Transactions of the Korean Nuclear Society Spring Meeting
Chuncheon, Korea, May 25-26 2006

A Preliminary MCNP Solution to the IAEA CRP-5 Pebble Box Benchmark Problem

Hong Qian, Hyun Chul Lee, Kang-Seog Kim, Jae Man Noh
Korea Atomic Energy Research Institute, 150 Deokjin-Dong, Yuseong-Gu, Daejeon, Korea, 305-353

1. Introduction

Recently, the IAEA CRP-5 Pebble Box benchmark problem was proposed for a code-to-code comparison.[1] To investigate the effect of the core/reflector spectral interaction and the effect of heterogeneity, the problem defines four cases(extended to six cases later) depending on the presence of reflector and the level of heterogeneity. The core in the problem consists of a box with dimensions of $1m \times 1m \times 1m$. For some cases, there is a graphite reflector with a thickness of $1m$ around the core and the resultant dimension of the problem becomes $3m \times 3m \times 3m$ in those cases.

In this paper, we present two geometry models for the IAEA CRP-5 Pebble Box benchmark problem and a preliminary MCNP[2] solution to the problem with the two models.

2. Methods and Results

2.1 Description of the Benchmark Problem

Table 1 shows the configurations of the eight cases. We added Case 1.5 and Case 4.5 besides the extended six cases. Reflective boundary conditions are imposed at the surface of the pebble box in the cases without a graphite reflector while black boundary conditions are imposed at the outer surface of the reflector in the cases with the reflector.

Table 2 shows the modeling parameters for the benchmark problem. The temperature of the system was assumed to be room temperature (=300K). The multiplication factor and two group fluxes/currents with cut-off energy of 1.86eV are required for the results.

Table 1. Case specifications of the problem

	Without Reflector	With Reflector
Homogeneous Core	Case 1	Case 4
Homogeneous Pebbles	Case 1.5	Case 4.5
Homogeneous Fuel Zone in Pebbles	Case 2	Case 5
Doubly Heterogeneous Pebbles	Case 3	Case 6

2.2 MCNP Models for the Problem

Figure 1 shows the two geometry models for the problem used in this work. No broken pebble is allowed in model A while broken pebbles are allowed at the boundary of the pebble box in model B. In model A, the pebble box core is divided into $14 \times 14 \times 15$ basic cells each of which contains a pebble at its center and several octant pebbles

Table 2. Modeling parameters for the benchmark problem

Parameter	Unit	Data
Heavy metal loading	g/pebble	9.0
Enrichment	$^{wt}/_{0}$	9.6
UO_2 density	g/cm^3	10.4
Diameter of pebble	mm	60.0
Fuel matrix density	g/cm^3	1.74
Fuel-free zone density	g/cm^3	1.74
Thickness of fuel-free zone	mm	5.0
Fuel kernel diameter	μ m	500.0
Buffer layer thickness	μ m	95.0
Inner PyC layer thickness	μ m	40.0
SiC layer thickness	μ m	35.0
Outer PyC layer thickness	μ m	40.0
Buffer layer density	g/cm^3	1.05
Inner PyC layer density	g/cm^3	1.90
SiC layer density	g/cm^3	3.18
Outer PyC layer density	g/cm^3	1.90
Packing fraction of pebbles	%	61.0
Reflector graphite density	g/cm^3	1.80

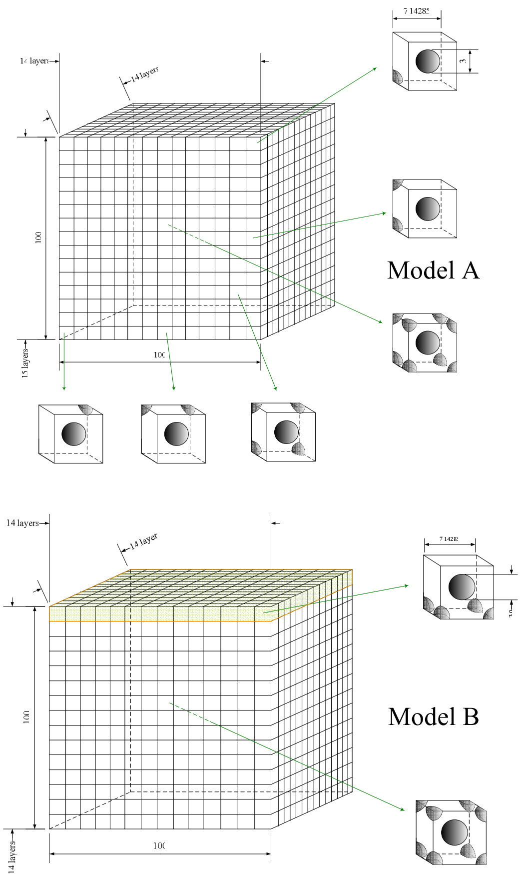

Figure 1. Two geometry models for the benchmark problem

depending on the location in the pebble box. Model A contains 5306 pebbles and the resultant packing fraction is about 60.02%. In model B, the pebble box core is divided into $14 \times 14 \times 14$ basic cells each of which contains a central pebble and eight octant pebbles except for the basic cells at the top plane. Each basic cell at the top plane has only four octant pebbles as shown in Figure 1. Model A contains 5390 pebbles and the resultant packing fraction is about 60.97%.

For double heterogeneous cases, Case 3 and Case 6, the coated particles in the fuel zone are located in a simple cubic lattice structure with a pitch of $0.1621cm$. Broken particles are allowed at the boundary of the fuel zone as shown in Figure 2.

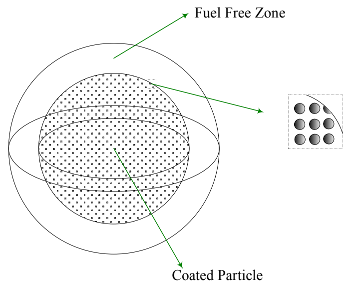

Figure 2. A model for doubly heterogeneous pebbles

2.3 Results and Discussions

Table 3 shows the multiplication factors of the cases with their standard deviations in the parenthesis. We can see that the multiplication factors of the two models for the cases without reflector agree well with each other within the statistical error range. The increasing trend of the multiplication factor along with the increase of heterogeneity is ascribed to the increase of self-shielding. Table 4 shows the epi-thermal to thermal flux ratio in the core region. We can see that the results of the two models for the cases without reflector are almost identical. The decreasing trend of epi-thermal to thermal flux ratio is also ascribed to the increase of self-shielding. Table 5 shows the leakage from the core to the reflector in the cases with reflector.

Table 3. The multiplication factors of the cases

	Model A	Model B
Case 1	1.38908 (33pcm)	
Case 1.5	1.38967 (34pcm)	1.38956 (54pcm)
Case 2	1.42464 (33pcm)	1.42506 (52pcm)
Case 3	1.52994(29pcm)	1.53016(30pcm)
Case 4	0.99490 (37pcm)	
Case 4.5	-	0.99551 (36pcm)
Case 5	-	1.00695 (36pcm)
Case 6	-	1.04034 (36pcm)

Table 4. Epi-thermal to thermal flux ratio in the core region

	Model A	Model B
Case 1	2.7146	
Case 1.5	2.7133	2.7125
Case 2	2.6302	2.6293
Case 3	2.4451	2.4425
Case 4	2.1682	
Case 4.5	-	2.1296
Case 5	-	2.0902
Case 6	-	2.0122

Table 5. Leakage from core to reflector ($\times 10^{-5}\ particles/cm^2$)

	Epi-thermal	Thermal	Total
Case 4	0.9845	-0.3698	0.6147
Case 4.5	0.9164	-0.3749	0.6166
Case 5	0.9937	-0.3741	0.6195
Case 6	1.0006	-0.3723	0.6284

3. Conclusion

In this paper, we presented two geometry models for the IAEA CRP-5 Pebble Box benchmark problem and we also presented a preliminary MCNP solution to the problem with the two models. We found that the results of the two models for the cases without reflector agreed well with each other within the statistical error range. We also observed an increasing trend of the multiplication factor and a decreasing trend of the epi-thermal to thermal flux ratio in the core region, which is ascribed to the increase of self-shielding. We didn't applied model A to the cases with reflector in this paper. A comparison between the two models for the cases with reflectors should be made in further work.

Acknowledgement

This study has been carried out under the Long-Term Nuclear R&D Program supported by the Ministry of Science and Technology (MOST) of Korea

REFERENCES

1. Eben Mulder , "CRP5 Problem Definition: 'Pebble Box' for code-to-code comparisons," March 2005 (Draft for IAEA CRP-5 TECDOC)
2. J. F. Breismeister and et al., "MCNP – A General Monte Carlo N-Particle Transport Code, Version 4B," LA-12625-M (1997)