A Packing Treatment of Stochastic Geometry in Pebble-bed Core with Monte Carlo Code MCNP

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1. Introduction

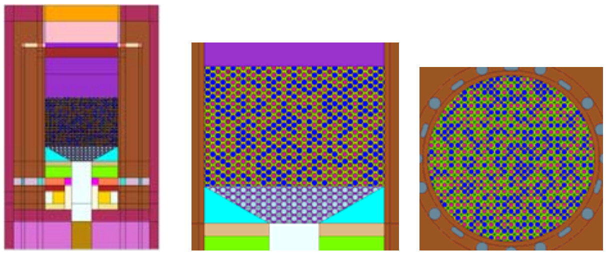
The pebbles are randomly packed, while they are dropped into the pebble-bed core. It is impossible that these pebbles are individually modeled using MCNP code, because of the large number of pebbles in a typical pebble-bed core. In conventional calculation, the core model relies on the repeated-geometry feature of the MCNP code, in which a unit cell is expanded throughout the core volume. One consequence of the feature of the code is the repetition of same unit cell and it is different from the actual core. For that reason, an efficient method has developed to simulate the core to be randomly mixed with fuel and moderator pebbles in this study. The developed method was applied to IAEA CRP benchmark problem[1] proposed for HTR-10 reactor and the calculation result was compared with the other ones. It was also investigated for the cases to make it possible to use this method. Results for benchmark problems have been obtained by MCNP5 Code[2].

2. Methodology

The idea of the method developed in this study is to make the material, which consisted of the unit cell expanded by repeated-geometry feature, to be random. It is noted that the geometry was not changed randomly. The unit cell to be expanded was assumed to be a BCC (body-centered cubic) lattice. The BCC lattice has one lattice point (one pebble) in the center of the unit cell in addition to the eight corner points. It has a net total of 2 lattice points (2 pebbles) per unit cell ($1/8 \times 8 + 1$). Assuming that one pebble is formed with one material, one unit cell can be consisted of maximum 9 kinds of materials, except void region. On the other hand, there are 2 kinds of pebbles, which are fuel and moderator pebbles, in the pebble-bed core. Also assuming that each of fuel and moderator pebbles is formed with one material, total 512 kinds of unit cells can be existed by ‘permutations with repetition’, as shown in Eq. (1).

$$ {}_2\prod_9 = 2^9 = 512 \qquad \text{Eq. (1)} $$

The unit cell expanded was assigned to 'universe card' in the MCNP code. Input script of the MCNP code was made by the universes chosen randomly among 512 different universes prepared previously. The continuity of materials between universes should be conserved. HTR-10 reactor in China was modeled by using this method, as shown in Figure 1. Fuel to moderator pebble ratio (F:M ratio) was 57:43.



(a) Vertical View-a (b) Vertical View-b (c) Horizontal View

Fig. 1. MCNP Modeling Results

3. Calculation Result

The CRP benchmark problem B1 was calculated by using the developed method. Spherical fuel region of a fuel pebble was divided into cubic lattice element in order to model a fuel pebble which contains, on average, 8335 CFPs (Coated Fuel Particles). Each element contained one CFP at its center. All of different 5 concentric shells of CFP were modeled. The calculations were pursued with ENDF/B-VI cross-section library and used sab2002 S(α, β) thermal cross-section library for graphite material. The results of this study and other research groups using MCNP code were represented in Table I.

Table I. Results of Benchmark Problem B1 [3]

	k_{eff}	Critical Height [cm]	No. of Mixed Pebbles
Experiment	1.0	123.06	16,890
MCNP4A (INET)	-	126.116	17,109
MCNP4B (MIT)[1)]	0.99980 ±0.00090	128.0	16,906
MCNP4B (MIT)[2)]	0.99961 ±0.00094	127.5	16,840
MCNP4A (Russia)	-	164.6	-
MCNP5 (This Study)	**1.00002 ±0.00061**	**125.0**	**17,156**

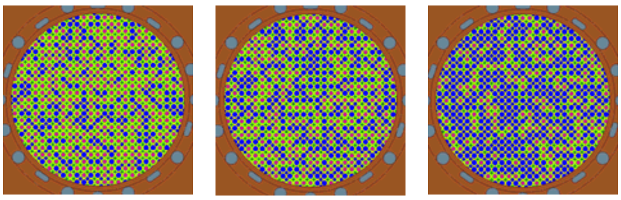
1) Using ENDF/B-VI Cross-section Data
2) Using UTXS Cross-section Data

It was found that the results from this study gave good agreements with the experiment and other MCNP results except the result by Russia. Even if the results were similar, it was different between the methods in this study and order research groups, because of the reason introduced in the following chapter.

4. Application Capability

4.1 Capability to Simulate Various F:M Ratio

In order to achieve the specified F/M ratio (0.57:0.43) in MIT work, a BCC lattice was employed with the size of the moderator sphere reduced. This treatment caused the different configuration from actual core. It could be also expected that the calculation produced a distortion result with the ratio increased of the fuel pebble to moderator one (e.g., F:M = 0.8:0.2) The any F:M ratio can be simulated without any distortion of actual pebble size by using the method developed in this study. Figure 2 showed the simulation results with various F:M ratios.



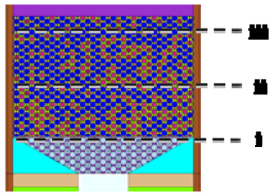
(a) F:M=2:1 (b) F:M=1:1 (c) F:M=1:2

Fig. 2. Horizontal View with Various F:M Ratio

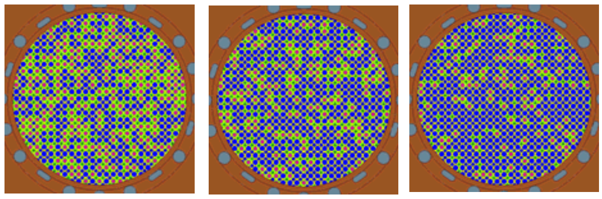
4.2 Capability to Simulate F:M Ratio Changed by Axial Position in a Core

It can be occurred that the mixed pebble packed into the core with new F:M ratio which was different from the existing one. In this case, there were various F:M ratios according to axial positions of the core. It was quite difficult to simulate the condition by using the method which was now known. The method in this study caused this condition to be easily possible through adjusting the F:M ratio to be different by the axial position. Figure 3 showed an instance for this condition. This simulation resulted from the quantity of moderator pebble increased by 4% pebbles more than moderator ones in the lowest position of the core whenever the core height was increased each time by 7cm, while the F:M ratio was 1:1 in lowest position of the core.

After modifying the method developed, it can be also simulated for F:M ratio changed by radial position in a core.



(a) Vetical View



(b) Horizontal View at Height i (c) Horizontal View at Height ii (d) Horizontal View at Height iii

Fig. 3. MCNP Modeling Results for F:M Ratio Changed by Axial Position in a Core

3. Conclusions

The method, which can efficiently simulate the pebble-bed core to be randomly mixed with fuel and moderator pebbles, was developed by using MCNP code in this study. This method is to make the material, which consisted of the unit cell expanded by repeated-geometry feature, to be random. In order to validate this method, CRP benchmark problem for HTR-10 reactor was chosen and pursued. The calculation result gave good agreements with the experiments and other MCNP results. The method developed in this study made it possible to simulate the core with various F:M ratio. If this method integrated into the MCNP code, more various analyses for the pebble-bed core could be possible.

Acknowledgment

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