Transmutation Option Studies for Enhancing Proliferation Resistance Using Heterogeneous Thorium-Based PWR Fuel Assemblies

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1. Introduction

Thorium fuel has an inherent advantage of less TRU production than uranium fuel cycle in its spent fuel. Kyung Hee Thorium Fuel (KTF) was proven as an alternative fuel cycle concept compared to conventional UO_2 fuel cycle in a Pressurized Water Reactor (PWR) [1].

Preliminary evaluation of the Kyung Hee Thorium Transmutation Fuel (KTTF) design concept showed a good feasibility of Transuranics (TRU) transmutation in a thermal reactor [2]. This is due to high fission cross section of fissile plutonium isotopes.

In this paper, KTTF design was improved to have high proliferation resistance potential combined with various transmutation cycle options.

2. Methods and Results

2.1 KTTF fuel Assembly Design

The KTF design was used to assess transmutation feasibility of various fuel cycle options. The KTTF concept which is composed of the whole seed and blanket assembly with the ratio of 1 to 1 was shown in Figure 1. Basically, Seed fuel of KTTF concept composed of uranium with 10% zirconium of metal fuel form and blanket fuel composed of 15% UO_2 with ThO_2. TRU, Pu-only and MAs came from conventional PWR and CANDU spent fuel were added to seed and blanket fuel assemblies respectively. Therefore, various options of fuel type are suggested; U/Zr+TRU, U/Zr+Pu, U/Zr+MAs, $(U+Th+TRU)O_2$ and $(U+Th+Pu)O_2$. Fuel cycle options are relied on various decay time of spent fuel and amount of loading mass. Once through fuel cycle strategy was applied to the heterogeneous thorium fuel cycle concept to have same fuel cycle length of 18 months. However, each assembly design was not optimized for a pin peaking factor because our studies only are focused on a good proliferation resistance potential. Average discharged burnup of seed fuel assemblies is 83.0 MWd/kgHM and one of blanket fuel assemblies is 95.9 MWd/kgHM. Blanket fuel assemblies are resided in the core during 13.5 years with one batch fuel strategy while seed fuel assemblies are stayed in the core up to 4.5 years with three batchs.

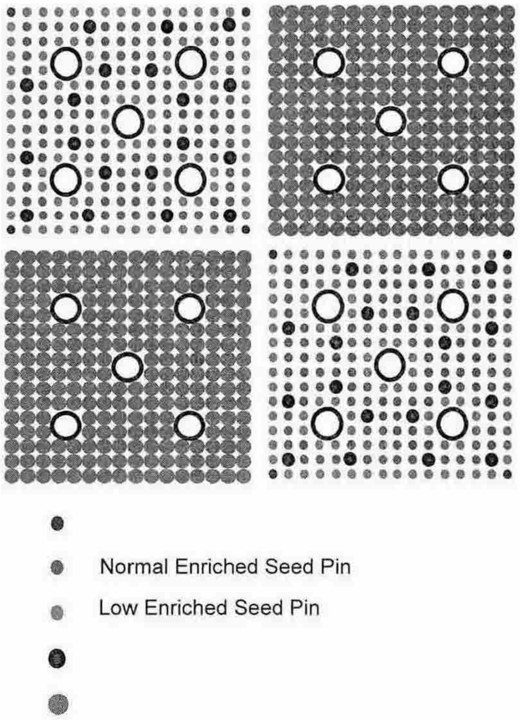

Figure 1. KTTF Assembly Model.

2.2 Calculation Methods

Net TRU transmutation rates based on APR-1400 core were evaluated by HELIOS lattices code with 35 group neutron library. Moderator Temperature Coefficient (MTC) and Fuel Temperature Coefficient (FTC) were also evaluated. A proliferation resistance potential was evaluated by measuring indices; Bare Critical Mass (BCM), Spontaneous Neutron Source rate (SNS) and Thermal Generation rate (TG). Each proliferation resistance indices are normalized by annual plutonium generation rate of seed and blanket assembly.

2.3 Calculation Results

TRU mass balances and proliferation resistance potential of all cases were compared in Table I. It was noted that TRU transmutation rate was depended upon an initial loading mass. The Surpport Ratio (SR) of 20% of TRU loaded at seed assembly is nearly 2.0 which is same as that of Fast Reactor (FR) core [3]. The maximum transmutation amount of TRU in KTF concept is 514.7 kg/Gwe-yr which is much higher than that of FR. This is due to large fissile plutonium mass burned in a thermal neutron spectrum condition. For the decay time options, they have almost same proliferation resistance potential. However, it reveals that shorter decay time is much better for transmutation capability because Pu-241 isotope fraction is decreased rapidly with decay time. Reactivity coefficients are similar or less negative than those of conventional PWR that is due to neutron spectrum hardening by TRU. In order to increase proliferation resistance potential of BCM, TRU should be loaded at the blanket or Pu-only should be loaded at the seed assembly. It is also shown that use of MAs in seed assemblies is good for TG, however, the plutonium production is much higher than MAs transmutation.

3. Conclusions

From the above results, KTTF transmutation concept in a conventional PWR can be an alternative transmutation system before using FR or ADS facility. For the higher proliferation resistance potential of thorium based KTTF design in a PWR, TRU should be added to blanket assemblies. Further studies are in progress to optimize KTTF design concept within safety limits.

REFERENCES

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Table I. Summary of TRU Mass Flow and Proliferation Resistance Potential Indices

Cases			Net TRU Production* (Pu / MAs), kg/GWe-yr	BCM** Kg	SNS** #/cm^2-sec	TG** Watts/k g
Reference PWR			213.6 (194.5/20.1)	22.2	4.33E5	19.8
KTF			121.0 (100.3/20.7)	28.0	7.78E5	48.3
Seed	Spent Fuel of PWR	10% TRU	-228.7 (-214.3/-14.4)	31.7	8.90E5	66.1
		20% TRU	-429.9 (-386.1/-43.8)	29.9	8.23E5	57.5
		25% TRU	-514.7 (-457.3/-57.4)	29.3	80.0E5	54.7
		10% PU	-283.4 (-332.2/48.8)	35.6	81.0E5	28.6
		1.3% MAs	85.7 (139.4/-53.6)	23.4	9.55E5	126.2
	Spent Fuel of CANDU	10% TRU	-302.4 (-321.4/19.0)	29.9	6.99E5	28.5
		10% Pu	-316.0 (-350.8/34.8)	30.6	6.72E5	18.3
		1.3% MAs	87.4 (141.8/-54.4)	24.7	9.64E5	125.3
Blanket	Spent Fuel of PWR	10% TRU-10y decay	-69.9 (-73.9/3.9)	31.3	8.54E5	62.6
		10% TRU-20y decay	-60.1 (-56.4/-3.7)	30.6	8.70E5	69.2
		10% TRU-30y decay	-53.0 (-44.2/-8.8)	30.1	8.76E5	73.0
		10% TRU-40y decay	-49.0 (-37.2/-11.8)	29.8	8.81E5	75.2
	Spent Fuel of CANDU	10% TRU	-99.2 (-117.9/18.7)	29.5	6.88E5	32.0
		10% Pu	-105.8 (-130.9/25.1)	29.9	6.63E5	24.0

* : Final TRU Mass – Initial TRU Mass

** : Calculated based on annual Plutonium production of seed and blanket