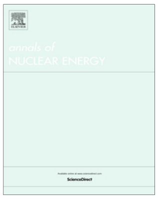
Annals of Nuclear Energy 90 (2016) 191–194

Contents lists available at ScienceDirect

Annals of Nuclear Energy

journal homepage: www.elsevier.com/locate/anucene



Technical note

Study on the relation between Doppler reactivity coefficient and resonance integrals of Thorium and Uranium in PWR fuels

Noboru Dobuchi [a,*], Satoshi Takeda [a,b], Takanori Kitada [a]

[a] Division of Sustainable Energy and Environmental Engineering, Graduate School of Engineering, Osaka University, 2-1 Yamadaoka, Suita-shi, Osaka 565-0871, Japan
[b] Fuel Engineering and Development Department, Kumatori Works, Nuclear Fuel Industries, LTD., 950 Asashiro-Nishi 1-chome, Kumatori-cho, Sennan-gun, Osaka 590-0481, Japan

ARTICLE INFO

Article history:
Received 15 July 2015
Received in revised form 13 November 2015
Accepted 14 November 2015
Available online 28 December 2015

Keywords:
Thorium fuel
Uranium fuel
Doppler reactivity coefficient
Resonance integral
Resonance width

ABSTRACT

Doppler reactivity coefficient of Thorium fuel is negatively larger than that of Uranium fuel, although resonance integral of Th-232 is smaller than that of U-238.

The purpose of this study is to reveal the mechanism of the opposite tendency of Doppler reactivity coefficient and resonance integral between Thorium fuel and Uranium fuel.

Larger Doppler reactivity coefficient is caused by larger relative change of capture cross-section of Th-232, and the larger change results from narrower resonance width. In addition, narrower resonance width causes smaller resonance integral.

It was found that resonance width is the key parameter to understand the opposite tendency of Doppler reactivity coefficient and resonance integral between Thorium fuels and Uranium fuels.

1. Introduction

Recently, Thorium fuel (Th-fuel) attracts rising attention. This is because Thorium inventory is more than Uranium in the earth's crust, and Th-fuel cycle is expected to reduce nuclear wastes and promote non-proliferation (IAEA, 2005).

In order to use Th-fuel, it is necessary to know the characteristics of Th-fuel. Doppler reactivity is one of the most important characteristics for reactor safety to evaluate the impact of reactivity feedback.

Meanwhile, resonance integral is the parameter which evaluates largeness of cross-section especially in resonance region. Resonance integrals of Th-232 and U-238 in JENDL-4.0(u) (Shibata et al., 2011) are shown in Table 1. As shown in Table 1, resonance integral of capture cross-section of Th-232 is about one third of that of U-238. Therefore, there is a literature which expects that Doppler reactivity coefficient (DRC) of Th-fuel is negatively smaller than that of Uranium fuel (U-fuel) (Yamawaki et al., 2005). On the contrary, Doppler reactivity of Th-fuel is negatively larger than that of U-fuel, which is shown in Table 2 (Dobuchi et al., 2014).

As described above, there is confuscation of DRC of Th-fuel. The purpose of this study is to reveal the relation between DRC and resonance integral through the comparison between Th-fuel and U-fuel.

2. Methodology

2.1. Decomposition of Doppler reactivity coefficient

DRC is decomposed into components (nuclide, reaction type and energy group) by the following method using sensitivity coefficients.

DRC is defined as:

$$\mathrm{DRC} \equiv \frac{1/k - 1/k'}{dT} = \frac{dk/kk'}{dT} \tag{1}$$

where dT shows change of temperature; k and k' show multiplication factors before and after temperature change, respectively.

Sensitivity coefficient is defined as the ratio of relative change of multiplication factor to relative change of cross-section. Thereby sensitivity coefficient is expressed as:

$$S^k_{i,R,g} \equiv \frac{dk/k}{(d\sigma/\sigma)_{i,R,g}} \tag{2}$$

where S^k is sensitivity coefficient of multiplication factor: k; σ is cross-section; suffix i, R and g are nuclide, reaction type and energy group, respectively.

According to Eqs. (1) and (2), DRC is expressed by the sensitivity coefficient of multiplication factor as follows:

---

[*] Corresponding author.

E-mail addresses: n-dobuchi@ne.see.eng.osaka-u.ac.jp (N. Dobuchi), s-takeda@ne.see.eng.osaka-u.ac.jp (S. Takeda), kitada@see.eng.osaka-u.ac.jp (T. Kitada).

http://dx.doi.org/10.1016/j.anucene.2015.11.018
0306-4549/

Table 1
Resonance integrals of Th-232 and U-238 in JENDL-4.0(u).

	Th-232	U-238
Resonance integral of capture cross-section (barn)	84.29	275.6

Table 2
Doppler reactivity evaluated for Thorium and Uranium fuels in LWR.

Fuel type	k_{inf}		Doppler reactivity ($\%dk/kk'$)
	600 K	900 K	
Thorium	1.20505 (0.0026%[*])	1.19373 (0.0027%)	−0.787 (0.40%)
Uranium	1.36860 (0.0032%)	1.35863 (0.0033%)	−0.536 (0.63%)

[*] Standard deviation (1σ).

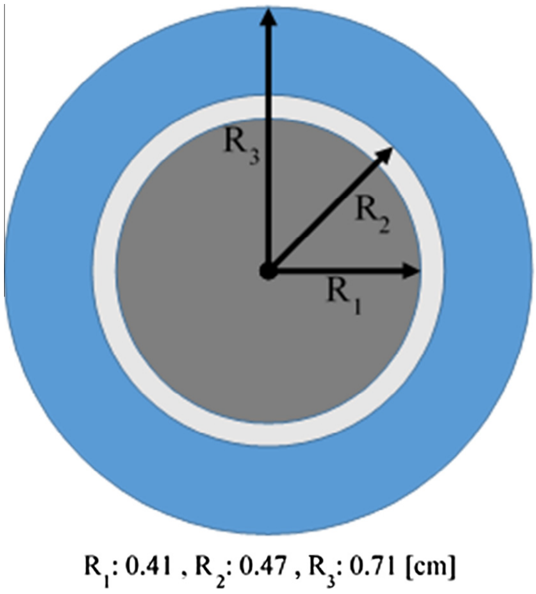


Fig. 1. PWR pin cell model.

Table 3
Calculation conditions.

Fuel	Th-fuel: (U-235 + Th-232)O_2 U-fuel: (U-235 + U-238)O_2
U-235	3.0 wt%
Temperature	600 K, 900 K
Cladding	Zircalloy-4
Temperature	600 K
Moderator	H_2O (1.0 g/cc)
Temperature	600 K
Boundary condition	White reflection

$$\mathrm{DRC} = \sum_i \sum_R \sum_g \frac{\frac{dk/k}{(d\sigma/\sigma)_{i,R,g}} \times (d\sigma/\sigma)_{i,R,g} \times \frac{1}{k'}}{dT} = \sum_i \sum_R \sum_g \frac{S^k_{i,R,g} \times (d\sigma/\sigma)_{i,R,g}}{dT \times k'} \tag{3}$$

DRC can be evaluated as the sum of the products of sensitivity coefficient and relative change of cross-section. Therefore, DRC respect to reaction type: R of nuclide: i ($\mathrm{DRC}_{i,R}$) can be obtained as the sum of the DRC components only by energy group: g,

$$\mathrm{DRC}_{i,R} = \sum_g \frac{S^k_{i,R,g} \times (d\sigma/\sigma)_{i,R,g}}{dT \times k'} \tag{4}$$

Thus DRC can be decomposed into components by using the expression of Eq. (3) with the usage of sensitivity coefficient.

2.2. Calculation procedure and condition

In order to evaluate DRC components, SRAC2006 (Okumura et al., 2007) and SAINT-II (Nakano et al., 1986) were used as calculation codes. SRAC2006 is a comprehensive neutronics calculation code system developed at JAEA, and SAINT-II is a sensitivity analysis code based on generalized perturbation theory based on first flight collision probability method developed at Osaka University. Macroscopic and microscopic cross-sections were calculated from JENDL-4.0(u) by SRAC2006, then sensitivity coefficient was calculated by SAINT-II with these cross-sections in 107 energy group structure.

Calculations were performed for pin cell model in PWR system. The configuration of the model is shown in Fig. 1 and other calculation conditions are summarized in Table 3. In order to consider the impacts of the difference between Th-232 and U-238 on DRC, fissile nuclide of both fuels are fixed to U-235 with 3.0 wt%.

3. Results and discussions

3.1. Components of Doppler reactivity coefficient

Energy integrated DRC components of capture and fission cross-section of Th-232, U-238 and U-235 are shown in Table 4. The sum of DRC components is in good agreement with DRC calculated by MVP II, and the difference between Th-fuel and U-fuel is also shown in Table 4. Table 4 shows that the major component of DRC comes from capture cross-section of Th-232 or U-238 and those are dominant to the difference of DRC between Th-fuel and U-fuel, although there are some difference in DRC components of U-235 between Th-fuel and U-fuel.

Energy decomposed DRC components of capture cross-section are compared between Th-232 and U-238 in Fig. 2. Almost of all components of DRC and significant difference in DRC between Th-232 and U-238 exist in resonance energy region.

In order to consider in detail, sensitivity coefficient and relative change of capture cross-section due to the temperature change are compared between Th-232 and U-238.

Table 4
Components of DRCs ($dk/kk'/K$).

	Th-232, U-238		U-235		Total
	Capture	Fission	Capture	Fission	
Th-fuel	−2.52E−5[*]	9.92E−13	−5.95E−7	1.42E−7	−2.56E−5
U-fuel	−1.65E−5	7.53E−10	−4.12E−7	1.04E−7	−1.68E−5
Difference (Th-fuel–U-fuel)	−8.65E−6	−7.52E−10	−1.83E−7	+3.78E−8	−8.79E−6

[*] Read as -2.52×10^{-5}.