

Use of Void Duct Assemblies for TRU Transmutation Core Design

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1. Introduction

It has been well-known[1,2,3] that the radiotoxicity of the long-lived nuclides (e.g., Pu, Np, Am, Cm, ^{129}I , ^{99}Tc) contained in LWR spent fuel lasts over very long time period. Therefore, many countries have launched their own national program and have participated international collaborative projects (e.g., Gen-IV) to investigate the possibility of reduction of these nuclides by the nuclear transmutation.

In this paper, a new design concept for the effective transmutation of transuranics (TRU) (i.e., Pu, Am, Cm, Np) nuclides is presented. In this core design concept, the void duct assemblies are used to reduce the coolant void reactivity that is one of the technical issues related with core safety and to achieve power flattening under single enrichment fuel.

2. Core Design and Performance Analysis

2.1 Description of the Core Design

For this study, the KALIMER-600 (Korea Advanced Liquid Metal Cooled Reactor) having the breakeven breeding characteristics[4] is used as a reference core. In the KALIMER-600 core design, the power peaking control under single enrichment fuel was achieved by the special fuel assembly designs where non-fuel rods such as moderator rods, B_4C absorber rods, and vacancy rods are used to replace some of fuel rods. In this study of transmutation core, B_4C absorber rods and vacancy rods are removed while the six moderator ($\text{ZrH}_{1.8}$) rods are kept to minimize the degradation of the fuel Doppler effect. The reduction of the breeding ratio in order to increase the transmutation rate is done by reducing the fuel rod outer diameter and core height, and using the void duct assemblies. The void duct assemblies play the important roles in reducing the sodium coolant void reactivity and in achieving the power flattening under single enrichment fuel. It has been recognized that the positive reactivity insertion by voiding of the coolant is one of the technical issues related to the core safety of the fast spectrum reactors.

Table I summarizes the basic design parameters used in the transmutation core and Figure 1 shows the configuration of the core. As shown in Table I, in comparison with the KALIMER-600 core, the active core height was reduced from 100cm to 90cm and the fuel rod outer diameter was reduced from 0.85cm to 0.75cm. The lattice P/D ratio is slightly increased to 1.227 in order to increase the coolant volume fraction. The fuel is the IFR metallic fuel form of TRU-U-10Zr.

Additionally, to further increase the neutron loss, the 30cm B_4C region was added to the bottom of the fuel rod. As shown in Figure 1, the first two central rings are occupied by the void duct assemblies and the shield assemblies with absorber to absorb the leaking neutrons through the core inner surface are located in the third ring. The duct assemblies are also located in the fourth ring in order to enhance leakage. These non-fuel assemblies in the central core region plays an important role in reducing the power peaking.

Table I Basic Design Parameters

Parameters	Design value
Fuel type	TRU-U-10Zr
Number of rods/FA	271
Number of fuel rods/FA	265
Number of moderator rods/FA	6
B_4C region height (cm)	30
Boron enrichment of B_4C region (wt%)	50
Structural material	HT-9M
Active core height (cm, hot (cold))	94.5 (90.0)
Assembly pitch (cm)	16.68
Void duct assembly composition	20%HT-9M
Rod outer diameter (mm)	7.5
Cladding thickness (mm)	0.53
Pin pitch (mm)	9.2
Pin P/D ratio	1.227
Volume fractions (Fuel/coolant/structure,%)	36.3/38.9/24.0

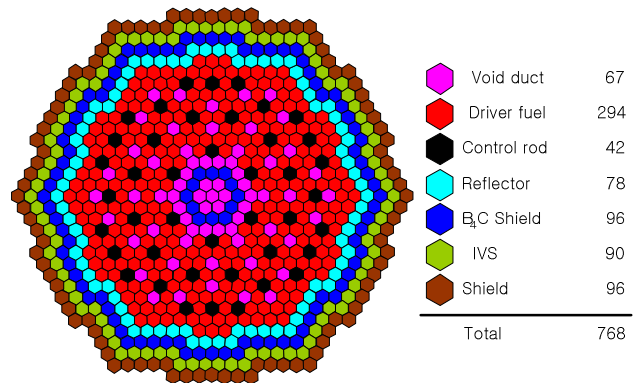


Figure 1 Core configuration

2.2 Core Performance Analysis Results

The REBUS-3 equilibrium model with a nine group cross section was used to perform the core depletion analysis. The cycle length is 332EFPD and the refueling interval is 13months with a capacity factor of 85%. The six batch fuel management scheme is used to increase the fuel discharge burnup.

Table II shows the summary of the core performance analysis results. The burnup reactivity swing and the

conversion ratio over one cycle were estimated to be 3014pcm and 0.656, respectively. This relatively large value of burnup reactivity swing is due to the small breeding. To compensate this large value of burnup reactivity swing, the number of control assemblies and the B-10 enrichment of control rods are increased. The total number of control assemblies is 42 and 50%B-10

was used in the control rod. The average fuel discharge burnup was estimated to be 122MWD/kg and this core can transmute 278kg/cycle of TRU that corresponds to the TRU amount produced from two LWRs of the same power. The uranium consumption rate was estimated to be 248.4kg/cycle.

Table II Summary of the core performances

Performance parameter	Value	Performance parameters	Value (BOEC/EOEC)
Refueling intervals (EFPD)	332	Fuel Doppler coefficient (sodium flooded, dp/dT)	-0.003T ^{-1.0} /-0.0031T ^{-1.0}
Average conversion ratio	0.6562	Radial expansion reactivity coefficient (dk/kk')(dH/H)	-662/-645 (pcm/%)
Burnup reactivity swing (pcm)	3014	Fuel axial expansion reactivity coefficient (dk/kk')(dH/H)	
Number of fuel management batches	6	Fuel only	-177/-186 (pcm/%)
Average discharge burnup (MWD/kg)	121.7	Fuel+clad	-141/-147 (pcm/%)
Peak discharge burnup (MWD/kg)	181.7	Sodium void reactivity (\$)	
Average TRU wt% in HM		Total core (active core+gas plenum)	+2.83/+2.85
BOEC/EOEC	34.2/33.8	Control rod worth (\$)	
Pu inventory (kg, BOEC/EOEC)	6857/6624	Inner	1.86/1.92
MA inventory (kg, BOEC/EOEC)	1030/986	Middle	15.64/15.96
HM inventory (kg, BOEC/EOEC)	23031/22505	Outer	24.67/25.62
TRU consumption rate (kg/cycle)	278.4	Total	50.86/52.46
U consumption rate (kg/cycle)	248.4	β_{eff}	0.00312/0.00313
Supporting ratio	~2.0	Neutron life time (μsec)	0.612/0.630
Average power density (W/cc)	223.8		
Average linear heat rate (W/cm, BOEC)	203.5		
Peak linear heat rate (W/cm, BOEC)	307.1		
Peak fast neutron fluence (n/cm ²)	3.83x10 ²³		

In comparison with the KALIMER-600 breakeven core, this transmutation core has higher values of average and peak linear heat rate because of its reduced core height and the number of driver fuel assemblies. The peak linear heat rate exceeds slightly 300W/cm. The average TRU content in the heavy metal (HM) of the fuel is larger than 30wt%. However, it was reported that there were no experience of the metallic fuel of high TRU contents over 30wt% TRU of HM in the IFR metal fuel testing program. Therefore, there can be some material issues in the metallic fuel used in this study.

The fuel Doppler coefficient of this core was estimated to be $\sim -0.003T^{-1.0}$ while that of the KALIMER-600 core is $\sim -0.00736T^{-1.05}$. This temperature dependency implies that this transmutation core has softer core neutron spectrum than the KALIMER-600 breakeven core. The absolute value of the fuel Doppler coefficient is smaller than that of the KALIMER-600 breakeven core. The effective delayed neutron fraction that is one of the safety-related key parameters is also degraded relatively to the KALIMER-600 core. These degradations of the fuel Doppler coefficient and the effective delayed neutron fraction is due to the lower U-238 content. On the other hand, this transmutation core has much smaller value of the sodium void reactivity (<3\$) than the KALIMER-600 core. This is because the void duct assemblies enhance the neutron leakage in the case of the coolant voiding.

3. Conclusion

In this paper, a new design concept for the effective transmutation of TRU nuclides is presented. In this core design concept, the void duct assemblies are used to reduce the coolant void reactivity that is one of the technical issues related with core safety and to achieve power flattening under single enrichment fuel. The core performance analysis results show that the transmutation core has its TRU supporting ratio of ~ 2.0 and small value of coolant void reactivity (<3\$) while the fuel Doppler coefficient is degraded in comparison with the KALIMER-600 breakeven core but it still keeps still negative value of significant magnitude.

Acknowledgement

This study was supported by the Korean Ministry of Science & Technology through its National Nuclear Technology Program.

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