Some Relations of Neutronic Noise with Fluctuation of
Inlet Coolant Temperature and Vibration of a Control Rod
Obtained by Simultaneous Measurements at KUR

Yoshiaki OKA, Shigehiro AN

Nuclear Engineering Research Laboratory*, Faculty of Engineering,
University of Tokyo

Yasuhiro KIMURA, Itsuro KIMURA

Research Reactor Institute, Kyoto University**

Received October 22, 1976
Revised June 15, 1977

Experiments on reactor noise were conducted at KUR. Depending on the operating
condition of the reactor, the cause of the noise are classified into the following four types.
(1) Zero-power noise source due to the branching process of fission neutrons and/or due
to random bombardment of neutrons to the detector—under natural circulation of
coolant and at essentially zero-power level.
(2) Coolant temperature fluctuation due to natural convection—under natural circulation
and at relatively high power level.
(3) Flow induced vibration of shim control rods—under forced circulation of coolant
and at low power level.
(4) Fluctuation of inlet coolant temperature—under forced circulation and near the
maximum power level.

Vibration of a spare shim control rod and fluctuation of inlet coolant temperature
were measured simultaneously with the neutronic noise. Then the noise sources of the
types (3) and (4) were verified. The vibration of a control rod has a broad spectrum in
low frequency region besides the large peak at 14 Hz. The fluctuation of inlet coolant
temperature is non-white noise and consists of large low frequency component. The
theoretically predicted sink structures in the neutronic PSD relating to the transit time
of inlet coolant temperature fluctuation through the core were not observed in the
experimental results.

KEYWORDS: fluctuations, reactor kinetics, reactor noise, variations, correlation
functions, neutron flux, control elements, inlet coolant temperature, swimming pool type reactor

I. INTRODUCTION

Analysis and experiment of power reactor noise have been attracting the concern of
many researchers(1)(2)(3). In a theoretical treatment noise sources were postulated and in-
corporated into a model and an estimated power spectral density (PSD) of neutronic
noise was compared with measurements. If the estimates and the measurements do not
agree reasonably, it would not be possible to deduce whether the reason for this discrepan-
cy lies in the poor guess for the noise source and/or the poor modeling(5). On the other
hand, noise sources were experimentally inferred from physical consideration of the
characteristics of observed neutronic noise.

* Tokai-mura, Ibaraki-ken.
** Kumatori-cho, Sennan-gun, Osaka.
Several experiments have suggested that types of the dominant noise source depend on the configuration of individual reactor and its operating condition\(^{(6)}\)\(^{\text{--}}\)\(^{(10)}\). Fluctuation of inlet coolant temperature or vibration of control rod is suspected to be the cause of noise in several heterogeneous research or experimental reactors\(^{(7)}\)\(^{\text{--}}\)\(^{(12)}\). These results were inferred based only on the behavior of neutron noise. The measurement of these noise sources themselves and the comparison with neutronic noise have hardly been performed because of the difficulty in measuring these noise sources with the detectors which have good time response and are well located in the core. It is, however, required to measure the source of noise itself simultaneously with the fluctuation of neutron flux under reactor operating condition in order to clarify the causes of noise and to provide accurate experimental results for theoretical analysis. Furthermore as to the fluctuation of inlet coolant temperature it is theoretically predicted but have never been experimentally verified that sink frequencies should be observed in the neutronic PSD relating to the transit time of the fluctuation of inlet coolant temperature through the core\(^{(4)}\)\(^{(8)}\). In the present study, reactor noise experiments were conducted at Kyoto University Reactor (KUR) six times over 3 yr. Fluctuation of inlet coolant temperature and vibration of a spare shim control rod were measured simultaneously with the neutronic noise. Comparison of the neutronic noise with these fluctuations were performed. Causes of the neutronic noise in KUR are classified into four types depending on the operating condition of the reactor.

II. EXPERIMENT

KUR is a research reactor of tank type\(^{(13)}\). The rated maximum power is 5 MWt. Usual configuration of the core is shown in Fig. 1. The fuel element is of usual MTR type containing 93% enriched uranium. The light water that serves as well as moderator flows into the tank on both sides of the reactor and cools the core downward. Three neutron detectors were used for the present measurement, two of which were compensated ionization chambers (CIC) placed firmly out of the core and the remaining one was in-core fission chamber installed at the position 1-f in Fig. 1. Since there was no difference between the signals from the three detectors, the record of one of the CICs was mainly analyzed. When recording the signals, any automatic or manual control motion of the regulating rod was inhibited. PSDs, variances and coherences were calculated by a hybrid computer.

Firstly fluctuation of neutron flux was measured under various operating conditions and cause of the noise was inferred from these experimental results. The variances and the PSDs of neutronic noise at several power levels and coolant flow rates are presented in Figs. 2~7 respectively. Normalized by the square of the average output current of the detector or normalized by the square of the reactor power, the values are shown in relative unit. The following facts are pointed out from these figures.
(a) Under natural circulation of coolant and below 1 kW power level the relative variance of neutronic noise is inversely proportional to the power level (Fig. 2). This result shows the behavior of the well-known zero power noise.

(b) At 1 kW power level the magnitude and the frequency spectrum show quite different features between under natural and forced circulation. The former has white noise spectrum due to the random bombardment of neutrons on the detector, while the latter has non-white spectrum and larger magnitude (Fig. 3). The components below 0.1 Hz in the former spectrum are probably due to the coolant temperature fluctuation caused by decay heat of fission products which had been accumulated in the fuel. The heat was probably more than several kilowatts.

(c) The zero-power noise due to fission neutron branching process is observed with in-core fission chamber at 10 W power level (Fig. 4).

(d) Under forced circulation of coolant the relative variances and its frequency spectra do not change from 1 kW to 2 MW power level (Figs. 2, 3 and 5).

(e) Near 5 MW power level very strong fluctuation is observed. Its PSD has larger low frequency component than the weak fluctuation below 2 MW (Figs. 2 and 5).

(f) Decrease in coolant flow rate below 2 MW makes the fluctuation weak but does not alter the frequency spectrum.

![Fig. 2 Variance of neutronic noise at various power levels and coolant flow rates](image2)

![Fig. 3 PSDs of neutronic noise under forced and natural circulation of coolant at 1 kW power level](image3)

![Fig. 4 PSD of neutronic noise at 10 W under natural convection and comparison with theoretical zero power noise spectrum (point model, six delayed neutron groups)](image4)
From these facts the sources of the neutronic noise in KUR are inferred to be classified into the following four types.

1. Zero power noise due to random bombardment of neutrons on a detector and/or due to branching process of fission neutrons under natural circulation of coolant and below 1 kW.

2. Temperature fluctuation of water coolant due to natural convection at relatively high power level. This noise source has already been affirmed by the foregoing noise analysis at KUR by Utsuro et al. and the simulated out-of-pile experiments on coolant temperature fluctuation in a natural convection water loop by Nishihara. It has been also theoretically analyzed by Morishima.

3. Reactivity perturbation which is independent of power level and increasing with coolant flow rate. The vibration of core components especially that of control rod is suspected.

4. Reactivity perturbation with large low frequency component and increasing with power level. Temperature fluctuation of inlet coolant is suspected.

In the following the noise sources of the types (3) and (4) are fully examined. In order to measure the inlet coolant temperature three chromel-alumel sheathed thermocouples of 1 mm dia. were fixed at about 10 cm above the fuel elements 3-d, 6-c and 7-c in Fig. 1. The thermocouple coating was removed for a distance of about 5 mm at the tip, and elements were spot-welded together. Then the 10% to 90% rise time obtained was about 10 msec which is adequately short for the
measurement of the low frequency fluctuation of inlet coolant temperature. It was impossible to measure the temperature in a coolant channel between fuel plates because the small width of the channel, about 3 mm, requires the fabrication of special fuel element for this measurement.

The variances of the inlet coolant temperature fluctuation are shown in Fig. 8 as well as the relative variances of the neutronic noise simultaneously measured with the former. The alphabetical signs denote the correspondence of the variances in both figures. The following results are presented:

(a) Near 5 MW power level the large neutronic noise is observed in accordance with strong fluctuation of inlet temperature. PSDs of both fluctuations have nearly the same shape. The value of coherence is about 0.7 between 0.1 and 0.4 Hz.

(b) Fluctuation of the inlet coolant temperature is strong just after the increase in power level to 5 MW and becomes weak consistently with elapse of time. The data a, b and c in Fig. 8 were the variances at 2, 8 and 30 min after raising the power level from 1 to 5 MW respectively.

(c) Even at 5 MW power level when the fluctuation of inlet coolant temperature is weak, the neutronic noise is weak and remains the same magnitude as those of lower power levels, which are also shown in Fig. 8. The neutronic PSD of the weak fluctuation at 5 MW is nearly identical with the PSD at 1 kW forced circulation. The comparison is presented in Fig. 9.

(d) Under low flow rate, 500 m$^3$/hr, and at 2.8 MW power level strong fluctuation of inlet coolant temperature is also observed, which has the same characteristics as the strong fluctuation at 5 MW. In Fig. 10 PSD of the temperature...
fluctuation is compared with the neutronic PSD. It is shown that both frequency components are nearly identical. This comparison is valid because the transfer function is nearly constant in the main frequency range of this figure. The value of coherence is about 0.6 between 0.1 and 0.4 Hz. The traces of both fluctuation signals on pen recorder chart are presented in Fig. 11. This trace is the best one that shows most clearly the correspondence of both fluctuations among the whole data of the strong fluctuation.

From these results it is verified that the cause of the strong fluctuation is the fluctuation of inlet coolant temperature. This fluctuation is probably caused by the mixing of tank water and inlet water. Then the strong fluctuation is observed when large temperature difference between both water exists shortly after raising the power level. Since temperature rise of the coolant through the core at 2.8 MW and 500 m³/hr is about 5°C which is nearly the same as that at 5 MW and 735 m³/hr, it is natural that the strong fluctuation were observed on both operating conditions.

Finally the noise source of type (3) which was suspected to be the vibration of control rods was examined. The control rods of KUR consist of four shim rods and one regulating rod whose worth is about 1/8 of a shim rod. Effective part of a shim rod has the shape of rounded rectangular measuring 2.2 cm × 5.7 cm in cross section and 69.5 cm long, which is connected to the control drive mechanism located at the top of the reactor by a long pipe measuring 3.0 cm diam. and 567 cm long. From the standpoint of safety it was not allowed to measure the vibration of any one of the shim rods itself.
As a substitute a spare shim rod which was the same size and worth as those was inserted in the core and its vibration was measured. The core configuration at that time is shown in Fig. 12. The location of spare shim rod was 2-f which was surrounded by fuel elements. A inductance type vibration-sensor was fixed to the top of a mock-up fuel element that had the same size as the fuel elements and was located at the position 2-d, from which a pickup of the sensor was stretched out to the spare shim rod. Its reliability had already confirmed by a measurement in JRR-4(10). Calibration of the vibration amplitude to the output signal was performed with the spare rod itself prior to the measurement.

At 1 kW power level the vibration of the spare shim rod was measured simultaneously with the neutronic noise under forced circulation of coolant. PSDs of both fluctuations are compared in Fig. 13. The shapes and the frequency components of both fluctuations are similar. The vibration PSD has a large peak at 14 Hz and weak peaks at 4 and 2 Hz, at which frequencies the peaks also appear in the PSD of neutronic noise. Although the value of coherence between neutronic noise and the vibration is not sufficient, which is probably due to the contribution of the vibrations of other four shim rods, the similarity of both spectra leads to the conclusion that the cause of the noise under forced circulation of coolant and at low power level is the vibration of the shim rods.

III. DISCUSSION

It is theoretically predicted that the neutronic PSD shows sinks at the frequencies related to the inverse of the transit time of the coolant through the core. In the present the transit time is about 0.3 sec. Then the sink frequencies should exist at 3.3 \( n \) Hz, where \( n \) is positive integer. There are, however, no sinks in the neutronic PSDs obtained in the present experiment. It is
suspected that this is partly because above 1 Hz there exists the contribution of the vibration of the shim rods and partly because the fluctuation of inlet coolant temperature is not perfect enough to excite the whole core synchronously. This latter reason is affirmed by the observation that the signals from the thermocouples at remote positions hardly synchronized with each other. The small peaks observed in the neutronic PSD is probably due to the vibration of control rods and does not show sink structure mentioned in the above.

IV. CONCLUSIONS

(1) Depending on the operating condition of the reactor the causes of the noise of KUR are classified into the four types, which are summarized in Table 1.

(2) The vibration of a spare shim rod was measured simultaneously with neutronic noise under reactor operating condition. PSDs of both fluctuation are similar. The frequency components of the vibration are large at low frequency region.

(3) The fluctuation of inlet coolant temperature was measured simultaneously with neutronic noise. Similarity of both fluctuations and large values of coherence in low frequency region are observed in both fluctuations.

Table 1 Noise sources of KUR

<table>
<thead>
<tr>
<th>Flow rate</th>
<th>Power level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>Natural circulation</td>
<td>Branching process of fission neutrons or random bombardment of neutrons to a detector</td>
</tr>
<tr>
<td>Forced circulation</td>
<td>Flow induced vibration of shim control rods</td>
</tr>
</tbody>
</table>

(4) The PSD of inlet coolant temperature is non-white and has very large low frequency components.

(5) In the neutronic PSD the sinks relating to the transit time of the fluctuation of inlet coolant temperature through the core were not observed in this experiment.

ACKNOWLEDGMENT

The authors wish to express their gratitude to Profs. Y. Togo, A. Furuhashi and S. Kondo for their useful suggestions and discussions, and also express thanks to Mr. M. Moriyama for his assistance with the experiments.
This work was performed in the visitors program in Research Reactor Institute of Kyoto University.

—References—