Burnup Evaluation of LEU Fission Moly Target Irradiation at HANARO

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1. Introduction

Molybdenum-99 production system is being developed for the application at Ki-Jang Research Reactor (KJRR), which has a main purpose of radioisotope production [1]. Among them, Fission Moly target that produces Molybdenum-99 by uranium fission manufactured by the atomization technology of Korea Atomic Energy Research Institute (KAERI) is considered. Although the target's uranium density is smaller than the fuel, the in-core performance must be verified under conservative conditions because it contains low enriched uranium (LEU) and will be loaded into the core. Therefore, the in-core testing of LEU Fission Moly target was conducted using HANARO irradiation facility [2].

It is important to accurately analyze the burnup of test fuel at HANARO. However, it is difficult to accurately evaluate it because the most of test fuels were irradiated during long duration in the core with many variables. The in-core testing duration for Fission Moly target is short just 10 days, which is advantageous for the burnup evaluation. Therefore, in this study, the burnup evaluation of Fission Moly target was conducted and compared with measured result. This evaluation can contribute to the in-core testing technology for the nuclear fuel at HANARO.

2. In-core testing of LEU Fission Moly target

Total six Fission Moly targets were installed in the test device that was irradiated at HANARO 97-2 cycle duration (2018-05-25 ~ 2018-06-04, 10.284 EFPD) in OR3 irradiation hole. Upper and lower structural housing respectively accommodated the three Fission Moly targets. Fig. 1 shows the MCNP analysis model for HANARO 97-2 cycle. The Fission Moly targets were installed with vertical direction of HANARO core. After the in-core testing, the test device was transferred to the Irradiated Material Examination Facility (IMEF) using the fuel cask on June 29th after cooling in the pool.

3. Burnup calculation

Fig. 2 shows the operation history of control rod height and reactor power at HANARO 97-2 cycle. Since the control rod is only used for the reactivity control at HANARO, it is known that the effect on the irradiated material is dominant. In the case of Fission Moly target, precise core calculation is required depending on the movement of the control rod because the effect of fuel depletion depends on the change of the axial neutron flux. Therefore, it is appropriate to simulate the core calculation according to the movement of the control rod.

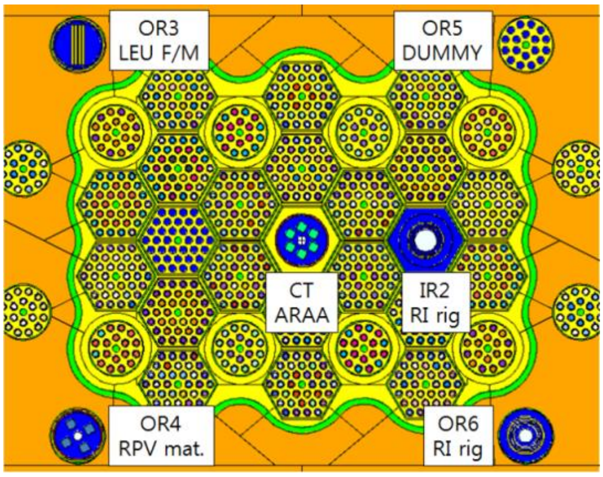

Fig. 1. The MCNP analysis model for HANARO 97-2 cycle

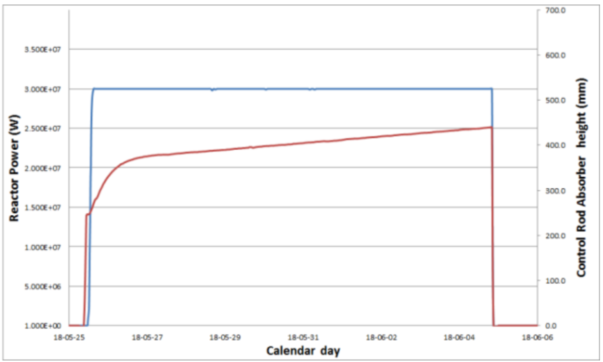

Fig. 2. The operation history at HANARO 97-2 cycle

HANARO Fuel Management System (HANAFMS), which is composed of H-Z model for HANARO fuel management, can quickly perform the HANARO core calculation [3]. However, since the Fission Moly target is plate-type, accurate and detailed calculation is difficult with the H-Z model. In order to overcome this problem, Monte Carlo N-Particle code (MCNP) version 6 [4] was used. The model of each cycle is constructed as shown in Fig. 1 using the HANAFMS output data including HANARO fuel burnup. As a result of comparing HANAFMS and MCNP, the maximum root mean square (RMS) error considering the power of fuel assemblies was 3.55%. Therefore, the MCNP calculation method used in this study is valid.

Fig. 3 shows the loading position of each Fission Moly target and partitioned model for the calculation of local power and burnup. One plate is divided into ten sections in the axial direction and four parts in the transverse direction in the calculation model. The power and burnup calculation of the Fission Moly target were sequentially applied considering the operation history. The typical composition of each representative burnup is obtained by standalone MCNP depletion calculation. It was utilized to make the input composition for next step.

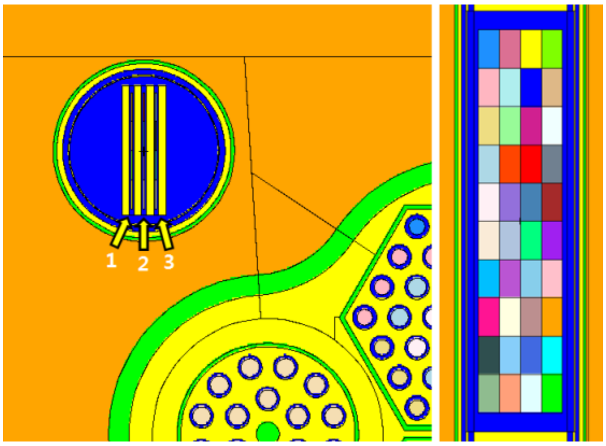

Fig. 3. The loading position and partitioned model of each Fission Mo target

Two methods were used for the burnup evaluation of Fission Moly target. The first method used the same calculation frequency of HANAFMS that constructed the average core model considering the control rod of each 50 mm movement from 250 mm. As shown in Fig. 2, since the beginning of control rod movement is rapid, only 0.2482 EFPD was required when moving from 250 to 300 mm. However, it was observed for several days afterwards. The second method used the more calculation frequency than HANAFMS. Although the test fuel is dynamically depleted during the irradiation, the calculation can only assume the state of the core on average. In order to conduct more precise calculations, the second method was limited to the maximum number of depletion by one day. The calculation frequency was only four times in the first method, but a dozen times was considered in the second method.

Table I shows the burnup calculation result of Fission Moly target irradiation using above two methods. Since the control rod was operated at a relatively low position, the burnup of targets in the lower housing was relatively higher. The overall depletion tendency shows that the lower burnup was observed as the increase the calculation frequency. This result might be caused that the factor of depletion distortion can be reduced by respectively accurate calculation of uranium burning and fission product generation. Although the result of the second calculation method is relatively accurate, the calculation time due to the calculation frequency of three times is consumed more than three times. Since the difference is small, we must consider it for the effectiveness evaluation of burnup calculation.

Table I : The burnup calculation result

Housing position	**Loaded position (Fig. 3)**	**Plate ID**	**Burnup calculation result (U-235 depletion)**			
			1st method		**2nd method**	
			Avg.	**Max.**	**Avg.**	**Max.**
Upper	**1**	**FM1604-017**	**8.24%**	**10.14%**	**8.18%**	**9.98%**
	2	**FM1604-011**	**7.93%**	**9.80%**	**7.88%**	**9.77%**
	3	**FM1604-009**	**8.32%**	**10.11%**	**8.22%**	**10.02%**
Lower	**1**	**FM1604-008**	**9.30%**	**10.57%**	**9.20%**	**10.22%**
	2	**FM1604-006**	**8.99%**	**10.21%**	**8.88%**	**10.05%**
	3	**FM1604-005**	**9.39%**	**10.39%**	**9.30%**	**10.37%**

4. Measurement by gamma scanning

After the irradiated Fission Moly targets were transferred to the IMEF, the burnup distribution was measured by gamma scanning. The collimator size of the measuring equipment was 1 x 1 mm and the measured points were 240 points in total, 12 points in the lateral direction and 20 points in the axial direction. In general, the measurement of each burnup through gamma scanning is determined by the relative proportion of fission products [5]. The ratio of Cs-134 and Cs-137 is mainly used, but Cs-134 was not observed in this measurement because the irradiation period and the cooling time were relatively short. Therefore, only the relative burnup distribution of the plate was compared using the measured values.

Fig. 4 shows the comparison of burnup calculation and gamma scanning measurement result for FM1604-009 with the relative distribution. The result of the gamma scanning measurements is shown in color and the numerical value of each position's burnup is overlapped in Fig. 4. Since FM1604-009 was installed in the upper housing and irradiated, the burnup distribution is obvious that the burnup of lower part is relatively higher. However, the gamma scanning result showed that the burnup of the outer region is not high. It is believed that this is due to the manufacturing characteristics of the target plate. In the burnup calculation, it was assumed that the density of uranium in all meat regions is homogeneous, but the density of uranium outside the meat is lowered in nature. Although it is difficult to make exact comparisons due to above reason, it can be shown that the tendency of the overall burnup distribution is similar.

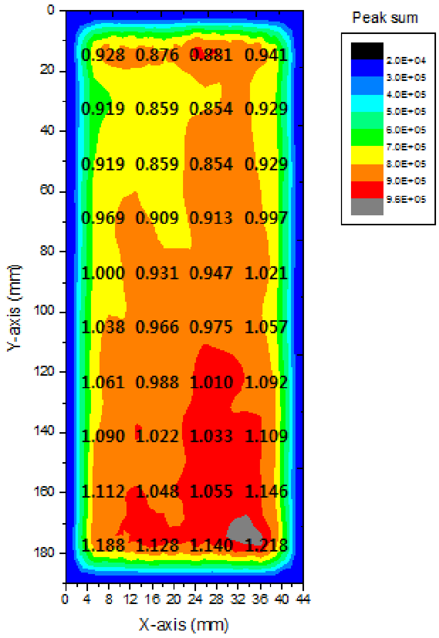

Fig. 4. The comparison of burnup calculation and gamma scanning measurement of FM1604-009

5. Conclusions

In order to verify the in-core performance of the Fission Moly target to be applied to KJRR, the test was carried out using HANARO irradiation facility. It was evaluated that the test was conducted under conservative conditions. The burnup calculation was performed using MCNP. The results are slight different depending on the frequency of calculation. However, the effectiveness should be discussed considering the calculation time. As a result of comparison between calculation and measurement result, it was confirmed that the tendency of the overall burnup distribution is similar.

REFERENCES

[1] S.K. Lee, G.J. Beyer, J.S. Lee, Development of Industrial-Scale Fission ^{99}Mo Production Using Low Enriched Uranium Target, Nuclear Engineering and Technology, Vol. 48, P. 613, 2016.

[2] S. Yang, S. Park, Y. Shin, H. Cho, M. Cho, K. Choo, In-Reactor Testing of Target for Fission ^{99}Mo Production at HANARO Irradiation Facility, Proceeding of the Korean Nuclear Society Spring Meeting, May 17-18, 2018, Jeju, Korea.

[3] C. S. Lee et al., Analysis of Reactor Characteristics for Equilibrium core of HANARO, KAERI/TR-2320/2002.

[4] D.B. Pelowitz, MCNP6^{TM} User's Manual Version 1.0, LA-CP-13-00634 Rev. 0, 2013.

[5] Determination of Research Reactor Fuel Burnup, IAEA-TECDOC-633, IAEA, Vienna, 1992.