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ANALYSIS OF ACOUSTIC DATA FROM UK SODIUM/WATER REACTION TEST FACILITIES

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SUMMARY

Evaluation of passive acoustic techniques for use in leak detection systems for Fast Reactor Steam Generator Units requires a knowledge of acoustic signal strength and characteristics which, along with data on acoustic transmission properties and background noise in the SGU, can be used to determine detection sensitivity.

This paper describes acoustic measurements made during a number of sodium/water reaction experiments in the UK. The tests have included water and steam injections through both realistic (fatigue crack) defects and machined orifices and have covered a range of experimental conditions including those appropriate to the inlet and outlet regions of the EFR steam generators. Injection rates were typically in the range 0.1 to 30 g/s. Where possible, gas injections were also included in the test programme for comparison, since it is anticipated that a practical SGU acoustic leak detection system would include a facility for gas injections to allow system calibration, and to confirm transmission properties within the SGU.

The test sections were instrumented with accelerometers on waveguides and in some cases included an under-sodium microphone situated about 300mm above the reaction zone. Tape recordings were made during the tests and used for detailed analysis off-line, although an audible output from the one of the acoustic channels was used to monitor the progress of the injections and provide information for the rig operators.

A comparison of the signal amplitudes measured during the experiments with typical reactor background noise was made and an estimate of the detection sensitivity of an acoustic monitoring system was deduced.

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INTRODUCTION

Evaluation of passive acoustic techniques for use in leak detection systems for Fast Reactor Steam Generator Units requires a knowledge of acoustic signal strength and characteristics which, along with data on acoustic transmission properties and background noise in the SGU, can be used to determine detection sensitivity.

Information on signal strength and characteristics can be obtained by monitoring sodium/water reaction experiments carried out in rig facilities. While rig experiments cannot be expected to model precisely the acoustic environment for a real leak in a large size steam generator, the results obtained can nonetheless provide valuable information on the consistency of the leak noise signal over a wide range of operating conditions and allow the variation with leak rate to be determined. In addition, since a practical SGU acoustic leak detection system could well include a gas jet for calibration purposes, rig experiments provide a means to test the relationship between the leak noise and the noise of a gas jet over a wide range of leak rates.

This paper describes acoustic recordings made during a number of sodium/water reaction experiments in the UK. A considerable amount of acoustic data has been obtained and the analysis is as yet only partially complete. However some preliminary results are presented here which, when compared with measurements of reactor background noise, allow an estimate of the sensitivity of an acoustic leak detection system to be made.

EXPERIMENTAL FACILITIES

The acoustic recordings were obtained from two experimental facilities at the UKAEA Dounreay establishment, the Small Water Leak Rig (SWLR) and the SUPER NOAH rig.

The SWLR, shown schematically in Figure 1, was designed for leak rates of up to approximately 50g/s and was the source of most of the information described here. The Reaction Test Vessel (RTV) was about 205mm in diameter and 2.3m high. Individual test sections could be mounted via a top flange which was bolted to the RTV. Facilities were available for sodium flow through the test vessel.

Figure 2 shows a schematic arrangement of the SUPER NOAH rig which has a much larger RTV, approximately 0.75m diameter and 6m high, and is capable of handling leak rates into the Kg/s range.

EXPERIMENTS MONITORED

The table gives a summary of the experiments in which acoustic recordings have been made. The tests have included water and steam injections through both realistic defects and machined orifices and have covered a wide range of leak rates between about 0.2 and 500g/s and a range of experimental conditions including those appropriate to the inlet and outlet regions of the EFR steam generators.

In some of the experiments the noise from a gas jet was also measured with a view to determining which gas injection parameters most nearly simulate the noise of a sodium/water reaction. The intention is that a gas jet could then be used in a real SGU to allow the sensitivity of the detection system to be determined.

In general the experiments were performed for a campaign of code validation and wastage measurements, but two of the experiments in the SWLR were designed specifically for acoustic leak detection purposes. The first of these tests was designed to provide acoustic data for steam leaks between 1 and 20g/s at conditions representative of the superheated steam region of the EFR steam generators while the second test was to cover a similar range of leak rates at conditions appropriate to EFR steam generator inlet conditions.

Five of the injections in the SWLR were made with realistic defects which were fatigue cracks manufactured in France and designed to deliver an initial leak rate of between 0.1 and 0.5g/s. These injections formed an experimental series designed to determine the self evolution of leaks in Alloy 800 material. The remainder of the injections were made with machined orifices.

All of the injections, except for those in the special acoustic tests, were made with target tubes or plates.

ACOUSTIC MEASUREMENTS

In the SWLR experiments the test sections were instrumented with sensors on waveguides which penetrated the top flange of the RTV and terminated within the test section about 300mm above the reaction zone. The sensors included a number of different types of accelerometers covering a frequency range up to about 100KHz and an acoustic emission transducer with a frequency response in excess of 500KHz. Where possible, an accelerometer of a similar type to that used in the PFR SGU condition monitoring system[1] was included so that a comparison could be made with background noise in an operating SGU. In addition to the test section transducers an accelerometer attached to a waveguide on a branch pipe from the RTV was available for the later tests. Some experiments included an under sodium microphone, situated near the ends of the waveguides about 300mm above the reaction zone. The microphone was included to allow a signal amplitude comparison in terms of pressure and also as a possible aid to discriminate between the various noise sources produced during the experiments. The exact types of transducers used in each of the experiments depended on the test section design and the availability of instrumentation at the time of the test.

In the SUPER NOAH rig the acoustic instrumentation was more limited and consisted of an accelerometer and an acoustic emission transducer mounted on waveguides which were attached horizontally to the top flange of the RTV.

Preamplifiers for each of the transducers were positioned close to the rig and the main amplifiers and signal conditioning and recording equipment was situated in the remote control rooms which were up to a 100m from the rig areas.

Tape recordings of the acoustic signals were made during the tests and used for detailed analysis off-line, although an audible output from the one of the acoustic channels was used to monitor the progress of the injections and provide information for the rig operators.

ANALYSIS

A large amount of data is available in the form of magnetic tape recordings and this is currently being analysed. However, a preliminary analysis has been made to provide a first assessment of signal strength using simple rms amplitude measurements and the results are given here for selected experiments from the SWLR. The analysis so far has concentrated on the lower frequency accelerometer which is of the same type as that used on the PFR SGU condition monitor.

Figure 3 shows the variation of rms acoustic signal amplitude with leak rate for two of the Leak Evolution tests, LET3 and LET3A. The rms amplitude shown is for frequencies above 10Khz and was obtained from a spectrum analysis over a frequency range of 100KHz. The choice of frequency is not optimised for leak detection but chosen arbitrarily to match that most commonly used for the PFR SGU condition monitoring to facilitate a comparison with reactor background noise. For LET3A the injection rate varied from 0.12g/s to 30g/s during the evolution of the leak, while for test LET3 the leak rate was in the range 0.68g/s to 30g/s. As can be seen the acoustic amplitudes for the LET3A test were larger than for LET3, approximately by a factor of four in the lower leak rate range decreasing to a factor of two at the higher leak rates. However the data from each experiment follows a power law of the form:

amplitude = constant x $(\text{leak rate})^n$.

The value of n is 0.43 for LET3A and 0.63 for LET3. These values are in good agreement with those obtained by other workers, for example in reference 2. The different signal amplitudes in the two experiments may reflect the difference in noise production from defects of different shape and character as well as general differences in experimental parameters. This emphasises the importance of rig measurements in determining the statistics of the leak noise in a variety of conditions so that the reliability of the detection method can be determined.

Also shown in figure 3 is the rms acoustic amplitude for the argon injection performed test LET 3A which lies close to the best fit line for the steam injection.

Figure 4 shows the variation of rms acoustic signal amplitudes with leak rate for the acoustic monitoring tests (AMT) in the SWLR for water, steam and gas injections. Again the signal amplitudes are those measured for frequencies above 10KHz. Also shown for comparison are the data from Leak Evolution Tests LET3 and LET3A extracted from figure 3 but shown as lines for simplicity. The data show much more scatter than was obtained in the Leak Evolution Tests although 15 out of 21 points lie between the bounds of the results for the LET3 and LET3A tests, and in particular acoustic amplitudes for the steam injections in AMT1 form a good fit to a power law with n=0.36. A further, more detailed, analysis of the recordings from the acoustic monitoring tests is currently being made in the light of more detailed information which is now available on the experimental conditions which existed in the rig during the measurements, and it is anticipated that this will resolve some of the apparent scatter in the data.

FURTHER WORK

The above analysis is based on only part of the considerable quantity of recorded data available and further work is continuing to measure signal strength in the rig experiments not yet analysed and to determine optimum signal characteristics for an acoustic analysis system. In addition the results with different types of transducers will be compared along with the recordings from the under sodium microphone which should provide a calibration of signal strength in terms of sound pressure level.

ASSESSMENT OF DETECTION SENSITIVITY

As has been stated above the planned method of estimating sensitivity is to use a gas jet as a transportable acoustic source to compare the signal from sodium/water reactions in rigs with the background noise in a SGU. Depending on where the gas jet can be inserted this measurement could also take into account typical transmission losses. At present an injection of this type has not been carried out in the UK and an assessment has to be made from independent rig and SGU background noise measurements. This assessment uses the signal strength measured in the SWLR tests so far analysed and the background noise measured on the PFR vessels[1]. This comparison involves assumptions about the equivalence of transmission paths which are likely to be optimistic for some source locations.

This method is illustrated in Figure 5. The background noise is taken as the minimum and maximum levels observed on Superheater 3 and Reheater 2 respectively, and excludes the larger noise measured at the top levels of Evaporators 2 and 3 which are considered to be atypical. A value of 10dB has been arbitrarily added to the measured values to include an allowance for probable additional transmission losses. This figure may be optimistic for some leak locations but a better estimate should be possible when the current series of tube bundle transmission measurements[3] are completed. The variation of signal level with leak rate is represented by the bounds of the acoustic signal amplitude shown in Figures 3 and 4, the solid lines shown enclosing about eighty five percent of the data points shown for the various experiments and injection conditions. Referring to Figure 5, it can be seen that detection sensitivity can be estimated to be between 13 and 67g/s for the worst case of measured signal values (lower bound) or between 0.55 and 34g/s in the best case (the upper bound). Broadly, it seems that detection could be possible for leak rates of about 50g/s without any improvement in conditions or analytical technique.

The above estimate is based, however, on simple rms measurements and does not take advantage of differences in signal characteristics between the signal and background to improve sensitivity. It seems reasonable to anticipate that by optimisation of measurement parameters and with more sophisticated signal processing a detection sensitivity of only a few g/s could be achieved. However detection sensitivity will always be constrained by the related requirements of detection time, likely to be in the range of a few seconds, and acceptable spurious rate.

It is also clear that the physical construction of the actual SGU unit is a major parameter in the argument. Our estimates are based on background signal measurements taken from the PFR secondary circuit, yet it has already been demonstrated that these backgrounds vary considerably between the different vessels[1]. Figure 5 also indicates the influence of this variation for two units. For a noisy unit (PFR Reheater no 2) the sensitivity is in the range 34-67 g/s, whilst for the quieter Superheater No 3, the range is 0.55-13 g/s. It is clear that with the latter, a sensitivity of a few g/s is no great problem.

CONCLUSIONS

Acoustic signals have been recorded during a series of sodium/water reaction experiments performed on two facilities at Dounreay; the Small Water Leak Rig and Super Noah. The sensors included a variety of accelerometers, as well as a waveguide similar to that used on the PFR SGUs, and a sodium immersed transducer.

A preliminary analysis has been performed for experiments in which the leak rates varied from 0.1 to 30 g/s. It shows that the noise emission from the leaks follows an expected power law. The scatter of results is significant, however.

By combining these results with background information from the PFR secondary circuit units, it is possible to make a first estimate of leak detection sensitivity for a passive acoustic system relying only on changes in rms signal amplitude. Based on this, an initial estimate of at about 50 g/s leak rate sensitivity seems reasonable. However a higher sensitivity, of only a few g/s, should be achievable by either by more sophisticated signal processing, or if the background signal could be limited through the SGU design.

It is desirable that further measurements be made to improve the statistical knowledge of the acoustic signal strength to be expected from water/sodium leaks.

REFERENCES

1. Rowley R and Airey J. "Analysis of acoustic data from the PFR SGU condition monitor." IAEA IWGFR SM2: Steam generator: acoustic/ultrasonic detection of in-sodium water leaks, session 4. Aix-en-Provence, Oct 1990.

2. Pridöhl E, Fröhlich K J, Matal O and Konarik M. "Results of acoustic measurements during leak simulation experiments on a sodium-heated modular steam generator." Paper 29, pp 143-150, Liquid metal engineering and technology, BNES, London, 1984.

3. Rowley R and Airey J. "Acoustic Transmission in SGUs: Plant and Laboratory Measurements." IAEA IWGFR SM2: Steam generator: acoustic/ultrasonic detection of in-sodium water leaks, session 3. Aix-en-Provence, Oct 1990.

TABLE

Rig experiments used for acoustic measurements

Test No.	H_2O injection		Na conditions			Leak rate g/s	Gas injection g/s
	Bar	°C	°C	Bar	m/s		
Alloy 800 Leak Evolution Tests - SWLR							
LET1	170	350	350	3	0.4	0.2-2	-
LET2	170	510	510	3	0.4	0.2-45	-
LET2A	170	515	510	3	0.4	1-19	-
LET3	170	510	510	3	0.4	0.5-30	-
LET3A	170	510	510	3	0.4	0.2-20	33-55
Acoustic Monitoring Tests - SWLR							
AMT1	170	412	500	3	0.4	0.3-15.6	1.6-32
AMT2	170	250	340	3	0.4	0.2-50	0.4-6.4
PFR Evaporator Wastage Tests - SWLR							
EWT4	170	325	380-440	3	0.4	0.15-3.3	-
Alloy 800 Wastage Tests - SUPER NOAH							
6X18A	150	340	380	1	-	approx 100	60
6X18B	150	340	390	1	-	approx 500	-

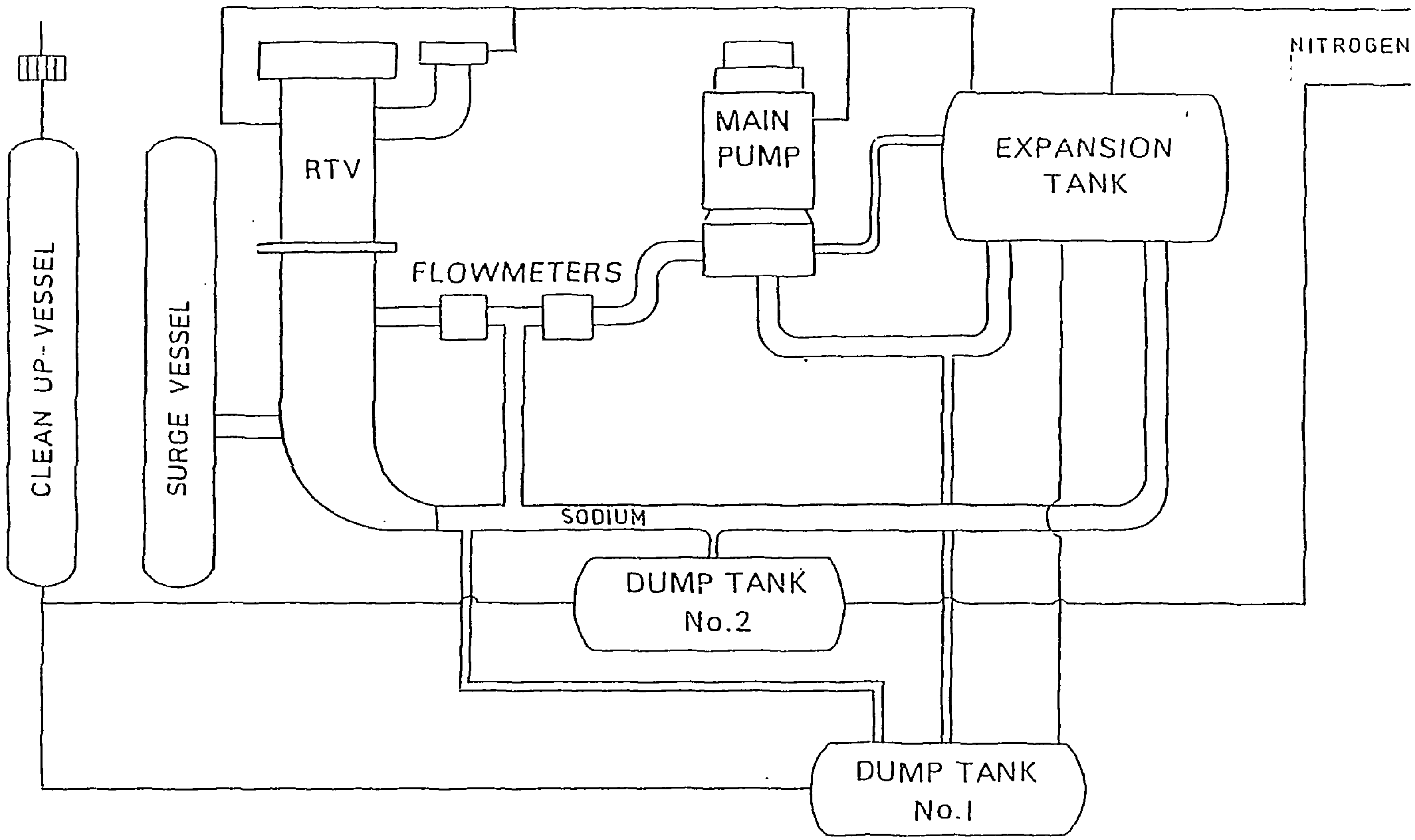

Fig 1 Small Water Leak Rig (SWLR) - Schematic Arrangement

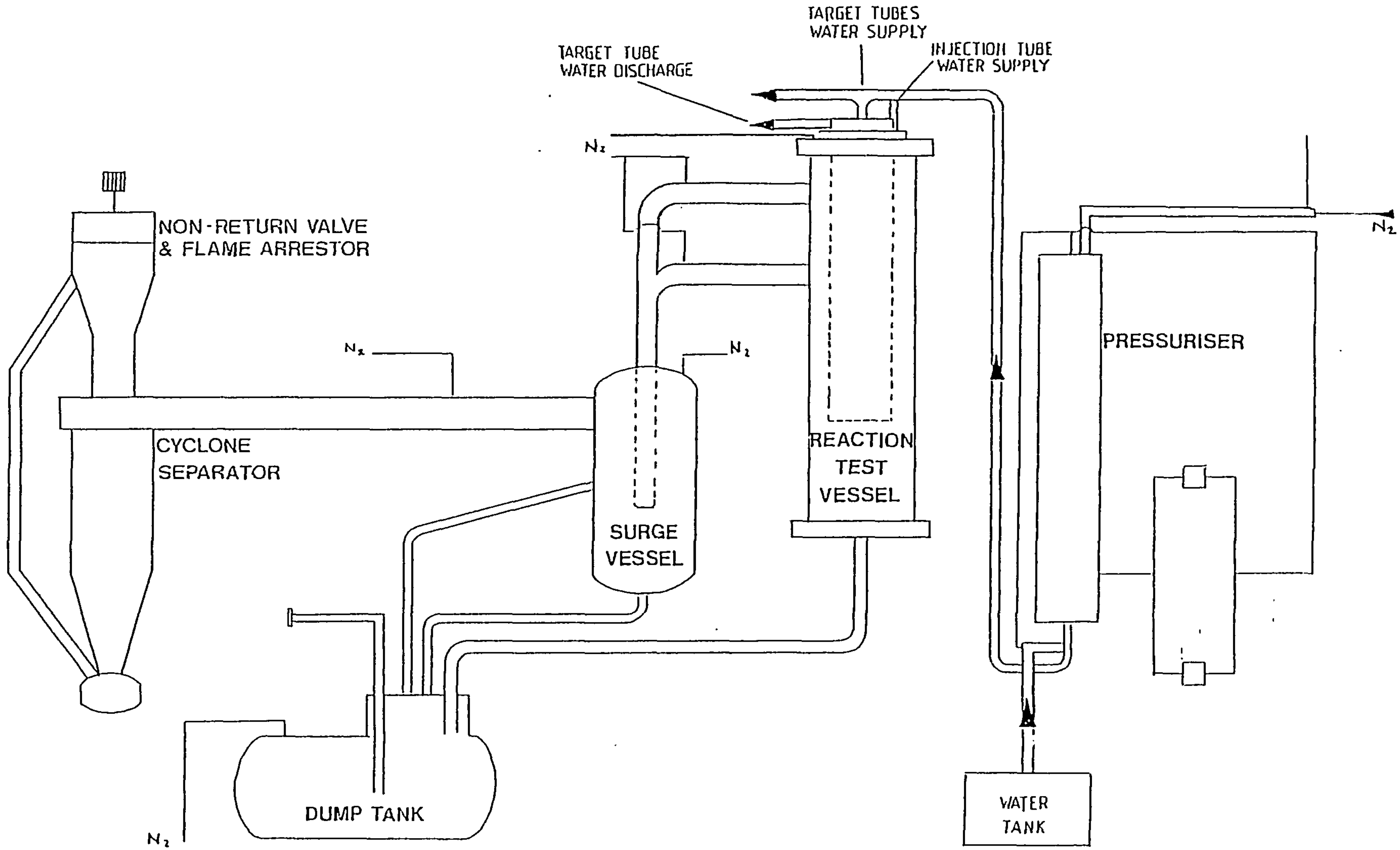

Fig 2 SUPER NOAH Rig - Schematic Arrangement

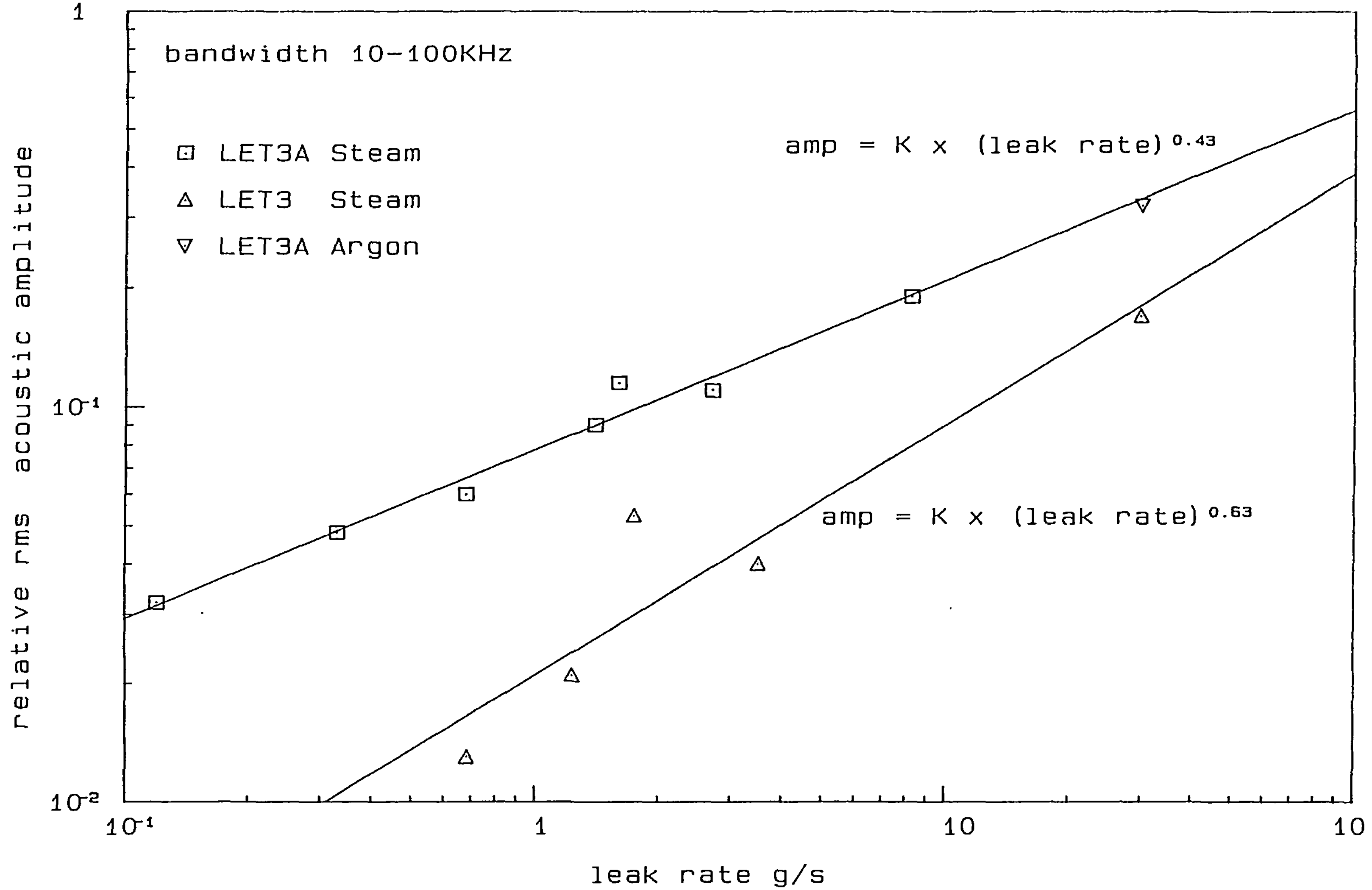

Fig 3 Acoustic amplitudes measured in SWLR - LET tests

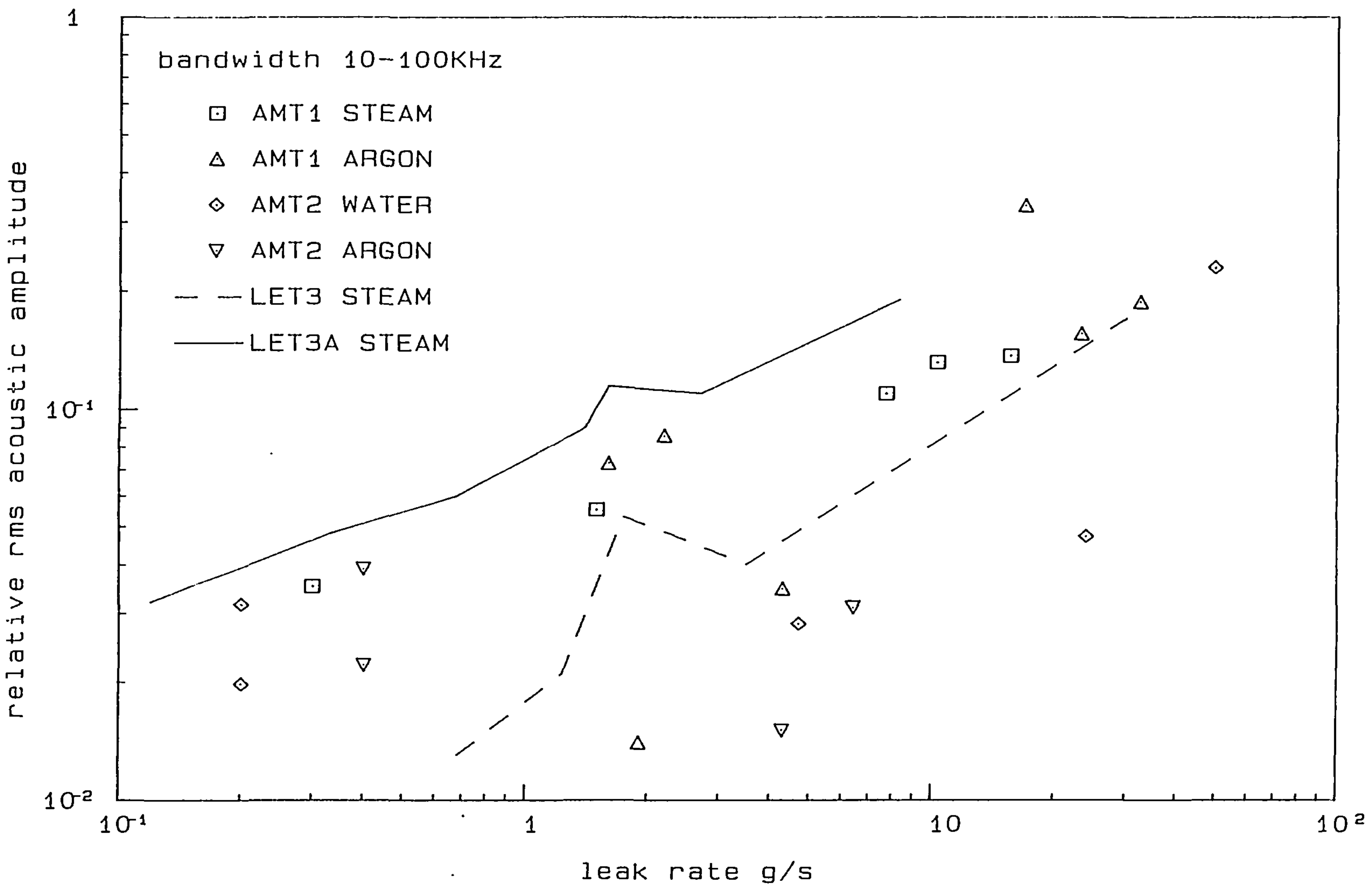

Fig 4 Acoustic amplitudes measured in SWLR - AMT & LET tests

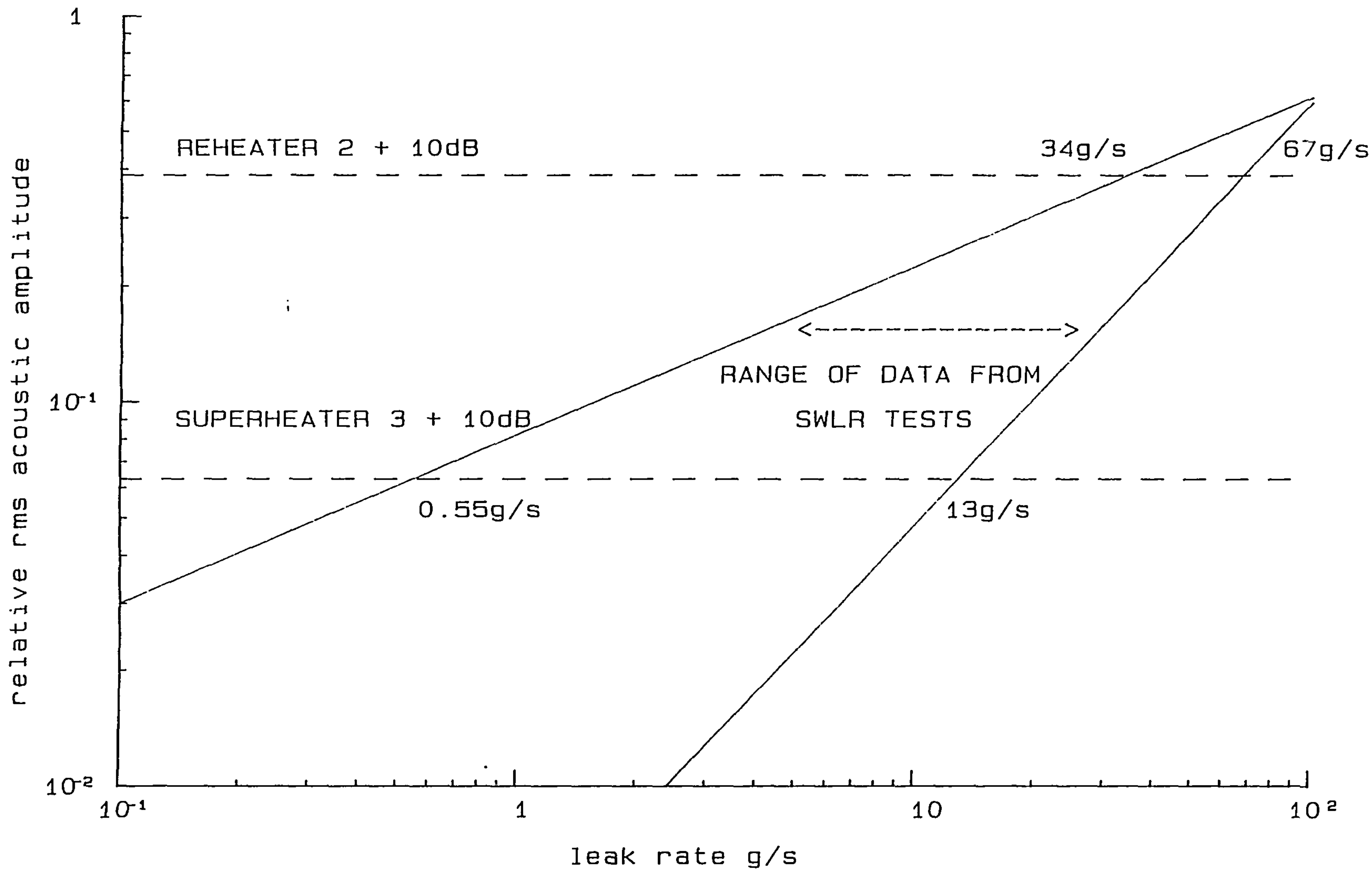

Fig 5 Estimated sensitivity for acoustic leak detection