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SMART Control Rod Heating Rate Evaluation with MCNP6 Depletion Calculation

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1. Introduction

MCNP code [1] has been developed and verified to be used in depletion capability in MCNP6 version [2]. Through MCNP6's deletion capability, we intended to calculate the heating rate of SMART reactor, an integral type of small and medium sized reactor with 365 MW_{th} and 30 months cycle length developed in Korea Atomic Energy Research Institute.

2. Methods and Results

Part of the flow into the reactor vessel is not directly used for core cooling, which is called bypass flow. Because some bypass flow rates cool control rod assembly (CRA), the heat content of the control rod has to be accurately evaluated to assess the cooling performance of the bypass flow rate for CRAs. The amount of heat in the control rod depends on the location of the FA and the heating rate. The variation in the heating amount can be verified by a detailed analysis of the depletion of the whole core, but it takes a lot of time to calculate. Therefore, in this study, a simplified method is presented to predict the amount of heating of the control rod. This simplified method is, that is, to evaluate heating rate by selecting an FA with an assembly-wise peaking factor in each depletion step and multiplying for each depletion phase.

2.1 Control Rod in Fuel Assembly

The SMART core consists of 17x17 fuel rods with CRAs. CRA consists of an absorber part made of Ag-In-Cd, SS304 cladding, HANA-6 guide tubes and is designed to be inserted into checkerboard patterns as shown in Fig. 1 and Fig. 2. In this evaluation, the CRA heating rate for a single FA was evaluated by selecting the bank position where the maximum assembly-wise peaking factor during cycle 1 (870 EFPD) is shown in Fig. 2. The selected FA consists of UO_2 fuel rods, UO_2-Gd_2O_3 fuel rods and CRAs as shown in Fig. 3. In this study, control rod heating rate is calculated based on the conservative assumption that the CRA is fully inserted into the FA even under nominal conditions.

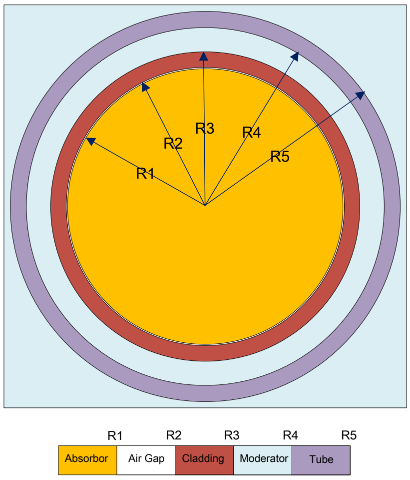

Fig. 1. Structure of control rod [3]

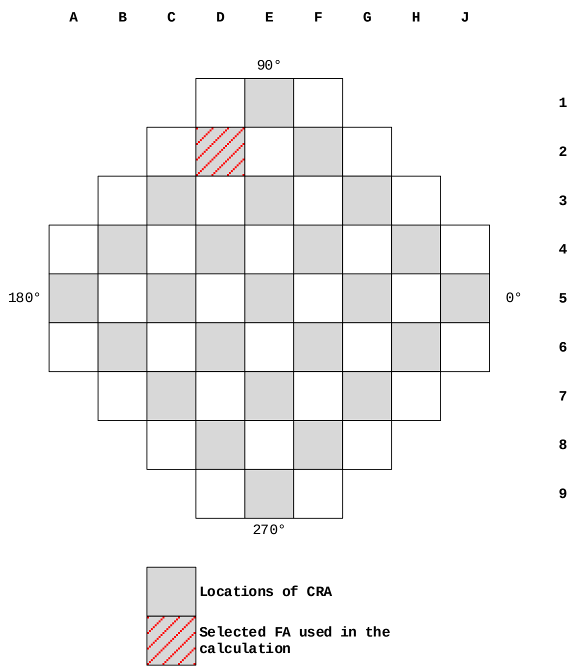

Fig. 2. Position of CRA and selected FA used in calculation [3]

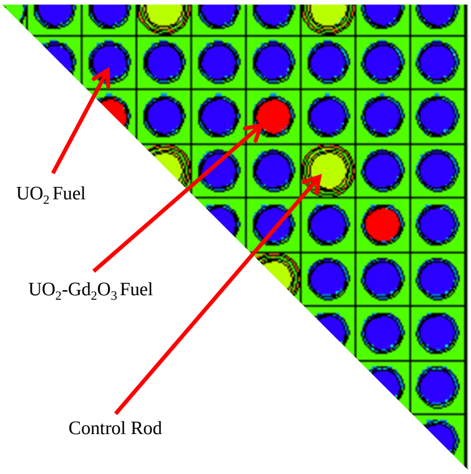

Fig. 3. Radial fuel configuration of 1/8 fuel assembly [3]

2.2 Heating Rate Calculation

The heating rate was calculated using the deletion capability and ENDF/B-VII.0 library in MCNP6 code. Using "F6:N,P tally" option in MCNP6 code which track length estimate of neutron energy deposition, the heating rate values of each cell are calculated as the unit of MeV/g. Heating rate is generally presented with unit W/cm^3, so the heating rate values of the calculation result are converted as shown in below equation [3].

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

An effective energy release per fission from a power-producing nuclear system is typically ~200MeV under steady-state conditions [4]. This fission rate produces neutrons per fission, where the average number of neutrons emitted per fission is shown in the output of MCNP code. 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 [5]. Finally, assembly-wise peaking factor is multiplied by each result according to following depletion steps [3].

2.3 Results

The calculated heating rate results for each depletion phase by MCNP6 code is multiplied by an assembly-wise peaking factor in each depletion are shown in Table I that the heating rate of each cell in control rod at the initial core, and for its minimum and maximum. Fig. 4. shows normalized heating rate by initial value of heating rate for each cell in control rod according to depletion step. The calculated raw data of heating rate by MCNP6 is gradually increased in value according to time depletion, but the values that multiplied by the assembly-wise peaking factor tended to follow the assembly-wise peaking factor trend, but the overall graph shows as increasing. Fig.5 shows a comparison of the heating rate calculated using the DeCART2D code depletion [3]. The reason for the different results is considered to be due to differences between the depletion libraries in MCNP6 code and the depletion libraries in DeCART2D.

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

	Heating Rate (W/cm^3)			
	Absorber	Cladding	Moderator	Tube
Initial	47.936	8.674	3.604	7.143
Min.	47.459	8.674	3.604	7.143
Max.	49.582	9.263	3.982	7.628

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

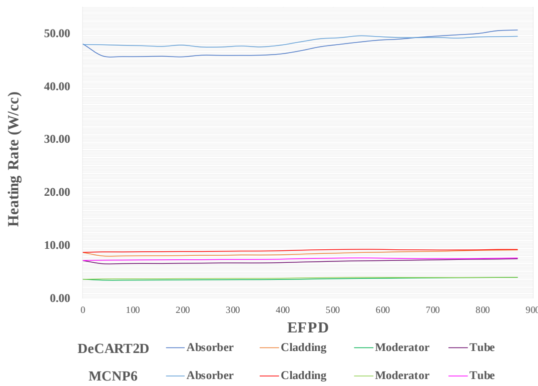

Fig. 5 Comparison of the heating rate calculated by MCNP6 and DeCART2D

3. Conclusions

In this paper, SMART control rod heating rate is evaluated with MCNP6 depletion capability with ENDF/B-VII.0 library for the bypass flow of the SMART design. In the future, we will compare the results obtained from evaluated control rod heating rate by other depletion computer code and will compare calculation with whole core for SMART and the methodology presented in this study.

ACKNOWLEDGMENT

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