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Nuclear Analysis on the HAMP-1 Irradiation Test Using the McCARD

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1. Introduction

KAERI has been operating the HANARO research reactor, which is a multi-purpose research reactor of 30 MW. The HANARO is supporting domestic nuclear research activities such as nuclear fuel and material irradiation tests, isotope production, and neutron beam research.

WIMS [1], VENTURE [2], HELIOS [3], and MCNP [4] have been used to support the core analysis needs of various fields. Among the various fields of application, the nuclear fuel irradiation test requires a more accurate core analysis. In order to verify new U-Mo fuel to be used in the KiJang research reactor (KJRR) [5], three times irradiation tests were scheduled in the HANARO. The McCARD [6] code was chosen for accurate analysis of the irradiation tests in HANARO.

This paper presents the results of the McCARD calculations and the comparison with experiments on the first U-Mo irradiation test using the HAMP-1 test rig.

2. Method

In order to accurately analyze the irradiation test of HAMP-1, HAMP-1 and HANARO were modeled with McCARD as close to actual as possible. HAMP-1 is a nuclear-fuel test rig with eight mini-plates designed to verify the U-Mo fuel in HANARO. Figure 1 shows the MCNP model that was used for a safety evaluation before the irradiation test, and the McCARD model was modeled the same as the MCNP model.

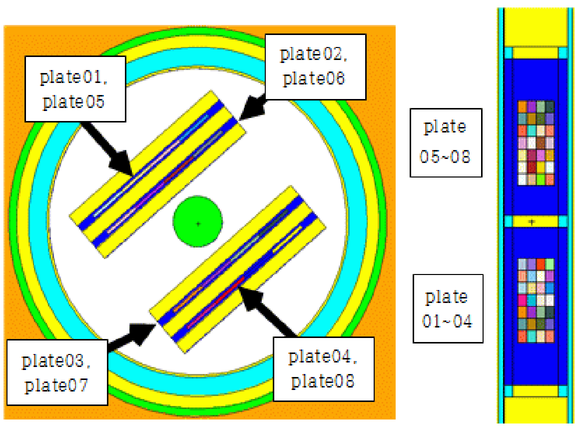


Fig. 1. HAMP-1 MCNP model for the safety analysis.

HAMP-1 was irradiated in OR3 for 4 cycles from cycle 92 to cycle 95. Figure 2 shows the layout of the HANARO fuel assemblies and the irradiation rigs loaded in the cycle 92 core. In order to obtain accurate core analysis results for HAMP-1, we have modeled all the irradiation devices loaded in the irradiation hole as well as the HANARO nuclear fuel assemblies.

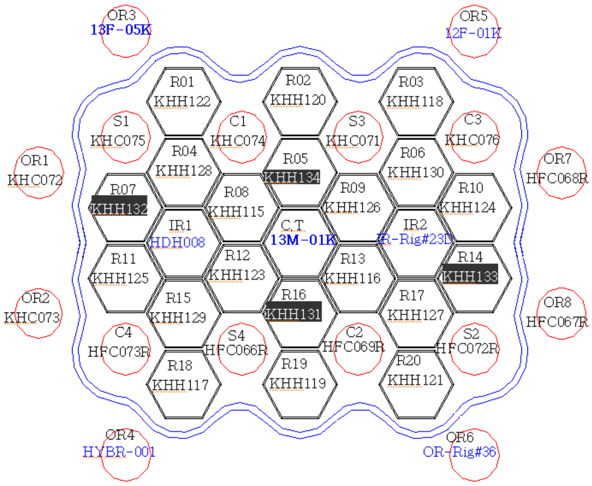


Fig. 2. HANARO core configuration for cycle 92.

Model for the number density of the nuclides as well as the geometric model is needed. In cycle 92, 32 HANARO fuel assemblies and 3 fuel irradiation devices are loaded into the core. 4 HANARO fuel assemblies (KHH131~134) and HAMP-1 (13F-05K) are in fresh state, but the burn-up conditions of other fuel assemblies and 2 fuel irradiation devices (HYBR-001, 12F-01K) should be considered. The burn-up history of HANARO fuel is tracked in units of the fuel rods by the VENTURE, but the complicated fuel irradiation devices is homogenized. In this paper, for the accurate analysis, the number densities of the radionuclides of HANARO fuel assemblies and fuel irradiation devices were independently obtained by using the McCARD calculations. The McCARD model for the HANARO fuel assembly was divided into 5 cm unit in axial direction of each fuel rod, and a total of 13,104 fuel segments were implemented in the model. The fuel irradiation devices were divided into 1 cm unit in axial direction, and HAMP-1, the plate-type fuel, was segmented in the lateral direction with a division of each 0.625 cm.

In this nuclear analysis, the McCARD code with the ENDF/B-VII.0 library was selected and the detailed HANARO core model [7] was upgraded using the measured core geometry data.

3. Results

The core analysis data required for fuel performance evaluation during the irradiation test is power history. There is no way to measure the fuel power of HAMP-1, which is designed as a non-instrumentation system, during the irradiation test. The power cannot be measured, but the fact that the core calculation is done normally can be confirmed by the criticality evaluation. What can be compared to the measurement is the fuel burn-up data after completion of the irradiation test. In the post irradiation test of the HAMP-1, the fuel burn-up was measured in a destructive manner.

3.1 Core Reactivity

The HANARO core is loaded with 20 hexagonal fuel assemblies and 12 circular fuel assemblies. The reference HANARO core with cycle length of 28 days is maintained by loading of 3 hexagonal assemblies and 2 circular fuel assemblies. The equilibrium HANARO core could be obtained with repeated calculation of the fixed fuel management. Figure 3 shows that the equilibrium reached almost after 7 cycles.

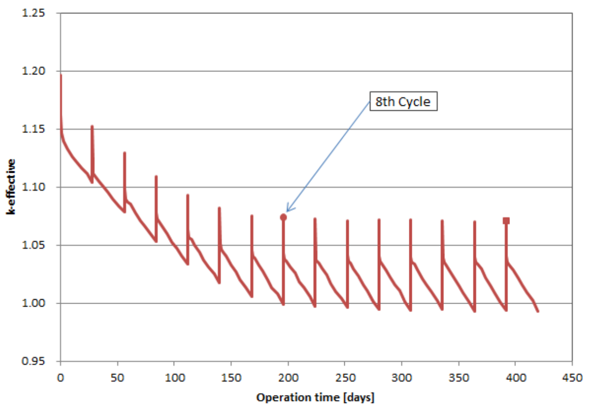


Fig. 3. Approach to a reference equilibrium core.

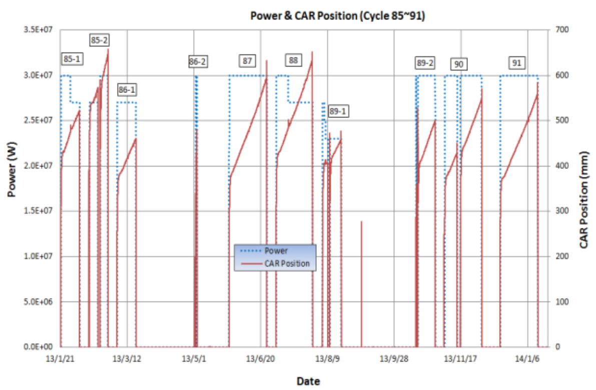


Fig. 4. Reactor power and CAR position for cycle 85~91.

In fact, the HANARO fuel management is not fixed, but it has been done in almost similar way, so that after 7 cycles, it can be expected to approach a real core state. In order to obtain a more precise core state, the burn-up distribution of cycle 85 evaluated by the VENTURE was applied to obtain the core state of cycle 92 in this paper.

Figure 4 shows the changes in reactor power and CAR (Control Absorber Rod) position, which have a significant effect on the power of the test fuel. Since the CAR position changes continuously due to the fuel burn-up, the CAR position is divided into appropriate steps for the core calculation and the stepwise CAR positions were applied as shown in Fig. 5.

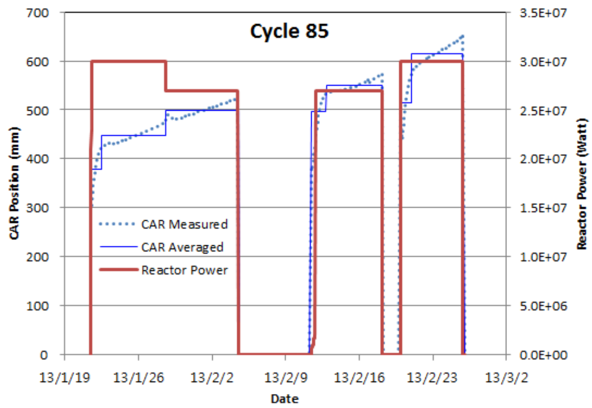


Fig. 5. Reactor power and CAR position for cycle 85.

Figure 6 shows the reactivity deviations of the McCARD calculation results for cycles 85 to 95. At first, there were some differences, but after 7 cycles, the difference was almost stable from cycle 92.

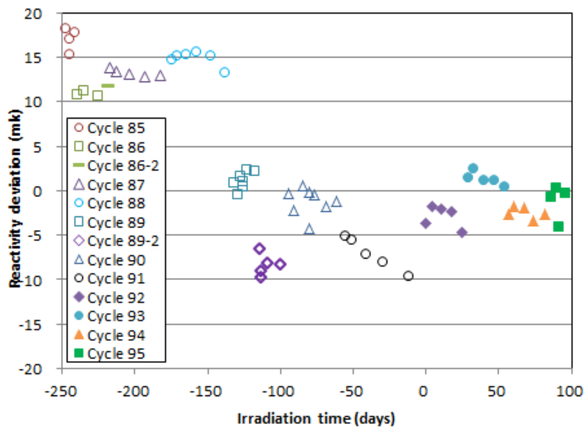
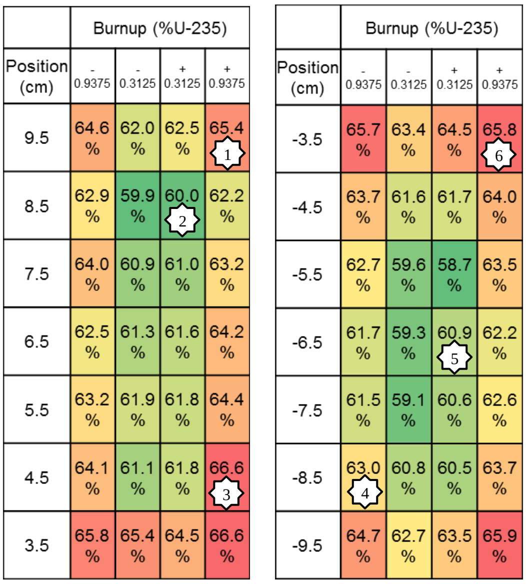


Fig. 6. Reactivity deviations of the McCARD calculation results for cycle 85~95.

3.2 Burnup

The burn-up of the HAMP-1 was chemically measured after the irradiation [8]. The burn-up was measured using the ND-148 method [9] by taking six specimens from two fuel plates. Figure 7 shows the calculated burn-up distributions and measurement points, and Table I compares with the calculated and measured burn-up data. The calculated burn-up distributions in Fig. 7 are the previous calculation results in reference [8], and the calculated burn-up data in Table I are this new calculation results.



a) plate08 in Fig. 1 b) plate03 in Fig. 1

Fig. 7. The calculated burn-up distributions in the irradiated fuel plates.

Table I: Comparison of the calculated and measured burn-up [%U-235].

Fuel plate	Sampling location	Calculated burn-up	Measured burn-up
plate08 (6.5 gU/cc)	1	67.9%	63.4%
	2	64.3%	64.1%
	3	67.9%	66.0%
plate03 (8.0 gU/cc)	4	66.2%	62.7%
	5	62.6%	62.2%
	6	68.2%	68.2%

4. Conclusions

In HANARO, the irradiation test of HAMP-1 was completed for the verification of the U-Mo fuel to be used in the KJRR. Core calculations were performed using the McCARD code.

To simulate the burnt HANARO core, the core follow-up calculation was started by using the burn-up distribution of the HANARO fuel management system before the irradiation test. The errors of the criticality calculations during the cycles with HAMP-1 irradiated were maintained within 5mk. The burn-up measurement results by the chemical method and the calculation results were found to be in good agreement with each other.

The HANARO McCARD system constructed for the HAMP-1 irradiation test can then be used to evaluate other irradiation tests. Currently, HAMP-2 and HAMP-3 irradiation tests started from cycle 97-3 and the as-run calculations are being performed in HANARO.

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