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Analysis of Doppler Reactivity Considering Thermal Agitation of Heavy Nuclide in Epithermal Range and Temperature Distribution in Fuel Region

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1. Introduction

To improve reactor safety, Doppler Reactivity (DR) needed to be evaluated accurately. In conventional evaluation methods of DR, however, the temperature in fuel region is assumed to be same at all regions, so it don't consider the effect of spatial dependence of the temperature distribution in fuel region. On the other hand, many researchers have studied the influence on DR by considering the thermal agitation of heavy nuclide in epithermal range, and they revealed that DR becomes more negative by approximately 10% in UO_2 fuel cell [1,2,3]. The purpose of this study is to evaluate the influence of introducing both effects of the thermal agitation of heavy nuclide and the temperature distribution on the analysis of DR. In addition, the comparison between UO_2 fuel cell and MOX fuel cell about DR was also conducted.

2. Calculation Procedure

In order to evaluate the effect of the temperature distribution and the thermal agitation of heavy nuclide, four cases were calculated. Table I summarizes condition of four cases. The calculations were performed for the UO_2(enrichment 5.0wt% and 0.71wt%) and MOX(enrichment 8.0wt% and 1.0wt%) fuel cell. Fig.1 shows the model of the fueled cell, based on a PWR's fuel cell. The compositions and model are based on benchmark test performed by D.Mosteller [4]. Table II and Fig.2 shows the temperature conditions. Those were obtained from the equation of heat conduction [5,6]. The higher temperature condition and the lower one were calculated for 500W/cm, 100W/cm of linear power. The composition of Pu in MOX fuel is shown in Table III. The continuous-energy Monte-Carlo code MVP [7] with JENDL-4.0 [8] was used for the evaluation of eigenvalue.

Table I. The Conditions of Four Cases

	Thermal Agitation Effect	Temperature Distribution
Case1	Not Considered	Flat
Case2	Not Considered	Para
Case3	Considered	Flat
Case4	Considered	Para

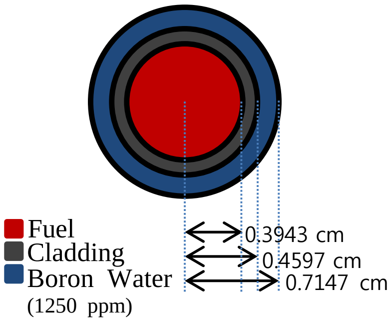

Fig.1 The model of fuel cell

Table II. The Temperature Condition

Distance From Pellet Center [mm]	Lower [K]	Higher [K]	Difference [K]
1.247	847.1	1965.3	1118.3
1.764	827.8	1849.3	1021.4
2.160	808.6	1733.2	924.6
2.494	789.4	1617.2	827.7
2.788	770.2	1501.1	730.9
3.054	751.0	1385.1	634.1
3.299	731.8	1269.0	537.2
3.527	712.6	1152.9	440.1
3.741	693.4	1036.9	343.5
3.943	674.2	920.86	246.7
Arithmetical Average In Fuel	760.6	1443.2	682.5
Cladding	615.0	615.0	615.0
Boron Water (1250 ppm)	578.0	578.0	578.0

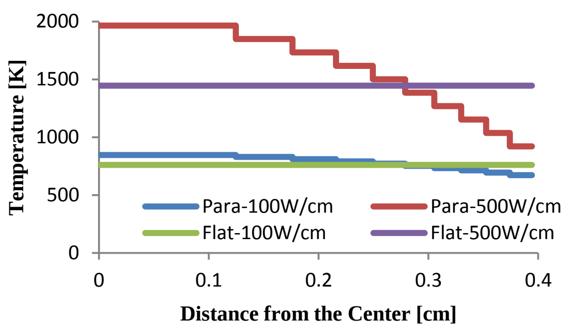

Fig.2 The fuel temperature condition

Table III. The Composition of Pu in MOX Fuel

Nuclide	Content[%]
Pu-239	45
Pu-240	30
Pu-241	15
Pu-242	10

3. Calculation Results and Discussions

The results of DR and the difference of DR from Case1 are shown in Table IV, Table V, Table VI, and Table VII for 0.71wt% or 5wt% of UO_2 fueled cell. As shown in these tables, we can see the followings, DR of Case2 is approximately 4~5% smaller than that of Case1 in any fuel cells. This is because the temperature change at fuel periphery is smaller in Case2 than that in Case1. Much nuclear reaction occurs at fuel periphery, so the magnitude of temperature change at the periphery has a large contribution on DR. DR of Case3 becomes larger than that of Case1 as reported in many papers [1,2,3]. Up scattering in epithermal energy range is considered by introducing the thermal agitation effect of heavy nuclide in Case3, so nuclear reactions, especially capture reactions increases in higher temperature. Thus DR becomes large in any fuel cells in Case3. These results show that the effect of introducing the thermal agitation of heavy nuclides and the temperature distribution on DR are opposite direction. Therefore DR of Case4 becomes larger than that of Case1, but smaller than that of Case3. In addition, the difference of DR from Case1 is approximately the same to the sum of Case2 and Case3.

The magnitude of DR of UO_2(enrichment 0.71wt%) is bigger than that of UO_2(enrichment 5.0wt%). This is because capture reaction of U-238 contributes strongly on DR in the case of 0.71wt% than 5.0wt%, in addition to the fact of different amount of U-238. In addition, the impact of DR by the change of capture reaction rate is larger in UO_2(enrichment 0.71wt%) than in UO_2(enrichment 5.0wt%). Fig.3 shows the change of the capture reaction rate normalized by the fission reaction rate in each case, and this figure shows why the magnitude of DR in 0.71wt% is bigger than that in 5.0wt%. The similar tendency about the magnitude of DR can be seen in MOX fueled cases, low enrich MOX fuel has larger DR than another. These results show that the effect of introducing the thermal agitation and the temperature distribution cause the similar tendency both in UO_2 and MOX fueled cells, but the magnitude of the effect of thermal agitation largely depends on the composition of fuel.

Table IV. DR of UO_2(enrichment 0.71wt%) Fueled Cell and Difference from Case1 in Each Cases

DR [$\times 10^{-2}$ Δk/kk']				Difference from Case1 [%] $(DR^{CaseX}-DR^{Case1})/DR^{Case1}$		
Case1	Case2	Case3	Case4	Case2	Case3	Case4
-2.70 (0.15%)*	-2.58 (0.33%)	-2.94 (0.23%)	-2.86 (0.24%)	-4.24 (8.3%)	8.92 (3.9%)	6.09 (4.8%)

*:standard deviation (1σ)

Table V. DR of UO_2(enrichment 5.0wt%) Fueled Cell and Difference from Case1 in Each Cases

DR [$\times 10^{-2}$ Δk/kk']				Difference from Case1 [%]		
Case1	Case2	Case3	Case4	Case2	Case3	Case4
-1.25 (0.10%)	-1.20 (0.11%)	-1.38 (0.13%)	-1.32 (0.13%)	-4.33 (3.3%)	10.30 (1.7%)	5.98 (2.9%)

Table VI. DR of MOX(enrichment 1.0wt%) Fueled Cell and Difference from Case1 in Each Cases

DR [$\times 10^{-2}$ Δk/kk']				Difference from Case1 [%]		
Case1	Case2	Case3	Case4	Case2	Case3	Case4
-2.25 (0.15%)	-2.16 (0.15%)	-2.43 (0.12%)	-2.34 (0.13%)	-4.00 (5.1%)	8.54 (2.3%)	4.65 (4.2%)

Table VII. DR of MOX(enrichment 8.0wt%) Fueled Cell and Difference from Case1 in Each Cases

DR [$\times 10^{-2}$ Δk/kk']				Difference from Case1 [%]		
Case1	Case2	Case3	Case4	Case2	Case3	Case4
-1.90 (0.11%)	-1.81 (0.16%)	-2.01 (0.12%)	-1.94 (0.13%)	-4.72 (4.0%)	6.01 (2.9%)	2.06 (8.4%)

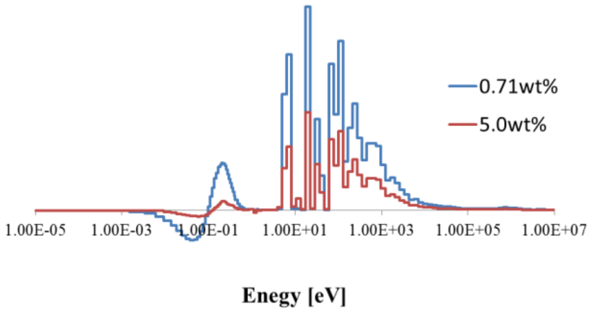

Fig. 3 The change of capture reaction rate

4. Conclusions

Analysis of Doppler Reactivity considering the thermal agitation in epithermal range and temperature distribution in fuel pellet was performed for UO_2 and MOX fueled cells by continuous-energy Monte-Carlo code MVP with JENDL-4.0. Considering the thermal agitation effect in epithermal energy range causes negative effect on DR, but considering the temperature distribution causes positive effect on DR.

DR by considering the both effects shows the negatively larger reactivity but the magnitude of the discrepancy is reduced by about 4% from the case where the thermal agitation is considered with flat temperature distribution.

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