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T/H Feedback Analysis for Thorium Epithermal Reactor with MCS code

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1. Introduction

Currently the world is faced with reality of global warming and high oil prices problem. In order to solve of the problem, nuclear energy has been re-evaluated as one of the replacement candidates for the fossil fuels such as gas, oil, and coal. Especially, thorium fuel has been conceived as an alternative to uranium fuel in existing reactor. India, China, United Kingdom, France, and Russia have been pursuing a steady research of thorium-based nuclear reactors [1].

Recently the thorium-based epithermal reactor has been researched in consideration of T/H feedback.

The main objective of this paper is to evaluate the power distribution due to thermal hydraulics effect using the MCS code.

The temperature distributions of fuel created by the thermal hydraulics effect are presented by using MCS code. Also, without considering T/H effects the control rod worth, CTC and FTC are compared by using MCNP 6.1 code.

2. Analysis Procedure

2.1 Analysis Tools

The Monte Carlo code MCS has been developed at Ulsan National Institute of Science and Technology (UNIST) to solve complex whole-core problems with high-fidelity and high-performance. MCS is a 3D continuous-energy computer code for particle transport based on the Monte Carlo method and it is designed for criticality problems and radiation shielding problems [2].

MCNP of Monte Carlo N-Particle code was developed for analysis of neutron, photon or electron transport at LANL (Los Alamos National Laboratory). The MCNP code is determined in accordance with the probability distribution for the various reactions, location and direction of the particle, and kinetic energy by using a random number [3][4].

In the analysis of MCNP code, the ENDF/B-VII.1 cross-section, 450 active cycles, 50 inactive cycles and 10,000 neutron histories per cycle are used.

2.2 Modeling Simulation and Analysis Method

As shown in Fig.1, PWR 16 x 16 has been selected as the fuel assembly type and the details of the assembly are given Table 1. Fig. 1 shows the 242 cm high by 148 cm diameter epithermal reactor vessel contains $(Th+U)O_2$ fuel, coolant and cladding. The output power designed is 100 MW(thermal)/ 40MW(electric) [5]. Also, a reliability of the MCS code is verified based on the neutron spectrum and k-eff results of the MCNP code. The thermal hydraulic effect for the epithermal reactor is carried out by using the MCS code (Flow late: 862 kg/s, Inlet temperature: 563.15 K) [6].

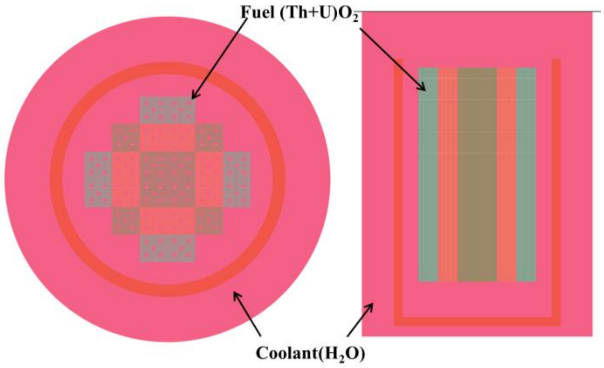


Fig. 1. $(Th+U)O_2$ core configuration (MCS)

Table 1. Parameter of $(Th+U)O_2$ reactor

Description	$(Th+U)O_2$ Reactor
Fuel Enrichment ($^{233}U/(^{232}Th+^{233}U)$)	5 %
Density (g/cc)	10.9
Fuel rod diameter (cm)	0.5
Cladding material	Zircaloy-4
Coolant	H_2O
Control rod	B_4C
Thermal power	100 MWth

3. Results and Discussion

The calculations of the core parameters were performed by using the MCS code and MCNP code. From the calculations the neutron spectrum, fuel temperature coefficient (FTC), coolant temperature coefficient (CTC), control rod worth, and power distribution and effect according to depletion were obtained. Fig.2 shows the results at full energy range of the MCNP and MCS code. The K-eff and neutron spectrum result of MCS are consistent to those of MCNP results. The k-eff is 1.25751 (standard deviation of 0.00049) at the MCNP code and 1.25727 (0.00058) at the MCS code, respectively.

Table 2 shows the excess core reactivity ρ and the control rod worth at initial core state as calculated by MCNP. The control rod worth is influenced when a control rod transfers from bottom to top of the core. The total control rod worth is about 445 mk and the maximum differential worth is about 11 mk/cm.

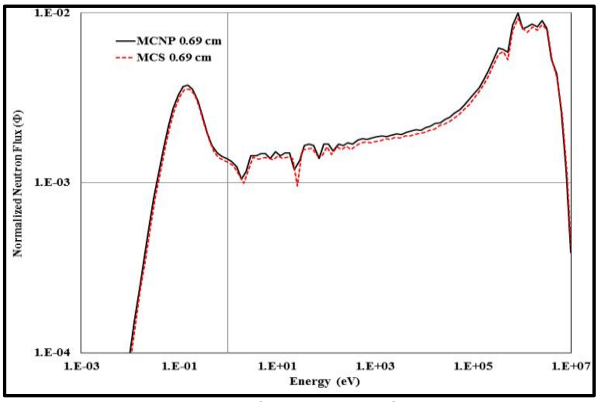


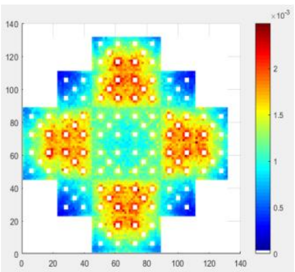
Fig. 2. Comparison of spectrum of MCS and MCNP

Table 2. Control rod worth with MCNP

Distance (cm)	k-eff	Reactivity (ρ)	Integral (mk)	Differential (mk)
0	0.712	-0.4049	0	0
11	0.732	-0.3665	38.472	3.497
22	0.857	-0.1671	237.863	10.812
33	0.921	-0.0858	319.140	9.671
44	0.960	-0.0415	363.414	8.259
55	0.985	-0.0153	389.638	7.084
66	0.994	-0.0056	399.297	6.050
77	1.012	0.0122	417.108	5.417
88	1.022	0.0212	426.120	4.842
99	1.022	0.0211	426.072	4.304
110	1.026	0.0249	429.851	3.908
121	1.035	0.0343	439.202	3.630
132	1.036	0.0346	439.547	3.330
143	1.038	0.0366	441.500	3.087
154	1.039	0.0379	442.807	2.875
165	1.041	0.0389	443.852	2.690
176	1.039	0.0377	442.613	2.515
187	1.044	0.0418	446.707	2.389
198	1.046	0.0440	448.924	2.267
209	1.041	0.0398	444.729	2.128
220	1.045	0.0431	448.046	2.037
231	1.045	0.0435	448.412	1.941
242	1.043	0.0408	445.769	1.842

The fuel and coolant temperature coefficients were calculated without T/H effects. In the case of safety parameter factor, FTC is estimated about -2.87 ± 332 pcm/°C and CTC is given as -17.01 ± 345 pcm/°C. All the reactivity feedback coefficients are negative, which demonstrates that the core is inherently safe.

From the MCS code, the flow rate is calculated by using the inlet temperature suitable at epithermal reactor. The power distribution of the core at the beginning of cycle for equilibrium core is provided in Fig 3.



		1.766	2.134		
	1.216	2.011	1.846	1.199	
1.990	1.806	1.291	1.346	1.830	1.967
1.904	1.966	1.267	1.253	1.912	1.927
	1.020	1.877	1.877	1.187	
		1.928	1.750		

Fig. 3. Power distribution at the epithermal reactor

The maximum power peaking factors is 2.011 for T/H effect application. However, due to asymmetry of power distribution, more reliable analysis is necessary by increasing cycle numbers. It is expected the power peaking factor change when control rod is considered later.

4. Conclusions

The T/H feedback analysis for thorium epithermal reactor was performed by MCS code. In the safety parameter analysis, negative fuel temperature coefficient and coolant temperature coefficient are obtained. It has been proven that the core is inherently safe since all the calculated reactivity feedback coefficients are negative.

As a further work, reliable detail calculation(design standard for Fr, Fq and fuel temperature) for MCS code will be performed for the suggested epithermal reactors.

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