Spectrum Dependence of Doppler Reactivity Coefficient Considering Thermal Agitation Effect

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1. Introduction

The scattering kernel model used in solving the slowing down equation in epithermal energy range is usually treated as the asymptotic one, which does not consider thermal motion of a target nuclide and then there is no up-scattering in conventional evaluation in epithermal energy range. Many conventional codes use the cross section library assembled without considering the thermal motion of heavy nuclides.

Recently, many researchers have investigated and reported the impact on the Doppler reactivity coefficient by considering the thermal motion of the target in epithermal energy range[1-7]. The impact on the coefficient was reported to become about 9% larger in UO_2 fueled cell[5, 7].

In this study, UA method[7]: a simplified treatment of exact scattering model for deterministic slowing down equation without iterative calculation, was used to calculate effective cross section considering thermal agitation. Neutron spectrum at lower energy range is expressed by narrow resonance approximation in UA method. UA method was applied to gadolinia(Gd_2O_3) added UO_2 fueled cell to evaluate spectrum dependence of Doppler reactivity coefficient by considering thermal agitation effect in epithermal energy range.

2. Calculation Procedure

Effective cross sections considering thermal agitation were calculated by the UA method. The impact of the thermal agitation on Doppler reactivity coefficient was evaluated through the usage of sensitivity coefficients of U-238 capture cross section on eigenvalue. Thus, the expected eigenvalue: k_{UA} for the cases using the UA method is expressed as Eq.(1).

$$k_{UA} = k_{conventional} \cdot (1 + \sum_g d^g S^g), \qquad (1)$$

where d^g shows the relative difference of U-238 capture cross section in energy group g between two cases of the conventional method and the UA method, S^g shows the sensitivity coefficients of cross section in energy group g on eigenvalue. The conventional eigenvalue: $k_{conventional}$ is obtained without considering thermal agitation.

Two expected eigenvalues: k_{UA} calculated by Eq.(1) at two different fuel temperatures were used to evaluate Doppler reactivity coefficient (*D.C.*) as expressed in Eq.(2).

$$D.C. = \left(\frac{1}{k_{low}} - \frac{1}{k_{high}} \right) \Big/ \Delta T, \qquad (2)$$

where k_{low} and k_{high} show the eigenvalues at low and high fuel temperatures respectively, and ΔT shows the difference in fuel temperature between low and high fuel temperature conditions. Difference in *D.C.* was calculated as Eq.(3).

$$Difference\ in\ D.C. = \frac{D.C._{UA} - D.C._{conventional}}{D.C._{conventional}}. \qquad (3)$$

To evaluate the impact of thermal agitation on Doppler reactivity coefficient by changing neutron spectrum, calculations were performed for gadolinia added UO_2 fueled cell. The cell geometry is shown in Fig. 1. The compositions and model are based on benchmark test performed by D. Mosteller[8]. U-235 enrichment is 4.8wt%, and fuel temperatures are set to 600K and 900K for low and high temperatures, respectively. The calculation codes used in this study are shown in Table I.

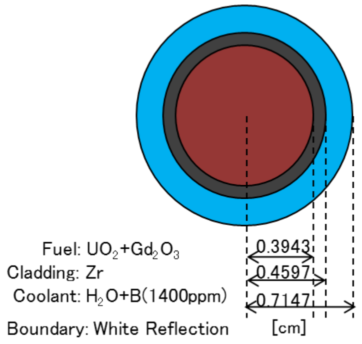

Fig. 1. Fuel cell geometry

Table I. Calculation Codes

	Code
Eigenvalue	SRAC2006[9]
Sensitivity Coefficient	SAINT-II[10]
Effective Cross Section	NJOY99[11]

3. Results and Discussions

Gadolinia added UO_2 fueled cell's neutron spectra are shown in Fig. 2. Neutron spectra change by changing the magnitude of absorbed neutrons in thermal energy range by Gd. Comparison of U-238 capture cross sections is shown in Fig. 3 for the energy range from 4eV to 200eV, where the thermal agitation effect on the effective cross section is dominant. The sensitivity coefficient of U-238 capture cross section from 4eV to 200eV for eigenvalue is shown in Fig. 4. Table II summarizes eigenvalues and the difference in Doppler reactivity coefficient. For the case of 0.2% gadolinia added UO_2 fueled cell, the impact of the thermal agitation on *D.C.* is maximum value of 12.4%. The impact of the thermal agitation on *D.C.* was found to be over 10% for 5% or less gadolinia added UO_2 fueled cell while that is about 10% for UO_2 fueled cell. Thermal agitation effect on *D.C.* is dominant at the energy range from 4eV to 100eV especially from 20eV to 40eV for U-238 capture cross section. A slight addition of gadolinia to UO_2 fuel cell cause the reduction of neutron spectrum in thermal energy range as shown in Fig. 2, thus the importance of capture reaction in epithermal energy range increases. This fact causes the larger difference in *D.C.* for the case of 0.2% gadolinia content, as shown in Table II.

On the other hand, the increase of gadolinia content brings the reduction of the difference in *D.C.*, because of the decrement of U-238 content and the increment of Gd absorption which has smaller thermal agitation effect on *D.C.* than U-238.

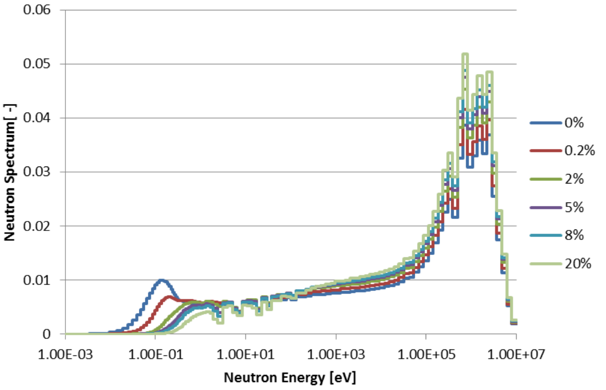

Fig. 2. Gadolinia dependence of neutron spectrum

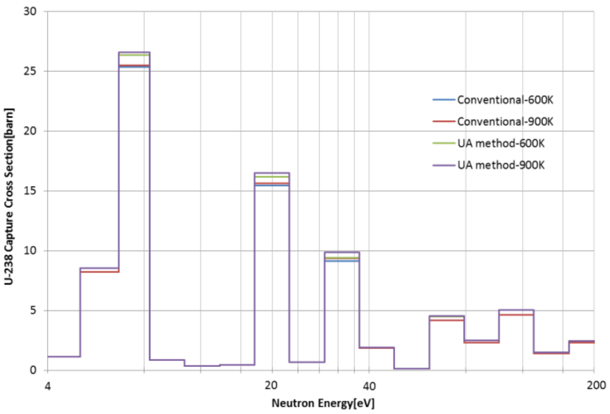

Fig. 3. Comparison of U-238 capture cross sections

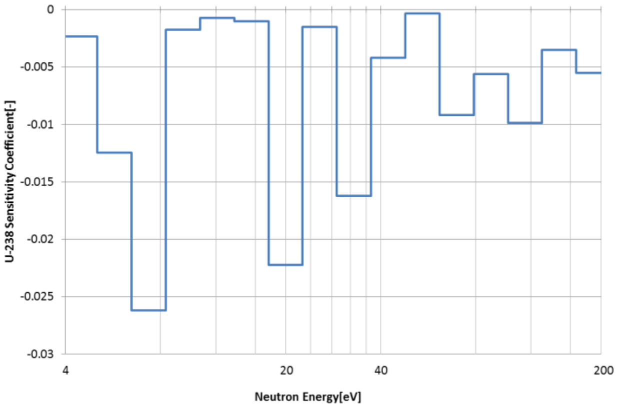

Fig. 4. Sensitivity coefficient of U-238 capture cross section for eigenvalue

Table II. Gadolinia Content Dependence of Eigenvalue and Difference in Doppler Reactivity Coefficient

Gadolinia Content [%]	600K		900K		Difference in D.C.[%]
	$k_{conventional}$	k_{UA}	$k_{conventional}$	k_{UA}	$((D.C._{UA}-D.C._{conventional})/D.C._{conventional})$
0	1.2890	1.2881	1.2756	1.2776	9.6
0.2	0.7641	0.7363	0.7549	0.7583	12.4
2	0.4748	0.4745	0.4723	0.4717	12.0
5	0.3867	0.3873	0.3856	0.3852	10.7
8	0.3428	0.3427	0.3410	0.3407	9.4
10	0.3210	0.3209	0.3192	0.3189	8.3
13	0.2945	0.2944	0.2928	0.2926	7.3
17	0.2662	0.2661	0.2645	0.2643	5.8
20	0.2482	0.2481	0.2465	0.2463	4.8

4. Conclusions

Spectrum dependence of Doppler reactivity coefficient considering thermal agitation effect was evaluated by changing the gadolinia content in UO_2 fuel cell. This study revealed that a low content (0.2%) of gadolinia cause a small change in spectrum but cause a large impact (up to 12%) on the difference in Doppler reactivity coefficient. A large content of gadolinia (~20%) brings a small difference in Doppler reactivity coefficient because of smaller content of U-238 and smaller neutron spectrum especially at the energy range from 4eV to 200eV, where thermal agitation effect is remarkable.

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