Isotope Separation Effect of Burnable Absorber for Long-cycle Boron-free Reactor Core

Chidong Kong [a], Jiwon Choe [a], Ho Cheol Shin [b], and Deokjung Lee [a*]
[a]*Ulsan National Institute of Science and Technology, 50, UNIST-gil, Eonyang-eup, Ulju-gun, Ulsan, 689-798, Korea*
[b]*Korea Hydro & Nuclear Power Co., Yuseong-daero, Yuseong-gu, Daejeon, 205-343, Korea*
[*]*Corresponding author: deokjung@unist.ac.kr*

1. Introduction

In a long-cycle boron-free reactor, a burnable absorber (BA) should meet the requirements that (1) excess reactivity at the beginning of cycle (BOC) be greatly reduced, (2) no rapid reactivity change occur during depletion, and (3) residual absorber penalty be completely diminished at the end of cycle (EOC). To satisfy these requirements, BA rods in the boron-free reactor should be depleted in proportion to the cycle depletion, and burned out completely at EOC. However, there remain residues of the BA to the end, which reduces the cycle length of the reactors. In order to create more economic profits, these residues should be minimized so that the cycle length can get longer. In this paper, to decrease them, ^{157}Gd, ^{149}Sm, ^{167}Er, ^{151}Eu, ^{177}Hf, and ^{133}Cd were separated from their naturally occurring elements so that the isotopes in the burnup chain of each BA were not produced. The effect of isotope separation was analyzed targeting a long-cycle boron-free reactor cycle length of which was 50 MWd/kgU.

2. Analysis Models

2.1 Introduction to SABA

From the idea of the R-BA [1], a Single-isotope Annular Burnable Absorber (SABA) was designed as Fig. 1. The Zr-BA mixture indicates the mixture of ZIRLO and a burnable absorber.

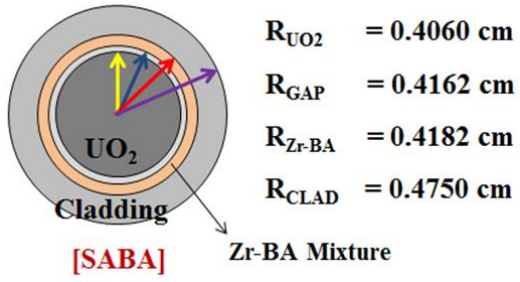

Fig. 1. SABA geometry.

As shown in Fig. 1, the radii of the SABA are 0.4060 cm for UO_2, 0.4162 cm for air gap, 0.4182 cm for the Zr-BA mixture, and 0.4750 cm for the cladding. On the other hand, the radii of the fuel pins are 0.4060 cm for UO_2, 0.4178 cm for air gap, and 0.4750 cm for the cladding. The UO_2 fuel used in this paper was enriched to 4.65 weight percent.

2.2 Case Description

As Fig. 2 shows, a 17x17 assembly was designed with 244 fuel pins, 20 SABA pins, and 25 guide tubes.

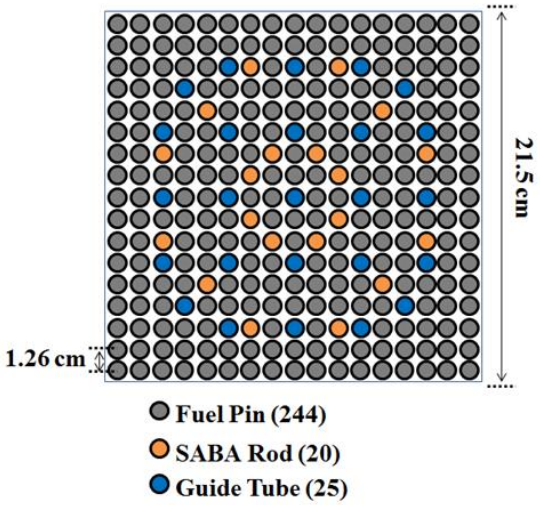

Fig. 2. 17x17 assembly configuration.

In the Zr-BA mixture of the SABA, the contents of Gd, Sm, Er, Hf, Eu, Cd, ^{157}Gd, ^{149}Sm, ^{167}Er, ^{177}Hf, ^{151}Eu, and ^{133}Cd was adjusted to make initial k_{inf} at BOC same as each other as in Table I. CASMO-4E [2] was used for all the BA analyses.

Table I: Weight Percent of Zr-BA Mixture in SABA

Isotope	Weight percent [%]	Isotope	Weight percent [%]
Gd	3.6940	^{157}Gd	0.7095
Sm	6.5450	^{149}Sm	0.9435
Er	95.2700	^{167}Er	28.5800
Hf	95.0000	^{177}Hf	37.8600
Eu	16.7700	^{151}Eu	8.6400
Cd	9.0400	^{113}Cd	1.1340

As Table I shows, the enrichment of each single isotopes is much lower than that of its naturally occurring elements because intermediate isotopes in the depletion chain are not produced. It is observed that Gadolinium, Samarium, and Cadmium show relatively low enrichment, whereas Erbium and Hafnium show high enrichment.

3. Results

3.1 Burning Rate

The amount of residue at EOC is expressed by the percent that the BA is burned. High burned percent means the small amount of residue at EOC. Figs. 3 and 4 show the percent that each naturally occurring element and single isotope is burned according to burnup.

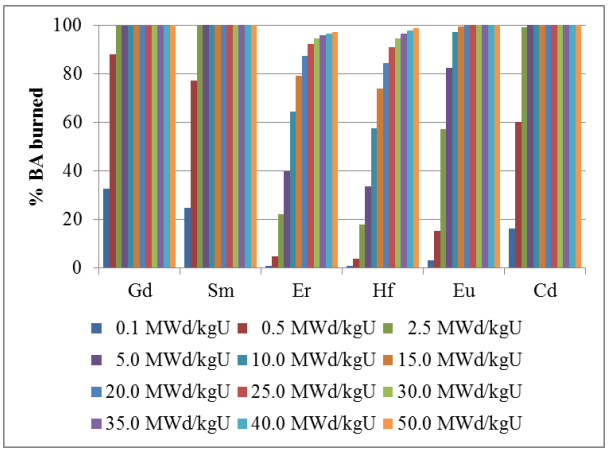

Fig. 3. Burning rate for naturally occurring elements.

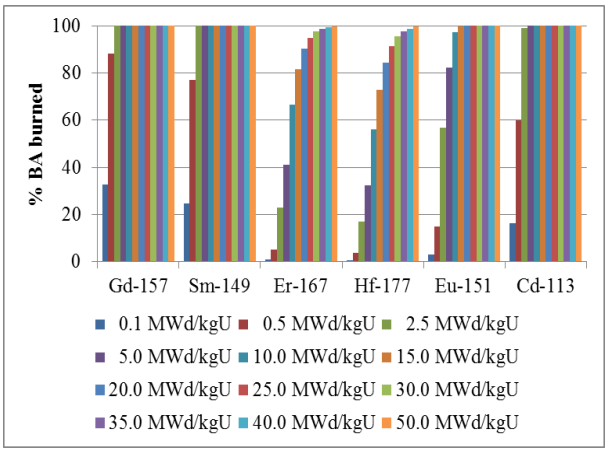

Fig. 4. Burning rate for single isotopes.

As shown in Figs. 3 and 4, Gd, Sm, Eu, Cd, ^{157}Gd, ^{149}Sm, ^{151}Eu, and ^{113}Cd were burned almost 100% within 20 MWd/kgU. On the other hand, it was confirmed that Erbium and Hafnium have big residuals left at the end. Comparing Fig. 3 with Fig. 4, it was observed that they showed a notable change between the natural elements and the single separated isotopes. In other words, ^{167}Er and ^{177}Hf showed almost 100% burned at 50 MWd/kgU, whereas their naturally occurring elements showed below the 95% burned.

Therefore, in long-cycle boron-free reactors the cycle length of which is about 50 MWd/kgU, ^{167}Er and ^{177}Hf are most appropriate among the BAs.

3.2 Assembly Lifetime

Table II shows lifetime of Erbium and Hafnium at the assembly level. Here, the assembly lifetime indicates the burnup that excess reactivity is completely vanished in the assembly calculation with the reflective boundaries. It is observed that the lifetime of each single isotope is longer than that of its naturally occurring element. Since improvement from Hf to ^{177}Hf is bigger than that from Er to ^{167}Er, it was confirmed that using ^{177}Hf is more appropriate than ^{167}Er for a long-cycle boron- free reactors.

Table II: Assembly Lifetime of Erbium and Hafnium

Case	Lifetime [MWd/kgU]	Case	Lifetime [MWd/kgU]
Er	41.1241	^{167}Er	41.4543
Hf	40.7629	^{177}Hf	41.4313

3.3 Temperature Reactivity Coefficient

Figs. 5 and 6 show the fuel temperature coefficient (FTC) and moderator temperature coefficient (MTC) of Erbium and Hafnium.

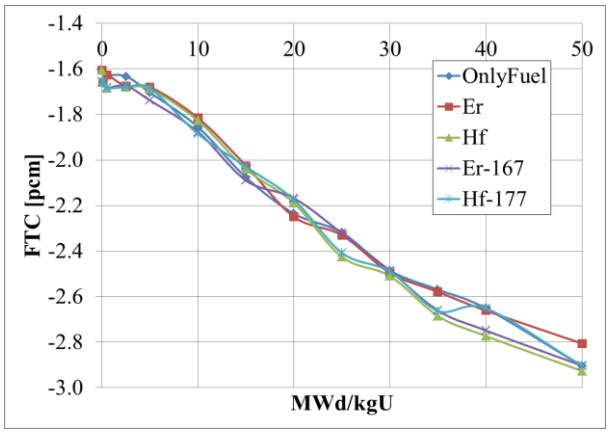

Fig. 5. Fuel temperature coefficient according to burnup

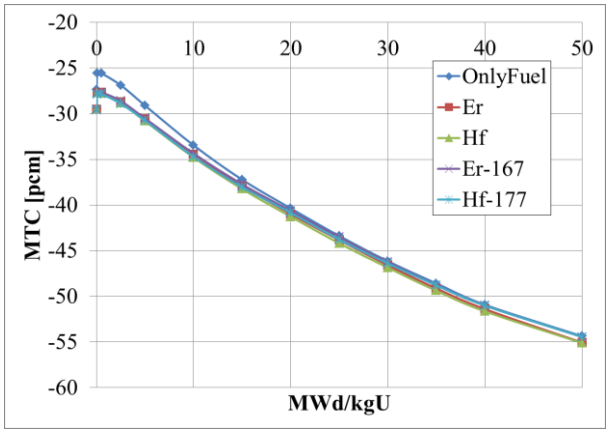

Fig. 6. Moderator temperature coefficient according to burnup

Fig. 5 shows that all cases showed similar tendency of the FTC. As shown in Fig. 6, both Hafnium and Erbium show smaller MTC than when only fuels were used.

4. Conclusions

The amount of burned BA and the corresponding assembly lifetime are analyzed to investigate the effectiveness of isotope separation for BA of a long-cycle boron-free reactor. It was noted that only Erbium and Hafnium can be burned relatively in a flat rate over the whole cycle, whereas Gd, Sm, Eu, Cd, ^{157}Gd, ^{149}Sm, ^{151}Eu, and ^{113}Cd are burned almost 100% even within the half of lifetime. In terms of assembly lifetime, Hafnium showed higher improvement than Erbium between the single isotope and its naturally occurring element. On the other hand, both burnable absorbers showed similar tendency with no-BA case in terms of FTC, and smaller MTC than that of no-BA case. In conclusion, ^{177}Hf is most appropriate for boron-free reactors the cycle length of which is 50 MWd/kgU.

REFERENCES

[1] J. Choe, C. Kong, H. C. Shin, and D. Lee, "New Burnable Absorber Design with ^{157}Gd and ^{167}Er for PWRs," In: Proceeding of ICAPP 2015, May 3-6, France, (2015).
[2] "CASMO-4E User's Manual," University Release, Studsvik Scandpower Inc., (2009).