Proceedings of the Reactor Physics Asia 2015 (RPHA15) Conference
Jeju, Korea, Sept. 16-18, 2015

Breeding performance improvement of Th-^{233}U fueled, Sodium-cooled fast reactor with low void reactivity

Naoki TAKAYAMA[a*], Ken NAKAJIMA[a] and Naoyuki TAKAKI[b,]
[a]*Kyoto University, Japan*
[b]*Tokyo City University, Japan*
[*]takayama.naoki.46r@st.kyoto-u.ac.jp

1. Introduction

Generally, an FBR (fast breeder reactor) core with U-Pu fuel has flat geometry to enhance a neutron leakage and reduce a sodium void reactivity. Thus, the neutron economy isn't good in the FBR core.

Although the η value of ^{233}U-Th fuel is smaller than U-Pu fuel in a fast spectrum, that of ^{233}U-Th fuel has smaller energy dependence than Pu-U fuel. Then, if we use ^{233}U-Th fuel for FBR, the sodium void reactivity will be decreased. In addition, we possibly can extend a core height to enhance the neutron economy [1].

In this paper, we assume to use a Th-^{233}UO$_2$ fuel for an FBR core to achieve a low void reactivity. We adjust the reactor specifications to obtain the optimized aspect ratio (core height/diameter) under the design constraint conditions which are quoted from Pu-U fueled JSFR. However, the breeding ratio is aimed at 1.0 as a first step. To obtain the exact breeding ratio, the effects of cooling time and loss in reprocessing etc. should be considered. Those are not treated in the present study, and they are the future tasks.

2. Calculation conditions

The JSFR (Japan Sodium cooled Fast Reactor) core [2] is employed as a reference core. Table 1 shows the basic specifications of the JSFR. In this reactor, one sixth of the loaded fuel is exchanged in a cycle. We found that the core become equilibrium after 8 cycles, because the change of keff's between 7- and 8-cycle (at the same time in a cycle) was very small, about 10^{-4}.

Table.1. Specifications of JSFR (Demonstration core)

Thermal power [MW]		1765
Electrical power [MW]		750
Cycle length [month]		18
Batch number	core	6
	blanket	6
Fuel assembly in core	inner	157
	outer	117
	total	274
Fuel assembly in radial blanket		66
Control rod		27
Radial shield	SUS	72
	Zr-H	162

The ^{233}U enrichments are adjusted by following condition : k-eff comes into 1.0018～1.0022 at EOC (end of cycle) and the difference of maximum linear heat generation ratio between inner core and outer core is smaller than 5%. Figure 1 shows the calculation geometry. The effective cross sections are processed by the SLAROM[3] with the JENDL-3.3[4] as nuclear data library. The core calculations and the burnup calculations are performed using the CITATION[3].

First, we assumed three cores with different aspect ratio as shown in Figure 2. These cores are based on the JFSR core. In order to change the aspect ratio, fuel assemblies at most outer layer in the outer core are removed and the core height is increased to keep the core volume (from now on, we call the JSFR core as "reference core", the cores in which fuel assemblies are removed from single or double layer as "single up core" or "double up core"). In addition, the number ratios of loaded fuel assemblies between the inner and the outer core (inner/outer) of these three cores are almost same. The thickness of the axial blanket is same length in three cores. Hence, we add radial blanket assemblies to keep the fuel inventory in all blankets.

Next, in order to adapt the design constraint conditions, we adjust the specifications of the double up core as follows;

1) The axial fuels are loaded heterogeneously to reduce maximum linear heat generation (see Figure 3).
2) The fuel pin pitch is expanded to reduce pressure loss.
3) The operational cycle length is decreased to enhance breeding performance by increasing fertile inventory.

We call the above core as modified double up core. Table2 shows the specifications of four cores.

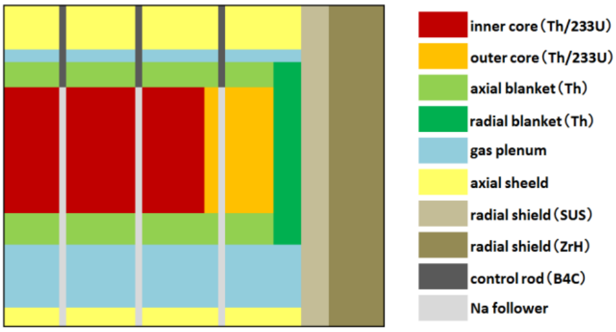

Figure.1. Cross section of reactor model (1/2core)

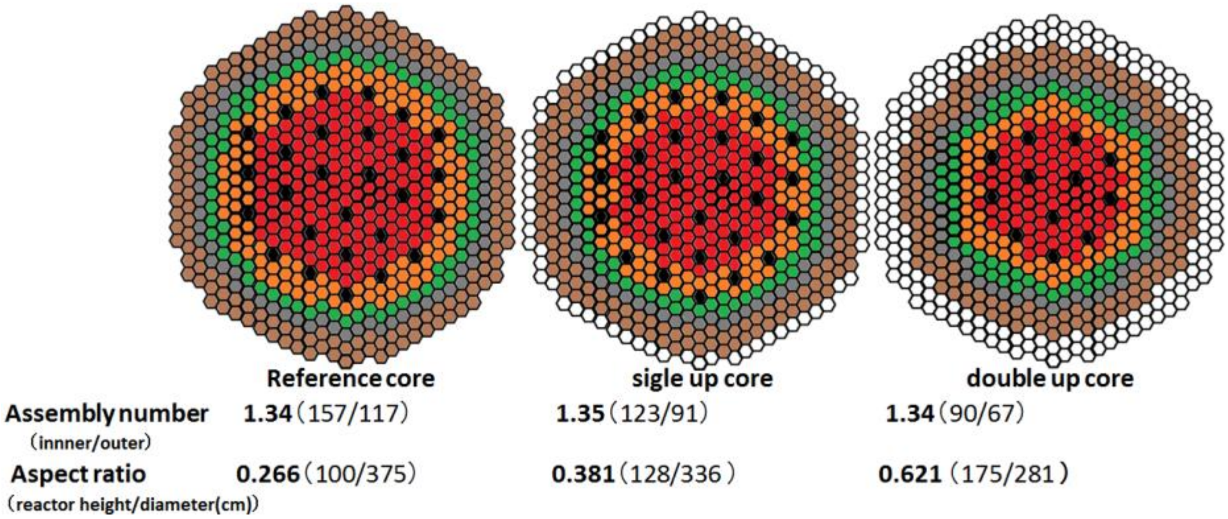

Figure.2. Core configurations (Fuel assembly layout

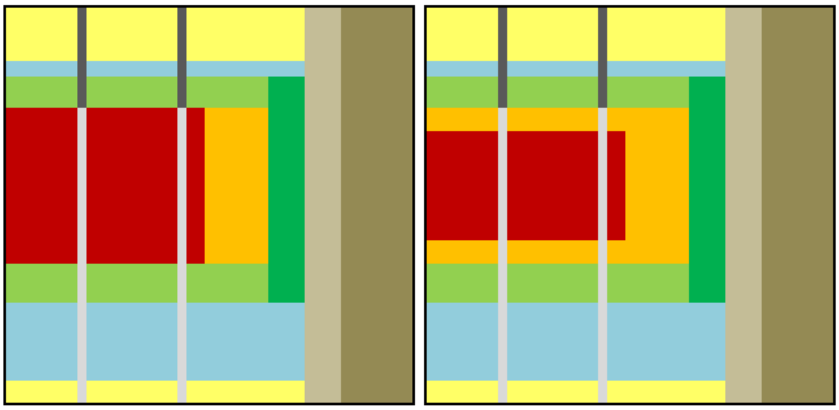
Double up core
Modified double up core

Figure.3. Axial profiles of the double up and modified double up cores

Table.2. Specifications of the investigated cores

	U-Pu core[1]	Reference core	Single up core	Double up core	Modified double up core
Aspect ratio	0.27	0.27	0.38	0.62	0.57
Fuel pin length[cm] core gas plenum	260 100 115	260 100 115	320 127 147	420 175 201	308 175 88
Equivalent diameter[cm] core	530 375	530 375	497 336	451 281	485 306
Pin gap[mm]	1.03	1.03	1.03	1.03	2.21
Cycle length[day]	548	548	548	548	274
Pu, ^{233}U enrichment (inner/outer[wt%])	18.0/23.4	15.2/19.2	13.9/18.5	12.8/18.0	11.2/16.3

3. Results and Discussion

Figure 4 shows neutron spectrum of the four cores. As seen in the figure, the neutron spectrum shifts to soft one with the larger aspect ratio due to the decrease of neutron leakage. Table 3 shows the numerical results of the core characteristics. The breeding ratios of single up and double up cores are increasing compared with the reference one. This means the neutron economy is improved (in other words, ^{233}U enrichment becomes low). Thus, the burnup reactivity and the Doppler coefficients of the single up and double up cores are also

Table.3. Reactor characteristics of the investigated cores

	U-Pu core[1]	Reference core	Single up core	Double up core	Modified double up core	Design constraint conditions
Breeding ratio(average)	1.1	0.88	0.91	0.95	1.00	≧ 1 (≧ 1.1～1.2)
Sodium void reactivity (BOC)[$]	5.0	1.1	1.9	2.5	1.9	< 6
Doppler coefficient [10^{-3}Tdk/dt]	-5.6	-8.8	-9.5	-10.0	-12.7	< -5
Maximum linear heat (inner/outer)[W/cm]	374/364	434/433	442/443	443/442	392/391	< 430
Pressure loss (except gas plenum) [MPa]	0.19	0.23	0.40	0.82	0.19	< 0.2
Burnup reactivity [Δk/kk'%]	1.8	4.6	4.5	4.1	1.8	< 3
Burnup (average over the driver fuel)[GWd/t]	151	167	168	169	87	< 150
Irradiation quantity by fast neutron [n/cm^2]	5.2×10^{23}	4.3×10^{23}	4.6×10^{23}	4.9×10^{23}	2.3×10^{23}	$< 5\times10^{23}$
CDF (clad)	0.36	0.16	0.15	0.17	0.49	< 0.5

improved. However, with the large aspect ratio, the maximum linear heat generation has large value, because the neutron leakage is decreased. Moreover, the pressure loss and the sodium void reactivity are increased because of increasing core height.

Consequently, we have employed the modified double up core that satisfies all of the constraint conditions shown in Table 3.

4. Conclusions

We have studied the breeding reactor fueled with Th-^{233}UO$_2$ on the basis of JSFR core design under the design constraint conditions. In order to improve the breeding ratio of single up or double up core with the improved neutron economy, the aspect ratio was changed in the range of 0.27 to 0.62. However, the evaluated parameters (including breeding ratio) did not agree with the design constraint conditions. As a countermeasure, by employing the fuel with axial heterogeneity, expansion of pin gap and decrease of the operational cycle length, it became possible to achieve the purpose.

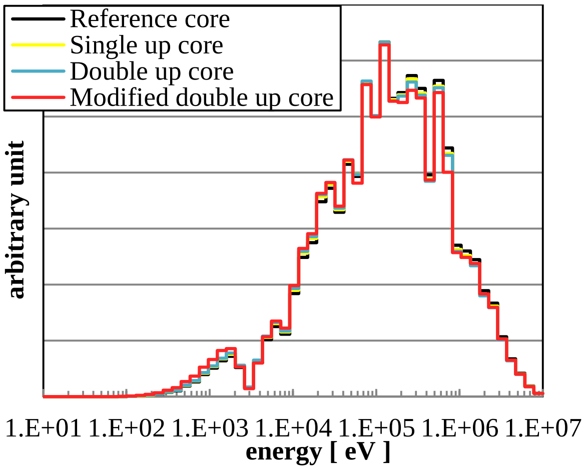

Figure.4. Neutron spectrum of investigated cores

References

1. T. Kabaya, "Neutronic performance evaluation for a medium-scale sodium cooled fast reactor using Th fuel," *AESJ annual meeting*, Hachinohe, Japan (2013).
2. Advanced Nuclear System Research and Development Directorate Research and Development Department, The Japan Atomic Power Company, "*Fast Reactor Cycle Technology Development Project (FaCT Project) -Phase I Report-*," JAEA- Evaluation 2011 -003 (2011).
3. M. Nakagawa, J. Abe and W. Sato, "*Code System for Fast Reactor Neutronics Analysis*," JAERI-M83-066, Japan Atomic Energy Research Institute (1998).
4. K. Shibata, T. Kawano, T. Nakagawa, O. Iwamoto, J. Katakura, T. Fukahori, S. Chiba, A. Hasegawa, T. Murata, H. Matsunobu, T. Ohsawa, Y. Nakajima, T. Yoshida, A. Zukeran, M. Kawai, M. Baba, M. Ishikawa, T. Asami, T. Watanabe, Y. Watanabe, M. Igashira, N. Yamamuro, H. Kitazawa, N. Yamano and H. Takano: "Japanese Evaluated Nuclear Data Library Version 3 Revision-3: JENDL-3.3," *J. Nucl. Sci. Technol.*, **39**, 1125 (2002).