Development of Acoustic Leak Detection System in PNC

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Abstract

The development of an acoustic leak detector is under way at PNC as a detection system that has potential of quick response and high reliability for larger steam generators of future LMFBR plants. The studies have two aspects, i.e., an acoustic wave analysis in various sodium-water reactions and a background noise (BGN) analysis in a sodium-heated 50MWt steam generator (50MWSG). In the former analysis, wave profiles of the sodium-water reaction sound were analyzed and compared with those of inert gas injection sound. The comparison revealed that there were no wave profiles specific to a sodium-water reaction sound. The latter clarified that major acoustic sources in the steam generator were sodium flow and steam generation/flow and that the water leak rate at which a noise level was comparable with that of the background noise was about 0.5 g/sec. in the evaporator of 50MWSG. The estimation of acceleration levels of BGN and leak sounds in other plants reveals that an intermediate leak is detectable in the Monju evaporator with a present acoustic detection system.

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1. Introduction[1)]

At present, the most reliable detector of a water leak in steam generators of LMFBR plants is thought to be a hydrogenmeter, especially because of its high sensitivity. However, the hydrogenmeter usually has a as long detection delay time as a minute or so because hydrogen has to transfer along piping from a leak point to an ion gauge of the hydrogenmeter. In a commercial plant, a steam generator will be scaled up, which would result in longer detection delay time. Therefore, a new type of leak detector that has a short response time as well as high sensitivity will become strictly necessary for larger steam generators. An acoustic leak detector promises to meet this requirement because its detection time is expected to shorten to about ten seconds at most. However, it can detect only the leak that generates bigger sound than the steam generator background noise (BGN) and the lowest detectable leak of the acoustic detector tends to be higher than that of the hydrogenmeter. Therefore, R&Ds on the acoustic leak detection system have been conducted at OEC/PNC for years to demonstrate its feasibility to the larger steam generators.

The two main methods are known in detecting acoustic signals generated by a leak; a high frequency type (50 kHz -) and a low frequency type (- 20 kHz). In order to determine which type is more suitable to leak detection, a preliminary study was executed by injecting an inert gas into water. It was concluded from the preliminary study that high frequency components above around 3 kHz attenuated quickly before reaching the outer shell because generating bubbles behave as sound absorbers. Thus, the low frequency type was chosen for its higher attainable sensitivity in the case of the leak detection using the sensors mounted at the outer shell.

At first, characteristics of sodium-water reaction sounds were studied using the SWAT test rigs. Then the BGN in a sodium-heated 50MWt steam generator (50MWSG) was examined and compared with the sodium-water reaction sound. Finally an inert gas was injected into an evaporator of 50MWSG, and the water leak rate that produces a leak sound level almost equal to the BGN level was determined.

2. Analysis of the Sodium-Water Reaction Sound

2.1 RMS Value of the Sodium-Water Reaction

Sodium-water reaction tests were conducted using the test rigs of SWAT-1 through -4 to investigate leak development behavior from a micro-leak to a large leak. To analyze the sodium-water reaction sound, accelerometer type acoustic sensors were placed on outer wall of the test vessels. Figure 1 illustrates accelerometer mounting. The wave guide rods made of steel were welded on the vessel wall by welding and each accelerometer was screwed on the top of the rod. In some tests, cooling fins were attached at the middle of the rod. Then acoustic signals of the sodium-water reaction were analyzed from various points of view. As an example, Figure 2 shows acceleration level changes during a failure propagation simulation test in SWAT-3. At least, three times of level increases are observed clearly from the figure. In SWAT-2, similar tests showed that the root mean square (RMS) values of the acoustic signal generating from the sodium-water reaction are proportional to one third power of water injection rates just as indicated in Figure 3.

2.2 Frequency Analysis of the Sodium-Water Reaction Sound

A frequency spectrum analysis revealed that the sodium-water reaction sound was almost white noise without any peak but a natural frequency of the wave-guide rod. It reveals also that there was no appreciable difference in the spectrum profiles between the sodium-water reaction and inert gas injections. Additionally, it was also confirmed that a gas flow rate could be converted into a water leak rate by expressing both as a volumetric flow rate. This means that the reaction sound can be simulated by an inert gas injection in an experimental study in both senses of sound quality and amplitude.

3. Analysis of Background Noise in 50MWSG

For the development of the acoustic leak detection system, it is important to understand the characteristics of the background noise in a sodium-heated steam generator. Thus, accelerometers were mounted on the outer wall of the evaporator of 50MWSG. Figure 4 shows the schematic of the evaporator.

3.1 Relation between Various Noise Sources and BGN Level

(1) The effect of thermal load

The RMS value of BGN in 50MWSG was plainly dependent on its operational conditions. The relation between a thermal load and the BGN level is shown in Figure 5, where black triangles denote the data obtained when a superheater was also operated. However, these data points indicated that no sound generating in the superheater reached the evaporator. When the thermal load changes, other conditions such as a sodium flow rate, a sodium temperature, and a steam generation rate also change simultaneously. Consequently, it is difficult to distinguish one effect on BGN level from the others. For this reason, the individual effects were investigated in the following measurements.

(2) The effect of sodium temperature

The relation between the sodium temperature and the RMS value of BGN level was studied at a constant sodium flow rate under a hot standby condition as shown in Figure 6. Although a rise in the sodium temperature causes an increase in the accelerometer temperature, a thermal drift of the accelerometers in this range is too small to cause an output increase compared with the observed BGN level. Therefore, the BGN level dependence on the sodium temperature is explained to as the change of absorption or scattering of sound at the internals and a change of sodium viscosity.

(3) The effect of sodium flow rate

The relation of the BGN RMS value and a sodium flow rate at a constant sodium temperature of 240 °C is shown in Figure 6. The level increases monotonously with the increase of the sodium flow rate. In the same figure, acceleration levels are shown with different sodium temperatures and under a steam generation condition, too. The acceleration level was about 0.007G [G = 9.8 m/sec^2] at 315 °C of the sodium temperature as a rated sodium flow rate. Black circles denote accelerations during the steam generation where the sodium temperature ranged from 300 to 315 °C. The acceleration under a rated power is about 0.01G in Figure 6.

(4) The evaluation of the effect of steam generation/flow

It is postulated that the acceleration during the steam generation is larger than that on a hot standby due to noise caused by steam generation/flow inside tubes. Then, the acceleration from steam is calculated as about 0.007G which is coincidentally same level as that of the sodium flow.

3.2 BGN Wave Spectrum Analysis

The BGN wave spectra were investigated under various operating conditions. The BGN is explained to be almost white from their rather flat spectra. Although an overall noise level becomes higher with the increase in the thermal load, the spectrum structure does not change even then. Similarly, other parameters like the sodium flow rate does not affect the spectrum either. The spectra of the sodium-water reaction sound in SWAT-2, the inert gas injection sound in 50MWSG, and the BGN of 50MWSG are compared with one another in Figure 7. The spectrum profiles of the sodium-water reaction and BGN are similar but the inert gas injection sound is slightly different from others in the frequency range lower than 1kHz. However, the spectrum differences are not clear enough to distinguish one wave from the others by the spectrum profile. It is concluded that a sound source could not be identified from its spectrum profile.

4. Evaluation of Applicability to Actual Plants

4.1 Inert Gas Injection Test in 50MWSG

The most important number in the feasibility study of the acoustic detection system is the minimum detectable water leak rate. To determine the limit, argon gas was injected into the evaporator of 50MWSG. According to the thesis that a gas flow at the same volumetric flow rate generates the same sound power, flow rates of the argon gas are converted into the water leak rate by a certain exchange rate. Here, the water gushing out of the tube is thought to be in a steam phase. The gas was injected at the lower or upper tube bundle region. Figure 8 indicates that the acceleration levels are proportional to the one third power of the converted water leak rate just in the same manner as the SWAT-2 results described in 2.1. The water leak rate at which the RMS value becomes equal to that of the BGN level (0.01G) is estimated as about 0.5 g/sec. from the figure. Thus, the water leak rate above 1 g/sec. is detectable in the evaporator of 50 MWSG.

4.2 Extrapolation of the Test Results to Other Plants

Our major concern, however, is not merely obtaining the minimum detectable leak rate in 50MWSG but estimating them in larger steam generators. To extrapolate the above obtained results to future larger steam generators similar to 50MWSG in structure, it is necessary to evaluate the levels of the BGN and the leak sound in those SGs. Since the information on acoustic characteristics of the larger plants is not sufficiently known at present, we dare to include somewhat rough estimation.

From the results described in 3.1 (3) and (4), the major sources of BGN are the sodium flow and the steam generation/flow. Based on three assumptions; the BGN from the sodium flow is proportional to a volume of a heat transfer region, the BGN from the steam generation/flow is proportional to a surface area of the heat transfer region, and the absorption of sound is proportional to a surface area of internal structures, a BGN level of a certain scale helically coiled steam generator is basically expressed by:

$$A_N = \left\{A^2_{Na50}\left(\frac{V_h}{V_{h50}}\right) + A^2_{H_2O50}\left(\frac{S_h}{S_{h50}}\right)\right\}^{0.5} \left(\frac{S_{i50}}{S_i}\right)^{0.5} \quad (4.1)$$

where, A_N : BGN RMS level of a given steam generator
A_{Na} : BGN RMS from a sodium flow
A_{H2O}: BGN RMS from a steam generation/flow
S_i : surface area of the internals
S_h : surface area of heat transfer region

and the suffix '50' indicates the data of 50MWSG. By substituting 0.007G into A_{Na50} and A_{H2O50}, respectively, in the above formula, the BGN levels of any given steam generators including a Monju evaporator and a future larger steam generator can be evaluated. On the other hand, the leak sound levels of any given leak sizes in any steam generators can also be evaluated by assuming that the leak sound attenuates by absorption into the internal structures such as tube bundle and the level, A_S, is in inverse proportion to square root of the internal surface area, S_i. Thus, the relation is expressed by:

$$A_S = A_{S50}\left(\frac{S_{i50}}{S_i}\right)^{0.5} \quad (4.2)$$

where, A_S : the leak sound RMS level at a given water leak rate.

Water leak sound levels at leak rates of 1, 10, and 100 g/sec. are compared with BGN level in Figure 9, where the abscissa represents the internal surface area of various steam generators. The RMS levels at those leak rates in the Monju evaporator are 0.005G, 0.012G, and 0.025G, respectively, whereas the BGN level is 0.009G. Then, it can be expressed that intermediate leaks are detectable in Monju evaporators. Applying the similar comparison to larger future steam generators, the minimum detectable leak rate might increase to about 100 g/sec. in the intermediate leak range. To validate the above estimation for Monju, accelerometers are mounted on outer wall of an evaporator and a superheater. The BGN level is to be measured in various operational modes during shakedown tests scheduled in 1991.

5. Application to Leak Location

In the contrast to other system, one of the advantages of acoustic detection system different from others is the potential of on-line leak location.[2] The effort of acoustic leak location has been made using a prototype steam generator model, which is a helical coil type, at OEC.

Eight accelerometers were mounted circumferentially outside wall of the shell, argon gas was injected into the tube bundle region of the SG model which was filled with water instead of sodium. Simulated leak points were changed in each tests to demonstrate the potential of the leak location. As a result of the present study, although the leak can be located generally in lower U-tube region where a center pipe does not exist, location is difficult in a general tube bundle region because the leak sound is reflected and scattered at the center pipe.

6. Conclusion

Various experimental studies were performed at OEC/PNC to develop an acoustic leak detection system. At first, low frequency type sensors were selected because of low attenuation due to bubbles. From the feasibility study using accelerometer type sensors in the SWAT rigs and 50MWSG, the following are concluded:

1) The frequency spectrum analysis reveals that it is difficult to distinguish water leaks from background noise by their spectrum profiles because of similarity.
2) The BGN analysis in 50MWSG clarifies that major acoustic sources in the steam generator are sodium flow and steam generation/ flow.
3) The inert gas injection tests in 50MWSG indicates that the S/N ratio becomes almost unity at the leak rate of 0.5 g/sec. in the evaporator of 50MWSG.
4) According to the estimation of acceleration levels of BGN and leak sounds, an intermediate leak is detectable in the Monju evaporator.

REFERENCES

1) M. Kuroha, et al., "PNC Status Report on Leak Detector Development for LMFBR Steam Generator," IAEA/IWGFR Specialists' Meeting on Theoretical Work on Steam Generator Integrity and Reliability with Particular Reference to Leak Development and Detection, The Hague, November 1983.

2) D. A. Green, et al., "Acoustic Leak Detection/Location System for Sodium Heated Stem Generators," ANS 2nd Intl. Conference on Liquid Metal Technology in Energy Production, Richland, USA, April 1980.

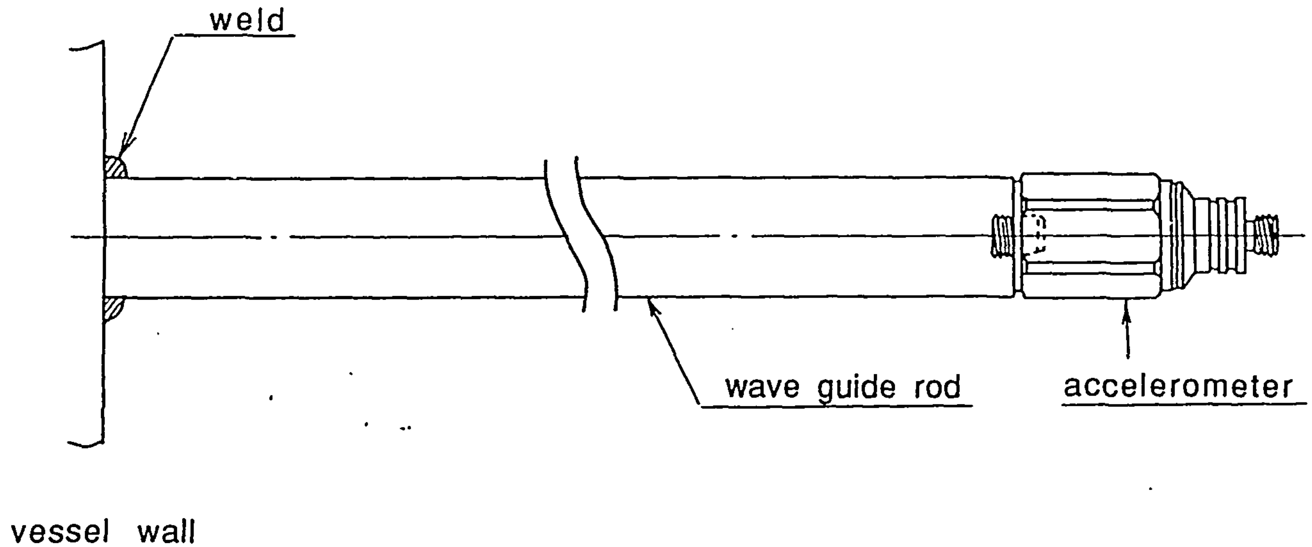

Figure 1 Accelerometer mounting

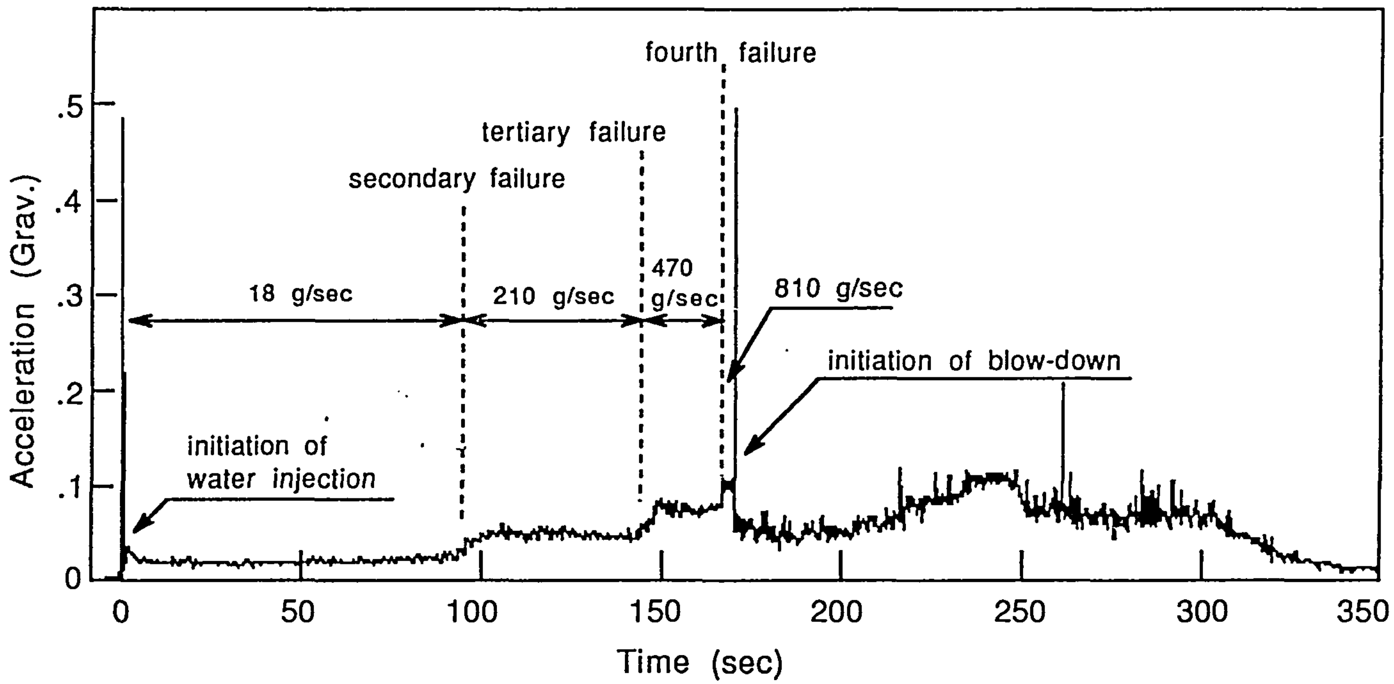

Figure 2 Acceleration change during a failure propagation test

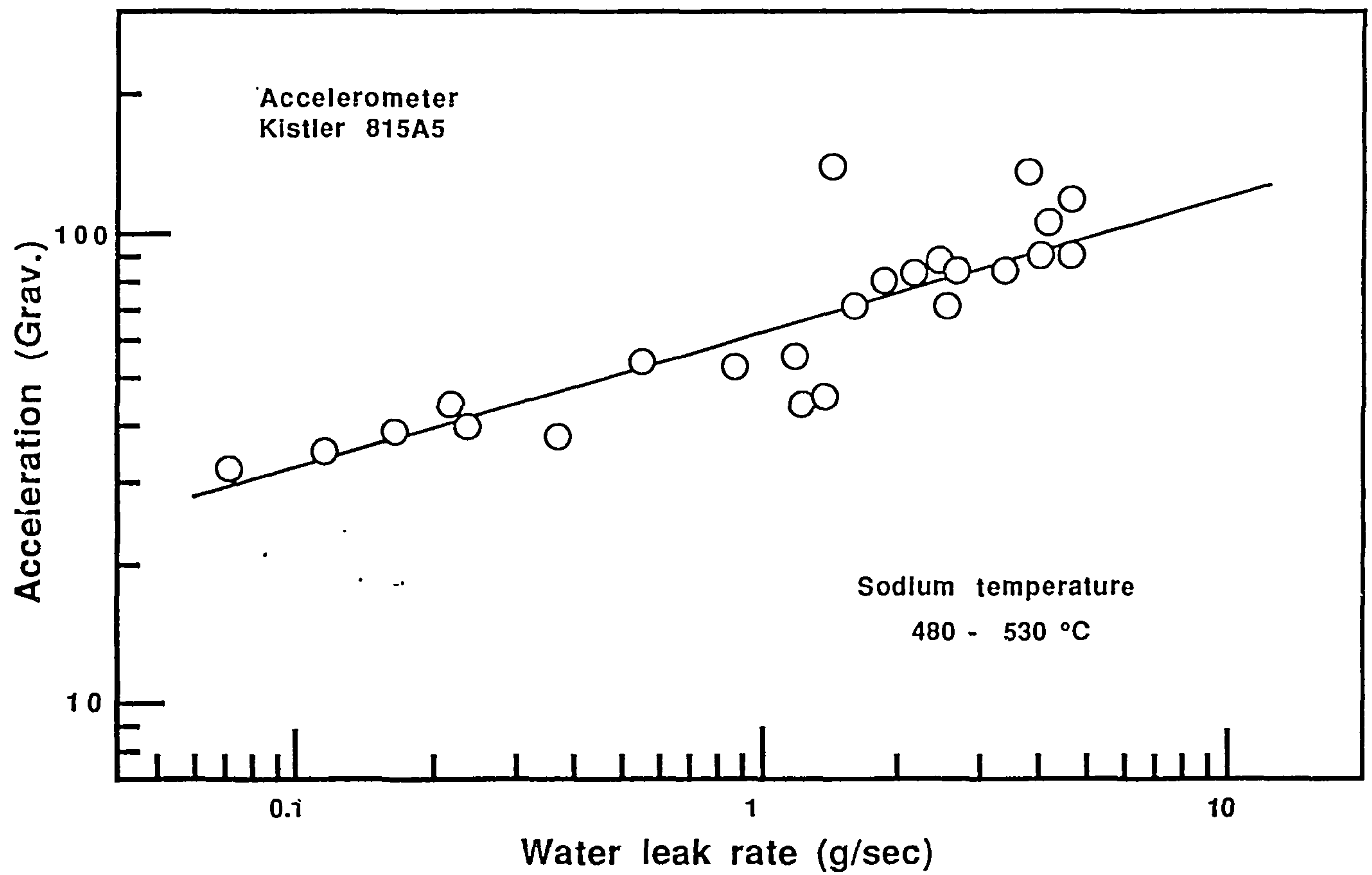

Figure 3 Relation betwen water leak rate and acceleration in SWAT-2

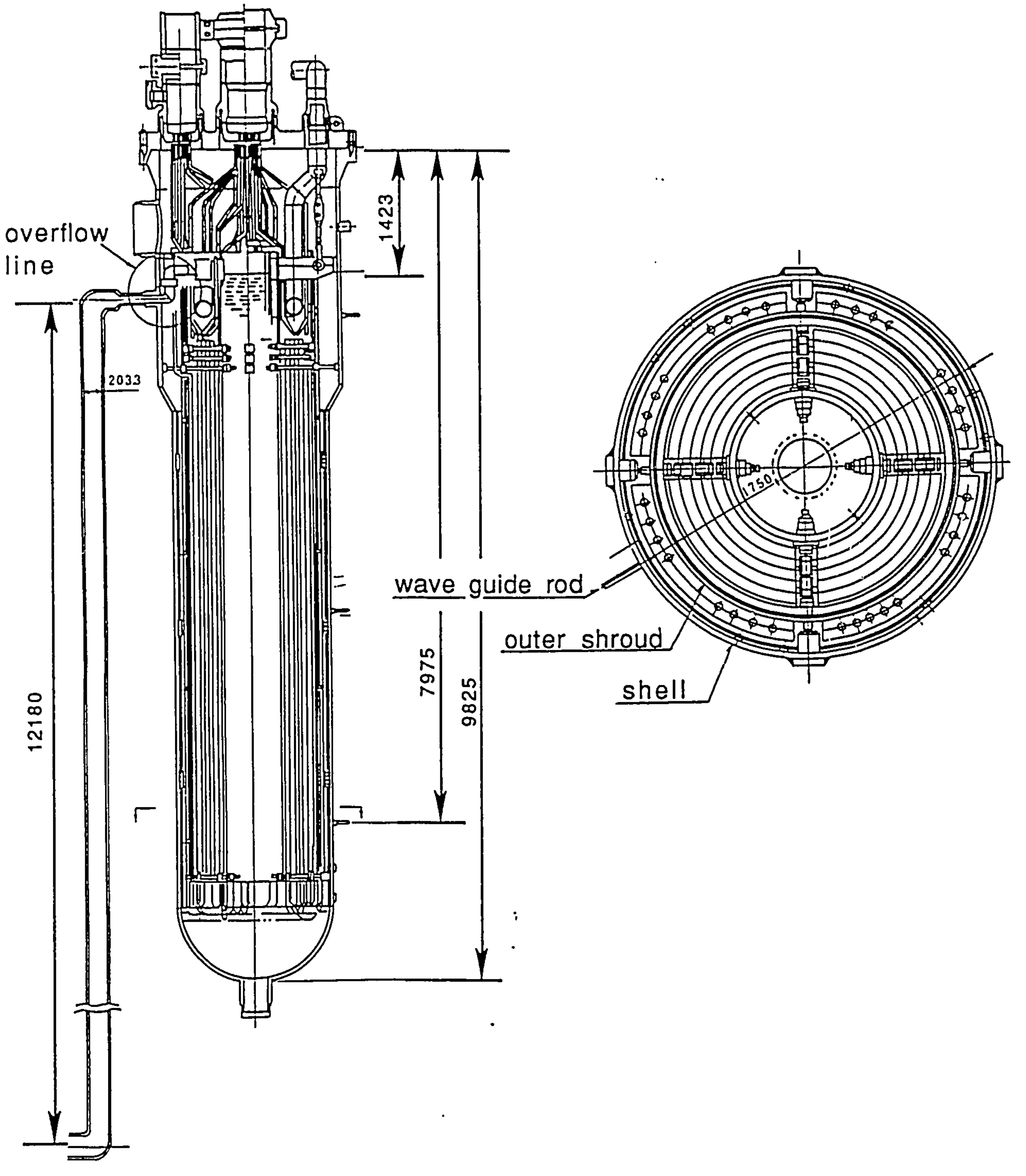

Figure 4 Evaporator of 50MWSG

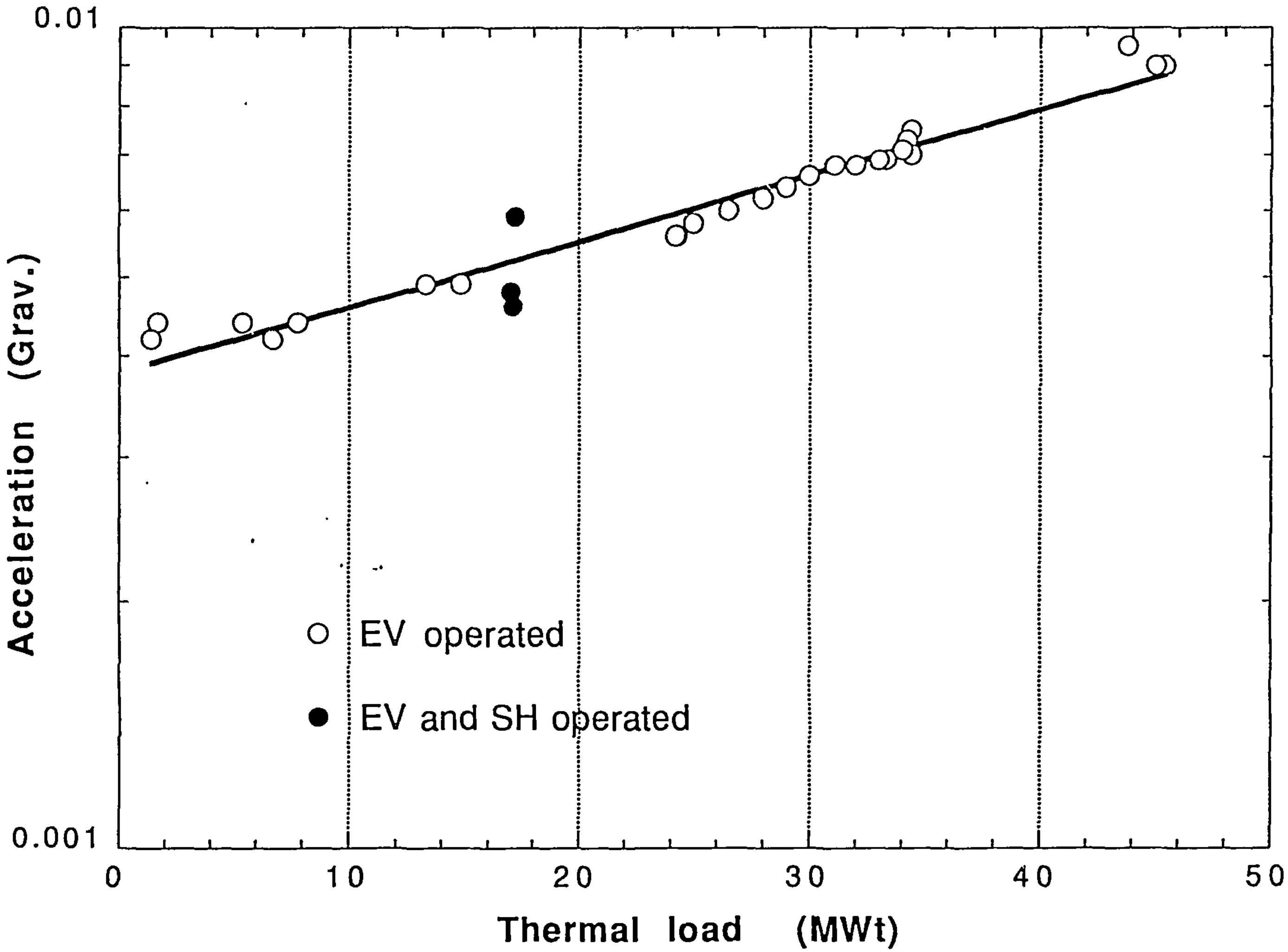

Figure 5 BGN level change with thermal load in 50MWSG

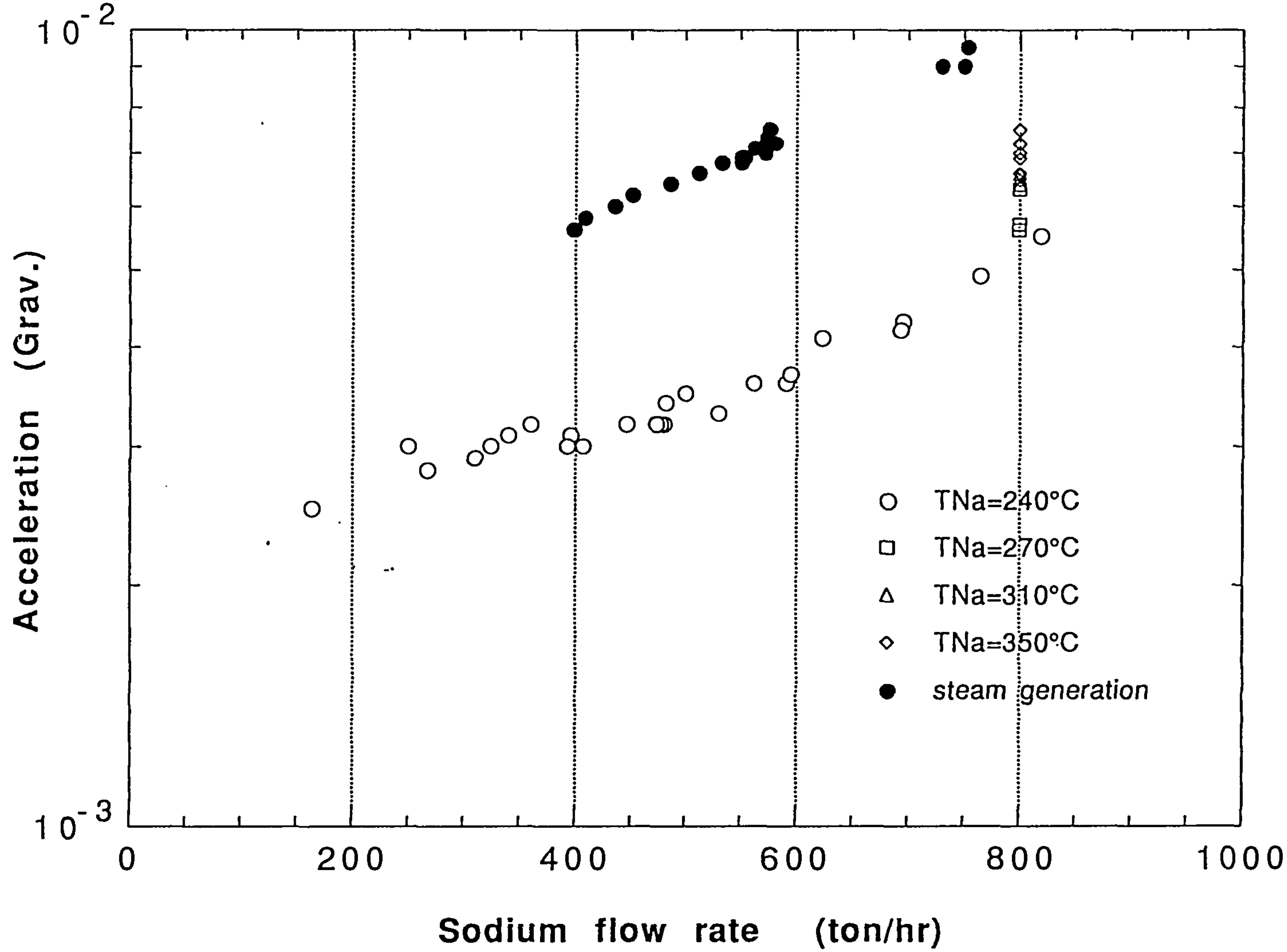

Figure 6 BGN level change by sodium flow and steam generation/flow

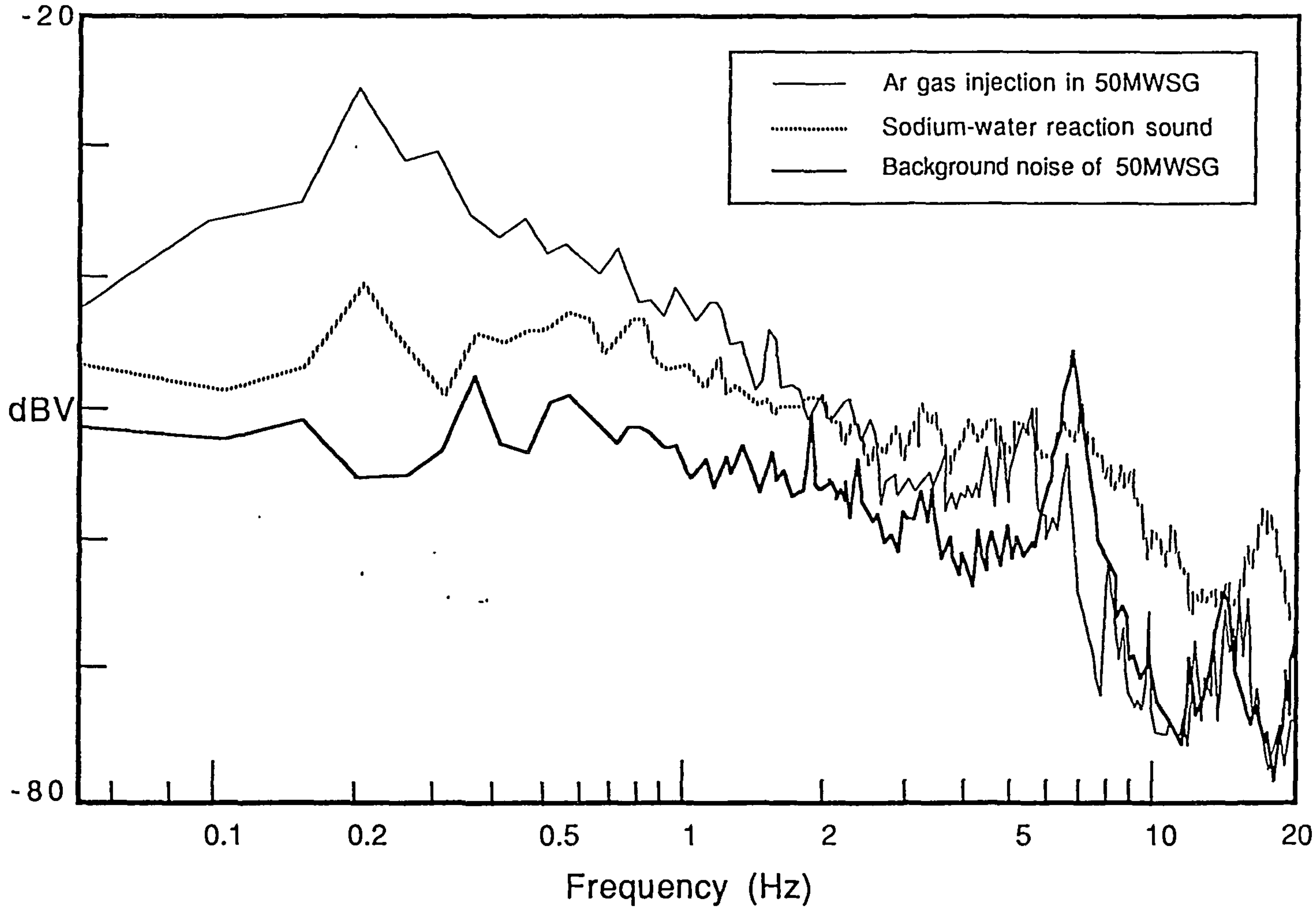

Figure 7 Frequency spectra of sodium-water reaction, BGN, and Ar gas injection

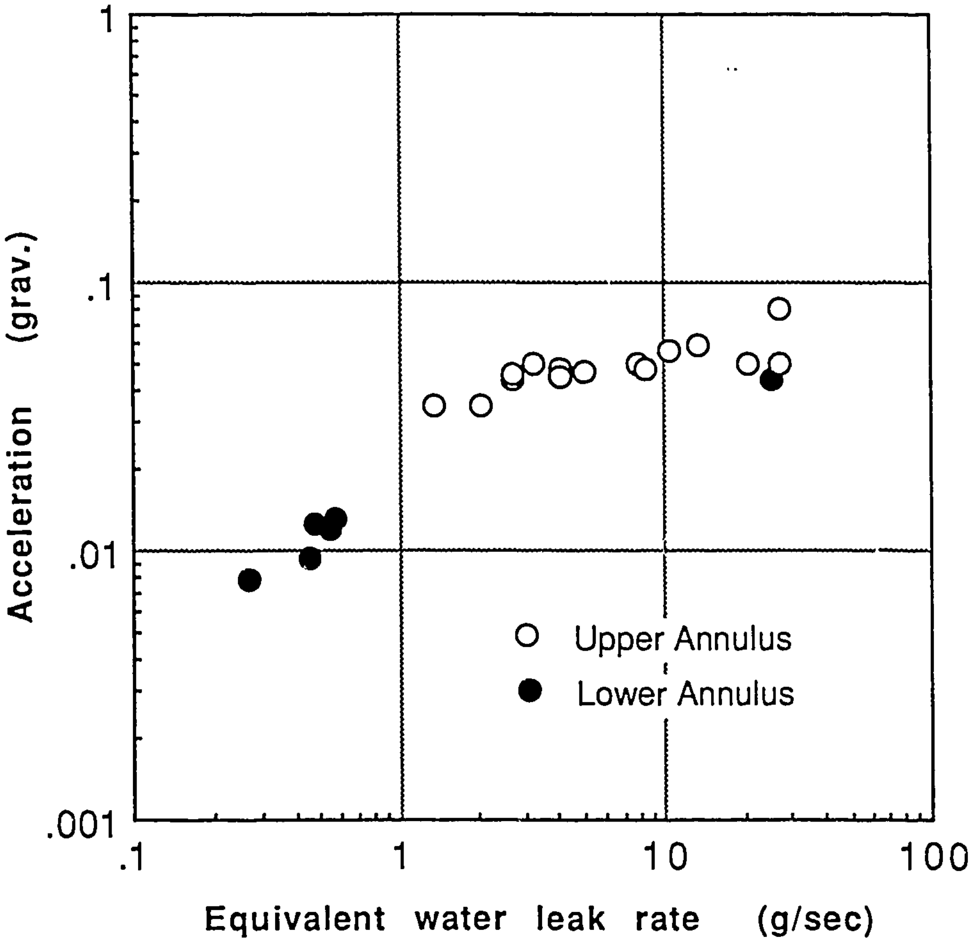

Figure 8 Relation between equivalent water leak rate and acceleration

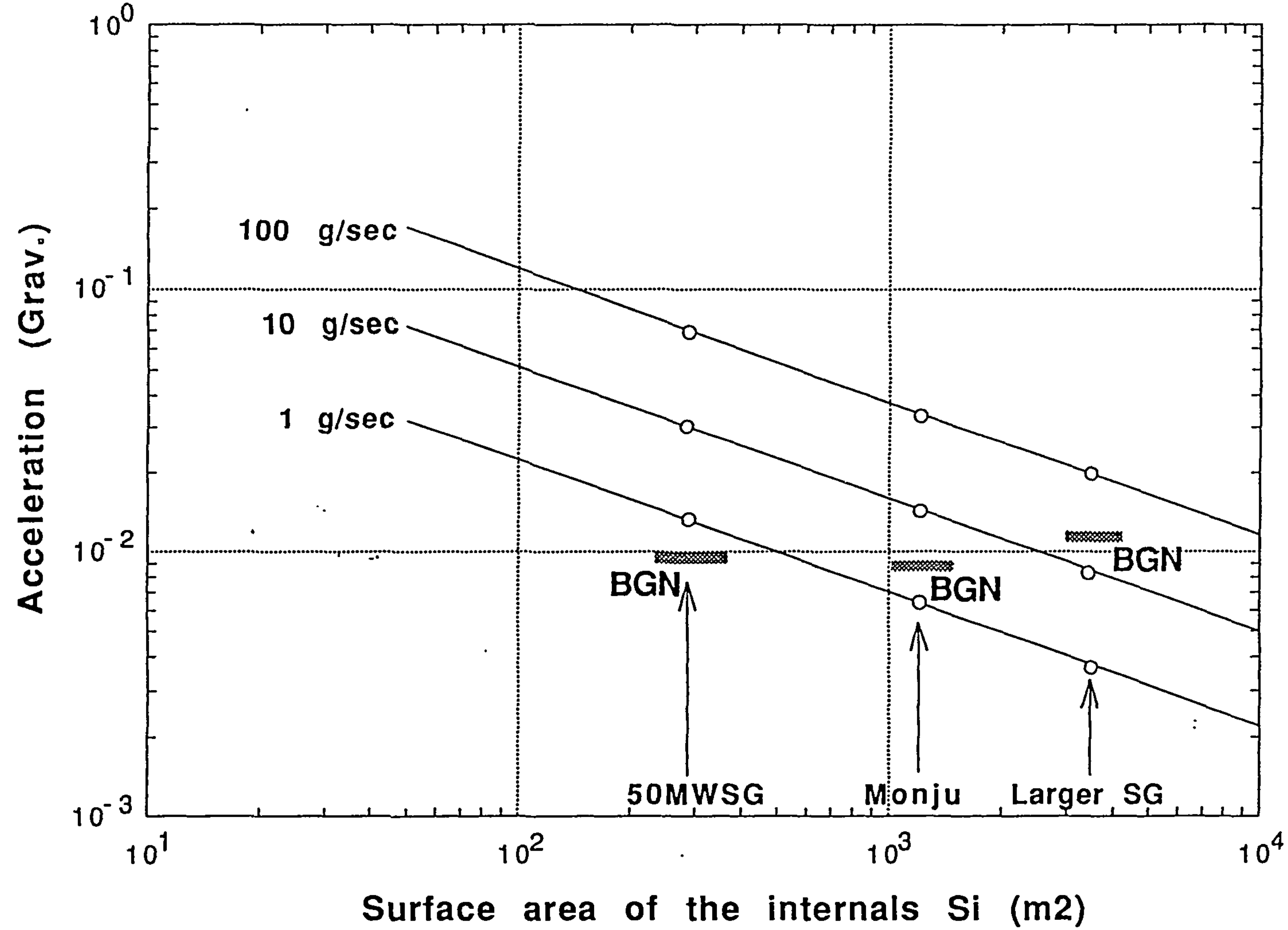

Figure 9 Detectablity map for various SGs