A Study on MCNP Modeling Method for Pebble-type Core with Statistical Geometry

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1. Introduction

When spheres are dropped into a large cylinder such as the pebble-bed reactor core, they pack randomly. This random packing feature cannot be modeled directly with MCNP code, because of the large number of spheres in a typical core (e.g., approximately 10,000 spheres in the HTR-PROTEUS). Therefore, the core model relies on the repeated-geometry feature of the code, in which a unit cell is expanded throughout the core volume. In this work, the unit cell to be expanded was assumed to be a BCC lattice. One consequence of the repeated-geometry feature of MCNP code is the presence of partial spheres (Figure 1) at the core edge, which might overestimate the amount of fuel in the system. As a way to solve this problem, an exclusion zone [1] was suggested in MIT. The utilization of this method induces necessarily a change of core diameter. Therefore, an effort to solve the problem not changing core diameter was tried out in this work by adjustment of unit cell pith.

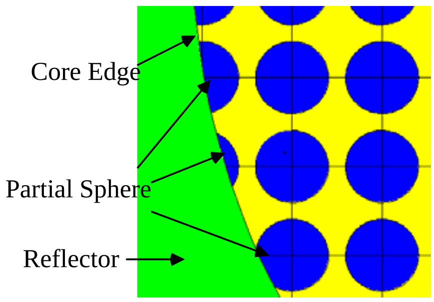

Figure 1. Partial Spheres

2. Methods and Results

Core 4.3 configuration, which is a random packing core, among the pebble-bed cores of HTR-PROTEUS critical facility in Swiss [2] is selected for the benchmark model. The detailed MCNP modeling was carried out for the whole facility. Core region was modeled by three methods ((a) Reference model (b) Exclusion zone model (c) Pitch adjustment model by this work). Criticality calculations were then carried out for each model using KCODE option in MCNP5 code.

2.1 Core Modeling

2.1.1 Reference Model (Model 1)

BCC lattice pitch was determined to be 7.215532cm to equalize the packing fraction within BCC lattice to that within whole core. Then the BCC unit cell was expanded throughout the core volume, as presented in Figure 2. This model comes to overestimate the amount of the fuel in the core.

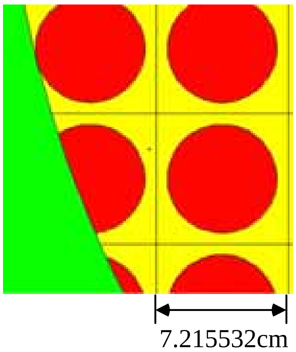

Figure 2. Reference Model (Model 1)

2.1.2 Exclusion Zone Model (Model 2)

Starting from Model 1, exclusion zone [1] was set in this model not to overestimate the fuel quantity in the core. This zone is filled with void to eliminate the physically unrealizable partial spheres. Although its dimension is known to be generally equal to the radius of the sphere scaled by the fraction of fuel spheres in the unit cell, in this work the dimension was calculated by a stochastic method (Monte Carlo method) using FORTRAN program and to be 0.37954cm as presented in Figure 3.

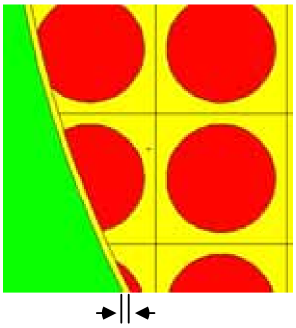

Figure 3. Exclusion Zone Model (Model 2)

2.1.3 Pitch Adjustment Model (Model 3)

While exclusion zone model causes the change of the active core volume, total core volume is not changed in this model. The new method to not change core geometry was considered. The method is to adjust a pitch of unit cell to conserve the fuel quantity in the core.

Starting from Model 1, the pitch of BCC lattice was investigated to conserve the fuel quantity in this model. The pitch was calculated using FORTRAN program as in Model 2 and to be 7.259576cm as presented in Figure 4.

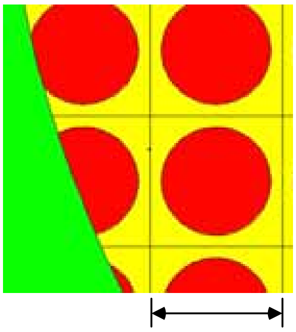

Figure 4. Pitch Adjustment Model (Model 3)

2.2 Calculation Results

k-eff values were calculated for the three models and compared with the results from the experiment as summarized in Table 1.

The result from Model 1 to overestimate the fuel quantity gives an agreement of about 0.7% relative error in comparison with the experimental value of 1.0132. On the other hand, it shows that the results from Models 2 and 3 give an agreement of about 0.5% relative error. It was investigated that little difference was appeared in the results from the Models 2 and 3.

Table 1. Criticality Calculation Results for Each Model

	k-eff	Relative Error [%]
Experiment	1.0132±0.0007	
Model 1	1.02071±0.00060	0.741
Model 2	1.01811±0.00063	0.485
Model 3	1.01802±0.00053	0.476

3. Conclusion

A new method to model the core with statistical geometry exactly and effectively was introduced by adjusting the unit cell pitch to conserve the amount of fuel in reactor core. Core diameter is not changed in this method unlikely the concept of exclusion zone and, the k-eff values were comparable with one from the exclusion zone method.

It is, therefore, that the pitch adjustment model from this study can be used to model the core with statistical geometry.

Acknowledgment

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REFERENCES

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[2] T. Williams, “LEU-HTR PROTEUS: Configuration Description and Critical Balances for the Cores of the HTR-PROTEUS Experimental Programme,” Paul Scherrer Institut (1996).