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Contribution of External Gamma Rays to SPND at HANARO

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1. Introduction

Self-Powered Neutron Detectors (SPNDs) have been widely used for monitoring the neutron flux in reactors as well as in irradiation facilities. In its simplest form, the detector operates on the basis of directly measuring the beta decay current following neutron capture [1].

The neutron capture cross-section of ^{103}Rh, which is used for an emitter of the SPND, is 142.13 barns for thermal neutron (0.0253 eV) [2]. After neuron capture of ^{103}Rh, the compound nuclei of ^{104}Rh (92.6%) and ^{104m}Rh (7.4%) are produced. The sensitivity of SPND is generally defined as [3]

$$S \equiv I/\phi \quad (1)$$

where I is the current signal of the SPND and ϕ is the thermal neutron flux in the vicinity of the SPND location. The signal current of the SPND is mainly produced from the components of the detector as follows

$$I = I(\beta^-) + I(\gamma_{detector}) + I(\gamma_{external}) + I(cable) \quad (2)$$

where $I(\beta^-)$ is current signals through β^- decay after the (n,γ) reaction of ^{103}Rh. And $I(\gamma_{detector})$ is the current signal caused by Compton and photoelectrons produced from prompt gamma rays following neutron captures of ^{103}Rh and other materials in the detector. $I(\gamma_{external})$ is the current signal produced by a similar mechanism to the $I(\gamma_{detector})$ not from the detector but from external materials such as water in the pool-type reactor and an irradiation basket. $I(cable)$ is caused from the connecting cable, and can be considered negligible for standard SPND by compensated lead wire. $I(\beta^-)$ and $I(\gamma_{detector})$ are proportional to the neutron flux, whereas $I(\gamma_{external})$ is dependent on the reactor characteristics and affected by materials around the detector. The current signals can be either positive or negative, in that the net flow of the current may be either in the same or the opposite direction as the neutron-induced current.

HANARO, a 30 MW research reactor in KAERI, is a good tool for a determination of the sensitivity of the SPND. In order to estimate the sensitivity of the SPND precisely, the reactor should be operated at low-power, and in this situation, influence of the external gamma rays is not insignificant. In this study, contribution of the external gamma rays was analyzed using the Monte Carlo simulation for various irradiation conditions in HANARO of the rhodium-based SPND.

2. Methods

In order to predict the contribution of external gamma rays to the SPND current signal, the MCNP6 code was used to calculate the spatial distributions of the neutron capture reaction and total photon interaction rates. The MCNP equilibrium core model was employed for a detailed whole core representation of the HANARO to calculate the reaction rate in each component of the SPND. In the core model, the isotopic density distributions of each fuel of HANARO core were investigated by WIMS and VENURE. The reactor power of HANARO was assumed to be 1 kW for all calculations. A big size irradiation hole of the HANARO was considered for irradiation of multiple SPNDs simultaneously. In the calculation, SPNDs were assumed to be loaded at the NTD2 vertical hole. 40 irradiation positions were located in a circle along the irradiation basket. The axial position of the center of the rhodium emitter was assumed to be 12.5 cm from the longitudinal center of the reactor core.

Figure 1 shows a schematic diagram of a typical SPN detector [1]. The main components of the SPND are rhodium emitter, an Inconel wire, an Inconel sheath, and an aluminum oxide insulator. In the SPND modeling, the dimensions and materials of each component were based on a typical type of rhodium emitter SPND. An irradiation basket for the SPND irradiation was assumed in a cylindrical shape, which was made of polycarbonate to minimize the delayed gamma rays from neutron activation. And two types of irradiation baskets containing light water inside the basket or not were considered to investigate the influence of water on the spatial distribution of the reaction rate.

3. Results

Figure 2 shows the neutron capture reaction (n,γ) and total photon interaction (γ,tot) rates calculated by the MCNP code at each component of the SPNDs, which were installed at different positions (1 ~ 40) of the irradiation basket with water. For all components, the maximum reaction rate was recorded at position 10, which was the nearest position to the reactor core. On

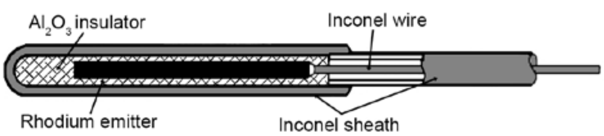

Fig. 1. Cross-sectional view of a typical rhodium emitter SPND applied to the calculation [1].

the other hand, the minimum reaction rate was recorded at position 30, which was opposite the direction to position 10. In the case of the irradiation basket with water, the (n,γ) rate at the rhodium emitter, which was installed at position 30 was 22.6% of that at position 10 by the absorption and scattering of neutrons in water in the irradiation basket.

The basis of neutron response of the SPND is a (n,γ) reaction at the rhodium emitter. The response to the external gamma rays can also be quite significant. The (γ,tot) rate at the Inconel sheath is higher than those at the other components. Secondary electrons, which are produced at an Inconel sheath by photon interactions and collected at the rhodium emitter, contribute to the negative current. However, partial electrons can be collected to the emitter because the diameter of the emitter is quite small.

Secondary electrons produced at the rhodium emitter, are collected to the collector and contribute to the positive current. In eq. (2), if the ratio of $I(\gamma_{external})$ to the sum of the other components is same at each position, the sensitivity of the SPND can be determined irrelevant to the irradiation position. As shown in figure 2, the ratio of (γ,tot) to (n,γ) rate at the rhodium emitter is 28.8% at position 10, but increases 70.4% at position 30. In this case, therefore, the gamma-ray induced signal should be corrected for a reliable determination of SPND sensitivity at each irradiation position.

Figure 3 shows the (n,γ) and (γ,tot) reaction rates at each component of the SPND installed at the irradiation basket without water as a function of irradiation position. In this case, neutron absorption and scattering by water disappear. The (n,γ) rate at the rhodium emitter at position 30 was 66.6% of that at position 10. The ratios of (γ,tot) to (n,γ) rate at the rhodium emitter are the same within 2% at all positions, e.g., 23.3% and 25.1% at positions 10 and 30, respectively.

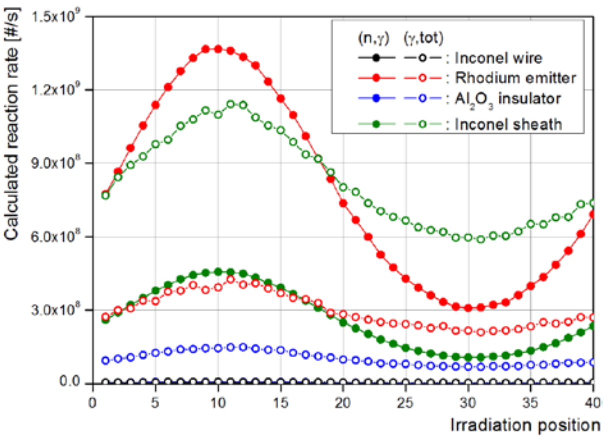

Fig. 2. Neutron capture reaction and total photon interaction rates at each irradiation position of the irradiation basket with water.

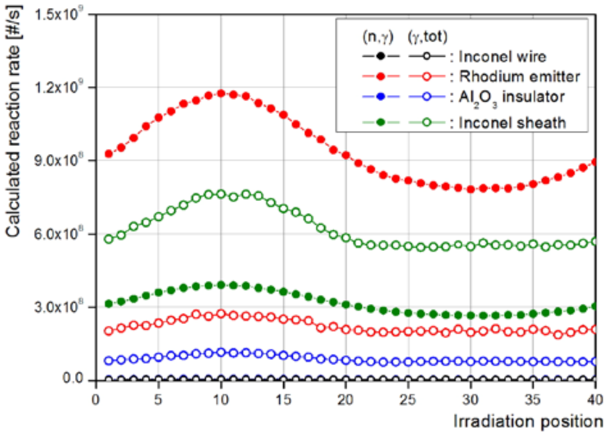

Fig. 3. Neutron capture reaction and total photon interaction rates at each irradiation position of the irradiation basket without water.

4. Conclusion

The influence of water in the irradiation basket on the external gamma rays is determined by calculations of neutron capture reaction and photon interaction rates at various irradiation positions in HANARO. Since it is not easy to correct the contribution of the external gamma rays to the current signal by measurements at the research reactor, it is advantageous to reduce materials such as water at the irradiation position.

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