Monte Carlo Criticality Calculation for Pebble-type HTR-PROTEUS Core

Hong-Chul KIM [a], Chang-ho SHIN [a], Chi Young HAN [a], Jong Kyung KIM [a], Soon Young KIM [b], and Jae Man NOH [c]
a Dept. of Nuclear Engr., Hanyang Univ., 17 Haengdang, Seongdong, Seoul, 133-791,nuclear1995@nural.hanyang.ac.kr
b Innovative Technology center of Radiation Safety, Hanyang Univ., 17 Haengdang, Seongdong, Seoul, 133-791
c Korea Atomic Energy Research Institute, 150 Duckjin, Yuseong, Daejeon, 305-353

1. Introduction

These days, pebble-bed and other high-temperature gas-cooled reactor (HTGR) designs are once again in vogue in connection with hydrogen production. In this study, as a part of establishing Monte Carlo computation system for HTGR core analysis, some criticality calculations for pebble-type HTGR were carried out using MCNP code. Firstly, the pebble-bed cores of HTR-PROTEUS critical facility in Swiss [1] were selected for the benchmark model, and, after the detailed MCNP modeling of the whole facility, criticality calculations were performed. It was also investigated the homogenization effect of TRISO fuel on criticality.

2. Methods and Results

In this study, Core 4.3 and Core 5 (reference state #3) [1] among the many PROTEUS cores were chosen to be analyzed in order to treat different core geometry. The former is a random packing model and the latter deterministic packing model. Criticality calculations were then carried out for each model using KCODE option in MCNP5 code.

2.1 Fuel Pebble Modeling

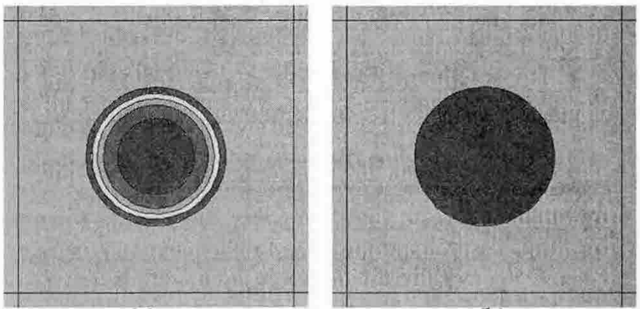
2.1.1 TRISO Heterogeneity Model

The pebble unit cell model has two concentric spherical shells. The outer region has an outer radius of 3.0006 cm and inner radius of 2.35 cm and is comprised of graphite. The inner spherical region of 2.35 cm in radius is divided into cubic lattice elements. Each element contains one TRISO fuel having a radius of 0.04577 cm at its center. In this study, the side length of each cubic lattice element to have the same amount of fuel was calculated to be 0.179513 cm. The remaining volume of each lattice element was filled with graphite.

A TRISO fuel consists of a UO_2 kernel, buffer layer, inner pyrolytic carbon (PyC) layer, silicon carbide (SiC) layer, and another outer PyC layer. In the TRISO heterogeneity model, all of these 5 concentric shells were modeled as shown in Figure 1-(a).

2.1.2 TRISO Homogeneity Model

The way of modeling for a fuel pebble is the same as that used in the TRISO heterogeneity model, but, in the TRISO homogeneity model, the 5 concentric shells were homogenized as shown in Figure 1-(b).



(a) (b)

Figure 1. (a) TRISO Hete. Model, (b) TRISO Homo. Model

2.2 Random Packing Modeling

The Core 4.3 in HTR-PROTEUS critical experiments was modeled [1]. In order to achieve the random packing core model, BCC (body-centered cubic) lattice model was employed in this study, since BCC lattice is known to be worked well for the loose packing typically encountered in pebble-bed reactor cores [2].

When it is modeled using the repeated-structure feature of MCNP code, the partial spheres is produced at the core edge. It can overestimate the amount of fuel in the system. Therefore, the MCNP model of the reactor needs the employment of an exclusion zone [3] around the periphery of the pebble-bed core to compensate for the partial fuel spheres. In this study, 1.5 cm exclusion zone was used [2]. The fuel pebble was separately modeled with the two TRISO models, heterogeneity and homogeneity model, presented in Section 2.1.

The criticality calculation results are summarized in Table 1 together with the previous MCNP results [4].

In this study, the result gives an agreement of 0.8% relative error. This overestimates more or less in comparison with the different institutes. Reactivity difference with TRSIO homogeneity model was found to be 919 pcm.

Table 1. The Multiplication Constants for the Random Packing Model of HTR-PROTEUS Core 4.3

		k_{eff}	Relative Error [%]
Experiment		1.01320±0.0011	
MCNP4B (MIT)		1.01760±0.0011	0.43
MCNP-BALL (JAERI)		1.01720±0.0011	0.39
MCNP5 (This Work)	TRISO hete.	1.02130±0.0010	0.80
	TRISO homo.	1.01180±0.0010	-0.14

2.3 Deterministic Packing Modeling

The Core 5 (reference state #3) in HTR-PROTEUS critical experiments was modeled [1]. The purpose of this packing model is a near-to-exact modeling of the investigated experimental geometries. Thereby, heterogeneity effect in the core region (fuel/moderator pebble arrangement for the lattice) was treated explicitly.

As well as in the random packing modeling, the fuel pebble was separately modeled with the two TRISO models.

The criticality calculation results are summarized in Table 2 together with the previous MCNP calculation result [4].

In this study, the result gives an agreement of 1.52% relative error. This overestimates more or less in comparison with the different institute. Reactivity difference with TRSIO homogeneity model was found to be 844 pcm.

Table 2. The Multiplication Constants for the Deterministic Packing Model of HTR-PROTEUS Core 5 (reference state #3)

		k_{eff}	Relative Error [%]
Experiment		1.00000	
MCNP4B (PSI)		0.99472±0.00035	-0.53
MCNP5 (This	TRISO hete.	1.01522±0.00089	1.52
	TRISO homo.	1.00660±0.00095	0.66

It is found that the results give an agreement of 0.8% and 1.52% relative error for the random and deterministic packing model, respectively. Also, it is found that reactivity difference between the two TRISO models was found to be about 900 pcm, which is relatively high than expected.

Acknowledgment

This study was supported by Korea Atomic Energy Research Institute (KAERI) and Innovative Technology Center for Radiation Safety (iTRS).

REFERENCES

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

[2] William K. Terry, "Modular Pebble-bed Reactor Project," INEEL/EXT-01-01623, 46-47, Idaho National Engi-neering and Environment Laboratory (INEEL) and the Ma-ssachusetts Institute of Technology (MIT) (2001).

[3] Isao Murata et al., "New Sampling Method in Continuous Energy Monte Carlo Calculation for Pebble Bed Reactors," *Journal of Nuclear Science and Technology*, **34**, *8*, 734-744 (1997).

[4] "Critical Experiments and Reactor Physics Calculation for Low-Enriched High Temperature Gas Cooled Reactors," IAEA-TECDOC-1249, IAEA (2001).