The Application of the Delayed Neutron Measurements to the Fuel Failure Detection System in HANARO

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ABSTRACT

In HANARO, the fuel failure detection system(FFDS) based on the delayed neutron measurement is suggested, and the field application test is performed. In order to investigate the origins of the neutrons detected at the primary cooling circuit during normal operation of the reactor, the changes of neutron count rate before and after reactor shutdown are measured by a BF_3 detector, and predicted by assuming the neutrons as the photoneutrons emitted by N-16 gamma rays and delayed neutrons by the fuel surface contamination, From the comparison of predictions and measurements, it is confirmed that about 70 % of the measured neutrons are delayed neutrons, and 30 % are photoneutrons. Also, the neutron generation and transportation are simulated by the Monte Carlo method, and the neutron count rates at detector position are calculated. The count rate of photoneutron is calculated to be 11 % of the whole neutron count rate. The amount of uranium exposed to the coolant in the core is also estimated by the delayed neutron transport calculation, and it is lower than the allowable level of surface contamination of the fuel rods. Since a small amount of the delayed neutrons generated from the fuel surface contamination are sensitively detected, the delayed neutron measurement is very useful for monitoring the fuel failure. After the step-wise field application test, the new delayed neutron FFDS system has started its formal service as a trip parameter for the reactor protection system, and it has been carrying out its intended role of fuel failure detection effectively up to now.

1. INTRODUCTION

In research reactors, any fuel failure should be detected as soon as possible for the reactor safety and the radiation protection of all personnel in the reactor hall[1]. In HANARO, the fuel failure detection system(FFDS) by measuring the gamma activity from the fission products in the coolant has been installed and operated for years. Three NaI detectors were placed under the common return line of the primary cooling circuit in order to monitor the gamma activity in the coolant. From the operating experiences and various analyses, it was confirmed that the FFDS using NaI detector was facing difficulties in monitoring the fuel failure due to the N-16 which is a major gamma ray source in the coolant. The gamma energies of the fission and activation products except N-16 are mostly lower than 2 MeV. Measuring the total gamma activity below 2 MeV is not sensitive enough to detect fuel failure due to the high energy gamma from the N-16 builds high Compton background to the detector. The N-16 effect could be compensated by using two single channel analyzers and the net count rate of 0.6-2.0 MeV is used to trip the reactor. It was sensitive to detect the fuel failure but not so stable because of the statistical fluctuation of count rate. Also, the net count rate of 0.6-2.0 MeV increases when the reactor power is decreasing due to the slower decay of the activation products than the rapid decay of the N-16, which causes an unscheduled reactor trip[2].

In order to improve the system performance, the FFDS based on the measurement of delayed neutron has been suggested[3,4]. A lot of field tests and analyses have been performed to verify if the new concept could be applicable to HANARO.

2. NEUTRON MEASUREMENTS AND VERIFICATIONS OF THEIR ORIGINS

The BF_3 proportional detectors are used in measuring the neutrons of the primary cooling circuit. The effect of the high energy gamma rays on the neutron pulse spectrum of the BF_3 detector and the source of neutrons in the primary cooling circuit and the method to enhance the sensitivity detecting neutrons are studied.

No noticeable effect of high energy gamma rays to the neutron pulse spectrum of the BF_3 detector is found even if the detector is not shielded. Also, the changes of count rates at the BF_3 detector are checked when the detector is lead and/or cadmium shielded, and it is confirmed that the main contribution to the detector is the neutron.

In the normal operation of reactor, the possible neutron sources around the primary cooling pipes are the delayed neutrons coming from the contaminated uranium at the fuel surface, and the photoneutrons from the deuterium in the coolant. The high energy gamma rays emitted from the N-16 are a major source for the photoneutron production. If the photoneutron is large portion of detected neutron, the neutron detection cannot be so sensitive for the detection of fuel failure. So, the portions of photoneutron and delayed neutron are measured by utilizing the difference between half lives of N-16 and delayed neutron precursors. The changes of neutron count rates before and after reactor shutdown are measured together with the power variation. The power variation is measured using compensated ion chambers(CIC). The variations of the photoneutron and delayed neutron count rates according to the measured power history after the reactor trip are calculated using the coolant flow rate and half lives of N-16 and delayed neutron precursors.

Fig. 1 shows the calculated values of the changes of the photoneutrons and the delayed neutrons after reactor shutdown and the experimental measurements. In the figure, the steps in calculation curve are generated by assuming that the coolant is not mixed and has the constant velocity. The decrease of the BF_3 count rate begins after about 4 sec from the reactor shutdown because of the delayed arrival of coolant at the detector position. From figure, it is confirmed that the count rate of the photoneutron is decreased more rapidly than that of the delayed neutron. Also, the measurements are located between the two calculated values.

The time trend of the neutrons generated from different sources is fitted with the measurements, and the portion of each neutron source resulting in good agreement between the measurements and predictions are searched.

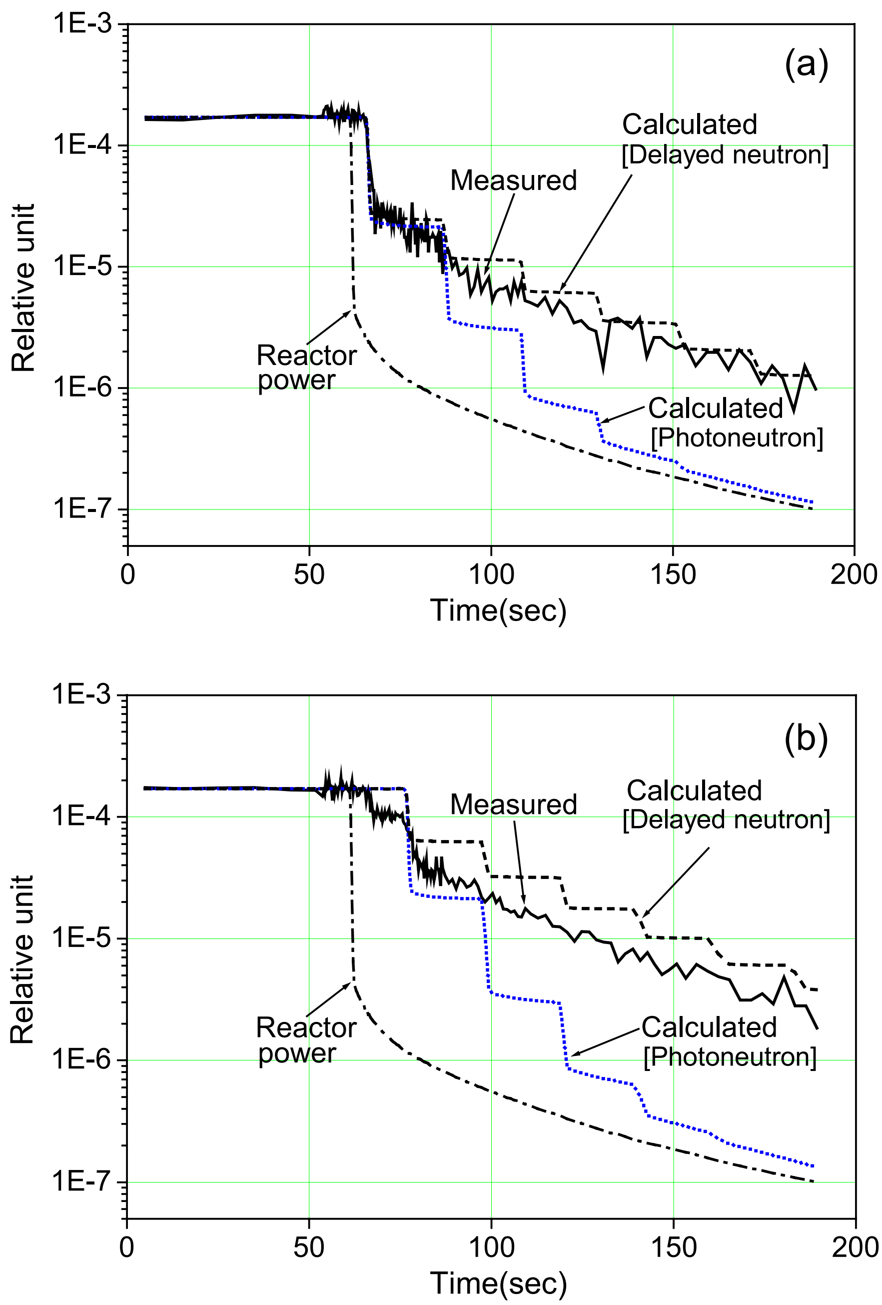

Fig. 1. Measured neutron count rates and calculation values of photoneutron and delayed neutron count rate at core outlet(a) and inlet(b) before and after reactor shutdown.

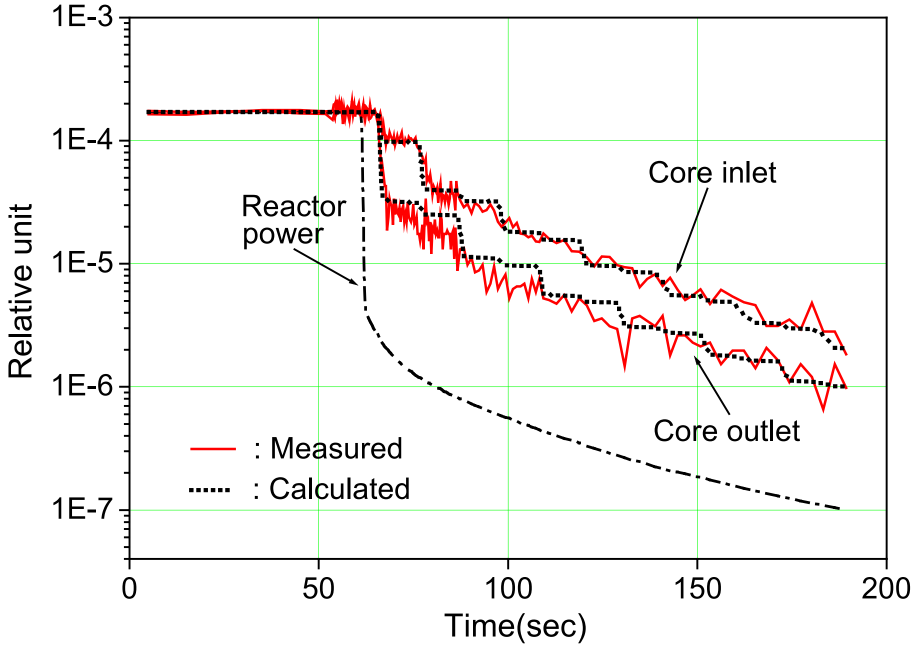

Fig. 2. Measured and calculated neutron count rates before and after the reactor shutdown.

Fig. 2 shows the measured and calculated count rates assuming the effects of core inlet and outlet pipes and the contributions of delayed neutrons and photoneutrons to the detector. From the comparison of predictions and measurements, it is predicted that about 70 % of the measured neutrons are delayed neutrons, and 30 % are photoneutrons. As a result, the count rate from the photoneutron is approximately half of that from the delayed neutron.

In order to enhance the sensitivity of neutron detection, BF_3 detectors are positioned near the primary cooling pipe and polyethylene reflector is arranged around the detector. So, the count rate of the BF_3 detector is much enhanced.

3. CALCULATION OF DETECTED NEUTRON COUNT

The neutron count rate at the detector position is calculated by Monte Carlo method in order to support the analyses on the neutron sources[5,6]. The generations and transportations of high energy gamma rays from N-16, photoneutrons and delayed neutrons are simulated at the similar geometry with BF_3 detector used at experiments. And then, the count rates of the photoneutron and the delayed neutron at the detector position are calculated. The N-16 production rate in the flow tube of the reactor core is obtained from the calculation of the $O^{16}(n,p)N^{16}$ reaction rate by MCNP. The calculated count rate of the photoneutron is 11 % of the whole measured neutron count rate. The amount of uranium exposed to the coolant in the core is also predicted by the delayed neutron transport calculation. The neutron count rate of 800 cps at 20 MW reactor power can be obtained from the U-235 exposure of 130 g, which is lower than the allowable level of surface contamination of fuel rod[7]. It is sensitive enough to detect fuel failure, and the count rate is high enough for stable signal with short counting time.

4. IMPLEMENTATION OF FUEL FAILURE DETECTION SYSTEM BY DELAYED NEUTRON MEASUREMENTS

For field application of the new concept the design modification to the existing system was started in 2000. The same BF_3 model, which had been used during the feasibility study and verified its appropriateness for HANARO, has been selected as a neutron detector. Considering that the new system would be used for reactor safety, all the equipment was class-1E qualified and designed as per the safety codes and standard. The new system arrived at site on August 2001 and soon subjected to the performance test. The good performance of the measuring channel was satisfactorily demonstrated through the pulse spectrum analysis and system response characteristics for the delayed neutron.

New FFDS being used as a trip parameter of reactor protection system embraces not only the delayed neutron channel but also the NaI-based gamma detection channel. Fig.3 depicts a comprehensive FFDS consisting of 1 neutron channel and 2 gamma channels. The BF_3 counters at the naked condition are installed directly under the primary exit pipes with about 15 cm gap.

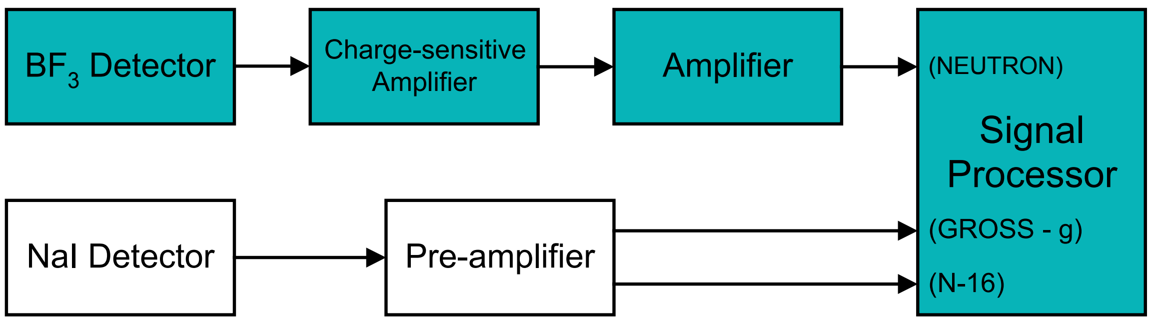

Fig. 3. Channel Equipment Layout of the comprehensive FFDS.

The trip setpoint was then properly determined based on the fuel property and environment at the detector installation. Prior to the official use as a trip parameter, two months of off-line function test was carried out at reactor operating condition. After the completion of the step-wise verification process, the new delayed neutron system started its formal service as a trip parameter for reactor protection system. Through the fine tuning and adjustment at full power operating condition, the new system has been doing its intended role of fuel failure detection up to now.

CONCLUSIONS

Since the level of delayed neutrons generated from the surface contamination of fuel rods are sensitively monitored by the neutron detection method in the primary cooling circuit, it is confirmed that the detection of the delayed neutron is very useful for the monitoring the fuel failure. After the step-wise field application test, the new delayed neutron FFDS system has started its formal service as a trip parameter for the reactor protection system, and it has been carrying out its intended role of fuel failure detection effectively up to now.

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