Acoustic Monitoring of Relief Valve Position

EPRI

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EPRI NP-1313
Project 1246-1
Interim Report
February 1980

Prepared by
Technology for Energy Corporation
Knoxville, Tennessee

ELECTRIC POWER RESEARCH INSTITUTE

Acoustic Monitoring of Relief Valve Position

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Research Project 1246-1

Interim Report, February 1980

Prepared by

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NOTICE

Prepared by
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EPRI PERSPECTIVE

PROJECT DESCRIPTION

A contributing factor to the accident at Three Mile Island was the fact that control room operators were unaware that a relief valve (designed to open in the event of excessively high steam pressures) had not shut automatically. The instruments used to monitor the relief valve did not clearly indicate valve position.

One technique for indicating steam flow through a valve is acoustic monitoring. Sensitive acoustic sensors (similar in function to microphones) are attached to the outside of a valve or its nearby piping to monitor noise levels. The noise created by steam flowing through the valve is much greater than the ordinary background noise present when the valve is tightly shut. One of the tasks in Research Project 1246-1 was to evaluate acoustic monitoring of safety and relief valves in nuclear power plants.

PROJECT OBJECTIVE

Prior to the accident, acoustic monitoring had been tested successfully in this project as an aid to maintenance planning for one type of relief valve. The purpose of the tests described in this interim report was to extend the application of acoustic monitoring to other types of safety and relief valves commonly used in light water reactor plants. Data were collected under actual and simulated plant conditions so that instrumentation system designers would know what the acoustic levels would be both during normal operating conditions and when a safety or relief valve was open.

PROJECT RESULTS

Test results show that acoustic monitoring positively indicates that a safety or relief valve is open. The technique is also very sensitive: in one in-plant test the instruments immediately indicated that a relief valve had not shut completely and was leaking.

Results of these tests were presented at an EPRI workshop on August 22, 1979. Since the workshop, several utilities have installed acoustic monitors on safety and relief valves in their nuclear plants. This report documents further the test procedures and results presented at the workshop.

This report will be of interest to instrumentation and licensing engineers in utilities and design organizations, especially to those engineers responsible for implementing plant modifications in response to the "lessons learned" from Three Mile Island. It will also be of interest to government regulators and to manufacturers of acoustic monitoring equipment.

Gordon Shugars, Project Manager
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ABSTRACT

In response to the accident at Three Mile Island Unit 2, EPRI sponsored a series of tests to establish the feasibility of monitoring relief valve positions using acoustic sensors. The sensors respond to noise generated when steam flows through the valve.

Six types of safety and relief valves commonly used in light water reactor plants were instrumented and actuated under simulated plant conditions. In addition, background noise was measured in both pressurized water reactor plant and a boiling water reactor plant so that relative signal levels (valve open versus valve shut) could be determined.

Results show that acoustic levels with the relief valves open are from one hundred to one thousand times greater than the levels with the valves shut, depending upon the valve type. Data are presented that will help system designers predict the acoustic levels that will be encountered when a relief valve opens.

ACKNOWLEDGMENTS

Technology for Energy Corporation and EPRI wish to thank the Tennessee Valley Authority for the assistance of its operating staff at the Sequoyah Nuclear Plant, and the Philadelphia Electric Company for its cooperation during the testing described in this report.

W. F. Hartman, TEC
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SUMMARY

A contributing factor to the accident at the Three Mile Island (TMI) nuclear station was that operators were unaware that a relief valve had stuck open. A quick, clear indication that the valve had failed to close automatically would have led to early isolation of the malfunctioning valve, thereby preventing excessive depressurization. This report describes work performed to determine whether an unequivocal indication of valve position can be obtained through acoustic monitoring of steam flow.

Based on the results of earlier tests performed on one type of relief valve, it was known that a piezoelectric acoustic sensing device mounted on the exhaust pipe of a valve measured the noise which was generated by flow through the valve. The detected signals were processed and interpreted using electronic instrumentation which is similar to that used for loose part monitoring, vibration measurement and acoustic emission leak detection. In order to establish the feasibility of using acoustic monitoring for indicating valve actuation in general, acoustic data were collected from one BWR plant, one PWR plant, and during valve testing at three laboratory facilities. Six types of valves were monitored.

Two types of sensors were used in these tests. The first type was an accelerometer that responsed to low-frequency signals (below about 30 kHz). The second was an acoustic emission sensor that responded to high-frequency signals (100-400 kHz). Both types of sensors had proved successful in earlier tests.

The acoustic data were analyzed with a power spectral density (PSD) and fast Fourier transform (FFT) instruments to determine the frequency content of the signals. In addition, the root mean square (RMS) value of the signals were also determined.

The results of the measurements demonstrate that valve actuation produces acoustic levels which are a hundred to a thousand times greater than the acoustic levels present when the valves are closed. Therefore, acoustic monitoring of safety/relief valves clearly indicates valve actuation. The method is already being utilized by many utilities, in responding to the TMI-related plant modifications required by the U.S. Nuclear Regulatory Commission.

Section 1
INTRODUCTION

PROJECT MOTIVATION

A contributing factor to the accident at the Three Mile Island (TMI) nuclear station was that plant operators were unaware that a relief valve had not shut automatically, following the relief of excessively high steam pressures. The pressurizer relief valve, which had stuck open, was similar to valves in other PWR plants which had also experienced excessive plant depressurization caused by the relief valves sticking open. In addition, several incidents have been reported of both pilot-actuated and solenoid-actuated safety/relief valves sticking open in BWR plants.

A method of direct indication of valve actuation is detection of the acoustic noise generated by flow through the valve. Such an indication that a relief valve is open or shut can aid the operator in diagnosing a failure and in taking prompt corrective action. In the case of the TMI accident, a quick reliable indication that a relief valve had failed to close would have led to early isolation of the malfunctioning valve using the remotely-operated block valve.

At the time of the TMI accident, EPRI already had been investigating acoustic monitoring of power plant valves. The overall objective of the program was to improve nuclear power plant availability, productivity and safety through the application of advanced surveillance techniques to power plant valves. The program was studying safety/relief valves for BWRs and feedwater-control valves for PWRs. With respect to safety/relief valves, the project had focused on detecting leakage in typical BWR pilot-operated valves. Following the TMI accident, this task was extended to perform acoustic monitoring during full actuation of typical safety and relief valves used in both BWR and PWR plants. The objective of this additional work was to obtain data that could be used to specify for a given type of relief or safety valve, methods of detecting the acoustic signal levels that can indicate unequivocally whether the valve is open or shut. It was planned to obtain both plant background noise data and valve actuation data.

PROJECT TASKS

Under the existing research project, it was learned that acoustic data obtained with low frequency (below 30 kHz) accelerometers or with high-frequency (100-400 kHz) acoustic emission sensors provided clear indications of flow noise. Therefore, it was planned to use both types of sensors for the tasks described here. The tasks are defined into Background Signal Measurements and Collection of Data for Valve Actuation and Closing.

Background Signal Measurements

The Tennessee Valley Authority (TVA) agreed to cooperate with the project and allowed the installation of sensors on the pressurizer on Unit 1 of the Sequoyah nuclear plant, so that data could be obtained during the hot-functional testing of that nuclear unit. This enabled the recording of background signals which were typical of a PWR pressurizer.

The measurement of background signals in a typical BWR plant was accomplished through the assistance of Philadelphia Electric Company. For several years, accelerometers have been installed on the main steam safety/relief valves at the Peach Bottom nuclear station. The amplified outputs of these accelerometers were recorded for general reference.

Collection of Data for Valve Actuation and Closing

Valves were tested at two valve manufacturing facilities, one independent testing laboratory, and in-place on a pressurizer during hot-functional testing. Acoustic data were recorded for the actuations and closings of each valve. Six valves were monitored during actuation. They were manufactured by Target Rock, Masoneilan, Dresser and Crosby.

Section 2

DATA ACQUISITION

DESCRIPTION OF INSTRUMENTATION

The data acquisition system consisted of a variety of acoustic sensors, preamplifiers, signal amplification and filtering electronics and an instrumentation-grade tape recorder. The sensors, preamplifiers and tape recorder were commercially available units and were not modified for this effort. The signal amplification and filtering equipment was designed and developed by TEC. The following sections describe the data acquisition system in greater detail.

Sensors and Preamplifiers

The sensors used for acoustic monitoring consisted of accelerometers manufactured by Endevco and BBN, and an acoustic emission sensor manufactured by Trodyne. A prototype acoustic emission sensor was also used.

The accelerometer used to measure surface vibrations caused by steam flow utilizes a piezoelectric crystal as the generating element. The charge sensitivity is expressed in units of capacitance (pico coulombs) per unit acceleration (g's). For example, the charge sensitivity of the Endevco 2273AM1 accelerometer is specified as 10.0 pC/g and the BBN 424 accelerometer is specified at 100 pC/g. Other pertinent characteristics for the accelerometers used in support of this effort are listed in Table 2-1. The accelerometers were attached to the discharge line adjacent to the valve using a stainless steel clamp.

Table 2-1

ACCELEROMETER CHARACTERISTICS

	BBN 424	Endevco 2273AM1
Charge Sensitivity	100 pC/g ± 10%	10 pC/g ± 10%
Transverse Sensitivity	5%	1%
Transducer Capacitance	1000 pf ± 10%	660 ± 100 pf
Frequency Response (±3 dB)	.7 Hz - 11 kHz	1 Hz - 12 kHz
Typical Mounted Resonance Frequency	27 kHz	27 kHz ± 3K
Linearity	1%	1%
Maximum Continuous Operating Temperature	550° F	700° F
Weight	100 grams	32 grams
Mounting	1/4-28 STUD	10/32 STUD

The charge signal from the accelerometer was converted by the charge converter to a voltage signal proportional to acceleration. These units, powered from the signal amplification and filtering electronics, have a low output impedance and are capable of driving long lengths of cable. The charge gain and other applicable characteristics of the charge converters are contained in Table 2-2.

Table 2-2

CHARGE CONVERTER CHARACTERISTICS

	Endevco 2652	Endevco 2731B
Charge Gain	2 mV/pC ± 2%	.35 mV/pC
Frequency Response	3 Hz - 10 kHz ± 5%	5 Hz - 10 kHz ± 5%
Output Impedance	5 Ω max.	5 Ω max.
Maximum Temperature Range	85°C	85°C
Bias Current	15 mA max.	15 mA max.

The acoustic emission sensors used to detect surface acoustic waves also utilize a piezoelectric crystal as the transducing element. At the frequencies of operation, typically between 100 kHz and 1 mHz, the transducer sensitivity is specified as a voltage per atmosphere. The two acoustic emission transducers used for this program, the Trodyne 7537B differential output sensor, and a prototype, the TEC Model AE-3, have a transducer sensitivity of 175 V/atm and 750 V/atm, respectively. Other characteristic parameters of these sensors are given in Table 2-3.

Table 2-3

ACOUSTIC EMISSION SENSOR CHARACTERISTICS

	Trodyne 7537B	TEC AE-3
Input Configuration	Differential	Single-Ended
Transducer Sensitivity	175 V/atm	750 V/atm
Resonance Frequency	250 kHz	100 kHz
Maximum Temperature	320° C	70° C

A magnetic mounting assembly was used to mount the transducer on the valve body or exhaust line. The sensor is threaded into the assembly with an acoustic couplant to enhance the transmission of acoustic waves from the waveguide contacting the valve to the transducer.

The electrical signals, generated by the sensors, were amplified by Trodyne Type 7529A Differential Preamplifier. This unit has a fixed differential gain of 40 dB over a broad bandwidth, 8 kHz to 15 mHz. The operating power is derived from the signal processing electronics.

Amplification and Filtering

The TEC Model 1301 BiModal Acoustic Leak Monitor was designed and developed to process signals from both the accelerometer and AE type sensor. It is a portable assembly designed to work in conjunction with remote charge converter/preamplifiers and acoustic sensors and to provide amplification, filtering, and RMS display of the analog signals. Its general specifications are given in Table 2-4.

The accelerometer signal, prior to recording, is filtered over a 3 dB filter bandwidth of 550 Hz to 33 kHz as shown in Fig. 2-1. An LED meter on the faceplate provides a volts rms indication of the bandpassed signal over the 7 to 16 kHz frequency range. Analog outputs from the amplification and filtering module are available in two frequency ranges, the bandpassed signal on a faceplate BNC connector and a wideband signal from a rear connector.

The AE signal is bandpassd through the frequency range 100-400 kHz. The characteristic of the filter is shown in Fig. 2-2.

Instrument Grade Tape Recorder

The amplified and filtered data was recorded on magnetic tape by a portable four-channel, reel-to-reel instrumentation tape recorder. The lower frequency accelerometer data was recorded on the FM channel, while the higher frequency data from the AE sensor was recorded on the direct channel. The majority of the recordings were performed at 60 inches per second to utilize the full bandwidth of the channels. One channel was used for voice recording allowing verbal comments to be placed on the tape during tests. Pertinent specifications of the tape recorder are given in Table 2-5 and Figs. 2-3 and 2-4.

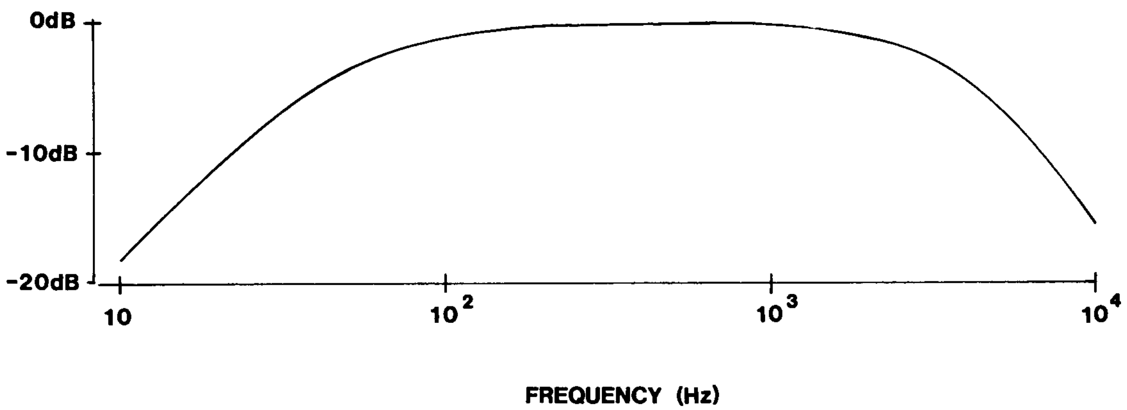

Figure 2-1. Frequency Response of TEC 1301 Leak Monitor, Accelerometer Channel

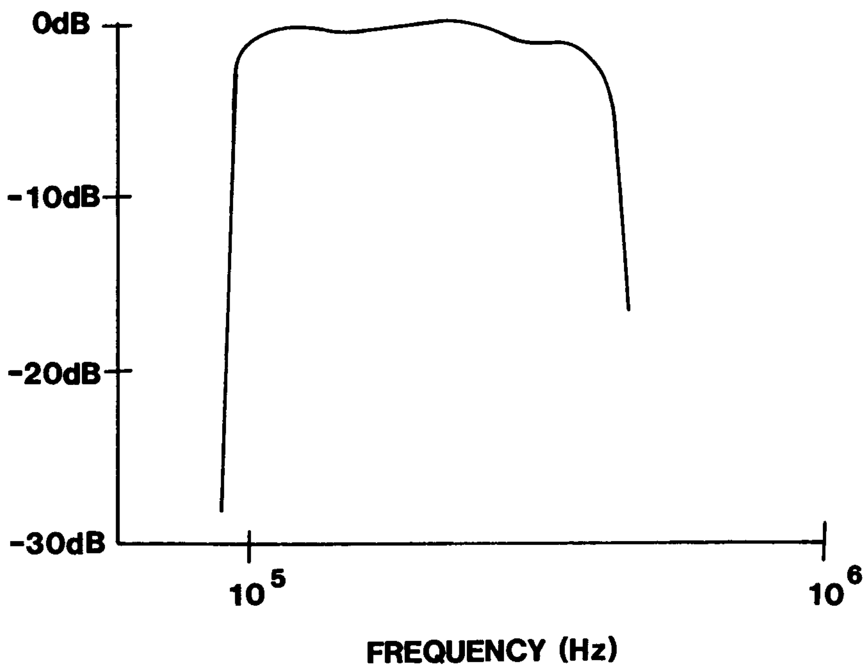

Figure 2-2. Frequency Response of TEC 1301 Leak Monitor, Acoustic Emission Channel

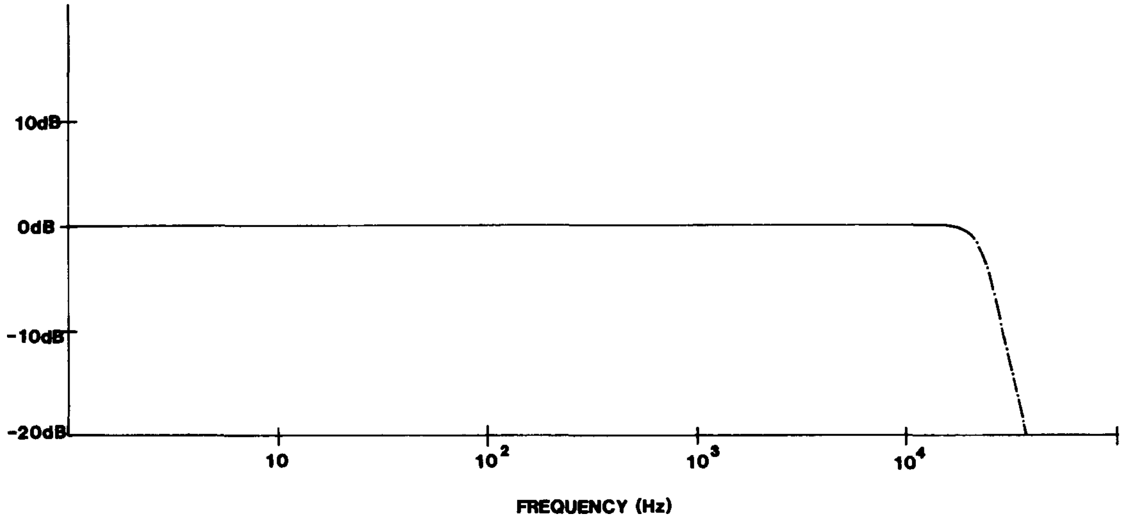

Figure 2-3. Frequency Response of Tape Recorder, "FM-Record" Channel

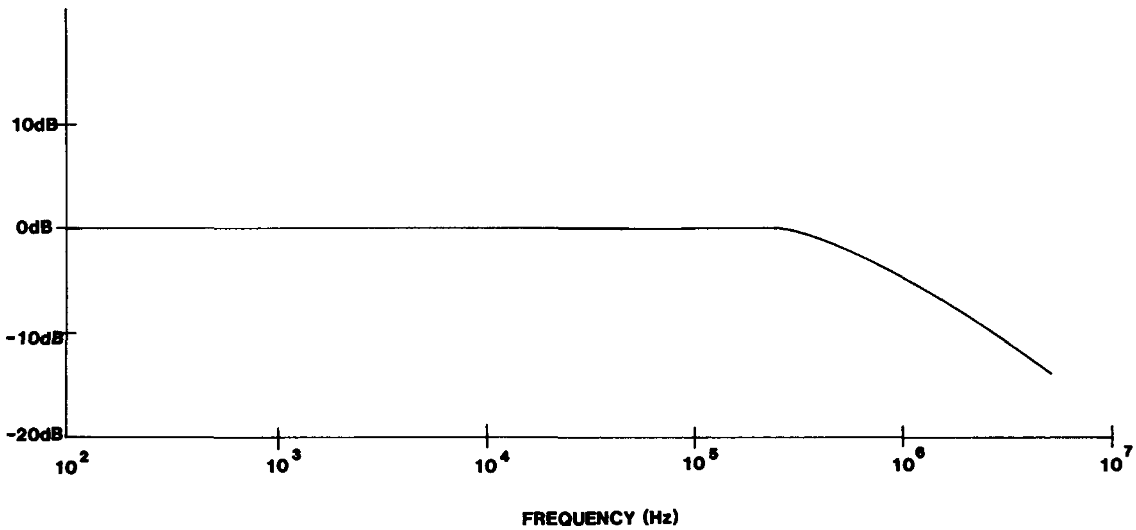

Figure 2-4. Frequency Response of Tape Recorder, "Direct Record" Channel

Table 2-4

ACOUSTIC LEAK MONITOR SPECIFICATIONS

Signal Processing - Acceleration Signals

Input:

Input Configuration	Differential
Input Voltage Gain	1, 2, 5, 10 1000
Accuracy of Gain	± 2%
Input Voltage Range	25vp-p (ac), 50v max dc + ac
Common Mode Rejection Ratio	50 db min @ 60 Hz
Bandwidth (± 3db) Bandpassed	7 kHz - 16 kHz
Wide-Band	550 Hz - 33 kHz

Outputs

Analog Output Impedance	51 ohm ± 2%
Digital Volt Meter (Bandpassed Signal)	0-1999 mvrms

Signal Processing - Acoustic Emission Signals

Input

Input Configuration	Differential
Input Voltage Gain	1, 2, 5, 10 100
Accuracy of Gain	± 2%
Input Voltage Range	25vp-p ac,
Bandwidth (± 3db)	100 kHz - 400 kHz

Ouputs

Analog Output Impedance	51 ohm ± 2%
Digital Volt Meter	0-1999 mvrms

Power Source

The built-in power supplies and current source allows the 1301 system to power the remote charge converter and preamplifier through the signal cable.

Charge Converter

Normal Current	9 ma ± 5%
Output Impedance	greater than 1 M ohm

Preamplifier

Output Voltage	± 15 vdc

Power Requirements

115VAC 60 Hz 1 amp

Table 2-5

TAPE RECORDER SPECIFICATIONS

Tape Speed (in/s)	Bandwidth (+0.1, -1 dB)	Signal - Noise Ratio (dB)
FM 60	DC to 20,000 Hz (see Fig. 2.3)	48
DR 60	300 Hz to 300 kHz (see Fig. 2.4)	40

Input Sensitivity: A twelve position switch on each channel is calibrated in volts peak for full carrier deviation. Range 0.1 to 20V.

Output: ± 1 volt for full deviation

The FM signal specifications conform to the Intermediate Band standard of I.R.I.G. 106-73.

DESCRIPTION OF TEST ARTICLES

Six different safety/relief valves manufactured by four companies were actuated at normal operating pressure to acquire acoustic data. Power-actuated pressure relief valves and pneumatically controlled valves as well as spring type safety valves were tested. The following sections describe each type of valve in detail.

Masoneilan 38-20771

The Masoneilan 38-20771 type valve is a pneumatically actuated control valve commonly used in nuclear applications. A schematic illustraton of the valve is given in Fig. 2-5. This valve requires a minimum air pressure, about 29 psig, to cause the main disc to lift from the seat, and a 55 psig air supply to force the main disc to the fully retracted position. A reverse acting characteristic ensures fail close operation. General specifications of the valve are given in Table 2-6.

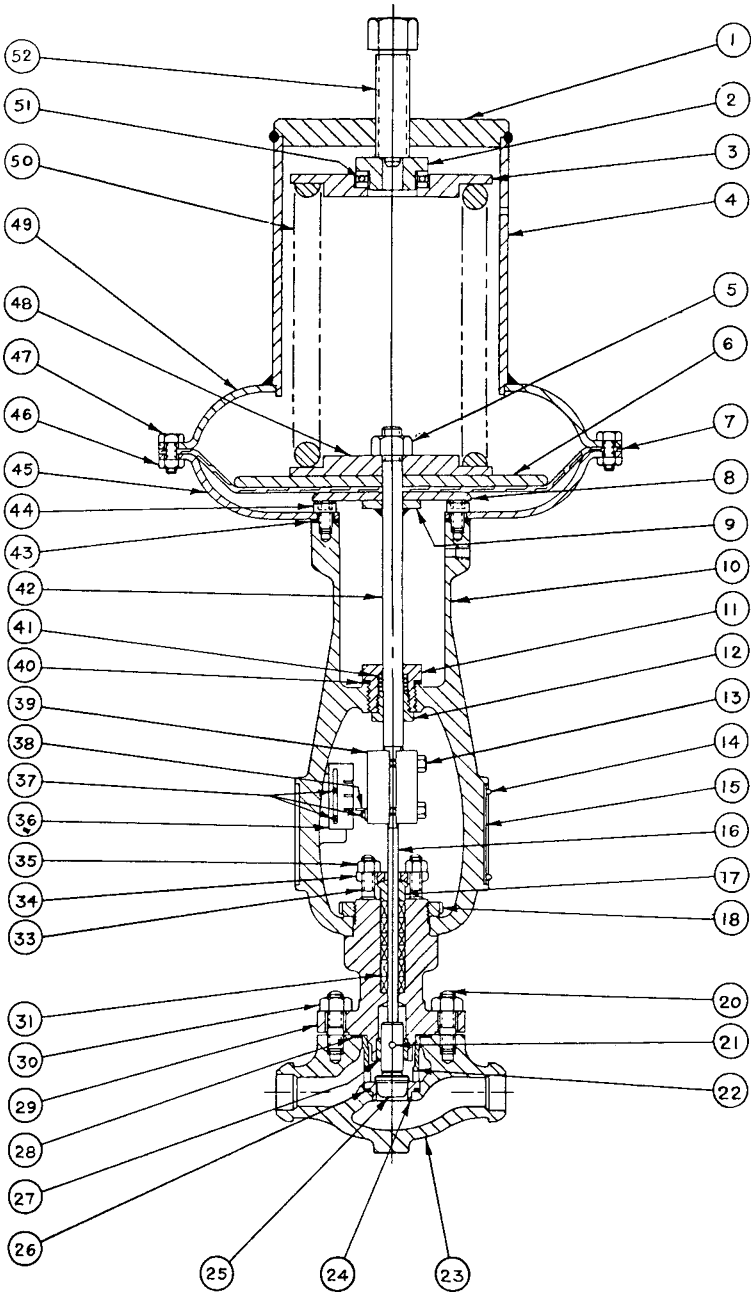

Figure 2-5. Masoneilan Valve Type 38-20771

Table 2-6

SPECIFICATIONS - MASONEILAN VALVE

Inlet Size	3 in.
Outlet Size	3 in.
Rated Flow	~ 210,000 lb/hr @ 2485 psig
Maximum Temperature	650°F
Maximum Pressure	3130 psig

Target Rock

The Target Rock safety/relief valve used for the acoustic characterization tests is of the type commonly used on the main steam lines in BWR nuclear power plants. Its function is to provide, by automatic actuation, overpressure relief for the main steam system.

The valve, as shown in Fig. 2-6, is a pilot-operated type, having a two stage pilot valve section and a main valve section. During normal plant operating pressures, the pilot stage is held closed by the internal pressure acting over the pilot stage seat area. As the pressure increases, bellows expansion reduces the abutment gap between the stem and disc yoke. When the stem abuts against the yoke, further pressure increase lifts the disc from its seat, admitting steam to the operating piston of the second stage, causing it to open. This vents the chamber over the main valve piston to the downstream side of the valve, thus creating a pressure differential across the main valve piston and the valve opens.

Dresser 31533VX-30

The Dresser 31533VX, shown in Fig. 2-7, is an electrically controlled, solenoid-operated, straight through safety/relief valve commonly mounted on the

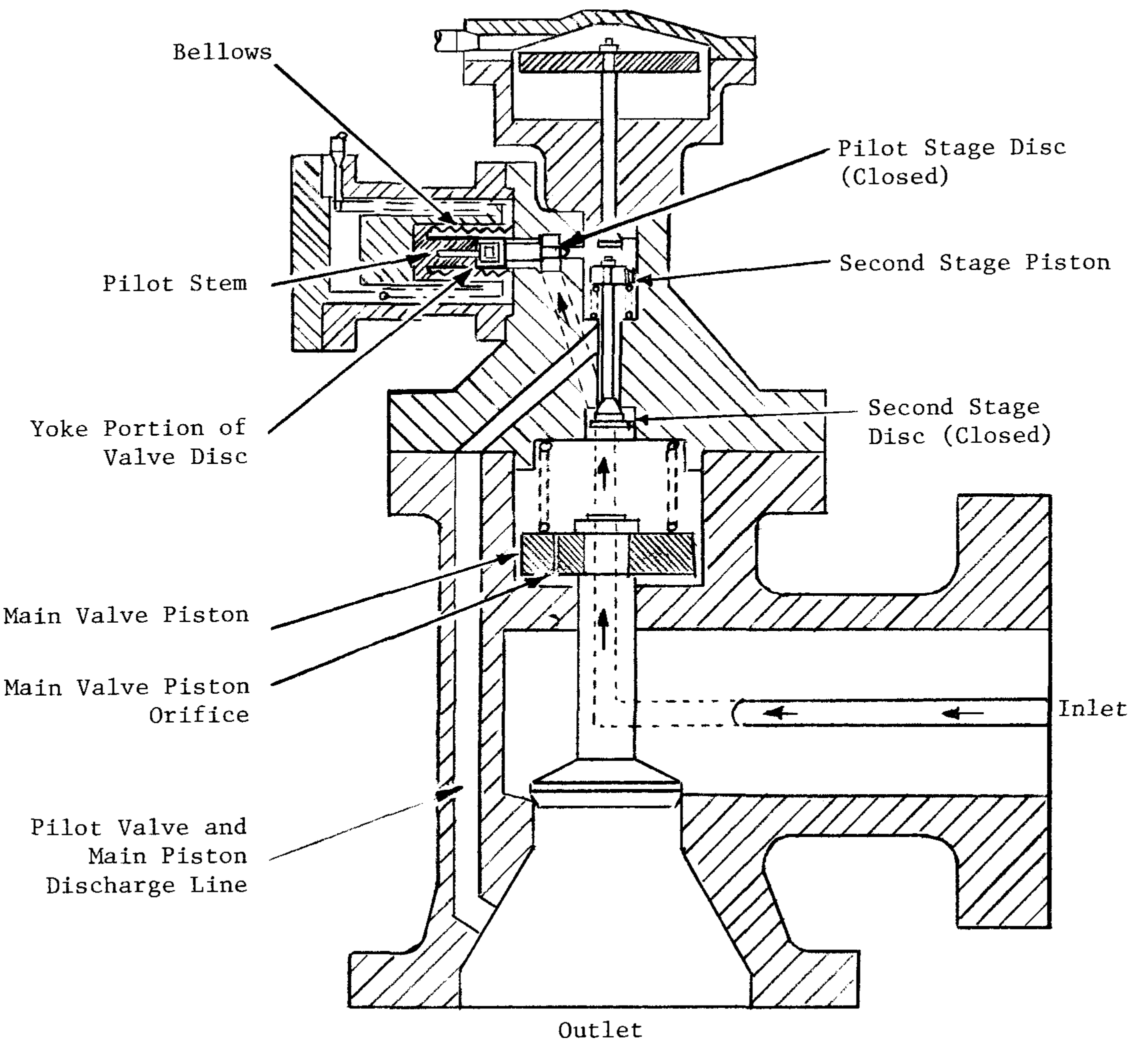

Figure 2-6. Target Rock S/R Valve

pressurizer in a PWR nuclear plant or the main steam lines in a BWR plant. Its function is to provide, by automatic or manual control, relief of overpressure conditions.

In the automatic mode, pressure sensing control switches enable automatic actuation at pressures below the set point of the main safety valves.

Steam under pressure enters the main valve through the inlet chamber (A), and passes upward through the cage (K) into the chamber (B). Steam enters chamber (C) through the port (D). The main valve disc (3) is held in the closed position by steam pressure in chamber (C). The pressure in chamber (C) is the same as in chamber (F) when escape through port (D) is prevented by the closure of the pilot valve disc (10).

The pilot valve disc (10) is held in the closed position by pilot valve spring (11) and by the steam pressure in chamber (F). It is opened by the operating lever (18) under the action of the solenoid plunger head (23).

When the pilot valve is opened, steam is released from chamber (F) and port (E) through port (G), at a faster rate than supplied through the drilled hole in port (D). The resultant unbalance of pressures in chambers (B) and (C) produces a force which moves the main valve disc from its seat, permitting steam to escape from chamber (B) to the outlet (H).

When the pilot valve closes as a result of the solenoid being de-energized, steam is trapped in chamber (C) where it builds up pressure and forces the main valve disc (3) back down on its seat thereby closing the main valve. General specifications are given in Table 2-7.

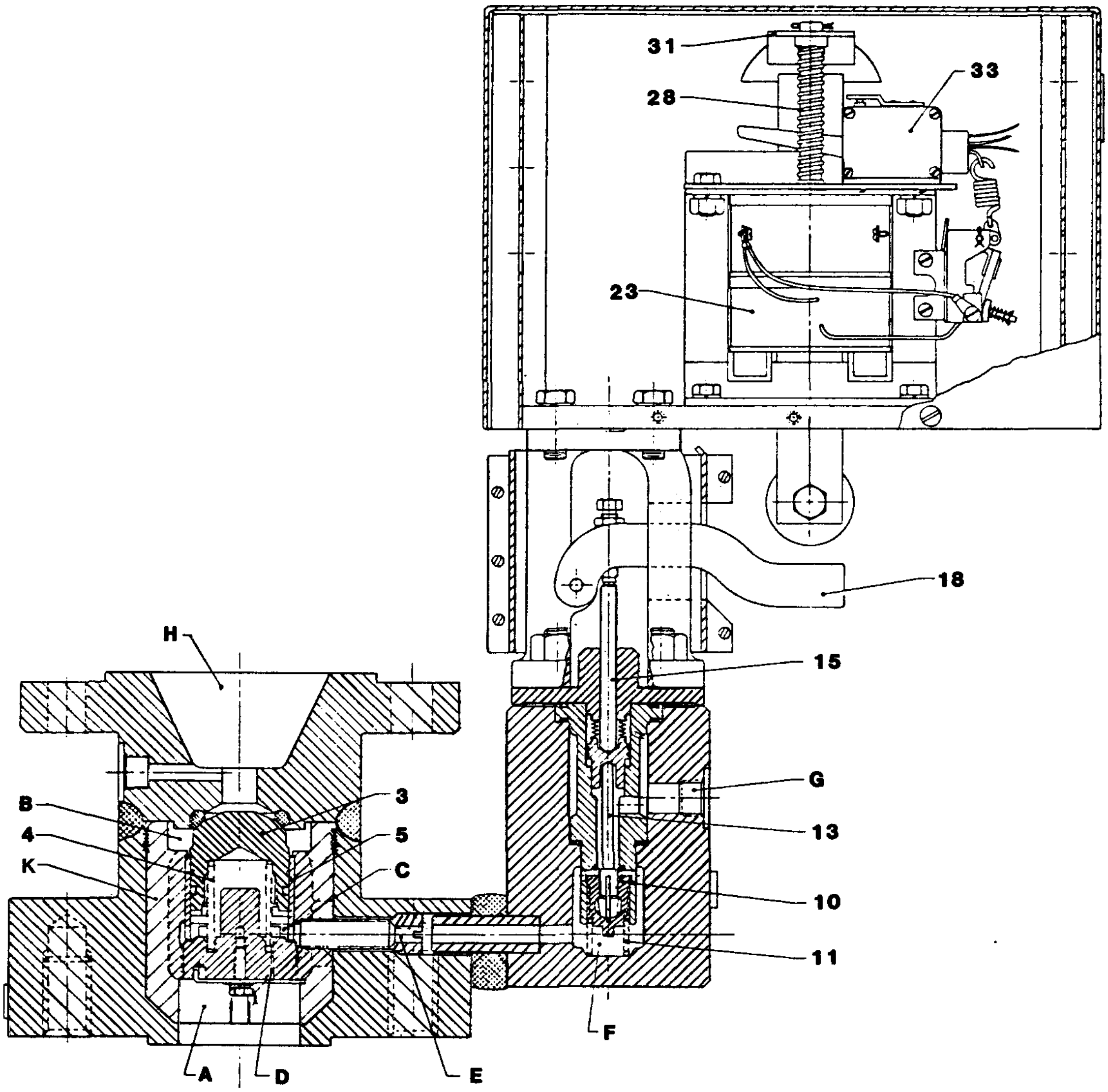

Figure 2-7. Dresser 31533 VX-30 Electromatic Relief Valve

Table 2-7

SPECIFICATIONS - DRESSER VALVE

Inlet Size	2½ in.
Outlet Size	4 in.
Orfice Area	1.354 in^2
Design Flow	158,968 lb/hr @ 2385 psig
Design Pressure	2385 psig
Design Temperature	700°F

Crosby HPV-SN

The Crosby HPV-SN is an electrically controlled, straight-through, pilot-operated pressure relief valve manufactured with a stainless steel body for use in nuclear power plants. Its function is to provide, by way of automatic or manual control, over pressure relief for the primary steam system. The valve is usually used in conjunction with pressure - sensing control switches that enable activation at a pressure lower than the main safety valves, thus prolonging the service life and tightness of the main safety's. Actuation can also be initiated by a remote electric panel switch.

The actuation sequence begins with energizing the main solenoid from the controlling system. Movement of the solenoid, transmitted by the solenoid link, forces the pilot valve disc from its seat. The resulting pressure changes within internal chambers cause the main disc to open and vent the pressure. Valve closure is initiated by deenergizing the solenoid, thus forcing the pilot valve disc to reseat. Pressure gains within the valve cavities eventually overcome the force holding the main valve disc open, resulting in the main valve disc reseating. General specifications of the valve are listed in Table 2-8.

Table 2-8

SPECIFICATIONS - CROSBY VALVE HPV-SN

Inlet Size	2½ in.
Outlet Size	4 in.
Orfice Area	1.368 in^2
Design Flow	125, 258 lb/hr @ 2315 psig
Maximum Pressure	3000 psig
Maximum Temperature	1020°F

Crosby 6M6-HB-BP-86

The Crosby type HB is a spring-operated safety/relief valve used in PWR nuclear power plants to provide overpressure relief for the pressurizer. Activation of the valve occurs when the inlet pressure reaches the set pressure. Changes in chamber pressure plus the action of other internal parts causes the valve to pop open. As the inlet pressure decays, reducing the dynamic steam forces on the lower face of the disc, the safety valve disc begins to close. Assisted by pressure within internal chambers, the valve at this point closes sharply. General specifications of the valve are listed in Table 2-9.

Table 2-9

SPECIFICATIONS - CROSBY VALVE HB TYPE

Inlet Size	6 in.
Outlet Size	6 in.
Set Pressure	2385 psig
Orfice Area	3.644 in^2
Design Flow	~420,000 lb/hr @ 2485 psig
Maximum Temperature	650°F

Crosby 6R10-HA

The Crosby type HA is a spring operated safety/relief valve used in PWR nuclear power plants to provide overpressure relief for the main steam lines. The valve opens as a result of inlet pressure exceeding the setpoint and closes automatically when the pressure drops to the reseat pressure. General specifications of the valve are listed in Table 2-10.

Table 2-10

SPECIFICATIONS - CROSBY VALVE HA TYPE

Inlet Size	6 in.
Outlet Size	10 in.
Set Pressure	1140 psig
Orfice Area	16.0 in^2
Design Flow	~ 785,000 lb/hr @ 1140 psig
Maximum Temperature	570°F

TEST PROCEDURES

Introduction

The objective of the in-plant and test stand tests was to acquire acoustic data during several actuations and closings of the test articles described above. In the following section, the installation procedures used to apply the acoustic data acquisition system are discussed. Subsequent sections individually address specific procedures used for each test.

The sensors were attached to the valve body or exhaust stack depending upon sensor type and accessability. The accelerometers were attached with a stainless steel strap with an integral stud sized for the sensor used. This bracket is machined such that the radius of the pipe or flange mates with the base of the bracket, and, thereby enhancing acoustic coupling. The strap is secured to the pipe by tightening the worm-drive screw. The accelerometer is then torqued onto the integral stud. The acoustic emission transducer was attached to the valve using a magnetic mounting bracket. The AE sensor was threaded into the top of the magnet assembly using acoustic couplant between mating surfaces. Prior to installation, the surface below the proposed sensor was sanded to remove rust, dirt, etc. Acoustic couplant was again used between the discharge pipe surface and the magnet's waveguide. As illustrated in Fig. 2-8, a stainless steel strap was also used when securing the magnetic assembly to the discharge line.

Each sensor was connected to its own charge converter/preamplifier with a short length of coaxial cable. Coaxial cables from the charge converter/preamplifier carried the signals to the data acquisition instrumentation.

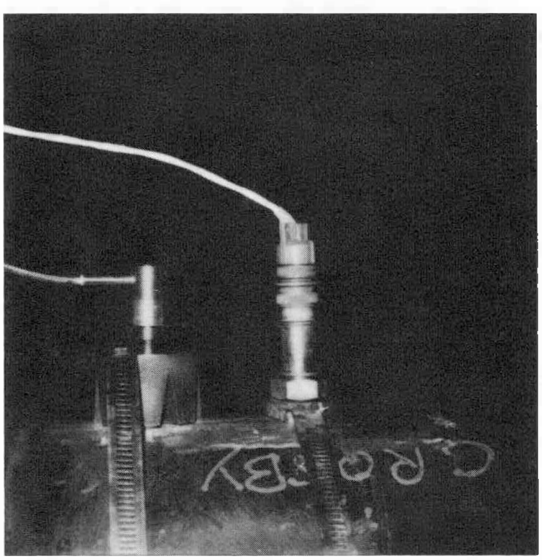

Figure 2-8. Sensor Mounting Methods - The accelerometer is on the right; the AE sensor on the left.

All signals were amplified and filtered by the TEC 1301 assembly prior to recording on magnetic tape. In the case of the accelerometer channel, the amplified, broadband signal was recorded utilizing the FM mode. The signal from the AE instrumentation was recorded utilizing the direct recording method. The data acquisition equipment is shown in Fig. 2-9.

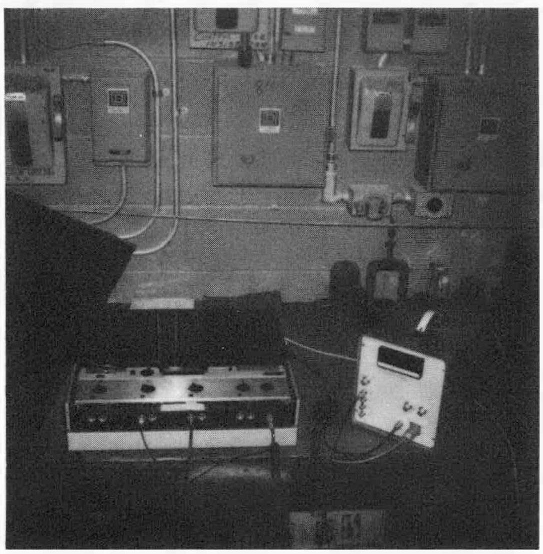

Figure 2-9. Data Acquisition Instrumentation

In-Plant Tests

Masoneilan Relief Valve - Sequoyah Nuclear Power Plant. The pneumatically operated pressurizer relief valve at TVA's Sequoyah Unit 1 Nuclear Power Plant was instrumented with acoustic sensors as discussed in the previous section. Sensors were installed on the discharge pipe of the valve. The plant was undergoing hot functional testing at the time.

A series of recordings were made, starting with the plant background noise with the valve closed. Several recordings were then made of valve actuation. Finally, plant background signals were recorded again after the test actuations. Frequency domain data from this test is located in Section 3.

Test Stand Tests

Crosby HPV, HB, HA. Each of the valves tested at the Crosby test facility was instrumented with a BBN 424 accelerometer and a Trodyne acoustic emission sensor. In all cases, the sensors were mounted on the discharge line within one foot of the flange. Figures 2-10, 11, and 12 show sensor mounting locations and sensor installation methods.

The HA type valve was mounted on a 500 cu ft drum with an 8" gate, short tail pipe with open dischage. The HB type valve was mounted on the Crosby Navy Test Drum with a short tail pipe. The HPV-SN type valve was mounted on the small Bessler drum with a long vertical tail pipe venting to the roof.

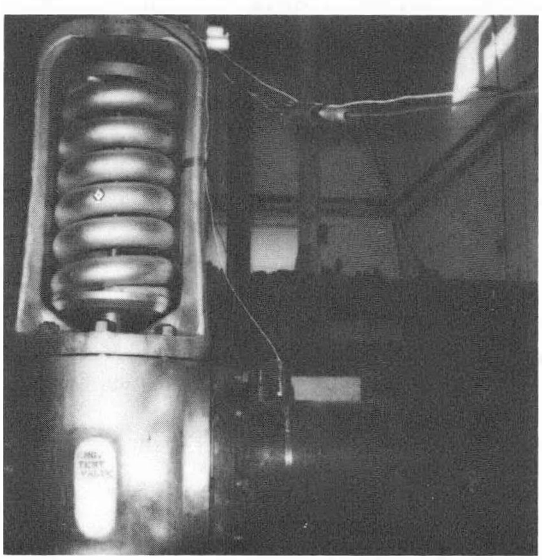

Figure 2-10. Crosby HB Type Spring Safety Valve

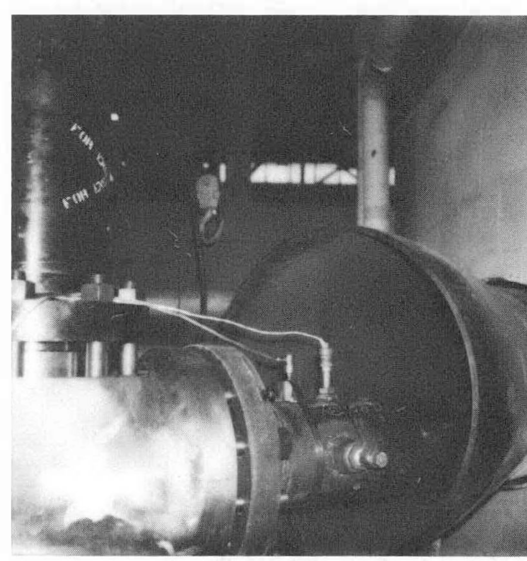

Figure 2-11. Crosby HA Type Relief Valve

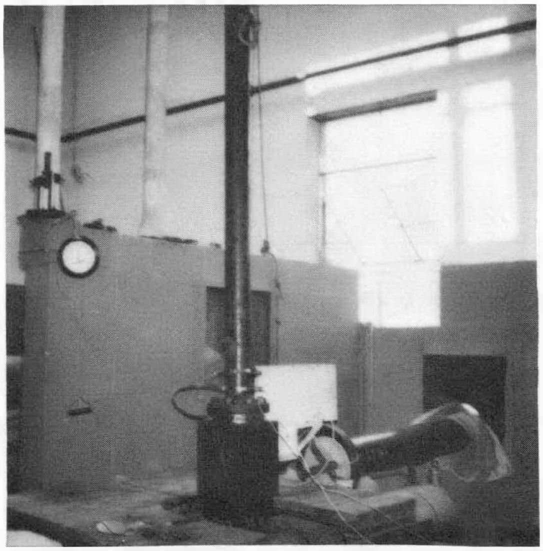

Figure 2-12. Crosby HPV-SN Electrically
Operated Relief Valve

During testing of the spring type safety valves, several recordings were made during actuation and closure of the valves. For the HB type valve, 660°F steam was used. The valve was set to actuate at 2460 psig and reseat occurred at 2400 psig. The HA type valve was also actuated with steam. This valve was set to open at approximately 1140 psig and reseat at 1080 psig resulting in an average blowdown of 60 psig. The duration of the tests was several seconds for the HPV valve, and approximately 1/2 second for the HA and HB types.

Two acoustic tests were conducted in conjunction with the electromagnetic valve. In the first test, the accelerometer and the AE sensor were mounted within one foot of the valve. Signal charge conversion/preamplification, final amplification with filtering, and tape recording were performed by the same equipment as previously used for the spring type valves. The HPV-SN was operated at 1200 psig, 1800 psig, and 2300 psig with test drum temperature at 550°F. Several recordings were made at each inlet pressure level. The inlet pressure at reseat was typically 300 psig for the 1200 and 1800 psig tests and 600 psig for the 2300 psig tests enabling long duration recordings.

An additional test was performed to measure the attentuation of acoustic signals as a function of frequency and distance from the valve. Both the accelerometer and the acoustic emission transducer were relocated up the exhaust stack nine feet from the original position. Two actuations at 2300 psig were performed with blowdown to 600 psig. Frequency domain data for the acoustic testing performed at Crosby can be found in Section 3.

Dresser Electromatic. The electromatic relief valve was mounted on the Dresser test stand with a vertical discharge line. Acoustic instrumentation consisted of a strap mounted accelerometer and a magnetically mounted AE sensor. Sensor mounting and arrangement is shown in Fig. 2-13.

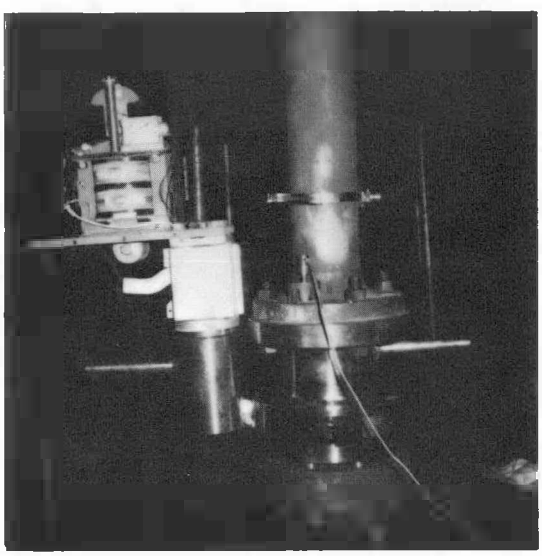

Figure 2-13. Dresser Electromatic Relief Valve

Several recordings were made during actuations and closings at inlet pressures of 600 psig, 1200 psig, 1800 psig and 2385 psig. All tests were conducted with 465°F steam. The valve was held fully open for approximately five seconds.

An additional test was performed to measure the acoustic energy as a function of inlet pressure during a continuous blowdown. The blowdown began at 2385 psig and continued down to 600 psig. This test was conducted using 530°F steam. The duration of the blowdown was 45 seconds.

Target Rock Safety/Relief Valve. The Target Rock safety/relief valve was tested in a high pressure test cell at the Wyle Laboratorie's valve refurbishment/recertification facilities located in Huntsville, Alabama. Acoustic monitoring was performed by a BBN 424 accelerometer, strap mounted to the pilot housing.

Several recordings were made during actuation and closings of the valve. The inlet pressure was slowly increased until the valve "popped" open and recordings continued until after the main disc was reseated.

Section 3

TEST RESULTS

DATA ANALYSIS METHOD

The acoustic signals, which were generated by steam flow through the various valves, were recorded so that analysis could be performed later. The major objective is to obtain comparisons of those signals with recorded plant background signals. Because the overall level of each signal was noted from the rms display on the TEC Model 1301 acoustic monitor, general comparisons of signal levels can be obtained without analysis of the recorded data. However, it was considered appropriate to also perform spectral analysis of the signals, so that excitation of any peculiar resonances could be observed and documented. Furthermore, comparison of the flow signals to the background signals over a broad bandwidth enables possible recognition of specific narrow bandwidths wherein the signal-to-background ratio might be maximized.

Spectral analysis was performed using either TEC's Power Spectral Density (PSD) analyzer system or a Nicolet Model 446A Fast Fourier Transform (FFT) Analyzer. For the accelerometer signals, analysis was usually performed over the range 0-50 kHz. For the acoustic emission signals, attention was restricted to the bandwidth of 100-400 kHz, because of the sharp filter used in the AE amplifier channel.

The frequency spectra are used to illustrate the level of background noise, flow noise, leak noise, and the degree of attenuation of flow noise downstream from the valve.

BACKGROUND DATA

Plant background noise, as detected on or near a safety/relief valve, needed to be measured for both a typical BWR and PWR plant. Philadelphia Electric Company's Peach Bottom BWR Plant and TVA's Sequoyah PWR Plant agreed to cooperate with the program.

BWR Background

For several years, accelerometers have been installed on the main steam S/R valves at the Peach Bottom Nuclear Station. These accelerometers are used for detecting leakage in the pilot stage of the valves. The results of some of the recordings of the acoustic signals, present under normal operating conditions, are shown in Fig. 3-1. In general, the amplitudes of the acoustic signals above 20 kHz is about ten times less than those below 5 kHz. The rms signal for the noisiest valve, E, over the entire bandwidth of detection had a value of 0.26 g. The value in the bandwidth 7-16 kHz is actually less, because there is appreciable energy below 7 kHz. Nevertheless, the value 0.26 g will be used as a conservative reference.

The background noise in the AE bandwidth has not been measured on an operating BWR mainsteam line.

PWR Background

During hot functionals testing at the Sequoyah Nuclear Plant, acoustic monitoring of a Masoneilan relief valve was performed. The background spectra are shown in Figs. 3-2 and 3-3. Note that the acoustic energy detected by the accelerometer, Fig. 3-2, is appreciably less at frequencies above 5 kHz than below 5 kHz. In the bandwidth 7-16 kHz, the overall rms value corresponded to 0.05 g. For the AE bandwidth, the rms value corresponded to 1.5×10^{-3} Pa.

VALVE FLOW NOISE

Target Rock S/R Valve

The spectrum of acoustic energy detected during actuation of this valve is shown in Fig. 3-4, where it is compared to the background noise recorded at the Peach Bottom Plant. In the frequency range 7-16 kHz, the flow noise exceeds the background by a factor of approximately 200.

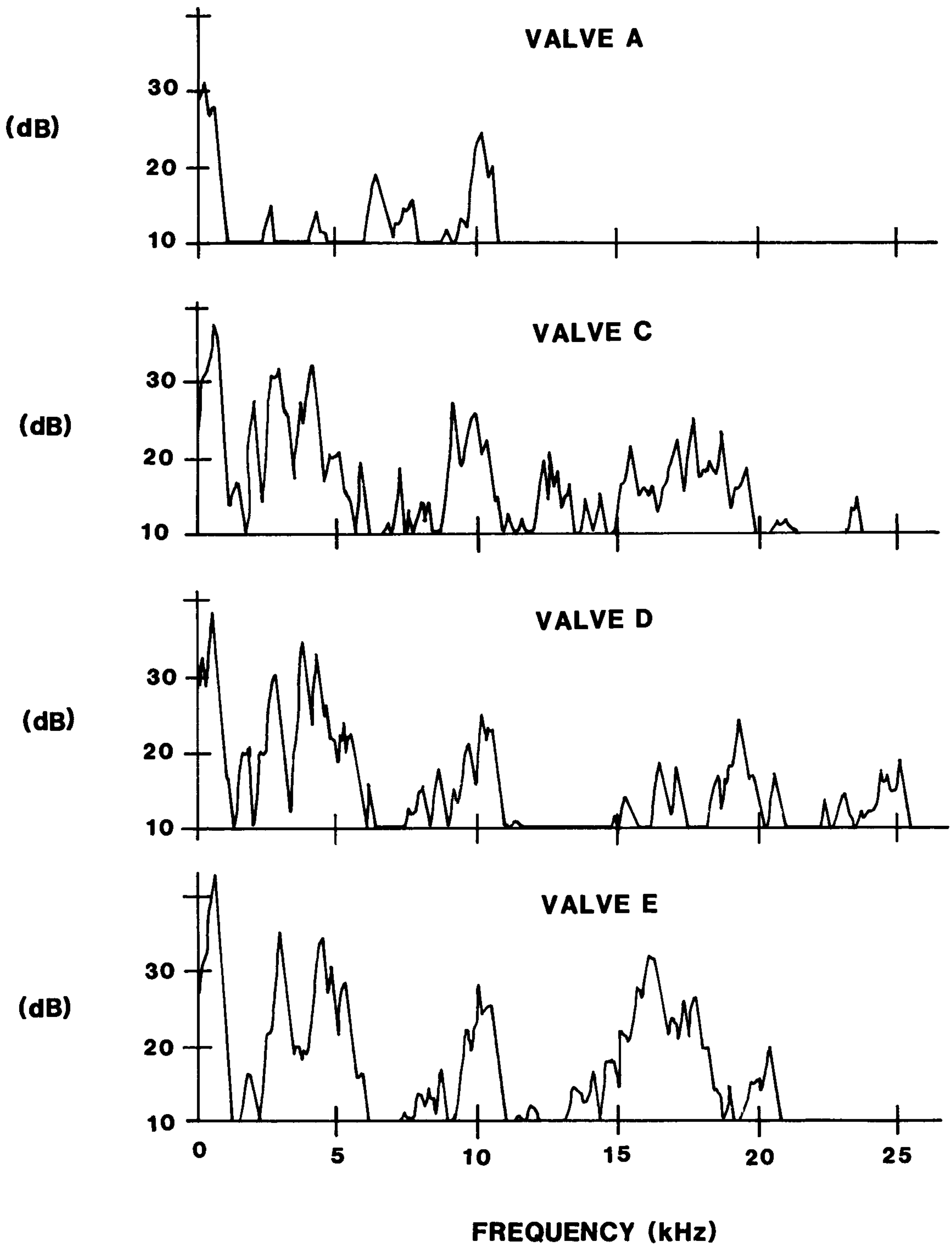

Figure 3-1. Background Noise Spectra for Four Target Rock Valves on Main Steam Lines at the Peach Bottom BWR Plant

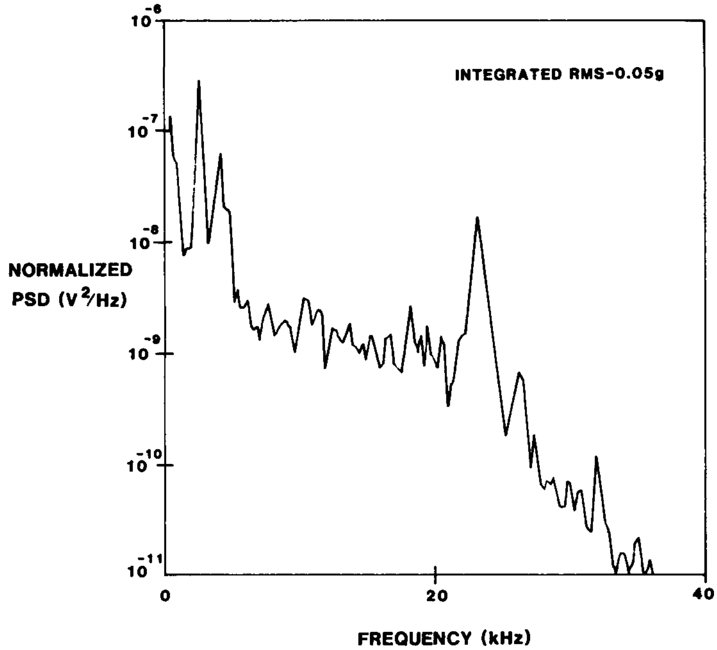

Figure 3-2. Background Noise at Sequoyah PWR Pressurizer Valve - Detected by Accelerometer

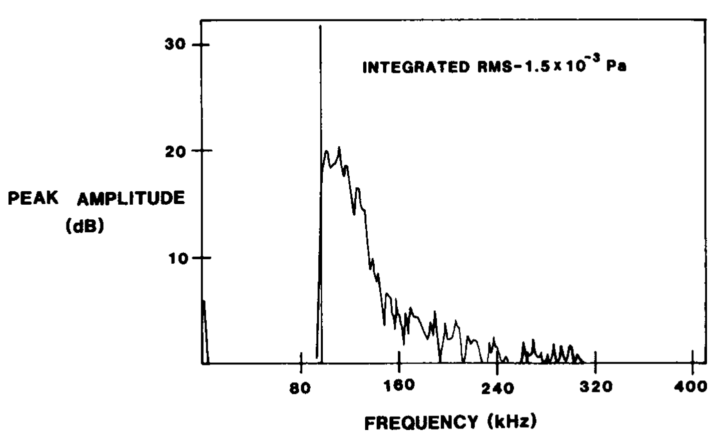

Figure 3-3. Background Noise at Sequoyah PWR Pressurizer Valve - Detected by Acoustic Emission Sensor

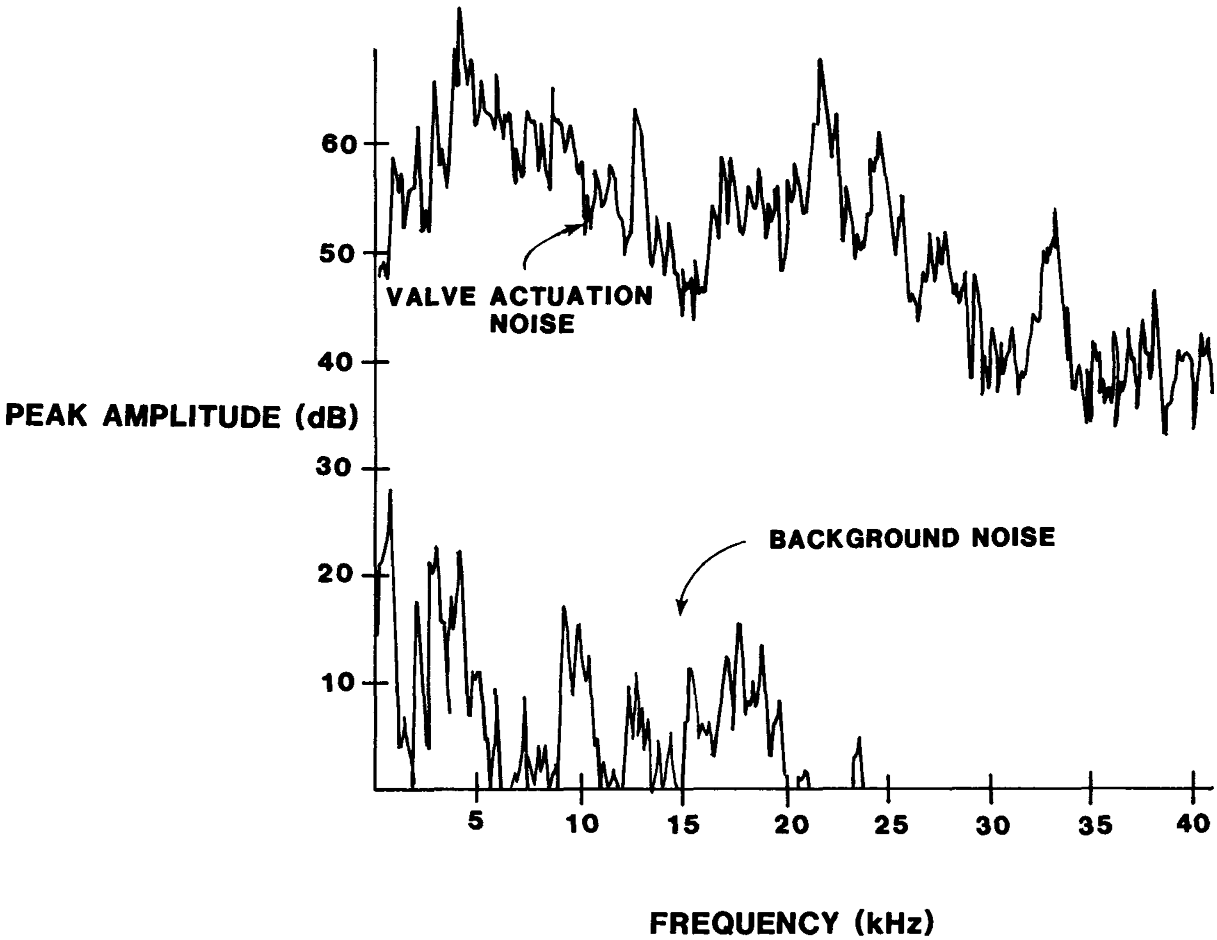

Figure 3-4. Target Rock S/R Valve Spectra

Masoneilan Valve

The acoustic levels caused by the activation of this valve were underestimated when setting the system gains for both the accelerometer and AE channels. As a result, the electronics (amplifiers) were saturated while the valve was fully opened. This means that the maximum value of the recorded signals is less than the true maximum. Figure 3-5 shows the full opened flow spectra together with the background spectra and an intermediate spectra corresponding to leak noise when the valve failed to completely seat. A similar comparison is given in Fig. 3-6 for the AE spectras.

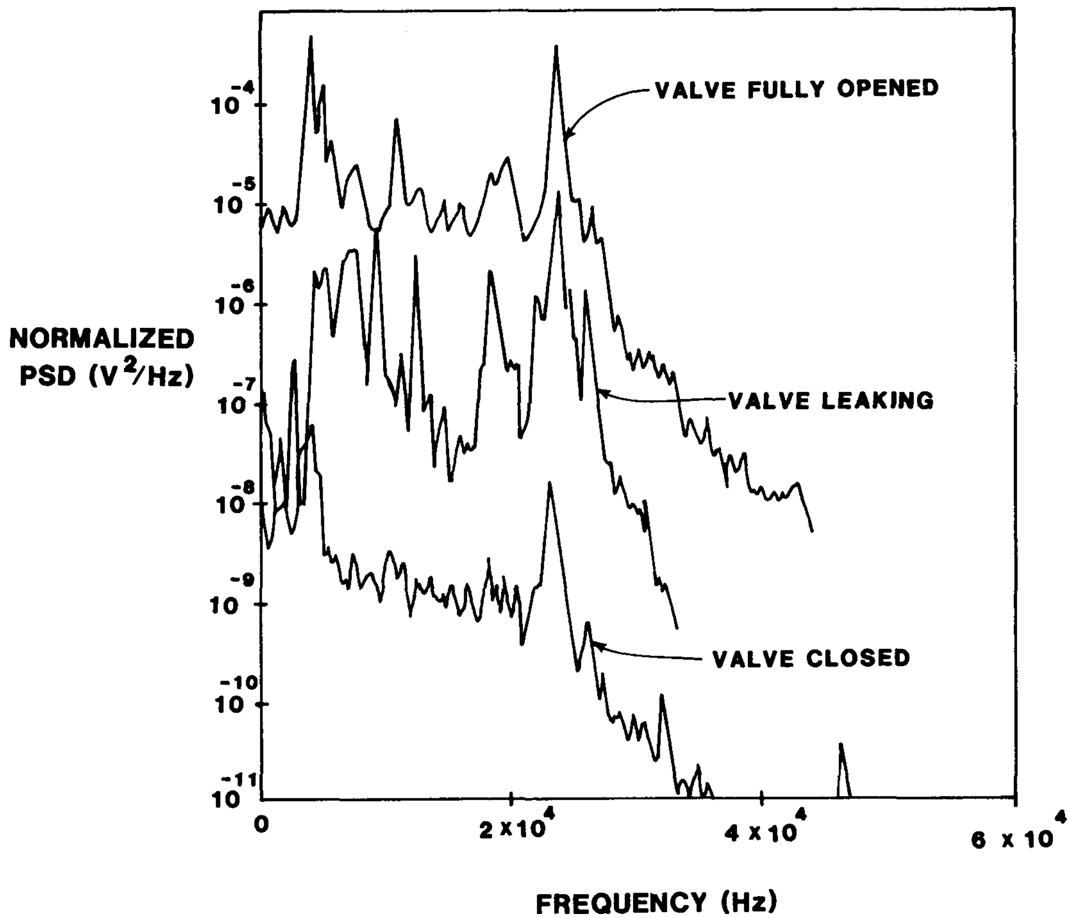

Figure 3-5. Masoneilan Valve - Accelerometer Spectra (The ranges of the amplifiers were exceeded for the "valve fully opened" condition.)

Dresser Valve 31533VX

At a pressure of 2385 psi, this valve was actuated and held open until the pressure dropped to 600 psi. Figure 3-7 shows the decrease in the bandpassed rms output of the accelerometer as the pressure drops from 2385 to 600 psi, in approximately 43 seconds. A 75% decrease in pressure produces only a 30% reduction in rms signal. The rms value during flow at 2385 psi corresponds to 88 g, approximatley 2000 times greater than the background levels at Sequoyah. Similarly, the AE signal level was measured as approximately 600 times greater than the level at Sequoyah. The accelerometer and AE spectra are shown in Figs. 3-8 and 3-9, respectively.

Crosby Valves

The results for the three types of Crosby valves are shown in Figs. 3-8 and 3-9, along with the spectra of the Dresser valve. The spectra for the accelerometer data (Fig. 3-8) show that the full flow acoustic level for the Crosby HPV-SN is about 6 db less than that of the Dresser valve. These valves have similar sized orifices, 1.368 in^2 and 1.354 in^2, and identical inlet and outlet diameters. The actuation pressures were very similar, 2300 psig and 2385 psig. These small differences, and the differences in steam temperature should cause about 10% difference in the acoustic level. Some of the remaining differences could be attributed to transducer coupling efficiency and possibly the length of exhaust pipe. However, the main source of a factor of two difference is unknown. This uncertainty is further confused by the fact that the AE results (Fig. 3-9) show the Dresser valve's AE level to be about 10 db less than that of the Crosby HPV-SN.

The low levels shown in Fig. 3-8 for the HA and HB valves are probably attributable to the fact that these actuations are only brief "pops" and therefore full flow did not develop in the exhaust pipe, nor did the associated flow induce vibrations and pipe reasonances, which surely contribute to the

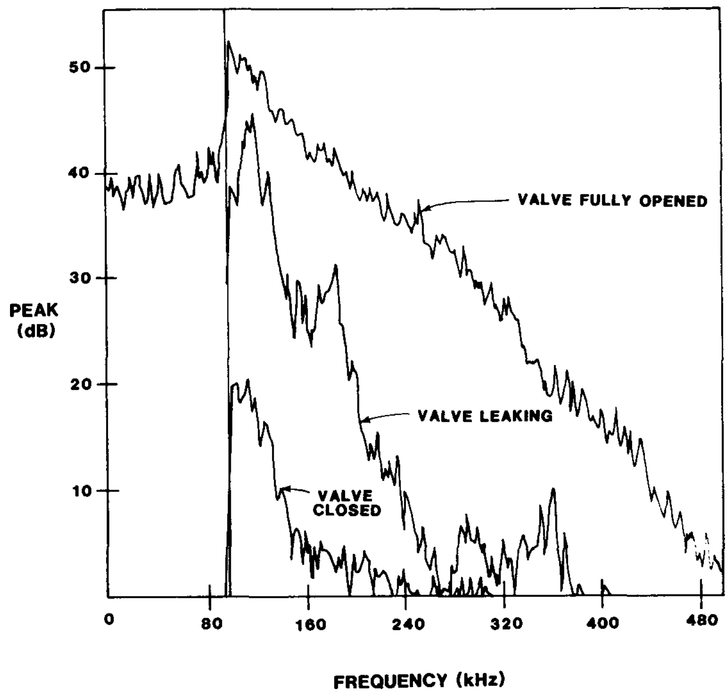

Figure 3-6. Masoneilan Valve - Acoustic Emission Sensor Spectra
(The ranges of the amplifiers were exceeded
for "valve fully opened" condition.)

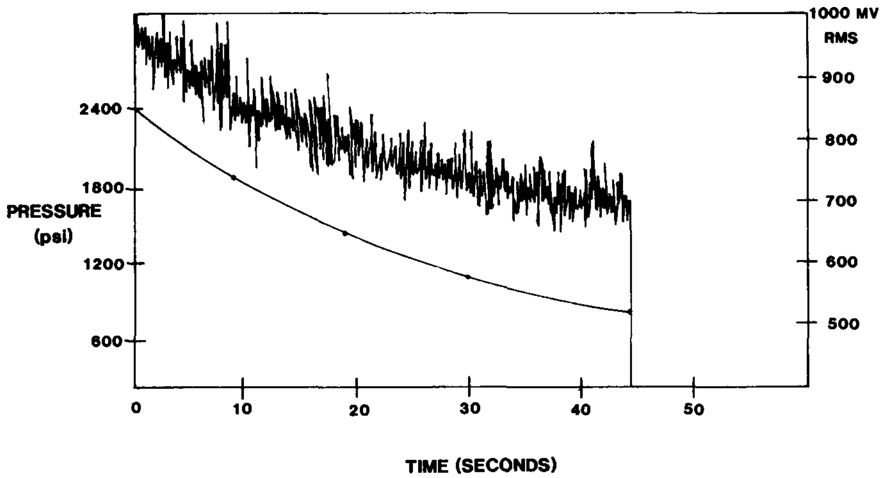

Figure 3-7. Time Record of Pressure and RMS Output of Accelerometer During Blowdown of Dresser Valve

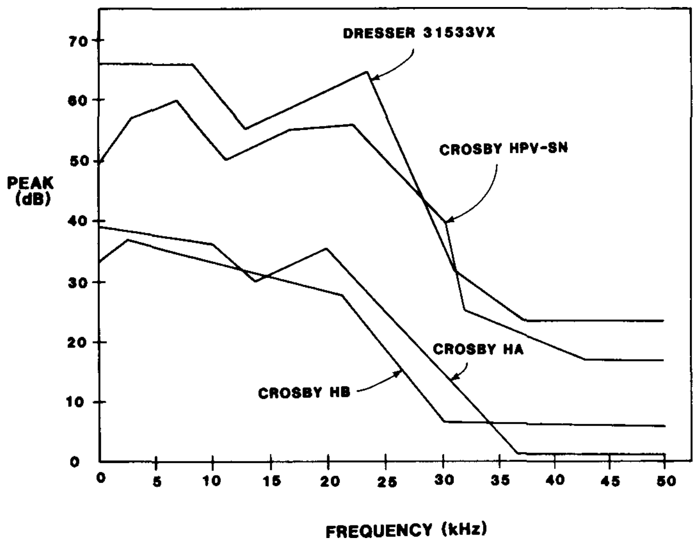

Figure 3-8. Accelerometer Spectra for Actuation of Four Valves

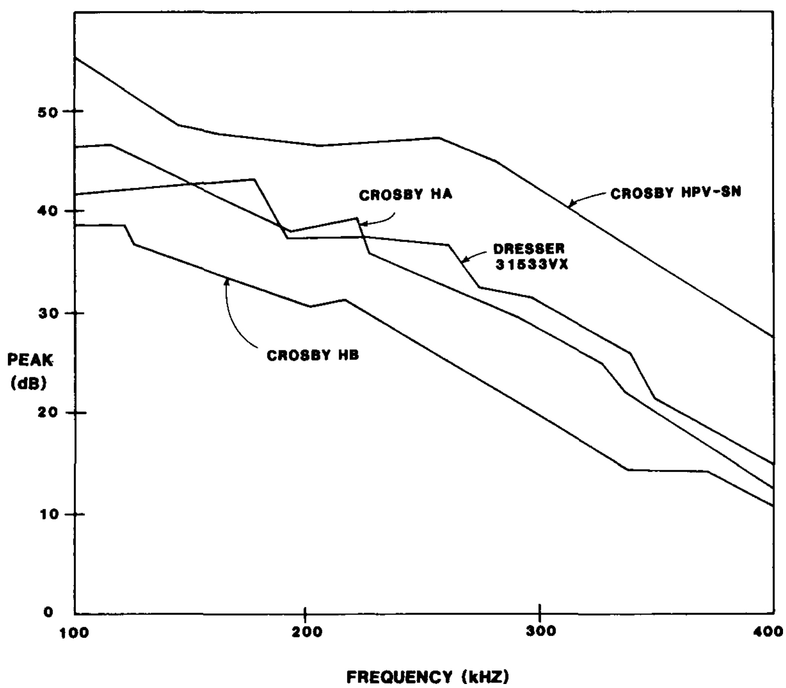

Figure 3-9. AE Sensor Spectra for Actuation of Four Valves

acoustic level in the audio range of frequencies. The difference in the AE level and the HA and HB valves is not understood. Nevertheless, all of the measured levels can be confidently used as conservative representative valves of the acoustic levels caused by actuation of the specific valves.

Attenuation Measurements

During the testing of the Crosby HPV-SN valve, the accelerometer and AE sensor were relocated on the four inch exhaust pipe, approximately nine feet from the valve outlet. The valve was again actuated at 2300 psig in order to determine the degree of attenuation affecting bandwidths. The results are shown in Figs. 3-10 and 3-11. For the accelerometer, little decrease in signal level was observed. On the other hand, the signal detected by the AE sensor is about 30 db less than when the sensor is located near the valve. For frequencies higher than 25 kHz, there is no discernible contribution above the local background conditions. These results suggest that most of the sound detected in the lower frequency range is flow-generated noise in the pipe; while the higher-frequency ultrasound is associated only with a near-valve source, probably the jet at the orifice.

The attenuation of the AE signal can be useful if one wishes to minimize the amount of "cross talk" between acoustic monitors on valves. This could be used in order to obtain a clear identity of an open valve which is near other monitored valves. Also, significant changes in plant background noise are less likely to be detected in the AE bandwidth. On the other hand, the lack of attenuation at the lower frequencies means that actuation of several valves could possibly be monitored by one accelerometer mounted on a common exhaust pipe. Of course, such an installation would not be sensitive to partial flow or leakage; and could not provide any indication of which valve was open.

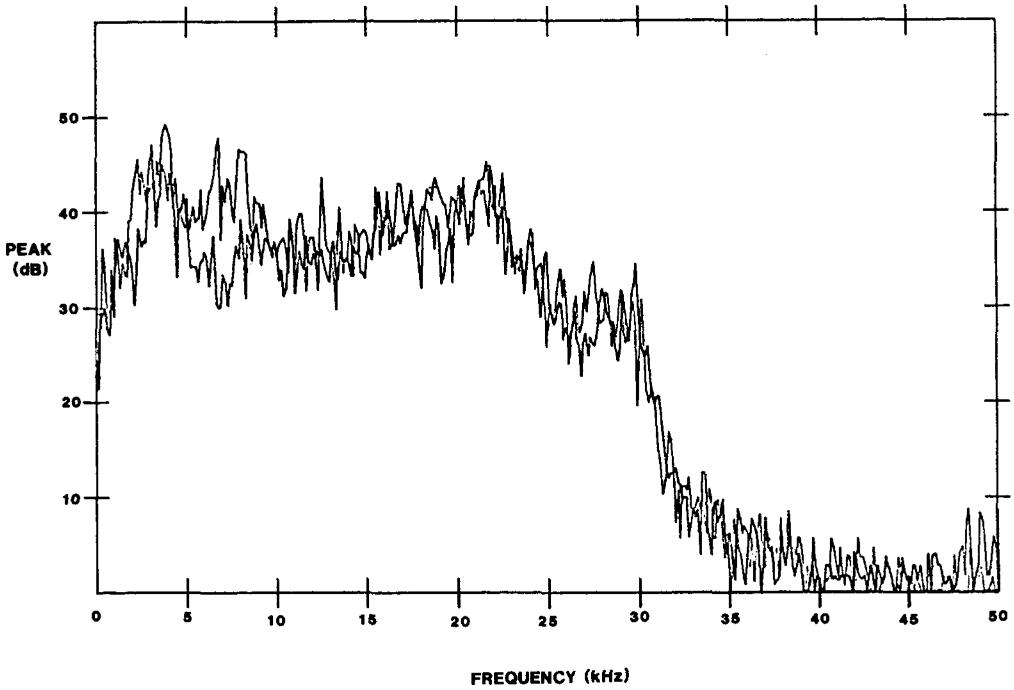

Figure 3-10. Two Spectra of Accelerometer Signal (one 6 inches from valve, the other 108 inches from valve)

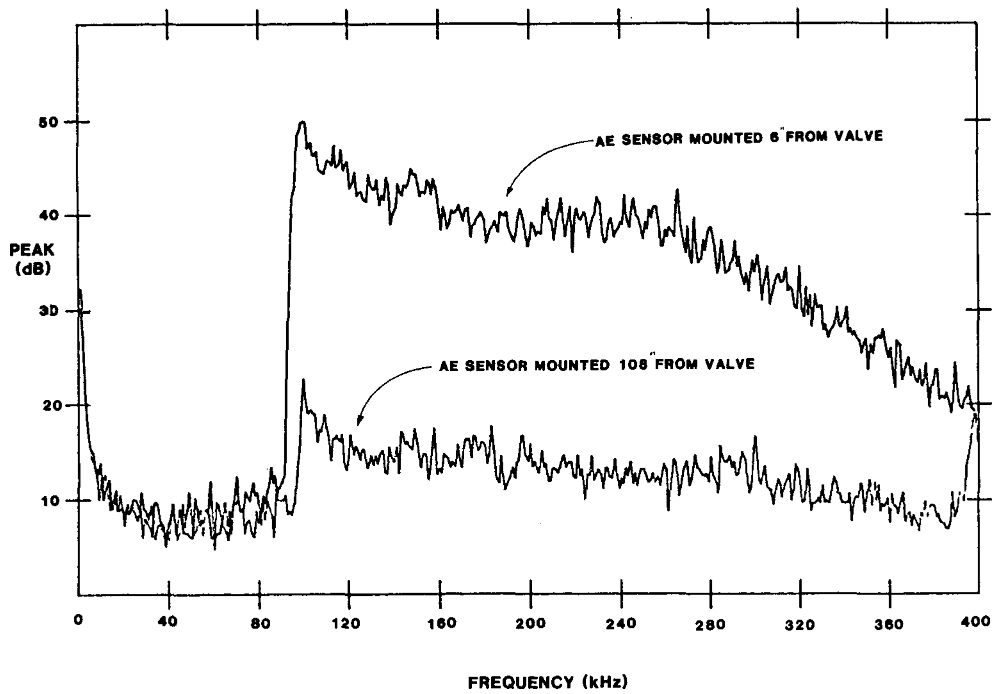

Figure 3-11. Spectra Showing Attenuation of AE Signals

SUMMARY OF TEST RESULTS

A tabulation of the measured acoustic levels of typical plant background noise and valve flow noise is given in Table 3-1. These values are conservative, in that the listed background noise values are considered to be high and the flow noise values to be low. The ranges of values are comparable for both the accelerometer-detected signals and the AE-sensor detected signals. However, there is no obvious correlation between the two types of signals. In fact, two valves, which have the largest difference between the accelerometer signals, have identical signal levels as detected by the high-frequency AE sensor. It is believed that the low frequency acoustic activity is associated with flow-induced vibrations and pipe resonances, and therefore is dependent on both the level of flow and the geometry and constraints of the pipe. The high frequency acoustic activity is probably generated by the sonic turbulent jet at the valve's orifice and is conducted to the sensor on the exhaust pipe both through the gas-pipe interface and directly through the valve metal-pipe connection.

Conservative ratios of the measured valve flow noises to typical plant background noises are given in Table 3-2. The values have been rounded off for easy comparison. It is reasonable to quote, as a rule of thumb, "The rms valve flow noise will be 100 to 1000 times the rms background noise."

Table 3-1

MEASURED ACOUSTIC LEVELS OF TYPICAL BACKGROUND NOISE AND VALVE FLOW NOISE

Plant or Valve	Accelerometer	AE Sensor
Peach Bottom [BWR (Background)]	0.26 g	--
Sequoyah [PWR (Background)]	0.05 g	0.0015 Pa
Target Rock	61 g	--
Masoneilan	>57 g	>0.2 Pa
Dresser 31533VX	88 g	0.9 Pa
Crosby HPV-SN	46 g	2.8 Pa
Crosby HA	7 g	0.9 Pa
Crosby HB	9 g	0.3 Pa

Table 3-2

CONSERVATIVE RATIOS OF VALVE FLOW NOISE TO TYPICAL PLANT BACKGROUND NOISE

	Flow Signal / Typical Background	
Valve	Accelerometer	AE Sensor
Target Rock	2×10^2	--
Masoneilan	1×10^3	1×10^2
Dresser 31533VX	2×10^3	6×10^2
Crosby HPV-SN	1×10^3	2×10^3
Crosby HA	1×10^2	6×10^2
Crosby HB	2×10^2	2×10^2

Section 4

CONCLUSIONS AND RECOMMENDATIONS

The results of the measurements demonstrate that valve actuation produces acoustic signal levels which are a hundred to a thousand times greater than the acoustic levels present when the valves are closed. Therefore, acoustic monitoring of safety/relief valves can provide clear indication of valve actuation. Furthermore, the technique gives indications of leaking valves. Although acoustic levels associated with the entire range of flows, from leaking to full flow, were not quantitatively studied, the ability to use acoustic monitoring for reliably estimating valve position has been established.

Both sonic and ultrasonic detectors can be used to sense acoustic emission generated by the flow of steam through a valve. The higher frequency devices (100-400 kHz) are better for distinguishing the near-field acoustics from the flow-induced acoustics along the pipe line. Either type of device will give reliable indication when installed on the exhaust pipe, close to the valve. Also, the low-frequency-type accelerometer can provide indication of valve actuation when installed on the exhaust pipe at a distance (10 feet and greater) from the valve.

IMMEDIATE IMPLEMENTATION OF THE METHOD

Owing to the schedules imposed by the Nuclear Regulatory Commission, the nuclear power industry recently evaluated various methods for valve-position indication. Many utilities have chosen the method of acoustic monitoring. Acoustic sensing devices, such as high-temperature accelerometers and acoustic emission sensors are available from several suppliers. The electronic instrumentation is comparable to that which is used for loose part monitoring, vibration measurement and acoustic emission leak detection. Several manufacturers of this type of instrumentation have now supplied to the nuclear power industry acoustic valve monitoring equipment.

The devices which are located within the reactor containment should be qualified to withstand the environmental conditions associated with small-break loss-of-coolant accidents, and also should be capable of operating through seismic events. Regarding such qualifications, NRC has provided "Design Criteria" in the "Proposed Revision 2 to Regulatory Guide 1.97: Instrumentation for Light-Water-Cooled Nuclear Power Plants to Assess Plant and Environs Conditions During and Following An Accident," which was released for comment in December, 1979.