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TRU Transmutation Using ThO_2-UO_2 and Fully Ceramic Micro-encapsulated Fuels in LWR Fuel Assemblies

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1. Introduction

The objective of this work is to design new LWR fuel assemblies which are able to efficiently destroy TRU (transuranics) nuclide without degradation of safety aspects by using ThO_2-UO_2 fuel pins and FCM (Fully Ceramic Micro-encapsulated) fuel pins containing TRU fuel particles[1,2,3,4]. Thorium was mixed to UO_2 in order to reduce the generation of plutonium nuclides and to save the uranium resources in the UO_2 pins. Additionally, the use of thorium contributes to the extension of the fuel cycle length. All calculations were performed by using DeCART (Deterministic Core Analysis based on Ray Tracing) code[5]. The results show that the new concept of fuel assembly has the TRU destruction rates of ~40% and ~25% per 1200EFPD (Effective Full Power Day) over the TRU FCM pins and the overall fuel assembly, respectively, without degradation of FTC and MTC.

2. Methods and Results

The fuel assembly depletion calculations were performed with the DeCART code which is a whole core neutron transport code capable of 3D core depletion analysis and developed by Korea Atomic Energy Research Institute (KAERI). Our fuel assembly analyzes were done with two-dimensional transport calculations assuming a fixed axial thickness of 1cm and the reflective boundary conditions both on the top and bottom boundaries. The multi-group cross section library of HELIOS code was used in this study. The numbers of energy groups for neutron and gamma are 47 and 18, respectively. We performed the fuel assembly depletion analyzes over 1200 EFPD and 500ppm of boron concentration is assumed.

In this study, the reference fuel assembly is the ABB/CE 16x16 type fuel assembly which has four water holes for control rods and one central water hole for instrumentation. In this study, some of UO_2 pins are replaced with FCM pins to destroy TRU nuclides from LWR spent fuel. A TRU FCM pin consists of the typical cladding and the matrix in which the TRISO particle fuels containing a central TRU kernel are distributed. Also, we used BISO particles containing a central BP (burnable poison) kernel. On the other hand, thorium oxide fuel (ThO_2)[6] is mixed with UO_2 fuel in UO_2 pins to reduce the generation of TRU nuclides and to extend the fuel cycle length. The number of FCM TRU pins in an assembly is determined to be 84 through the case studies. Fig. 1 shows how the UO_2-ThO_2 pins and FCM TRU pins are arranged in 1/4 fuel assembly. In the case of UO_2-ThO_2 pins, ThO_2 occupies 50 wt%. And UO_2 has 12 wt% enrichment of U-235. Table I shows the composition of the fuel pins and design parameters. We considered two cases of different kernel composition. Initial heavy metal composition of TRISO kernel is fixed and the TRU composition corresponds to that of LWR spent fuel irradiated to 50MWD/kg and cooled for 10years. For Case 1, the kernel is composed of only Pu nuclides after removing minor actinides from LWR spent fuel TRU. The packing fractions of TRISO and BISO particles are 45% and 2%, respectively. The fuel assembly of Case 2 is the same as that of Case 1 except that minor actinides are kept and packing fractions of TRISO and BISO are 50% and 1%, respectively.

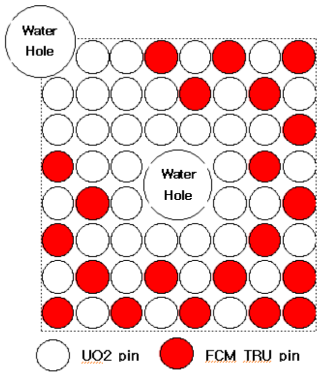

Fig. 1 Configuration of new fuel assembly (1/4)

Table I Composition of fuel pins in case 1 and 2

Items	Case 1	Case 2
FCM TRU pin		
Kernel diameter	600μ m	
The number of pin	84(in an assembly)	
Matrix	SiC	
Matrix density	3.18g/cm	
Kernel composition	PuO_2	$TRUO_2$
Packing fractions (TRISO/BISO)	45%/2%	50%/1%
UO_2 pin		
Uranium enrichment	12 wt%	
Weight percent ThO_2	50 wt%	

Figure 2 compares the infinite multiplication factors (k-inf) for Cases 1 and 2. Even if Case 1 has lower packing fraction of TRISO than one of Case 2, k-inf of

Case 1 is higher for the entire burn-up cycle than those of Case 2. This result is due to the fact that the kernel of Case 1 does not include the minor actinides. Although the pin power peaking factors are not shown here, these two cases have relatively large pin power peakings (~1.2) at fresh state but they are small at 1200EFPD. It is considered that these initial peakings can be lowered by splitting the enrichment of UO_2 fuels.

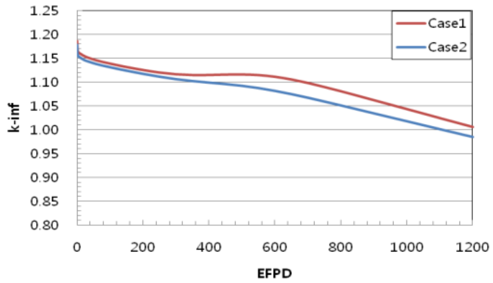

Fig. 2 Comparison of k-inf for case 1 and 2

Fig. 3 shows TRU mass changes over time. The amount of TRU destruction in FCM TRU pins is much larger than the production of TRU in UO_2 pins. The assembly TRU destruction rates over 1200 EFPD are 28.7% and 25.6% for Cases 1 and 2, respectively while the destruction rates only in TRU FCM pins are 43.9% and 39.5%, respectively.

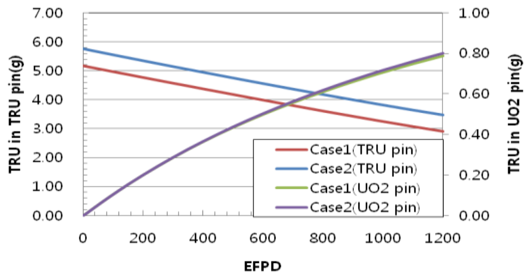

Fig. 3 TRU mass change in FCM TRU and UO2 pins

Table II shows the fuel temperature coefficients (FTC) and the moderator temperature coefficients (MTC) of Cases 1 and 2. They are also compared with those of the typical LWR fuel assembly having no FCM TRU pins.

Table II Comparison of FTC and MTC (pcm/°C)

EFPD	Commercial assembly (no FCM pins)		Case 1		Case 2	
	FTC	MTC	FTC	MTC	FTC	MTC
0	-2.00	-31.25	-2.68	-37.44	-2.67	-46.03
150	-2.04	-27.19	-2.75	-34.95	-2.75	-43.89
600	-2.57	-43.18	-2.99	-46.23	-3.04	-52.17
1200	-2.95	-55.85	-3.44	-57.58	-3.47	-60.27

As shown in Table II, new fuel assemblies studied in this work have slightly more negative FTC and MTC than the typical LWR fuel assembly considered here. Finally, we analyzed the effect of thorium on the fuel cycle length. For this purpose, we changed in the contents of ThO_2 in UO_2-ThO_2 pins for Case-2 but we adjusted the uranium enrichments such that the initial k-infs are the same as that of Case-2. Fig. 7 compares the evolutions of k-inf over time for three cases of the different ThO_2 contents (50wt%, 25wt%, 0wt%). The first case of 50wt% ThO_2 is just the Case-2 considered above. This figure shows how the use of thorium contributes to the extension of the fuel cycle length.

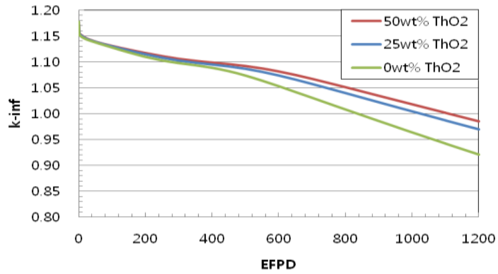

Fig. 4. Comparison of the changes of k-inf for three different ThO_2 contents

3. Conclusions

We designed new fuel assemblies having ThO_2-UO_2 pins and TRU FCM pins to effectively destroy TRU nuclides from LWR spent fuel. The results of the analyses show that the new fuel assemblies have the TRU destruction rates of ~40% and ~25% per 1200EFPD (Effective Full Power Day) over the TRU FCM pins and the overall fuel assembly, respectively, without degradation of FTC and MTC.

Acknowledgement

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