In-reactor Testing Design for Long-lived SPND at HANARO

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1. Introduction

Korea Hydro & Nuclear Power Co., Ltd. (KHNP) is developing long-lived self-powered neutron detector (SPND) for economic benefits and reduction of radioactive waste and worker's exposure[1]. The in-reactor testing of SPND was planned to investigate the performance that is an important requirement to be applied to commercial nuclear power plants. The most interest of HANARO test is to observe the signal change according to the depletion of emitter. Since HANARO has a higher thermal neutron flux than the commercial nuclear reactor, it is easy to observe the depletion characteristics. SPNDs mounted on an instrumented capsule will be irradiated in the HANARO core. In this paper, we show the design of the test method and the device to satisfy the test requirements.

2. Testing method and device design

2.1 In-reactor testing method

We designed the SPND testing method and device based on the in-reactor testing experiences[2] at HANARO. SPND measures the micro-current generated by the delayed beta from the emitter, so it should be physically and electrically protected from the harsh environment of HANARO core. The instrumented capsule used for the irradiation testing for reactor vessel materials was selected to be suitable for the application in this test because it is capable of controlling electrical signals such as thermocouples and micro heaters to control the temperature of the test specimen. Therefore, we referred to the design of the instrumented capsule consisting of a capsule body, a protection tube and a guide tube. The SPND emitter is located on the capsule body and the MI cable is connected to the junction box located at the top of the reactor pool through the protection tube and guide tube. The signal from the junction box to the data acquisition system (DAS) is transmitted through the electrical cable to measure the SPND signal during the test.

In general, the important requirements for the in-reactor testing are neutron fluence and specimen temperature. We need high neutron fluence to observe SPND's performance whether it is maintained for more than 10 years. Although central thimble (CT) hole and outer region (OR) holes have high neutron flux, the test duration in CT hole is limited due to its characteristics, so we selected the OR hole for this test. We set the initial target of test duration to 280 effective full power days (EFPD) which is about 540 EFPD in the commercial reactor. When SPND is irradiated in the HANARO core, the target temperature is about 300℃. However, since the MI cable is vulnerable to heat, it is possible to affect the integrity by the brazing isolation that allows us to control the pressure of inert gas in the capsule. Therefore, we cannot control the specimen temperature. We only designed to reach around 300℃ by adjusting the cooling gap between specimen and structural material of capsule at the normal operation.

2.2 SPND arrangement

Since the OR hole is located in the reflector region, it is known that large neutron flux gradient in the hole is observed. Therefore, the neutron flux of SPND is affected by installation position. We proposed initial three layouts to evaluate the neutron flux according to the installation position of SPND as shown in fig. 1. We calculated the neutron flux of SPND and evaluated the effect of installation position. Finally, we selected the SPND arrangement as shown in fig. 2. In order to conduct the in-reactor testing for SPND under high neutron flux environment, it was considered to install SPND as far as possible outside the capsule. The SPND located in the center was considered to directly compare the effect of emitter depletion. It was designed to be inserted and withdrawn during the test to minimize the depletion.

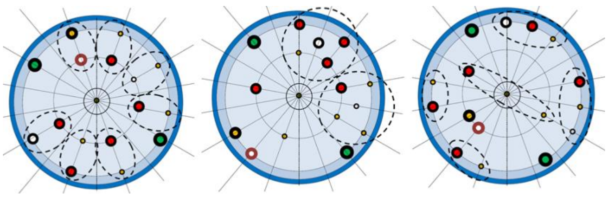

Fig. 1. Initial three layouts for selection of SPND arrangement

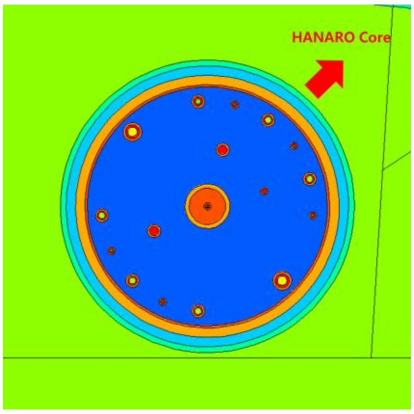

Fig. 2. Selected SPND arrangement (MCNP model)

2.3 Shielding design against signal interference

The dominant mechanism of SPND signal generation is the delayed beta from the interaction between the neutron and emitter. Since the generated current is known to be very fine, the interference should be restrained as much as possible. R. Van Nieuwenhove observed and evaluated that the beta generated from the outside SPND affects the SPND signal in HBWR[3]. In case of HANARO test, quantitative evaluation should be conducted because beta generated by the structural materials may affect the SPND signal.

Table 1 shows the relative value generated by structural materials compared to the emitter signal. We observed that relatively large interference may be generated when aluminum thermal media is used. This is because the neutron absorption cross-section of aluminum is large, the half-life of activated nuclide is short, the beta energy is high, and shielding effectiveness against beta is low. On the other hand, if a zirconium thermal media is used, the signal interference may be less than aluminum. Therefore, it is appropriate to use the zirconium alloy as the material of thermal media.

Table 1. Relative interference by structural materials

Region	Radioactivity (Ci)	
	Al thermal media (Al-28)	Zr thermal media (Zr-97, Nb-97)
1st ring (0 ~ 1 mm)	213.8	3.132
2nd ring (1 ~ 2 mm)	319.9	4.688
3rd ring (2 ~ 3 mm)	426	6.242
4th ring (3 ~ 4 mm)	532.2	-
Region	Relative value (structual material/emitter)	
	Al thermal media	Zr thermal media
1st ring (0 ~ 1 mm)	2.44E-01	1.06E-03
2nd ring (1 ~ 2 mm)	9.24E-02	3.53E-07
3rd ring (2 ~ 3 mm)	2.70E-02	-
4th ring (3 ~ 4 mm)	5.23E-03	-
Total	36.88%	0.11%

However, it is difficult to secure the zirconium alloy because it is classified as strategic materials. We proposed a method that 1.5 mm thick zirconium alloy is inserted around the SPND to exclude signal interference caused by aluminum thermal media. When using this method, it was evaluated that the signal was not significantly different with zirconium thermal media. Fig. 3 shows the fabricated thermal media that the zirconium tubes were inserted around SPND.

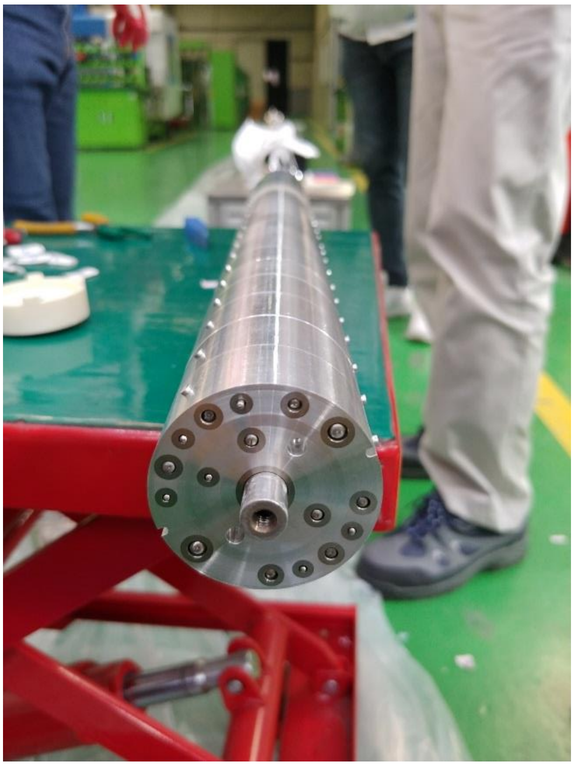

Fig. 3. Fabricated thermal media

2.4 Thermal design

The computer code used for thermal design is GENGTC[4], which is the most reliable because it has various analysis experiences for in-reactor testing at HANARO. A one-dimensional model was used for the purpose of calculating the temperature of SPND. The cooling gap between thermal media and external tube of capsule was calculated to satisfy the 300℃ of SPND temperatures based on the evaluation result of heat generation rate. There are many pins at the outer of thermal media to maintain designed gaps as shown in fig. 3.

3. Safety analysis for SPND withdrawal during reactor operation

It should be confirmed that the test can affect the HANARO operation before the test. In this test, a SPND located at the center of the device will be withdrawn during the reactor operation for the minimization of emitter depletion. In the HANARO technical specification, the increasing amount of positive reactivity during reactor operation is limited to 1.5 mk, and the reactivity change speed is limited to 0.125 mk/s. Therefore, we evaluated the reactivity change between the insertion and withdrawal of the SPND using MCNP code[5]. The highest reactivity change in the several models is the result when the 450 mm of control rod absorber in the equilibrium core. It shows 0.2244 mk considering fractional standard deviation. If we assume that the analysis uncertainty is 20%, it was estimated that the maximum rate of reactivity change would not exceed 0.3 mk. Therefore, it was confirmed that if the withdrawal time is sufficiently long more than 3 seconds, the limit value could be satisfied.

4. Conclusions

The test method and device were designed for the long-term in-reactor testing for long-lived SPND, which is being developed by KHNP. The optimal SPND arrangement was determined. Shielding tubes of zirconium alloy were installed around SPND to minimize interference by the structural material. The optimum spacing between the thermal media and external tube was evaluated to satisfy the temperatures of SPND. As the result of evaluation of reactivity change to apply the withdrawal of the SPND during the reactor operation, it was confirmed that the test will be possible. In-reactor testing of long-lived SPND will be started from HANARO 100^{th} operation cycle.

REFERENCES

[1] S.W. Yang, S.J. Park, M.S. Cho, J.T. Wallick, G.E. Miller, H.C. Shin, K. H. Cha, PERFORMANCE TEST OF SPND FOR THE DEVELOPMENT OF LLICI AT THE UCI TRIGA REACTOR, Proceeding of RRFM/IGORR-2016, Mar. 13-17, 2016, Berlin, Germany.
[2] Kee Nam Choo, Man Soon Cho, Sung Woo Yang, Sang Jun Park, CONTRIBUTION OF HANARO IRRADIATION TECHNOLOGIES TO NATIONAL NUCLEAR R&D, Nuclear Engineering and Technology, Vol. 46, p. 501, 2014.
[3] R. Van Nieuwenhove, "Effect of Fission Betas, Activated Structures and Hydrogen on Self Powered Neutron Detectors", IEEE TRANSACTIONS ON NUCLEAR SCIENCE, vol. 61, p.2006, 2014.
[4] Hall C. Roland, GENGTC, A One Dimentional CEIR Computer for Capsule Temperature Calculation in Cylindrical Geometry, ORNL-TM-1942, 1967.
[5] D.B. Pelowitz, MCNP6™ User's Manual Version 1.0, LA-CP-13-00634 Rev. 0, 2013.