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A Development of Monte Carlo Evaluation Method with Particle Sampling Technique for Pebble Bed Reactor

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1. Introduction

In the pebble bed reactor, the fuel element consists of a double-layered structure: the TRISO particles, which are containing UO_2 fuel, are randomly distributed in the fuel elements, which are called as pebbles. The pebbles are also randomly distributed in the reactor core. Due to the geometrical characteristic, some modeling methods in Monte Carlo simulation are used for the pebble bed reactor.

There are three kinds of the particle modeling methods: (1) repeated structure method, (2) explicit method and (3) implicit method. Repeated structure is a conventional method that the spherical particles are modeled in a unit lattice, and the lattice is repeated within the user-defined boundaries. However, the problems, which are the occurrence of broken geometries and neglecting the random distributions, are accompanied in using the repeated structure. Explicit modeling method is that all positions of the particles are modeled. In the other side, there are some disadvantages; the positions must be re-calculated whenever the reactor geometries are changed, and the distortion of the result can be occurred because only one distribution is represented to the all random distribution cases. Implicit modeling method uses the particle sampling on the neutron track in random sense. Conveniently, the implicit method performs the automatic geometry modeling; however, the calculation accuracy of the implicit method is not guaranteed at the high particle packing fraction.

In this study, a Monte Carlo simulation method with introducing an implicit modeling method [1] is developed with the improvement of the particle sampling ability at the high packing fraction.

2. Methods

The overall algorithm developed in this study is shown in Fig. 1. The basic algorithm for Monte Carlo simulation was constructed by introducing the method of the MCNP5 k-code [2, 3]. The Watt fission spectrum was used for the decision of the fission source energy. For the thermal scattering treatment of the graphite, S(α, β) treatment, which is used in MCNP5 code, was used in the algorithm. The inelastic scattering reaction is ignored due to the extremely small number of the inelastic reactions in the pebble bed core. In the program, the cross section data used for the calculation is selectively loaded from the ENDF/B-VII cross-section library and sab2002 S(α, β) cross-section library to the computer memory.

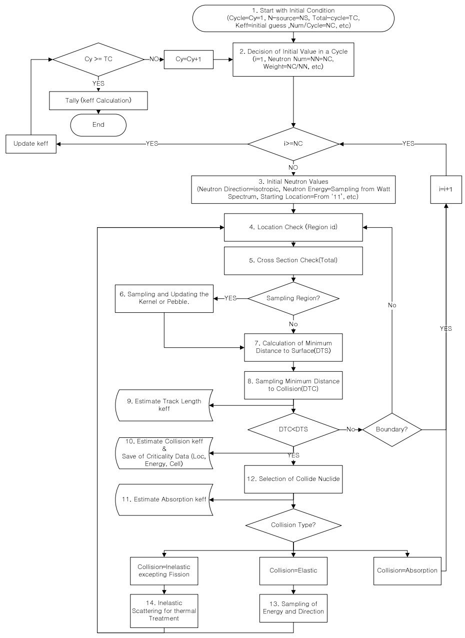

Fig. 1. Overall Algorithm of the Proposed Method

For the geometry modeling of the core, a sampling method was introduced from a study of the Dancoff factor analysis [1]. The specific characteristic in the method is that the positions of the pebbles and TRISO particles are not fixed. In the algorithm, a new particle position during the neutron transport is sampled and previous position is removed whenever the neutron is escaped from the previous particle. Also, the locations of the pebble and TRISO particle are recorded when the fission site is stored for the use as source point in the next cycle. The detail of the sampling method is described in the reference [1].

The particle sampled by the method can be overlapped with the previous particle. To solve the problem, a particle movement method is proposed as shown in Fig. 2: the position of the sampled particle is moved to the outside of the previous particle boundary on the neutron transport direction in case of the particle overlapping.

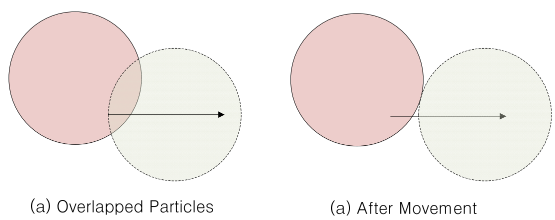

Fig. 2. Particle Movement Method for the Sampled Particle Overlapping Problem

However, it is found that the number density is changed by using the particle movement method. For the correction of the number density, a simulation algorithm based on the proposed sampling method is developed. In the algorithm, a new particle sampling and removal of the previous particle are repeated until the number of particle samplings is over 10^8. The real packing fraction, which is estimated by the algorithm with initial packing fraction, is calculated by Equation (1).

$$f_r = \frac{l_p}{l_t} \tag{1}$$

where, f_r is real packing fraction calculated with initial packing fraction, l_p is the track length through the particle, and l_t is the total track length. The result of the real packing fraction is shown in Fig. 2.

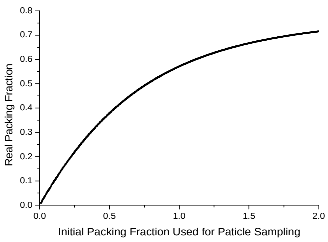

Fig. 2. Real Packing Fraction Estimated by Particle Sampling

The number density corrected by the real packing fraction is given in Equation (2).

$$\rho_{cp} = \frac{f_i}{f_r}\rho_p \tag{2}$$

where, f_i is initial packing fraction used for the particle sampling and ρ_{cp} is the number density corrected for the use of the particle sampling.

3. Results

By using the proposed method, a test version for eigenvalue evaluation was developed for the verification of the method. The test version was developed with the C++ program. HTR-PROTEUS Core-4 [4] was selected for the evaluation. In the reactor, the control rods and the guide tubes were ignored. In the given condition of the target reactor, the k_{eff} was evaluated as the changes of the active core height, core radius, and fuel region radius. To confirm the results, MCNP5 code [5] calculations were performed by using the repeated structure. The k_{eff} results are shown in Table I. It shows that all results with proposed method give a good agreement with that of MCNP5 run within 1% relative difference.

Table I. k_{eff} Results for the HTR-PROTEUS Core-4

Variable	Value	MCNP5 Result	Result in This Study	Relative Difference
Active Core Height	100 cm	0.92384	0.91893	- 0.53%
	140 cm	1.04386	1.04414	+ 0.03%
	180 cm	1.12087	1.12444	+ 0.32%
Core Inner Radius	50 cm	0.9616	0.95728	- 0.45%
	60 cm	1.05012	1.04719	- 0.28%
	70 cm	1.10974	1.11514	+ 0.49%
Fuel Region Radius	2.3 cm	1.05565	1.05849	+ 0.27%
	2.4 cm	1.07776	1.07904	+ 0.12%
	2.5 cm	1.10012	1.09638	- 0.34%

4. Conclusions

In this study, a Monte Carlo simulation algorithm based on the particle sampling method was developed for the pebble bed reactor analysis. The sampling method was introduced and modified by the correction of the particle number density. For the verification of the method, the eigenvalue of the HTR-PROTEUS core was evaluated and compared with the result using the MCNP code. The results by using the proposed method agree well with that of MCNP run within 1% relative difference. The method can simply model the geometries of the fuel particles without the direct modeling of the pebble bed reactor geometries. Also, the sampling accuracy at the high packing fraction was innovatively enhanced by this study. Therefore, it will be a powerful Monte Carlo simulation method for pebble bed reactor with consideration of a real geometry as well as a good accuracy.

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