MHTGR-350 Benchmark Analysis by MCS Code

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1. Introduction

MHTGR-350MW Benchmark is designed to verify the solution methods for high temperature reactor (HTR) [1-2]. This benchmark contains various problems in three phases, which require the results for neutronics, thermal fluids solutions, transient calculation, and depletion calculation. The Phase-I exercise-1 problem was solved with MCS Monte Carlo (MC) code developed at UNIST [3-4]. The global parameters and power distribution was compared with the results of McCARD MC code developed by SNU [5] and a finite element method (FEM) - based diffusion code CAPP developed by KAERI [6].

2. Methods and Results

The MHTGR benchmark Phase-I exercise-I is a multi-group problem. The multi-group cross sections are given in the benchmark specification. The geometry of the MHTGR is based on simplified whole core meshes. There are 271 radial meshes which contain 66 fuels blocks, 97 replaceable reflector blocks and 108 permanent reflector blocks. In axial direction, there are 14 layers consisting of 10 layers containing fuel regions and two layers for upper and lower reflector regions. Benchmark provides two types of control rods (CRs): hexagonal and triangular CRs. Since it is a multi-group problem, the benchmark provides two types of cross section for each CR.

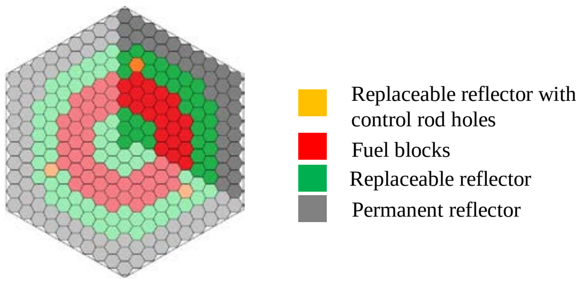

Fig. 1. Radial meshes.

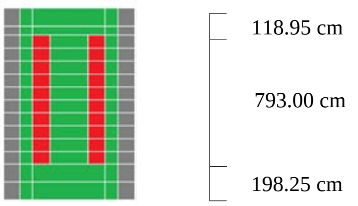

Fig. 2. Axial layer meshes.

2.1 Global Parameter Comparisons

The MCS uses 1,000 inactive cycle, 1,000 active cycle, and 50,000 histories per cycle for the calculation. The MCS results of k_{eff}, CR worth, axial offset (AO), and the maximum power density are compared with those of McCARD with a similar standard deviation and those of CAPP with cubic element option. Table I summarizes the k_{eff} results of three codes. The MCS results match well with those of McCARD, and CAPP code shows difference of 190 pcm, which can be attributed to the fact that CAPP is a diffusion code while the others are MC transport codes.

Table I: Criticality calculation (k_{eff}) results

CR type	Code	k_{eff}	STD
Hex	MCS	1.06884	0.00004
	McCARD	1.06889	0.00004
	CAPP	1.06694	-
Tri	MCS	1.06855	0.00004
	McCARD	1.06872	0.00004
	CAPP	1.06667	-

Table II shows the CR worths. Two different simulations were performed with different control rod positions: 1184.80 cm and 391.81 cm.

$$\Delta\rho = 1\times10^{5}\left(\frac{k_{out}-k_{in}}{k_{out}k_{in}}\right), \quad (1)$$

where k_{in} and k_{out} are the k_{eff} values with the control rod position of 391.81 cm and 1184.80 cm, respectively.

Table II: Control rod worth

CR type	Code	CR worth [pcm]
Hex	MCS	853
	McCARD	846
	CAPP	822
Tri	MCS	1135
	McCARD	1124
	CAPP	1088

2.2 Fission Source Distributions

The fission source distribution is normalized to the power of 350MWt. Table III shows the axial offset and the maximum power density of three codes. The Axial offset of MCS code agrees well with the other codes. However, the maximum power density of MCS code is much lower than that of CAPP code while it is similar to that of McCARD code. The CAPP code is based on the FEM and the power distribution in the elements is readily known. Therefore, the maximum power density in CAPP code was evaluated as the point-wise maximum value while the maximum power densities of the other codes were evaluated as the maximum value among the homogeneous-zone averaged power density.

Table III: Axial offset and maximum power density

CR type	Code	Axial Offset	Max. Power Density [W/cc]
Hex	MCS	0.1672	13.28
	McCARD	0.1635	13.20
	CAPP	0.1664	23.04
Tri	MCS	0.1428	13.04
	McCARD	0.1501	13.10
	CAPP	0.1502	22.90

The axial offset is defined as

$$AO = \left(\frac{P_{top} - P_{bottom}}{P_{top} + P_{bottom}} \right), \qquad (2)$$

where P_{top} means total power produced in the top half of core and P_{bottom} is the power in the bottom half of core.

The hexagonal assembly was composed of 6 triangle cells. And MCS tallies the power density for each cell. The statistical errors of power density for each triangle cell are 0.3-0.6%. Figs. 3-4 show the average power density distribution with hexagonal CR, and Figs. 5-6 show the average power distribution with triangular CR. Figs. 3 and 5 show the axial distribution, and the results match well. Figs. 4 and 6 show the radial distribution. MCS and McCARD match well, but CAPP results shows difference.

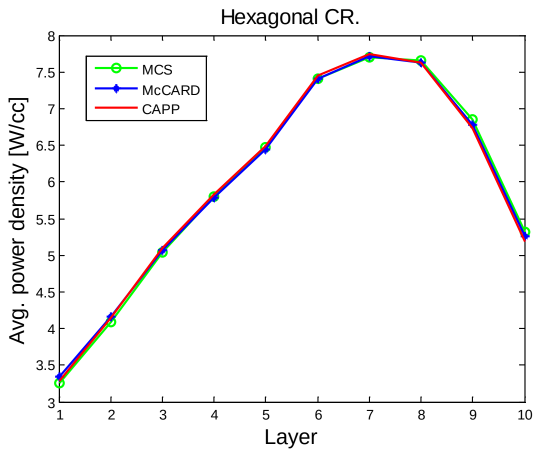

Fig. 3. Axial power distribution (Hexagonal CR).

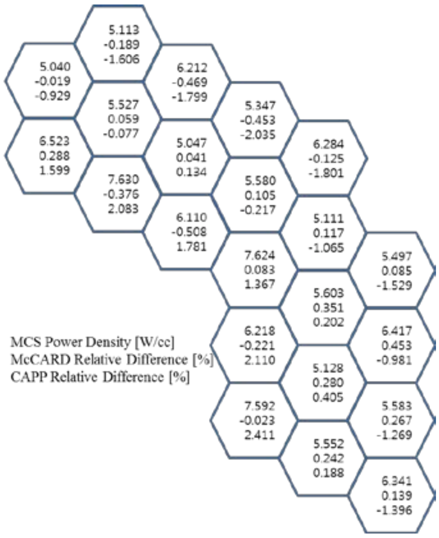

Fig. 4. Radial power distribution (Hexagonal CR).

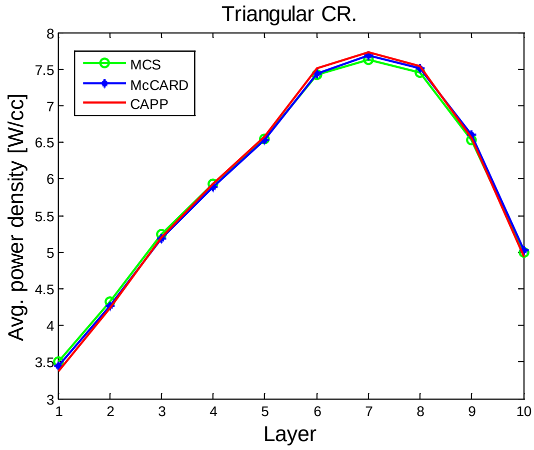

Fig. 5. Axial power distribution (Triangular CR).

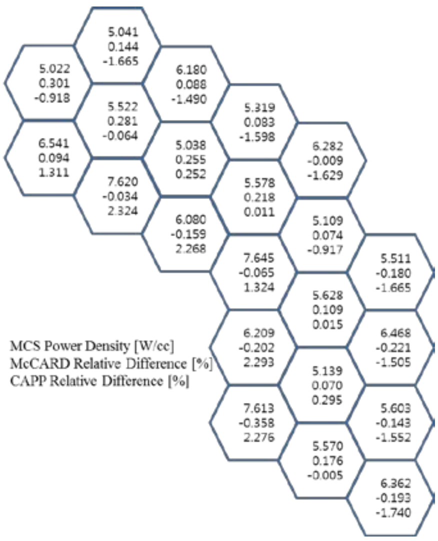

Fig. 6. Radial power distribution (Triangular CR).

3. Conclusions

The MHTGR-350 benchmark Phase-I exercise 1 was solved with MCS. The results of MCS are compared with those of McCARD and CAPP. The results of MCS code showed good agreements with those of McCARD code while they showed considerable disagreements with those of CAPP code, which can be attributed to the fact that CAPP is a diffusion code while the others are MC transport codes.

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