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Performance Analysis of 400MWe Sodium Cooled Fast Reactor Cores using Thick Duct Assembly for TRU burning

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1. Introduction

Of the nuclides contained in LWR spent fuel, TRU (Tranusuranics) nuclides which include plutonium and minor actinides occupy only small portion in amount but they have significant contribution to the long term radiotoxicity of LWR spent fuel in repository. To incinerate TRU from LWR spent fuel, the SFR (Sodium cooled Fast Reactor) burner cores[1,2] have been considered as the effective way due to their hard neutron spectrum and technical maturities.

In this work, new SFR core design concept where thick duct assemblies having small number of fuel pins are used in the inner core region is proposed to achieve power flattening under a single enrichment fuel and to improve TRU consumption rate. In particular, we analyzed the effect of the core height and moderators on the core performances.

2. Methods, Results, and Discussions

2.1 Description of the Core Designs

Table I summarizes the main core design parameters. We considered a fixed rating power of 400MWe (1015.6MWt). In this work, we devised a new fuel assembly concept having thick duct which is obtained by removing the fuel pins in the last ring of the normal assembly and by increasing the duck wall thickness with keeping the same assembly pitch.

Table I : Basic Design Parameters of the cores

Design parameters	*Specification*
Power [MW(electric)/MW(thermal)]	400/1015.6
Cycle length (EFPD)	332
Fuel type	TRU-U-10Zr
Number of rods per FA	[a]**271/217**
Smear density of fuel	75% TD
Duct wall thickness (mm)	[a]**3.7/11.5**
Assembly pitch (cm)	16.22
Rod outer diameter (mm)	7.5
Clad thickness (mm)	0.53

[a]Values for the normal and thick duct assemblies

As shown in Table I, the normal fuel assembly consists of 271 fuel pins (i.e., 10 rings of pins) while the new one consists of 217 pins (i.e., 9 rings of pins) and the duct wall thickness of new assembly is increased from 3.7mm to 11.5mm. So, this new fuel assembly has smaller fuel and coolant volume fractions but larger structure volume fraction than those of the normal 271 pin assembly. We located this new fuel assembly in the inner core region to achieve power flattening under a single enrichment fuel and to increase TRU consumption rate. Also, it is expected that the reduction of coolant volume fraction in the inner core region leads to the smaller coolant void worth.

In particular, we analyzed the effect of active core height and use of the moderator materials (MgO, $ZrH_{1.8}$) on the performances of the new core designs. We considered five different core heights of 90, 70, 50, and 40cm with nearly the same linear power density of ~230W/cm for all the cases, and considered different wire wrap materials of MgO and $ZrH_{1.8}$ to analyze the moderator effect. The configurations of the cores are given in Fig.1.

2.2 Core Performance Analysis

The REBUS-3 equilibrium model[3] with a nine group cross section was used to perform the core depletion analysis while the reactivity coefficients including control rod worth were evaluated using DIF3D HEX-Z nodal option and 80 group cross sections. All the cores use the four batch fuel management scheme and cycle length of 332 effective full-power days (EFPDs). Table II compare the core performances and the reactivity coefficients. First, we have to note from Table II that the core equivalent diameter only for active core region increases from 188cm to 276cm as the active core height decreases from 90cm to 40cm, which means the increase of reactor vessel size by factor of ~1.5. Also, Table II shows that the reduction of active core height from 90cm to 40cm leads to 1) an increase of the TRU support ratio from 1.03 to 2.03, 2) a decrease of the fissile conversion ration from 0.83 to 0.64, 3) an increase of TRU contents in HM (heavy metal) from 23.6 to 33.3wt% at BOEC, 4) an increase of burnup reactivity swing by ~600pcm, and 5) a substantial decrease of peak fast neutron fluence. Also, it is shown that the reduction of active core height leads to more negative reactivity coefficients except for the Doppler coefficient, reduction of sodium void worth (4.6$ to 1.7$) and a significant reduction of control rod worth. We think that some ways are required to increase the control rod worth for the short height cores. Also, it is shown that the use of $ZrH_{1.8}$ wire wrap led to significant reduction of fast neutron fluence, improvement of the Doppler coefficient, reduction of control rod worth, reduction of TRU consumption and the reduction of the sodium void worth while the effects of MgO wire wrap were minor although we did not gave the data for the core having MgO wire. Also, we gave the results for a core having normal duct assemblies both in inner and outer cores for comparison in Table II.

3. Conclusion

From the core design study, it is concluded that 1) the new assembly design concept having thick duct wall can be effectively used in SFR transmutation reactor core as a way to improve the TRU consumption rate and to achieve power flattening under a single enrichment fuel 2) the reduction of core height down to 40cm leads to a substantial increase of TRU support ratio and sodium void worth but a substantial decrease of control rod worth, and 3) $ZrH_{1.8}$ wire wrap reduces sodium void worth considerably and control rod worth while it improves the Doppler coefficient.

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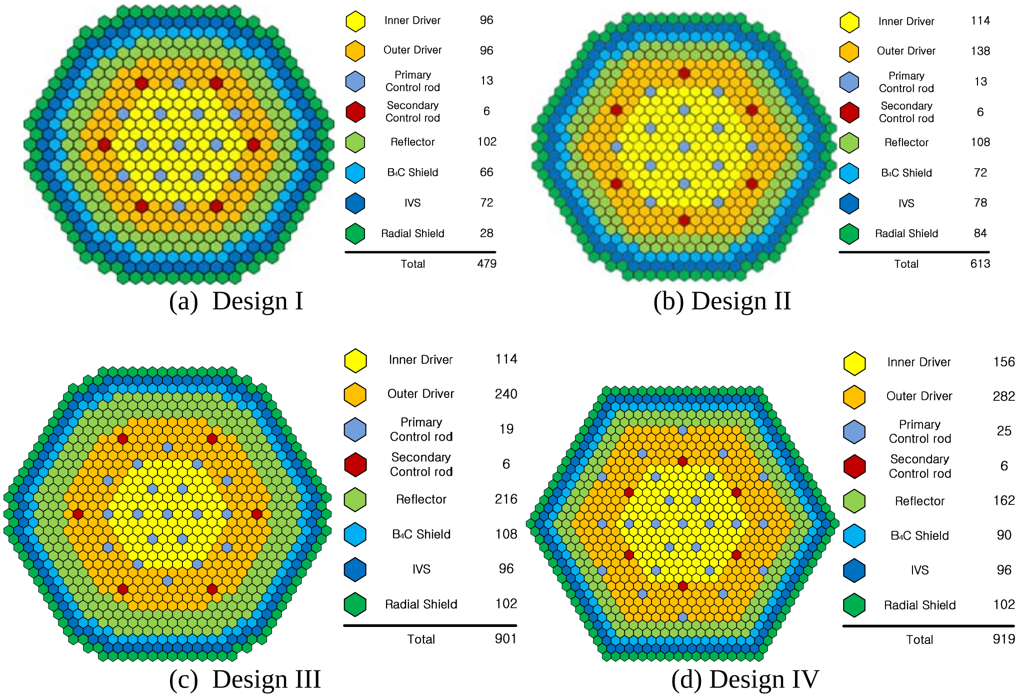

Fig.2. Configurations of the cores with different heights fuel regions in core

Table II: Comparison of Core Performances

Performance Parameters	Design I	Design II	Design III	Design IV	Design I Normal Duct	Design I Wire($ZrH_{1.80}$)
Core height	90	70	50	40	90	90
Effective core diameter (cm)	188	210	254	276	188	188
Average conversion ratio	**0.8337**	**0.7858**	**0.7091**	**0.6413**	**0.8889**	**0.8613**
Burnup reactivity swing (pcm)	2364	2587	2806	2977	1336	1718
Fuel average discharge burnup (MWD/kg)	88.64	87.20	85.25	85.11	80.93	88.5
TRU wt% in HM (BOEC/EOEC)	23.6/23.5	26.0/25.0	30.4/30.1	33.3/32.8	20.0/20.0	20.9/20.8
TRU consumption rate (kg/cycle)	97	125	161	191	67.7	94
TRU support ratio	**1.03**	**1.33**	**1.70**	**2.03**	**0.7**	**1.00**
3D power peaking factor (BOEC/EOEC)	1.50/1.48	1.47/1.45	1.44/1.41	1.44/1.41	1.54/1.48	1.73/1.69
Fast neutron fluence (n/cm^2)	$3.81x10^{23}$	$3.25x10^{23}$	$2.79x10^{23}$	$2.59x10^{23}$	$3.30x10^{23}$	$3.00x10^{23}$
Radial expansion coefficient (pcm/%)	-704	-755	-837	-887	-711	-603
Fuel axial expansion coeffient (pcm/%)	-350	-376	-416	-441	-354	-299
Sodium density coefficient (pcm/%)	18	15	7	1	21	13
Doppler coefficient ($pcm/^oC$)	-23	-19	-15	-13	-21	-44
Primary+secondary control worth (pcm)	20299	14276	11360	9733	18792	17326
Total sodium void worth (pcm)	1820	1523	996	647	2093	1357
β_{eff}	0.0033195	0.0032979	0.0032286	0.0031483	0.0034422	0.0033405