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Evaluation of Control Rod Heating Rate in SMART for Cycle 1

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1. Introduction

The SMART (System-integrated Modular Advanced ReacTor) is an integral type of small and medium sized reactor (SMR) with 365 MW_{th} which was developed by Korea Atomic Energy Research Institute (KAERI).

In this paper, heating rate of the control rod assembly (CRA) in SMART for cycle 1 is evaluated using DeCART2D [1] code and MCNP6 with ENDF/B-VII.0 library [2].

2. Methods and Results

Some of the flow into the reactor vessel is not directly used for core cooling, which is referred to as core bypass flow. Some of bypass flow cools CRA and it is required an accurate evaluation of heating rate in control rods to investigate coolability of thimble bypass flow for CRA. On the other hand, the heating rate of the control rod varies depending on the position of the fuel assembly (FA) and burnup. The change of the heating rate can be tracked through the detailed analysis of the whole core according to the burnup, but the calculation cost (time) is required to be large, and the simplified method is presented in this study. In other words, control rod having maximum assembly-wise peaking factor is selected and the material composition of FA for each depletion step. The acquired FA composition for each depletion step is to evaluate the heating rate.

2.1 Control Rod in Fuel Assembly

The SMART core is designed with 57 FAs, and the CRA is designed to be inserted in a checkerboard pattern as shown in Fig. 1. In this evaluation, the CRA heating rate for a single FA is evaluated by choosing a bank position where the maximum assembly-wise peaking factor appeared during the cycle 1.

The selected FA consists of UO_2 fuel rods, UO_2-Gd_2O_3 fuel rods, and CRA as shown in Fig. 2. The structure of the control rod consists of an absorber part made of Ag-In-Cd, a cladding made of SS304, and a guide tube made of HANA-6 as shown in Fig. 3. In this evaluation, the heating rate is calculated based on a conservative assumption that the CRA is fully inserted into the FA even under nominal condition.

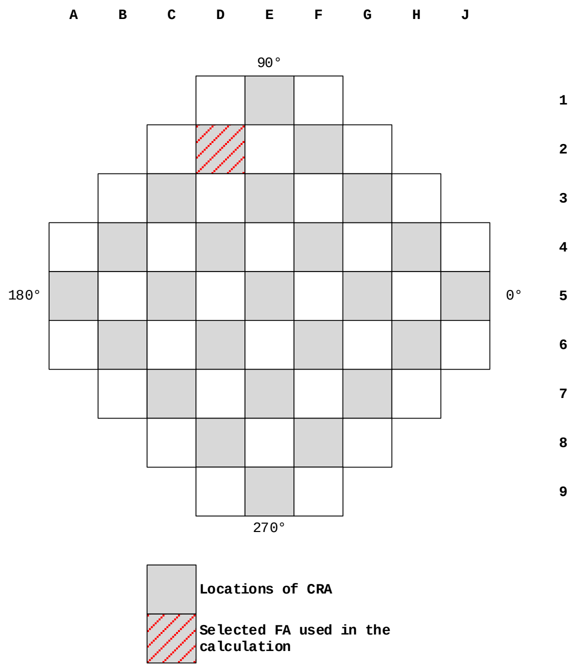

Fig. 1. Position of CRA and selected FA used in calculation

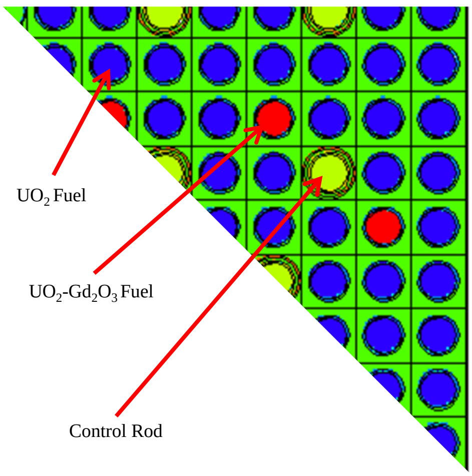

Fig. 2. Radial fuel configuration of 1/8 fuel assembly

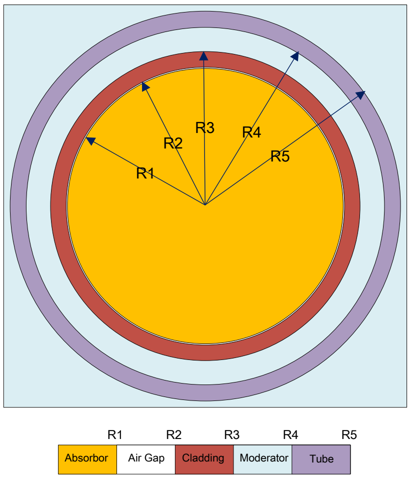

Fig. 3. Structure of control rod

2.2 Heating Rate Calculation

In order to obtain the heating rate of each depletion step, each material composition is calculated using DeCART2D [1] code. DeCART2D is a neutron transport code based on 2-D MOC (Method Of Characteristics) and its main purpose is to generate assembly-wise homogenized and group condensed effective group constant. Since DeCART2D generates assembly-wise homogenized group constants, the material compositions for each UO_2 and UO_2-Gd_2O_3 is retrieved according to the depletion step.

The values from DeCART2D are used to calculate the heating rate using the MCNP6 code with ENDF/B-VII.0 library [2] code. In MCNP6 code, the heating rate values of each cell is calculated using “F6:N,P tally” function which track length estimate of both neutron and photon energy deposition and its unit is MeV/g with SD card. For SD card, calculated mass values for each cell were used.

In general, heating rate is presented in W/cm^3. Therefore, the results of heating rate is re-calculated using the conversion in below equation. The system producing power needs fissions per seconds, where effective energy released per fission event. It is typically ~200 MeV for steady state condition [3]. This fission rate produces neutrons per second, where the average number of neutrons released per fission is shown in MCNP6 output. KCODE tallies for subcritical and supercritical system do not include any multiplication effects because fission is treated as absorption. Therefore, the tally results must be adjusted by multiplying 1/k_{eff} for subcritical and supercritical systems [4]. Finally, assembly-wise peaking factor is multiplied by each result according to each depletion step.

$$H_r\left({}^{W}/_{cm^3}\right) = H_{MCNP}\left({}^{MeV}/_{g}\right) * 10^6\left({}^{eV}/_{MeV}\right) * 1.602 * 10^{-19}\left({}^{J}/_{eV}\right) * \text{Density}\left({}^{g}/_{cm^3}\right) * Power(MW) * \frac{10^6\left({}^{J}/_{s}\right)}{MW} * \frac{1\,(MeV)}{1.602*10^{-13}\,(J)} * \frac{1\,fission}{\sim 200\,(MeV)} * \mathrm{n}\left({}^{neutrons}/_{fission}\right) * 1/k_{eff} * Assembly\ wise\ peaking\ factor$$

2.3 Results

The heating rate of each cell in control rod is calculated by MCNP6 with ENDF/B-VII.0 library. The calculated heating rate results are shown in Table I that the heating rate of each cell in control rod at the initial core, and for its Min., and Max. The largest power per volume in the absorber region, which occupied the largest portion of the CRA, and the other parts have smaller values. Fig. 4. shows normalized heating rate by initial core heating rate for each cell in control rod according to depletion step. The trend shows that heating rate goes down right after depletion start, increase gradually, and have Max. heating rate in the end of cycle. The reason why the value is decreased could be the influence of xenon and iodine after depletion. Moreover, the reason for the gradually increased could be the number density of the fuel is getting decreased by burnup to the fixed power causes the flux is increased.

Table I: BOC, Min., and Max. heating rate for each cell

	Heating Rate (W/cm^3)			
	Absorber	Cladding	Moderator	Tube
Initial	48.026	8.657	3.620	7.127
Min.	45.645	8.001	3.440	6.542
Max.	50.674	9.133	3.961	7.479

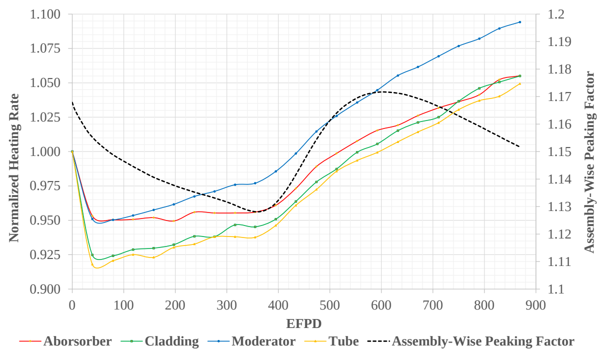

Fig. 4 Normalized heating rate results for each cell in control rod with assembly-wise peaking factor

3. Conclusions

In this paper, the heating rate of control rod in SMART core for fuel cycle 1 is calculated using the DeCART2D and MCNP6 with ENDF/B-VII.0 library. This study is needed to evaluate the bypass flow of the SMART design. In the future, we will compare the results obtained from the detailed analysis of the whole core for SMART and the methodology presented in this study.

ACKNOWLEDGMENT

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