Design of Neutron Irradiation Testing at HANARO for Control Rod Neutron Absorber Materials

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1. Introduction

Korea Atomic Energy Research Institute and KEPCO Nuclear Fuel Company, LTD. are developing new materials for control rod neutron absorber for its life extension and enhancement of safety[1]. The conventional material, boron carbide (B_4C), is known that it has some performance issues. A lot of helium is generated by neutron induced reaction with boron, so it can cause excessive expansion itself and increasing internal pressure. It is also known that the oxidation, volatilization and eutectic reaction can occur at relatively low temperature. Furthermore, its performance at the accident condition is vulnerable than the nuclear fuel. Therefore, new materials are being developed to overcome above drawbacks. HANARO irradiation test was planned to observe its in-core performance.

In this paper, we present the design and evaluation result for HANARO irradiation test. We designed test rods and a rig to investigate the performance of candidates bearing europium, dysprosium, zirconium, titanium, tantalum and hafnium oxides. The neutronic evaluation such as reactivity change to the HANARO core, neutron flux and heat generation rate was already conducted[2]. Based on the evaluation result, we analyze the thermal performance and safety for the test. Since some elements can cause a lot of decay heat after the irradiation, the decay heat is also calculated each material.

2. Design and Fabrication of Test Rods and Rig

It is an important objective to observe the expansion of candidates by the neutron irradiation. In the case of control rod at the commercial nuclear power plant, the neutron absorber is made by cylindrical shape like a fuel rod. So we designed the test rod with reference to conventional nuclear fuel test rod. We have some experiences to irradiate the nuclear fuel at HANARO. Although we conduct the test for neutron absorber for the first time, it will be easily applied because the test for nuclear fuel under severe environment was performed without any safety problems.

Fig.1 shows the schematic drawing of test rig (22M-02K) for neutron absorber. Total sixteen test rods are installed in the rig. Among them, B_4C reference materials are inserted in two rods and new materials are inserted in fourteen rods. Each diameter and stacking length of test specimen in the test rod are about 7.8 mm and 60 mm. The test rods are separately accommodated into two (upper and lower) clusters. Fig. 2 shows the manufactured test rods. The cladding material for test rods is Zircaloy-4. Its end cap was sealed by tungsten inert gas (TIG) welding. The manufacturing process of test rods is identical with nuclear fuel testing. This welding performance was verified by microstructure observation, tensile test and helium leak test. Therefore, we prepared the test rods for this test without any problems.

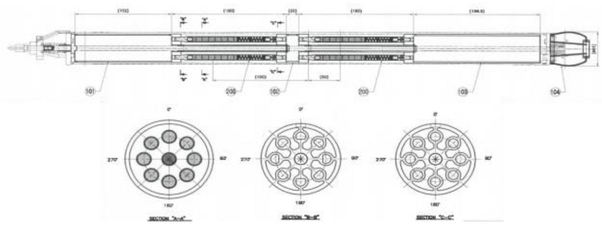

Fig. 1. The schematic drawing of test rig (22M-02K)

Fig. 2. The manufactured test rods: before (left) and after (right) welding

3. Performance and Safety Analysis

Before the HANARO test, the performance of manufactured test rig and rods should be verified by the hydraulic test. We installed test rods in the test rig as shown in fig. 3. We also conducted the hydraulic test under HANARO normal operation condition in single channel test loop. The flow rate of channel of 8.4 kg/s was measured, so it showed less than limitation value (12.7 kg/s). The maximum displacement of vibration of the rig was 64 μm, also less than limitation value (300 μm). Since the suggested irradiation duration in HANARO is about 240 EFPD, its durability might be sufficient based on the similar test results. Therefore, we determined that the test for neutron absorber can be performed at HANARO.

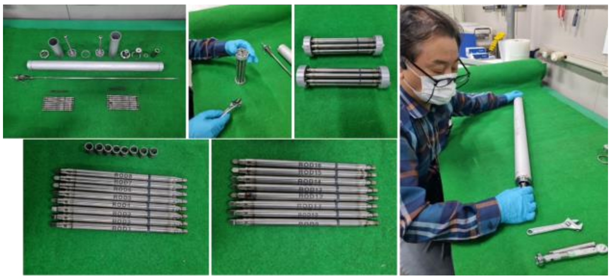

Fig. 3. Assembling test rig with test rods

The temperature of test specimen is an important value to satisfy the test requirement and safety. It might be safer than nuclear fuel testing considering the thermal effect because the heat generation rate is about 1/5 of nuclear fuel. Of course, the amount of radioactive emission is much less than nuclear fuel testing. We evaluated the specimen temperatures using GENGTC[3]. The maximum temperature of specimen is 738℃ under normal operation, which is much lower than melting temperature of 2,200℃. When we assumed the densification at the initial stage of the irradiation up to 50% conservatively, the maximum specimen temperature is 910℃. Therefore, we concluded that the test has a sufficient margin for the safety.

4. Decay Heat Evaluation

We evaluated the decay heat of each neutron absorber material after the irradiation. It can be used for not only the thermal performance analysis of neutron absorber in the nuclear power plant but also the transportation to post irradiation examination facility. The decay heat was evaluated by ORIGEN-2.2[4]. Since HANARO irradiation library is not included in the ORIGEN-2.2, we made it by MCNP6[5] calculation using overall nuclides and reactions in ENDF/B-VII.1[6]. Although the dynamic effect is not considered in this method, it can be used to compare each neutron absorber material relatively. Fig. 4 shows the decay heat evaluation result of each specimens after 224 EFPD irradiation. The decay heat of B_4C is rapidly decreased. However, we can observe that the decay heat of new neutron absorber materials is relatively high. In particular, europium-bearing neutron absorber shows the highest decay heat generation rate. In case of 36 rods HANARO fuel, the average linear decay heat generation rate is about 0.5 W/cm after one-month decay for 120 GWD/MTU burnup fuel[7]. In the case of europium-bearing neutron absorber, it is about 0.4 W/cm at same decay time, so we should be careful in handling. The irradiated fuel was generally transported to post irradiation examination facility after from three to six months to reduce the heat generation and radioactivity. We must evaluate and consider the decay heat of europium-bearing neutron absorber to conduct the examinations in hot cell.

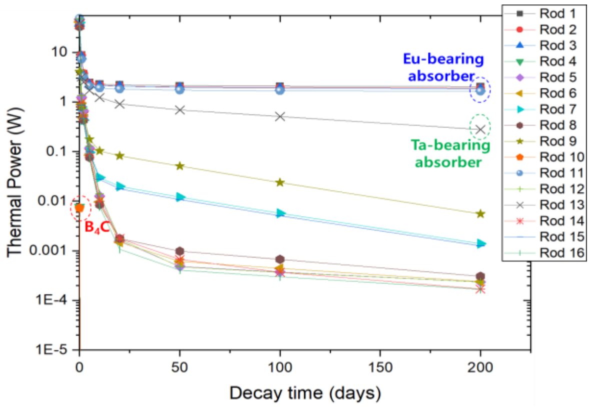

Fig. 4. The decay heat evaluation result after 224 EFPD irradiation

5. Conclusions

We prepared the HANARO irradiation test for new control rod neutron absorber materials to observe their in-core performance. The test specimens, rods and rig were manufactured without any problems. We concluded that the test can be conducted by the evaluation of its in-core performance and safety. Among them, we should carefully handle europium-bearing neutron absorber due to its high decay heat generation rate. We will conduct the test from HANARO 106th operation cycle.

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