TRU Transmutation Core Design with a Single Enrichment Fuel

Hoon Song, Sang Ji Kim and Yeong Il Kim
Korea Atomic Energy Research Institute, 150 Duckjin-Dong, Yuseong-Gu, Daejon, 305-353, hsong@kaeri.re.kr

1. Introduction

To improve a possibility of a sodium cooled reactor's commercialization, Korea Atomic Energy Research Institute(KAERI) has developed a 600MWe sodium cooled fast reactor[1], the KALIMER-600 reactor using a single enrichment fuel. As an alternative plan, a transmutation core design is also being performed. In the early stage of the development of a fast reactor, the main purpose is an economical use of a uranium resource but nowadays in addition to the maximum utilization of a uranium resource, the transmutation of a high level radioactive waste is taken as an additional interest for the harmony of the environment.

In this paper, the design work has been preformed using the KALIMER-600 breakeven core for a transmutation core. For this, we tried to maintain the fuel design of the KALIMER-600 breakeven core as much as possible and to increase the fuel cladding thickness and reduce the active core height to ensure its transmutation capability.

2. Core Design and Performance Analysis

2.1 Description of the Core Design

The KALIMER-600 (Korea Advanced Liquid Metal Cooled Reactor) having the breakeven breeding characteristics[1] is used as a reference core. In the KALIMER-600 core design, the power peaking control under single enrichment was achieved by using the region-wise cladding thickness but all non-fuel rods are removed to simplify the fuel assembly design.

Table 1 summarizes the basic design parameters used in the reference core. The hexagonal driver fuel assembly consists of 271 rods within a duct wrapper. The rod outer diameter is 0.9cm and the wire wrap diameter is 0.14mm. The duct wall thickness is 3.7mm and the gap distance between ducts is 4mm.

Figure 1 shows the selected core configuration. The core configuration is a radially homogeneous one that incorporates annular rings with a single enrichment. The active core consists of three driver fuel regions (i.e., inner, middle, outer core regions) and three annular core regions have 117, 96, and 120 fuel assemblies, respectively.

Two transmutation core designs are developed to get supporting ratio around 2.0. The first core design, Design-1, inherited the basic concept of a reference core so that the region-wise cladding thickness was varied to reduce the conversion ratio and control power flattening. The second core, Design-2, used the concept of reducing the active core height. Design-1 was established by way of finding the proper average fuel cladding thickness to give a supporting ratio around 2.0 with an average fuel cladding thickness varying from 0.1cm to 0.2cm in the case of a 9.0mm rod outer diameter. After the selection of 0.17cm for an average fuel cladding thickness a region-wise search varying the fuel cladding thickness was performed to reduce the power peaking factor. For design-2, the active core height varied from 90cm to 50cm with a fuel rod outer diameter between 9.0mm and 7.0mm.

Table 1 Basic design parameters

Parameters	Design value
Fuel type	TRU-U-10Zr
Number of rods/FA	271
Number of fuel rods/FA (Inner/middle/outer core)	 (117/96/120)
Core height(cm)	94
Material of the region below fuel	Graphite
Thickness(cm) of the region below fuel	15
Structural material	HT-9M

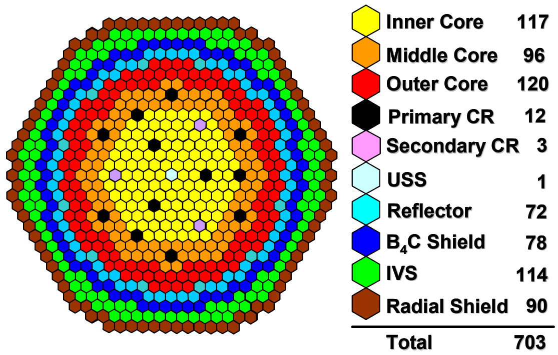

Figure 1 Core configuration

2.2 Core Performance Analysis Results

The REBUS-3[2] equilibrium model with a nine group cross section was used to perform the core depletion analysis. The cycle length is adjusted to get the reactivity swing around 3000pcm because the large reactivity swing can be a burden for control requirement.

Table 2 shows the summary of the core performance analysis results meeting the design target that the supporting ratio is around 2.0. The design-1 core has the same height as the reference core but does the thick fuel cladding thickness. Design-2 has the same fuel cladding thickness but has the reduced active core height to get the sufficient conversion ratio which is related to the transmutation amount. The burnup reactivity swing was adjusted to around 3000pcm because the reactivity swing has a direct impact on the available shutdown worth of the control system. This relatively large value of a burnup reactivity swing is due to the small conversion ratio. The reference core has 4 batches while the transmutation cores have 6 batches. To adjust the reactivity swing, the fuel cycle length and the number of fuel batches are adjusted

Table 2 Core performance comparison

Performance parameter	Reference	Design-I	Design-2
Fuel rod outer diameter(mm)	9	9	7
Core height(cm)	94	94	52
Batch	4	6	6
Cycle length(EFPD)	540	332	200
Fuel cladding thickness(inner)	0.102	0.190	0.102
Fuel cladding thickness(middle)	0.072	0.170	0.072
Fuel cladding thickness(outer)	0.059	0.152	0.059
TRU enrichment(%)BOEC	15.51	35.91	36.96
TRU enrichment(%)EOEC	15.86	35.53	36.38
Conversion ratio	1.00	0.70	0.63
Peak fast fluence(10^{23}) n/cm^2	3.91	3.56	4.07
TRU consumption(kg)/cycle	3	263	177
Power density(W/cm^3)	148	148	393
Peak_to_avg	1.49	1.45	1.38
Supporting ratio	0.01	1.86	2.08
Reactivity swing(pcm)	341	2833	3412

The peak discharge fast fluence is estimated to satisfy the design limit of 4.0x10^{23} n/cm^2. The average power density is 148 W/cm^3 in Design-1 core. On the other hand, the fact that Design-2 core has 393 W/cm^3 suggests that the active core volume in Dsign-2 is small compared to Dsign-1 core.

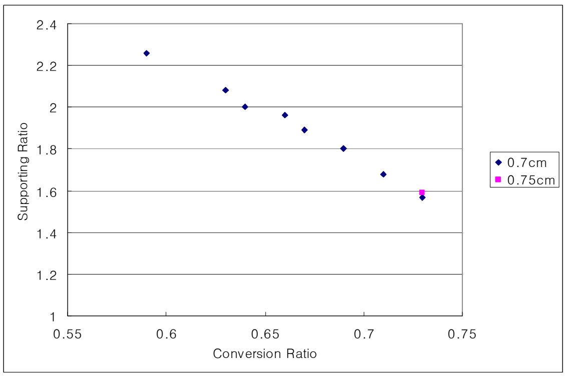

Figure 2 Supporting ratio vs. conversion ratio

The calculation shows that TRU conversion ratio is inversely proportional to the TRU enrichment and supporting ratio. Figure 2 shows the relation between the supporting ratio and conversion ratio. Supporting ratio is a kind of transmutation performance index. Figure shows that the necessary conversion ratio to get a supporting ratio around 2.0 is less than 0.65 which is related to the TRU content in the fuel assembly. It is found that the necessary TRU content to get a conversion ratio around 0.65 is around 36%.

3. Conclusion

In this paper, a TRU transmutation core was designed using the previous KALIMER 600 breakeven core as a reference core in which a power flattening is achieved by using a region-wise cladding thickness with a single enrichment fuel. In this core design, the conversion rate necessary for obtaining a sufficient transmutation quantity is obtained by varying the fuel cladding thickness and active core height. The calculation results show that the fuel cladding thickness necessary for having a TRU supporting ratio around 1.8 are 1.9, 1.7, and 1.52mm for the inner, middle, and outer core regions in the case of 9mm fuel rod outer diameter. It is also found that the TRU conversion ratio is inversely proportional to the TRU enrichment and supporting ratio.

Acknowledgement

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

REFERENCES

[1] Ser Gi Hong et al., "The KALIMER-600 Reactor Core Design Concept with Varying Fuel Cladding Thickness", Proceedings of the Korean Nuclear Society Autumn Meeting(2006).
[2] B. J. TOPPEL, "A User's Guide for the REBUS-3 Fuel Cycle Analysis Capability," ANL Report, Argonne National Laboratory 83-2, March (1983).