In-reactor Experiment for Cobalt SPND at HANARO IP Irradiation Hole

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1. Introduction

The in-core instrumentation (ICI) is an important facility that provides signal for monitoring and evaluating the condition of reactor core in a nuclear power plant [1]. Since the most important component is the neutron detector among ICI, its performance should be verified under neutron irradiation environment. Korea Hydro & Nuclear Power Co., Ltd., Woojin Co., Ltd. and USERS are developing cobalt self-powered neutron detector (SPND) and monitoring system. It is known to have a different mechanism of generating signal with conventional (rhodium) SPND. Therefore, the irradiation test for cobalt SPND was planned using HANARO.

In this paper, we present the comprehensive contents for HANARO test of cobalt SPND. We selected an irradiation hole considering the test concept and method. We evaluated the neutron flux according to the arrangement of the SPNDs to design the test device. It was determined that the test could be performed in a sufficiently safe environment through the test performance and safety evaluation. The test was conducted during HANARO 103rd operation cycle.

2. Test Concept and Design

We are currently conducting a depletion test of long-lived SPND [2]. Since the objective of this test is to observe the depletion characteristics of emitter, the OR5 irradiation hole with higher neutron flux than in the core of nuclear power plant had been used. The OR5 is located in the core region of HANARO with high speed coolant. Therefore, the SPNDs must be inserted and installed in an irradiation device for testing to secure the integrity. However, in this case, a lot of cost and time are required to design and manufacture the device.

For the above reason, we decided that the cobalt SPND test is conducted using the irradiation hole located in the reflector region. It has the advantage of not only having no forced convection of coolant but also easy access. We can also simplify the test device design. Additionally, it has the relatively higher thermal neutron flux level of 10^{13} n/cm^2-sec. Therefore, we selected the IP irradiation hole for the test of cobalt SPND. Recently, the irradiation test of a chemical vapor deposition (CVD) diamond detector was performed in the IP5 irradiation hole during HANARO 100th-2 operation cycle [3]. This test is also planned to be similarly conducted.

3. Test Evaluation

We analyzed the nuclear characteristics for the test of cobalt SPND. MCNP6 [4] was used for it assuming the test device is inserted in the IP5 irradiation hole. The neutron flux for five SPNDs (diameter: 4.6, 5.2, 5.6, 6.0, 6.6 mm) was evaluated to determine the arrangement of SPNDs. Fig. 1 shows the assumed arrangements of SPNDs in the test device. It is divided into a straight and a circular arrangement, and it is subdivided into two models.

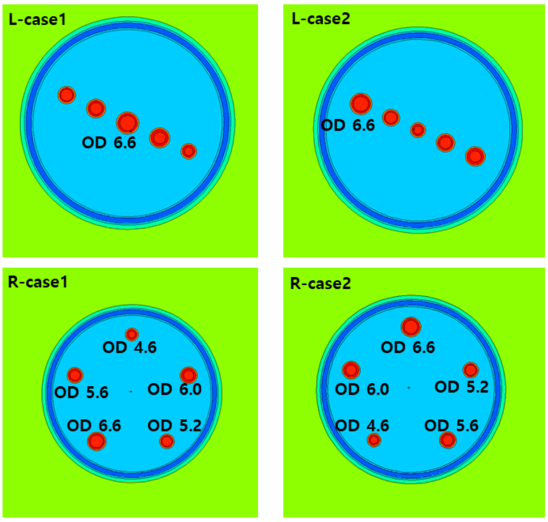

Fig. 1. Assumed cobalt SPND arrangement models

We used KCODE mode of MCNP6 with whole core calculation. We assumed the HANARO fuel burnup of middle of cycle (MOC) and control absorber rod (CAR) height of 450 mm from the bottom of active fuel length. Table I shows the evaluation result of thermal neutron flux by four arrangement models of cobalt SPNDs. In the case of the straight arrangement (L-case), the overall neutron flux was lower than that of the circular arrangement (R-case). This is because neutrons are incident from the outside of the irradiation hole to the inside due to the irradiation hole in the reflector region. In addition, in the case of the straight arrangement, the effect by mutual interface was shown because it was more concentrated in the local area than the circular arrangement. In the case of R-case2, the neutron flux of each SPND appeared relatively flat, so the design of the test device was based on R-case2.

Table I: Thermal neutron (< 0.625 eV) flux evaluation by arrangement of SPNDs

diameter (mm)	L-case1	L-case2	R-case1	R-case2
4.6	4.06E+13	2.64E+13	5.04E+13	3.34E+13
5.2	2.97E+13	2.35E+13	3.28E+13	4.21E+13
5.6	2.37E+13	2.62E+13	3.22E+13	3.32E+13
6.0	2.70E+13	3.42E+13	4.38E+13	3.25E+13
6.6	2.03E+13	2.59E+13	2.40E+13	3.59E+13
average	2.83E+13	2.72E+13	3.66E+13	3.54E+13

Fig. 2 shows the MCNP model for the design of actual test device and SPNDs. A total of four SPNDs were installed in the test device. The outer diameters of each are 6.6, 6.0, 3.6 and 2.0 mm. Finally, we determined the test hole of IP4, because the IP5 is expected to be used for radioisotope production. Table II shows the evaluation result of thermal neutron flux by the actual design model of test device. Since the test hole was changed from the originally planned IP5 to IP4, the neutron flux decreased due to the increased distance from the core. In addition, the neutron flux of large size SPND was evaluated to be relatively low. This is to be self-shielding effect of cobalt.

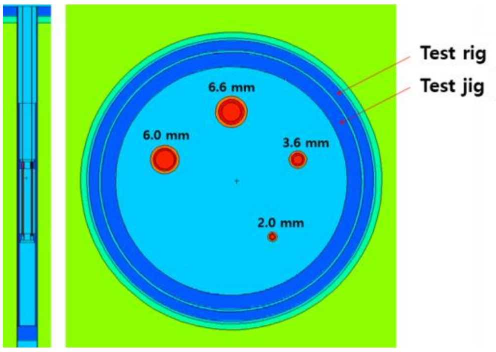

Fig. 2. Actual MCNP model for cobalt SPND test

Table II: Thermal neutron (< 0.625 eV) flux evaluation by actual model

diameter (mm)	Neutron flux
6.6	2.16E+13
6.0	1.81E+13
2.0	3.54E+13
3.6	3.23E+13
average	2.69E+13

4. Manufacturing and Assembling of Test Device

Based on the above analysis result, we considered the design of test device. The test device is divided into two sections, the rig for the installation in the IP irradiation hole and the jig for maintaining the arrangement of cobalt SPNDs in the rig. We decided to reuse 14F-17K used for the depleted uranium (DU) Fission Moly target irradiation [5] as the rig. We designed and manufactured the jig (21M-01I) for the installation in the 14F-17K.

In order to conduct the irradiation test using HANARO, the performance and safety of the test should be verified by out-of-reactor test to prove compatibility with HANARO. We conducted the test using single channel test loop. Fig.3 shows the picture of out-of-reactor test for cobalt SPND HANARO test. We concluded from the test as follows.

(1) It was impossible to check the installation direction because the jig was not visible when the jig and rig for SPND installation test were assembled.
(2) Since the test was conducted using stainless wires instead of the actual SPND, it was not possible to change the direction. However, it was expected that the change of direction will be possible.
(3) When installing the test rig in the IP hole, it is necessary to maintain MI cable loosely against the direction change of SPND installation.
(4) It was confirmed that the engraved direction of the jig name (21M-01I) is not matched with the manufacturing specification.

Fig. 3. Out-of-reactor test for cobalt SPND HANARO test

In spite of above issues, we concluded that the test could be conducted without any problems. We assembled the cobalt SPNDs and the test jig as shown in Fig. 4.

Fig. 4. Assembled test jig (21M-01I)

5. HANARO test

The test for cobalt SPND has been conducted during HANARO 103rd operation cycle (2022.03.11~04.08). Fig. 5 shows the picture of installed test rig into the IP4 irradiation hole. We could observe the SPND signal and its characteristics by the change of reactor power.

Fig. 5. Test rig installation into the IP4 irradiation hole

6. Conclusions

We designed for the irradiation test of cobalt SPND under development and manufactured the device. As the result of performance and safety evaluation by neutronic analysis and out-of-reactor test, we concluded that the test would be conducted without any problems. The test was started with HANARO 103rd operation cycle. It is expected that we will be able to evaluate the dynamic performance and the sensitivity of cobalt SPND with various size from the result of this test.

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