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LONG-LIFE IN-CORE NEUTRON DETECTOR FOR PROTOTYPE HEAVY WATER REACTOR FUGEN

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LONG-LIFE IN-CORE NEUTRON DETECTOR FOR PROTOTYPE HEAVY WATER REACTOR "FUGEN"

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ABSTRACT

A long-life in-core neutron detector was developed from 1973 through 1978 and since then, it has been applied to the prototype Heavy Water Reactor "FUGEN" as a local power monitor.

More than 10 year's operation experience of the detector proved its performance as was expected. The detector is a fission chamber of regenerative type whose tube is made of Zircaloy-2 metal for neutron economy.

In-core neutron detectors for the Local Power Monitor are placed in heavy water moderator of 50 ℃. The in-core conditions bring a high level thermal neutron flux environment. It tends to hurt the lineality and shorten the life time of the detectors because of rapid burnup of the neutron conversion material (^{235}U) in the detector compared to the light water reactors.

These problems were solved by some improvements and it was demonstrated that the detector had the performance of high linearity and long-life characteristics.

1. INTRODUCTION

A neutron detector, which detects neutron flux change instantaneously and measures neutron flux distribution in a reactor core, is an important monitor for the safe and effective reactor operation.

Application of neutron flux monitoring systems to a nuclear power plant is classified into two types: one is the type to install neutron detectors into a reactor core and the other is to install neutron detectors outside the reactor core.

In the FUGEN which is a 165MWe prototype heavy water moderated, boiling light water cooled pressure tube type reactor, the in-core neutron monitoring system is employed where three kinds of neutron detectors are installed in a heavy water tank in the core. A number of in-core fission chambers are used for power range monitoring and Zircaloy-2 is applied to an in-core neutron detector assembly as a structural material to reduce assembly material's neutron absorption effect. On the other hand, in-core neutron detectors which are fission type ionization chamber are installed in the 50℃ heavy water moderator so that the thermal neutron flux level at the detector position is higher than that of a same size other type reactor such as Boiling Water Reactor (BWR). This high thermal neutron flux should effect in a certain level on the linearity characteristics of the fission chamber and should cause rapid degradation of sensitivity because of high burn-up of neutron converter in the fission chamber. The former effect has a risk to let a fission chamber indicate a lower neutron flux value than actual one. This effect is important from the view point of the reactor safety and the fuel integrity. The latter leads to the frequent exchange of neutron detector assemblies and increases radioactive waste materials.

Based on the requirement of a new in-core neutron monitor for power range flux monitoring of FUGEN, the development of a high linearity and long life neutron detector and assembly started from 1973 and has completed in 1978. This kind of detectors and assemblies have been installed in the FUGEN reactor core from the first criticality in 1978 and their performance has been examined during 10 years.

2. NEUTRON MONITORING SYSTEM OF "FUGEN"

Neutron monitoring of the advanced thermal reactor "FUGEN" is done by using several kinds of in-core fission ionization chambers installed in the heavy water in a calandria tank. The neutron flux monitoring range is 12 decades which are covered by three kinds of neutron flux monitoring systems of (1) Start Up Monitor(SUM),(2) Power Up Monitor(PUM) and (3) Local Power Monitor (LPM). These monitors share their monitoring regions with appropriate overlapped region. The structure and monitoring specification of the "FUGEN" neutron monitoring system is schematically shown in Figure 1. Local Power Monitor is composed of 64 channels which monitor neutron flux through 16 neutron detector assemblies. Each assembly has 4 neutron detectors located with the same spacing in axial direction. These neutron detectors are fission type ionization chambers which are calibrated by Power Calibration Monitor(PCM). Based on 64 channel LPM signals, 2 channel Rod Stop Monitor(RSM), 2 channel Total Power Monitor (TPM) and 8 channel Region Power Monitor(RPM) are organized to control the reactor power, to monitor the integrity of fuels and to manage the burn-up of fuels. Figure 2 shows the location of neutron detectors in the FUGEN reactor.

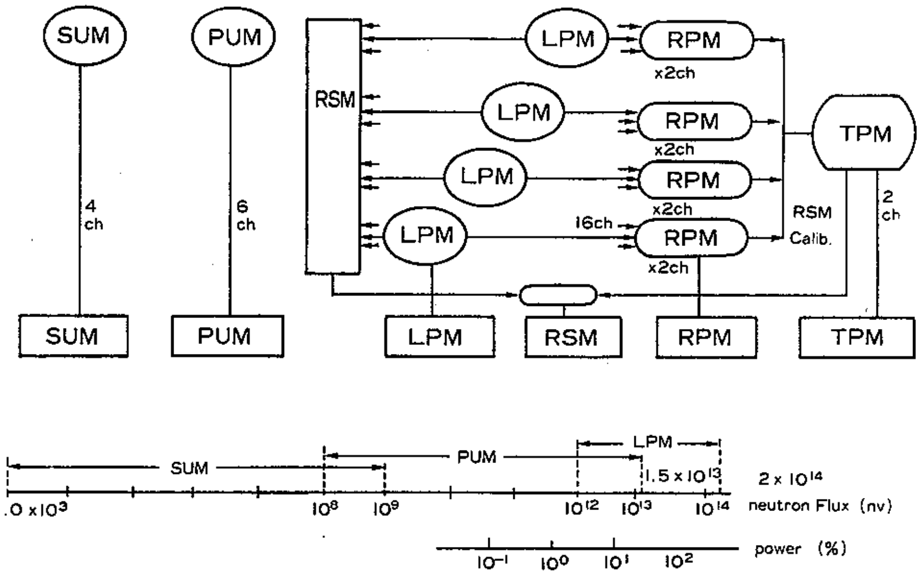

Fig.1 Neutron Monitoring System of Fugen

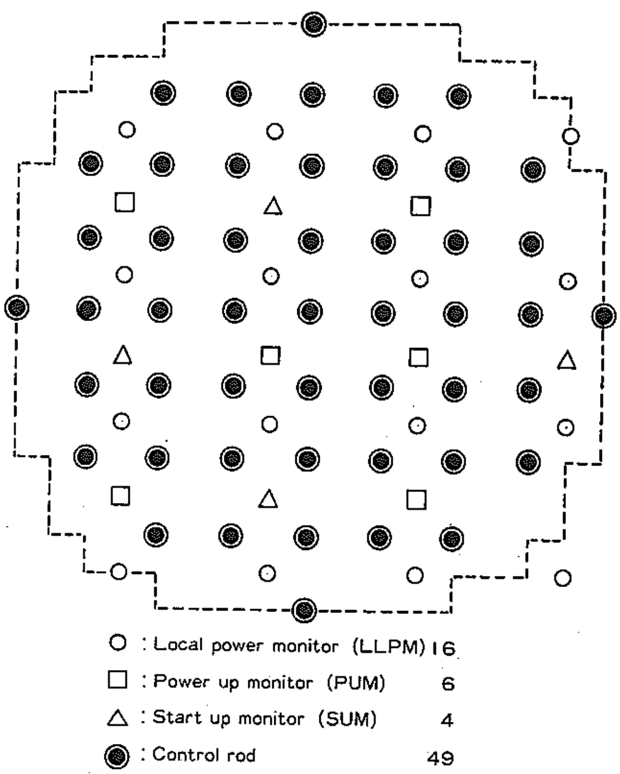

Fig.2 In-core Monitor Location in Fugen Reactor Core

3. NEUTRON DETECTOR FOR LOCAL POWER MONITOR

Neutron detectors applied to the power range monitor of "FUGEN" should resist against the strong radiation and instantaneously respond to the neutron flux change from the view point of the safety. Fission type ionization chamber satisfies these criteria and have long experience in the BWR. Application of the fission type ionization chamber to LPM had been required with the following conditions;

(1) to use less neutron absorption materials for neutron economy
(2) to resist higher neutron irradiation than BWR
(3) to hold the linearity characteristics under high neutron flux
(4) to prolong a life time under high neutron flux.

In the FUGEN, almost all structures materials in the reactor core are made of Zircaloy-2 which has low neutron absorption cross section compared to iron or steel. For the same reason, Zircaloy-2 has been selected as a structural material of the detector assembly. The thermal neutron flux level at the detector position, however, elevates because of the employment of Zircaloy-2 as structural material. Besides the high thermal neutron flux, the temperature of the moderator around the neutron detector is about 50℃, so that the reaction rate of the neutron converter uranium 235 in the fission chamber is higher than the case in the BWR. At the same time, the high gamma ray flux in the reactor core heats up the structural material and affects the sensitivity of the fission chamber.

The developed neutron detector has resolved these severe conditions by adopting the following design.

(1) Amount of uranium 235 is reduced to a half of the detector for the ordinary BWR neutron detector
(2) Anode structure is improved not to raise the temperature of the anode even if it is irradiated with high gamma ray.
(3) Detector housing and PCM guide tube are made of Zircaloy-2 material
(4) Neutron converter in the fission chamber is a mixed material of uranium 235 and uranium 234 to regenerate uranium 235 and to prolong the life time of the detector.

On the design item (4), evaluation studies and tests have been done several times. Regeneration of the fission material uranium 235 is most effectively performed by the neutron irradiation of uranium 234.

In case where the neutron converter is a mixture of uranium 234 and 235, , neutron sensitivity of the detector is formulated in good approximation, based on the uranium 235 quantity, as follows:

$$Sn/So = \exp(-\sigma_5 \phi) + \frac{\sigma_4}{\sigma_5 - \sigma_4} N \left[\exp(-\sigma_4 \phi) - \exp(-\sigma_5 \phi) \right]$$

where, Sn : neutron sensitivity
So : initial neutron sensitivity
ϕ : integral neutron irradiation dose (nvt)
N : ratio of uranium 234 to uranium 235
σ_5 : effective neutron absorption cross section of uranium 235
σ_4 : effective neutron absorption cross section of uranium 234

For the neutron detector of the FUGEN, the ratio N of uranium 234 to 235 has been decided to 3 based on the experimental study at the JMTR(Japan Atomic Research Institute Material Test Reactor), in order to prolong the life time to four times compared to that of the ordinary uranium 235 fission chamber.

4.IRRADIATION TEST AT JMTR

In the experimental study at the JMTR, several kinds of neutron fission chamber with different mixing ratio of uranium 235 and uranium 234 have been analytically investigated at first. The mixing ratio has spread from 1:0 to 1:12.
Secondly, based on the evaluated result of the first step study, two kinds of mixing ratios have been selected and the neutron detectors with those mixing ratios have been manufactured and tested in the JMTR. Selected mixing ratios are 1:3 and 1:6. Result of the 10^{21}nvt irradiation test showed that the neutron detctor with a mixing ratio 1:3 could have a fourfold life time of the ordinary one and that the detector with a mixing ratio of 1:6 could have 9 times as long as the ordinary one. The JMTR test results and the evaluation have suggested that the fission chamber for the FUGEN should have a converter's mixing ratio of 1:3 based on the stability evaluation result and on the structural material's life time. A schematic diagram of the long-life neutron detector is shown in Figure 3.

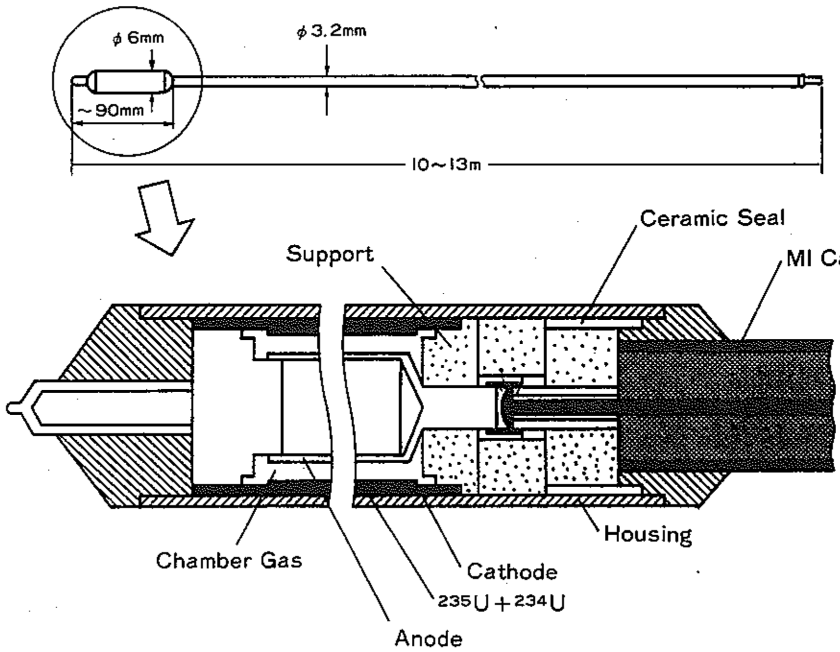

Fig.3 Schematic Diagram of Neutron Detector for Fugen LLPM

5.LONG-LIFE LPM OPERATION EXPERIENCE IN FUGEN REACTOR

As a first step, two LPM assemblies containing 8 long-life neutron detectors, in total, have been installed in the FUGEN in 1978 just after the first criticality. An outside dimension of the neutron detector assembly is shown in Figure 4. The specification of the long-life neutron detector is summarized in Table 1. The other 14 LPM assemblies were ordinary type neutron detector assemblies.
Monitored parameters were as follows:

(1)LPM neutron detector output current versus operating time,
(2)current(I)to voltage(V) characteristics of LPM neutron detector,

Table 1 Specification of LLPM Detector

Type	Fission chamber $^{234}U/^{235}U=3/1$
Neutron sensitivity (A/nv)	5×10^{-18}
γ sensitivity (A/R/h)	2.5×10^{-14}
Applied voltage (V)	75～175
Insulation resistance (Ωmin)	1×10^{10}
Design temperature (℃)	117
Design pressure (kg/cm^2·G))	0.7
Material	SUS304/ Zircaloy-2
Insulator	Al_2O_3
Chamber gas	Ar

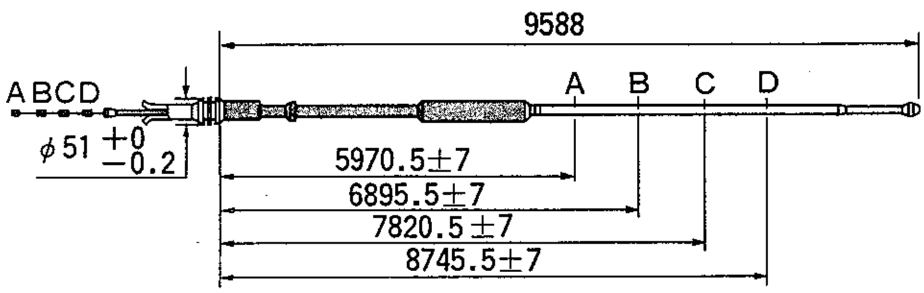

Fig.4 Neutron Detector Assembly (LLPM)

Figure 5 shows the irradiation history of the FUGEN long-life LPM (LLPM) neutron detector.

Vast data of two assemblies have been analysed and evaluated regards to

(1) linearity characteristics,

(2) neutron sensitivity degradation characteristics.

Linearity characteristics have been important subject on the LLPM. And these have been justified by confirming the chamber saturation characteristics under the operating voltage. Saturation voltage which indicates the ionization chamber's saturation region has been analyzed by applying V/I-V diagram method to the I-V curve.

The V/I-V diagram method is an efficient method to get a saturation voltage and saturation current of the ionization chamber, where V/I versus V data are plotted. And it can be estimated in good approximation that a cross point of both straight lines shows a saturation point and that a slope of the right side straight line shows the saturation current of the fission chamber as shown in Figure 6.

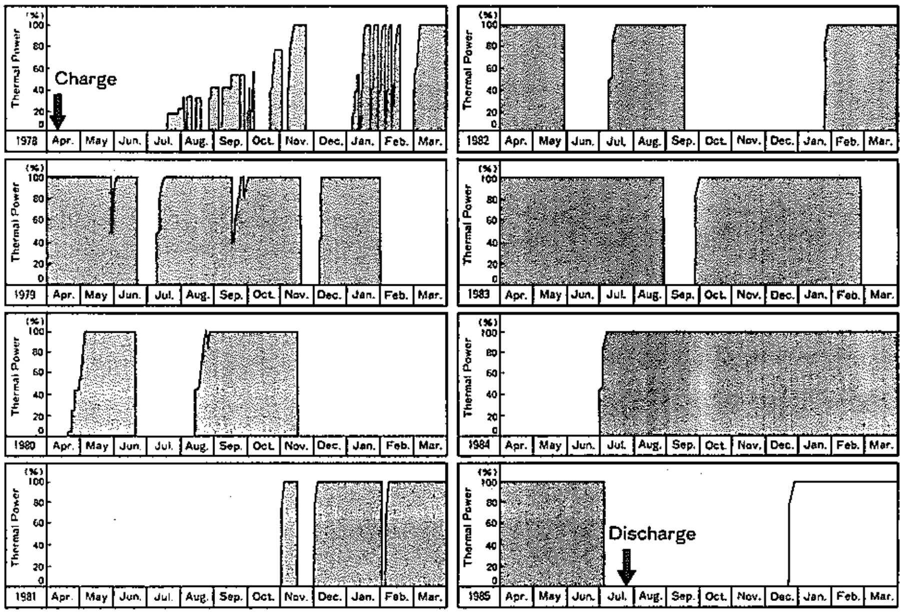

Fig.5 Irradiation History of LLPM

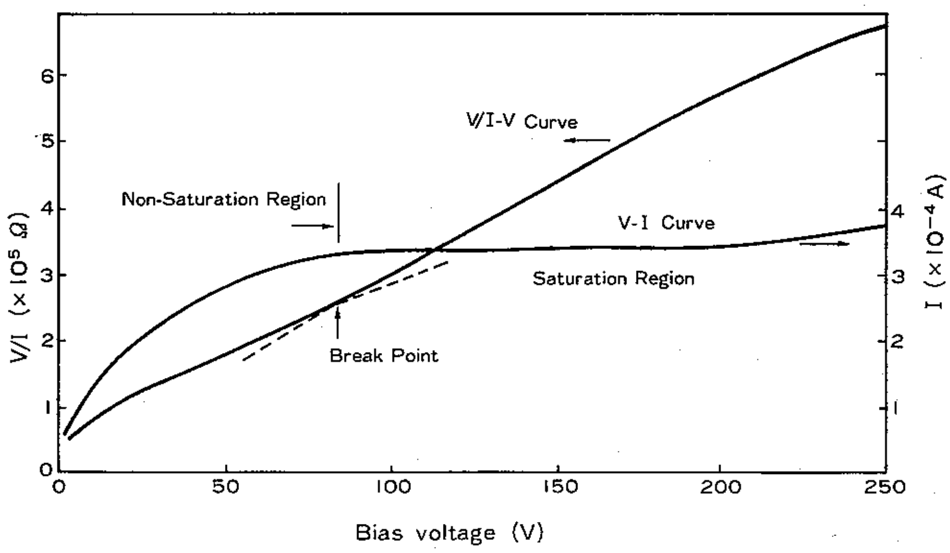

Fig.6 V/I-V Diagram and I-V Characteristics

Saturation voltage at each reactor power level estimated through the preceeding V/I-V diagram method is, as shown in Figure 7, in good agreement with a theoretical formula

$$Vs \propto \sqrt{Is}$$

where Vs is a saturation voltage and Is is a saturation current of the neutron detector. The saturation current Is is estimated by the following relation

$$Is = \lim_{V \to \infty} \frac{V}{kV+C} = \frac{1}{k}$$

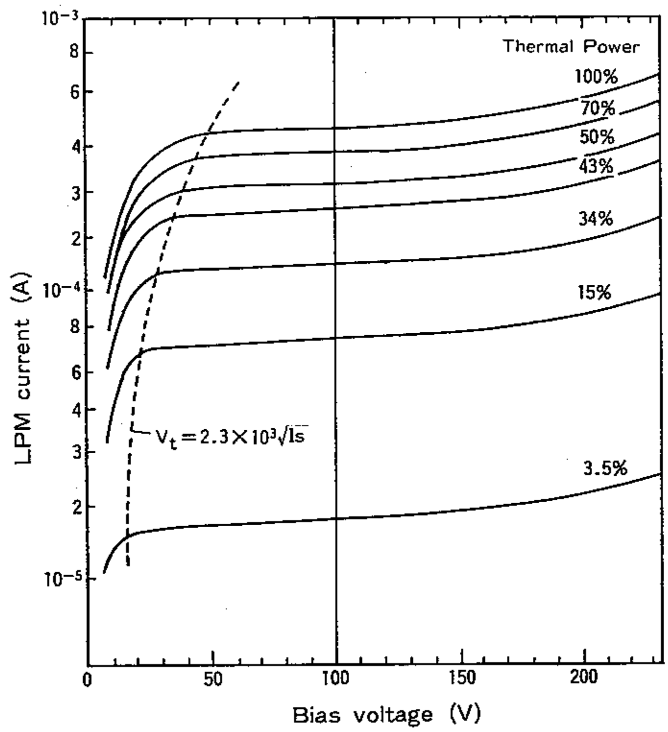

Fig.7 Saturation characteristics of LLPM Neutron Detector

Neutron sensitivity degradation characteristics was observed by measuring periodically the current (I_1) of the LLPM in-core neutron detector and that (I_2) of the PCM neutron detector which is set aside of the LLPM in-core neutron detector, and by calculating the ratio of I_1/I_2. Degradation characteristics of the total irradiation dose of 1.3 x 10^{22}nvt is shown in Figure 8. As the operation of the FUGEN reactor proceeds, 14 ordinary type LPM assemblies have been successively replaced to the LLPM assemblies during each period of maintenance work. At present, all neutron detectors have been replaced to LLPM and functioned satisfactorily. Now the life time of the LLPM is evaluated to be about 1.6 x 10^{22}nvt. It is four times as long as the life time 4 x 10^{21}nvt of the ordinary type LPM detector.

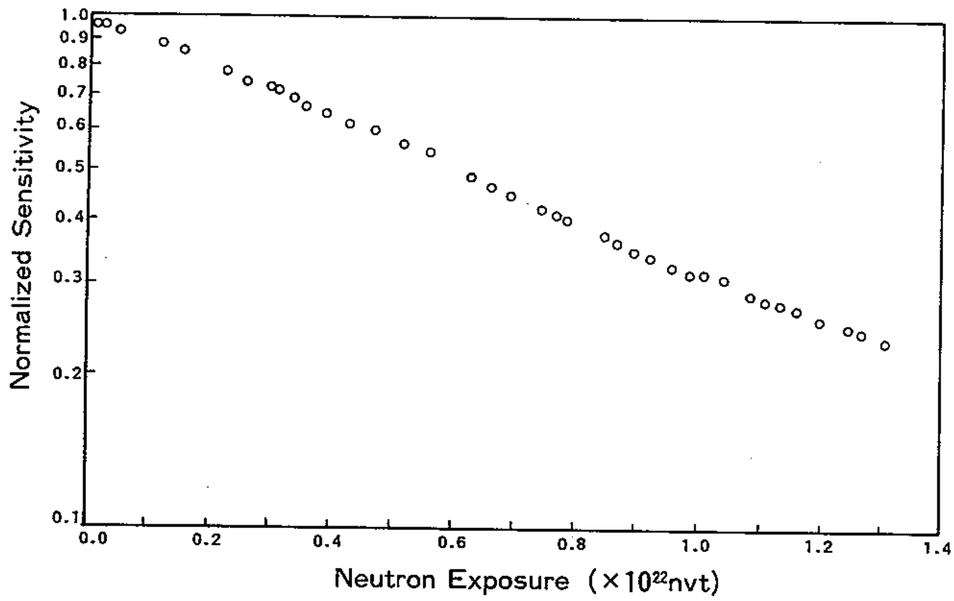

Fig.8 Sensitivity Degradation Characteristics of LLPM Detector

6.SUMMARY

A high linearity and long life neutron detector has been developed and proved to work as it was specified and designed. Long term field experience has confirmed the following results:

(1) Good linearity characteristics were measured,
(2) Detector assembly made of Zircaloy-2 has worked satisfactorily,
(3) Long-life characteristics have been confirmed and the life time was proved to be four times as long as that of the ordinary one.

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