Transactions of the Korean Nuclear Society Spring Meeting
Chuncheon, Korea, May 25-26 2006

600 MWe Sodium Cooled Fast Reactor Core Designs for Efficient TRU Transmutation

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1. Introduction

One of the Gen IV reactor development goals is the management of high-level radioactive waste arising from the LWR spent fuels because the radiotoxicity of the long-lived nuclides (e.g., Pu, Np, Am, Cm, ^{129}I, ^{99}Tc) contained in LWR spent fuel lasts for very long time period. Fast spectrum reactors have several desirable neutronic characteristics for nuclear transmutation of the long-lived nuclides[1,2]. In this paper, core design studies for 600MWe sodium cooled fast reactors for an effective transmutation of the TRU nuclides are given. In particular, two types of TRU transmutation core are introduced; the first type is the reference core that is based on the KALIMER-600 breakeven core[3] and the second type is an annular type core where void duct assemblies and a central island region of non-fuel assemblies are introduced to reduce sodium void reactivity and to achieve power flattening under a single enrichment fuel.

2. Core Design and Performance Analysis

2.1 Description of Core Design

In the reference core, B_4C absorber rods, dummy rods and moderator rods are used to make it possible to use a single enrichment fuel, to reduce the degradation of fuel Doppler coefficient and to reduce sodium void reactivity worth. In comparison with the KALIMER-600 breakeven core, the fuel rod outer diameter is reduced from 0.85cm to 0.75cm and the active core height from 100cm to 90cm in order to reduce the breeding ratio. All fuel assemblies have 234 fuel rods and 6 moderator rods ($ZrH_{1.80}$) and 25 dummy rods. The fuel assemblies in the inner and middle core regions have 6 B_4C rods while these 6 B_4C rods in the outer core region fuel assemblies are treated as the hollow rods that have the same cladding as the original B_4C rods but the internal region is assumed to be void. For power flattening under a single enrichment fuel, the boron enrichments for the inner and middle core regions are adjusted to be 60wt%B^{10} and 25wt%B^{10}, respectively. Figure 1 shows the core configuration. The fuel for all cases in this study is the IFR metallic fuel form of TRU-U-10Zr.

For the transmutation cores having void duct assemblies[4], the reduction of breeding ratio in order to increase transmutation rate is done by reducing the fuel rod outer diameter and core height, and using the void duct assemblies.

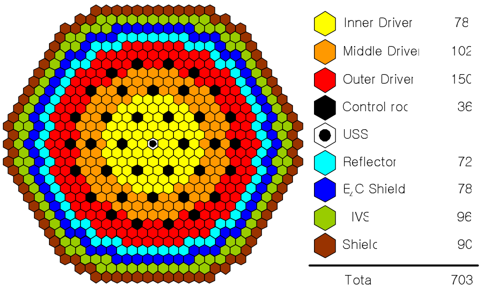

Figure 1 Configuration of the reference core

In particular, the void duct assemblies are introduced to reduce the sodium coolant void reactivity further and to achieve power flattening under a single enrichment fuel. Figure 2 shows the configuration of the core. The active core height is 90cm at hot state. The fuel rod dimensions are the same as those of the reference core. A fuel assembly consists of 267 fuel rods and 6 moderator rods. To further increase the neutron loss, two cases are considered for a 30 cm region below fuel; B_4C (50wt% B^{10}) for the first case and void for the second case.

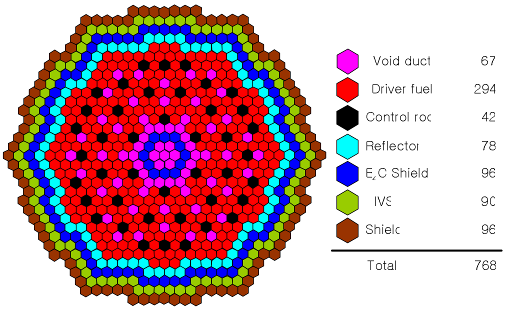

Figure 2 Configuration of the core having void duct assemblies

As shown in Figure 2, the core has a central island region consisting of non-fuel assemblies that are devised to increase neutron leakage and to reduce power peaking[4].

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 and four batch fuel management schemes are used for the reference core and the cores having the void duct assemblies, respectively. Table I shows the summary of the core performance analysis results of the reference core and two cores having void duct assemblies of 90cm core height. Of these three cores, the reference core has the largest burnup reactivity swing, the highest TRU weight percent at BOEC, and the largest positive value of the sodium void reactivity. This core can transmute 307.1kg/cycle of TRU that corresponds to the TRU amount produced from about two LWRs of the same power and cycle length. The core having void duct assemblies and using a B_4C region below fuel has the smallest value of sodium void reactivity (~994pcm at BOEC) but a least negative value of Doppler coefficient. On the other hand, the core having void duct assemblies and a void region below fuel has larger positive value of sodium void reactivity by ~400pcm than the core having void duct assemblies and a B_4C region.

Table I Core performances comparison between the reference core and the cores having void duct assemblies

Parameters	Reference core	B_4C below fuel	Void below fuel
Average conversion ratio	0.6493	0.6588	0.7190
Burnup reactivity swing (pcm)	3127	2879	2634
Average discharge burnup (MWD/kg)	116.3	121.7	121.0
Average TRU wt% in HM (BOEC)	40.6	34.4	31.3
TRU consumption rate (kg/cycle)	307.1	279.5	239.8
TRU support ratio	2.18	1.98	1.70
Average power density (W/cc)	207.9	223.6	223.1
Peak linear power (W/cm, BOEC/EOEC)	298.5/290.7	307.0/301.1	292.6/287.2
Fast neutron fluence (n/cm^2, E>0.1MeV)	2.945×10^{23}	3.835×10^{23}	3.777×10^{23}
Doppler coefficient (BOEC, dρ/dT)	$-0.00272T^{-0.98}$	$-0.00321T^{-1.01}$	$-0.00391T^{-1.0}$
Sodium void reactivity (pcm, BOEC/EOEC)	2145/2199	994/1070	1432/1514

Table II Core performances changes versus the active core height

Parameters	B_4C below fuel (H=80cm)	B_4C below fuel (H=70cm)	Void below fuel (H=80cm)	Void below fuel (H=70cm)
Average conversion ratio	0.6067	0.5451	0.6749	0.6222
Burnup reactivity swing (pcm)	3323	3834	3093	3649
Average TRU wt% in HM (BOEC)	37.9	42.7	34.2	38.0
TRU consumption rate (kg/cycle)	312.7	349.8	270.5	305.5
TRU support ratio	2.21	2.47	1.91	2.16
Average power density (W/cc)	251.3	286.9	250.7	286.1
Peak linear power (W/cm, BOEC/EOEC)	339.2/332.3	379.7/370.9	321.3/315.0	358.2/351.1
Fast neutron fluence (n/cm^2, E>0.1MeV)	4.045×10^{23}	4.269×10^{23}	4.012×10^{23}	4.276×10^{23}
Doppler coefficient (BOEC, dρ/dT)	$-0.00266T^{-1.02}$	$-0.00212T^{-1.02}$	$-0.00339T^{-1.0}$	$-0.00280T^{-1.0}$
Sodium void reactivity (pcm, BOEC/EOEC)	821/899	626/705	1129/1211	947/1032

Table II compares the core performances of the cores having void duct assemblies for 80cm and 70cm core heights. For the case of using a B_4C region below fuel, the reduction of core height from 90cm to 80cm leads to an increase of TRU wt% by 8.3wt% (24%), an increase of burnup reactivity swing by 955pcm (33%), a reduction of sodium void reactivity by 368pcm (37%), and a degradation of the Doppler coefficient from -3.332E-06 to -2.0559E-06 at BOEC (at 900K).

3. Conclusion

In this paper, 600MWe sodium cooled fast reactor core designs for the effective transmutation of TRU nuclides are presented. The core performance analysis results show that the TRU support ratio ranges from 1.7 to 2.5 and that the cores having void duct assemblies have much smaller value of sodium void reactivity worth than the reference core. In particular, the core having void duct assemblies and a B_4C region below fuel has the best core performance from the view point of sodium void reactivity worth and transmutation capability. In the near future, a core T/H and a safety analysis are planned to be performed so as to show the overall feasibility of the core design considered here.

Acknowledgement

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

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