Transactions of the Korean Nuclear Society Autumn Meeting
Pyeongchang, Korea, October 30-31, 2014

Burnable Absorbers with Enriched Er-167 in PWR Fuel Assembly

Jiwon Choe [a], Chidong Kong[a], Deokjung Lee[a*], Ho Cheol Shin[b]
[a]*Ulsan National Institute of Science and Technology, UNIST-gil 50, Eonyang-eup, Ulju-gun, Ulsan, 689-798, Korea*
[b]*KHNP-CRI, 70 Yuseongdaero 1312beon-gil, Yuseong-gu, Daejeon 305-343, Korea*
[*]*Corresponding author: deokjung@unist.ac.kr*

1. Introduction

Most PWRs and BWRs employ burnable absorbers to reduce the soluble boron concentration at the beginning-of-cycle (BOC) and to maintain the peak pin power below its constraint during the core depletion. Many advanced PWRs are required to have a 24-month operating cycle to improve plant economy, and to keep the boron concentration low to allow an adequately negative moderator feedback during any ATWS event through 100% core life. Unfortunately, longer cycles require higher uranium-235 enrichment and initial boron concentration in the reactor coolant. The amount of soluble boron is limited due to the requirement that the MTC must remain negative over the fuel cycle. Too much boron, typically greater than 1,300 ppm at full power, will make the MTC positive. The optimal design of burnable absorbers is key to the feasibility of this extended cycle and low boron core below the design limit of peak pin power. New concepts for burnable absorbers include changing the materials and geometry in the burnable absorber. k_{inf}, peaking factor, MTC, and control rod worth of new BAs were compared with those of the conventional BA. Fuel depletion calculations for burnable absorber evaluation were performed by the CASMO-4e lattice physics code with the ENDF/B-VI library. [3]

2. New Concept Design of Burnable Absorbers

2.1 Conventional BA

Gadolinium oxide (Gd_2O_3) is a common material used in LWR burnable absorbers. All PWR plants in Korea except Kori Unit 1 have used Gd_2O_3 for burnable absorbers. Problems with loading of Gd_2O_3 are the following [1] :

- Gd_2O_3 displaces uranium in a fuel rod and leads to a reduced heavy metal mass in the fuel assembly,
- Fuel rods mixed with Gd_2O_3 and UO_2 have lower heat conductivity, so the U-235 enrichment (2~3w/o) in the fuel rod with Gd BA is reduced to meet the design criterion regarding maximum fuel temperature.
- After the burnout of the Gd, there still remains a residual reactivity binding by the needless daughter isotopes of Gd^{155} and Gd^{157}.

The Gd2O3 and Er2O3 is dispersed homogeneously throughout the fuel pellets of a number of fuel rods. Integral Fuel Burnable Absorber (IFBA), developed by Westinghouse, has the configuration of a thin coating of ZrB2 to the perimeter of the fuel pellets. IFBAs can be contained within a fuel assembly in a variety of patterns with 8, 16, 64, or 104 IFBAs. The advantage of IFBA is the reduction of the peak pin power in the fuel assembly and the minimum displacement of uranium with burnable absorber materials in a fuel rod. IFBA can be distributed such that over 99% is burned in the first 120 days, but this is not ideal if a long fuel cycle is desired. Another disadvantage of IFBA is the production of helium by the reaction between B10 and neutrons. The helium increases the internal pressure of the fuel rods. [2]

2.2 New inner clad coated BA

An ideal burnable absorber for a longer cycle (24 or 34 months) should:

- have a low residual penalty at EOC
- maintain the peak pin power below its constraint
- keep the excess reactivity evenly throughout core life
- control the magnitude of the excess reactivity easily.

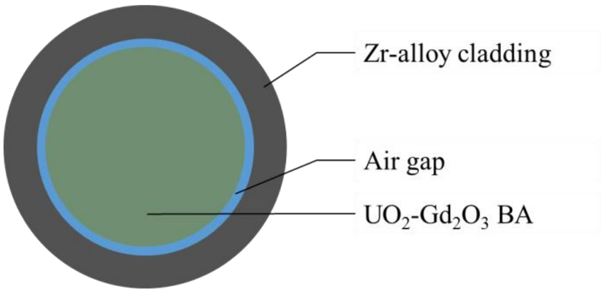

Fig. 1. UO_2-Gd_2O_3 burnable absorber pin

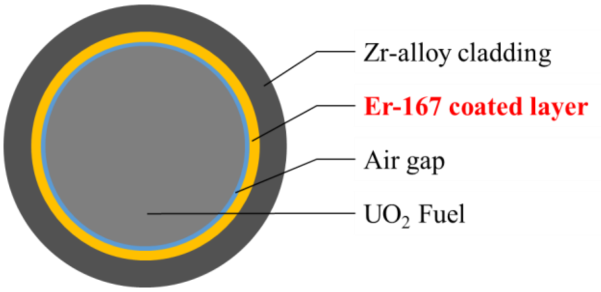

Fig. 2. Er-167 coated fuel pin

The new BA has two major differences from Gd BA shown in Fig. 1 and Fig. 2. The first one is that the fuel pellets are surrounded with a thin tube of $ZrEr_2$ for a number of fuel rods or the inside wall of fuel cladding is coated with $ZrEr_2$. It is useful to reduce the amount of UO2 displaced by the materials of BA and to contain more BAs in the fuel assembly. The second one is the usage of enriched Er^{167} (22.9% natural isotopic abundance) among the natural Erbium. It is useful to reduce the residual penalty of BA and to extend the length of cycle at the EOL.

2.3 Test cases

There are 3 test cases to evaluate characteristics of the new type of burnable absorber. The fuel assembly model is a Westinghouse type 17x17 assembly. The fuel rod material is UO_2 which is 4.65 wt% enriched U-235. The boron concentration is 0 ppm. Case01 is the reference case and its information is presented in Table I and Fig. 3. Case02, summarized in Table II and Fig. 4, contains Gd_2O_3 BA rods. [4] Case03, shown in Table III and Fig. 5, contains ZrEr2 BA layered cladding.

Table I: Case01 fuel assembly information

Case	Case01
Fuel rod	UO2 4.65 wt% U-235
No. of fuel pin	264 pins
Burnable absorber	None
No. of Burnable absorber	None

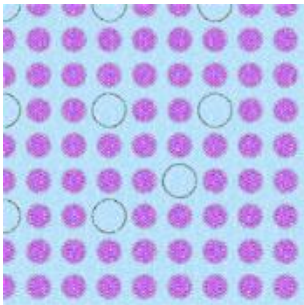

Fig. 3. Fuel assembly layout of case01

Table II: Case02 fuel assembly information

Case	Case02
Fuel rod	UO2 4.65 wt% U-235
No. of fuel pin	244 pins
Burnable absorber	UO2-Gd2O3 2.60 wt% U-235 8.00% of Gd2O3
No. of Burnable absorber	20 pins

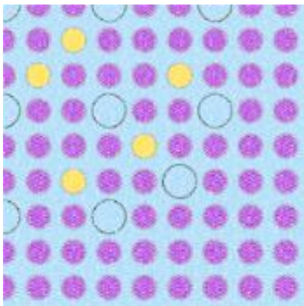

Fig. 4. Fuel assembly layout of case02

Table III: Case03 fuel assembly information

Case	Case03
Fuel rod	UO2 4.65 wt% U-235
No. of fuel pin	264 pins
Burnable absorber	Er-167 12.5 % Er-167 87.5 % of Zirlo
No. of Burnable absorber	264 pins

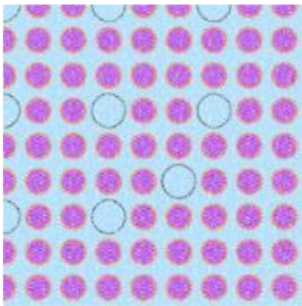

Fig. 5. Fuel assembly layout of case03

2.4 Fuel Assembly Depletion Results

The k_{inf} results are shown in Fig. 6. k_{inf} of both case02 and case03 are flattened compared with case01 due to the burnable absorbers. In the case of case02, Gd is burned out at 20 MWD/kg. In the case of case03, Er is burned out at 30 MWD/kg. Case03 is advantageous to long-cycle operation.

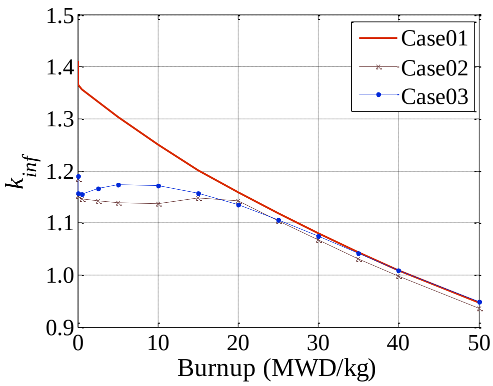

Fig. 6. k_{inf} trends

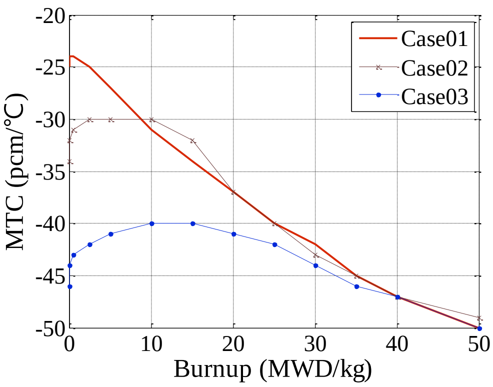

Fig. 7. Moderator temperature coefficient trends

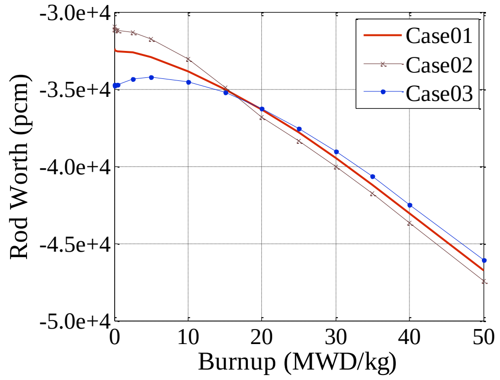

Fig. 8. Control rod worth trends

Fig. 7 shows the moderator temperature coefficient results. MTC in case03 is the most negative value, so control rod worth should possess a wide shutdown margin. Er-167 is distributed evenly, so neutrons are captured more easily by control rods. Thus, the rod worth of case03 is bigger than the other cases as shown in Fig. 8. Therefore, the shutdown margin can be secure enough.

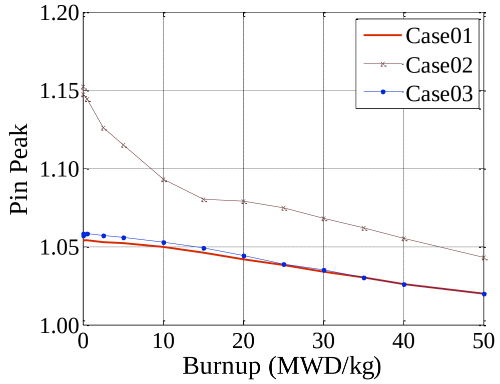

Fig. 9. Pin peak factor trends

Pin peak factor trends are shown in Fig. 9. The peak power is higher near the water slot in case02 due to Gd pins inserted inside. Fuel pins near the boundary side are more moderated than fuel pins inside. Power distribution is spread more evenly in case03 since Er-167 is located in the cladding.

3. Conclusions

A new enriched Er-167 based BA has been proposed and, from three test cases, it was shown that the Erbium burnable absorber is favorable to counterbalance the power peak and Gadolinium burnable absorber is favorable to flattening k_{inf} trends over burnup.

REFERENCES

[1] Optimization of fuel assembly with gadolinium for LWRS, Pavol Cudrnak, Vladimir Necas, Journal of Power Technologies 91 (4) (2011) 186–190

[2] C. E. Sanders, J. C. Wagner, Impact of Integral Burnable Absorbers on PWR Burnup Credit Criticality Safety Analyses Impact of Integral Burnable Absorbers on PWR Burnup Credit Criticality Safety Analyses. 2001 ANS Embedded Topical Meeting, 2001, Reno, Nevada, USA.

[3] J. Rhodes, M. Edenius, CASMO-4: A Fuel Assembly Burnup Program User's Manual, Studsvik Scandpower, 2004

[4] V. V. Novikov, E. N. Mikheev, A. V. Lysikov, I. V. Petrov, V. V. Petrov, V. V. Basov, A. S. Lupanin, Y. V. Pimenov, Property Investigations Of (U,Gd)O_2 Fuel With Higher Content Of Gadolinium Oxide, International conference on WWER fuel performance, modelling and experimental support, Burgas. Bulgaria, 2009