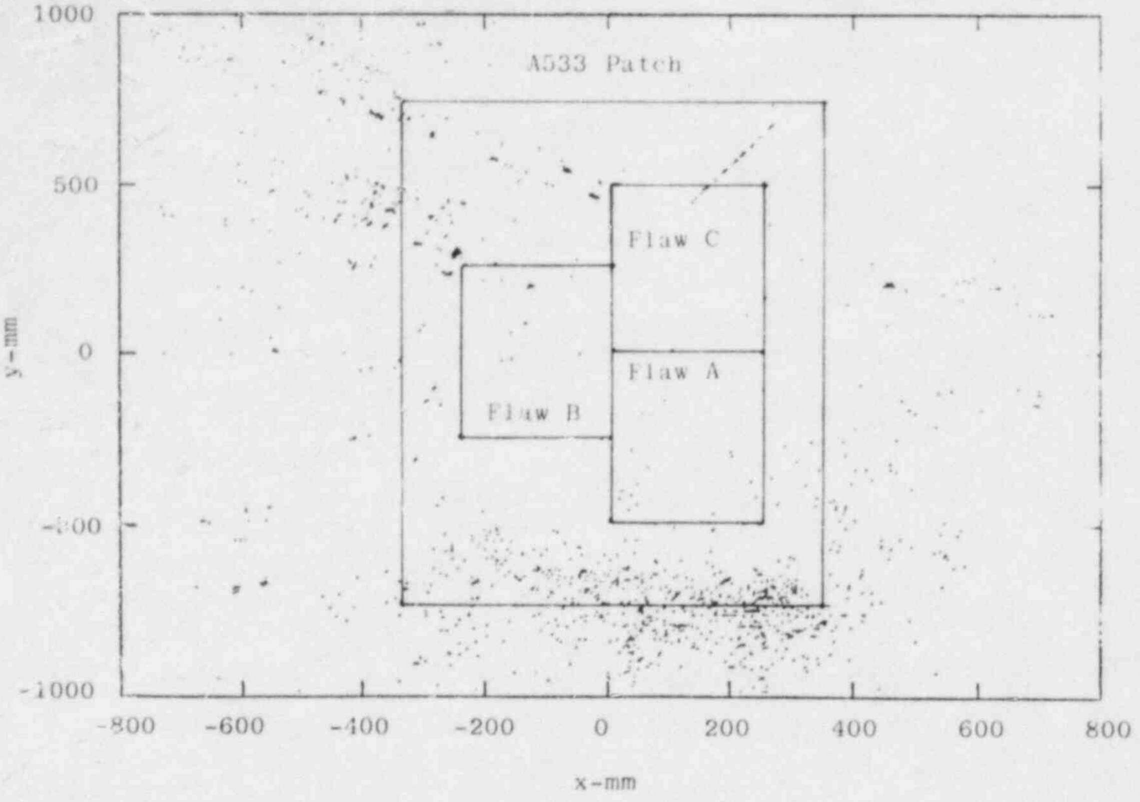


Figure 2. Step 9, Array 1, ZB-1 Test, Filtered: Load Position 65-80.

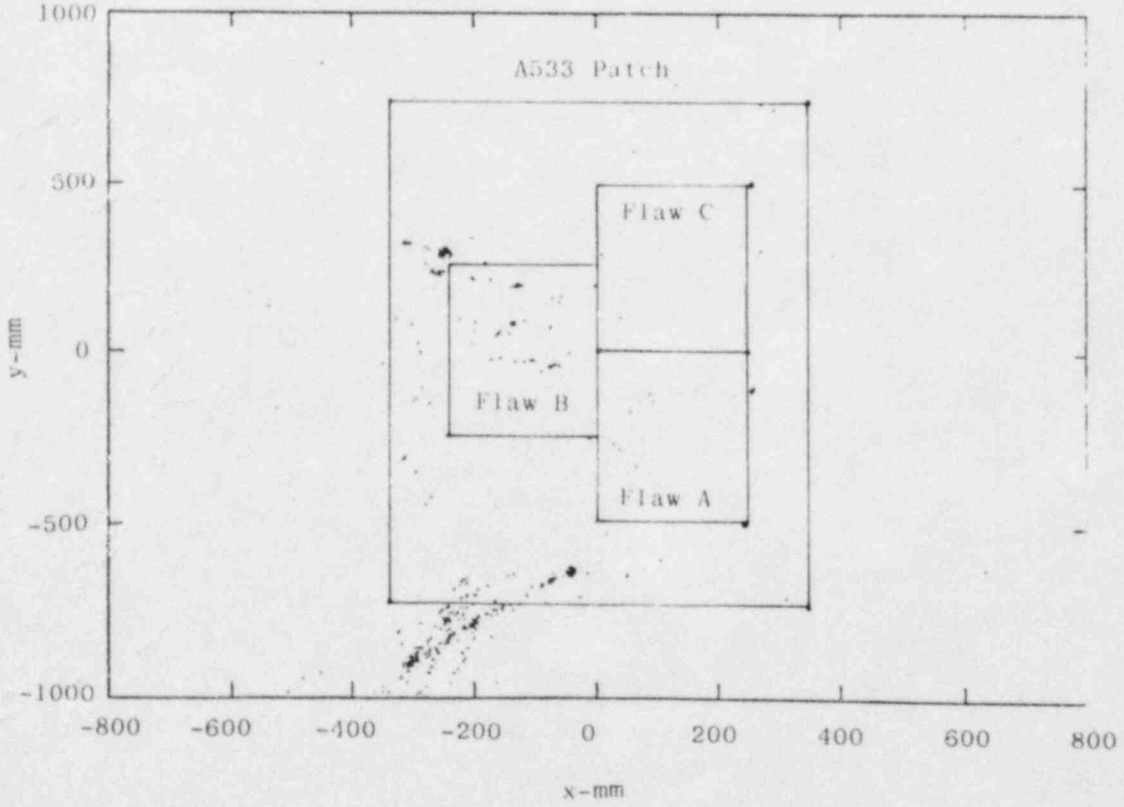


Figure 3. Step 9, Array 1, ZB-1 Test, Filtered: Amplitude 8-10 Volts.

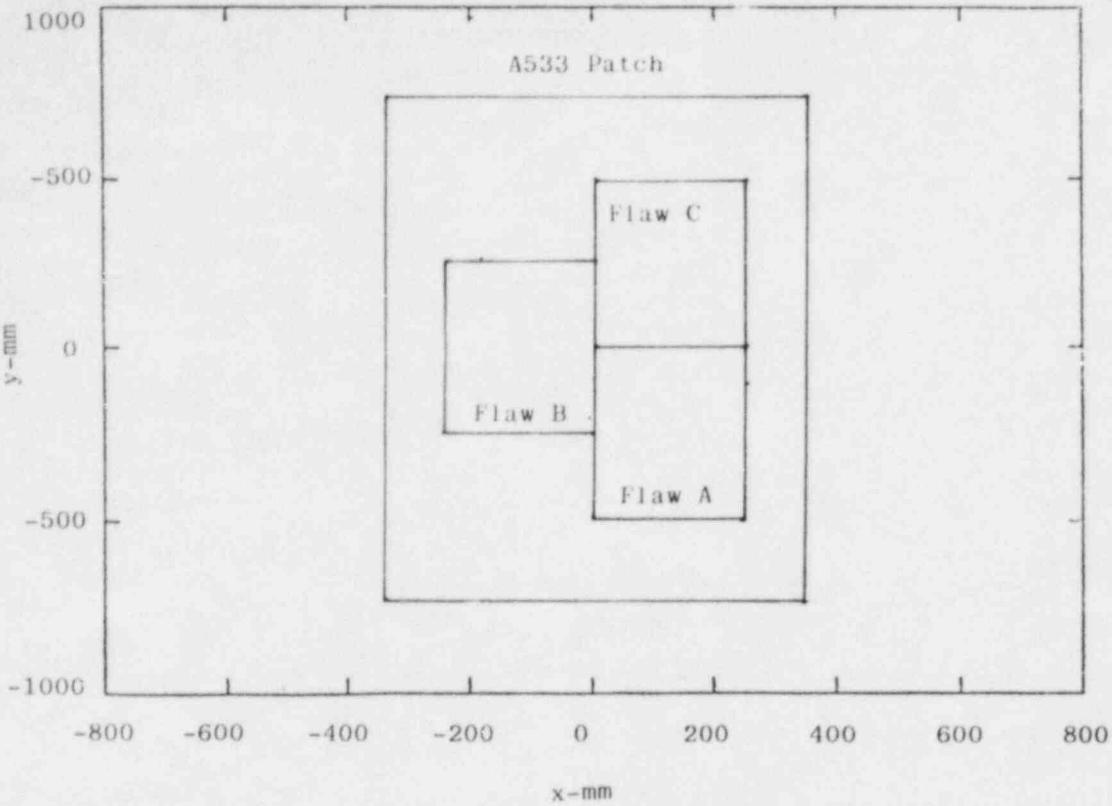


Figure 4. Step 9, Array 1, ZB-1 Test, Filtered: Load Position 65-80, Amplitude 8-10 Volts.

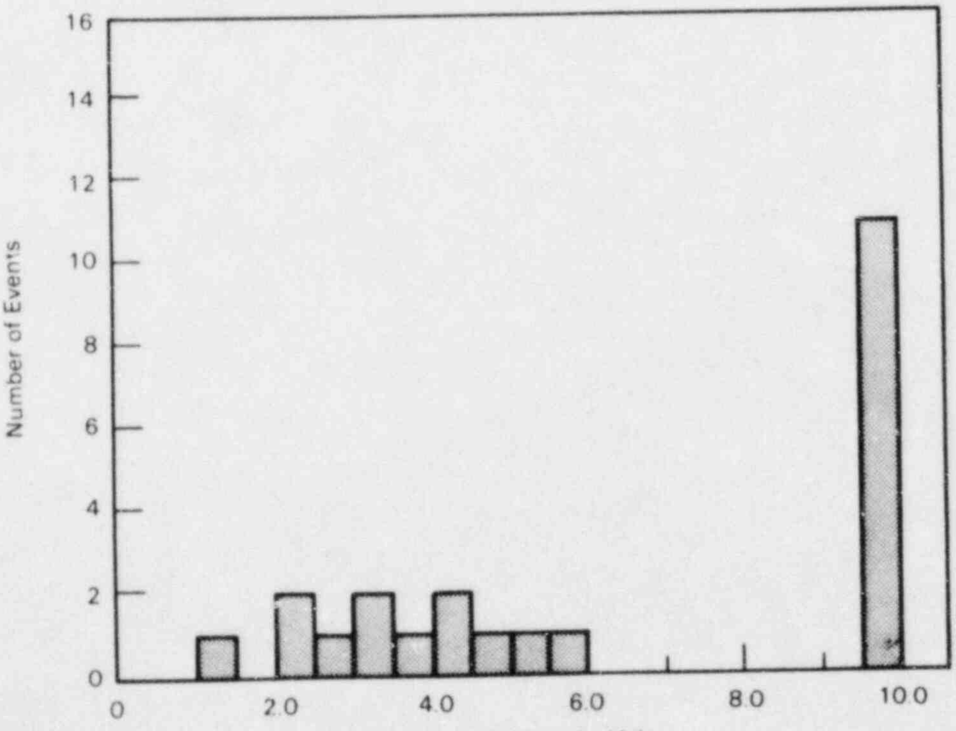


Figure 5. Amplitude Histogram for Flaw A, Array 2, Step 8.

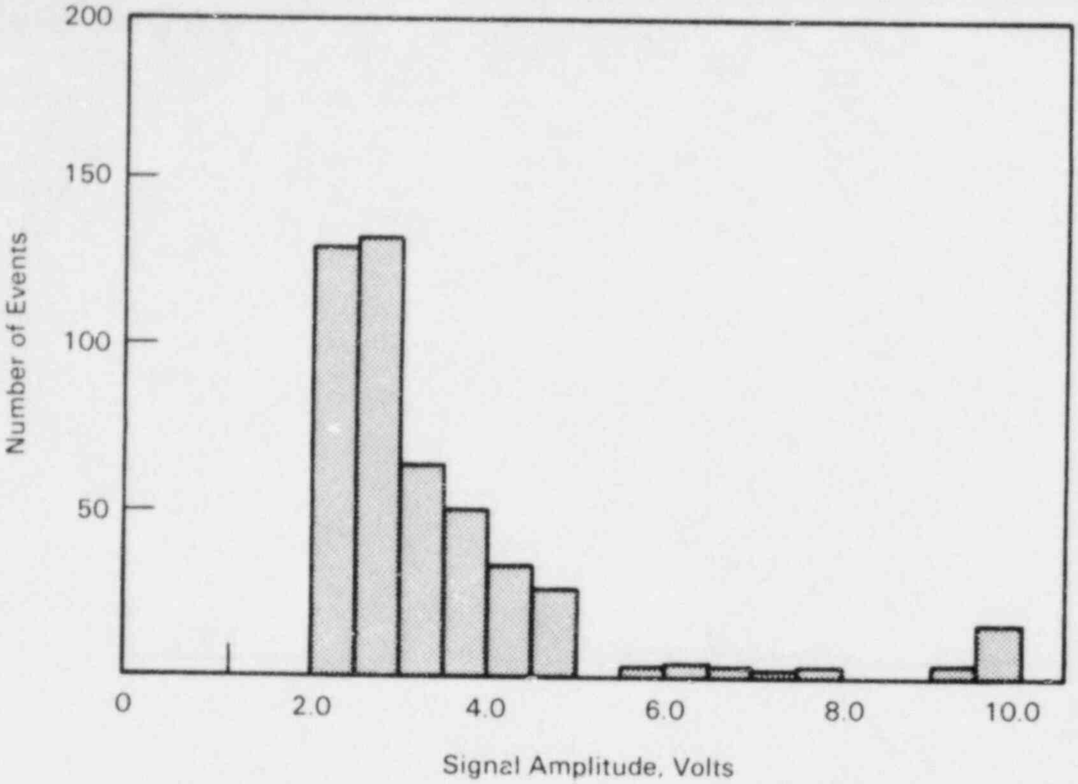


Figure 6. Amplitude Histogram for Flaw A, Array 2, Step 9.

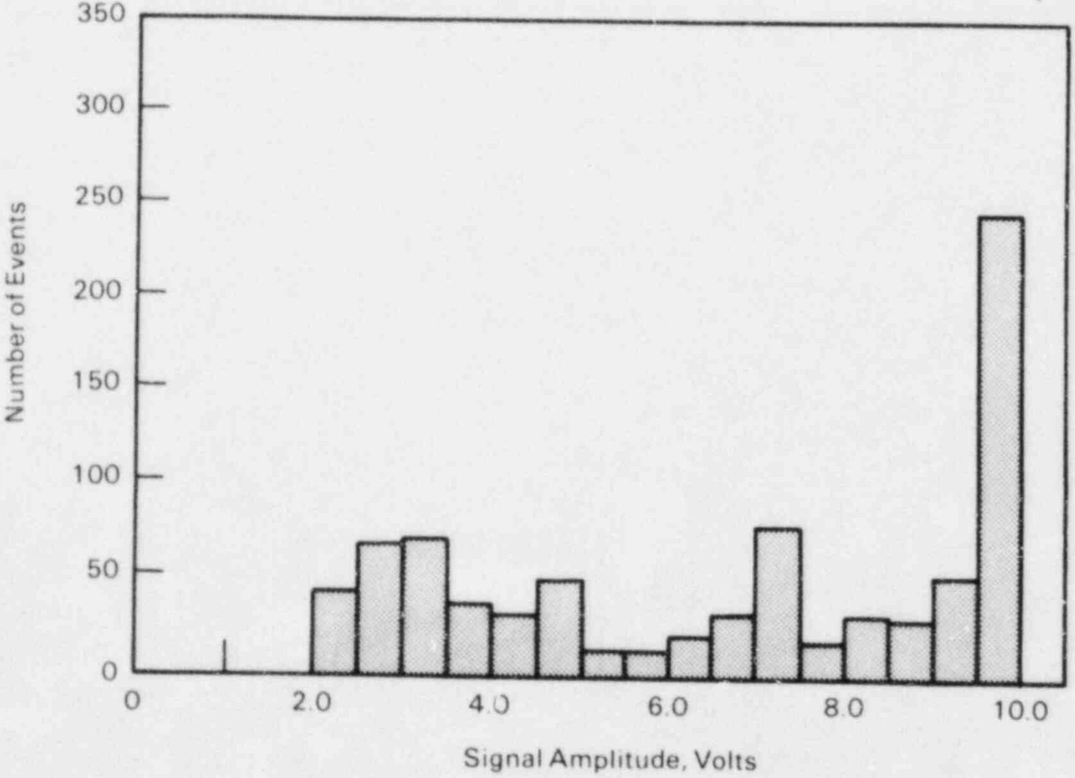


Figure 7. Amplitude Histogram for Flaw B, Array 2, Step 8.

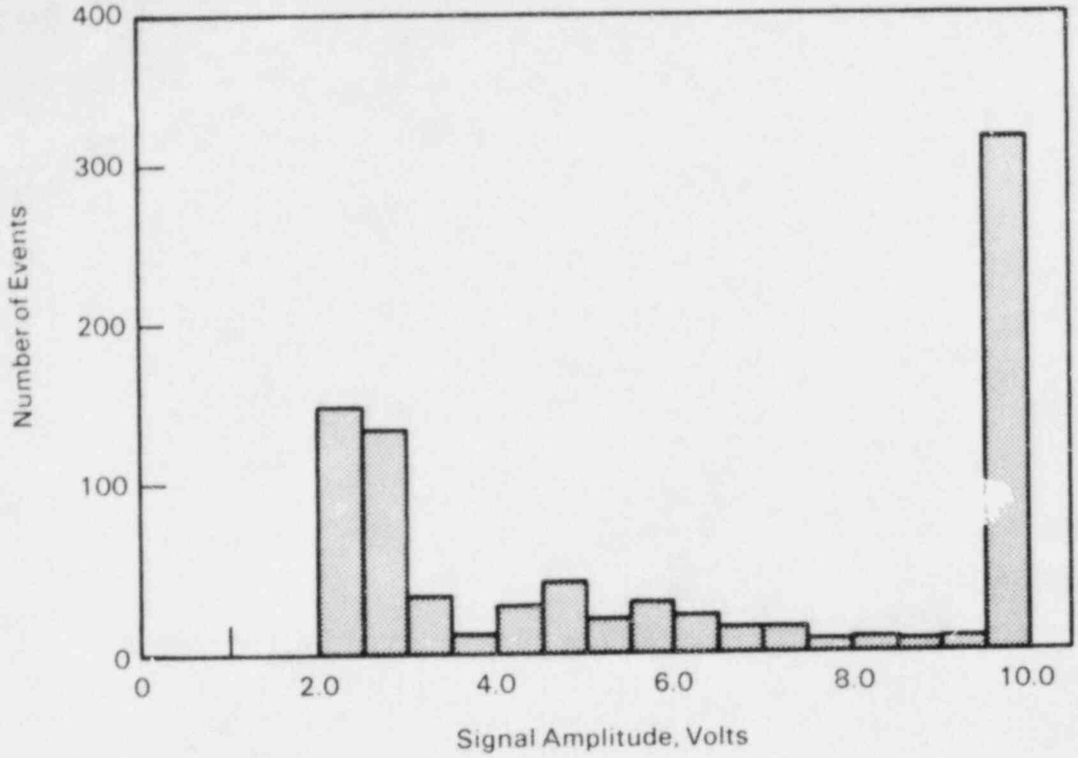


Figure 8. Amplitude Histogram for Flaw B, Array 2, Step 9.

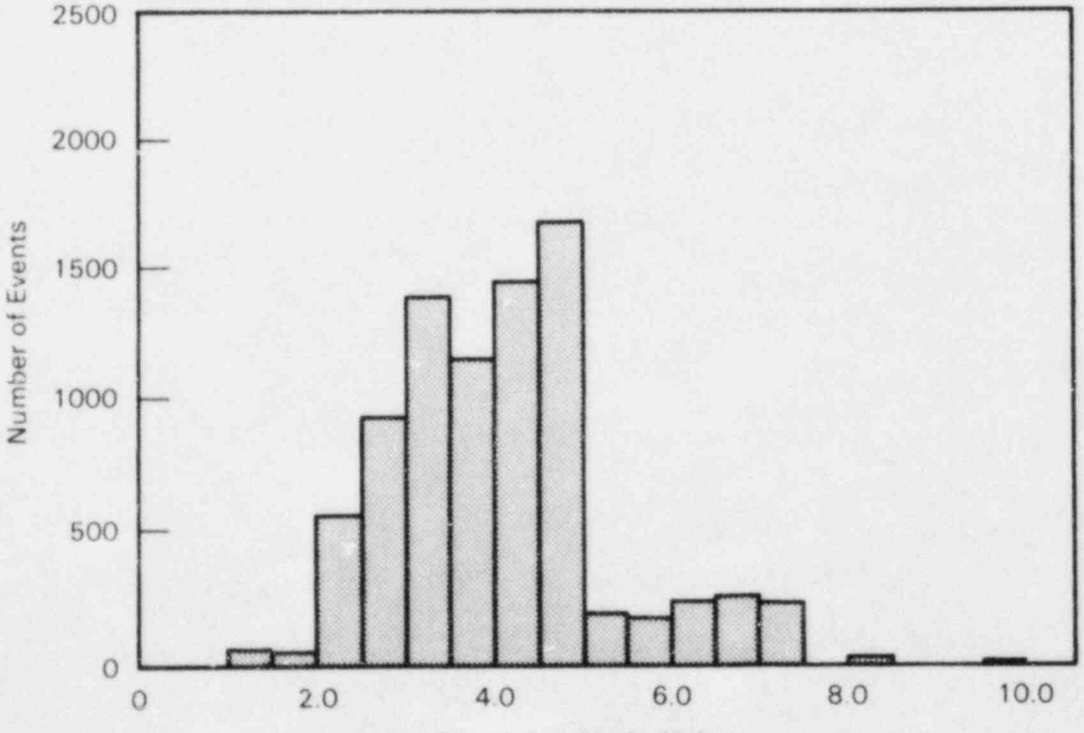


Figure 9. Amplitude Histogram for Flaw C, Array 2, Step 8.

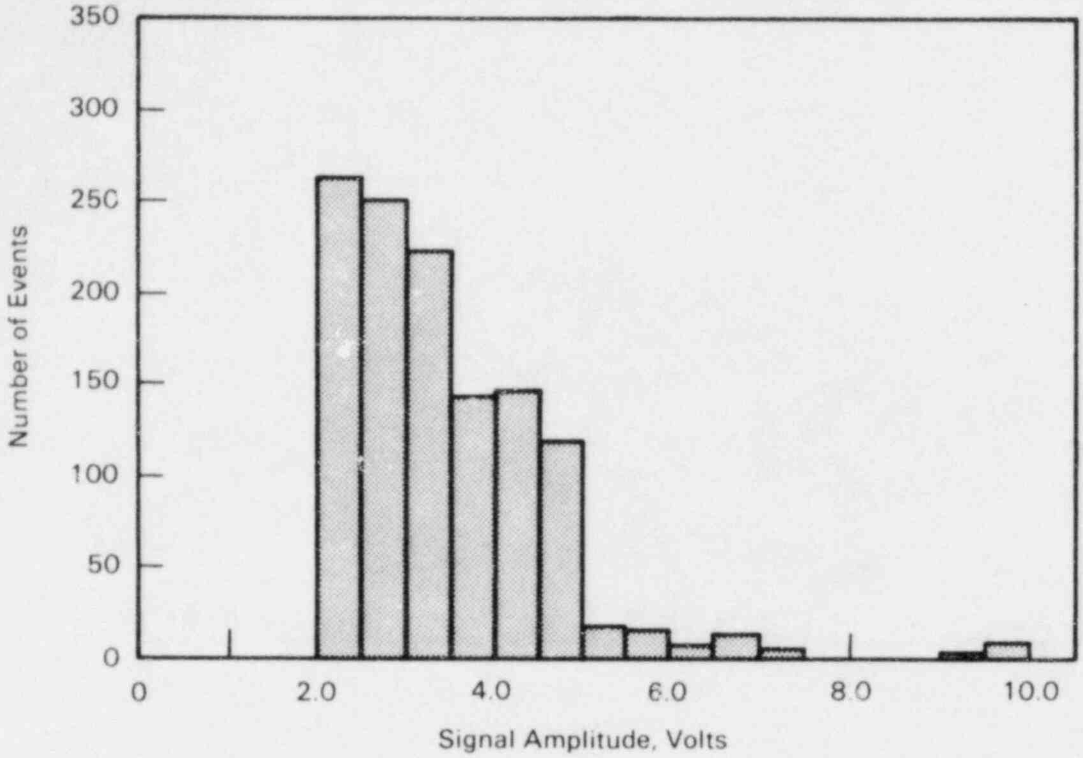


Figure 10. Amplitude Histogram for Flaw C, Array 2, Step 9.

Both Arrays 1 and 2 discussed above were quad arrays located around the machined defects in the A533B insert. Array 3 was a cylindrical array of sensors which monitored the whole vessel. Figures 11-14 show the evolution of cracking in the upper longitudinal weld of the KS07 replacement. This appears near the right-hand border of the plot. In Figure 11, the only distinct data points on this scale in Step 8 are noise from the manhole cover. Figures 12-14 show the development of cracking in the upper weld during Step 9 with a small indication from the lower weld (left edge of Figure 12). Figure 12 also shows some data from Flaw B. These plots are on a relatively coarse scale to accommodate the large amount of data from the upper KS07 weld.

Array 3 was sensitive primarily to Flaw B growth in the A533B insert. Flaw B data is in the left center box of the three inner boxes in Figure 15. A limited amount of data also appears in the Flaw A region (near center box). The other major data point in Figure 15 by the near end of the A533 insert results from an artificial signal source used to test the AE system periodically.

Work is continuing to summarize data from the remaining Step 11 cyclic testing plus the hydrostatic tests.

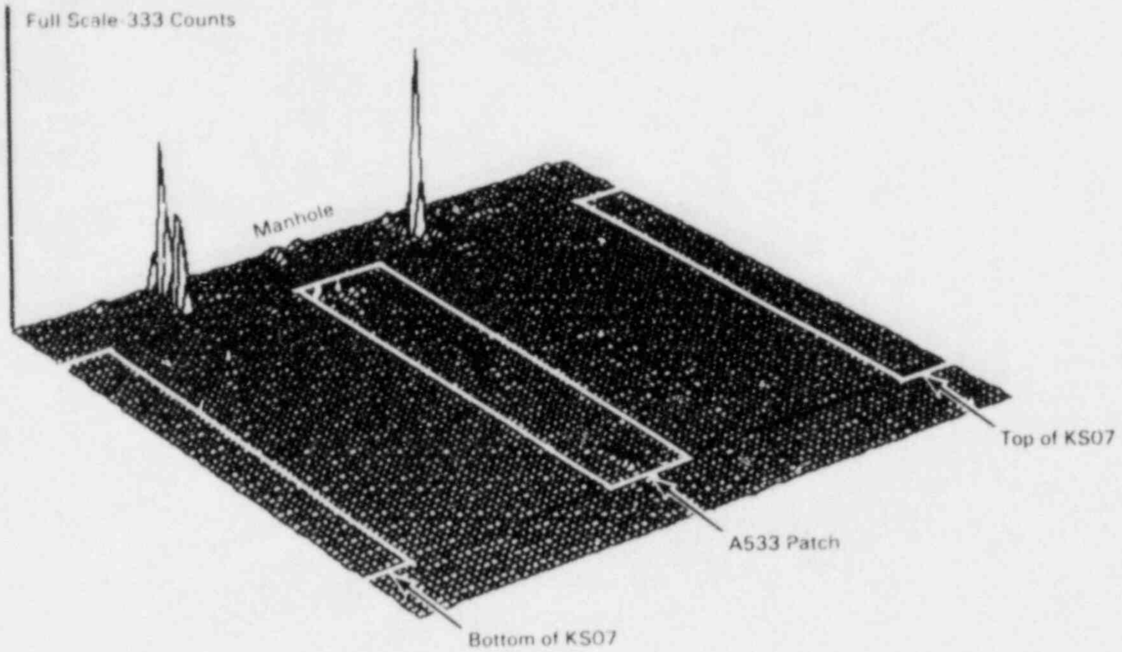


Figure 11. Step 8, Array 3, ZB-1 Test, Vessel Barrel, No Filter.

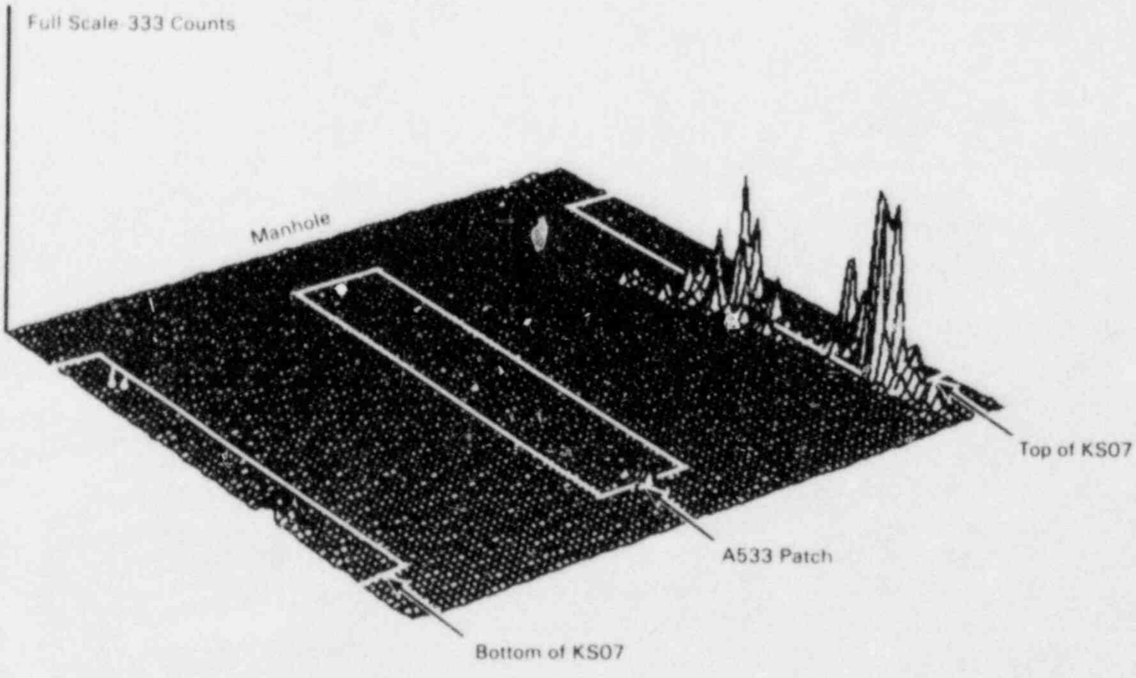


Figure 12. Step 9, 0-1800 Cycles, Array 3, ZB-1 Test, Vessel Barrel, No Filter.

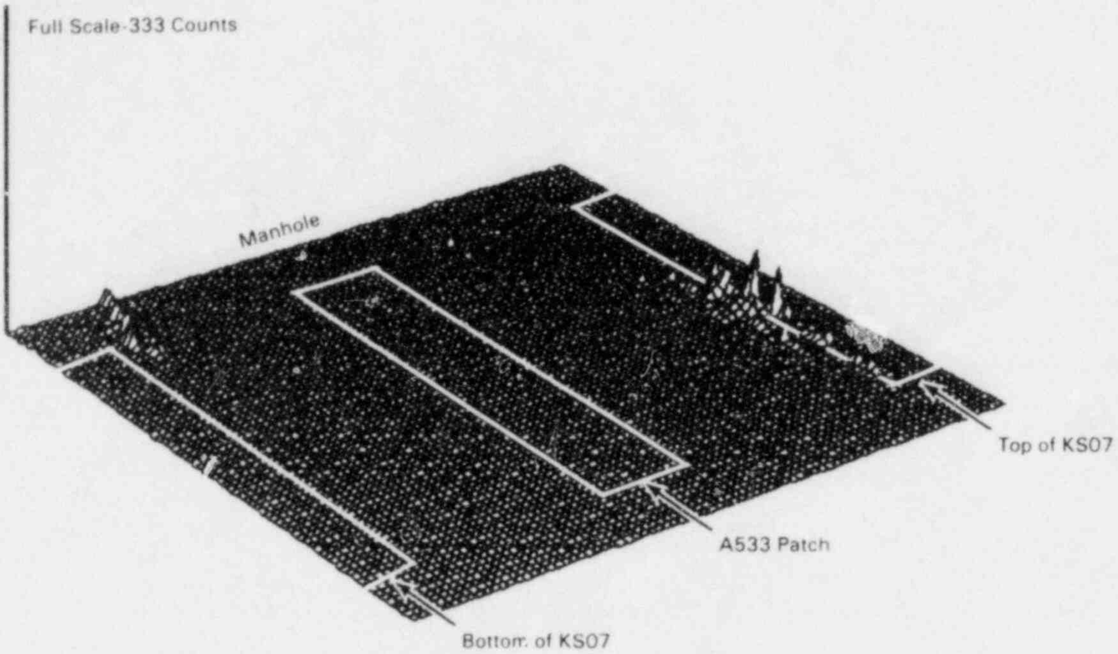


Figure 13. Step 9, 3391-3445 Cycles, Array 3, ZB-1 Test, Vessel Barrel, No Filter.

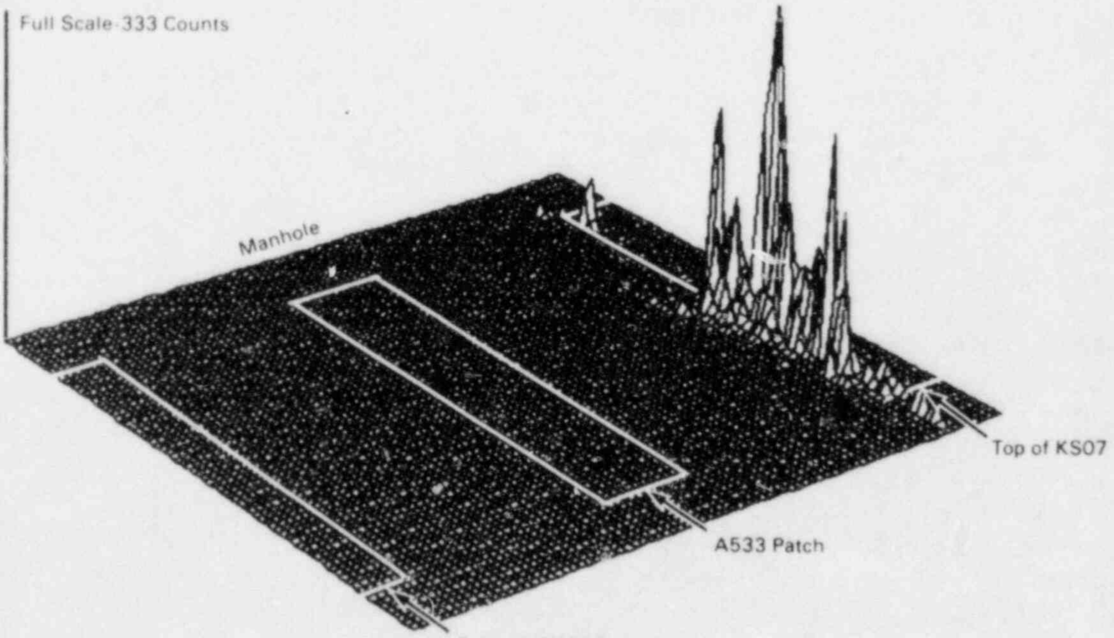


Figure 14. Step 9, 3851-4000 Cycles, Array 3, ZB-1 Test, Vessel Barrel.

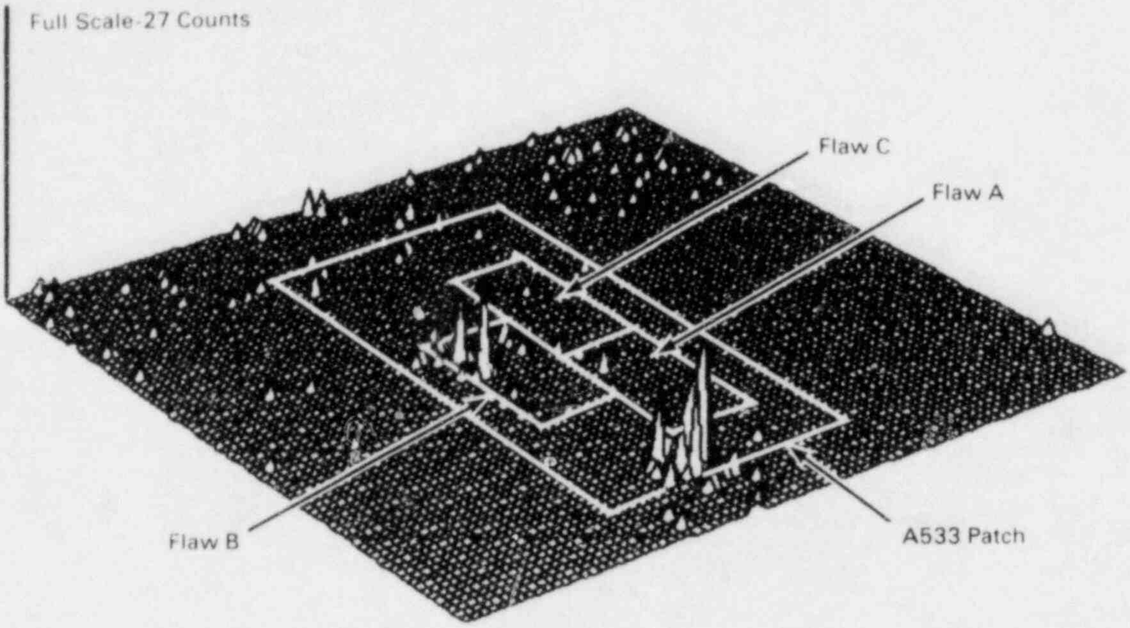


Figure 15. Step 9, Array 3, ZB-1 Test, A533 Patch, No Filter.

The A533B insert was retrieved from the ZB-1 vessel after completion of testing. The purpose is to break open the flaws and examine the fracture surfaces to obtain a more precise history of crack growth. By design, each cyclic test step was performed at a different R-ratio compared to its neighbor steps to hopefully mark the associated crack growth region. The flaws have been broken open. Although they have not been thoroughly examined, it appears that the crack front marking technique was reasonably successful (Figures 16-18).

Two trepan specimens taken from the ID weld overlay cladding have been metallographically examined. Although it was intended that this area include underclad cracking and an area of unbond, neither were observed in these specimens. This is consistent with the lack of AE from that area.

As discussed previously, fatigue cracking developed in the weld for a replacement to the original KS07 German insert and this was definitely detected by AE. Trepan specimens (3) of the cracked area have been obtained to preliminarily characterize the crack. Metallographic examination of these trepans is in progress; however, it appears that the maximum depth of this cracking is about 43 mm which is 36% through the wall.

REACTOR MONITORING

The Tennessee Valley Authority is cooperating in this program by permitting AE monitoring of selected pressure bound-

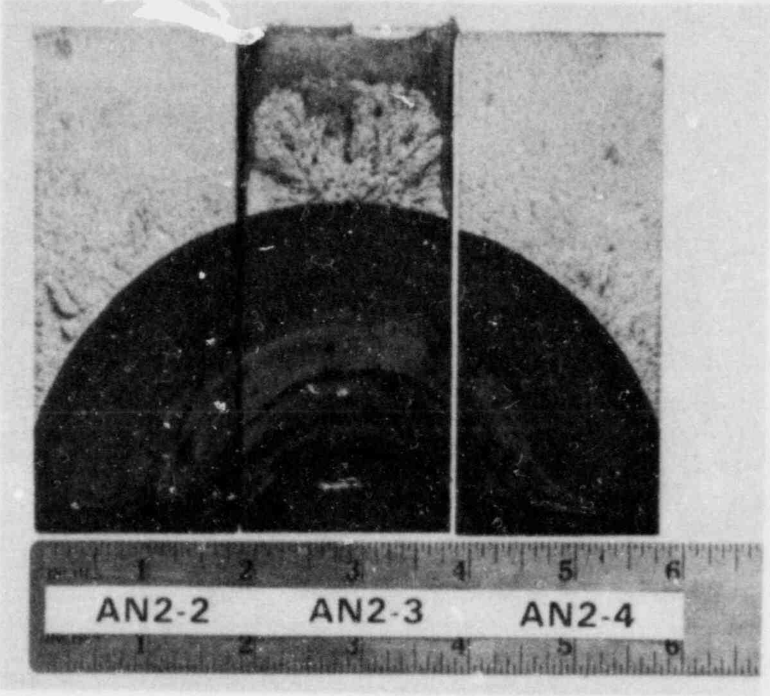


Figure 16. Lower Fracture Surface for Flaw A.

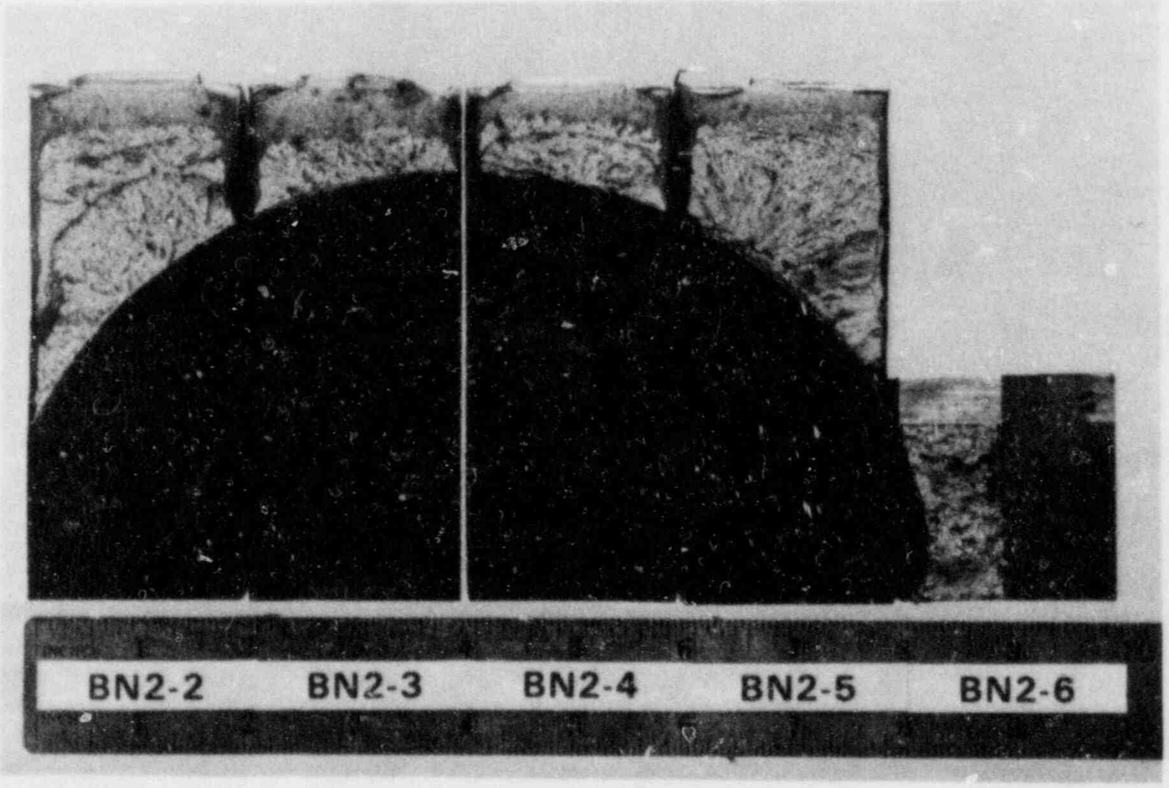


Figure 17. Lower Fracture Surface for Flaw B.

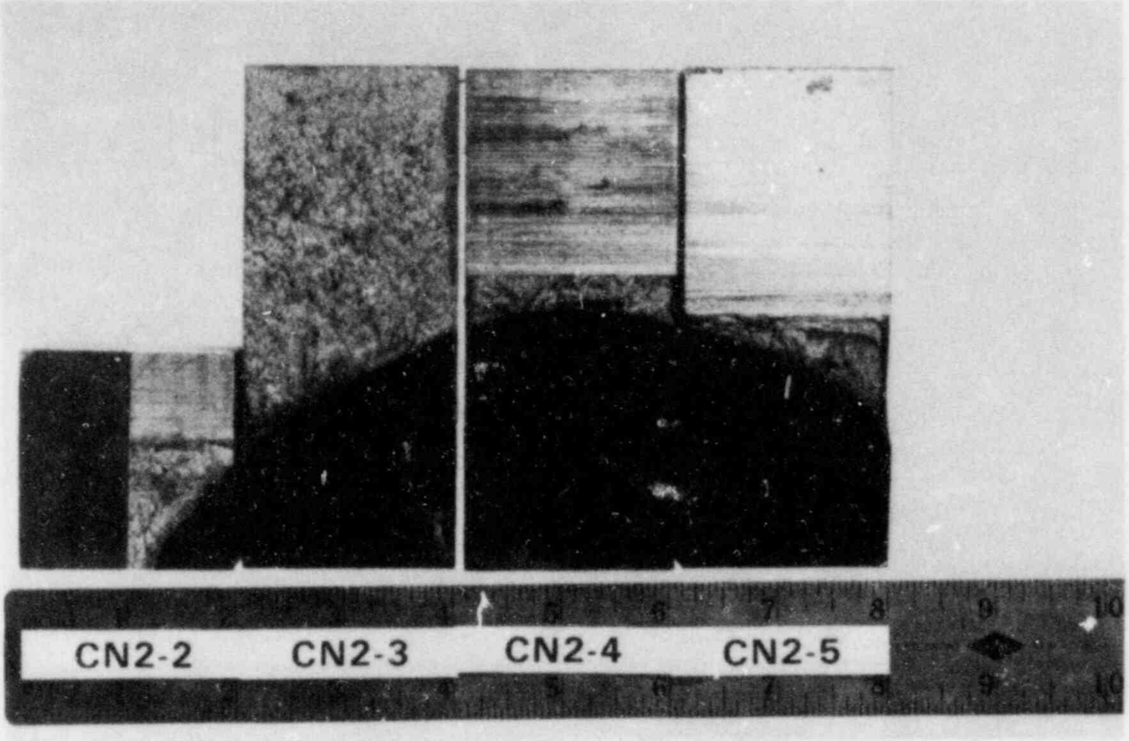


Figure 18. Lower Fracture Surface for Flaw C.

ary areas during prestartup testing and during reactor operation at Watts Bar, Unit 1. The areas being monitored are the #2 inlet nozzle, the safety injection line adjacent to the #2 cold leg, and a section of the vessel wall. AE monitoring was performed during cold hydrostatic testing in late 1981 and the results were summarized in NUREG/CR-2880.

Hot functional testing at Watts Bar, Unit 1 was performed in July 1983. The same pressure boundary areas were AE monitored during that period. A topical report describing that work is ready for publication.

During the final increase in reactor coolant temperature/pressure (450°F/1700 psig to 557°F/2235 psig) as part of hot functional testing, acoustic signals were detected on the No. 2 inlet nozzle. A feature of the data that was of particular interest was the clustering of source location points in the vicinity of the 270° position on the nozzle (Figure 19). The source of this data is not obvious. One possible source is mirror insulation rubbing on the nozzle. This should not happen because the insulation is installed with a clearance, and also, the signals are much shorter than would be expected from rubbing. Another potential source is one or more indications identified in the nozzle-to-vessel weld during earlier inspection.

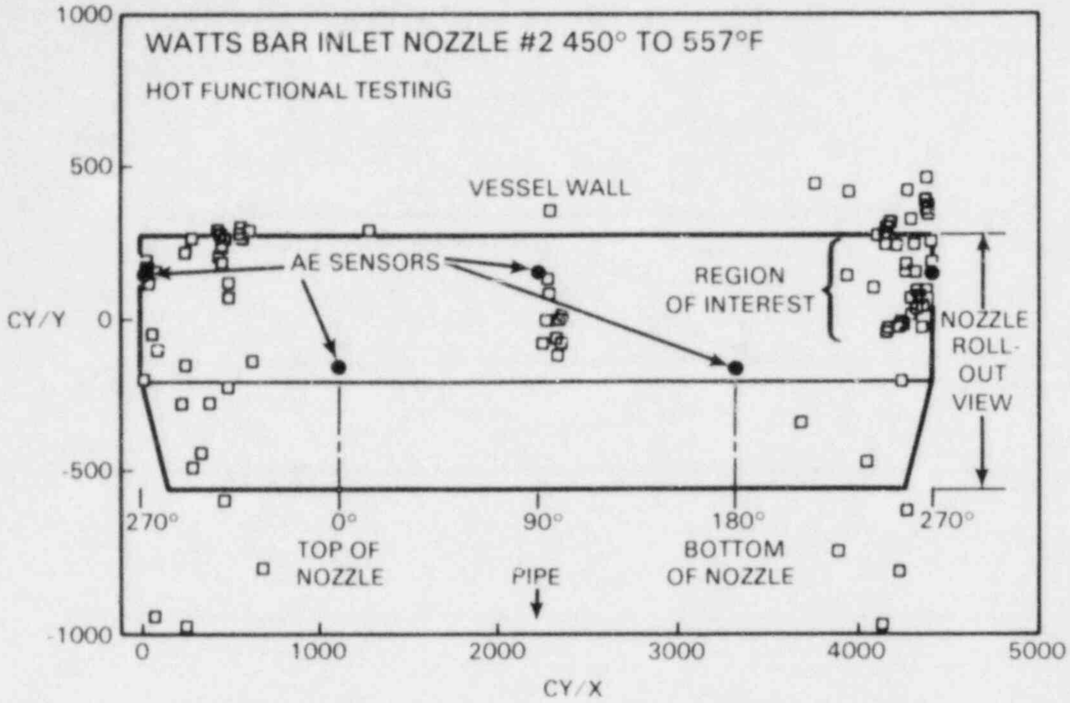


Figure 19. Acoustic Data Detected on No. 2 Inlet Nozzle During Final Pressure/Temperature Increase - Hot Functional - Watts Bar, Unit 1.

The cluster is comprised of about 400 signals which were rather evenly distributed over the final step. Figure 20 shows the accumulation of acoustic data from the No. 2 inlet nozzle over the region of the test from 350^{O}F/400 psig to 557^{O}F/2235 psig. (Below 350^{O}F/400 psig, background noise interferes with data identification.) It is evident that the data accumulation in the last step is more pronounced than in the earlier parts of the test. Also, there was little indication of data clustering during the earlier test steps. The acoustic data appears to be influenced by both temperature and pressure of the reactor coolant. As illustrated in Figures 21 and 22, the clustered signals appear to be somewhat unique within the total acoustic data from the No. 2 inlet nozzle. The most prevalent signal duration is in the 1 to 3 millisecond range for clustered signals as opposed to less than 1 millisecond for the total data (Figure 21). A duration of 1 to 3 msec. is in the range we would expect for flaw generated AE. Insulation rubbing should produce much longer signals (greater than 10 msec.). Also, the amplitude of the clustered signals was higher than for the total data (Figure 22).

Test results have been discussed with TVA engineers and a cooperative effort to determine the significance of the data has been planned.

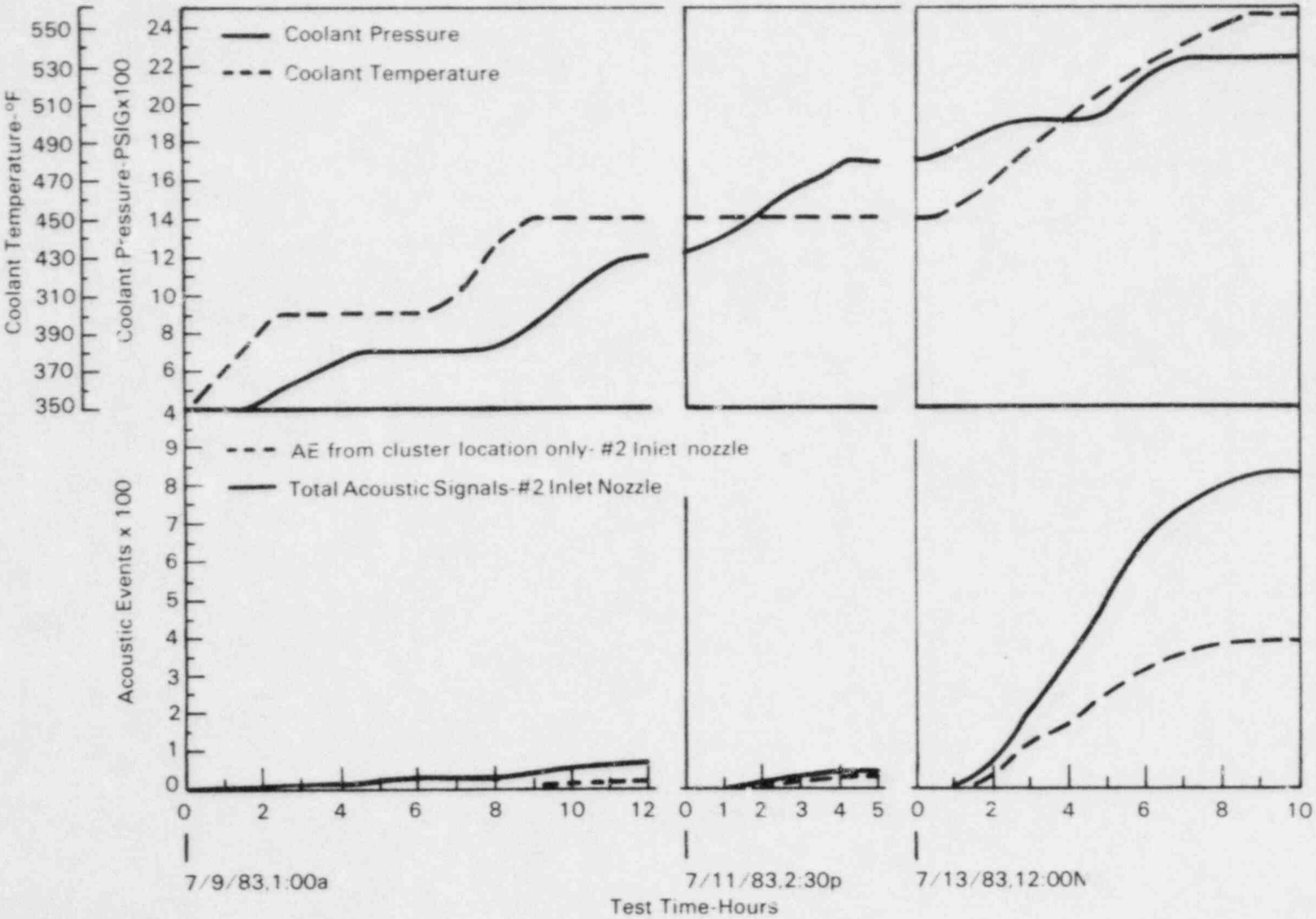


Figure 20. Acoustic Data from #2 Inlet Nozzle as a Function of Coolant Temperature and Pressure.

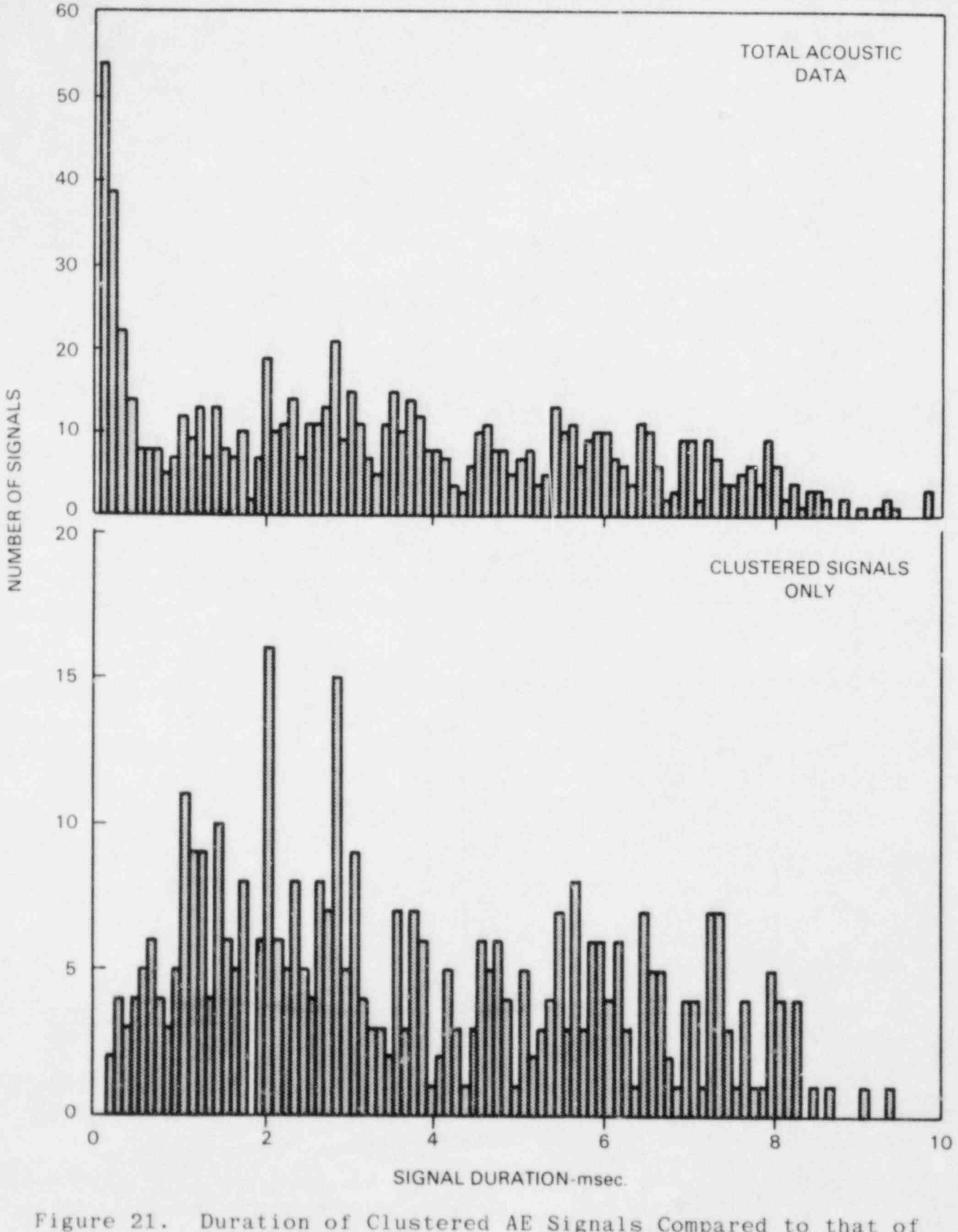


Figure 21. Duration of Clustered AE Signals Compared to that of Total Acoustic Data, No. 2 Inlet Nozzle - Watts Bar, Unit 1.

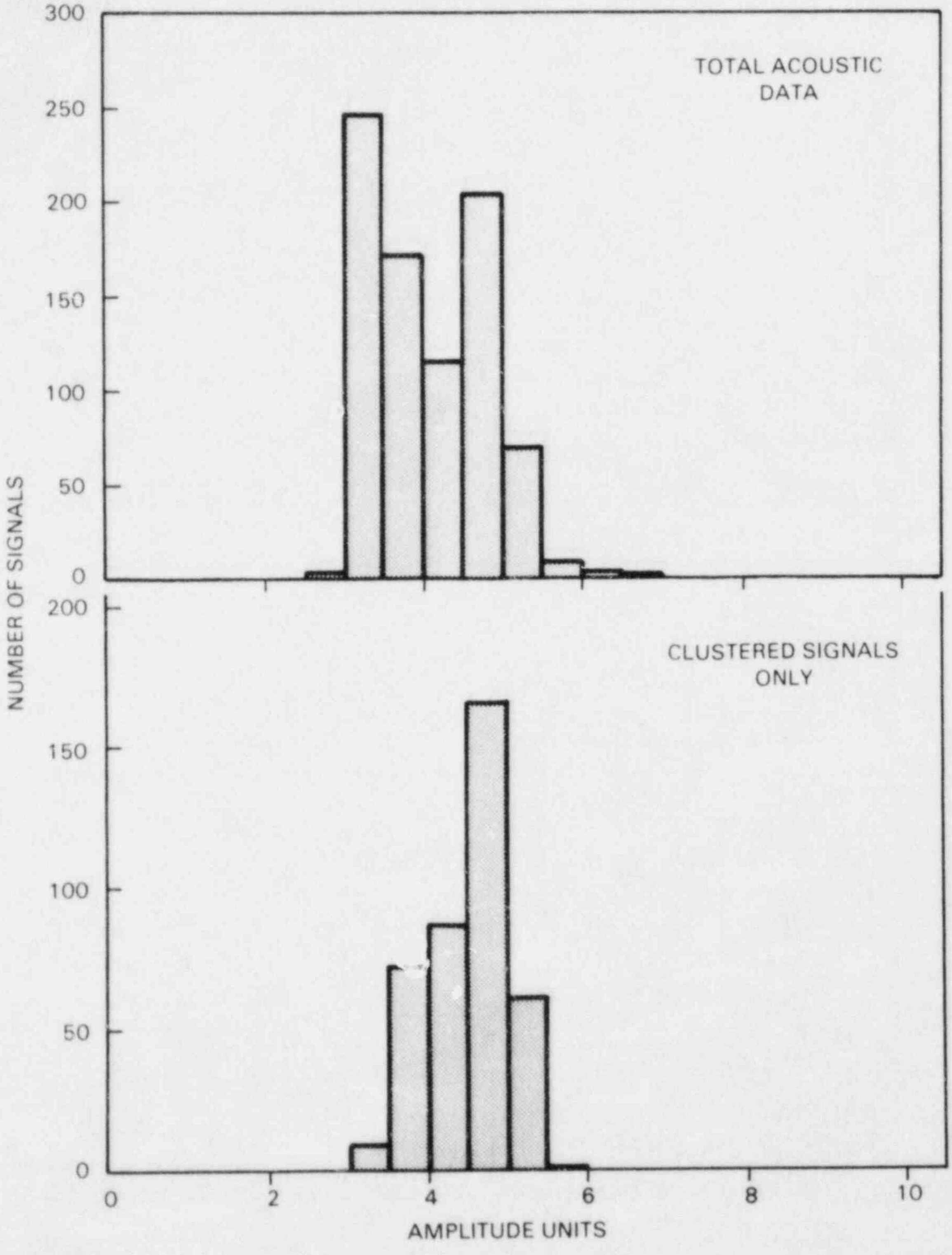


Figure 22. Amplitude of Clustered AE Signals Compared to that of Total Acoustic Data, No. 2 Inlet Nozzle - Watts Bar, Unit 1.

Preparations are in process for operational AE monitoring. Fuel loading is currently scheduled to start July 24, 1984.

AE SIGNAL PATTERN RECOGNITION

Waveform recordings, source locations, and other parameters obtained from the ZB-1 test have enabled identification of waveforms due to fracture or fracture-related processes. Visual examination revealed that waveforms associated with known flaws exhibit a distinct pattern comprised of three pulses, which represent principle wavemodes in the waveguide response resulting from excitation by an incident sharply rising acoustical signal. Since no other sources identified in the cold cyclic testing phase have shown the three pulse pattern, the current emphasis is on developing a method for identifying waveforms containing the three pulse waveguide response. In light of the fact that other sources such as cavitation could produce a response in the waveform measuring device similar to those observed from crack growth in the ZB-1 test, extraction of waveforms exhibiting the three pulse pattern is considered as a first step in acoustic signal analysis. This step will likely be followed by the previously developed pattern recognition to perform the final separation of crack growth AE.

Other attributes of flaw related acoustic signals were noted during visual examination of the waveform data. Observations found to be important during development of methods for identifying the three pulse pattern are:

a. The three pulses are separated by time intervals which depend primarily on the waveguide length. These intervals are therefore constant for a given waveform recording apparatus.

b. Many waveforms for the same source are nearly identical.

c. Differences between "clean" waveforms (those which do not exhibit any background acoustic signal in addition to the three pulses) usually involve only relative pulse magnitude.

d. The three pulses are generally of significantly higher amplitude than the remainder of the acoustic signal.

e. Many waveforms show overlapping three pulse patterns. This behavior is probably due to multiple signal production at the source and/or wavemode separation by the test vesssel before the signal reaches the waveguide. Overlapping patterns caused by wavemode separation might be exploited to yield the distance between the waveguide and the emission source.

Rather than concentrate on a single technique for extracting the three pulse waveforms, three simple methods are being investigated in order to expedite determination of which would produce the best result in practice. Because frequency differences between pulses in various waveform records were observed, the envelopes of the waveforms are considered to be a more reliable basis of comparison. Two techniques require comparison of a test waveform and a template waveform representing a typical flaw-related acoustic signal. The first technique is simple cross-correlation between the template and test waveforms. The maximum value of the correlation coefficient is computed and used as a basis of waveform discrimination. Cross-correlation of identical waveforms would produce a correlation coefficient of 1, while uncorrelated waveforms would have a coefficient of 0. Although the waveform is greatly influenced by the response of the measuring system, the differences between various waveforms should be great enough to allow discrimination.

A second technique aligns the waveforms and finds the point-to-point variance (difference) between the test and template waveforms. For identical waveforms the total variance should be small, but the locations of the greatest variances between the waveforms should also aid determination of the class of the test waveform.

A third method does not rely or a template waveform, but takes advantage of constant pulse separation and the greater relative magnitude of the waveform in the pulse regions. By measuring the maximum amplitude of the signal in the pulse regions and comparing to relative maxima elsewhere in the signal, it should be possible to identify flaw related waveforms. While the first two techniques require that a reference waveform be found, the latter technique has the advantage that only the waveguide length and wavemode group speeds (constant for a given material) be provided as input.

The cross-correlation technique has been examined in detail. A training set was formed of 27 waveforms of five distinct types. Three types of waveforms are those from the machined flaws, those associated with flaws found at a nozzle, and waveforms identified as occurring at the KS07 patch weld flaw. The other two groups were comprised of noise of uncertain origin observed during the test. Except for the machined flaw waveforms which contained four "clean" signals and one "dirty" signal, at least five waveforms were chosen at random from the other four groups.

Using an initial envelope approximation algorithm, the results of Table 1 were obtained when cross-correlating the training set with a "clean" machined flaw waveform and with a waveform from the nozzle. Using a cutoff coefficient of 0.7, it was possible to distinguish 15 of 16 flaw related waveforms while including 2 of 11 noise waveforms when the machined flaw was used as a reference. Using a nozzle waveform reference produced somewhat poorer results, correctly identifying only 12 of 16 flaw waveforms and still including 2 noise waveforms using a coefficient of 0.8. The best result was obtained when the results of the two comparisons were combined. By simply adding the correlation coefficients for the two reference waveforms, it was possible to discriminate 15 of 16 flaw waveforms while excluding all noise waveforms. These results are considered to be very promising for the cross-correlation discriminator. Cursory examination of the variance technique and the pulse magnitude comparison technique has indicated that they also can provide some degree of waveform discrimination.

Effort in the immediate future will be directed towards completion of the computer programs necessary to run a complete evaluation of the three techniques on ZB-1 cold phase data. If successful with cold phase data, the techniques will then be applied to ZB-1 test hot phase data and Watts Bar hot functional test data. Application of the waveform differentiation methods to these tests should point out application problems not yet identified, and permit determination of the best discrimination method or combination of methods.

PIPE MATERIAL TESTING

Room temperature fatigue testing of a specimen of A106 ferritic pipe material has been completed and preliminary analysis of AE data from specimen A106B-2 has been completed. The specimen geometry was single-edge-notch with gage section dimensions of one by six inches. Fatigue crack growth testing was performed in room temperature laboratory air. A sinusoidal load waveform was employed at a frequency of 1.0 Hz. Two R-ratios (0.1 and 0.6) were investigated. Crack length measurements were made on both sides of the specimen with a 32X traveling stage microscope.

AE measurements were made with two broadband surface mounted sensors configured in a linear array. One sensor was located at each end of the specimen gage section.

Initial data analysis concentrated on determining the amplitude and load position distributions, and the relationship between AE event rate and fatigue crack growth rate. Figure 23 shows the amplitude histograms for the different R-ratios in-

Table 1

RESULTS FROM FIRST USE OF CROSS-CORRELATION METHOD TO ISOLATE THREE ELEMENT AE SIGNALS PRODUCED BY CRACK GROWTH

A. Correlation coefficients from cross-correlation of training set waveforms with a machined flaw crack growth waveform, ZB-1 test

Mach.	Nozzle	KS07	Per. Noise	LF Noise
1.000	.788	.763	.734	.659
.945	.754	.730	.638	.750
.936	.758	.788	.636	.656
.963	.783	.851	.654	.675
.795	.785	.660	.664	.664
	.767		.666	

B. Correlation coefficients from cross-correlation of training set waveforms with a nozzle cracking waveform, ZB-1 test

Mach.	Nozzle	KS07	Per. Noise	LF Noise
.754	1.000	.826	.770	.734
.854	.964	.803	.734	.777
.675	.961	.833	.730	.710
.695	.964	.832	.812	.748
.919	.961	.785	.787	.787
	.992		.803	

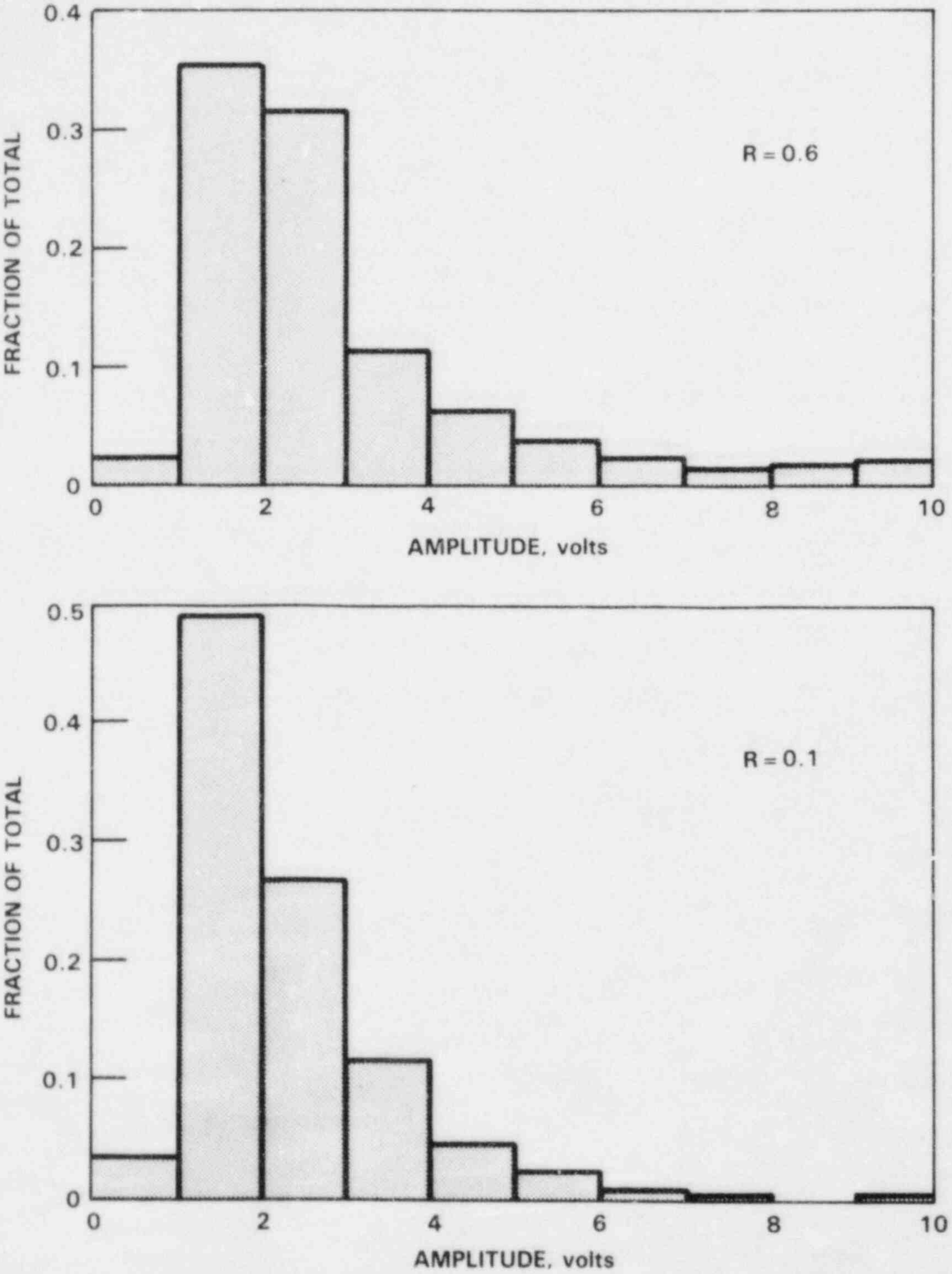


Figure 23. Amplitude Histograms for Data from A106B Steel.

vestigated during the test. The shape of the two distributions is similar to A533B steel laboratory data. Most of the events were low amplitude emissions just above the detection threshold. The effect of R-ratio on the amplitude distributions does not appear go be very significant. The R=0.6 data is shifted somewhat to higher amplitudes when compared to the R=0.1 data.

The load position histograms for specimen A106B-2 data are given in Figure 24. The R=0.1 distribution correlates well with data from A533B laboratory specimens in that very few events were observed near maximum or minimum load. The majority of the events in this instance tended to occur during the rapidly increasing and decreasing portions of the load cycle. This result suggests crack tip strain rate may have an influence on the production of AE. (This comment is contradicted by the cycle rate effects test which showed no significant influence of cycle rate on AE behavior between 0.1 and 1.0 Hz.) The high R-ratio data, on the other hand, showed a different trend. In this case, 35 percent of the events occurred near the maximum load.

A graph showing the effect of R-ratio on the AE event rate - fatigue crack growth relationship for specimen A106B-2 is given in Figure 25. The points along the abscissa with attached arrows represent instances where no emissions were detected during a crack growth increment. The data plotted in Figure 25 shows that the event rate for R=0.6 loading conditions was generally less than the event rate for R=0.1 testing. This result conflicts with data obtained from A533B steel specimens and from an earlier test run on this steel (specimen A106B-1). Figures 26 and 27 compare the results from the two tests on A106B steel. In both instances the A106B-2 specimens appear to be somewhat less emissive, but is definitely less active at R=0.6 loading conditions.

STANDARDS AND CODES

A revised outline for a "Standard Practice for Continuous Monitoring of Pressure Boundaries Using Acoustic Emission" was approved for further development at the ASTM E.07.04.04 meeting in Ft. Lauderdale, Florida in January. We plan to have the first draft of the standard ready for submission at the June ASTM meeting. A copy of the outline is attached as Appendix A for information.

REPORTS

NUREG/CR-3693, "Acoustic Emission Monitoring of Hot Functional Testing, Watts Bar Unit 1 Nuclear Reactor," has been completed and will be submitted for publication in May 1984.

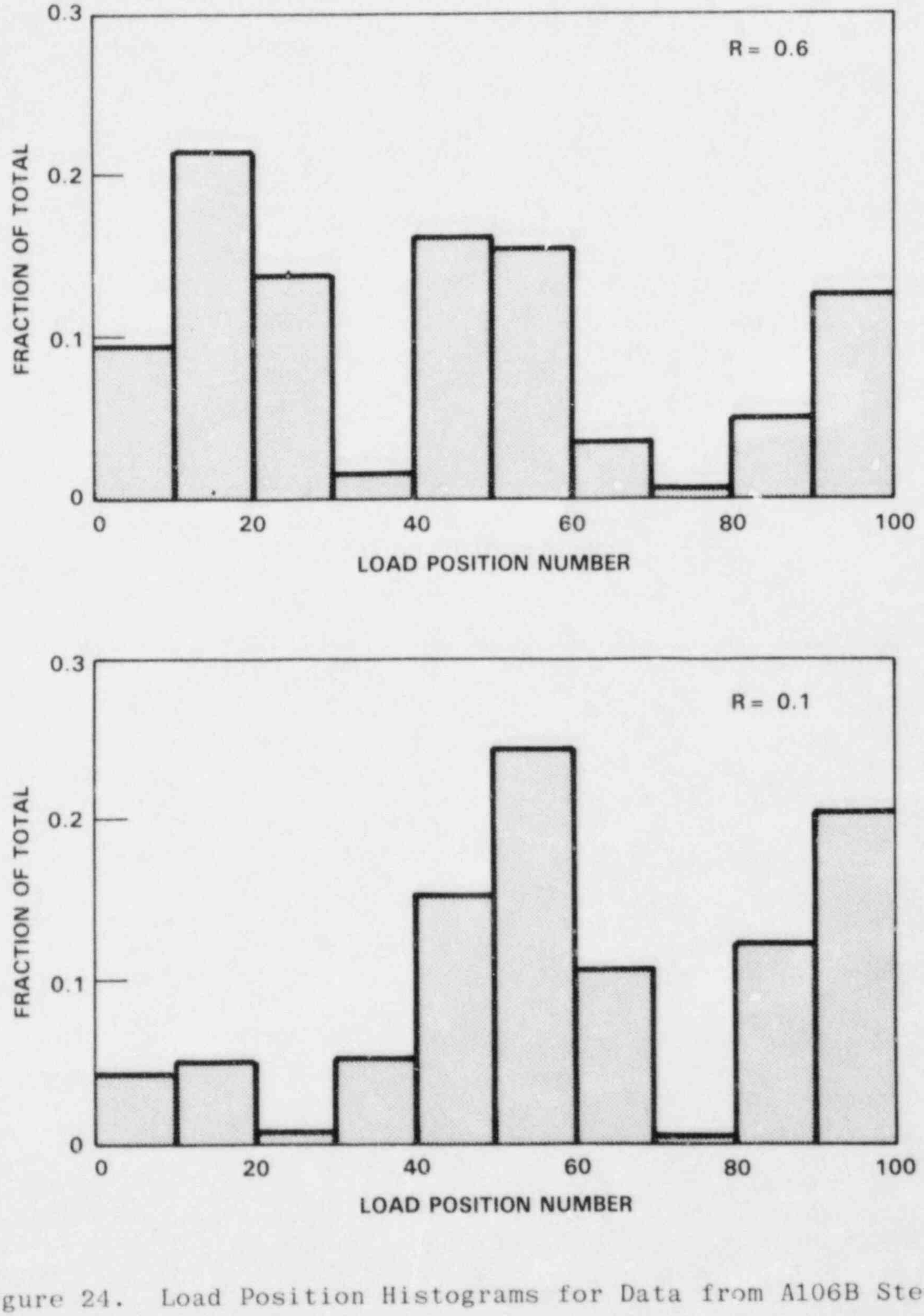


Figure 24. Load Position Histograms for Data from A106B Steel.

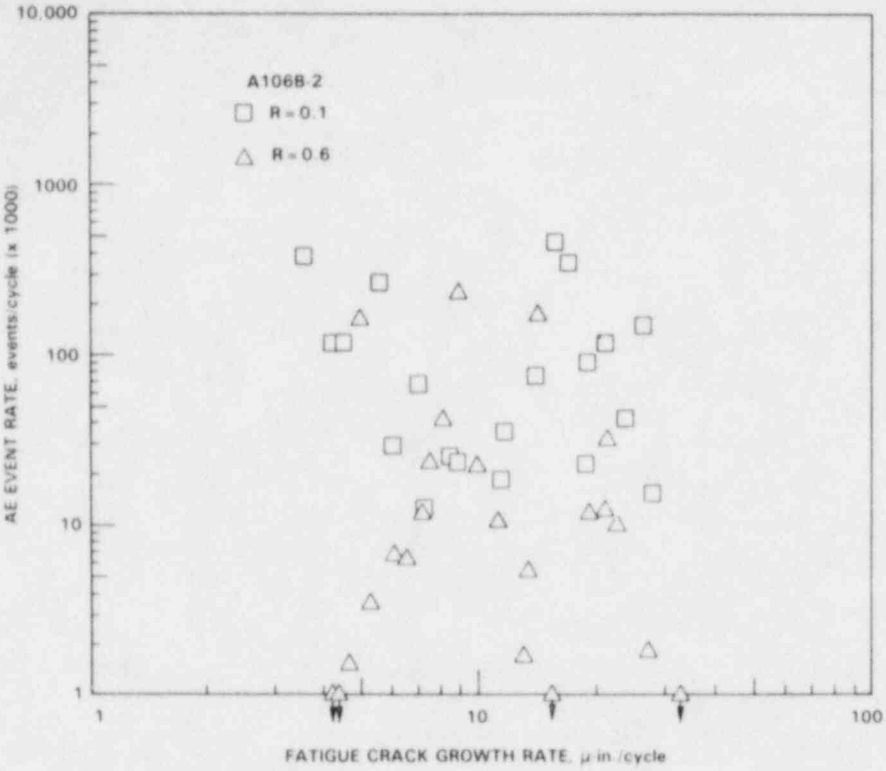


Figure 25. Effect of R-Ratio on the AE Event Rate Versus Fatigue Crack Growth Rate for Specimen A106B-2.

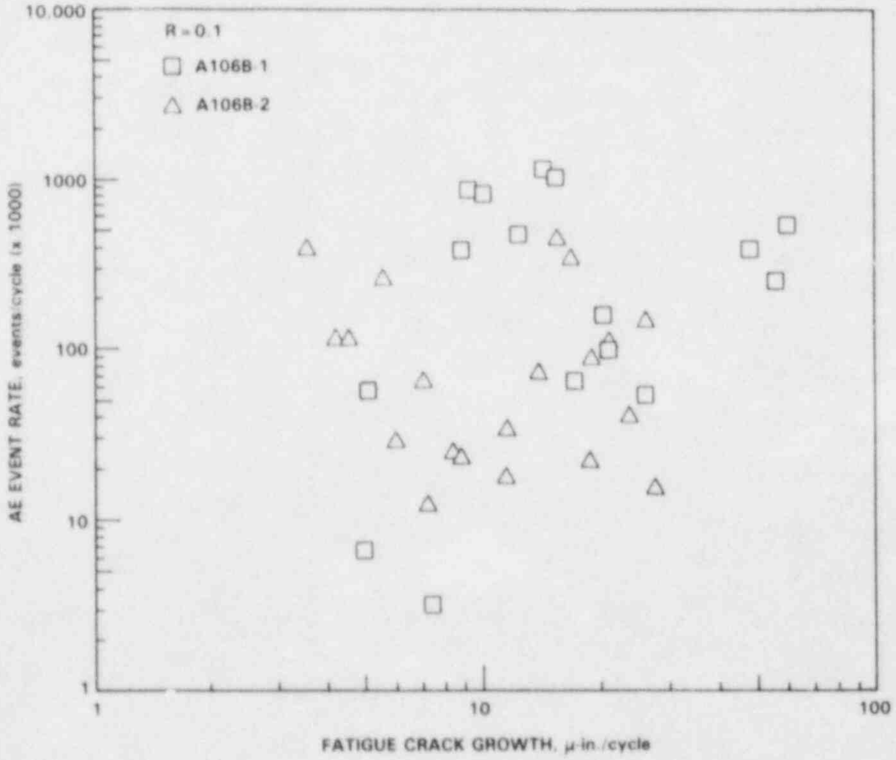


Figure 26. Comparison of the AE Event Rate Versus Fatigue Crack Growth Rate for Specimens A106B-1 and A106B-2 Tested at R=0.1.

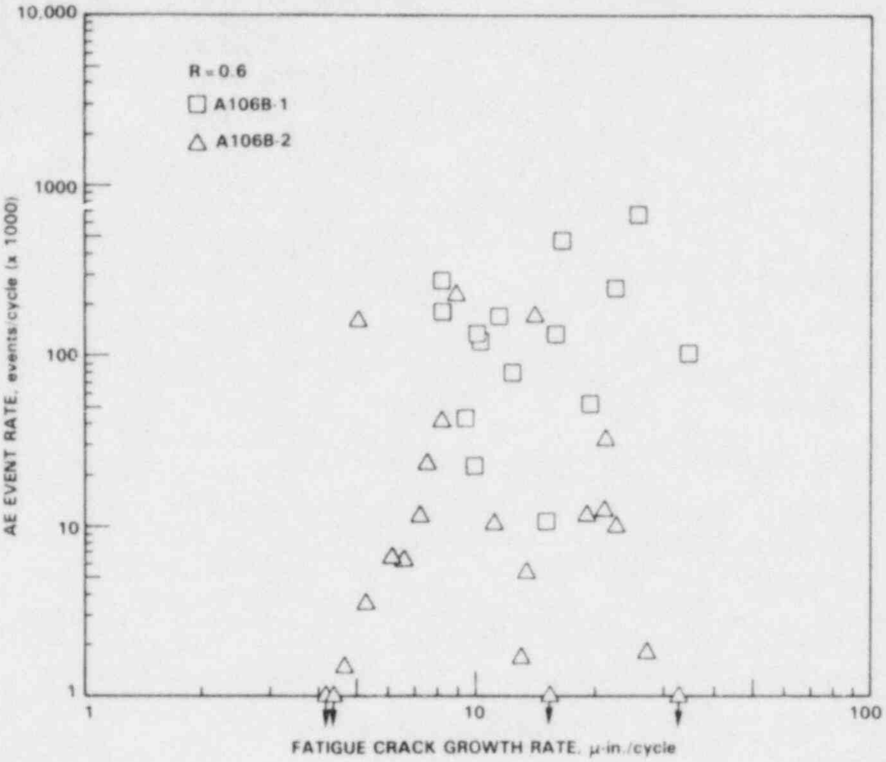


Figure 27. Comparison of the AE Event Rate Versus Fatigue Crack Growth Rate for Specimens A106B-1 and A106B-2 Tested at R=0.6.

FUTURE WORK

- Complete ZB-1 test data analysis.
- Prepare a NUREG document on ZB-1 vessel test results.
- Prepare an information document on application of AE to pipe weld monitoring.
- Initiate testing to define AE characteristics of ISGCC in austenitic stainless steel.
- Prepare for operational AE monitoring at Watts Bar, Unit 1 reactor.

APPENDIX A

OUTLINE OF ASTM STANDARD PRACTICE FOR CONTINUOUS MONITORING OF PRESSURE BOUNDARIES USING ACOUSTIC EMISSION

ASTM E07.04.04

Designation: 4.04/83-04-01

Standard Practice for Continuous Monitoring of Pressure Boundaries Using Acoustic Emission

OUTLINE

1.0 SCOPE

- What does the standard cover?
- What is the product of applying the standard?

2.0 APPLICABLE DOCUMENTS

- What other ASTM Standards and recognized public documents apply to this standard?

3.0 SUMMARY

- Brief description of what is contained in the Standard.

4.0 SIGNIFICANCE AND USE

- Brief description of the basis for the Standard, how it is applied, and the expected result or benefit.

5.0 TERMINOLOGY

- Definition of unique terminology used in the Standard.

6.0 MONITOR SYSTEM FUNCTIONAL REQUIREMENTS AND QUALIFICATIONS

- What is the general functional make-up of a monitor system?
- What criteria is to be used in selecting an AE system - i.e., environmental conditions, parameters to be measured, sensor mounting constraints, continuity of operation, raw data storage, processed data storage, protection against loss of data, information presentation, nuclear versus non-nuclear, etc.?
- What functional qualification tests are to be applied to assure correct operation of the system prior to installation? - After installation - How often?

7.0 MONITOR SYSTEM CALIBRATION

- System response characterization such as frequency range, dynamic range, data rate limit, etc. to be performed prior to installation.
- System calibration such as response characterization, sensitivity, source location accuracy to be performed on the installed system - how often?
- System response to fluid flow background noise.

8.0 PRECAUTIONS

- Precautions for personnel safety.
- Precautions for pressure system safety.
- Precautions for administrative and legal protection.

9.0 PERSONNEL QUALIFICATIONS

- What requirements must be fulfilled by personnel responsible for installing and operating the AE monitor system?
- How is the required qualification to be accomplished?

10.0 MONITOR SYSTEM INSTALLATION

- Special requirements imposed by the facility to be monitored - nuclear and non-nuclear - such as seismic qualification, need for running leads in conduit, penetration of protective barriers, etc.
- Sequence of installation, calibration, and performance tests.

11.0 PROCEDURE

- Observations required and how often.

12.0 INTERPRETATION OF MONITORING RESULTS

- What criteria is to be used to evaluate data significance?
- What cross-check or verification measures should be applied?
- What action is called for by various data conditions?

13.0 DATA RECORD REQUIREMENTS

- What information is to be retained - calibration, routine data, functional tests, parametrics, etc.?
- Information form and format to be stored and for how long?

14.0 ADMINISTRATIVE RECORD REQUIREMENTS

- Records and reports to be supplied for administrative purposes.

NOTE: Items 1.0, 4.0, 8.0, and 11.0 are mandatory elements of the Standard per ASTM guide.

PROPOSED STANDARD PRACTICE FOR CONTINUOUS MONITORING OF PRESSURE BOUNDARIES USING ACOUSTIC EMISSION

1. SCOPE

1.1 This standard practice provides guidelines for continuous monitoring of acoustic emission (AE) from metal pressure boundaries in industrial pressure systems during operation. Examples are pressure vessels, piping, and other system components which serve to contain system pressure. Pressure boundaries other than metals, such as composites, are specifically not covered by this document.

1.2 The functions of the AE monitoring are to detect, locate, and evaluate the significance of AE sources. These sources are those activated during system operation - i.e., no special stimulus is applied to produce AE. Other methods of nondestructive testing (NDT) may be used, when the pressure boundary is accessible, to further evaluate/substantiate the significance of the AE sources.

3. SUMMARY

3.1 This standard describes the use of a passive monitor system which is sensitive to AE to detect, locate, and evaluate crack growth in metal pressure boundaries.

3.2 The standard provides guidelines for selection, qualification, calibration, and installation of the AE monitor system. Qualification of personnel is also addressed.

3.3 The standard provides guidelines for use of the AE information to estimate the significance of a detected flaw to continued pressure system operation.

4. SIGNIFICANCE AND USE

4.1 Acoustic emission examination of a structure usually requires application of a mechanical or thermal stimulus - in this case, system operating conditions. Such stimulation produces changes in the stresses in the structure. During stimulation of a structure, AE from active discontinuities such as cracks or from other acoustic sources such as leakage of high pressure, high temperature fluids can be detected by an instrumentation system using sensors mounted on the structure. When the sensors are excited by AE stress waves, they transform the mechanical excitations into electrical signals. The sensors are acoustically coupled to the surface of the structure by means of a couplant material or pressure on the interface between the sensing device and the structure that improves the transmission of stress waves to the sensor. The detected AE signals are electronically conditioned and processed to facilitate recording of raw data and analysis to produce information on source location and parameters needed for flaw evaluation.

4.2 Application of AE monitoring on a continuous basis is the only currently available method to achieve continuous surveillance of a system structure to assess continued integrity. The use in this context is to identify the existance and location of crack growth. Also, it will provide information with which to estimate the significance of the detected flaw to continued system operation.

4.3 In addition to immediate evaluation of the emissions detected, a permanent record of the total data detected provides an archival record which can be re-evaluated if desirable.

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16. ABSTRACT *(200 words or less)*

This report describes technical progress on a program to apply acoustic emission for continuous integrity surveillance of nuclear reactor pressure boundaries. The period is October 1983-March 1984. Test data from the completed intermediate scale vessel (ZB-1) test is being analyzed to isolate AE from crack growth for the purpose of refining AE signal identification and AE interpretation methods. Fatigue crack growth in the ZB-1 vessel is being characterized by destructive examination. Acoustic data obtained from the No. 2 inlet nozzle during hot functional testing at Watts Bar Unit 1 reactor showed a source concentration. A cooperative effort between TVA and PNL is planned to evaluate the significance of the data. Identification of crack growth AE by pattern recognition is showing much improved results. Fatigue testing of A106B ferritic pipe material is showing mixed AE results related to previous relationships developed for A533B steel. Development of an ASTM Standard Practice for continuous AE monitoring of pressure boundaries has been initiated. A NUREG document on results from AE monitoring at Watts Bar, Unit 1 reactor during hot functional testing has been completed.

17. KEY WORDS AND DOCUMENT ANALYSIS

17a. DESCRIPTORS

Acoustic emission monitoring of reactor pressure boundaries for flaw detection.

17b. IDENTIFIERS/OPEN-ENDED TERMS

acoustic emission, AE, reactor pressure boundaries, continuous monitoring, flaw detection

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