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Neutronics Analysis for Thorium Epithermal Reactor with T/H Feedback Effect

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1. Introduction

Currently, the more concerns for safe reactor concepts have been increased after the accident at Fukushima. In order to ensure safe reactor concept, the thorium fuel has been conceived as one of the replacement candidates for the uranium fuel. In the earth, the thorium is more abundant than the uranium and provides lots of merits [1].

Recently the thorium based epithermal reactor concept has been studied. The thorium epithermal reactor concept is suggested by adjusting moderation ratio or changing fuel compositions [2].

The main objective of this paper is to evaluate the thermal hydraulics effect on the thorium epithermal reactor on the basis of the previous study in order to estimate the power distribution and safety parameters due to temperature dependent cross sections [3].

The temperature distributions for fuel, coolant were obtained by using MARS (Multi-dimensional Analysis of Reactor Safety) code [4], and the power peak factors, control rod worth, MTC and FTC via the thermal hydraulics effect were calculated by using MCNP 6.1 code [5].

2. Analysis Procedure

2.1 Analysis Tools

MARS code was developed for a multi-dimensional and multi-purpose realistic thermal hydraulic system analysis at KAERI. The background of the MARS code are the RELAP5/MOD3 and COBRA-TF codes developed by the USNRC, and MARS is a multi-dimensional thermal-hydraulic system code developed for optimum estimate analyses of two-phase flow transients in PWR.

MCNP6.1 code was developed for analysis of mostly neutron and gamma at LANL (Los Alamos National Laboratory). The MCNP code is determined according with the probability distribution for the kinetic energy, various reactions, location and direction of the particle by using a random number. Also, MCNP is a transport system that can calculate the transport of radiation particles (photons, electrons and neutrons) in the space of the complex geometry and variety materials.

Temperature dependent cross-section library are provided by NJOY code [6]. In the analysis of MCNP code, the ENDF/B-VII.1 cross-section, 350 active cycles, 50 inactive cycles and 10,000 neutron histories per cycle are used.

2.2 Modeling simulation

The fuel assembly is selected in a typical PWR 16 x 16 fuel assembly such as Fig. 1 and the details of assembly are given Table 1. Fig. 1 shows the 126 cm high by 136 cm diameter epithermal reactor vessel contains (Th+U)O_2 fuel, coolant, cladding and control rod. Coolant is mixed H_2O and D_2O in order to realize epithermal spectrum [7]. Also, the enriched ^{233}U separation is assumed by following the THREX process [1].

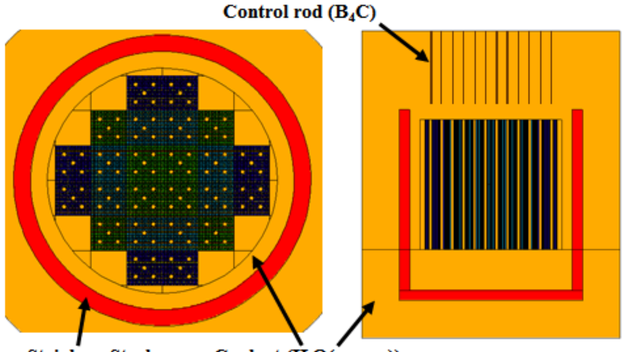

Fig. 1. (Th+U)O_2 core configuration

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
Number of Fuel assembly	24
Number of Fuel rod per FA	236
Active core height (cm)	126
Fuel rod diameter (cm)	0.5
Cladding material	Zircaloy-4
Coolant	H_2O:90% + D_2O:10%
Control rod	B_4C
Thermal power	100 MWth

2.3 Analysis method

The thermal hydraulic calculation of the epithermal reactor was carried out by using the MARS code and MCNP code as shown in Fig.2.

At the beginning, uniform temperature distribution is assumed. And given loading pattern, core depletion calculation is done. Then, the thermal hydraulic calculation for fuel and coolant is performed in the MARS code. From the results of T/H feedback effect, temperature cross-section is provided in NJOY code.

Finally, several iterations are carried out until converging temperature distribution. In this study, 2 iterative calculations are carried out due to fast convergence of temperature distribution in the small sized core.

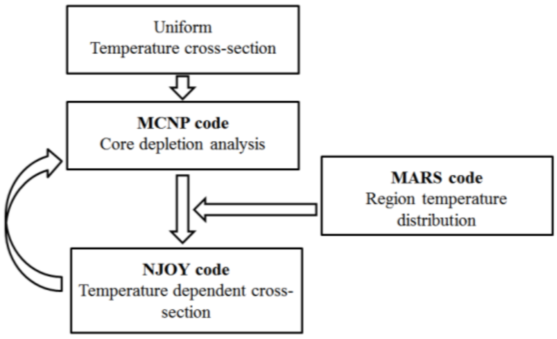

Fig.2. Calculation flow chart

3. Results and Discussion

Fig.3 shows the various loading patterns for searching the optimal refueling scheme. 24 fuel assemblies are grouped into 3 regions or batches which are composed of fresh region, once burned region, and twice burned region.

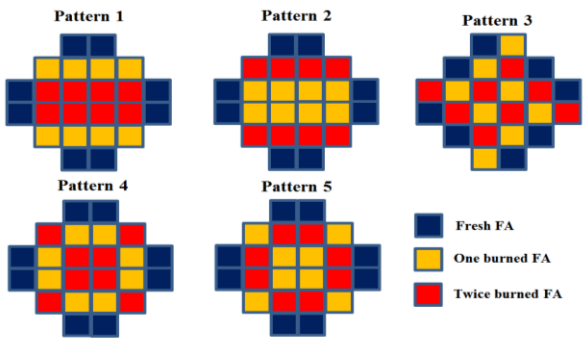

Fig. 3. Various schemes of loading pattern

In order to search the equilibrium core, average cycle length is fixed as about 1,000 days per cycle, which is estimated by the linear reactivity model. Fig.4 shows k-eff change for the equilibrium core search for loading pattern 1.

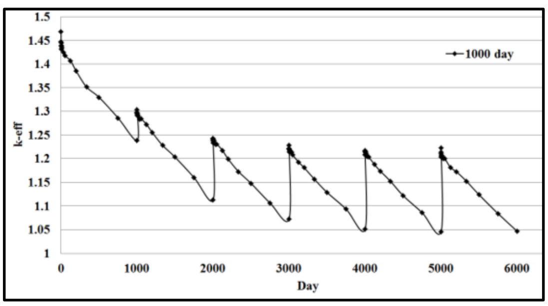

Fig.4. k-eff change for loading pattern 1

From the MARS code, the average temperatures of core and coolant regions are obtained about 960 K and 620 K, respectively. Because of small temperature change in axial direction, an averaged axial temperature is used. For the searched equilibrium cores for various patterns, fuel and moderator temperature coefficients are obtained. Table 2 summarizes reactivity feedback coefficients for five patterns. FTC distributes between -3.1 pcm/K and -2.8 pcm/K and MTC provides more negative values between -44 pcm/K and -34 pcm/K. In general, the reactivity coefficients for T/H feedback effect are similar as those of without T/H feedback cases due to small difference in temperature distribution. However, due to low values of FTC and MTC, more reliable analysis is necessary by increasing cycle numbers in order to decrease standard deviation of k-eff less than a few pcm.

Table 2. Reactivity coefficient for various patterns

	FTC (pcm/K)	
	With T/H	Without T/H
Pattern 1	-3.04	-2.90
Pattern 2	-2.97	-2.80
Pattern 3	-3.04	-3.07
Pattern 4	-2.86	-2.90
Pattern 5	-3.02	-2.90
	MTC (pcm/K)	
	With T/H	Without T/H
Pattern 1	-41.46	-38.06
Pattern 2	-43.04	-41.16
Pattern 3	-41.31	-36.84
Pattern 4	-39.05	-35.73
Pattern 5	-43.09	-40.02

We also carried out control design for small thorium reactor. Control rod material is B_4C and it is assumed 4 control rod assembly is inserted in one fuel assembly and total 24 control rod assemblies are inserted in all core region. The integral worth of each pattern of control rods is depicted in Fig 5. The similar trend of the integral rod worths for various cases shows that it is insignificantly affected by the fuel and coolant temperatures.

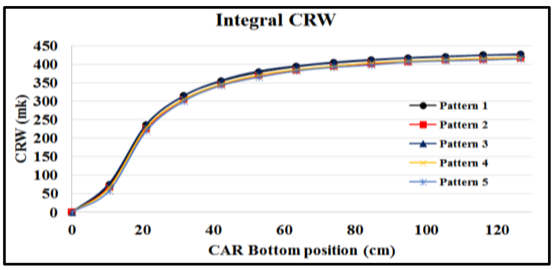

Fig. 5. Integral CRW for each pattern

In addition, the power distribution of the equilibrium core at the beginning of cycle is provided in Fig. 6 for various patterns. The maximum power peaking factors are 1.89, 2.32, 1.84, 1.65, and 1.37 for different patterns. Therefore, the pattern 5 shows the more uniform power distribution. And it is expected the power peaking factor increases when axial division is considered later.

pattern 1 **pattern 2** **pattern 3** **pattern 4** **pattern 5**		0.74 1.87 0.7 1.62 **1.37**	0.72 1.85 1.26 1.02 1.3		
	0.51 0.72 0.71 0.59 0.79	0.55 1.19 1.17 1.07 0.83	0.54 1.18 0.48 1.02 0.77	0.47 0.73 1.65 0.5 0.7	
1.89 0.82 0.56 **1.65** 1.23	1.41 0.47 1.15 1.08 0.78	1.23 0.5 0.57 0.6 1.2	1.23 0.52 1.38 0.55 1.15	1.3 0.5 0.51 0.86 0.69	1.62 0.84 1.64 1.22 1.05
1.87 0.85 0.69 1.59 1.22	1.42 0.5 0.5 1.06 0.76	1.24 0.57 1.27 0.59 1.15	1.22 0.56 0.56 0.54 1.16	1.3 0.51 1.19 0.87 0.71	1.63 0.83 0.56 1.23 1.07
	0.49 0.82 0.71 0.57 1.15	0.5 1.38 0.52 0.97 0.8	0.51 1.39 1.18 0.93 0.78	0.46 0.79 1.83 0.5 0.7	
		0.57 2.29 1.36 1.45 1.34	0.57 **2.32** **1.84** 1.36 1.32		

Fig. 6. Power distribution at the epithermal reactor

3. Conclusions

The T/H feedback analysis for thorium epithermal reactor was performed by combining MCNP6 and MARS code. Several different loading schemes were considered to search for the equilibrium core with 3 batches. For the equilibrium core, thermal hydraulic effect is accomplished by the temperature distribution from the MARS code. Then, the cross section is modified depending on the temperature and iterative calculations are performed. For the established core analysis system with T/H feedback, the marginal negative values of MTC and FTC are obtained and reasonable uniform power distributions are provided for thorium reactor. Conclusively, more reliable neutronics parameters will be evaluated for thorium epithermal reactor by considering axial T/H feedback effect in the near future.

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