Monte Carlo Criticality Calculations for PBMR Core

Hong-Chul KIM a, Soon Young KIM b, Jong Kyung KIM a, and Jae Man NOH c
a Department of Nuclear Engineering, Hanyang University, 17 Haengdang, Seongdong, Seoul 133-791, Korea
jkkim1@hanyang.ac.kr
b Innovative Technology Center for Radiation Safety, Hanyang Univ., 17 Haengdang, Seongdong, Seoul, 133-791
c Korea Atomic Energy Research Institute, 150 Deockjin, Yuseong, Daejeon, 305-353

1. Introduction

A large interest in high-temperature gas-cooled reactors (HTGR) has been shown in connection with hydrogen production in recent year. In this study, as a part of establishing Monte Carlo computation system for HTGR core analysis, criticality calculations for pebble-type HTGR were carried out using MCNP code. As for Korea, the experiences for the commercial reactor of pebble-type to be developed for hydrogen production are poorly accumulated. Therefore, as a benchmark model, the core of the 400MW_{th} Pebble-bed Modular Reactor (PBMR), being developed in South Africa through a world wide international collaborative effort led by Escom, was selected. After the detailed MCNP modeling of the whole facility, criticality calculations were performed. The core height to achieve initial criticality and control rod worth were obtained by MCNP5 Code [1] in this study.

2. PBMR Modeling with MCNP Code

2.1 Fuel Pebble Modeling

A fuel pebble contains on average 15000 Coated Fuel Particles (CFPs) within the central region of 2.5cm radius. This spherical region is divided into cubic lattice elements. Each element contains one CFP having a radius of 0.046cm 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 0.1635cm. The remaining volume of each lattice element was filled with graphite. The CFP is a TRISO-type particle and consists of the UO_2 fuel kernel and 4 outer layers. All of these 5 concentric shells were modeled.

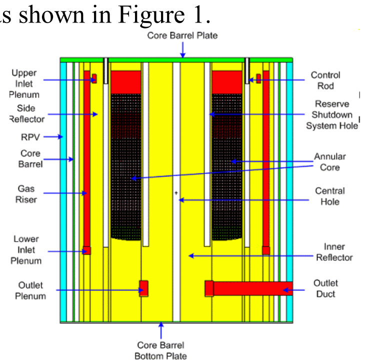
2.2 Core Modeling

The PBMR core consists of approximately 452000 pebbles in annular core with an inner radius of 1.0m and an outer radius of 1.85m.The active height of the core is 11.0m. The pebbles gradually move downward in the core bed from top loading locations and exit via one of three de-fueling chutes at the bottom of the bed.

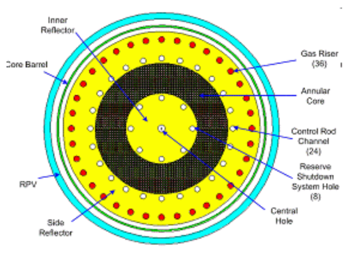
It was assumed that the positions of fuel and moderator pebbles are determined entirely by dropping randomly from the top of the core with the F/M ratio of 1:1. In order to achieve the random packing core model using MCNP Code, the feature must be assumed to be a specified lattice model. Body-centered cubic (BCC) lattice was employed and this unit cell was expanded throughout the volume of the core while preserving the 1:1 F/M ratio and the void fraction of 0.39. At this time, the BCC lattice pitch to conserve the fuel quantity or void fraction within one BCC cell was calculated to be about 7.18 and the number of pebbles for full core was obtained to 415531.

2.3 Whole Facility Modeling

The major components of the reactor were also modeled, which are 24 reactivity control systems (RCS), 8 reserve shutdown systems (RSS), 3 de-fueling chutes, 36 gas risers, 2 inlet ducts, outlet duct, 2 inlet plenum, outlet plenum, and reflectors as well as the core. Whole facility modeling was shown in Figure 1.



a) Vertical View



b) Horizontal View
Figure 1. MCNP Modeling for Whole Facility

3. Calculation Results and Disscussion

3.1 Initial Critical Core Height

The height of initial critical core above de-fueling chutes region was searched for the state without any control rod insertion.

Initial criticality calculations were made by adjusting the core height from 100cm to 1100cm. Criticality height was searched by interpolating, and then, criticality calculation was pursued on this height. The k_{eff} for each height was shown in Figure 2. The resulting critical height was calculated to be 189.5cm while about 78000 mixed pebbles were packed.

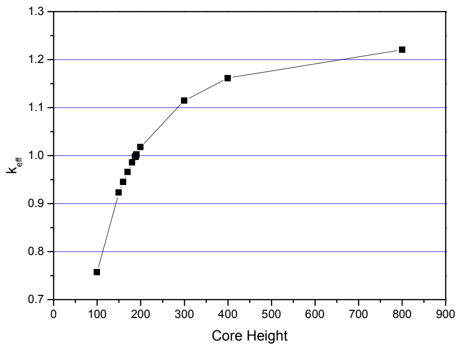
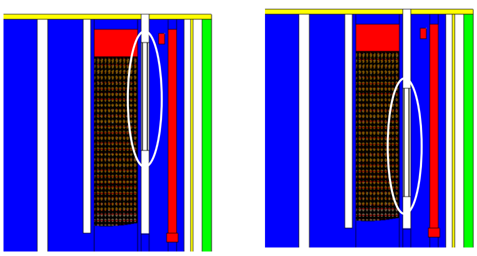


Figure 2. The resulting k_{eff} for each height

3.2 Control Rod Worths

Reactivity control system (RCS) consists of 24 active control elements divided into two groups of 12 (with every other control rod belonging to a group). When fully inserted, Group 1 (Bank 1) is positioned in the upper half of the core, while Group 2 (Bank 2) is positioned in the lower half, with the two groups of control elements overlapping in the center, presented in Figure 3.

In this study, reactivity differences were calculated for full core when Bank 1, Bank 2, and both Bank 1 and Bank 2 were fully inserted, respectively. The calculation results were represented in Table 1.The results indicated that the k_{eff} decrements due to control rod insertion in Bank 2 are larger than those in the Bank 1 and are also more sensitive.



(a) Bank 1 Inserted (b) Bank 2 Inserted

Figure 3. The Position of Control Rod When Fully Inserted

Table 1. The Results of Control Rod Worth

	State	Reactivity Difference [pcm]
Bank 1	Bank 1 Fully Inserted	3889
Bank 2	Bank 2 Fully Inserted	9695
Bank 1 and 2	Both Bank 1 and 2 Fully Inserted	13581

4. Conclusion

In this study, some Monte Carlo criticality calculations were carried out for the PBMR with MCNP5 code. This calculation deals with initial critical height and control rod worth.

It was found that initial criticality was achieved at about 1/6 height of the full core. It was also investigated that the control rod group positioned in the lower half of core has more reactivity worth than the group positioned in the upper half. It is, therefore, expected that this study would be utilized in the validation of a deterministic computer code for HTGR core analysis which will be developed in near future in Korea.

Acknowledgment

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[1] X-5 Monte Carlo Team, "MCNP-A General Monte Carlo N-Particle Transport Code, Version 5, Volume II: User's Guide," LA-CP-03-0245, Los Alamos National Laboratory (2003).