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Monte Carlo Benchmark Calculations for HTR-10 Initial Core

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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 benchmark calculations for pebble-type HTGR were carried out using MCNP code. As a benchmark model, the initial core of the 10MW High Temperature Gas-cooled Reactor-Test Module (HTR-10) in China was selected. After the detailed MCNP modeling of the whole facility, benchmark calculations were performed. This study deals with the core physics benchmark problems proposed for HTR-10 reactor initial core [1]. Results to benchmark problems have been obtained by MCNP5 Code [2].

2. HTR-10 Modeling with MCNP Code

2.1 Fuel Pebble Modeling

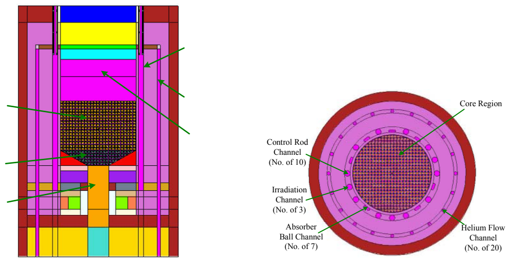
A fuel pebble contains on average 8335 CFPs (Coated Fuel Particles) within the central region of 2.5cm radius. This spherical region is divided into cubic lattice elements. Each element contains one CFP having a radius of 0.0455cm at its center. In this study, the side length of each cubic lattice element to have the same amount of fuel was calculated to be 0.19871cm. 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

In order to achieve the random packing core model, a BCC (body-centered cubic) lattice was employed with the size of the moderator sphere reduced in a manner that reproduces the specified F/M ratio (0.57:0.43) while preserving the void fraction of 0.39. The reduced radius of moderator pebble was calculated to about 2.73cm. The BCC lattice pitch to conserve the fuel quantity within one BCC cell was calculated to about 6.88cm.

2.3 Whole Facility Modeling

The major components of the reactor, which are ten control rod channels, seven small absorber ball channels, three irradiation channels, twenty helium flow channels, fuel discharge tube, and reflectors as well as the core were also modeled. Whole facility modeling was shown in Figure 1.



a) Vertical View　　b) Horizontal View

Figure 1. MCNP Modeling for Whole Facility

3. Results of Benchmark Problems

3.1 Problem B1

: The height of critical core above the conus region is expected to be determined under the helium atmosphere and at 20 ℃ without any control rod insertion.

Table 1. Results of Benchmark Problem B1

	k_{eff}	Critical Height [cm]	No. of Mixed Pebbles
Experiment	1.0	123.06	16,890
VSOP (INET)	-	125.804	17,267
MCNP4A (INET)	-	126.116	17,109
MCNP4B (MIT)	0.99980 ±0.00090	128.0	16,906
MCNP5 (This Work)	**0.99933 ±0.00061**	**124.88**	**17,144**

Initial criticality calculations were repeated by increasing the core height each time by 10cm from 100cm. Critical height was searched by interpolating, and then, criticality calculation was pursued on this height. The k_{eff}, critical height, and number of mixed pebbles were compared with the results from the experiment and other research groups [3] in Table 1. The resulting critical height was calculated to be 124.88cm while 17,144 mixed pebbles were packed. It turns out that the results from this study are quite good compared with the experiment.

3.2 Problem B2

: Effective multiplication factor is to be determined for the full core (5m^3) under helium atmosphere and at temperatures of (a) 20℃ (B21), (b) 120℃ (B22), (c) 250℃ (B23) without any control rod insertion.

Cross-sections were produced using NJOY [4] code for the different temperatures with ENDF/B-VI library for all materials constituted the facility. MCNP results were also compared with other research groups [3] as shown in Table 2. It is found that the effects ρ(T)[1)] by increasing the temperature give a similar results.

Table 2. Results of Benchmark Problem B2

		B21	B22	B23
Temperature [℃]		20	120	250
VSOP (INET)	k_{eff}	1.119747	1.110435	1.095961
	ρ(T)[1)]	-7.49E-05	-9.15E-05	
VSOP-PBMR (South Africa)	k_{eff}	1.12861	1.11956	1.10469
	ρ(T)[1)]	-7.16E-05	-9.25E-05	
WIMS/D4 (Indonesia)	k_{eff}	1.1197	1.1104	1.0956
	ρ(T)[1)]	-7.48E-05	-9.36E-05	
MCNP5 (This Work)	**k_{eff}**	**1.12607 ±0.00063**	**1.11439 ±0.00065**	**1.10079 ±0.00062**
	ρ(T)[1)]	**-9.31E-05**	**-8.53E-05**	

[1)] $\rho(T)=(k_{t1}-k_{t2})/((k_{21}*k_{t2})*(T_1-T_2))$

3.3 Problem B3

: This Problem requires the calculation reactivity worth of (a) ten fully inserted control rods (B31) and (b) one fully inserted control rod (B32) under the helium atmosphere and the temperature of 20℃ for full core.

Table 3. Results of Benchmark Problem B3

[%△k/k]

	B31	B32
State	Ten rods insert	One rod insert
VSOP (INET)	15.24	-
MCNP4A (INET)	16.56	1.413
VSOP (Germany)	16.6	1.56
MCNP5 (This Work)	**15.93**	**1.47**

The results of this study and other research groups [3] were summarized in Table 3. The reactivity worths of ten control rods and one control rod had been evaluated to be 15.93% and 1.47% in this study, respectively. These results were comparable with the results from other research groups.

4. Conclusion

In this study, some Monte Carlo benchmark calculations were carried out for the HTR-10 initial core with MCNP5 code. This calculation deals with the core physics benchmark problems proposed for HTR-10 reactor initial core.

It is found that the MCNP model of the HTR-10 initial core is expected to predict the core characteristics well. The calculation results of the benchmark problems to see the effects of temperature and control rod were also comparable with the results from other research groups. It is, therefore, expected that this study would be utilized in the validation of a computer code for HTGR core analysis which will be developed in near future in Korea.

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