Preliminary Core Design Analysis of a Dedicated Burner Loading Thorium-based Oxide Fuel

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1. Introduction

Spent nuclear fuel is a pressing issue in most nuclear power generation countries including Korea, because onsite storage facilities are filling up with no further solutions available. As a way of reducing the burden of spent nuclear fuel, partitioning and transmutation (P&T) based on pyroprocess-SFR system can eliminate 99.9% of transuranic elements (TRU). Still, 0.1% of TRU, 10kg per year [1, 2], is remaining despite of such P&T process when Korean nuclear power fleet produces 1,000 tons of SNF per year. TORIA using thorium-based oxide fuel aims to incinerate the rest, leaving behind only low and intermediate level wastes. Hence, the aim of this study is to design a dedicated burner which is loading thorium and TRU to incinerate the residue.

2. Characteristics of TORIA

A system which uses thorium-based oxide fuel for the purpose of managing spent nuclear fuel by burning TRU and long live fission product has been designated as TORIA (Thorium Optimized Radionuclide Incineration Arena).

Thorium based fuel has better performance compared to U based fuel. For example, thorium is three to four times more abundant than uranium and it is more widely distributed in worldwide. And thorium fuel cycle has inherent proliferation resistance, because 233U is generated from thorium. 233U has high dose, so it is detected easily.

TORIA is a dedicated burner. Thorium fuel cycle generates much less quantity of plutonium and long-lived minor actinides compared to conventional uranium fuel cycle. By adopting thorium based oxide fuel, the support ratio [3] can be increased over that of uranium based oxide fuel because there is less additional TRU generation during operation. So reactor using thorium-base fuel can incinerate the high level waste more effectively compared to conventional reactor.

Fabrication of thorium-based oxide fuel is already shown to be feasible on industrial scale [4]. In addition, TORIA has high temperature feedback property [5] and low void coefficient.

3. Design of TORIA

TORIA's core is designed based on earlier critical reactor design designated as PASCAR. PASCAR is Proliferation-resistant, accident-tolerant, self-supported, capsular, and assured reactor which was designed by NUTRECK [6]. Basic design requirements are to maintain geometrical profiles and core power density of PASCAR by proportional reduction of the core size. Thermal power is reduced from $100MW_{th}$ to $30MW_{th}$ and refueling interval is 800days. Average effective multiplication factor during effective full power days is 1.01104. Fuel composition was determined using the flowsheet of PyroGreen [1]. Mass ratio between Th and TRU is decided to be Th:TRU=0.650:0.350. For coolant lead-bismuth is selected. Table 1 shows the TORIA core specifications and Fig 1 shows the core model.

Table 1: Specification of the TORIA

Parameter	Value
Thermal power	30MWth
Power plant efficiency	35%
Refueling interval	800 days
Primary coolant	Lead-bismuth eutectic
Fuel type	(Th-TRU)O2
Cladding, structure material	HT9
Pellet nominal density (%TD)	100.0
Active core height/equivalent diameter (H/Deq)	<1
Number of pins per one assembly	64 including 4 skeletal bar
Average effective multiplication factor	1.01104
Average core power density	28.856W/cc
Average linear power density	4.252kW/m

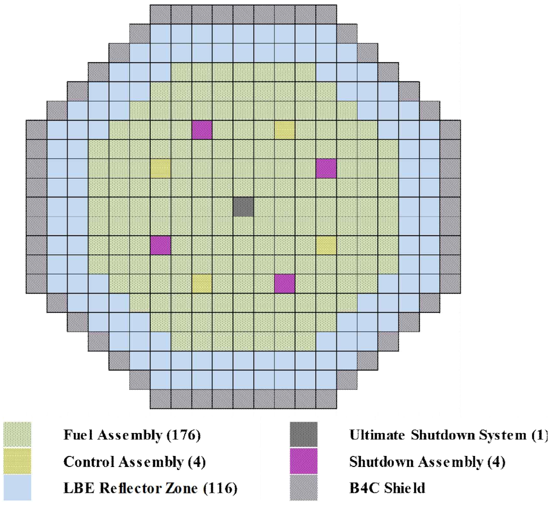

Fig 1. TORIA core model

3. Analysis Results and Discussion

3.1 Multiplication factor

The McCARD which is a monte carlo code system is used for TORIA core calculation. Calculation result analysis is focused on the ability of burning TRU.

First of all, Fig 2 shows effective multiplication factor during effective full power days. Reactivity swing during effective full power days is about 2069pcm. This defect is compensated by production of 233U. 232Th transmuted to 233U through several steps.

The excess reactivity at the beginning of the cycle is 2119pcm. In the safety aspect, it is better to have as small excess reactivity as possible. To lower the excess reactivity, it is planned to design accelerator driven system based on this critical TORIA core. Furthermore, refueling interval can be extended under the subcritical mode.

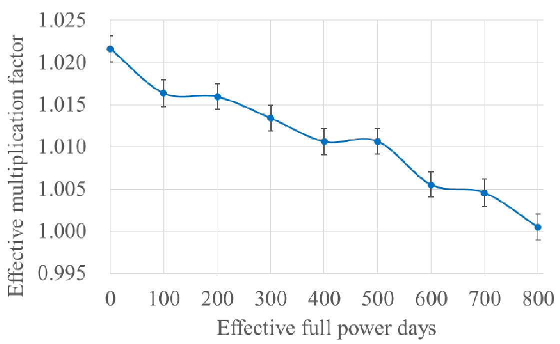

Fig 2. Effective multiplication factor during effective full power days

3.2 TRU burning

By summing every TRU isotopes mass variation, total TRU destruction rate can be gained. TRU destruction rate is 11.528 kg per year. As stated earlier, TORIA aims to incinerate the 10kg of TRU per year. This critical TORIA core has enough burning capability in the view point of TRU burner. Total fuel loading would be decreased by substituting several fuel assemblies to target material in accelerator driven system. This is the reason why TRU destruction rate is set to be higher than design goal.

There is a thing to be improved in the point of long lived minor actinides burner. 241Am is generated 1.94kg per year. 241Am have to be destructed for spent nuclear fuel control because it has half-lives of 432.2 years. It is planned to be studied by adopting external neutron source under the accelerator driven system. Table 2 and table 3 shows the uranium, palladium, and TRU elements' production and destruction rates of critical TORIA.

Table 2: Production rates of isotopes

Isotope	Production Rate (g/year)	Isotope	Production rate (g/year)
231Pa	31.4	238Pu	3747.4
233Pa	263.4	242Pu	45.4
232U	1.0	241Am	1937.3
233U	4932.1	242Am	0.8
234U	178.8	243Am	160.2
236U	25.2	243Cm	4.2
238Np	2.0	245Cm	6.4
239Np	2.8	246Cm	0.3

Table 3: Destruction rates of isotopes

Isotope	Destruction rate (g/year)
232Th	5654.2
235U	33.0
238U	781.1
237Np	638.3
239Pu	9519.9
240Pu	218.0
241Pu	3912.1
242Cm	3254.1

4. Conclusions

Critical TORIA shows enough TRU burning capability, but reactivity swing is large. This critical core design is the preliminary step for a dedicated burner design having accelerator driven system. It is expected to be useful in the step of detailed subcritical core design by understanding characteristics of core loaded with thorium-based oxide fuel. Accelerator driven system which is based on this critical TORIA aims to have destruction ability of 10kg per year, smaller reactivity swing, and longer refueling period than critical TORIA. Detailed core design should consider external neutron source, and optimization about fuel composition, geometrical arrangements, etc.

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