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Transmutation of tansuranium nuclides with FBR

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ABSTRACT: High-level wastes contain transuranics (TRUs) such as neptunium, americium and curium, some of which have several millions years of half life and toxicity remaining over long period. Transmutation of TRUs in a FBR core was studied from points of; 1)Development of the analysis code that can treat complicated nuclear transformation of TRUs, 2)Comparison of transmutation rates between metallic fuel core and oxide fuel core.

TRUs of 5, 10, or 15% was charged with uniform distribution into each reactor core. Through this study, it was obvious that; 1)The charge of TRUs causes the increase of reactivity at the end of cycle for both metallic fuel and oxide fuel cores, 2)The transmutation rates of TRUs were higher in the metallic fuel core than in the oxide fuel core, 3)The amounts of plutonium to be charged could be reduced by adding TRUs for both metallic fuel and oxide fuel cores.

(FBR,TRUs,transmutation,metallic fuel,oxide fuel)

1. Introduction

One of means of transmutation of TRUs by transforming them to non-radioactive nuclides or those with shorter half life is to react them with neutrons in a FBR core. Some studies[1-3] showed that the transmutation by FBR is technically feasible. In this report, we evaluated the difference of transmutation rate depending on FBR core characteristics between oxide fuel core and metallic fuel core with a realistic core design.

Calculations were performed for a 1000 MWe oxide fuel FBR core[4] designed as a demonstration reactor shown in Figure 1 and a FBR core of metallic fuel with identical structure as the oxide core, in which TRUs of 5, 10 or 15% were charged to be uniformly distributed in the core.

This report describes, at first, the systems used for burnup calculations, the core structure, diffusion meshes and burnup zones for calculation. Based on the calcultion, we summarize the reactivity changes due to the charge of TRUs with increasing burnup of a cycle, the changes in transmutation rates of TRUs, and the changes in the amount of plutonium charge by introducing TRUs.

2. Burnup calculation systems

The average effective cross section for each reactor core region was obtained by SLAROM code[5] and the values obtained were used as input data for CITATION-TRU code to calculate burnup. JAERI-FAST set (JFS-3-J2)[6], which was developed from JENDL-2 by 70 energy groups, was used as input data for SLAROM code. Table 1 lists the nuclides used for the calculation. The table shows that nuclear data on Am and Cm,whose data set was insufficient in JFS-3-J2, were supplemented by MGCL data based on ENDF/B-V through the CRIEPI multi-group constants library (MGCL) generation system[7] This systems use SUPERTOG code as a module. These nuclear data were used to generate cross sections of 12 groups of energy structures through PREP and EIND parts of SLAROM code.

CITATION code developed in ORNL, which had been commonly used for burnup calculation, could not however treat the complicated loop-like nuclear transformation caused by reaction with neutrons. For this reason, we developed a new code called CITATION-TRU deriving in CITATION code, which can easily treat the loop-like transformation due to TRUs burnup and can take account of (n, 2n) reaction. Figure 2 shows the burnup chains to be accounted in CITATION-TRU code.

3. Core structure

Figure 1 shows the core structure used for the burnup calculation. The core part is composed of two homogenous regions of inner and outer cores; The enrichment of inner core is a little smaller than that of the outer. The two regions were homogenously charged with TRUs. Calculation of the neutron distribution was performed by dividing the objective region into 84 meshes along both radial and axial directions. The burnup calculation was performed by dividing the each region of the object core part into specific number of zones: 18 zones for both inner and outer cores, 20 zones for radial blanket region, 12 zones for both upper and lower axial blanket regions, and 4 zones for shield region. Three batch fuel reloading was executed once a year and calculations were performed periodically for certain years.

4. Reactivity change with TRUs charged

4.1 Amount of TRUs charged

The following table shows the content of TRUs,coming from a light water reactor after three years cooling.

Nuclide	NP237	Am241	Am243	Cm244
Weight(%)	53.6	23.1	17.4	5.93

The inner and outer cores were charged with TRUs of 5, 10 or 15 % of fuel keeping the fuel density constant, which suggests that the amount of Pu and U in a fuel was decreased by adding TRUs.

4.2 Reactor core charged with TRUs

Figure 3 shows the variation of reactivity between BOC and EOC in an equilibrium cycle. The reactivity in EOC remarkably increased as the increase of the content of TRUs for both oxide and metallic fuel cores. The increase can be mainly attributed to the transformation of Np237, a less fissionable nuclide, to Pu238, a fissionable nuclide. Transformation of Am241 to Am242m and of Am243 to Cm244 or Cm245 can be also suggested. Figure 4 shows the reactivity change depending on groups of (Np237, Pu238), (Am241,Am242m) and (Am243, Cm244, Cm245) when the oxide fuel core was charged with fuel containing 15 % TRUs. The figure indicates that the transformation of Np 237 to Pu238 caused approximately a half of the total change of reactivity.

5. Transmutation of TRUs

Figure 5 shows the transmutation rates of TRUs by reactor core type and content of TRUs. The transmutation rates for the oxide fuel reactor core was between 11 and 12 % and that for the metallic fuel core between 14 and 15 %. Here the transmutation rates is defined with:

$$\text{TRU transmutation rate} = \frac{(Mb-Me)}{Mb} \times \frac{E}{Em} \times 100\ (\%)$$

where Mb:content of TRU by weight in BOC
Me:content of TRU by weight in EOC
Em:burnup for oxide fuel core per cycle
E :burnup for core per cycle

The above equation includes an adjusting factor with consideration for the fact that the metallic core is charged with larger amount of fuel than the oxide core making also the burnup different. The above equation bases on the burnup for the oxide fuel core. The transmutation rate for the metallic fuel core was higher than that for the oxide fuel one. The difference can be attributable to :(1) the difference between the neutron energy distribution in metallic and oxide cores(see Figure 6), (2) the fission cross section of TRUs contributing to transmutation which becomes large in a part with high energy.

6.Change in amount of plutonium charge

Adjustment was executed for enrichment by adding TRUs. This was to adjust the amount of plutonium charge. Figure 7 shows the change in the amount of plutonium charge for the cases with 5, 10 and 15% of TRUs. For most cases, the amount of plutonium charge can be reduced by adding TRUs for both a metallic fuel and oxide fuel cores.

In the metallic fuel core, in particular, the amount of plutonium charge could be reduced remarkably. It was caused by increase of high energy neutrons by adding TRUs.

Summary

Calculations were performed for a 1000 MWe oxide fuel FBR core designed assuming a demonstration reactor and a FBR core of metallic fuel with the identical structure, where 5, 10 and 15% of TRUs were charged to be homogenously distributed in it. SLAROM code and CITATION-TRU code were used in order to evaluate the relationship among the amount of TRUs charged and transmutation rates of TRUs. From this evaluation, it was clarified that ;

(1)The reactivity increased remarkably in EOC in comparison with in BOC by adding TRUs. This is advantageous in a designing FBR core,

(2)Transmutation rates of TRUs were between 11 and 12% for a oxide fuel core and between 14 and 15% for a metallic fuel core,

(3)Adjusting enrichment, the amounts of plutonium charge could be reduced for most cases by adding TRUs.

Acknowlegment

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Reference

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Nuclide	JFS-3-J2	MGCL	Nuclide	JFS-3-J2	MGCL
B-10	0		Np-237	0	
B-11	0		Pu-238	0	
C	0		Pu-239	0	
O	0		Pu-240	0	
Na	0		Pu-241	0	
Cr	0		Pu-242	0	
Mn	0		Am-241	0	
Fe	0		Am-242m		0
Ni	0		Am-243		0
Zr	0		Cm-242		0
Mo	0		Cm-243		0
U-233	0		Cm-244		0
U-234	0		Cm-245		0
U-235	0		FP(U-235)	0	
U-236	0		FP(U-238)	0	
U-237	0		FP(Pu-239)	0	
U-238	0		FP(Pu-241)	0	

Table 1 Nuclides used for calculation

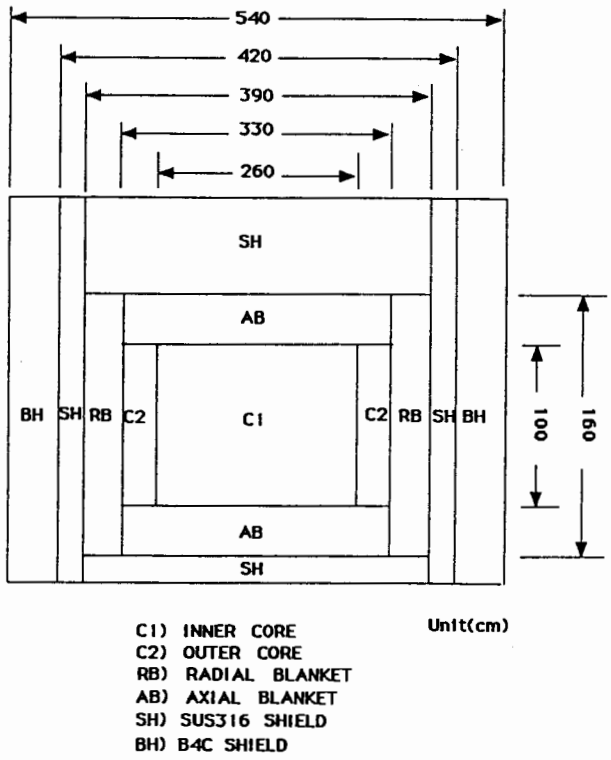

Fig.1 1000MWe FBR core

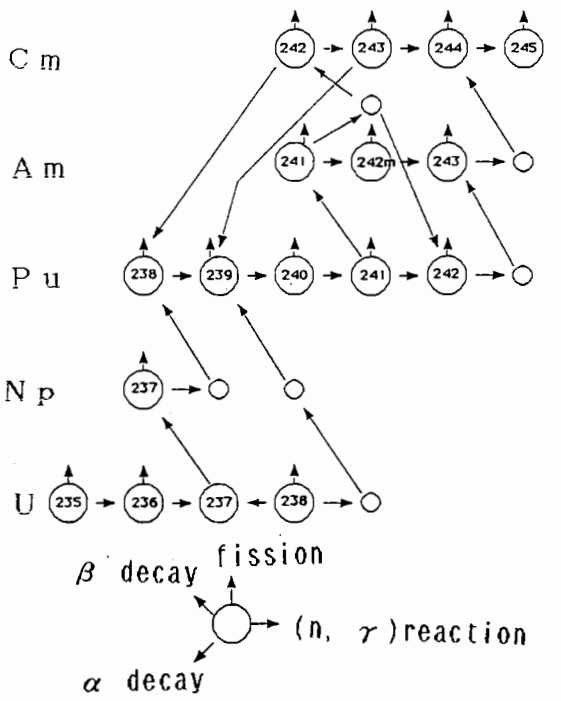

Fig.2 Burnup diagram of actinides

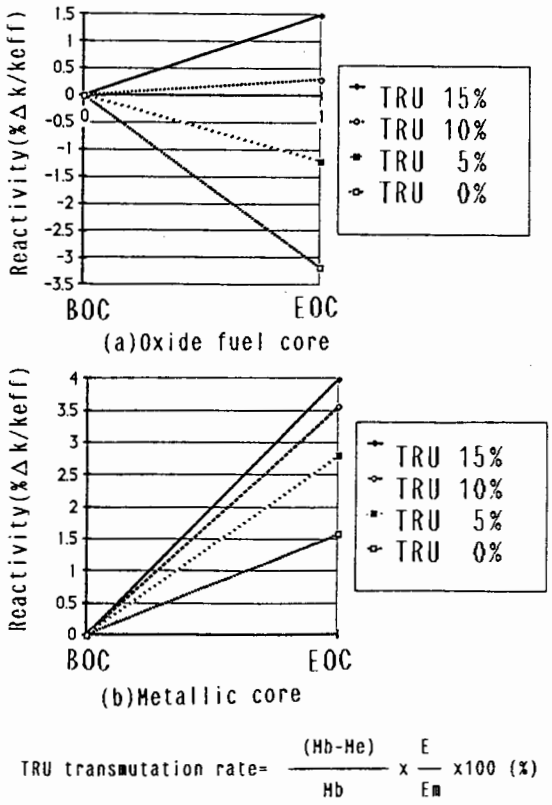

Fig.3 %Δk/keff VS. burnup cycle

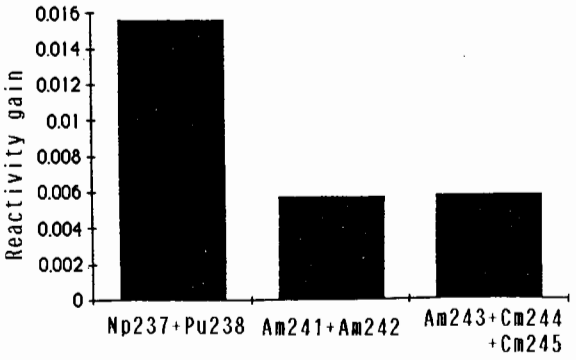

Fig.4 Reactivity gain at EOC BY adding TRUs

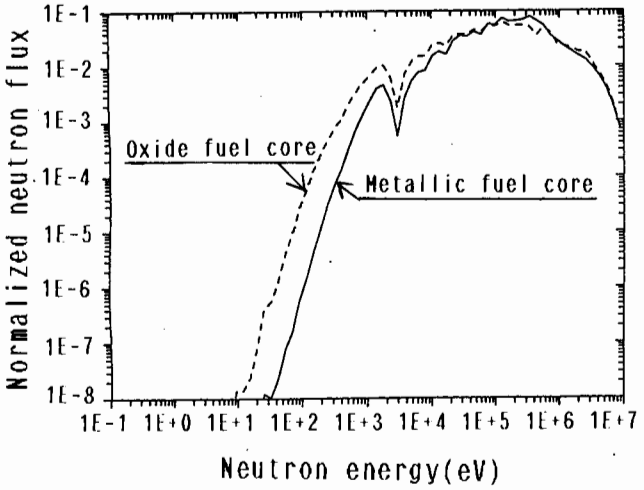

Fig.6 Neutron spectrum for oxide and metallic fuel cores

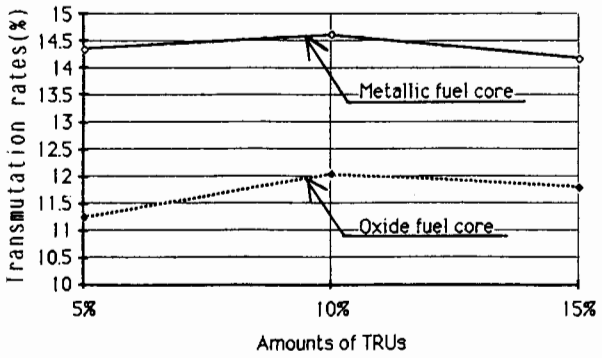

Fig.5 Transmutation rates

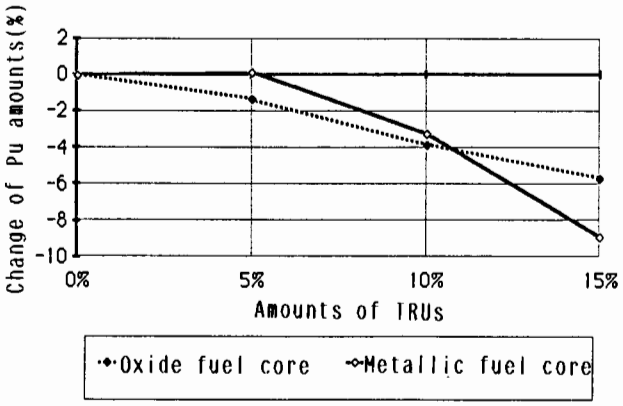

Fig.7 Amounts of Pu