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Physical Interpretation of MA Transmutation in Ultra-Long Life FR Cores

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Abstract

The transmutation rates of minor actinides (MAs) are compared in two ultra-long life fast reactors; MOX fueled Na cooled core (MOX-Na core) and metal fueled Pb cooled core (metal-Pb core). The transmutation rates are decomposed into two terms; direct fission term and indirect fission term. The direct fission term expresses the transmutation of MAs by direct fission reactions, while the indirect fission term expresses that by fission reactions of other nuclides which are transmuted by capture reactions from the original MA. The direct fission term in the metal-Pb core is generally larger than that in the MOX-Na core, but the indirect fission term is less than that in the MOX-Na core. Thus, the overall transmutation rates are a little larger for the MOX-Na core.

1. Introduction

The transmutation of MAs and fission products (FPs) included in the radioactive waste is an alternate selection to the disposal in radioactive wastes repository in deep ground. The transmutation rates of MAs in conventional thermal and fast reactors are, however, rather small: The transmutation rate by fission is about 3% and 5% annually for the thermal and fast reactors.(1)(2) The fuel resides in the reactor for about 3 years. Thus we can transmute 10~15% in a cycle, and many recycling of MAs is required to perfectly transmute MAs. The recycling also leads to difficulty in treating MA fuel because the MA fuel emit α and γ rays and neutrons, furthermore fuel temperature is high.

Therefore more effective procedures of transmuting MAs are desirable. One way is to use special MA fuel without containing Pu (or U). Rock-type fuel is one of the examples.(3) Another effective way of transmuting MAs is to burn fuel assemblies containing MA for very long time, usually the reactor life time of about 40 years.

In this paper we compare the MA transmutation rate in two fast reactor cores, MOX-Na Fast Reactor (FR) core and metal-Pb FR core. The MA transmutation rate is decomposed into direct and indirect fission components. The direct fission term denotes the transmutation rate of MAs at which the MAs make their fission reactions; the indirect fission term denotes the transmutation rate of MAs at while the MAs transmute to other MAs and Pu by mainly by capture reactions and make fission reactions.

By comparing the direct and the indirect fission terms for the two reactors, we can physically understand what neutron spectrum is suitable to the transmutation of MAs in the ultra-long life fast reactor core. The direct and indirect fission terms are estimated nuclide-wise. So we can estimate the effect of neutron spectrum to the transmutation rates of individual nuclides.

2. Calculation Model and Method

We considered two 1000 MWe fast reactors, MOX-Na core and metal-Pb core. The main specification of the two reactors is shown in Table1. The Pu enrichment was fixed to 14% for the MOX fueled core and the MA enrichment was chosen to make keff unity. For the metal fueled core, Pu enrichment of 14% was too large, so we reduced it to 9% and determined the MA enrichment to make keff unity.

The group cross sections were produced from JENDL3.2 by using the cell calculation code CASUP.[(4)] The cross sections were utilized to calculate flux distributions in RZ geometry by the CITATION code.[(5)] The calculated fluxes in individual regions were used in the ORIGEN2 code to carry out burnup calculations during 46 years. The burnup calculations were performed every 4.6 years.

Table1 Specification of two ultra-long life fast reactors of 1000 MWe

parameters	MOX-Na core	metal-Pb core
Assembly pitch	217.0mm	
Number of fuel rod/assembly	217	
Outside diameter of fuel clad	13.0mm	
Diameter of fuel pellet	10.8mm	
Fuel rod pitch	14.0mm	
Core radius	322cm	
Core hight	150cm	
Blanket radial thickness	42cm	
Blanket axial thickness	35cm	
Volume fraction fuel/coolant/structure	55.0/29.4/25.5	
Fuel smear density (Inner core)	83.8%	61.1%
(Outer core)	75.0%	61.1%
Pu enrichment	14.0w/o	9.0w/o
MA enrichment	20.0w/o	20.0w/o

3. Numerical Results and Discussions

First let us compare the neutron spectrum in the two reactors. Fig1 shows the neutron spectrum in the center of the two cores at the beginning of burnup. The metal fueled Pb cooled reactor has a hard spectrum compared to the MOX-Na core. However it is noted the neutron spectrum above 1 MeV is small for the metal-Pb core because of the inelastic scattering of Pb. The burnup swing of keff is shown in Fig2 for the two cores. Because of the high breeding in the metal fueled Pb cooled reaction keff shows a large increase with burnup.

Table2 compares the transmutation rate of each MA nuclide and its components (direct and indirect fission terms). For Np-237, the transmutation rate is 29.8 and 26.2% for the MOX-Na core and the metal-Pb core, respectively. The direct fission term of Np-237 is, however, larger for the metal fueled core. But the indirect fission term is larger for the MOX fueled core. As the sum, the transmutation is better for the MOX fueled core. Similar trend is seen for Am-241 and Am-243.

Fig.3 shows the direct and indirect fission terms of the transmutation rate of Np-237 for the two cores. The indirect fission term is further divided into individual contribution to fission reactions of different nuclides. From this figure it is seen that the indirect fission term, especially the contribution of Pu-238 and Pu-239, is large for the MOX fueled Na cooled core.

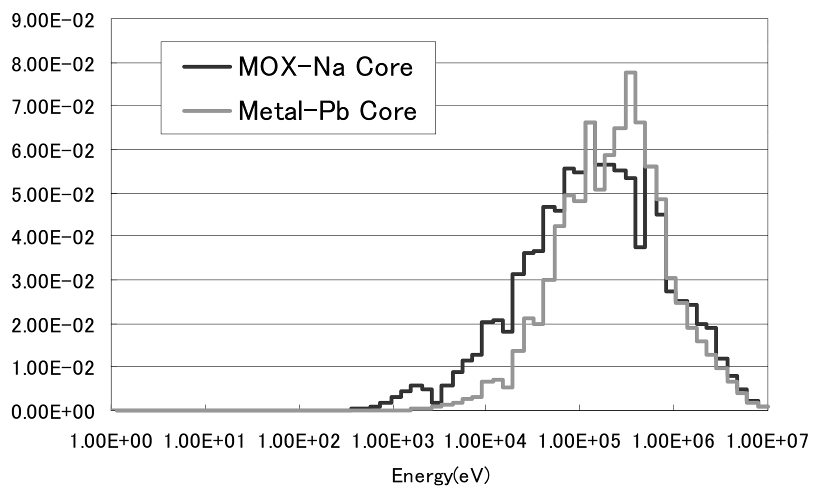


Fig1 Neutron Spectra in two core at the beginning of burnup

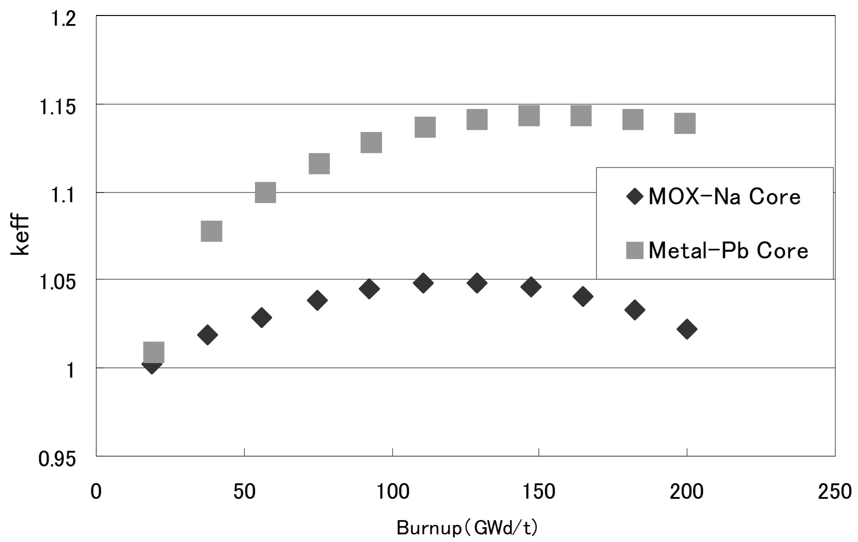
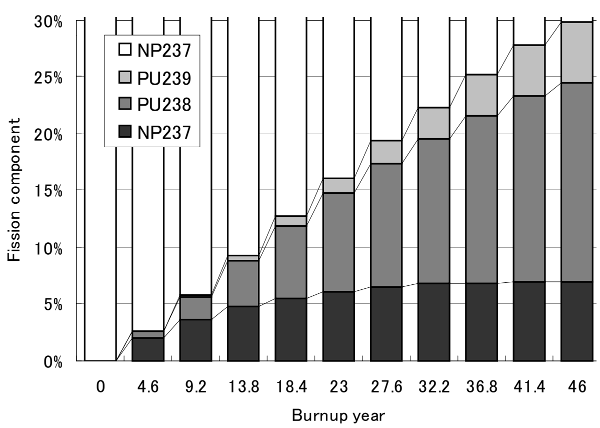


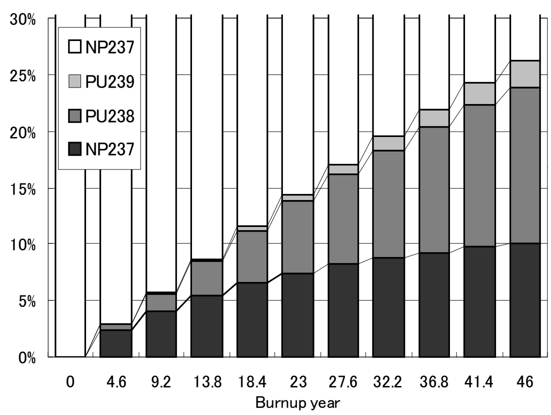
Fig2 Burnup swing of keff for two cores

Table2 MA Transmutation rate and its component

Core	MA	Direct fission(%)	Indirect fission(%)	Sum(%)
MOX-Na Core	Np237	6.93	22.91	29.84
	Am241	5.20	19.32	24.52
	Am243	4.72	15.64	20.36
	Cm244	2.52	18.39	20.91
Metal-Pb Core	Np237	10.00	16.18	26.18
	Am241	7.07	15.66	22.73
	Am243	6.16	10.67	16.83
	Cm244	3.00	18.06	21.06



MOX-Na core



metal-Pb core

Fig3 Direct and indirect fission terms of transmutation rate of Np-237 as burnup for the two cores

4. Conclusions

The transmutation rate of MAs in the ultra-long life fast reactors was investigated by decomposing the rate into the direct and indirect fission terms. The transmutation rate was compared for the two cores; MOX-Na core and metal-Pb core.

The transmutation rate of Np-237 during 46 years was 29.8% and 26.2% for the MOX fueled Na cooled reactor and the metal fueled Pb cooled reactor, respectively. The large transmutation for the MOX fueled Na cooled reactor is due to the large indirect fission contribution of 22.9% compared to 16.2% of metal fueled Pb cooled reactor.

The similar trend was seen for other MAs. So it is concluded that the overall transmutation rate is large for the MOX fueled Na cooled reactor.

References

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