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Thorium based lattice analysis through enhanced epithermal neutron spectrum

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1. Introduction

Currently, most commercial reactors consider as a fuel uranium, but some disadvantages of those uranium reactors occur after the Fukushima nuclear reactor accident. As a results, innovative and safe reactor concepts are taken into consideration of such as thorium reactor [1]. The earth's reserve of thorium is abundant as three times as uranium [2]. The thorium is not a fissile but a fertile thus it cannot maintain a nuclear chain reaction in itself. It requires a fissile material, such as U-233, U-235 or Pu-239. It can also prevent the plutonium production in raw material of nuclear weapons and it mitigates concerns about production of nuclear weapons and can reduce the amount of nuclear waste.

Table 1. Thorium reactor data

Name	Type	Power	Fuel	Moderator	Coolant
MSRE (USA)	MSBR	7.5 MWt	^{233}U Molten Fluorides	Graphite	FLiBe
Shippingport (USA)	LWBR	100 MWe	$Th+^{233}U$	Light water	Light water
Indian Point1 (USA)	LWBR	285 MWe	$Th+^{233}U$	Light water	Light water
KAPS 1&2 (India)	PHWR	220 MWe	ThO_2	Heavy water	Heavy water
JAPAN (JAERI)	*RMWR	3000 MWt	$(Th-^{233}U)O_2$	Heavy water	Heavy water
KOREA	LWR	308 MWt	ThO_2-UO_2	Light water	Light water

* RMWR = Reduced-Moderation Water Reactor

Table 1 summarizes the thorium based reactor. Currently proposed thorium reactors are including MSRE, Shippingport. Most fuels are using $Th+^{233}U$ and ThO_2 and moderator as graphite, light water and heavy water [3].

In the case of thorium cycle, it is larger than 2 in reproduction factor at epithermal energy range. The epithermal reactor is a capable of breeding, with a critical mass decently smaller than that required for a fast reactor. It can make much more compact size than thermal, fast reactors.

In this research, the objectives of the concept evaluation for thorium epithermal reactor is to select the most suitable nuclear fuel among widely-known materials and simultaneously optimize the moderator thickness with a selected neutron moderator. A computational optimization study on the design parameters of the intermediate reactor is conducted using NEWT code of SCALE 6.1 [4]. The simulation results are evaluated regarding to the neutron spectrum and four factor formula and their results are confirmed simulation model by comparing MCNP calculations.

2. Analysis Procedure

2.1 NEWT code

NEWT (New ESC-based Weighting Transport code) is a two-dimensional (2D) discrete ordinates transport code developed at ORNL (Oak Ridge National Laboratory). 2-D transport equation calculates a solution in terms of the particle flux [5]. This code provides important functionality to support forward and lattice-physics calculations, material-weighted cross-section collapse and diffusion coefficients, pin powers, and multi-group flux spectrum.

2.2 MCNP6 code

MCNP6 (Monte Carlo N-particle) code was develop ping for analysis of mostly neutron and gamma at LANL (Los Alamos National Laboratory) in USA.

The MCNP code is determined according to the probability distribution for the various reactions and kinetic-energy, direction, and location of the particle by using a random number. Also, MCNP is a transport system that can calculate the transport of radiation particles (neutrons, photons and electrons) in the space of the complex geometry and variety materials.

2.3 Modeling simulation (Lattice)

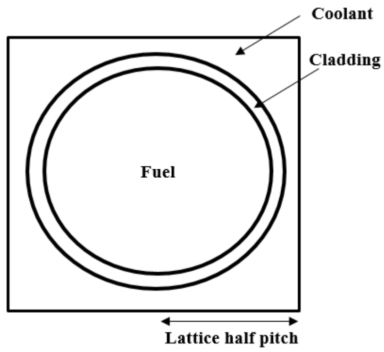


Fig. 1. Simulated simple lattice geometry

Simulation of epithermal reactor was using NEWT in transport code. Figure 1 shows the simple lattice geometry of simulation structure designed to compare the neutron spectrum (thermal, epithermal, and fast cores) and parameters are given in Table 2. The cladding and fuel is a cylinder type. To effectively trace the epithermal spectrum following the change in the moderator size, the lattice half pitch of 0.7 cm thick layer was divided.

Table 2. Parameter of lattice geometry simulation

Parameter	Thermal	Epithermal	Fast	Epithermal
Lattice half pitch (cm)	0.7 (0.69,…0.51)	0.68	0.7	0.7
Fuel radius (cm)	0.5	0.5	0.5	0.5
Fuel material	$ThUO_2$	$ThUO_2$	ThUZr	ThUZr($H_{0.1}$)
Fuel density (g/cm^3)	10.9	10.9	15.4	15.4
Cladding thickness (cm)	0.05	0.05	0.05	0.05
Cladding material	Zircaloy-4	Zircaloy-4	Stainless-Steel	Stainless-Steel
Cladding density (g/cm^3)	6.56	6.56	7.94	7.94
Coolant material	H_2O	H_2O	Na	Na

3. Results and Discussion

3.1 Normalized Neutron Spectra

Figure 2 shows the normalized neutron spectra of a $ThUO_2$ (0.7, 0.68 cm) and ThUZr ($ThUZrH_{0.1}$) fuel lattices.

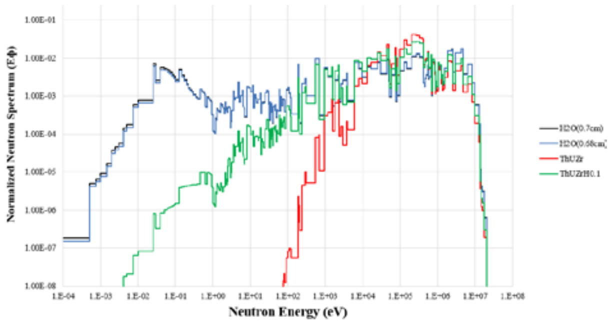


Fig. 2. Normalized neutron energy spectra

ThUO2 fuel spectrum showed a relatively lower change rate in general in comparison to the ThUZr fuel. For the case of 0.7 cm thick layers for both materials (ThUZr, $ThUZrH_{0.1}$), the neutron energy spectrum for $ThUZrH_{0.1}$ fuel shifted lower energy than for ThUZr fuel. It is apparent that in the fast spectrum can realize the epithermal spectrum.

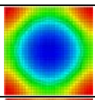
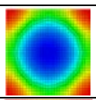
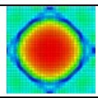
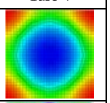
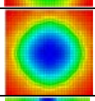
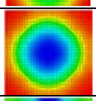
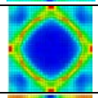
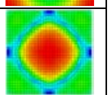
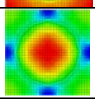
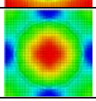
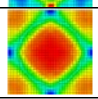
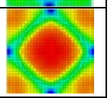
Fuel	$ThUO_2$		ThUZr	$ThUZrH_{0.1}$
Moderator	H2O 0.7 cm	H2O 0.68 cm	Stainless-Steel	
Case	Case 1	Case 2	Case 3	Case 4
Thermal energy (0.0253 ~ 0.03 eV)				
Epi-thermal energy (10 ~ 11 eV)				
Fast energy (1.85 ~ 2 MeV)				

Fig. 3. Neutrons spectra according to case

Figure 3 shows the visualization when varying the energy region of each case (thermal, epithermal, and fast energy). The neutrons spectra of cases 1, 2 are slightly difference. But, the case 3, 4 are considerable difference because of hydrogen.

3.2 Four factor formula

Four factor formula analysis is applied to the four case of the table 3. The ε is the fast fission factor, the f is the thermal utilization factor, the p is the resonance escape probability, and the η is the thermal neutron production factor. The thermal utilization factor (f) are similar at each case. However, for the case of $ThUO_2$ fuel type, the thermal neutron production factor (η) is approximately 0.5 lower than for ThUZr fuel.

Table 3. Four factor formula

Fuel	$ThUO_2$		ThUZr	$ThUZrH_{0.1}$
Moderator	H2O 0.7 cm	H2O 0.68 cm	Stainless-Steel	
Case	Case 1	Case 2	Case 3	Case 4
ε	1.460786	1.516337		110.750334
f	0.92831	0.936886	0.968163	0.968163
P	0.629944	0.600339	0	0.005694
η	1.498367	1.499316	2.055908	2.045639

Figure 4 shows the resonance escape probability results for the each case. The simulated resonance escape probability of the moderator are 0.629944 for $ThUO_2$ (H2O 0.7 cm), 0.600339 for $ThUO_2$ (H2O 0.68 cm), 0 for ThUZr, and 0.005694 for $ThUZrH_{0.1}$, and thus $ThUZrH_{0.1}$ is regarded as the most suitable epithermal spectrum. The tendency of epithermal can also be confirmed through resonance escape probability.

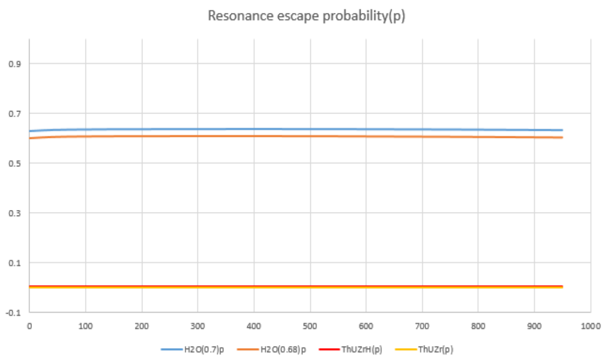


Fig. 4. Resonance escape probability (p)

Figure 5 shows quantity of fissile materials according to depletion. The uranium-233 is decreases proportionally to the depletion time. The results of depletion, the quantity of fissile materials confirmed on the difference in each case because of neutron production factor.

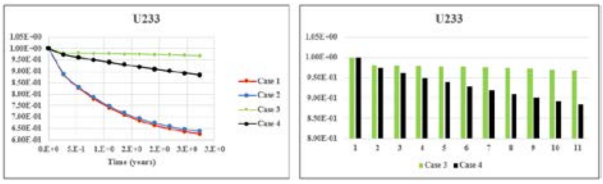


Fig. 5. Fissile material according to depletion

3.3 Neutron spectrum comparison

The neutron spectra of NEWT and MCNP 6 are compared. Figure 6 shows simulation of equal condition. Spectra of NEWT result are consistent to those of MCNP results. To run mcnp6 code, ENDF/B-VII.1 library is used ENDF active cycles (1,000) and ENDF inactive cycles (50) are used. The k-effs of NEWT and MCNP are 1.282 and 1.284, respectively.

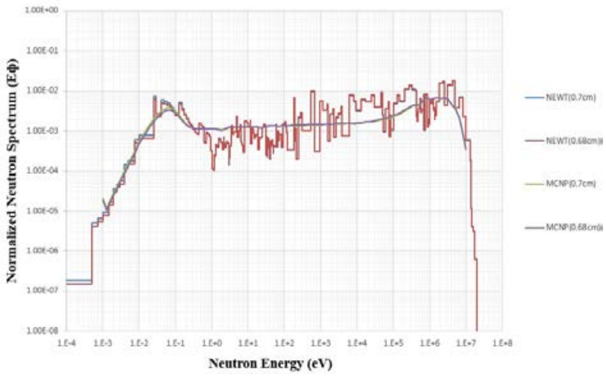


Fig. 6. Comparison of spectra of NEWT and MCNP

3. Conclusions

The concept for thorium intermediate reactor was conducted using NEWT code by evaluating the neutron energy spectrum and four factor formula. The $ThUO_2$, ThUZr fuel was regulated to size of moderator and ingredient of fuel.

Conclusively, the performance of hydrogen in ThUZr, as the moderator material for the fast system in combination with ThUZr fuel, was revealed to be available materials of transform epithermal energy into fast energy. A future work is underway to investigate possibility of thorium epithermal reactor for the expansion to full core.

5. ACKNOWLEDGMENTS

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