Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 23-25, 2013

Reactivity and Power Distribution Management in LEU-loaded Linear B&BR

Donny Hartanto* and Yonghee Kim
Korea Advanced Institute of Science and Technology
291 Daehak-ro, Yuseong-gu, Daejeon, Korea, 305-701
[*]Corresponding author: hartanto_donny@kaist.ac.kr

1. Introduction

A compact sodium-cooled breed-and-burn fast reactor (B&BR) with CANDLE configuration [1] has been studied from the neutronics point of view [2&3]. PWR spent nuclear fuel (SNF) is used as the blanket fuel in order to recycle the SNF. Low-enriched uranium (LEU) is used in the initial core which is located below the blanket fuel. Several design optimizations have been performed. In this paper, the relatively high excess reactivity issue during the initial transitional period was addressed. The design target is to achieve a maximum excess reactivity of about 1.0 dollar to prevent the possibility of the prompt jump critical accident.

The initial core is divided into 2 radial Zr-zones in order to reduce the excess reactivity. By doing this, the power profile at the BOC can also be flattened. After the optimum initial core configuration has been found, the blanket region is also divided into 2 radial Zr-zones in order to flatten the power distribution at EOC. The neutronic analyses were all performed using the Monte Carlo code McCARD [4] with ENDF-B/VII.0 library.

2. Compact B&BR Concepts

The compact sodium-cooled B&BR core configuration is identical to the one in Ref. 3. The reactor power is 250 MWth (100 MWe). The thermal efficiency is assumed to be around 40%. The fuel assemblies and the reflector assemblies are arranged in an 8-ring hexagonal core as shown in Fig. 1. The core consists of 78 fuel assemblies, 78 reflector assemblies, and 7 control rod assemblies. In the axial direction, a 40 cm axial HT-9 reflector is located at the bottom of the core, while a 40 cm-thick gas plenum filled with bonding sodium is placed at the top of the core. The equivalent core radius is 115 cm. The total core height is 150 cm.

The fuel assembly (FA) consists of 127 fuel pins. The fuel pin diameter and P/D ratio is 1.9 cm and 1.064, respectively. The HT-9 cladding thickness is 0.06 cm. The radial reflector consists of 91 pins. The pin diameter is 2.32 cm. The reflector is LME (Lead Magnesium Eutectic) [5]. The HT-9 cladding thickness in the reflector pin is 0.10 cm.

3. Analysis Results and Discussion

3.1 Initial core Optimization

The radial layout of the initial core in this study is shown in Fig. 1. The LEU fuel assemblies with a higher Zr content (LEU-10Zr) are located in the inner region of the initial core, and the LEU fuel assemblies with a lower Zr content (LEU-7Zr) are located in the peripheral region of the initial core. The Zr-zoning is to flatten the radial power distribution. Meanwhile, in the blanket region, uniform SNF-7Zr fuel is used. In the previous study [3] of the initial core without Zr-zoning, the LEU-7Zr and SNF-7Zr metallic fuels were used in the initial core and blanket region, respectively. The initial core height of the core without Zr-zoning is 70 cm.

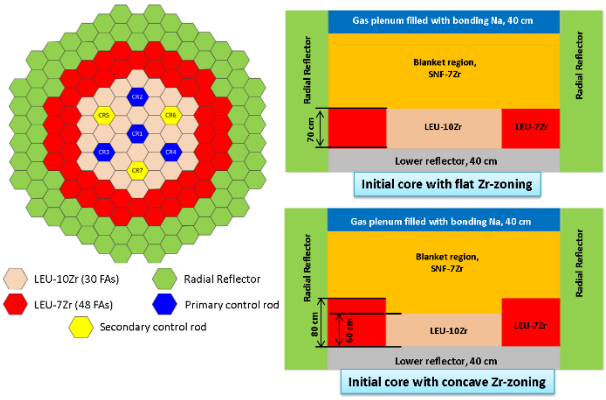

Fig. 1. Radial and axial core configuration with Zr-zoning

Two axial models were considered for the initial core region as shown in Fig. 1: the flat and the concave axial configurations. The height of the flat initial core model is the same for both the LEU-10Zr and LEU-7Zr fuel assemblies, which is 70 cm. However, in the concave configuration, the LEU-7Zr fuel assemblies are taller (80 cm) than the LEU-10Zr fuel assemblies (60 cm). The concave core is introduced to minimize the excess reactivity.

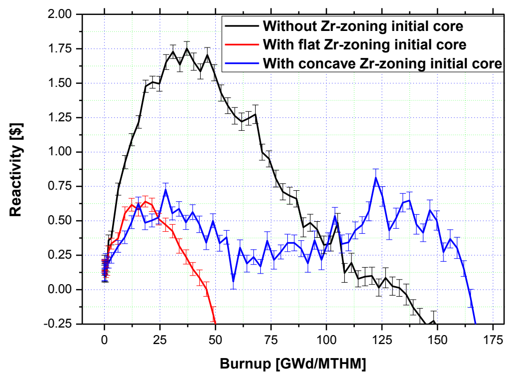

Fig. 2. Evolution of excess reactivity of each core

Monte Carlo depletion calculations have been performed with the McCARD code for the 3 core configurations: without Zr-zoning, with flat Zr-zoning, and with concave Zr-zoning initial core. The LEU enrichment in each core is 11.97%, 12.33%, and 12.50%. The comparison of the excess reactivity evolution through the core lifetime for the models is shown in Fig. 2. It is shown that the maximum excess reactivity can be maintained well below 1.0$ in the concave core, and the core lifetime can also be longer. The core lifetime for the concave Zr-zoning initial core is about 162 GWd/MTHM. It is interesting to note that the concave concept is advantageous in terms of the peak excess reactivity and the core lifetime. As shown in Fig. 3, one can note that the radial power distribution can be flattened particularly at BOC due to the Zr-zoning in the initial core.

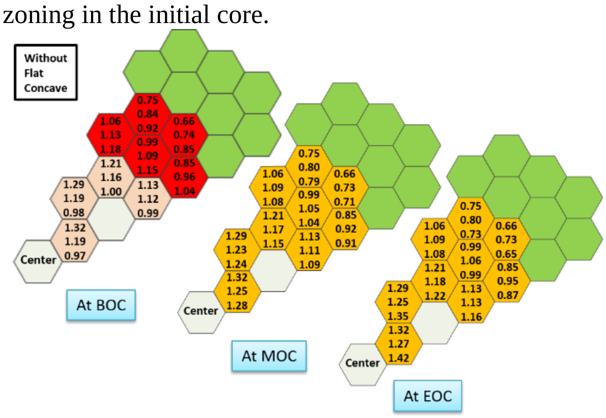

Fig. 3. Radial power distribution of each core

3.2 Zr-zoning in the blanket region

The radial Zr-zoning is applied to the blanket region in the concave initial core configuration in order to flatten the power profile at EOC. The SNF with higher Zr content (SNF-9Zr) is located only in the first and second ring of the hexagonal core because it is obvious from Fig. 4 that the peak power profile occurs on the fuel assemblies in those locations. The other blanket fuels are with lower Zr-content, SNF-6Zr.

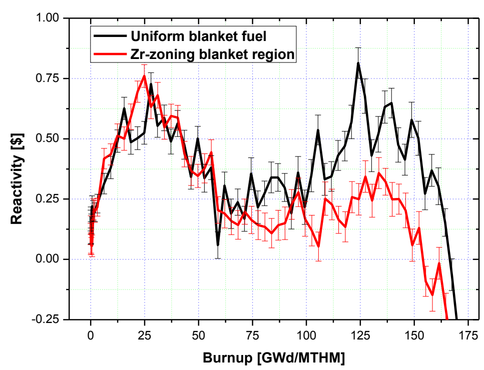

Fig. 4. Evolution of excess reactivity for uniform and Zr-zoning blanket region

The comparison of the excess reactivity through the core lifetime for core with uniform and Zr-zoning blanket is shown in Fig. 4. The excess reactivity is still lower than 1.0$. The core lifetime is reduced to 152.17 GWd/MTHM with Zr-zoning blanket region due to reduction of the SNF. To achieve a longer lifetime, the SNF blanket should be increased in 2 possible ways: either reducing the Zr-content further or increasing the core height.

In Fig. 5, the power profile of the core with Zr-zoning blanket region is shown. The peak radial power can be slightly reduced from 1.42 to 1.36 by using the Zr-zoning blanket core.

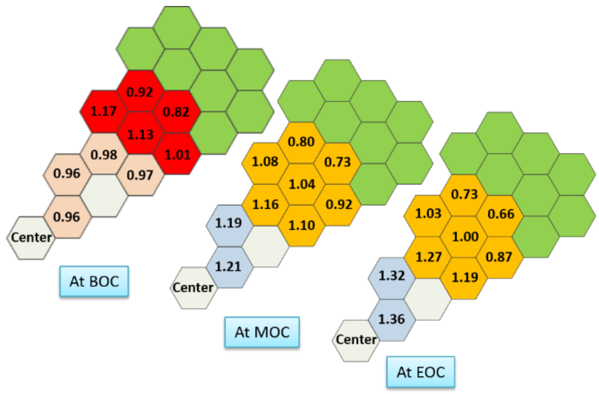

Fig. 5. Radial power distribution of core with Zr-zoned blanket region

4. Conclusions

It was found that by using the concave Zr-zoning in the initial core of B&BR, the maximum excess reactivity can be effectively lowered. The radial power profile can also be successfully flattened by using the Zr-zoning and concave initial core. The concave concept deserves more investigations for better performances of the B&BR core.

REFERENCES

[1] H. Sekimoto, K. Ryu, and Y. Yoshimura, CANDLE: The New Burnup Strategy, Nuclear Science and Engineering, Vol.139, p.306, 2001.
[2] D. Hartanto and Y. Kim, A Compact Breed and Burn Fast Reactor Using Spent Nuclear Fuel Blanket, Proceedings of PHYSOR 2012, April 15-20, 2012, Knoxville, Tennessee, USA.
[3] D. Hartanto and Y. Kim, Characterization of a Metallic-Fuelled B&BR with Non-Uniform Smear Density, Transactions of the Korean Nuclear Society Autumn Meeting 2012, October 25-26, 2012, Gyeongju, Korea.
[4] H. J. Shim and C. H. Kim, "McCARD User's Manual", Version 1.0, Nuclear Design and Analysis Laboratory, Seoul National University, 2010.
[5] D. Hartanto and Y. Kim, A Physics Study on Alternative Reflectors in a Compact Sodium-cooled Breed-and-Burn Fast Reactor, Proc. of ICAPP 2013, April 14-18, 2013, Jeju, Korea.