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A New Design Concept of Burnable Poison for Longer Cycle PWR

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1. Introduction

It is required to invent a new stronger burnable poison (BP) for designing of longer-cycle core of Pressurized Water Reactor (PWR). Existing designs of BP are working very well with 18 month cycle PWR, but when it comes to longer than 18 month cycle operation, the PWR core becomes very sensitive to the BP properties. The use of large quantity BP material is essential and prime solution to hold-down the higher excess reactivity accompanying with the longer period cycle operation. However, the design requirement goals can not be achieved well only by using the conventional BP designs [1, 2]. Therefore, there is a need to design a stronger BP with good properties without violating the design limitations of PWR core.

In this study, a new BP design concept is proposed and tested. Westinghouse (WH) 17×17 fuel assembly design is selected as a reference model. As the first step, k-infinite letdown curve, MTC and power peaking factor were calculated by DeCART-2D code and compared with the conventional BP designs.

2. Reference Design Model

In this paper only assembly calculation is done by DeCART2D code [3]. The reference design used here is WH 17×17 fuel assembly type as shown in Fig. 1. The Table I shows some of the design parameters of the same fuel assembly [4]. In the presented modeling all the design parameters are kept same as reference design except the fuel enrichment is changed into 6.96w/o which is the easy method to achieve long cycle operation length. Even though there are many different options in order to extend the cycle operation length, this method is chosen because the performance of BP is the main theme of this study [5, 6].

3. A New Design Concept

The main requirements to design BP suitable for long cycle are as follow; should be strong enough to hold-down the initial excess reactivity to adequate level, the depletion of BP should be remain as flat as possible, and the residual reactivity penalty should be as low as possible at End-Of-Cycle (EOC) [7]. The new BP design proposed in this paper is 'Matryoshka Doll Burnable Poison' (MDBP). This design consists of two tubes inside each other and covered with clad as shown in Fig.2. The outer tube consists of Al_2O_3-B_4C, where the boron is natural boron with concentration of 10.96w/o and the inner tube consists of ZIRLO mixed homogeneously with 50w/o of Er_2O_3. The expected performance from this design is to show a strong effect to hold-down the initial excess reactivity and to induce the moderator temperature coefficient (MTC) toward more negative value due to the fact that Erbium has a resonant behavior at the epithermal range (~0.5 eV) [8].

This design is not limited to two tubes and use natural boron and Erbium as absorber material only, but can contain more than two tubes inside each other and use different absorber materials with different concentrations for each tube, depend on the designer needs. MDBP design should be installed in the guide tubes that have no control rod positions. The advantages of this design are easy to manufacturing, flexible to optimize, the neutron flux can reach the absorber material from inside and outside and at refueling time MDBP can be removed from the fuel assembly. The last point means even though the absorber material dose not fully depleted, will not affect the next cycle.

In the present paper, the MDBP design is compared with the existing BP designs (Wet Annular Burnable Absorber (WABA), Gadolinia (Gad), Erbia and Integral Fuel Burnable Absorber (IFBA)) in regarding of k-infinite, MTC and power peaking factor. Figures 3, 4 and 5 show the comparison of the above BP designs with no BP case. Each case of WABA, Gad and MDBP consist of 24 pins. On the other hand, Erbia and IFBA consist of 96 pins loaded in the fuel assembly. In WABA case natural boron with concentration of 10.96w/o is used as absorber material. While, in Gad case 8.0w/o of Gd_2O_3 is mixed with 2.5w/o of UO_2. Lastly, in Erbia case 2.0w/o of Er_2O_3 is mixed with fully enriched UO_2. For all cases the normal fuel rods enrichment is about 6.96w/o.

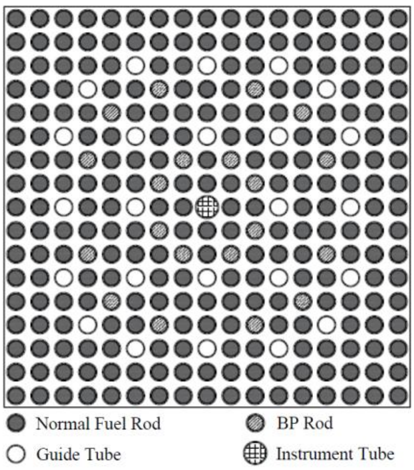

Fig. 1. Horizontal cross section of WH fuel assembly type

Table I: WH Fuel Assembly Design Parameters

Design Parameter	WH Fuel Assembly
Fuel Rod Array	17×17
Number of Fuel Rods	264
Active Fuel Length	365.76
Number of Guide Tube	24
Number of Instrumentation tube	1
Fuel Assembly Length (cm)	406.3
Fuel Assembly Pitch (cm)	21.5040
Fuel Rod Length (cm)	388.1
Cell Pitch (cm)	1.260
Fuel Diameter (cm)	0.8192
Cladding material	ZIRLO
Cladding I.D. (cm)	0.8357
Cladding O.D. (cm)	0.95
Guide Tube material	ZIRLO
Guide Tube I.D. (cm)	1.008
Guide Tube O.D. (cm)	1.224

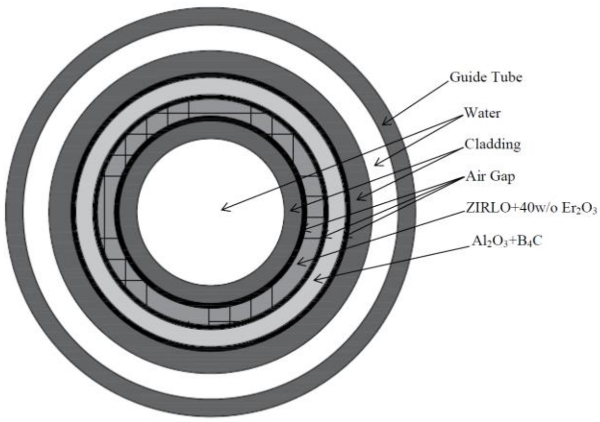

Fig. 2. Horizontal cross section of conceptual MDBP design

4. Calculation Results

As shown in Fig. 3, 96Erbia case has the lowest value of holding-down the initial excess reactivity by 7,576 pcm, due to lower neutron absorption cross section of Erbium [8]. Then 96IFBA and 24WABA cases have the values of 8,526 pcm, 10,006 pcm respectively. Finally, 24MDBP and 24Gad cases have almost same values about 12,500 pcm and 12,890 pcm respectively with difference about 390 pcm only. The values of k-infinite of all cases are decreasing gradually with the burnup steps except 96IFBA and 24Gad cases. In 96IFBA case the k-infinite starts to increase after the burnup step of 1.5 MWD/kgHM to 4.5 MWD/kgHM then decreases gradually with the burnup. Which means the boron in IFBA design is consumed very fast [8]. While, in 24Gad case the k-infinite is decreased slowly until the burnup step of 16 MWD/kgHM then starts to increase slowly until the burnup step of 22 MWD/kgHM before to start decreasing continuously with the burnup goes.

All the cases lost their ability to hold-down the excess reactivity in effective way around the burnup step of 25 MWD/kgHM (96IFBA case much before that), except 24MDBP case which it can hold-down the excess reactivity effectively until around 36 MWD/kgHM.

The residual reactivity penalty at End-Of-Life (EOL) for all cases is various. 24Gad and 96Erbia cases have the highest value of this penalty which is about 2,800 pcm and 1,180 pcm respectively. Due to the fact, Gad and Erbia displace some of the fissile material from the fuel matrix. Also, because of undestroyed high neutron absorption cross section isotopes that are generated by these two absorber materials. Furthermore, the fuel enrichment in Gad pins is not more than 2.5w/o in order to meet the design limitation for maximum fuel temperature [8]. In this study, since one of the tubes in MDBP design contains Erbia, thus some of undestroyed high neutron absorption cross section isotopes cause high residual reactivity penalty at EOL which is about 1,162 pcm. Since this design is similar to WABA design, at the EOC will be removed from the fuel assembly that makes any undestroyed high neutron absorption cross section isotopes have no effect on the flowing cycles. On the other hand, 24WABA and 96IFBA cases have residual reactivity penalty less than 300 pcm; the values in detail are 295 pcm and 111 pcm respectively. This can be explained as the latter designs do not reduce the fissile material from the fuel matrix and boron dose not generate isotopes with high neutron absorption cross section [8].

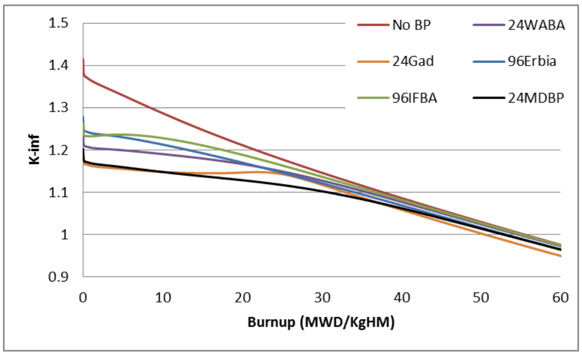

Fig. 3. Comparison of excess reactivity

Fig. 4 demonstrates the MTC (pcm/C°) versus burnup (MWD/kgHM) of No BP, 24WABA, 24Gad, 96Erbia, 96IFBA and 24MDBP cases. At the Beginning-Of-Life (BOL) 24MDBP and 96Erbia cases have the most negative MTC with values of -36.90 pcm/C° and -36.52 pcm/C° respectively. Then 24WABA, 24Gad and 96IFBA cases with values of -31.07 pcm/C°, -29.23 pcm/C° and -25.25 pcm/C° respectively. 24MDBP and 96Erbia cases continue with almost same values as the most negative MTC until the burnup step of 20 MWD/kgHM. After this burnup step 24MDBP case alone becomes the most negative MTC until the EOL. This good effect on the MTC of 24MDBP case is due to Erbia effect.

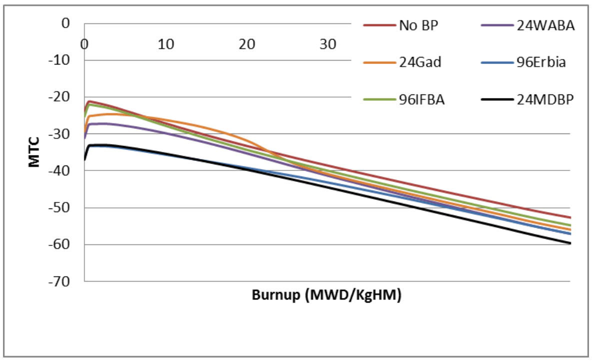

Fig. 4. Comparison of MTC

Fig. 5 shows the power peaking factor versus burnup (MWD/kgHM) of No BP, 24WABA, 24Gad, 96Erbia, 96IFBA and 24MDBP cases. At BOL the power peaking factor of 24Gad case is the highest value among all cases with value equal to 1.1326. Then 24MDBP and WABA cases have the values of 1.1193 and 1.0879 respectively. Finally, 96IFBA and 96Erbia cases have almost same values of 1.0655 and 1.0631 respectively. The power peaking values of all cases are decreasing with the increase of burnup until the EOL. Around the burnup step of 25 MWD/kgHM the values of power peaking factor of all cases become very close to each other except 24Gad case which has value much higher. Worth mentioning, for the power peaking factor any design satisfy the design limitation is acceptable. The values of power peaking factor no need to be very low.

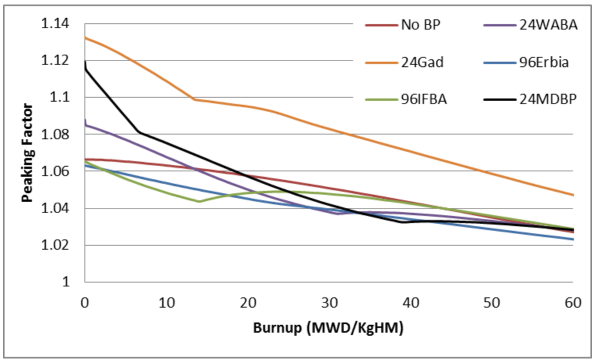

Fig. 5. Comparison of power peaking factor

5. Conclusions

Matryoshka Doll Burnable Poison (MDBP) is firstly introduced in this study. This design is a new concept of BP design that is suitable for long cycle operation PWR.

An assembly calculation was performed by DeCART2D code in order to make comparison between MDBP design and other conventional BP designs in regarding to k-infinite, MTC and power peaking factor.

24MDBP case shows an astonishing performance, which reduces the initial excess reactivity by about 43%. This performance is as strong as the performance of 24Gad case. Also, this design last longer than any other design by about 30%. Furthermore, MDBP design is same as WABA design that both of them can be removed from the fuel assembly during the refueling time which will eliminate the effect of any undestroyed high neutron absorption cross section isotopes on the following cycles. Due to the presence of Erbia in one tube of the MDBP design, guarantee the MTC value as negative as 96Erbia case. Even though any BP designs provide power peaking factor within the design limitation are acceptable, 24MDBP case has lower power peaking factor than 24Gad case.

In the near future, core calculation will be conducted to study the performance of MDBP design in whole core simulation. As well as feasibility test in core design, many aspects of engineering feasibility will be studied.

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