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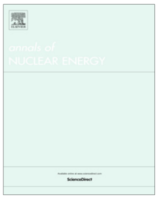

# Conceptual design of thorium based epithermal spectrum reactor

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ABSTRACT

The concept of the epithermal spectrum nuclear core by using thorium fuel is proposed newly in order to maximize thorium breeding capability. By changing lattice size of fuel rod in the typical light water reactors, less moderation is possible and epithermal neutron spectra are achieved. In order to check the feasibility of the epithermal reactor, the fuel lattice analysis has been carried out by using the NEWT code and MCNP6 code including depletion calculation. Additional test for epithermal reactor is performed from a fast reactor by introducing a new fuel composition such as $ThUZrH_x$. Due to small contents of hydrogen, the fast neutron spectrum is easily shifted to the epithermal region. Thorium epithermal core analysis is also carried out extending to 100 MWt power including some safety parameters such as void reactivity and Doppler coefficient.

## 1. Introduction

Currently, lots of fast breeding reactors (FBR) have been studied actively all around the world in order to supplement the disadvantages of thermal reactors and to increase utilization of uranium resources and to reduce radiation waste. (Lamarch, 1966) On the other hand, the epithermal reactors, or intermediate reactors are not being studied at the present time due to the strategic progress of the existing reactor technologies. However, Ref. Lamarch, 1966 describes the importance and possibility of epithermal reactors when utilizing that $\alpha$-value, the capture to fission ratio, is high around the 0.3 eV resonance for fissile isotopes. The values of $\alpha$ for nuclear fuel 233U is high for at the 0.3 eV resonance. Where, $\alpha = \sigma_\gamma/\sigma_f$ is referred to as the capture-to-fission ratio. The lower value of $\alpha$ simply means that an absorption reaction will result in the fission rather than in the radiative capture. The regeneration factor means that the number of fission neutrons produced per initial thermal neutron ($\eta$). The valued of $\eta$ is given by following equation:

$$\eta = v\frac{\sigma_f}{\sigma_f + \sigma_a}$$

In the above equation, $v$ is the number of neutrons produced per fission. $\sigma_f$ is the fission cross-section for thermal neutrons and, $\sigma_\alpha$ the absorption cross-section. The regeneration factor at equation is in inverse proportion to the values of $\alpha$. If the neutron spectrum is shifted to epithermal energy region to avoid the 0.3 eV resonance, $\alpha$ decreases and then the regeneration factor ($\eta$) increases and it is achievable long periods of reactor operation with breeding ($\eta > 2$). (Hong et al., 2015) Furthermore, the epithermal reactor makes it possible to provide the higher power density with the smaller critical mass than that required for a fast reactor. (Lung and Gremm, 1988) And the epithermal reactor can be miniaturized because smaller than moderator amount used for a thermal reactor. It is possible to obtain the higher $\eta$–value than 2 when using for $^{233}U$ around the epithermal neutron energy range as shown in Fig. 1 (Sidik, 2007).

The $^{233}U$ is generated from the capture reaction of thorium and it is well known that the thorium based fuel cycle is innovative and safe the earth's reserves of thorium are as abundant as three times as those of uranium and are widely distributed in the USA, India and China. (IAEA, 2005) (Penny, 2010).

The main objective of this paper is to evaluate the possibility of epithermal spectrum reactor by using thorium fuel. As the first step, the thorium based epithermal fuel rod is determined by changing lattice size based on the light water reactor. In the second, for the fast reactor application, lattice analysis for fuel rod by taking into consideration of the new fuel such as $ThUZrH_x$. (Yamamoto et al., 1997) As the third step, the whole core analysis has been performed to find out feasibility of epithermal spectrum reactor. To efficiently achieve fast calculation and accurate results, a computational optimization study on the design parameters of the epithermal reactor was conducted using NEWT code of

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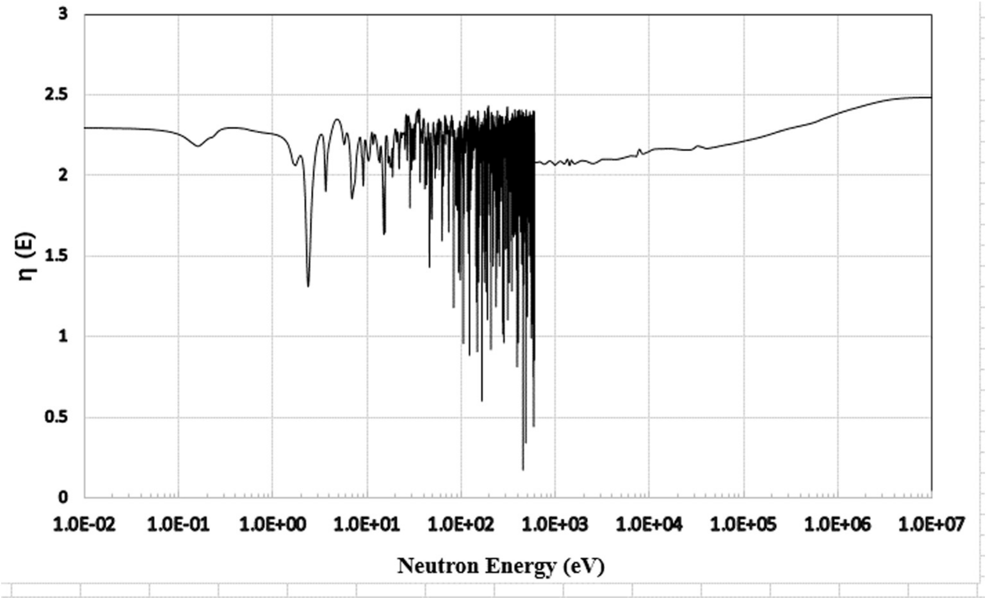

**Fig. 1.** Regeneration factor of $^{233}U$.

SCALE6.1. (ORNL, 2011) The simulation results are evaluated regarding the four factor formula and the neutron spectrum and the results obtained with the simulation model are validated by comparing with MCNP6 calculations (Pelowitz, 2013).

Section 2 describes analysis conditions and models for lattice simulation of fuel rods and some results are also given including depletion analysis. Section 3 provides the results of the whole core analysis including various safety related parameters such as neutron flux distribution, void coefficient, Doppler coefficient and reactor reactivity change. Finally, the summary and discussion of this study is given in Section 4.

## 2. Lattice analysis of fuel rod

In order to obtain optimal size of the fuel rod lattice, several tests are carried out by changing coolant materials, size and fuel composition. The NEWT code is used, which is based on the short characteristics solver for the Boltzmann neutron transport equation. (DeHart, 2005) The cross-section library is chosen as ENDF/B-VII.0. Fig. 2 shows a simple lattice geometry to compare the neutron spectrum. Table 1 shows the material information for two different types of reactors such as fast and thermal reactors.

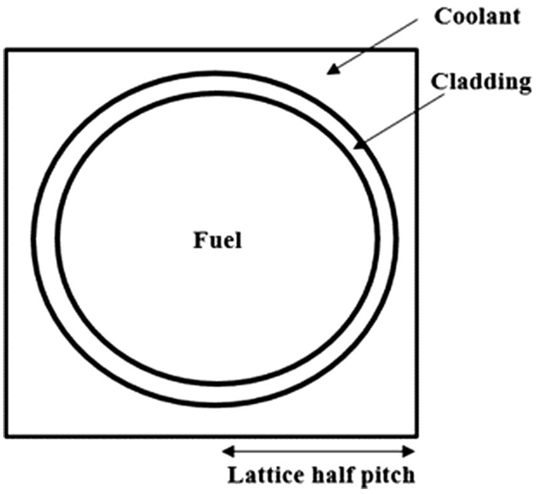

**Fig. 2.** Lattice model for fuel rod.

To identify spectrum shift to the epithermal region, the rod pitch size is varied and the infinite multiplication factor (k-inf) for various cases are obtained including four factors.

The first approach to the epithermal reactor from the thermal reactor is to reduce moderator, which decrease resonance escape probability and the neutron spectrum becomes less thermalized. The k-inf for 4 different moderators such as $H_2O$, $D_2O$, beryllium and graphite are depicted in Fig. 3. The flux normalization for all results were calculated form Eq. (1).

$$\textit{Normalized neutron flux}(\Phi) = \frac{\Phi_i}{\sum_{i=1}^{n}\Phi_i} \tag{1}$$

where $\Phi$ is the normalized neutron flux, $\Phi_i$ is flux of each energy and $\sum_{i=1}^{n}\Phi_i$ is total sum flux for all energy. Based on the results, the fully thermalized thickness is chosen as 0.7 cm for $H_2O$, 3.5 cm for $D_2O$, 2.1 cm for beryllium, and 3.1 cm for graphite.

The moderator of epithermal reactor selected the H2O, which thermalized at low half pitch in comparison to the other moderators. In the case of H2O moderator, 0.68 cm of lattice half pitch provides the highest neutron flux in the epithermal range between 0.26 eV and 0.3 eV among several pitches, which is shown in Fig. 4. And Fig. 5 shows the full neutron energy spectrum for two different pitch sizes of 0.68 cm and 0.7 cm. It is found that the neutron spectrum of 0.68 cm pitch is shifted to higher energy around the thermal energy range. Thus, the epithermal energy spectrum

**Table 1**
Parameters of two type reactors.

| Parameter | Thermal Reactor | Fast Reactor |
|---|---|---|
| Lattice half pitch (cm) | 0.7 | 0.7 |
| Fuel radius (cm) | 0.5 | 0.5 |
| Fuel material | $(Th + U)O_2$ | ThUZr |
| Fuel density (g/cm$^3$) | 10.9 | 15.4 |
| Cladding thickness (cm) | 0.05 | 0.05 |
| Cladding material | Zircaloy-4 | Stainless-Steel |
| Cladding density (g/cm$^3$) | 6.56 | 7.94 |
| Coolant material | $H_2O$ | Na |