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Criticality Bias of the HANARO McCARD System with ENDF/B-VIII.0 Library

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1. Introduction

HANARO is a multipurpose research reactor with 30 MW of thermal power, and it is utilized for various purposes such as fuel and material irradiation tests, radioisotope production, and neutron beam research. Accurate reactor core analysis serves as a fundamental basis for the reliable operation of the reactor and increases the value of HANARO's outcomes. To produce licensing data, McCARD[1] has been utilized for the three U-Mo fuel irradiation tests[2], and it has been confirmed that acceptable outcomes can be achieved according to the results for the first test. The current HANARO McCARD system[3] shows better results than existing HANARO MCNP depletion calculation system[4] or HANAFMS[5], but the accuracy needs to be further improved to develop it into an operation support program like 'Core Tracking Tool'[6], recently being developed. In particular, the power distribution in the HANARO core changes significantly depending on the position of the control rods, so the bias in the criticality calculation should be minimized.

This paper introduces the process of HANARO McCARD system for more rigorous criticality analysis, and describes the impact of ENDF/B-VIII.0 on the bias in criticality calculations.

2. HANARO McCARD System

HANARO McCARD system is comprised of McCARD 1.0, ENDF/B-VII.0 nuclear data library, optimized core analysis model, and experience-based evaluation techniques.

2.1 Core Tracking and Hf Burnup

Core tracking calculation should be performed from the first cycle to create a McCARD model with exact fuel burnup distribution, but a simple approach was adopted in HANARO McCARD system, because HANARO undergoes various irradiation tests and has a complex operational history. The burnup distribution of the fuel is obtained from HANAFMS, and the burnup distribution of the control rods that HANAFMS doesn't track is acquired through McCARD depletion calculation. Fig. 1 shows the result of comparing the difference in McCARD criticality calculations with and without the burnup of Hf in the control rods where the complex irradiation equipment and history were simplified with accumulated power. The burnup effect of Hf was evaluated to be approximately 5 mk, so it is confirmed that the existing HANARO calculation systems, which don't account for Hf burnup in the control rods, may have limitations in accurate evaluations.

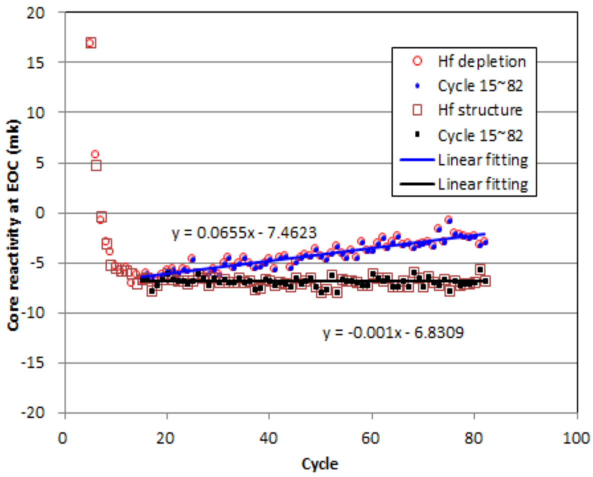

Fig. 1. Impact of Hf burnup in control rods on criticality calculation

The operating core to assess the first U-Mo irradiation test, which started from the 92nd cycle of HANARO, was modeled in McCARD by combining the fuel burnup distribution from the 85th cycle of HANAFMS and Hf burnup from McCARD. The bias in criticality calculation of initial cycle decreased sharply, and the bias from 92nd to 95th cycle where first U-Mo fuel irradiation test took place, was less than 5 mk.

2.2 Criticality Bias up to the Latest Core

After the completion of the first U-Mo irradiation test, the second and third tests have continued, and core tracking calculations with McCARD are still ongoing up to the current 105th cycle. The HANARO McCARD system has been observed to have consistent biases in criticality calculation, as shown in Fig. 2. The criticality bias appeared slightly different between the zero-power and full-power operation. The prediction of the critical position at zero-power with considering the bias has been used as a reference data before the start of operation, and it has been found to predict more accurately than HANAFMS.

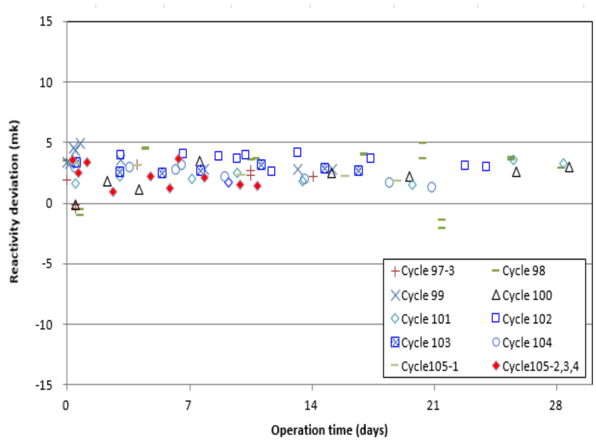

Fig. 2. Criticality bias of McCARD in the operating core

3. Impact of ENDF/B-VIII.0 on Criticality Analysis

To reduce the bias in criticality calculation, the calculation model has been improved, and the difference between the previous nuclear data library, ENDF/B-VII.0, and the newly imported one, ENDF/B-VIII.0, are compared. The comparisons are carried out for both a commissioning test core loaded with fresh fuel and a recently operated core loaded with burnt fuels. The new library, ENDF/B-VIII.0, additionally includes a Thermal Scattering Law (TSL) for the oxygen in heavy water, so the impact of TSL is investigated individually. The standard deviation for all McCARD criticality calculations are maintained at approximately 0.09 mk or less.

3.1 Commissioning Test Core

The HANARO commission test core in the first-cycle was only loaded with fresh fuel assemblies, devoid of the irradiation devices. The initial core had fuel assemblies with the same uranium enrichment and density as the current ones, but it was a partially loaded to achieve the criticality. The McCARD model to evaluate the criticality of the core is visualized in Fig. 3, plotted by McView[7]. The criticality measured at the control rod position of 269 mm was -0.64 mk, and the biases evaluated for each set of nuclear data library are presented in Table I. The core condition is denoted as 'Cold Zero Power', which is at zero power state without Xenon, and the temperature of the entire core is 22.2 degrees

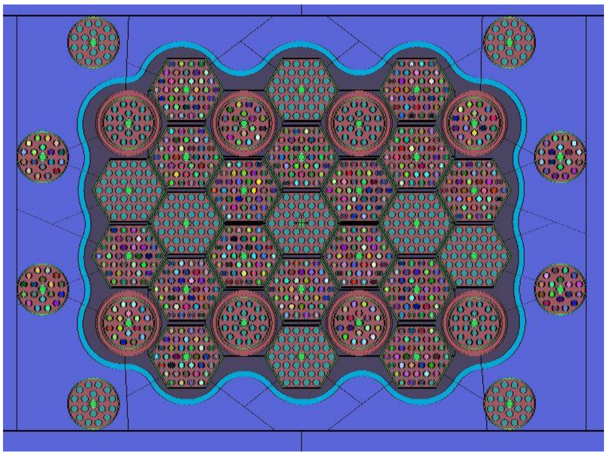

Fig. 3. McCARD model for the commissioning test core

Table I: Criticality Bias in the Commissioning Test Core [mk]

Core Status	ENDF/B-VII.0	ENDF/B-VIII.0	
	TSL(D)	TSL(D)	TSL(D&O)
Cold Zero Power	+1.99	+0.57	+0.82

3.2 Operating Core

The operating core contains burnt fuels and various irradiation devices, necessitating precise tracking of its operational history and more refined modeling for the devices. To reduce the criticality bias for that core, the devices were modeled with higher fidelity and the temperature distribution of the core materials was applied in greater detail. Fig. 4. shows the latest operating core of the 105th cycle.

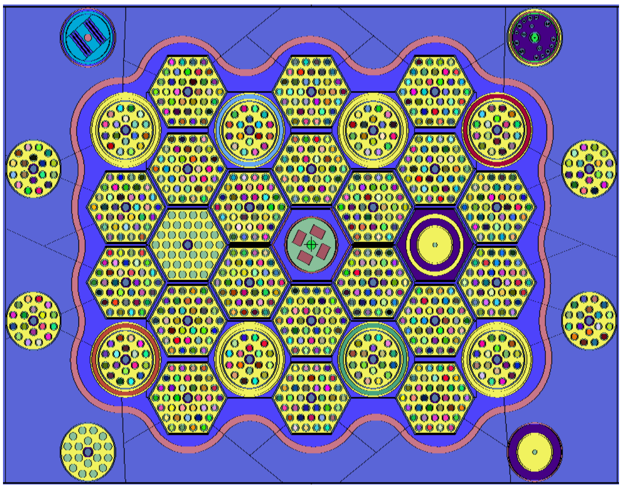

Fig. 4. McCARD model for the 105th cycle core

Using a refined core model, calculation to compare the differences between existing library (ENDF/B-VII.0) and new library (ENDF/B-VIII.0) was performed.

As shown in Table II, the criticality bias during reactor start-up in the 'Hot Zero Power' state decreased from 4.92 mk to 2.73 mk. During operation at 'Hot Full Power,' it reduced from 3.22 mk to 0.79 mk. The improvements in the model reduced the criticality bias irrespective of the nuclear data, and with the new nuclear data, the bias is approaching within 1.0 mk. The criticality difference at reactor start-up has also decreased, but there remains a gap of approximately 2.7 mk, necessitating more detailed analysis. The state labeled as 'Hot Zero Power' denotes the core condition without Xenon at a 500 Watt critical state before starting full-power operation, with an average core temperature of about 35 degrees Celsius. The 'Hot Full Power' indicates the core condition during power operation, causing the core temperature to rise with an average fuel temperature of about 100 degrees Celsius.

Table II: Criticality Bias in the Operating Core [mk]

Core Status	ENDF/B-VII.0	ENDF/B-VIII.0	
	TSL(D)	TSL(D)	TSL(D&O)
Hot Zero Power	+4.92	+2.83	+2.73
Hot Full Power	+3.22	+0.90	+0.79

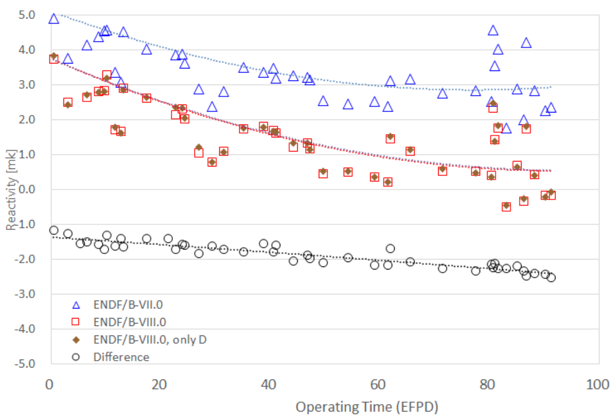

Fig. 5. Trends in the criticality bias of the operating core

3. Conclusions

To reduce the criticality bias in the HANARO McCARD system, the improved nuclear data library, ENDF/B-VIII.0, was applied to the commissioning test core with fresh fuels and the recent operating core with burnt fuels. For the commissioning test core, the bias has been observed as 1.17 mk lower than the previous nuclear data(ENDF/B-VII.0), showing a slight improvement in the criticality bias. For the operating core of 'Hot Full Power' state, the bias shows 2.43 mk lower than the previous data, and the reactivity deviation greatly improved, approaching within 1.0 mk. The reactivity difference checked just before the start of power operation in the zero-power state also showed improvement but still needs further refinement. The effects of different TSL treatment for the Oxygen in heavy water between ENDF/B-VII.0 and ENDF/B-VIII.0 were investigated, but no significant difference was observed.

With the significant reduction in criticality bias, the virtual core simulated by McCARD is expected to accurately represent the actual core. This suggests a promising future for the development of valuable operation support programs using McCARD.

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