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Evaluation for Application of Fuel Power Control Test in HANARO

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1. Introduction

The interest in the safety of nuclear fuel has increased due to the Fukushima accident so that the accident tolerant fuel (ATF) has been actively developed [1]. The candidate research method to evaluate the in-core performance of fuel is the utilization of research reactor, which has the advantage of simulating normal operating or accident condition of nuclear power plant. In Korea, although HANARO has been used to conduct the in-core performance test of fuel [2-5], the fission power of the test fuel during the irradiation could not be intentionally controlled, and it was only dependent on the change of the core variation such as the height of control absorber rod (CAR) and the depletion of HANARO fuel. Therefore, the purpose of the in-core performance test of fuel was limited to the measurement of physical properties at a specific burn-up. Some research reactors in foreign countries can freely change the fission power of test fuel during the irradiation, but the utilization of them is not easy because of the relatively high cost and technical difficulties. Therefore, in this study, the evaluation results for the test method that can control the fission power of test fuel during the irradiation were described to apply in HANARO.

There are several methods in the research reactor that can change the fuel power during the irradiation test, such as reactor power control, moving the position of test fuel and the utilization of neutron absorber like He-3. Halden reactor can conduct the test with the control of fuel power by moving fuel position and the utilization of He-3 [6]. Jules Horowitz Reactor (JHR), which is currently under construction, will prepare a facility called ADELINE and plan to use the method of inserting and withdrawing the test fuel into the core [7]. Therefore, the control method of fuel power is different for each reactor so that it is necessary to evaluate which method should be applied considering the HANARO characteristics. If the control of fuel power is possible in HANARO, it will be possible to carry out the dynamic safety research, the study of load following behavior and various basic studies.

2. Test design and evaluations

2.1 Test method

In order to conduct the in-core performance test of fuel, it is common to apply a loop facility to make the system condition of nuclear power plant. However, it is difficult to construct a loop facility due to lack of space in HANARO. Therefore, the system condition for the test cannot be controlled in HANARO and the in-core performance test should be carried out under HANARO core condition. For this reason, the main interest of this test is limited to the behavior inside the cladding tube.

The irradiation holes inside the core were selected because the test fuel must be cooled by forced convection of coolant. Among them, hexagonal irradiation holes are not suitable because they can largely affect the reactivity of the core and the flow rate of coolant is too large. OR circular irradiation hole, which has been used for many fuel tests, is considered in this evaluation. In order to control the fission power of test fuel, combining two kinds of method was proposed. The reactor power can roughly change the fission power of test fuel; also it can be controlled by the axial movement of fuel. The method using He-3 is not considered because tritium is generated by (n,p) reaction. It is difficult to operate a He-3 loop without a tritium treatment facility. The test fuel power during the irradiation can be determined by the measurement of neutron flux and neutronic analysis.

2.2 Device design

Since axial movement of test fuel is conducted and the signal wire of the instrumentation must be connected into the top of the working area for this test, the test device was designed based on the design of instrumentation capsule that has been used for the irradiation test in HANARO. The signal wire is wrapped with a protective tube to the chimney of HANARO. It is finally connected to the working area by the guide tube. Fig. 1 shows the conceptual design of test device. The fuel assembly was assumed to accommodate three fuel rods and five UO_2 pellets in a single fuel rod. The assembly is connected to a screw rod located at the center of the device, and the screw rod is connected to the contactless motor so that the position of test fuel is shifted in the axial direction by the rotation of the motor. The location of test fuel should be identified by a specific module. The driving part of contactless motor is isolated from the coolant to prevent the effect of coolant. The SPND is installed in the wall of the test device to measure the neutron flux.

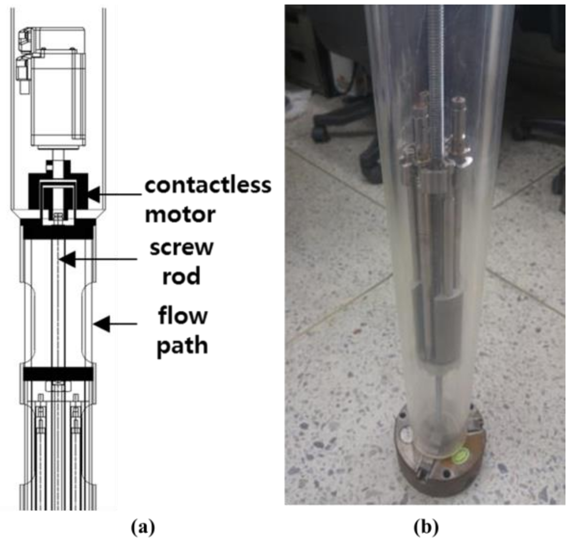

Fig. 1. The conceptual design of test device: (a) upper structure and (b) assembly connected to screw rod

2.3 Neutronic analysis

Although the test for the control of fuel power has various power maneuvering histories, it can be observed that the maximum power of fuel is less than 60 kW/m from the previous experiences [8-10]. Therefore, to achieve the goal of this test, the fission power of test fuel in HANARO irradiation must be satisfied up to 60 kW/m. To confirm the fission power of test fuel in HANARO, it was calculated by Monte Carlo N-Particle code version 6 [11]. The calculation model was assumed that CAR is located in 450 mm from the bottom in the equilibrium core and the dummies are loaded in the other irradiation holes. Fig. 2 shows the calculation result of fission power of each pellet according to the axial position of fuel. The fuel power was calculated when the center of the fuel rod was located from 150 mm to 750 mm. It was highest when the fuel rod was located at 350 mm. Among them, the maximum power requirement was satisfied in the several pellets. As the position of fuel rod was increased from 450 mm, the fission power of fuel was rapidly decreased.

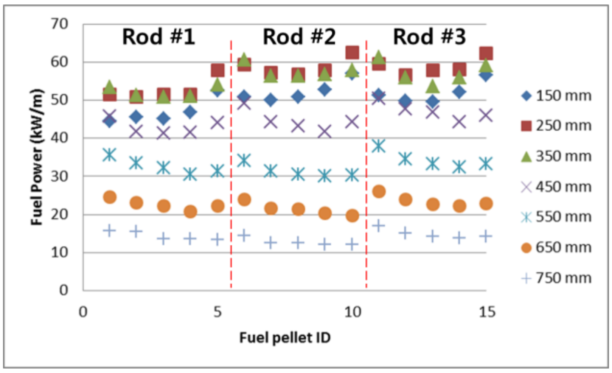

Fig. 2. The calculation result of fission power of each pellet according to the axial position of fuel

The technical specification of HANARO requires that a suitable drive mechanism must be installed if the insertion or withdrawal of the test device during the operation may result in insertion of 1.5 mk or more of positive reactivity [12]. Furthermore, the drive mechanism must be designed that the maximum speed of reactivity insertion shall not exceed 0.125 mk/s. As the result of calculation for core reactivity to observe the impact by the fuel movement, the maximum reactivity difference was 0.196 mk, which is much lower than the requirement. Therefore, there will be no problem in the safety of HANARO because the impact on the core by the fuel movement is quite small.

2.4 Test operation

Fig. 3 shows the example of fuel power history [8]. In this case, it consists of two modes: a bump mode in which the power rises sharply and a ramp mode in which the power rises stepwise. The stand-by power of two modes is about 22 kW/m. During the bump mode test, the target power of test fuel is reached within a fixed time. It can be achieved by axial fuel movement in HANARO. If the fuel transfer time is required, the reactor power can be adjusted to reduce the time. In the ramp mode test, it is estimated that the axial movement of the fuel is enough. It is expected that the long time will not be consumed because the axial movement of the fuel is only about 10 cm when the fuel power is required to increase 10 kW/m. In the case of test on fresh fuel, it is possible to conduct the test by the control of reactor power at a fixed position, but it is difficult to reach the correct power because the reactor power control must be performed according to the predetermined procedure. Therefore, the axial movement of test fuel is indispensable for this test in HANARO.

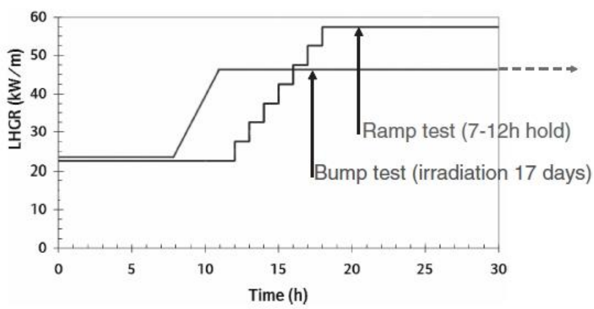

Fig. 3. The example of fuel power history [8]

2.5 Challenges

Although this analysis identified the possibility of fuel power control test during the irradiation, there are some challenges that must be overcome in order for this test to be available in HANARO.

(1) Since the upward forced convection of the coolant is formed in the OR irradiation hole, it is difficult to move smoothly in the axial direction of test fuel. Especially, if it is necessary to move

lower direction, it is opposite to the direction of the coolant flow path. Therefore, the fuel movement has to be verified despite the coolant flow.

(2) The axial position of test fuel must be measurable by a reliable method. It is important information because it greatly affects the calculation of fuel power.

(3) The fuel power must be accurately calculated by the development of calculating system. It can use the SPND signal installed in the device. Preliminary calculations based on various core configurations are required.

(4) Development of instrumentation and application technology is needed for the measurement of physical properties of test fuel.

3. Conclusions

In this study, we evaluated the performance of the fission power control of test fuel in HANARO. A preliminary design of the test device was carried out based on the consideration of the test method. As the result of the neutronic analysis to calculate the fuel power, it was shown that the fuel power is satisfied enough by the axial movement of fuel, and the effect of fuel movement is negligible. This study suggested that further research is needed to conduct the power control test of fuel in HANARO.

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