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ANALYSIS OF ACOUSTIC DATA FROM THE PFR SGU CONDITION MONITOR

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SUMMARY

In order to develop an acoustic monitoring system for Fast Reactor Steam Generator Units (SGU) a knowledge of the characteristics and amplitudes of background noise in the SGU is required to allow optimum signal processing techniques to be developed and allow leak detection thresholds to be set.

This paper gives an outline description of an acoustic monitoring system which has been installed on the SGU of the Prototype Fast Reactor (PFR) at Dounreay with the objective of giving early warning of any change in noise output which could be related to potentially damaging vibrations within the units. Data obtained from this PFR monitoring system is playing an important part in the development of acoustic instrumentation for leak detection although this had not been the primary objective of this particular installation.

The PFR has three secondary circuits each containing an evaporator, a superheater and a reheater giving a total of nine SGUs. Although the design of the units is different from that intended for EFR, the measurements provide a valuable source of information on the character and amplitude of acoustic background noise in operational steam generator units.

The vibration monitoring system uses the waveguides originally installed during reactor commissioning for leak detection studies. Twelve acoustic waveguides are fitted to the shell of each of the units. The superheaters and reheaters have three waveguides at each of four axial levels, while the evaporators have four waveguides at each of three axial levels. In addition the evaporators have a small number of waveguides attached to the top flange of the unit. Each waveguide is fitted with an accelerometer to record the acoustic signal from the SGU. Tape recordings of the acoustic noise from each unit are made on a regular basis and the tapes analysed on an automated analysis system which has been developed to extract and store in a database about 20 characteristic features from the data.

The paper gives examples of the background noise from the SGU. The data demonstrates the use of location techniques to identify prominent acoustic sources.

INTRODUCTION

In order to develop an acoustic monitoring system for Fast Reactor Steam Generator Units (SGU) a knowledge of the characteristics and amplitudes of background noise in the SGU is required. This will allow optimum signal processing techniques to be developed and detection thresholds to be set.

This paper gives an outline description of an acoustic monitoring system which has been installed on the SGU of the Prototype Fast Reactor (PFR) at Dounreay. The system has the objective of giving early warning of any change in noise output which could be related to potentially damaging vibrations within the units. Data obtained from this PFR monitoring system is playing an important part in the development of acoustic instrumentation for leak detection, although this has not been the primary objective of this particular installation.

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THE ACOUSTIC MONITORING SYSTEM

Twelve acoustic waveguides are fitted to the shell of each of the nine PFR SGUs and these form the principle part of the data collection for the on-line acoustic condition monitoring. The waveguide positions are shown schematically in Fig.1. The Superheaters and Reheaters have three waveguides at each of four axial levels, while the Evaporators have four waveguides at each of three axial levels. The waveguides are positioned to give good overall coverage of the unit and spaced so that any part of the SGU is not more than three metres from at least two transducers. The waveguides are attached to the SGU shell by welding, and the accelerometers are screwed on to the end of the waveguide. Each accelerometer has an integral signal conditioning amplifier which is remotely powered from the main signal amplifier in the instrumentation room. The accelerometer signals are multiplexed into the main amplifiers as required.

The condition monitoring is performed on an off-line basis using tape recordings of the acoustic signals which are made on a periodic basis. The tape recordings are then processed in a number of ways. Firstly an overall view is obtained by passing the signals through an rms to dc converter and displaying the conditioned signal on a chart recorder. Areas of particular interest can be identified for more detailed analysis. Also samples of the acoustic signals are digitised and processed to provide spectral and probability density estimates. A total of 20 features or characteristics of the noise signals are recorded and a graphical interface allows selected features to be plotted against reactor parameters, such as sodium pump speed, or time so that any trends which could indicate a deterioration in performance can be observed. For a typical survey of the SGU over 2000 acoustic features are stored in the data base.

EXAMPLE OF ANALYSIS FROM ACOUSTIC RECORDINGS

Influence of tube bundle design on noise level.

Figs. 2 and 3 show examples of the acoustic signals as recorded on Superheater No.3 with the original tube bundle design and with the replacement tube bundle (RTB) respectively at approximately full power operation. Although both signals are impulsive in nature the difference between the two waveforms can be clearly seen. The recording with the original tube bundle (Fig.2) shows a series of large, regularly occurring impulses. Analysis revealed time intervals of about 32 milliseconds between pulses. This is consistent with the resonant vibration of a loose part (eg tube) producing regular impacting. The comparison of Figures 2 and 3 shows that features of the design of the tube bundle can significantly affect the background noise which will be monitored by an acoustic leak detection system and correspondingly the system sensitivity to the additional signal from a leak.

General RMS Noise Pattern.

Figure 4 shows a summary of the rms signal amplitude for all waveguides on each of the nine units. The figures summarise data recorded on the SGU over a three year period from October 1987 and at close to full power operation. All graphs are plotted on the same relative scale, which is linear, and shows the range, minimum to maximum, of the recorded rms signal amplitude for frequencies above 10KHz. For the reheaters and the superheaters each unit has similar acoustic signal amplitudes indicating that each unit of a particular type and under a given operating condition can be expected to have a background noise level of approximately the same value and remaining essentially constant over a period of time. In general it can be seen that the acoustic signal amplitude measured on the reheaters is larger than that on the superheaters. While the acoustic amplitudes on evaporator 1 are within the range of those measured on the superheaters and reheaters, Figure 4 shows that signal levels are up to nearly four times larger on evaporators 2 and 3. These large amplitudes are seen in particular on the waveguides at the top level on each of these units and are thought to result from the effects of leakage flows which occur between diametral and circumferential baffles within the evaporators. Again this emphasises one requirement for an optimum acoustic leak detection, and that is to carefully examine the design of steam generator units to identify features which could contribute to an enhancement of acoustic background noise.

Analysis for Impulsive Sounds.

During examination of the data particular attention is given to the tails of the probability distribution for evidence of 'spikyness' in the signal which may be produced by the presence of impulses due to loose or impacting parts. Features that highlight this include the the commonly used kurtosis of the distribution. However, for the work reported here a more sensitive indicator has been developed, the 5-sigma power factor. This latter feature is a measure of the power in the signal which is greater than 5-standard deviations (sigma) from the mean normalised to that expected for random signals with a Gaussian distribution, a Gaussian signal therefore will have a 5-sigma power factor of 1. Signals identified from evidence of impulsiveness can then be examined in more detail to determine pulse count rate, distribution of time intervals between pulses and pulse amplitude distribution. Any particularly prominent pulses can be examined by more sophisticated techniques such as source location and pattern recognition so that these signals can be monitored for any change in position or quality.

Figure 5 shows a summary of the 5-sigma power factor for all waveguides on all units for the same three year period as figure 4. It can be seen that all units have, to a varying degree, values for this feature much greater than unity indicating that the acoustic signals have a significant impulsive content. This is an important factor that must be considered in designing a signal processing system for an acoustic leak detection system. Evaporator 3 in particular has a very large value of 5-sigma power factor which is observed on waveguides at the top level of the unit again, as discussed above, in the region of the leakage flows between baffles. The acoustic signal in this region of evaporator 3 consists principally of impulsive signals which occur randomly with repetition rates having a mean value of about 80 events per second. The repetition rate is in fact large enough to produce the correspondingly large rms signal amplitude which can be seen in Figure 4.

Location of Sources

While detecting the appearance of a new acoustic source is of primary importance for monitoring the condition of the steam generators, an estimation of its location is also particularly valuable since this can be used to assist inspection teams in the assessment of damage. In addition the location of a specific source would point to selective monitoring of this area in future. An example of acoustic source location for the PFR steam generators is given below.

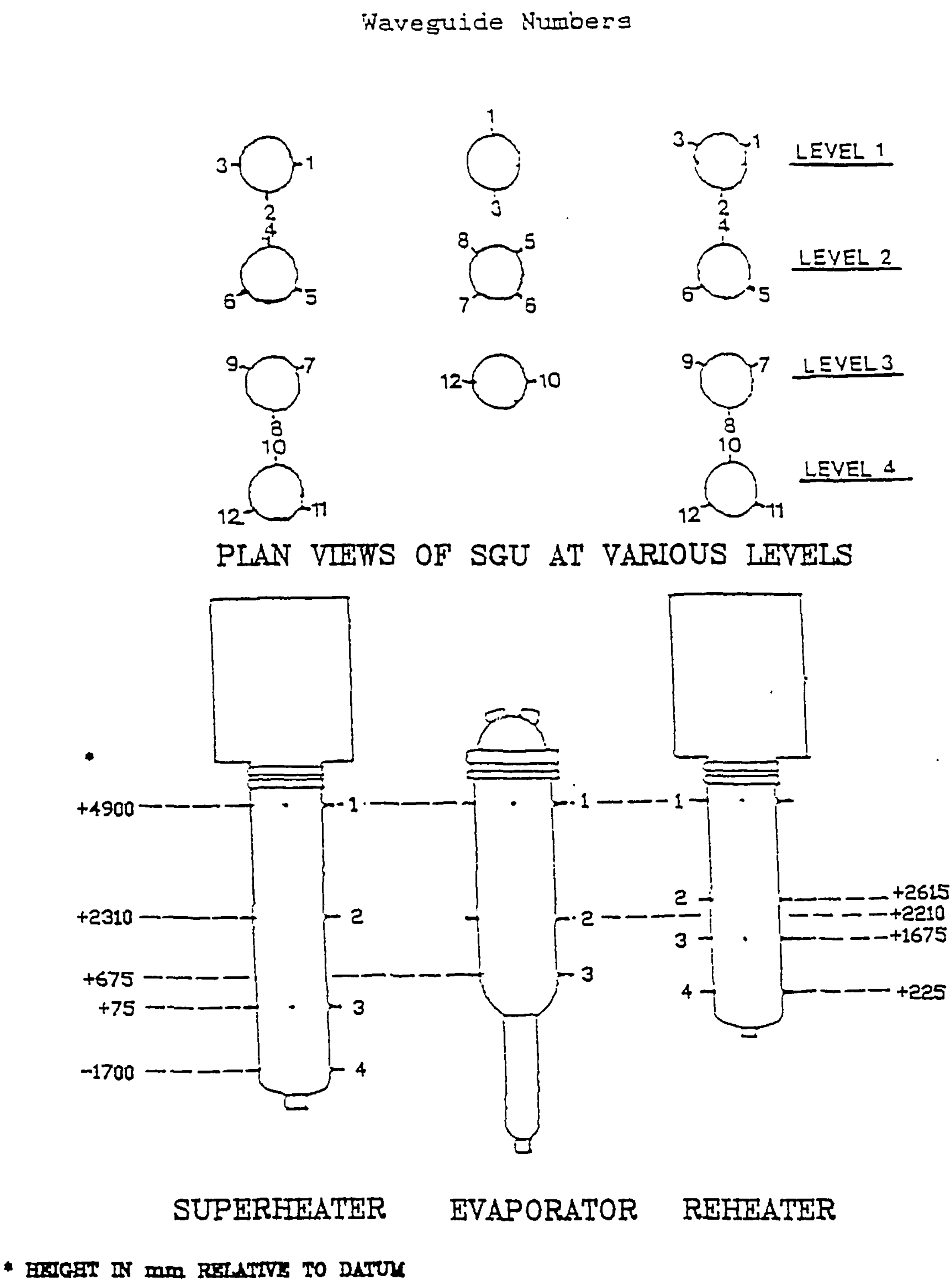
Fig. 6 shows an acoustic impulsive event in Superheater 3 as detected on a group of waveguides for data recorded in January 1990. This signal is typical of a series of pulses which occur intermittently on the unit, but when present appear to be periodic with a repetition rate of approximately 2.5Hz. The different arrival times of the pulse at the various waveguides can be clearly seen with the pulse arriving first at waveguide 4 and then closely following at waveguide 6. If the pulse arrival times are measured then the location of the noise source can be calculated using for example by plotting hyperbolae. This is illustrated in Fig. 7 which shows the area of the source location , indicated by the crossing points of the hyperbolae, relative to the waveguide positions on the shell. It is assumed in this analysis that the acoustic source is transmitted from within the unit to the nearest point on the shell and then around the shell to the various waveguides. The area of this source location on the superheater shell is shown in Figure 8 and for comparison the estimated location obtained for data recorded in January 1989. The circles enclose all the relevant hyperbola crossings to give a source between waveguides 4, 6 and 9. For the later data the pulses were smaller and consequently more difficult to time accurately and this is reflected in the larger circle of estimated source location. The origin of this noise source has not been determined at present but is close to the region at which the thermal insulation panels between the double walled central baffle terminates at grid 24. Subsequent recordings will be examined to monitor any changes in the noise characteristics in this region.

CONCLUSIONS

Acoustic monitoring gives a robust, non-intrusive method of condition monitoring for the PFR steam generators. The observation of key acoustic features give indications of possible problems within the units and there is now a growing database of acoustic analysis for the SGU. Location analysis has been used to identify prominent acoustic sources and to selectively monitor these areas during the operation of the units.

The data obtained from the condition monitoring programme is giving an important insight into the character and amplitudes of acoustic background signals from fast reactor steam generators and is proving valuable in the development of an effective acoustic leak detection system.

The sensitivity of an acoustic leak detection system can be improved by design features which eliminate or minimise sources of extraneous background noise such tube rattling, cavitation at grids and entrained free gas.



WAVEGUIDE LOCATIONS ON THE PFR SGU UNITS

FIG. 1

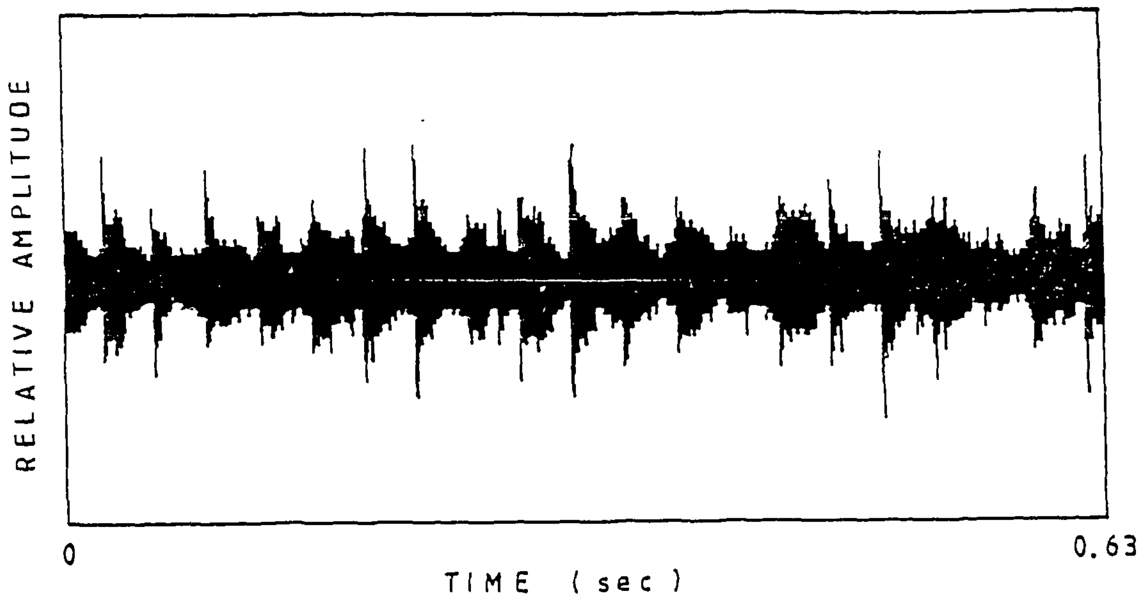


FIG.2 SAMPLE OF ACOUSTIC SIGNAL FROM STEAM GENERATOR WITH RESONANT TUBE RATTLING

FIG.3 SAMPLE OF ACOUSTIC SIGNAL FROM STEAM GENERATOR

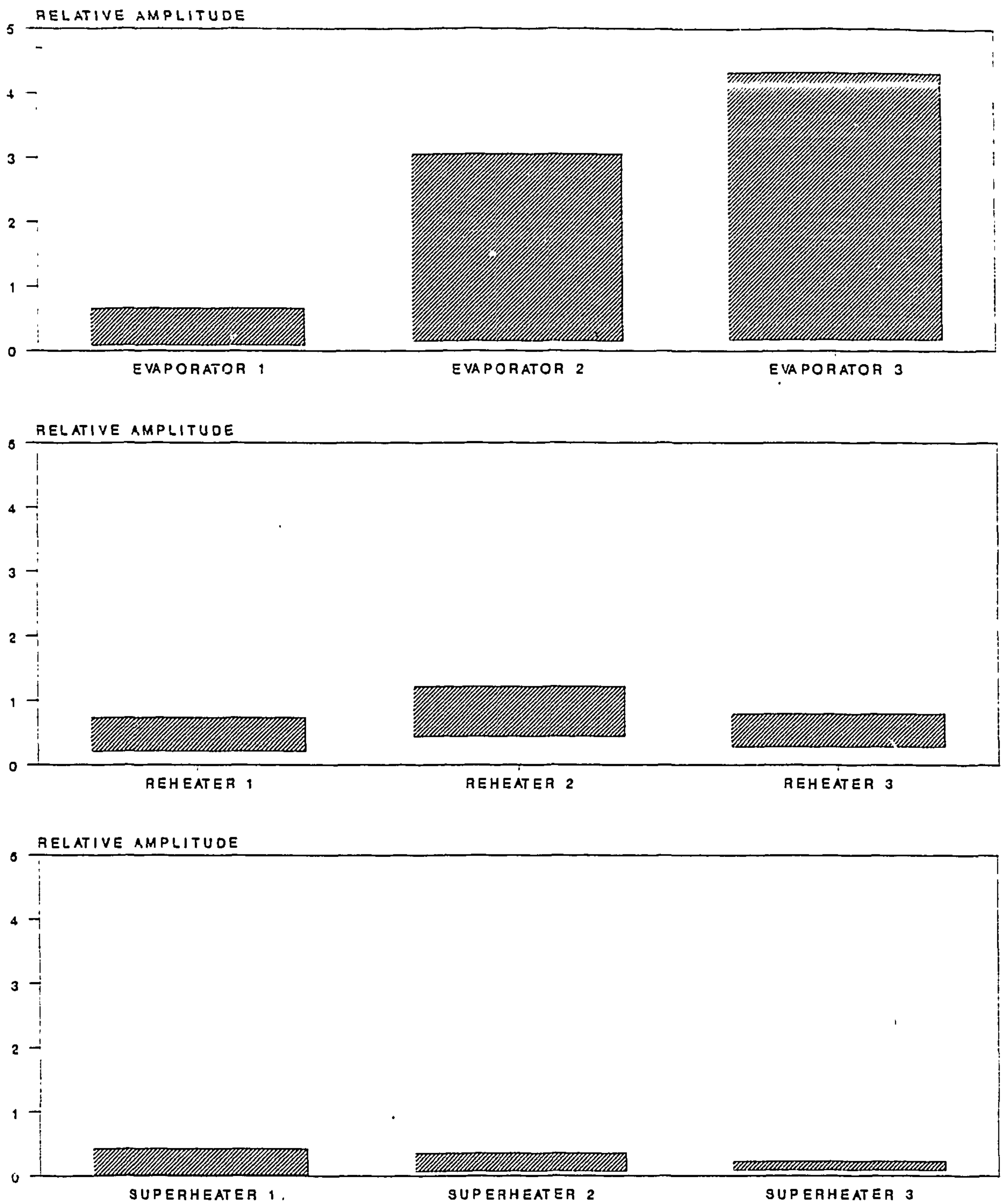
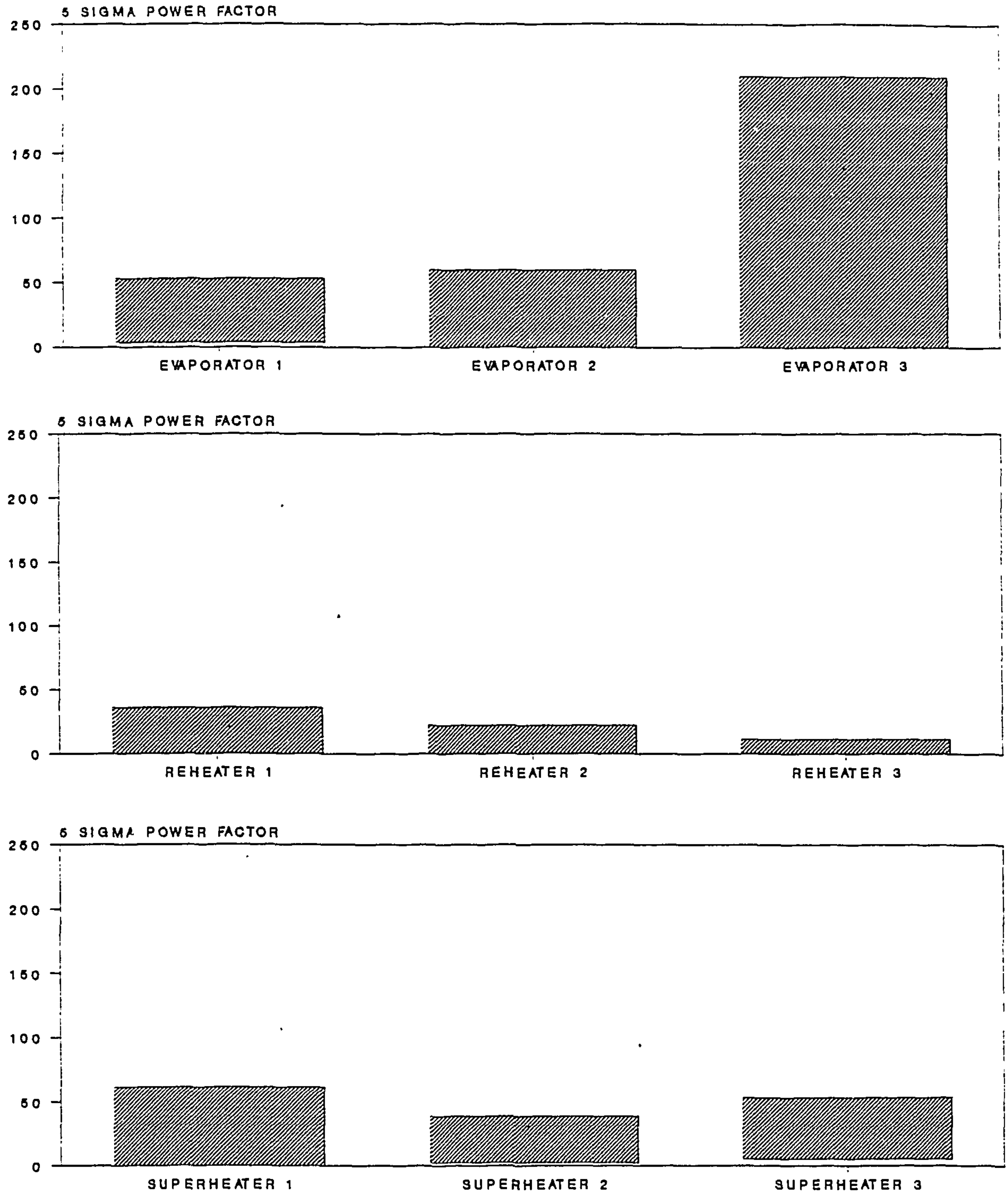


FIG.4 SUMMARY OF ALL UNITS ALL WAVEGUIDES

RMS SIGNAL AMPLITUDE (10KHz HIGH PASS FILTERED)



SUMMARY OF ALL UNITS ALL WAVEGUIDES

FIG.5

5 SIGMA POWER FACTOR

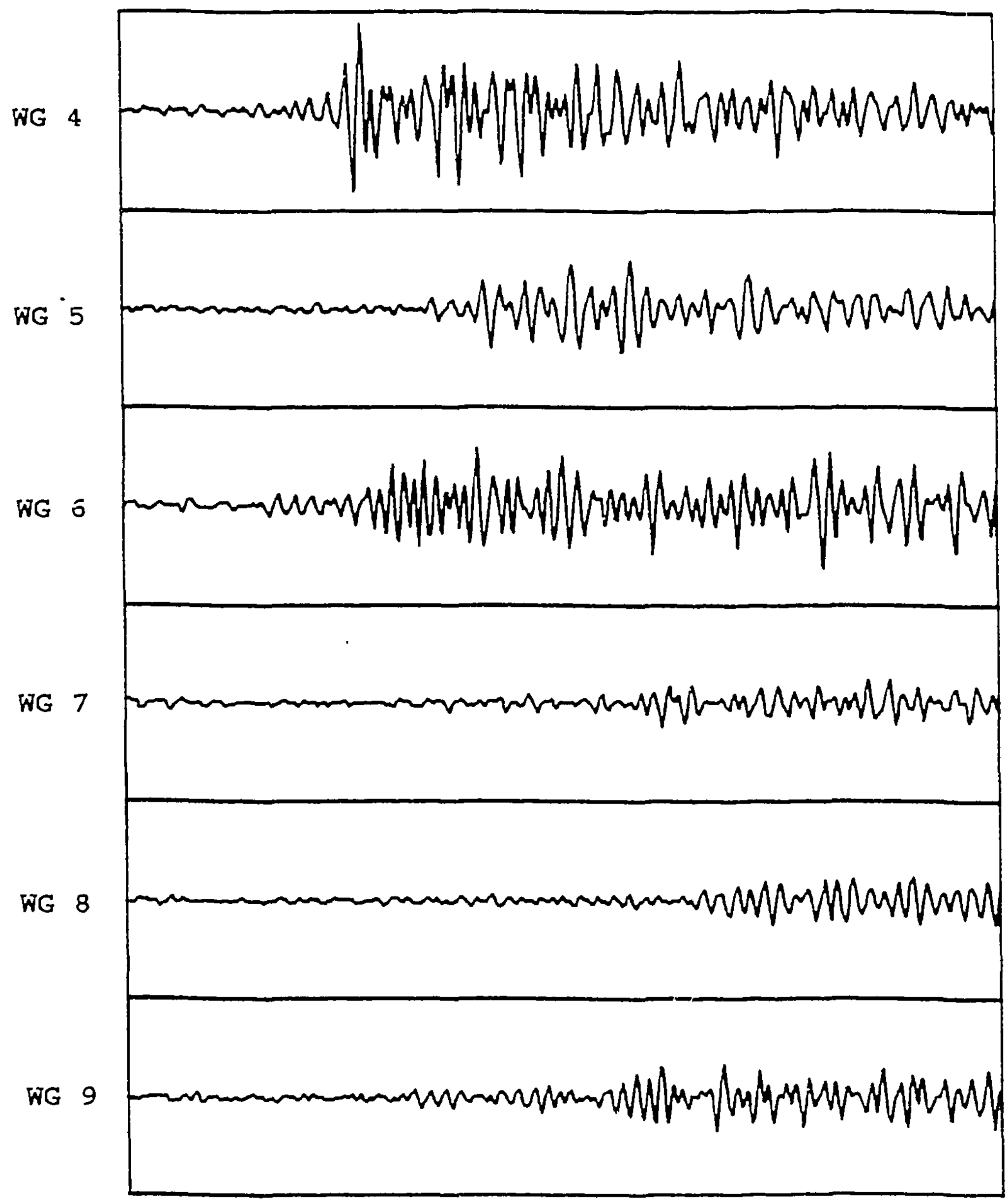


Fig 6 Typical acoustic pulse in PFR Superheater 3

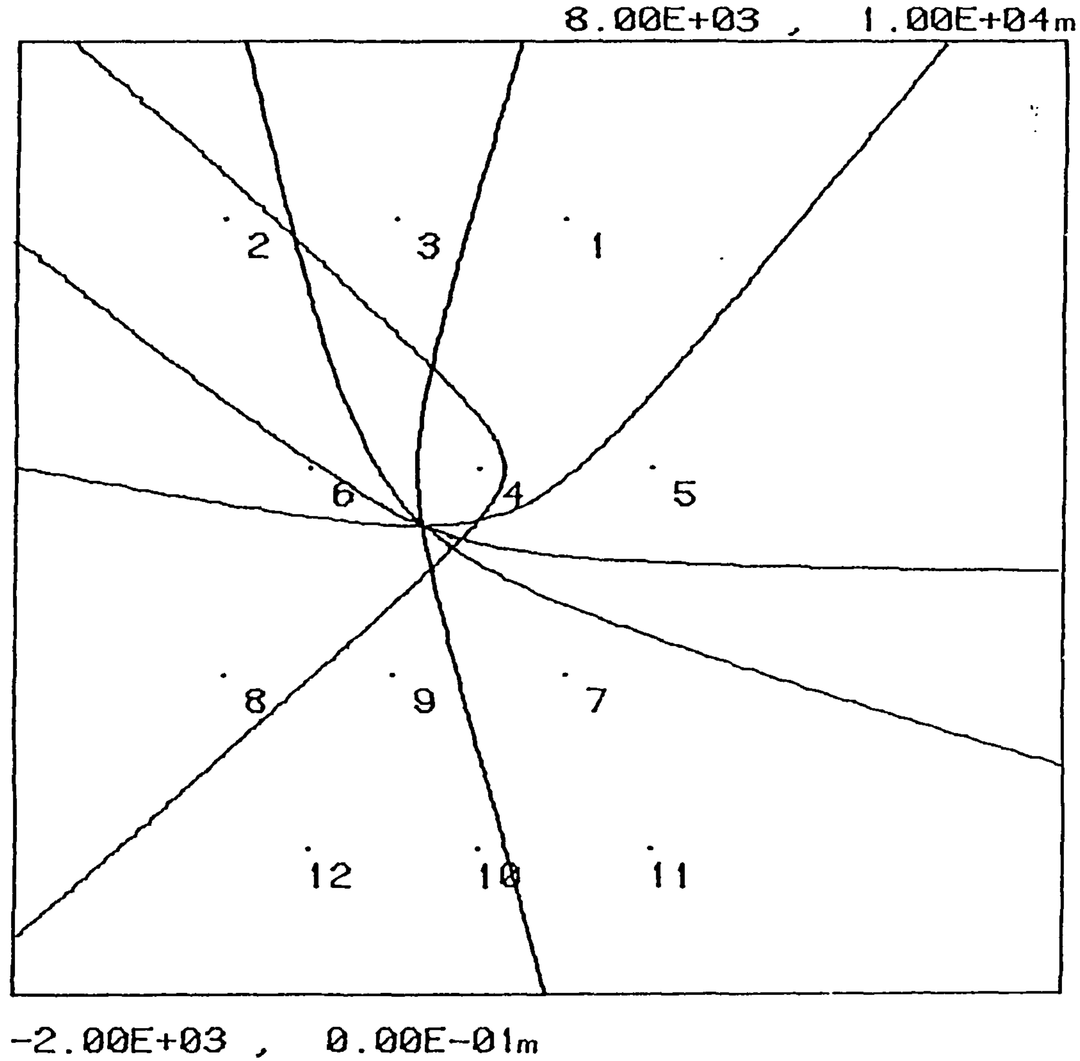


FIGURE 7 LOCATION OF ACOUSTIC SOURCE BY HYPERBOLA PLOTS.

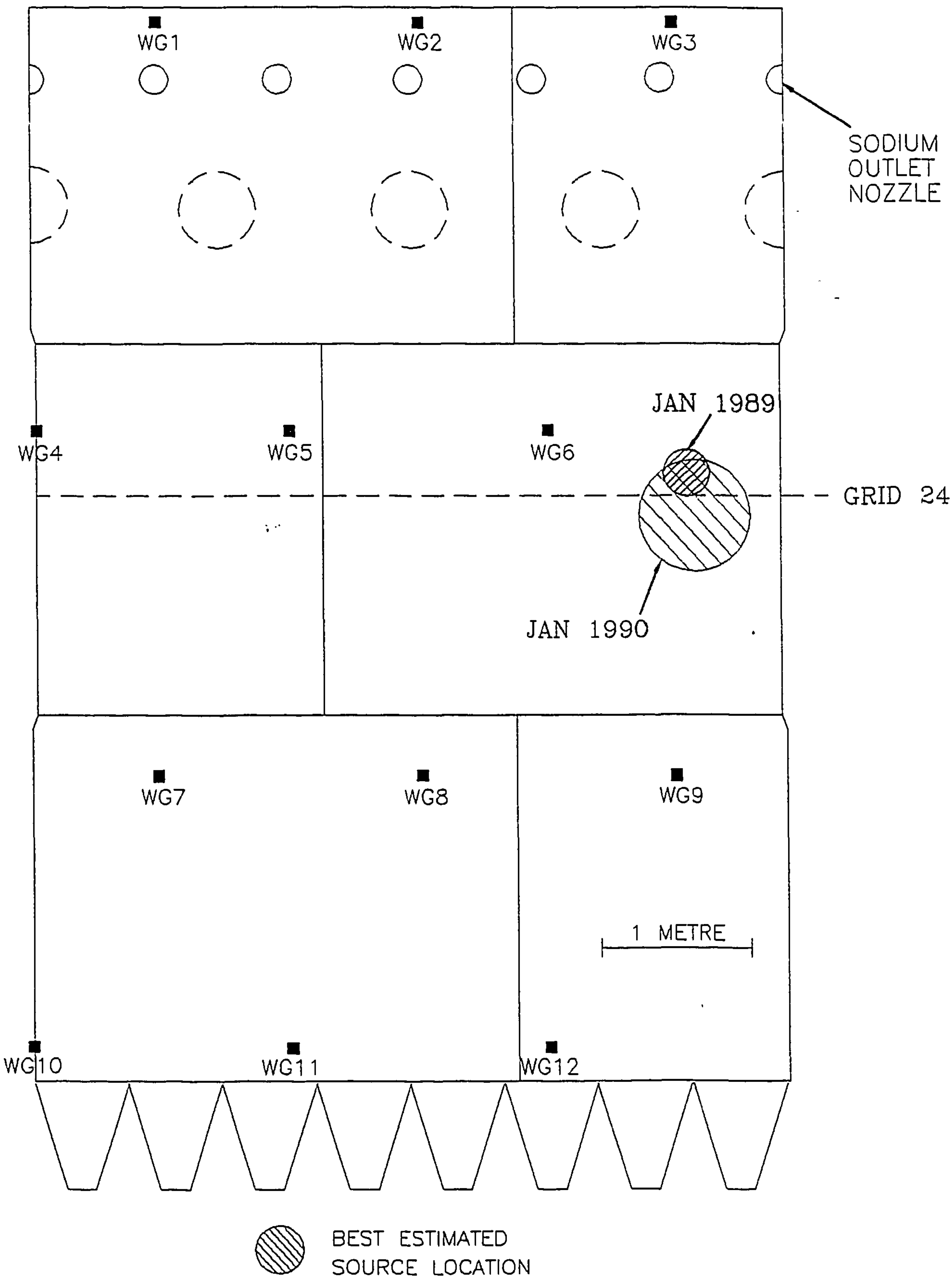


FIG.8 LOCATION OF ACOUSTIC SOURCE ON SUPERHEATER 3 SHELL