NUREG/CR-3693
PNL-5022

Acoustic Emission Monitoring of Hot Functional Testing

Watts Bar Unit 1 Nuclear Reactor

Prepared by P. H. Hutton, J. F. Dawson, M. A. Friesel,
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Pacific Northwest Laboratory
Operated by
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NUREG/CR-3693
PNL-5022
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Manuscript Completed: May 1984
Date Published: June 1984

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NRC FIN B2088

ABSTRACT

Acoustic emission (AE) monitoring of selected pressure boundary areas at TVA's Watts Bar, Unit 1 Nuclear Power Plant during hot functional preservice testing is described in this report. The report deals with background, methodology, and results. The work discussed here is a major milestone in a program supported by NRC to develop and demonstrate application of AE monitoring for continuous surveillance of reactor pressure boundaries to detect and evaluate growing flaws. The subject work demonstrated that anticipated problem areas can be overcome. Work is continuing toward AE monitoring during reactor operation.

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EXECUTIVE SUMMARY

A program devoted to developing and demonstrating the use of acoustic emission (AE) methods for continuous surveillance of reactor pressure boundaries to detect flaw growth is in process at Pacific Northwest Laboratory. This work is sponsored by the U.S. Nuclear Regulatory Commission. In an initial phase, technology was developed in the laboratory to identify AE from crack growth and to utilize that AE information to estimate flaw severity. Two key subsequent phases are concerned with evaluating and finalizing the technology through testing on an intermediate scale test vessel (Phase 2) and demonstrating the technology on an operating reactor (Phase 3). Phase 2 has been completed and the results are being reported separately.

Through the cooperation of the Tennessee Valley Authority (TVA), Phase 3 of the program is being conducted at the Watts Bar Unit 1 Nuclear Power Plant. Selected areas of the pressure boundary are being monitored with an AE system during preservice testing and initial reactor monitoring. The cold hydrostatic preservice test was monitored and results reported previously. This report is concerned with the more recent AE monitoring of the hot functional test.

Locations on the pressure system to be monitored were selected with the concurrence of the cognizant TVA, NRC, and PNL personnel. The following three areas were instrumented for AE monitoring:

- Reactor coolant inlet nozzle No. 2
- The loop 2 accumulator safety injection piping near the connection to loop 2 cold leg
- A section of the reactor pressure vessel bounded at the top by the loop 2 inlet and outlet nozzles.

AE equipment used consisted of steel waveguide sensors tuned to a selected frequency response, signal conditioners, a commercial data acquisition system, and a PNL-built waveform recorder for signal pattern recognition analysis. Monitoring instrumentation was located in the auxiliary instrument room with connection to the AE sensors on the reactor through permanently installed cabling. Cable connection through containment was by way of twisted three-wire penetration conductors.

The results obtained from AE monitoring hot functional testing are very significant to the objective of continuous AE monitoring. Reactor system temperature and coolant flow noise during hot functional should be similar to that during reactor

operation. Under these conditions, we were able to demonstrate the following major items:

- Coolant flow noise can be overcome as a problem to monitoring.
- AE signals from a fracture specimen were detected under essentially operating conditions.
- Spontaneous acoustic information was detected and located on the No. 2 inlet nozzle.

At coolant flow conditions of 350°F, 400 psig and above, the waveguide sensors show only limited response to coolant flow noise. They, however, readily detected AE signals from a fracture specimen mounted on piping in the vicinity of the sensors. Spontaneous AE from the No. 2 inlet nozzle was also detected and located. Both detection functions were accomplished at operating reactor coolant conditions (557°F, 2235 psig). The sensors and associated electronic amplifiers did not show any deterioration from exposure to the high temperature environment.

The significance of these results lies in the fact that they resolve what has been cited as primary obstacles to AE monitoring during reactor operation. The results demonstrate the feasibility of continuous AE monitoring to detect growing flaws in reactor pressure boundaries.

ACOUSTIC EMISSION MONITORING OF HOT FUNCTIONAL TESTING WATTS BAR UNIT 1 NUCLEAR REACTOR

1.0 INTRODUCTION

A program devoted to developing and demonstrating the use of acoustic emission (AE) methods for continuous surveillance of reactor pressure boundaries to detect flaw growth is in process at the Pacific Northwest Laboratory (PNL).[1] This work is sponsored by the U.S. Nuclear Regulatory Commission. In an initial phase, technology was developed in the laboratory to identify AE from crack growth and to utilize that AE information to estimate flaw severity.[2] Two key subsequent phases are concerned with evaluating and finalizing the technology through testing on an intermediate scale test vessel (Phase 2) and finally, demonstrating the technology on an operating reactor (Phase 3). Phase 2 testing has been completed at a test site in Mannheim, West Germany.

Through the cooperation of the Tennessee Valley Authority (TVA), Phase 3 of the program is being conducted at the Watts Bar Unit 1 Nuclear Power Plant. Selected areas of the pressure boundary are being monitored with an AE system during:

- Cold hydrostatic testing
- Hot functional testing
- Reactor startup and power operation.

Monitoring cold hydrostatic test has been completed and the results have been reported.[3] This report is concerned with results from AE monitoring hot functional testing.

2.0 PRESSURE BOUNDARY AREAS MONITORED

Locations on the pressure system to be monitored were selected with the concurrence of the cognizant TVA, NRC, and PNL personnel. The following three areas of the Watts Bar Unit 1 nuclear facility were instrumented for AE monitoring:

- Inlet nozzle No. 2 on reactor coolant loop.
- The loop 2 accumulator piping near the connection to loop 2 cold leg.

- A section of the reactor pressure vessel bounded at the top by the loop 2 inlet and outlet nozzles.

Figure 1 provides a general perspective of these locations in relation to the total reactor system.

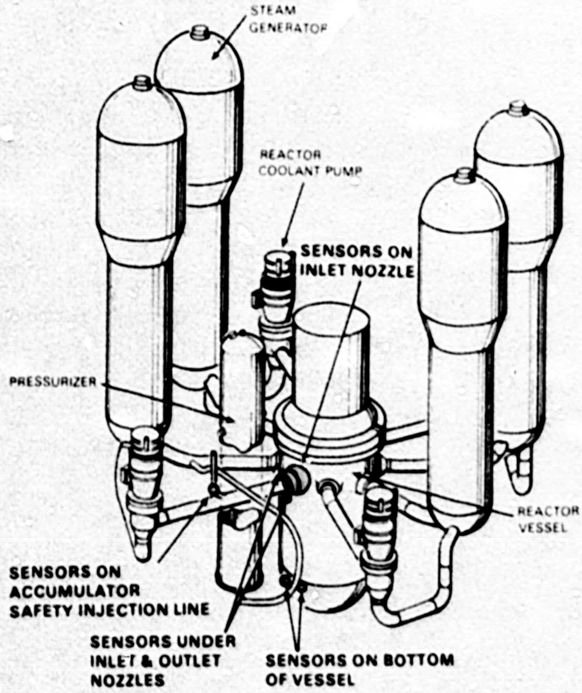


Figure 1. AE Monitoring Locations on Watts Bar, Unit 1 Reactor.

Inlet nozzle No. 2 was chosen because preservice ultrasonic examinations had revealed small indications in the nozzle due to underclad cracking. [Several crack like indications around inlet nozzle No. 2 were detected during preservice examinations. The larger indications were repaired and only indications allowable under Section XI remain.] Also, this is one of the locations where coolant flow noise should be at a maximum.

The accumulator safety injection pipe near the loop 2 cold leg was chosen as a good location to mount a fracture specimen in conjunction with an array of AE sensors. The objective being to evaluate detection of AE under essentially plant operating environment. Again, this location should experience a maximum coolant flow noise.

The section of vessel wall is being monitored to help assess the feasibility of AE monitoring the vessel belt line fabrication weld with sensors at the closest readily accessible locations on the vessel.

3.0 TEST EQUIPMENT AND INSTALLATION

The AE equipment used for monitoring the Watts Bar hot functional test consisted of tuned waveguide sensors, commercial high temperature sensors, signal conditioners, a Dunegan/Endevco 1032D data acquisition system, and a PNL-built waveform recorder for signal pattern recognition analysis. Monitoring instrumentation was located in the auxiliary instrument room with connection to the AE sensors through permanently installed cabling. Cable connection through containment was by way of twisted three wire penetration conductors.

3.1 SENSORS

Location of specific AE sensors installed is shown in Figure 2. The 14 sensors installed on the No. 2 inlet nozzle, the accumulator pipe, and on the vessel wall under the No. 2 inlet and outlet nozzles consist of 1/8 inch diameter by two to four feet long stainless steel waveguides with a differential sensing element and a 20 dB gain differential microamplifier mounted on one end. The other end of the waveguide is pressure coupled to the structure. The two sensors installed at the bottom of the vessel are Westinghouse high temperature AE sensors pressure coupled to the vessel surface.

The choice of 1/8 inch diameter for the waveguides is based on an experimental investigation. The propagation of elastic waves through cylinders is a complicated phenomenon, which depends strongly upon the cylinder dimensions, ultrasonic frequency, and especially the mode of propagation. Knowing this information allows a theoretical formulation of the effect to be generated. For the particular geometry and operating conditions of these sensors, however, it was not clear how to apply this theory because the modes of propagation and excitation of the waveguides are not well understood. As a result, it was decided to proceed with an experimental evaluation for choosing the proper waveguide.

The major effect to be dealt with in waveguide design is acoustic dispersion; i.e., different ultrasonic frequencies travel at different speeds. Dispersion causes short ultrasonic pulses (composed of many different frequencies) to be spread out in time. To quantify the effect of dispersion, a series of measurements of pulse spreading was performed on rods of differ-

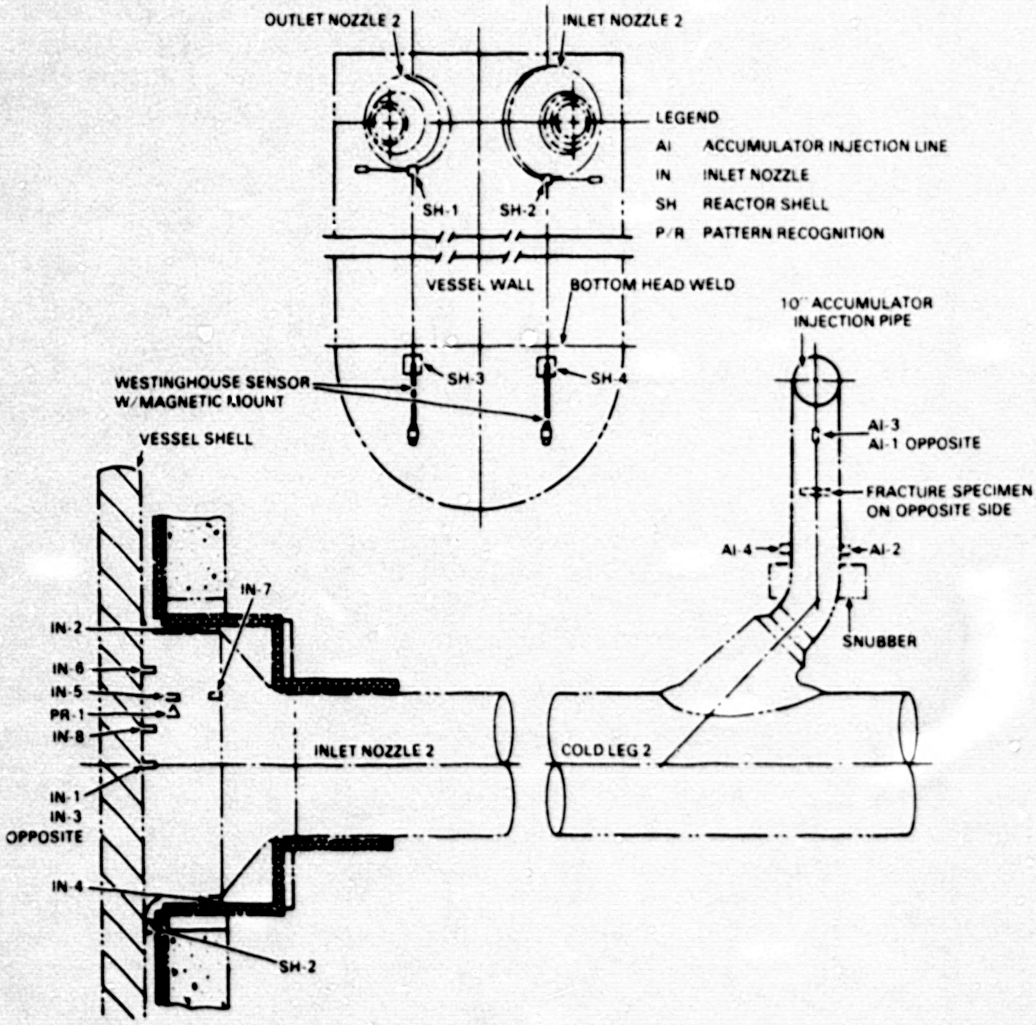


Figure 2. AE Sensors Installed on Watts Bar, Unit 1 Reactor.

ent diameters. In all cases the rods were 36 inches in length. A broadband pulse (center frequency of 500 kHz and bandwidth approximately 60%) approximately 2 microseconds long was transmitted down the rods and the received pulse after one transit through the rods was recorded. Table 1 shows the results of this experiment.

Table 1. Affect of Waveguide Diameter on Internal Dispersion of Pulse Energy

Diameter (inches)	Received Pulse Length (microsec)
0.315	300
0.190	300
0.155	150
0.125	50
0.095	20

From this simple experiment, it was determined that the thinnest rod was the most useful for faithfully transmitting pulses in the 300 - 500 kHz frequency range. The thin rods are also the least thermally conductive, and therefore, provide the best thermal isolation for piezoelectric crystals and electronics. The 0.125 inch rod was chosen as a compromise between the acoustical incentive to keep the waveguide very small and the need for sufficient mechanical strength to facilitate the sensor/microamp combination.

The sensors were characterized in the laboratory initially. They were mounted on a 12" x 12" x 4" steel block in a manner similar to the mounting on the reactor and a helium jet was impinged on the block. Helium pressure is 30 psig and it is fed through a #18 hypodermic needle. The needle is placed perpendicular to the block surface 1-1/2" from the sensor with a standoff distance of 1/8". The helium gas jet is also applicable as a field calibration method. Figure 3 shows typical responses of the three sensor types involved in Watts Bar monitoring plus a reference response of a broadband NBS sensor to the helium gas jet excitation. The significance of the NBS sensor response is to show the frequency profile of the helium gas jet input. The NBS sensor is essentially flat from 100 kHz to beyond 1 MHz. A Tektronix Model 7L5 spectrum analyzer was used to produce the spectral traces. The spectral traces are taken at the output of preamplification stages (microamplifier 20 dB plus the mid-amplifier 20 dB for waveguides and matching amplifier; 40 dB plus the midamplifier 20 dB for Westinghouse sensors and 60 dB for the NBS sensor). Differences in gain are accounted for in Figure 3 so that the traces can be compared directly. The waveguide sensors are tuned to a selected frequency response using inductive tuning coils at the microamplifier.

The spectral responses shown in Figure 3 are a logarithmic measure. The analyzer reference point is the top of the grid which corresponds to 0 dB on the logarithmic scale. Working from the top down, the logarithmic scale is in dB below reference (10 dB/division). The analyzer reference value is 1 miliwatt when a 50 ohm input is used. The corresponding voltage values can be determined by:

$$V_{peak} = \frac{0.224}{\log^{-}\left(\frac{dBm}{20}\right) \times 0.707}$$

Thus, on a voltage scale, the reference corresponds to 317 millivolts peak.

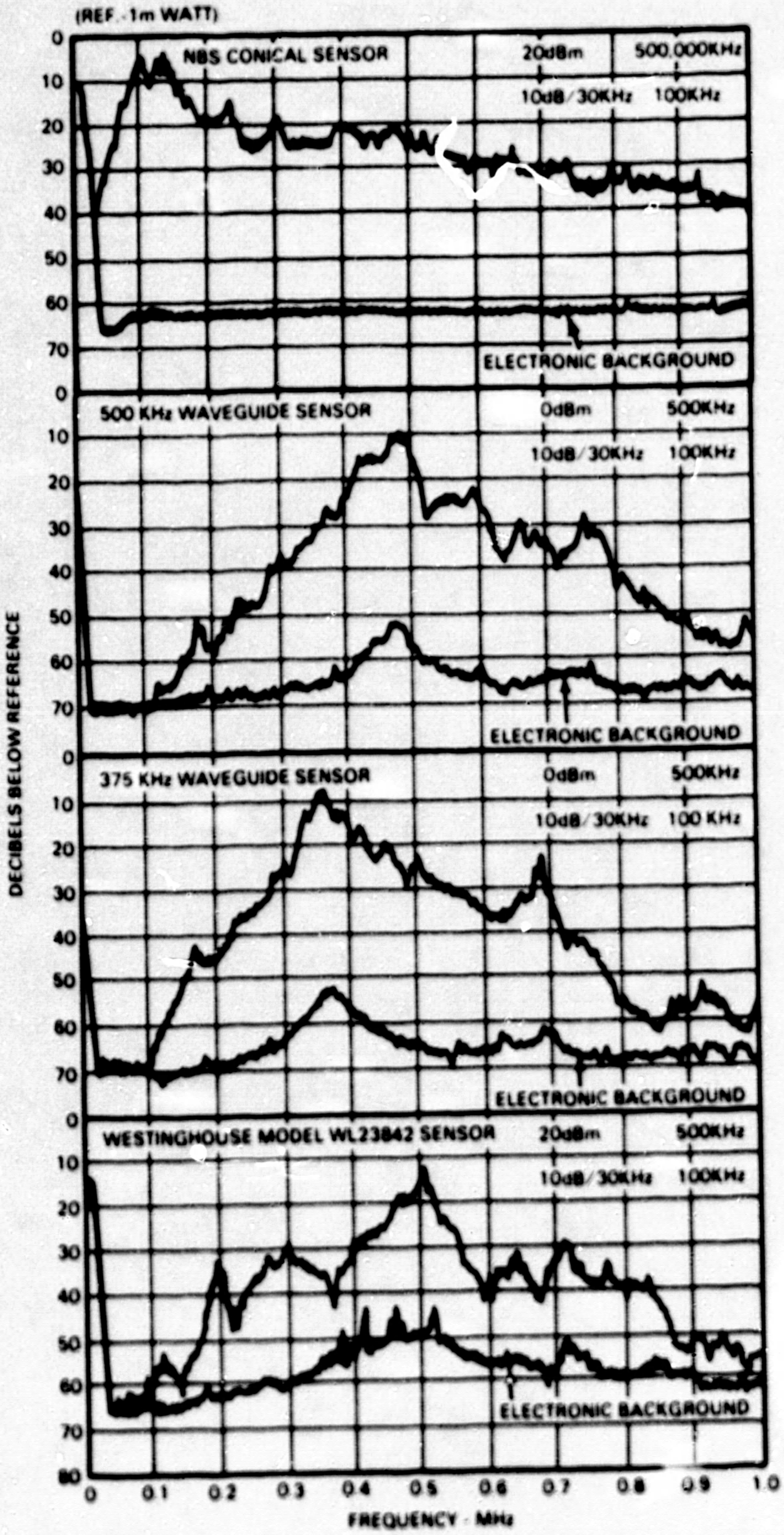


Figure 3. AE Sensor Characterization - Watts Bar.

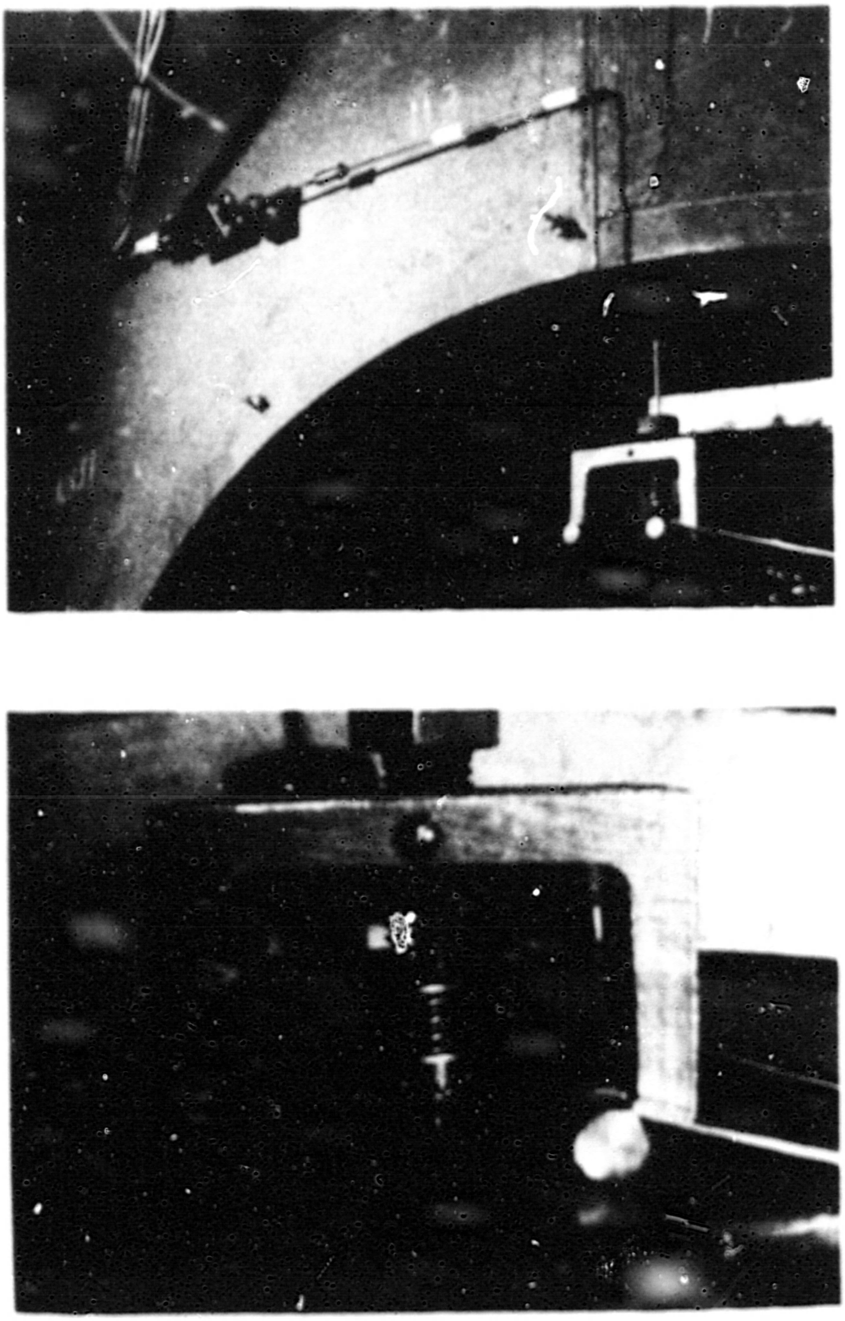


Figure 4. Waveguide AE Sensor IN-2 Installed on No. 2 Inlet Nozzle - Watts Bar, Unit 1.

A typical sensor installation on the No. 2 inlet nozzle is illustrated in Figure 4. Sensor IN-2 is shown here. The mounting fixture used is different from that used earlier in cold hydrostatic test monitoring. Stainless steel bands are used to secure the fixture in place. This has proven to be a much more satisfactory approach over the magnet mounting used previously.

The interface pressure required between the sensing device and the surface being monitored for effective acoustic coupling in the 300-500 kHz frequency range has been evaluated experimentally. The results indicate that about 15,000 psi is optimum; i.e., no sensitivity improvement is observed above that and sensitivity diminishes below that. With these waveguides having a 0.05 diameter tip, 30 pounds force produces 15,300 pounds per square inch pressure at the waveguide/structure interface.

The white sleeve sections on the waveguide are to prevent it from rubbing against the structure. The outer end of the waveguide is secured to the structure with a magnet for seismic considerations. Cutouts were made in the mirror insulation to accommodate the mounted sensors.

As illustrated in Figure 2, two AE sensor arrays were installed on the No. 2 inlet nozzle. One is a cylindrical array which monitors the whole nozzle circumference. The other is a quad array which concentrates on the region where AE information was detected from the nozzle/vessel weld during cold hydrostatic testing. All eight of the waveguide sensors in the two arrays installed on the No. 2 inlet nozzle are tuned to 500 kHz peak response. The final sensor mounted on the No. 2 inlet nozzle was a pattern recognition sensor (PR-1). This was fed directly to a waveform recorder where digitized waveforms were recorded for processing by a pattern recognition system. The response characteristics of this sensor are shown in Figure 5. The

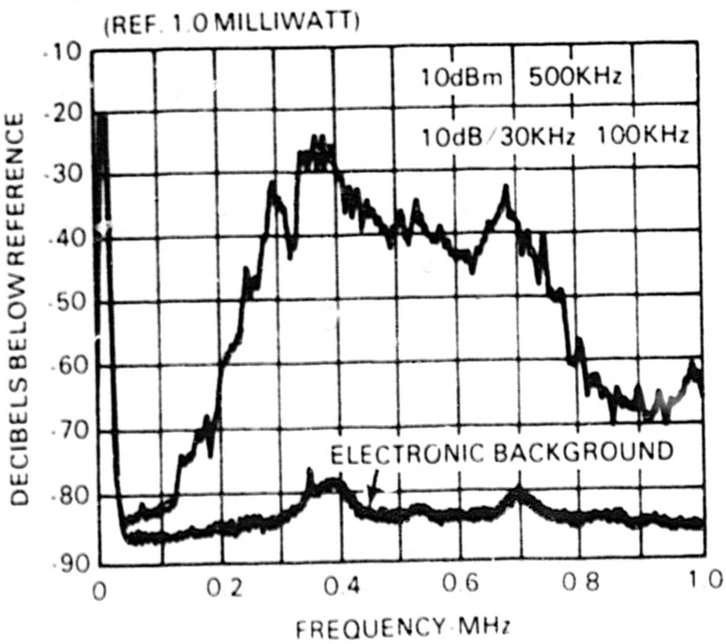


Figure 5. Response Characteristics of Pattern Recognition Sensor - Watts Bar, Unit 1.

primary difference between PR-1 and the 375 kHz tuned sensors in the arrays (Figure 3) is that 10 dB in peak sensitivity was sacrificed during tuning in order to improve the bandwidth up to 700 kHz.

Sensors installed on the accumulator line are shown in Figure 6. One sensor is not visible - it is on the back side of the pipe opposite the sensor marked 2839. No insulation was installed on the accumulator line at this location; hence, no special effort was made to keep the contour of the stainless steel bands close to the pipe as was done on the nozzle. Sensors on the accumulator line are tuned to 375 kHz.

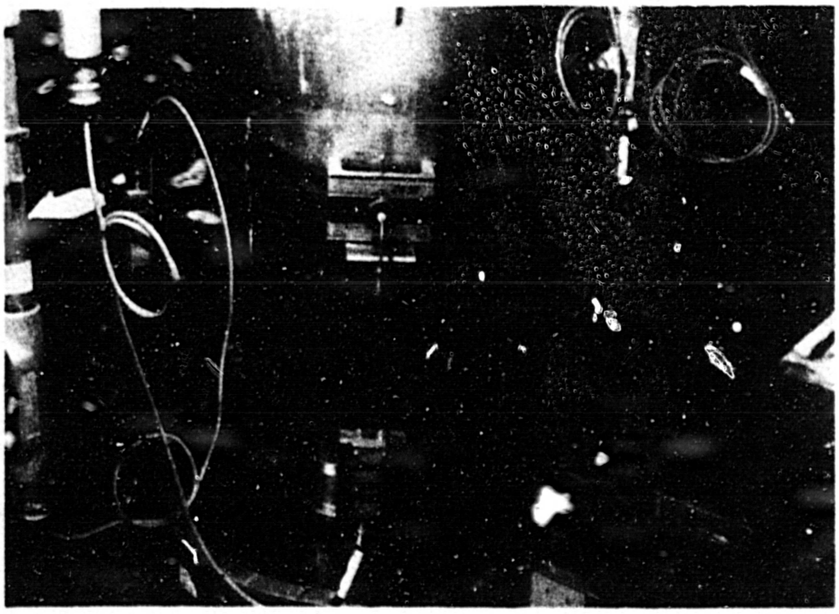


Figure 6. Waveguide AE Sensors Installed on No. 2 Accumulator Line - Watts Bar, Unit 1.

The two sensors placed under the No. 2 inlet and outlet nozzles to contact the vessel wall were 375 kHz tuned waveguides. They were mounted using a bracket attached to the bottom of the thermal shield annulus around the nozzles. See Figure 7. Some difficulty was experienced with this arrangement because the fixture placed the waveguide tip too high. It contacted the start of the nozzle fillet radius rather than the flat vessel wall. As a result, it was difficult to achieve the desired pressure on the waveguide tip. Redesign of the fixture should lower the waveguide enough to overcome the problem.

Figure 7. Waveguide AE Sensor Installed on Vessel Wall Under Inlet Nozzle No. 2 - Watts Bar, Unit 1.

In companion with the two sensors placed under the No. 2 nozzles are two sensors located directly below them near the bottom end closure-to-vessel shell weld. One of these can be seen in Figure 8. This sensor is a Westinghouse Model WL23842 high temperature AE sensor mounted with a magnetic fixture. The sensor is not tuned in its present form.

3.2 CABLING AND MIDAMPLIFIERS

Signal leads from the sensor/microamplifier output to the containment penetration are Belden RG 141A/U coaxial cable with a 50 ohm impedance. This cable is rated for an operating temperature up to 400°F. The cable is routed through rigid conduit inside of containment. The penetrations used are twisted pairs which proved to be satisfactory in lieu of the preferred coaxial penetrations. A penetration bundle was made available by TVA for testing in the laboratory in advance of system installation. This testing showed that the impedance mismatch between the penetration conductor and the coaxial cable caused the midamplifier to oscillate. This was overcome by installing a special buffer in the first stage of the midamplifier.

At the outer end of the penetration (Figure 9), signal leads transferred to RG-58 coaxial cable in cable trays. The midamplifiers were mounted in a wall panel near the penetration exit (Figure 10). From this point, the signal leads go to the

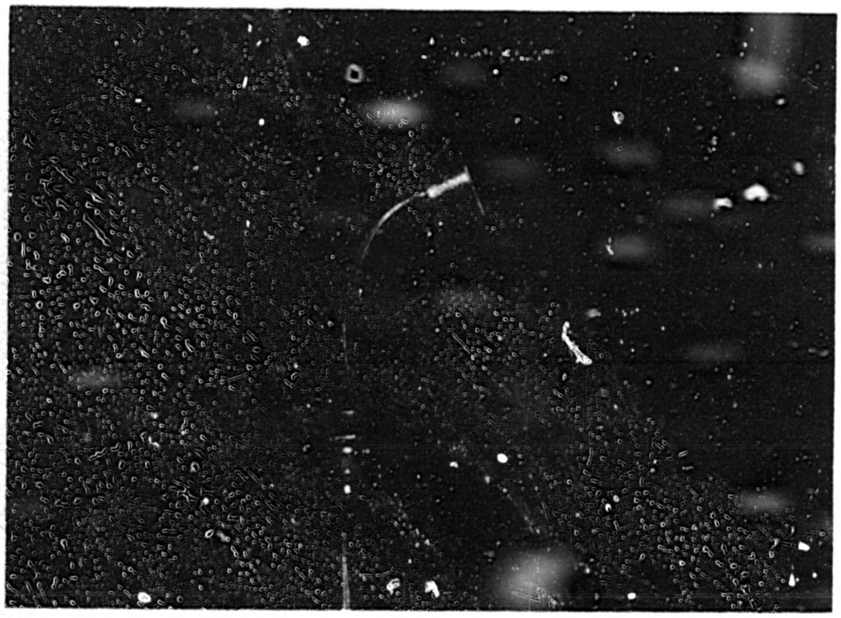


Figure 8. Westinghouse AE Sensor Installed at Bottom of Reactor Vessel - Watts Bar, Unit 1.

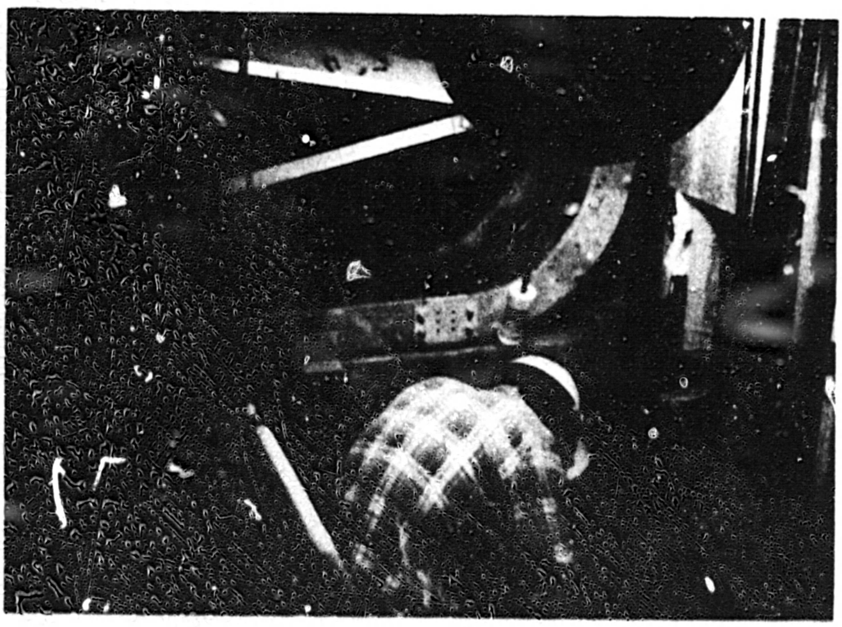


Figure 9. Containment Penetration Exit - Watts Bar.

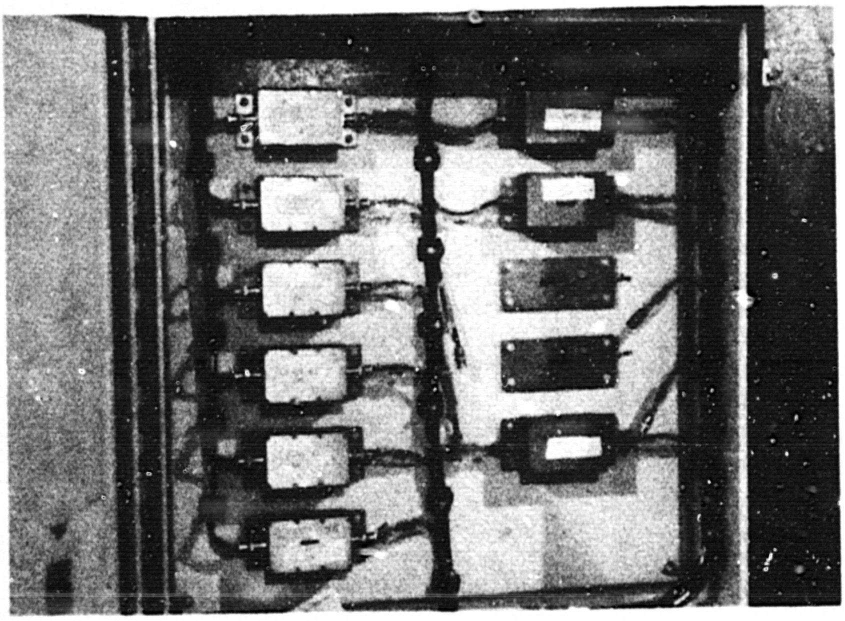


Figure 10. Midamplifiers Located Outside Containment - Watts Bar, Unit 1.

auxiliary instrument room where they terminate at three instrument racks installed to receive permanent AE monitoring instrumentation.

3.3 MONITORING INSTRUMENTATION

Instrumentation planned for long term AE monitoring at Watts Bar is not yet completed. In lieu of this, transportable laboratory equipment was shipped to the site for the duration of hot functional test monitoring. A Dunegan/Endevco Model 1032/D data acquisition system was used to receive and analyze analog information. In addition, arrangements were made to use a waveform recorder developed under a Naval Air Development Center program to record waveforms of acoustic signals produced in the course of the test.

The Dunegan/Endevco 1032/D data acquisition system which receives the output from the sensor assemblies is microprocessor controlled. Acoustic emission events are detected and characterized by signal processing circuit boards. The resulting data are displayed and also stored on floppy disks to be accessed for post-test analysis. A more detailed description of the Dunegan/Endevco 1032/D data acquisition system is presented in Appendix I.

The waveform recorder is a system developed at PNL to meet a need for accurate digitizing and recording of acoustic waveforms together with other related parametric information. The system is centered around a microprocessor and stores the digitized information on tape for retrieval and analysis. The purpose in applying this instrument during hot functional testing was to record the waveform of signals detected for processing by pattern recognition methods. Pattern recognition is a process being developed to help isolate AE signals produced by crack growth from other unimportant acoustic signals. Analysis of waveforms collected from an actual reactor structure during testing/operation is essential to refining the pattern recognition process. A more specific description of the waveform recorder instrument is given in Appendix II.

It is important to recognize that the AE system used is a "breadboard" system assembled to test the monitoring functions developed under the NRC program. As such, it does not represent the optimized data handling procedure. An engineering prototype system is being fabricated which will incorporate the finalized methodology.

4.0 TEST CONDITIONS

Hot functional testing is the last major reactor system preservice functional test scheduled prior to fuel loading. It has all of the elements of reactor operation present except for the fuel load. Hot functional testing thus offers an excellent opportunity to evaluate performance of a surveillance system such as the AE monitor system. In this instance, the evaluation was designed to consider the ability of the AE system to cope with the reactor environment and also to detect AE from crack growth produced by a fracture specimen installed on the 10 inch safety injection line.

The hot functional test is in process for about six weeks. Description of the total test does not serve a useful purpose in this report. The portion of the test during which AE testing was actively performed is described in Figure 11 in the context relevant to AE system evaluation. AE testing was performed continuously during the coolant temperature/pressure increase from 150°F, 400 psig to 557°F, 2235 psig over the period July 2-12, 1983. The AE system was then left on standby until July 30-August 1, 1983 at which time the system was again activated to determine if system response was still consistent with the initial results at 557°F, 2235 psig reactor coolant conditions.

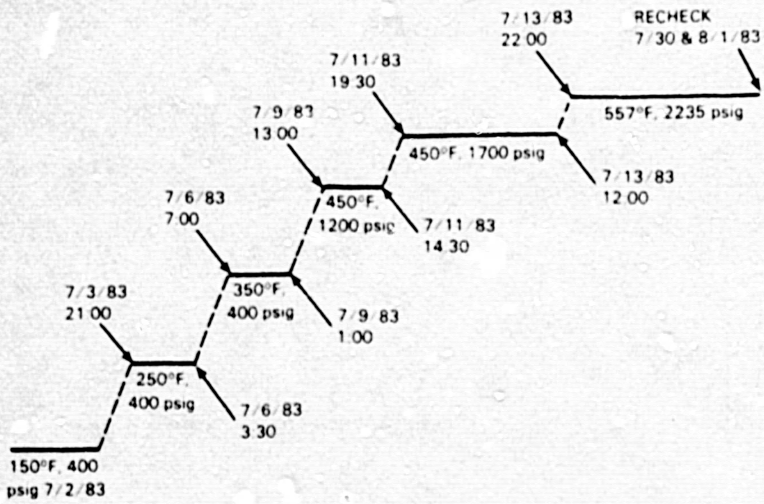


Figure 11. Hot Functional Test Sequence Relevant to AE Monitoring - Watts Bar, Unit 1.

In order to test the capability of the AE system to detect AE during simulated reactor operational conditions, a fracture specimen (Figure 12) was pressure coupled to the 10 inch safety injection line within the AE sensor array shown in Figure 6. The specimen was fabricated from tool steel, precracked, and heat treated to produce a very low toughness material. It was loaded mechanically before installation and then secured to the pipe with stainless steel bands. Crack growth was produced by thermal expansion of the brass pin insert. Two such specimens were tested.

5.0 TEST RESULTS

The results obtained from AE monitoring hot functional testing are very significant to the objective of continuous AE monitoring. Reactor system temperature and coolant flow noise during hot functional should be similar to that during reactor operation. Under these conditions, we were able to demonstrate the following major items:

1. Coolant flow noise can be overcome as a problem to monitoring.

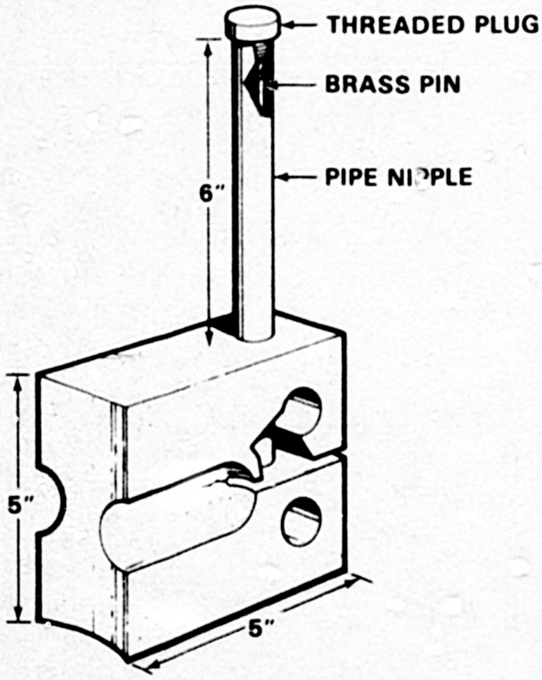


Figure 12. Fracture Specimen - Watts Bar, Unit 1.

2. AE signals from a fracture specimen could be detected under operating conditions.

3. Spontaneous acoustic information was detected and located on the No. 2 inlet nozzle.

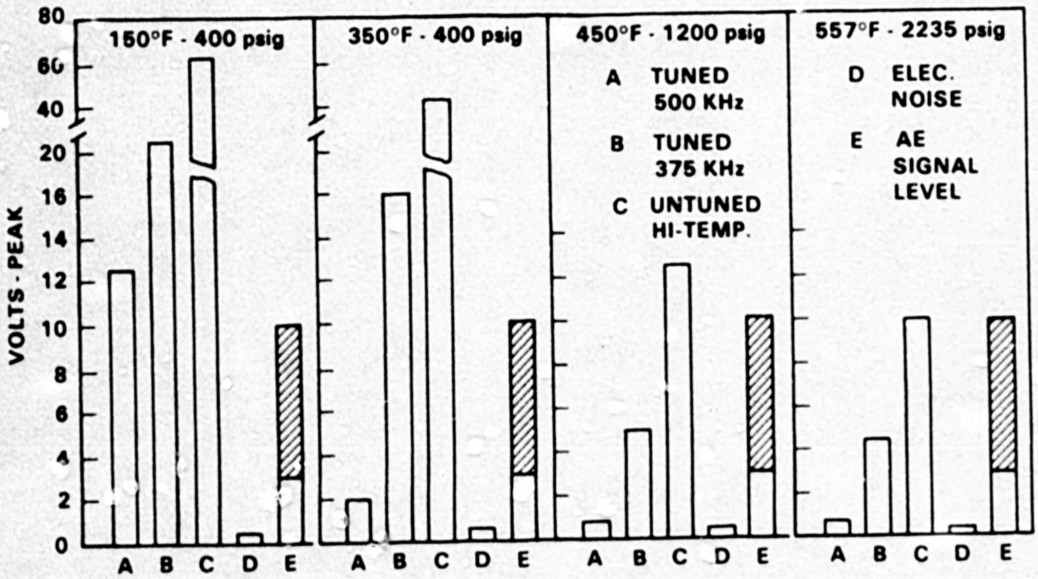
4. Sensors and preamplifiers were not adversely affected by the exposure to the high temperature environment.

5.1 COOLANT FLOW NOISE

Interference from coolant flow noise has been one of the major concerns relative to the validity of detecting flaw growth by continuous AE monitoring in a reactor environment. Work was done much earlier to characterize coolant flow noise from both BWR's and PWR's.[4,5] It appeared from these investigations that the noise problem was manageable. Subsequent work done by J.W. McElroy and W.F. Hartman at Philadelphia Electric Company's Peach Bottom, Unit 3 reactor[6,7] shows experimental evidence that the flow noise problem can be overcome using high frequency (400-500 kHz) sensors.

Hot functional testing at Watts Bar Unit 1 has shown conclusive evidence that the flow noise is manageable at operating conditions from an AE standpoint and also provides an indication of where in a start-up sequence one might expect to start effective monitoring. The flow noise conditions at the locations monitored represent a maximum. The noise will be less severe at points in the coolant system more remote from the pumps. In some instances, valve leakage has been successfully monitored with accelerometers responding below 100 kHz.[8]

Referring to Figure 13, the detected noise from coolant flow as a function of temperature/pressure and sensor type is



NOTES: 1) INFORMATION BASED ON 90 dB ELECTRONIC AMPLIFICATION

2) AE SIGNAL LEVEL COMES FROM VALUES MEASURED DURING FATIGUE CRACK GROWTH IN AN INTERMEDIATE VESSEL USING TUNED WAVE GUIDE SENSORS.

Figure 13. Coolant Flow Noise Vs. Temperature and Pressure as a Function of Sensor Type - Watts Bar, Unit 1.

shown in relation to measured AE signal levels. It is important to understand that the AE signal level range shown was measured from fatigue crack growth with tuned AE sensors on an intermediate scale vessel test which PNL recently monitored in West Germany. The material was five inch thick A533B steel, the sensors were similar to those used at Watts Bar, and test conditions simulated reactor operating conditions. On this basis, it is considered legitimate to use those levels as a reference here.

Noise level values were derived from measurements of the background noise level at the output of the mid-amps using an oscilloscope. At this point, all waveguide sensor channels had

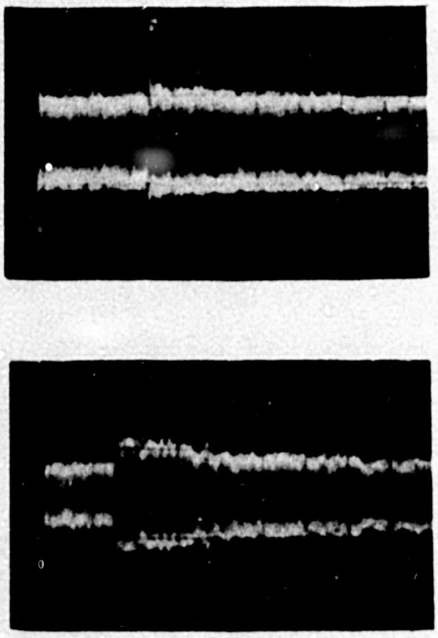
40 dB linear gain and the Westinghouse sensor channels had 60 dB linear gain. The results were then scaled up to a 90 dB gain to relate more closely to an AE monitoring system. Details are provided in Appendix III.

Figure 13 shows that the noise conditions at 150°F and 400 psig make detection of AE highly improbable even with 500 kHz tuned sensors under those conditions. As the coolant temperature and pressure increase, however, conditions improve rather dramatically. The temperature increase appears to produce a major portion of the change as illustrated by the increase to 350°F - 400 psig. At this point, the 500 kHz tuned sensors begin to become effective for AE detection with an average signal-to-noise ratio of about 3.

As the temperature and pressure increase to 450°F - 1200 psig and above, the coolant flow noise detected by the 500 kHz sensor drops to less than one volt which should make it quite effective for AE detection. The 375 kHz tuned sensor still shows an appreciable noise level (4-1/2 to 5 volts) but could be used for AE detection. The untuned high temperature sensor appears to be very marginal for AE detection in its present form. It appears that the effectiveness of this sensor could be improved by tuning to curtail low frequency response.

Considering the sensor response characteristics (Figure 3) and the data in Figure 13, the results indicate that the sensor peak response needs to be in the 400 to 500 kHz range with tuning to discriminate heavily (15-20 dB/100 kHz roll-off) against lower frequencies to control coolant flow noise. This is consistent with information gathered by J.W. McElroy in his recent report on AE monitoring(7) where he indicates 400 kHz as the low end of the monitoring frequency range. His later suggestion in that report that monitoring as low as 100 kHz may be feasible would be applicable to locations in the coolant system much more remote from the pumps.

One rather obvious question to ask concerning the reduction in detected coolant flow noise with increasing temperature and pressure is whether the sensor is simply loosing coupling due to thermal expansion of the mounting bands. This possibility was tested periodically using an ultrasonic pulser to introduce acoustic signals into the structure. This pulser was fixed in place to minimize variation in the pulser input. One example of the results of this testing is shown in Figure 14. This is a 375 kHz tuned sensor on the accumulator line. At 350°F - 400 psig, the pulser signal is barely visible one and a half divisions left of center. In the photo at 450°F - 1200 psig, the ambient noise leading up to the signal is substantially reduced but the pulser signal peak amplitude is identical in both cases showing that the



350°F-400 psig

OUTPUT FROM A LOG. AMPLIFIER
SCALE-BOTH PHOTOS
VERTICAL: 1 VOLT/DIVISION
HORIZONTAL: 0.5 m sec/DIVISION

450°F-1200 psig

Figure 14. Detection of Pulser Signal by Tuned 375 kHz AE Sensor - Watts Bar, Unit 1.

sensor sensitivity has not changed. The reduction in ambient noise appears different in these photos compared to what is shown in Figure 13 for that type of sensor. The reason is that Figure 13 is a linear comparison while Figure 14 is the output from a logarithmic amplifier.

Another point to consider relative to sensors is the AE detection range. Relating to the intermediate scale vessel test in West Germany described earlier provides a gauge of this critical parameter. The AE signal levels from fatigue crack growth shown in Figure 13 were detected with a tuned waveguide sensor array pressure coupled to the vessel surface similar to those at Watts Bar Unit 1. The most distant sensor in the array was about 10 feet from the source which indicates a detection range of at least that distance. The test environment included glass fiber blanket insulation on the vessel surface and a vessel temperature of 550°F. Other less direct investigation of this issue performed on a reactor vessel at the Washington Public Power Supply System Unit 4 at the Hanford, Washington site supports these results. The purpose of that work was to test detection of simulated AE signals originating at the vessel belt-line. Referring to Figure 15, sensors were located on the vessel in positions that can be reached on an installed vessel. The sensors used were tuned to about 400 kHz peak response and were surface mounted using an acoustic couplant. A simulated AE

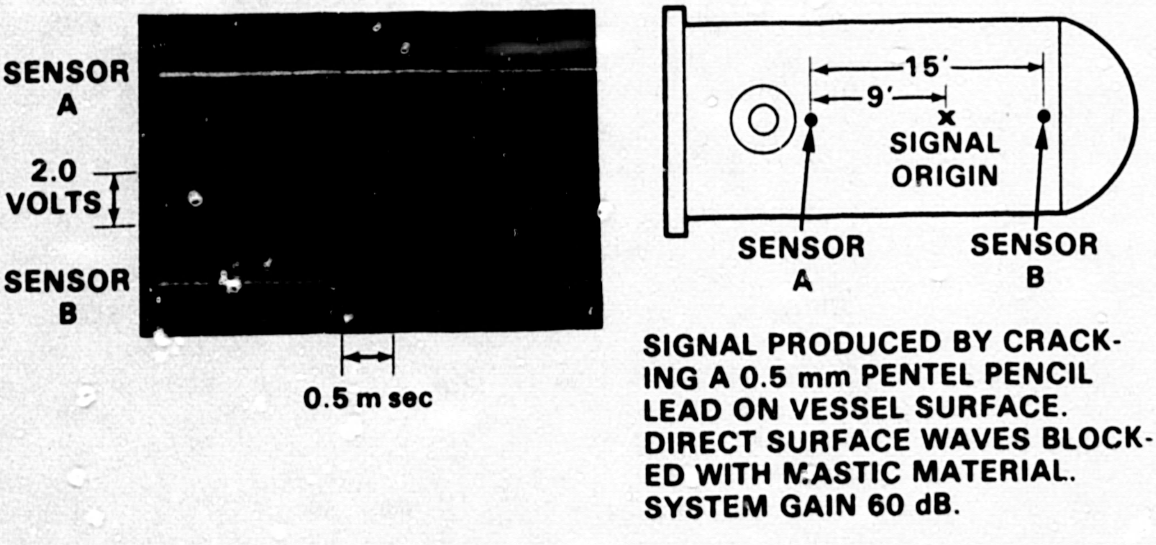


Figure 15. Detection of AE Signals from Reactor Vessel Belt Line - B&W PWR Vessel, WPPSS Unit 4.

signal was injected on the outer surface of the vessel between the sensors by fracturing a 0.5 mm Pentel pencil lead in contact with the vessel surface. A dam of absorbent mastic around the signal source prevented direct surface wave propagation to the sensors. As shown in Figure 15, these signals were readily detected. This approach of detecting signals reflected from the inside surface of the ferritic shell had to be used because the stainless cladding inside of the vessel proved to be very attenuative of signals generated at the stainless to air surface. Although a simulated AE signal was used and the sensors were surface mounted, this provides another data point which is consistent with the observation on the intermediate scale vessel test in Germany.

Summarizing the coolant flow noise results:

- Even in areas of maximum coolant flow noise, noise interference with detection of AE can be overcome for coolant conditions of 350°, 400 psig and above using sensors tuned to 500 kHz with a lower frequency roll off of 15-20 dB/100 kHz.

- Below 350°F - 400 psig coolant conditions, it appears that AE detection is not feasible even on a localized basis in these areas of highest coolant flow noise due to noise interference.

- In considering a given AE monitoring application on a reactor, characterization of the noise could justify alleviating some of the above constraints.

- Evidence indicates that AE from crack growth should be detectable at a distance of at least 10 feet using pressure coupled 500 kHz tuned waveguide sensors.

5.2 AE SIGNAL DETECTION-FRACTURE SPECIMEN

The fracture specimen described in Section 4.0 and Figure 12 was applied to test detection of AE signals under simulated reactor operating conditions in a maximum coolant flow noise area. The specimen was preloaded to a given value by tightening the threaded plug with a torque wrench. It was then mounted on the 10 inch accumulator pipe within the AE sensor array (Figure 6) while the reactor coolant was at the 557°F, 2235 psig condition. The specimen fracture as a result of thermal expansion of the brass pin insert took place over about a 45 second period as shown in Figure 16. These results are considered significant because they represent detection of actual AE signals in the high background noise using sensors suitable for long term reactor monitoring. These results should be conservative in the sense that the AE signals were required to traverse the pressure coupled specimen-to-pipe interface in order to reach the sensors. Such an intervening interface would not, of course, be present if the cracking were occurring in the pipe wall.

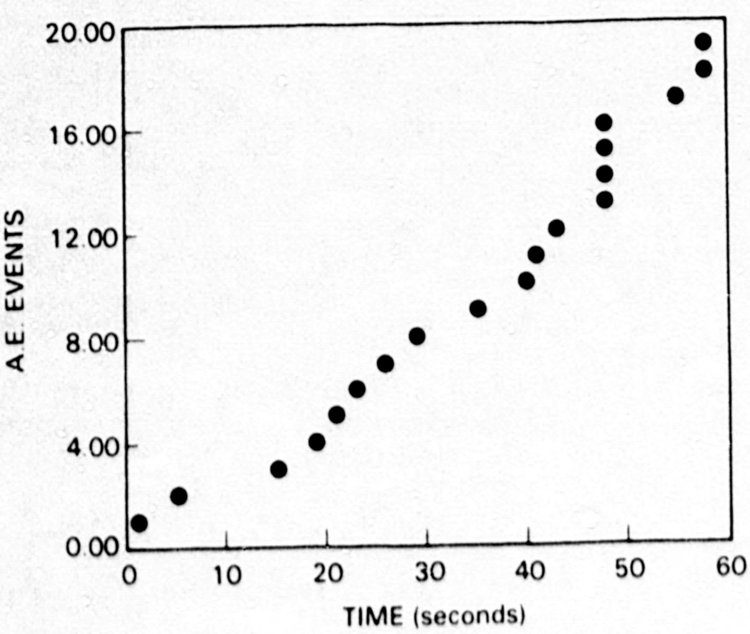


Figure 16. Data from Fracture Specimen - Watts Bar, Unit 1.

5.3 SPONTANEOUS AE DETECTED

During the final increase in reactor coolant temperature/ pressure (450°F/1700 psig to 557°F/2235 psig), 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 17). 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 indication identified in the nozzle-to-vessel weld during earlier inspection (page 25 of Reference 3).

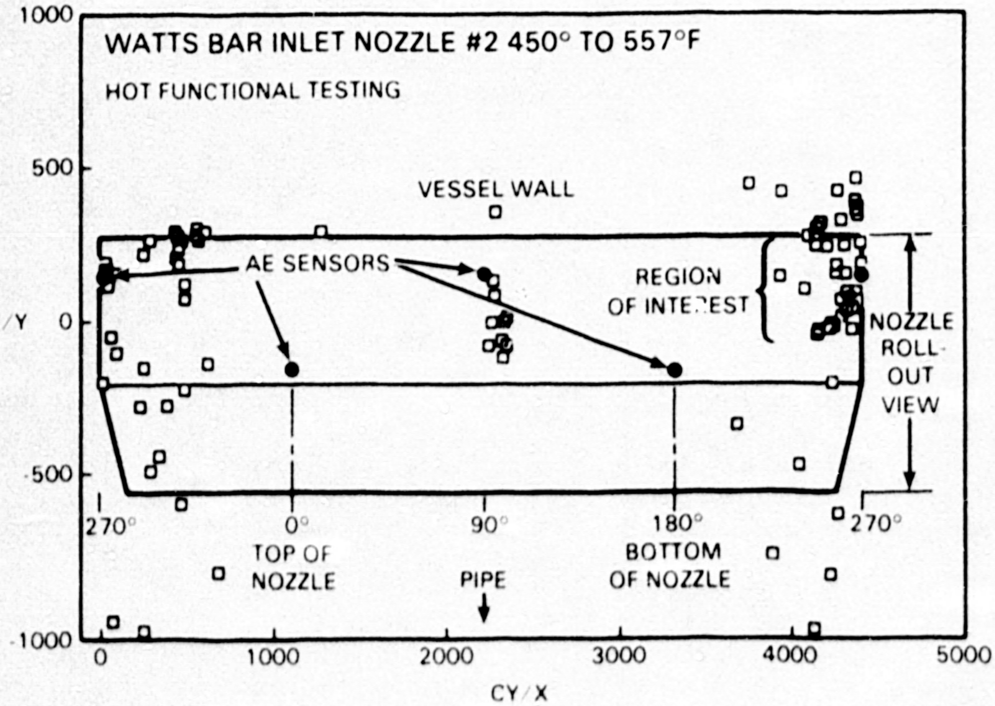


Figure 17. Acoustic Data Detected on No. 2 Inlet Nozzle During Final Pressure/Temperature Increase - Hot Functional - Watts Bar, Unit 1.

The cluster is comprised of about 400 signals which were rather evenly distributed over the final step. Figure 18 shows the accumulation of acoustic data from the No. 2 inlet nozzle and the coolant pressure/temperature conditions over the region of the test from 350°F/400 psig to 557°F/2235 psig. (Below 350°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. It is also interesting to note that the acoustic data appears to be influenced by temperature change as well as the pressure change. As illustrated in Figures 19 and 20, the clustered signals appear to be somewhat unique within the total acoustic data from the No. 2 inlet nozzle. The peak 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 19). 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 20).

These results have been discussed with cognizant TVA and NRC staff. TVA is working with PNL to better understand the significance of the AE indication. Continued AE monitoring of the No. 2 inl nozzle during initial reactor operation is planned as part of the NRC-sponsored AE program.

In addition to determining parametric features of the data collected (event count, amplitude, duration, etc.), digitized replicas of the signal waveforms were recorded. These are being used in work to refine a pattern recognition technique for identifying flaw generated AE signals in the midst of noise signals. This is discussed in Section 5.4.

5.4 ANALYSIS OF ACOUSTIC WAVEFORMS

One of the specific objectives of the NRC-sponsored AE program is to develop a method for distinguishing crack growth AE signals from other irrelevant acoustic signals. This becomes a very key element in the total approach being developed. It is a necessary supplement to AE source location in order to provide an accurate measure of the number of crack growth AE signals originating from a given location which is then used to estimate flaw severity. The approach selected for accomplishing AE signal identification is a pattern recognition analysis of the individual signal waveforms.

The pattern recognition approach goes on the assumption that each waveform contains information uniquely identifying the source process. Simple parameters such as signal rise time, energy, duration, and peak time, as well as more complex parameters such as statistics describing the frequency or power distribution, autoregressive parameters, etc., are examined for identifying characteristics. Earlier work in pattern recognition focused primarily on signal rise time, kurtosis, and other

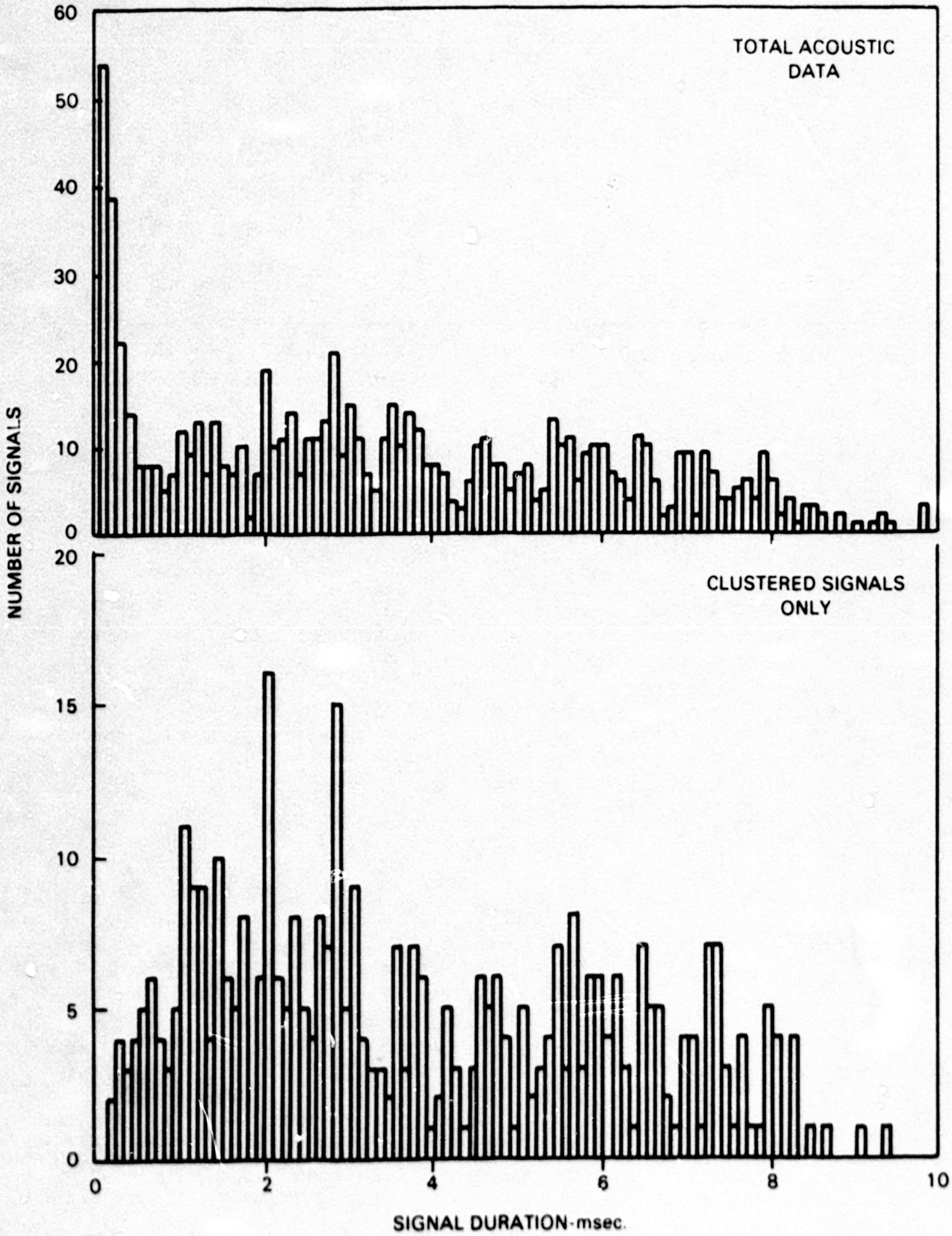


Figure 19. Duration of Clustered AE Signals Compared to that of Total Acoustic Data, No. 2 Inlet Nozzle - Watts Bar Unit 1.

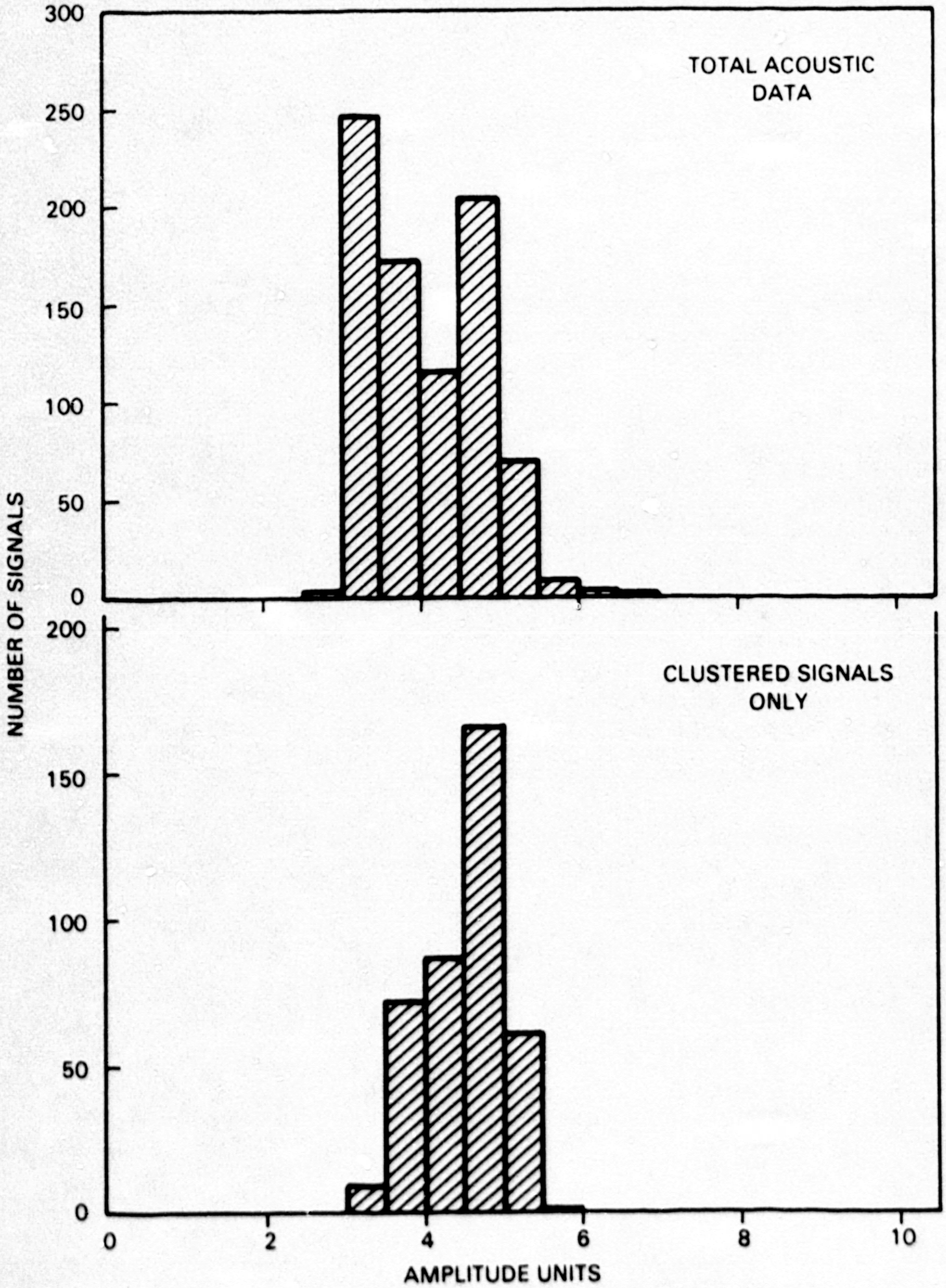


Figure 20. Amplitude of Clustered AE Signals Compared to that of Total Acoustic Data, No. 2 Inlet Nozzle - Watts Bar Unit 1.

statistical means, but unforeseen difficulties have made these features generally unsuitable, although still useful under controlled conditions. Autoregressive filters also appeared promising. Features derived from test sets achieved about 85% correct classification when applied to a new set of data from another controlled experiment. The results of the controlled experiment were considered good enough to justify testing autoregressive filters for classification of waveforms from field tests (intermediate scale vessel test and Watts Bar).

Acoustic signals from the intermediate scale vessel test selected on the basis of source location, amplitude, and load position were used as a training set to determine the features forming the classification categories. Although the categories were not as distinctly separated as one would prefer, this set of features was applied to the Watts Bar data from the No. 2 inlet nozzle. The cluster of data located near the root of a nozzle at about 270° was classified totally as crack related. In contrast, only about 33% of the waveforms from other locations on the nozzle were classified as crack related. The initial significance of these results lies in the fact that the pattern recognition algorithm is making a selective determination of waveform category and the determination appears to be logical. This information is not intended in the context of a conclusive determination but rather a test of pattern recognition using acoustic data from a reactor. We expect to obtain information from follow-up inspection of the No. 2 inlet nozzle which will reflect on the credibility of the pattern recognition determination and help in refining the technique.

Our concerns with using autoregressive filtering as a means of AE signal recogniton is with the difficulty in obtaining adequate calibration information; not with the fundamental feasibility. Work is continuing on an alternate approach which may circumvent some of the problems.

5.5 INSTRUMENT SYSTEM

Permanently installed cabling is now in place between the selected AE monitoring locations and the auxiliary instrument room. The cabling terminates in the instrument room in three installed cabinets designed to accommodate a prototypic AE monitor system. Thus, this portion of the required facilities for AE monitoring during reactor operation is now in place.

Some reassurance of the ability of the sensor-microamplifier units to withstand the reactor environment was gained. The units were in place through about six weeks of exposure to reactor operating temperature (550°F) without any evident deterioration. This result is further supported by the intermediate scale vessel test where similar sensors survived about six months of exposure to a simulated reactor environment of 550°F. Obviously, they were not exposed to nuclear radiation which is the other environmental element of major significance. Radiation resistance is currently being evaluated to determine if it will be necessary to shield the sensor-microamplifier during reactor operation.

6.0 CONCLUSIONS

AE monitoring during hot functional testing at Watts Bar Unit 1 provided results of major significance relative to continuous AE monitoring for detection of growing flaws. Interference from coolant flow noise has been one of the primary obstacles cited in arguments discounting the feasibility of continuous AE monitoring of reactors. The work at Watts Bar demonstrated that this problem can be effectively overcome.

Mounting of AE sensors to meet the reactor constraints and still be sensitive to AE signals has been a concern. The pressure coupled waveguide sensors are acceptable to reactor constraints on invasion of the primary pressure boundaries and they demonstrated sensitivity to AE signals.

The ability of the AE sensors and preamplifiers to withstand the reactor environment is still another question. Experience at Watts Bar and on the intermediate scale vessel test provides evidence that the waveguide sensor-microamplifier units can be used to monitor a 550°F insulated surface for an extended period without deteriorating.

In summary, we feel that the results described in this report demonstrate the feasibility of continuous AE monitoring to detect growing flaws in reactor pressure boundaries.

REFERENCES

1. P.H. Hutton, E.B. Schwenk, R.J. Kurtz, April 1979, Estimate of Feasibility to Develop Acoustic Emission-Flaw Relationships for Inservice Monitoring of Nuclear Pressure Vessels, NUREG/CR-0800, Pacific Northwest Laboratory, Richland, WA.

2. P.H. Hutton, R.J. Kurtz, June 1980, Reactor Safety Research Programs, Quarterly Report October-December, 1979, pg. 73-96, NUREG/CR-1349, Pacific Northwest Laboratory, Richland, WA.

3. P.H. Hutton, T.T. Taylor, et al., June 1982, Acoustic Emission Monitoring of ASME Section III Hydrostatic Test, Watts Bar Unit 1 Nuclear Reactor, NUREG/CR-2880, Pacific Northwest Laboratory, Richland, WA.

4. P.H. Hutton, Battelle Pacific Northwest Laboratory, January 7, 1972, "Summary Report on Investigation of Background Noise at the San Onofre Nuclear Power Reactor as Related to Structural Flaw Detection by Acoustic Emission," July 1971, in In-Service Inspection Program for Nuclear Reactor Vessels, Southwest Research Institute Project 17-2440, Biannual Progress Report No. 6, Vol. I, Projects I through IV.

5. S.P. Ying, J.E. Knight, and C.C. Scott, 1973, "Background Noise for Acoustic Emission in a Boiling Water and a Pressurized Water Nuclear-Power Reactor," The Journal of the Acoustical Society of America, 53 (6).

6. W.F. Hartman and J.W. McElroy, January 1979, Acoustic Emission Surveillance of Boiling Water Reactor Piping, Nozzles, and Valves, American Society for Testing and Materials Special Technical Publication 697.

7. J.W. McElroy, June 7, 1982, Topical Report - Acoustic Emission Crack Detection Methods for Light Water Reactor Application, DOE Report C00-35208-4, Philadelphia Electric Co., Philadelphia, PA.

8. J.W. McElroy, August 23, 1982, Topical Report - Acoustic Emission Leak Detection Methods for Light Water Reactor Application, DOE Report C00-35208-3, Philadelphia Electric Co., Philadelphia, PA.

APPENDIX I

EGAN/ENDEVCO 1032D DATA ACQUISITION SYSTEM DESCRIPTION

PURPOSE OF EQUIPMENT

The Acoustic Emission Data Acquisition System is a multichannel system which can be used as a real-time system or as a stand alone unit for monitoring of acoustic emission activity for structural integrity assessment. This microprocessor based system, which may include up to 32 separate monitoring channels, can be used to gather acoustic emission information for evaluation during real-time operation. Recorded data can then be analyzed using a 1032D system wherever located. In this way, the analysis capabilities of the 1032D can be used to present recorded data. In addition to source location (planar, linear, cylindrical and spherical), the event attributes of amplitude, rise time, counts, and pulse duration may be used to provide plots of: time history, distribution functions, and correlations with external parameters or one of the other attributes. Filter parameters (windows) can also be set with the 1032D system for further characterization of the source data.

EQUIPMENT DESCRIPTION

The Acoustic Emission Data Acquisition used at Watts Bar was configured as follows (see Figure I-1 for system block diagram):

1. D/E Model 6001 data acquisition system controller and interface.

2. D/E Model 6002 dual signal processor boards.

3. D/E Model 1111 system power supply.

4. Video terminal.

5. Model 74 Interdata computer.

The entire system, except for the video terminal and amplifiers, is housed in two 19-inch rack cabinets with casters. The major hardware items in a standard acoustic emission data acquisition system, and optional equipment, are discussed briefly in subsequent paragraphs.

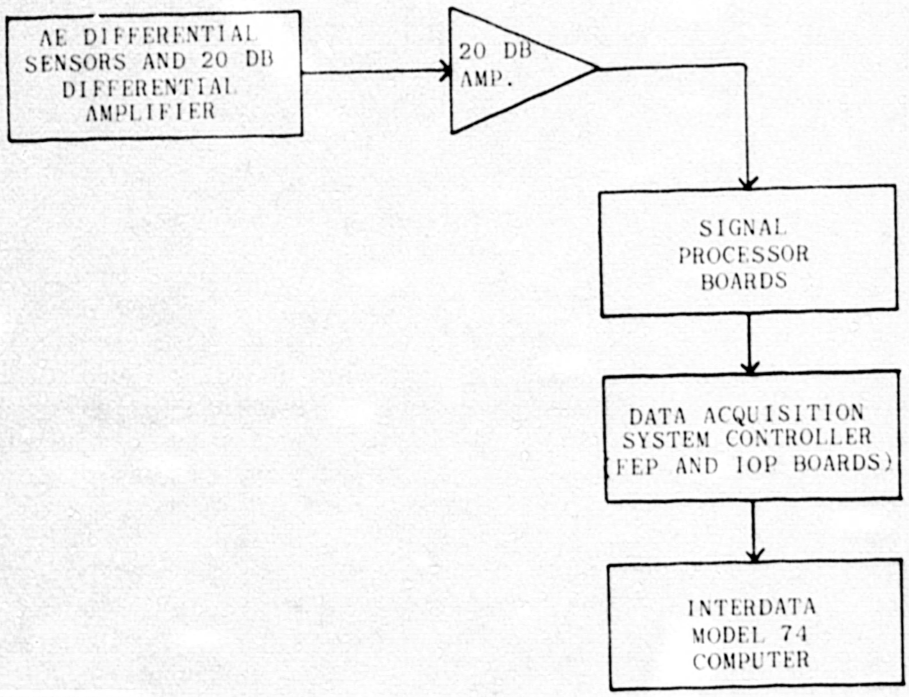


Figure I-1. System Block Diagram.

Data Acquisition System Controller and Interface

The Model 6001 data acquisition system controller and interface (DASCI) unit is an assembly with slots for 20 circuit boards (cards) and motherboard with connectors for interconnecting the circuit boards. One spare slot is allocated for extender board storage. The left most sixteen circuit board slots are reserved for signal processor (SP) circuit boards. Each signal processor board provides signal conditioning for two channels, permitting a total of 32 channels of signal processing in each data acquisition system controller and interface. If less than the full complement of 16 signal processor boards are used, the boards occupy the rightmost available slots, 16, 15, 14, ..., etc.

A front end processor (FEP) circuit board plugs into the 17th slot. The board has a full-function microprocessor which is dedicated to operating the sixteen signal processor boards and controlling event data transmission to the input/output processor board.

The input/output processor (IOP) board in slot 19, like the FEP board, is also microprocessor based. This board has primary functions associated with acquiring real-time event data from the FEP and from its own analog-to-digital inputs, buffering up to 500 incoming events, and providing formatted output to the Model 74 minicomputer with interactive control.

Power Supply

A power supply for the data acquisition system controller and interface is housed in a rack mounted assembly. This supply can be connected to either 115 VAC 50 Hz or 60 Hz power as specified. (Systems adapted, at the factory, to operate from a 200 VAC 50/60 CPS source, transform the higher voltage down to the 115 VAC range.) The output voltages and control signals are connected to the data acquisition system controller and interfaces chasses.

The unit uses a Pioneer Magnetics PM267A-1-4 switching power supply which provides up to 600 watts of dc output in multiple voltages. The outputs are:

+5 volts	40 amperes
+15 volts	10 amperes
-15 volts	10 amperes
+28 volts	3 amperes

NOTE: The ampere ratings are maximum for each channel. The power supply cannot have all channels operating simultaneously at full maximum.

Noise isolation of the switching portion of the power supply is provided by a heavy EMI filter which prevents switching regulator noise from being coupled out to the main power lines. This filter also serves to filter out incoming noise on the main power lines, effectively isolating the data acquisition system controller and interface from line noise.

DATA ACQUISITION

Data acquisition is performed by the data acquisition system controller and interface. It measures all data of interest relating to each acoustic emission event, stores the information temporarily in a buffer memory, and then outputs it in proper format to the permanent storage medium. For each event on each channel, the following signal attributes are measured: (1) counts; (2) peak amplitude; (3) average signal level; (4) duration; and (5) rise time.

NOTE: Relative time measurements of first threshold crossing (FTC), peak,, and end of event (EOE) are made and later processed in the FEP and IOP boards to give delta-T's (based on FTC or peaks), rise time, and duration.

The time of occurrence of the event was determined from the time of first threshold crossing (FTC).

The data acquisition system controller and interface allows selection of a fixed or automatic threshold for event signal detection on a per-channel basis. The automatic threshold was used with the threshold set at 0.25 volts above background.

APPENDIX II

ACOUSTIC WAVEFORM RECORDING SYSTEM

The need for which this instrument was developed was accurate digitizing and recording of AE and noise signal waveforms together with other related parametric information. No commercial instrument could be identified which was capable of performing the required function; therefore, a development/fabrication effort was performed to meet the need.

The AE Waveform Recording System, which grew out of the development effort, is a two-channel multi-purpose instrument for recording acoustic waveform data. The system provides a means for simultaneous recording of two waveforms in addition to the measuring and recording of other experimental parameters.

The instrument system concept chosen for this program is shown in Figure II-1. The data acquisition concept is centered around a high performance 8-bit microprocessor (Zilog Z-80). An industry standard bus system (known as STD) is used to implement the microprocessor system. Two Biomation 1010 transient analyzers are used to digitize the AE waveforms. Each waveform is characterized by 4096 digital words with each word having 10-bit resolution (1 part in 1024). Each digital word comprises a time sample of the analog waveform. A typical sampling rate is 5 MHz or 1 sample every two-tenths of a microsecond. A single microprocessor, rather than two, was chosen to extract the digital data from the Biomations. This was based upon information from a similar instrument system that showed that over 92% of the acquisition/record time was spent in writing to the digital tape deck. Actual acquisition of the waveform took only 3%. The remaining 5% was for acquiring miscellaneous header data (i.e., load position, cycle count, etc.).

A video terminal keyboard communicates with a Z-80 STD bussed microprocessor system that is mounted in the rear of the chassis. The microprocessor contains the operating system which, through prompts on the CRT, communicates with the operator for instrument setup and control of the test. In addition to containing the operating system, the Z-80 handles: (1) interfacing of the digitized data to the tape deck, and (2) acquisition of various external digital data (counters, etc.) and analog parameters (gauges, etc.). Each waveform written to tape has a header amended to it which contains test particulars keyed into the system plus acquired external data. The 9-track tape deck can store approximately 1,080 waveforms which include headers. A slave microprocessor (8085) handles displaying of the acquired external data on the CRT in near real-time.

Continuous waveform acquisition and recording speed is 1.5 signals/second. This is accomplished by using a DMA (direct memory access) process for inputting digitized waveform data into Z-80 memory where waveforms are stacked up and passed to the 9-track tape at a slower rate. The system has two banks of 40K bytes of buffer memory which can store five waveforms. When the buffer is full, it can only be emptied by transferring to tape and not by flushing due to additional incoming signals.

Three sensors are used with two of them (A and B) performing the zone isolation (spatial filtering). This provides an isolation zone which has both a floating position and variable width. Control of the zone is by front panel settings. When a signal originates within the zone, a digital command from the zone isolator (denoted as "VALID") simultaneously triggers both Biomations. This will, after a time delay which is adjustable from the front panel, stop the Biomations (which are in the pretrigger mode) from continuously recording. The end of record signals the Z-80 microprocessor to start a DMA transfer of the waveform data into system memory. The DMA concept is the fastest mode for accomplishing the transfer since the data goes directly into memory and not through the CPU as it would with a programmed I/O (input/output). When the two DMA's are complete, the Z-80 initiates a sequence of I/O transfers for acquiring the AE parameter data set. This set consists of:

- 7 load analysis parameters
- peak time and pulse height
- duration (16-bit capacity)
- flag registers
- total and valid counts (16-bit capacity)
- clock time (1 second resolution, 32-bit capacity)
- 8 analog parametrics with 8 bit resolution.

A vital attribute of the system is contained in the load analysis function. For a periodic mechanical load, the waveform is subdivided into 100 parts. When an acoustic event occurs, the point on the load waveform corresponding in time is recorded. The location on the load waveform at which an acoustic signal occurs has proven to be a valuable tool to identify the source mechanism producing the acoustic signal in a controlled laboratory test. The maximum and minimum load, load value, load frequency, and cycle count are also recorded with load position. The instrument is shown in Figure II-2.

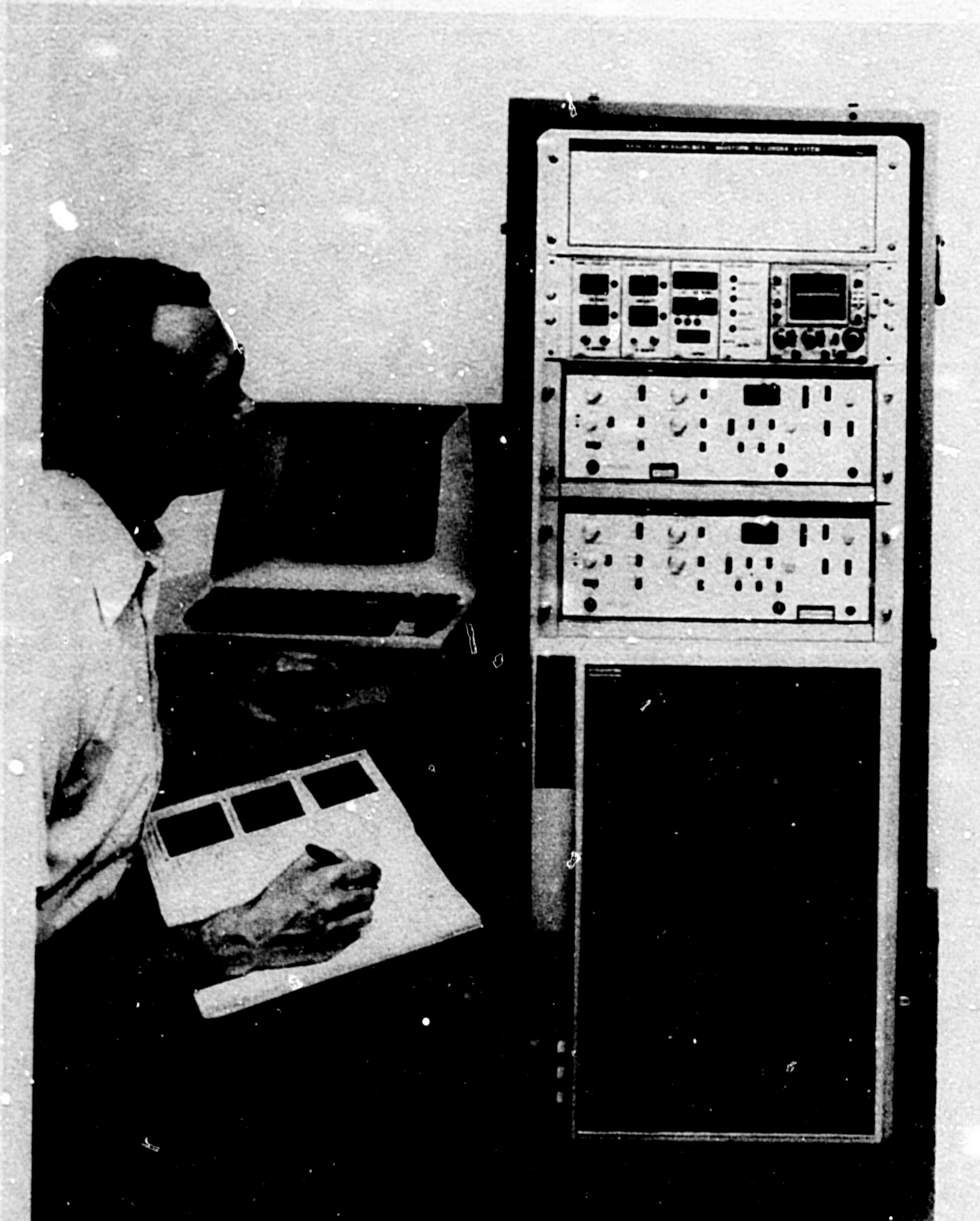


Figure II-2. Acoustic Emission Waveform Recording System.

APPENDIX III

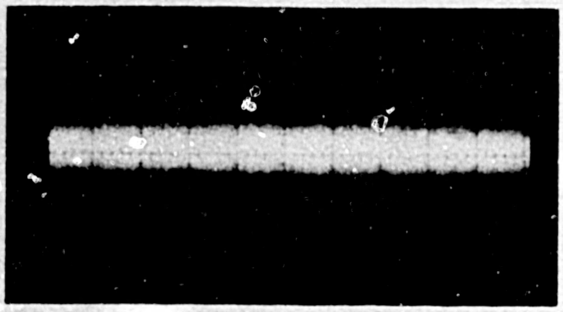
BACKGROUND NOISE LEVEL DETERMINATION AT WATTS BAR UNIT 1 DURING HOT FUNCTIONAL TESTING

The purpose of this appendix is to provide specific information on the procedure used in arriving at a measure of background noise during hot functional testing at Watts Bar Unit 1. In this instance, our interest was in quantifying the response of the AE sensors to noise produced by reactor coolant flow. The design of the sensor frequency response profile was based on noise spectrum measurements made previously (Ref. 4 and 5 Main Report).

The analog signal output at the midamplifier for each sensor channel was measured on an oscilloscope. At this point, all waveguide sensor channels had 40 dB linear electronic gain (amplification) and the Westinghouse sensor channels had 60 dB gain. The results were then normalized to an equivalent at 90 dB gain because this is the nominal gain we normally use into the AE monitor analyzer. Also, the values are given in $\text{volts}_{\text{Peak}}$ rather than $\text{volts}_{\text{Peak to Peak}}$. Thus, the results are more readily related to monitoring parameters such as detection threshold. Although all of the sensor responses were measured and averaged to produce the summary of response to background noise, only one typical sensor from each location is treated in Figure III-1 for simplicity.

The voltage response values are calculated by multiplying the height of the oscilloscope trace by the vertical sensitivity setting, times the dB adjustment to normalize to 90 dB gain and dividing by 2 to arrive at $\text{volts}_{\text{Peak}}$. In the case of the tuned waveguide sensors, the dB adjustment was 50 dB or a multiplication factor of 316.23. For the Westinghouse sensors, it was 30 dB for a multiplication of 31.62.

It appears that with increasing reactor coolant temperature and pressure (primarily temperature), the upper frequency content of the flow noise shifts downward. By examining the response characteristics of the different sensors used as given in Figure 3 of the main report, it appears that minimizing the sensor sensitivity below about 250 kHz is the key to reducing the sensor response to coolant flow noise.

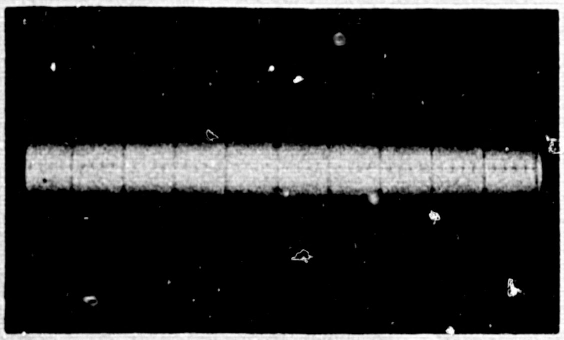


50. mV/div. - vertical

0.5 msec/div. - horizontal

1.5 div. x .05V x 50 dB + 2 =
12Vp @ 90 dB

Reactor Coolant: 150°F, 400 psig

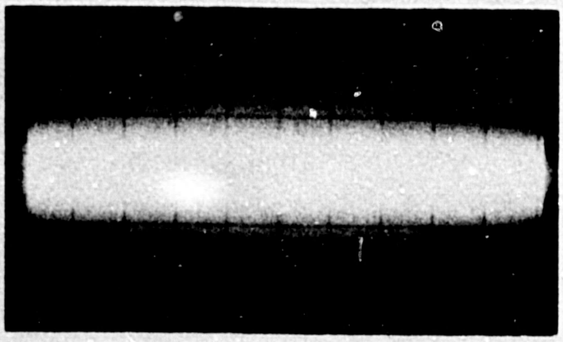


5. mV/div. - vertical

0.5 msec/div. - horizontal

2.0 div. x .005V x 50 dB + 2 =
1.6Vp @ 90 dB

Reactor Coolant: 350°F, 400 psig



2. mV/div. - vertical

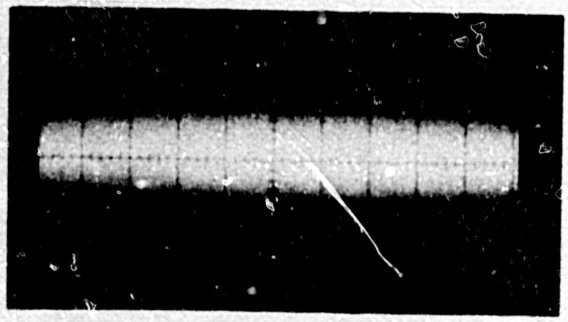
0.5 msec/div. - horizontal

2.2 div. x .002V x 50 dB + 2 =
0.7Vp @ 90 dB

Reactor Coolant: 557°F, 2235 psig

NOTE: Measurements made with 40 dB electronic gain.

Figure III-1a. Response to Reactor Coolant Flow Noise - Sensor IN-1, #2 Inlet Nozzle, Tuned to 500 kHz Peak Response.

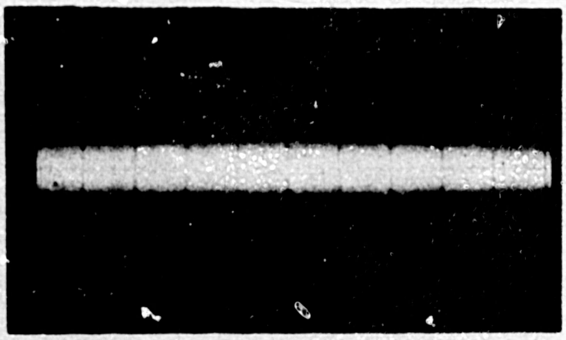


50. mV/div. - vertical

0.5 msec/div. - horizontal

2.8 div. x .05V x 50 dB ÷ 2 =
22V_p @ 90 dB

Reactor Coolant: 150°F, 400 psig

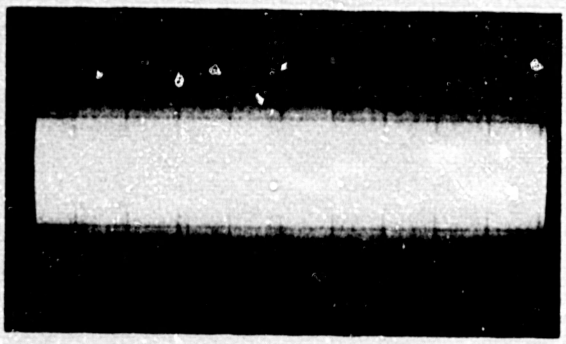


10. mV/div. - vertical

0.5 msec/div. - horizontal

2. div. x .01V x 50 dB ÷ 2 =
3.2V_p @ 90 dB

Reactor Coolant: 350°F, 400 psig



2 mV/div. - vertical

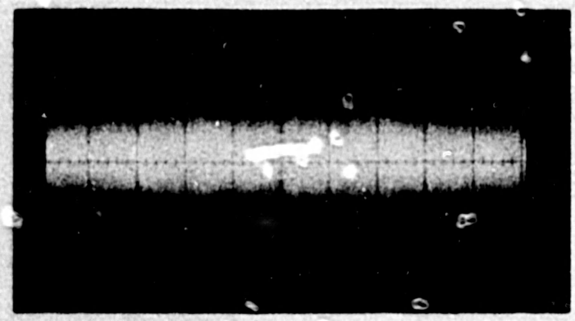
0.5 msec/div. - horizontal

3.4 div. x .002V x 50 dB ÷ 2 =
1.1V_p @ 90 dB

Reactor Coolant: 557°F, 2235 psig

NOTE: Measurements made with 40 dB electronic gain.

Figure III-1b. Response to Reactor Coolant Flow Noise - Sensor IN-5, #2 Inlet Nozzle, Tuned to 500 kHz Peak Response.

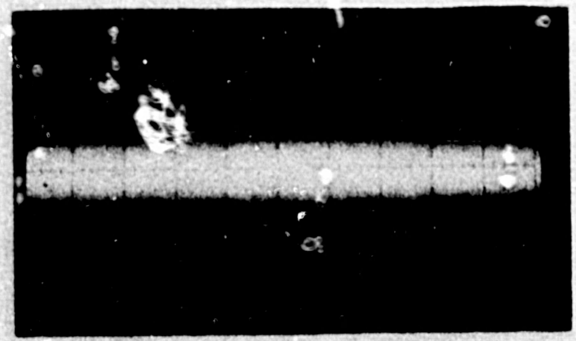


50. mV/div. - vertical

0.5 msec/div. - horizontal

3.2 div. x .05V x 50 dB + 2 = 25Vp @ 90 dB

Reactor Coolant: 150°F, 400 psig

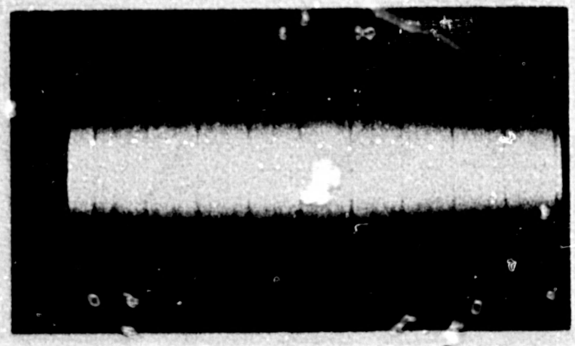


50. mV/div. - vertical

0.5 msec/div. - horizontal

2.0 div. x .05V x 50 dB + 2 = 16Vp @ 90 dB

Reactor Coolant: 350°F, 400 psig



10. mV/div. - vertical

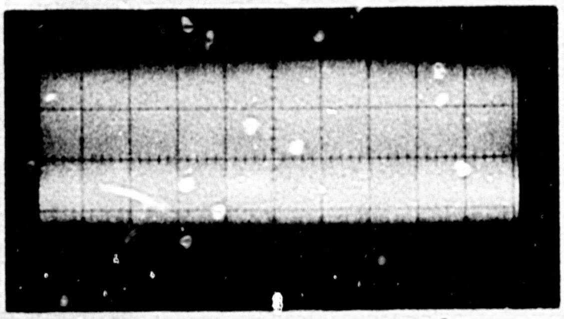
0.5 msec/div. - horizontal

2.6 div. x .01V x 50 dB + 2 = 4.0Vp @ 90 dB

Reactor Coolant: 557°F, 2235 psig

NOTE: Measurements made with 40 dB electronic gain.

Figure III-1c. Response to Reactor Coolant Flow Noise - Sensor AI-1, 10" Accumulator Pipe, Tuned to 375 kHz Peak Response.

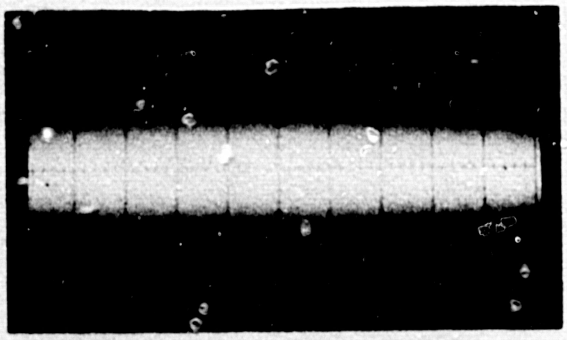


Reactor Coolant: 150°F, 400 psig

1. V/div. - vertical

0.5 msec/div. - horizontal

4.0 div. x 1.V x 30 dB + 2 =
63Vp @ 90 dB

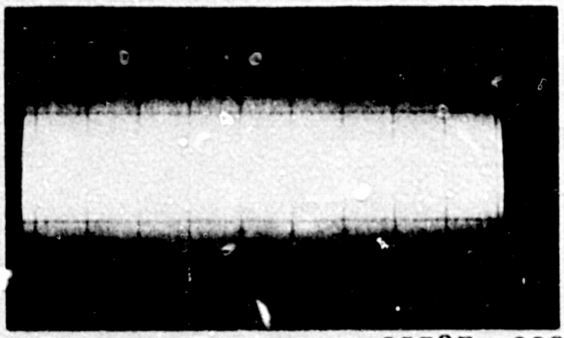


Reactor Coolant: 350°F, 400 psig

1. V/div. - vertical

0.5 msec/div. - horizontal

2.7 div. x 1.V x 30 dB + 2 =
43Vp @ 90 dB



Reactor Coolant: 557°F, 2235 psig

0.2 V/div. - vertical

0.5 msec/div. - horizontal

3.6 div. x .2V x 30 dB + 2 =
11.4Vp @ 90 dB

NOTE: Measurements made with 60 dB electronic gain.

Figure III-1d. Response to Reactor Coolant Flow Noise - Sensor SH-3, Bottom of Vessel, Westinghouse Model WL23842 Sensor

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NRC FORM 335 (2-84) NRCM 1102, 3201, 3202 — U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

SEE INSTRUCTIONS ON THE REVERSE

1. REPORT NUMBER (Assigned by TIDC, add Vol. No., if any)
NUREG/CR-3693
PNL-5022

2. TITLE AND SUBTITLE
Acoustic Emission Monitoring of Hot Functional Testing Watts Bar Unit 1 Nuclear Reactor

3. LEAVE BLANK

4. DATE REPORT COMPLETED
MONTH: May — YEAR: 1984

5. AUTHOR(S)
P.H. Hutton, J.F. Dawson, M.A. Friesel, J.C. Harris, R.A. Pappas

6. DATE REPORT ISSUED
MONTH: June — YEAR: 1984

7. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Pacific Northwest Laboratory
Richland, WA 99352

8. PROJECT/TASK/WORK UNIT NUMBER

9. FIN OR GRANT NUMBER
B2088

10. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Division of Engineering Technology
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555

11a. TYPE OF REPORT
Topical

b. PERIOD COVERED (Inclusive dates)
June - August 1983

12. SUPPLEMENTARY NOTES

13. ABSTRACT (200 words or less)

Acoustic emission (AE) monitoring of selected pressure boundary areas at TVA's Watts Bar Unit 1 Nuclear Power Plant during hot functional preservice testing is described in this report. The report deals with background, methodology, and results. The work discussed here is a major milestone in a program supported by NRC to develop and demonstrate application of AE monitoring for continuous surveillance of reactor pressure boundaries to detect and evaluate growing flaws. The subject work demonstrated that anticipated problem areas can be overcome. Work is continuing toward AE monitoring during reactor operation.

14. DOCUMENT ANALYSIS - a. KEYWORDS/DESCRIPTORS
Acoustic emission monitoring of reactor pressure boundaries for flaw detection.

b. IDENTIFIERS/OPEN ENDED TERMS
acoustic emission, reactor pressure boundaries, continuous monitoring, flaw detection

15. AVAILABILITY STATEMENT
Unlimited

16. SECURITY CLASSIFICATION
(This page) Unclassified
(This report) Unclassified

17. NUMBER OF PAGES

18. PRICE

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

FOURTH CLASS MAIL
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NUREG/CR-3693 ACOUSTIC EMISSION MONITORING OF HOT FUNCTIONAL TESTING JUNE 1984

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