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Sodium-cooled Fast Reactor Core Designs for the TRU burning with Thorium blanket

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1. Introduction

The use of thorium[1] which is much more abundant than uranium has promise in LWR and fast spectrum reactors because thorium fuel is very proliferation resistant, results in more stable and non-leachable waste form, and produces less high level waste per unit energy production.

In this study, the SFR(Sodium-cooled Fast Reactor) burner cores are designed with thorium blanket to have smaller burnup reactivity swing but higher TRU burning capability than the typical SFR burner cores using the TRU-U-10Zr fuel. Furthermore, we expect the SFR burner cores using thorium blanket have smaller coolant void reactivity because of the fact that the η-value increases much less with energy for ^{233}U than for ^{239}Pu and ^{232}Th is less fissile than ^{238}U.

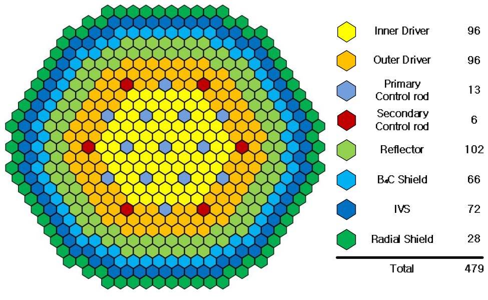
2. Core Design and Performance Analysis

2.1 Description of Core Design

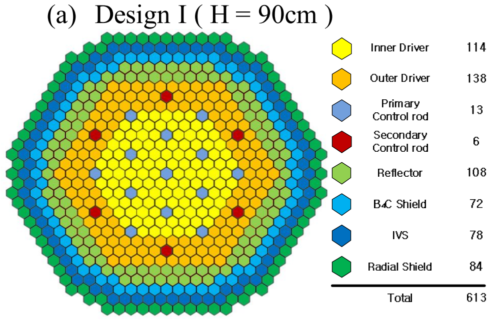
The reference layouts of SFR core are shown in Fig. 1. We considered two different active core heights of 90cm and 70cm respectively. The active fuel means the driver fuel plus blanket fuel. The cores consist of two different types of hexagonal fuel assemblies having duct. The normal fuel assemblies which are comprised of 271 fuel pins are located in the inner core region while the other type assemblies having 217pins and thick duct are in the outer core region[2]. Actually, the fuel assembly having thick duct is obtained by removing the fuel pins in the outermost ring of the normal assembly and by increasing the duck wall thickness with keeping the same assembly pitch. This type fuel assembly was devised to improve the TRU burning rate and to achieve power flattening under single fuel enrichment by reducing the fuel and sodium volume fractions. Table I summarized the main design parameters. Fig. 1(a) and (b) show the configurations of the cores having 90cm and 70cm active fuel lengths, respectively. The thorium blanket fuel (Th-10Zr) is loaded at the axially central region and the height of it is considered as a design parameter. For the 90cm high cores, we considered four different cores having the different thorium blanket heights (10cm, 20cm, 30cm, 40cm). We denote these cores by Design I(a), I(b), I(c), and I(d), respectively. For these cores, the thorium blanket is loaded both in the inner and outer cores. Also, we considered the different type cores where the thorium blanket is loaded only in the inner core. For this type of cores, we considered 30cm and 40cm thorium blanket heights that are denoted by Design II(a) and Design II(b), respectively. All the cores considered here rate 1015.6MWt (400MWe). Also, for the purpose of the comparison, we considered a reference core having no thorium blanket.

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 the DIF3D HEX-Z nodal option and 80 group cross sections. All the cores use four batch fuel management scheme and the cycle length of 332 effective full power days (EFPD). In this study, all of the actinides except for U-233 and U-234 are recycled with 99.9% recovery factor during reprocessing while U-233 and U-234 are retained without recovering in the waste. In the future, we will consider the recycling of all actinides. Table II compares the results of the core performance analysis including the reactivity coefficients for the Design I cores.



(a) Design I (H = 90cm)



(b) Design II (H = 70cm)

Fig. 1. Reference layouts of SFR core

Table II shows that the increase of the thorium blanket leads to the increase of TRU consumption rate (and TRU support ratio), the less negative Doppler coefficient, the increase of burnup reactivity swing, the decrease of control rod worth, the decrease of sodium void worth and the increase of the peaking factor. However, it should be noted in Table II that the Design I(d) core having the tallest thorium blanket has a larger burnup reactivity by only 600pcm and a smaller sodium void worth of 1329pcm at BOEC in spite of its high TRU support ratio (=2.58) in comparison with the reference core having no thorium blanket. These aspects are very promising results in designing the high performance burner cores. Also, the high power peaking resulted from the central thorium blanket seem to be no problem because the peak linear power density of 513W/cm is not too high. Table III summarizes the core performances for the Design II cores where the axially central thorium blanket is loaded only in the inner core.

Table. I. Basic Design Parameters of the Reference core

Design parameter	Specification
Power (MWe/MWt)	400/1015.6
Driver fuel type	TRU-U-10Zr
Thorium blanket fuel type	Th-10Zr
Number of rods per FA	[a]271 /217
Smear density of fuel	75%
Duct wall thickness(mm)	[a]3.7 / 11.5
Assembly pitch (cm)	16.22
Rod outer diameter(mm)	7.5
Wire wrap diameter(mm)	1.4
Clad thickness(mm)	0.53

[a]Values for the normal and thick duct assemblies

Table. II. Core performance comparison of the Cores loaded Thorium blanket (H=90cm, Th in IC/OC)

Parameters	Reference (No blanket)	Design I(a)	Design I(b)	Design I(c)	Design I(d)
Thorium blanket length	0	10	20	30	40
Average conversion ratio	0.83	0.81	0.80	0.78	0.77
Burnup reactivity swing (pcm)	2329	2199	2251	2498	2935
Average discharge burn-up (MWD/kg)	88.7	92	96	101	105
TRU wt% in HM (BOEC/EOEC)	23/23	29/28	35/34	43/43	53/52
TRU support ratio	1.05	1.47	1.88	2.25	2.58
TRU consumption rate (kg/cycle)	99	138	177	211	243
Th-232 mass (kg, BOEC/EOEC)	0	980/953	2073/2018	3116/3037	4163/4062
U-233 mass (kg, BOEC/EOEC)	0	28/43	58/90	84/131	109/170
3D power peaking factor (BOEC/EOEC)	1.51/1.49	1.57/1.55	1.78/1.69	2.07/1.92	2.52/2.25
Peaking *LPD(W/cm, IC/OC,EOEC)	369	389/331	412/359	451/406	513/476
Fast neutron fluence (n/cm^2)	3.7E+23	3.5E+23	3.4E+23	3.43E+23	3.4E+23
Doppler coefficient (pcm/K , 900K)	-22/-22	-21/-22	-20/-20	-18/-19	-16/-18
Total core sodium void worth (pcm)	1751/1850	1777/1822	1704/1722	1553/1567	1329/1356
Primary control rod worth (pcm)	17184/17500	17416/17814	16468/17072	15160/15995	13618/14640

*LPD :linear power density

Table. III. Core performances (H=70cm, Th in IC)

Parameters	Design II(a)	Design II(b)
Thorium blanket length	30	40
Average conversion ratio	0.75	0.74
Burnup reactivity swing (pcm)	3158	3619
Average discharge burn-up (MWD/kg)	93	95
TRU wt% in HM (BOEC/EOEC)	34/34	36/36
TRU support ratio	1.96	2.08
TRU consumption rate (kg/cycle)	186	139
Loading Mass of the Reactor		
Th232 (kg/cycle) (BOEC/EOEC)	1633/1598	2187/2146
U-233 (kg/cycle) (BOEC/EOEC)	39/61	47/75
3D power peaking factor	1.92/1.82	2.12/2.00
Peaking LPD(W/cm, IC/OC,EOEC)	330/660	332/966
Fast neutron fluence (n/cm^2)	3.45E+23	3.72E+23
Doppler coefficient (pcm/K , 900K)	-14/-15	-13/-14
Total core sodium void worth (pcm)	1019/1158	810/956
Primary control rod worth (pcm)	6267/7012	5251/5916

Table III shows that the loading of the thorium blanket only in the inner core slightly reduces the power peaking and sodium void worth significantly but the control rod worth is reduced considerably and the burnup reactivity swing is significantly increased due to the less breeding of U-233 because of low power in the thorium blanket region.

3. Conclusion

From the results, it is found that use of the thorium blanket both in inner and outer cores gives several desirable features such as the reduction of sodium void worth, small burnup reactivity swing but less negative Doppler coefficient and reduced control rod worth and that the use of thorium blanket only in the inner core gives much smaller sodium void worth but larger burnup reactivity swing than the cores using thorium blanket both in the inner and outer cores.

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REFERENCES

[1] Thorium Fuel Cycle-Potential Benefits and Challenges, IAEA-TECDOC-1450, IAEA, 2005.
[2] D. Y. Kim et al., "Performance Analysis of 400MWe Sodium Cooled Fast Reactor Cores using Thick Duct Assemblies for TRU Burning, submitted to this conference.
[3] B. J. Toppel, "A User's Guide to the REBUS-3 Fuel Cycle Analysis Capability," ANL-83-2, ANL (1983).