An Optimization Study of Gadolinia Burnable Absorber Design for Westinghouse Type 16x16 Fuel Assembly

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1. Introduction

In a nuclear reactor, there is much excess reactivity in the early stage of cycle to keep criticality until the end of cycle. To repress excess reactivity, there are used three ways of applications of neutron absorbing material: control rod, chemical shim, and burnable absorber. Since control rod makes high distortion in power distribution, it is not usually used in steady state. For chemical shim, boric acid which is easy to control and does not introduce local power distortion is used. But high concentration of boric acid causes positive moderator temperature coefficient. Thus concentration of the boric acid has limit, and burnable absorber is used for the control of additional excess reactivity. At late stage of a cycle, there is little excess reactivity. For long-term cycle operation, residual absorption effect of burnable absorber should vanish at the end of cycle. Additionally, since burnable absorber cannot be removed or changed in position during operation, it is important to optimize burnable absorber design.[1]

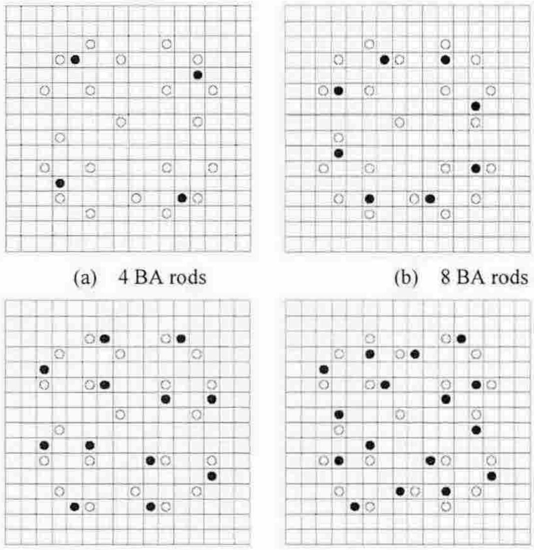
Here, we consider Gd_2O_3 as absorbing material. Gd_2O_3 has large absorption cross section which has advantage to repress excess reactivity in the early stage of cycle. In this paper, we performed several optimization processes such as positioning and determination of length of axial blanket of burnable absorber rod. The burnable absorber rod consists of 6w/o Gd_2O_3 and 2.6 w/o U-235 and is placed in 4.8 w/o U-235 fuel assembly.

2. Optimization of burnable absorber rod placement

To find optimal rod placement, we performed single-assembly burnup calculations using the HELIOS[2] code system for several models with different number of burnable absorber (BA) rods. The number of BA rods used is usually a multiple of four, considering symmetric positioning in a fuel assembly. We observed that peak power is sensitive to positions of BA rods and multiplication factor and temperature coefficients are relatively indifferent to BA rods positions. Thus, in this paper, we suggest optimal assembly types with 4, 8, 12, and 16 BA rods, where maximum peak power during depletion is minimum among the models of fuel assembly. The calculational parameters are shown in Table 1 and the resulting optimal models are shown in Figure 1.

Table 1: Calculational Parameters

moderator temperature	580K
fuel temperature	900K
boron concentration	1496 ppm
pellet outer radius	0.392176 cm
clad inner radius	0.40005 cm
clad outer radius	0.4572 cm
guide tube inner radius	0.55245 cm
guide tube outer radius	0.59817 cm
fuel enrichment	4.8 w/o
fuel density	10.34 g/cm^3



(a) 4 BA rods (b) 8 BA rods

(c) 12 BA rods (d) 16 BA rods

Figure 1. Results of optimal search of BA rod placement
(white circle : guide tube, black circle : BA rod)

3. Optimization of axial blanket length in burnable absorber rod

The axial blanket which consists of low enriched uranium is used at top and bottom of the fuel rod. For BA rod, the length of axial blanket is longer than that of fuel rod. This different use of axial blanket can lower axial peak power by removing absorbing material for relatively low power regions in axial direction. But use of too long axial blanket causes increase of radial peak power. So it would be useful to find optimal length of axial blanket in BA rod by detail burnup calculation.[4] We performed 3-D burnup calculations using the slightly modified AFEN-TH code [4] with assembly homogenized cross sections by the HELIOS code. We considered 6 inch axial blanket for normal fuel rods and 4.4 inch axial water reflector at both ends of top and bottom. The 16 month-cycle (including 1 month maintenance,450EFPD) is considered and calculational parameters are listed in Table 2 and radial configuration of a test core is shown in Figure 2.

Table 2: Calculational Parameters

Thermal Power	1876 MWth
HZP temperature	291.67 °C
System pressure	2250 psia
Total number of fuel assemblies	121
Total loading	45804 kg
Assembly pitch	19.8196 cm
Number of fuel rod per assembly	235
axial blanket	1.6 w/o U-235
Number of fresh fuel assembly	48
Active height of fuel rod	144 inch

T 40210	O 22600	T 32020	F 0 16 Gd	O 23560	F 0 8 Gd	O 23430
O 22600	O 23940	F 0 12 Gd	T 38270	F 0 16 Gd	F 0 4 Gd	T 37570
T 32020	F 0 12 Gd	T 34570	F 0 16 Gd	O 21150	O 23560	
F 0 16 Gd	T 38270	F 0 16 Gd	O 23290	F 0 4 Gd	O 19960	
O 23560	F 0 16 Gd	O 21150	F 0 4 Gd	O 23940		
F 0 8 Gd	F 0 4 Gd	O 23560	O 19960			
O 23430	T 37570					

F : Fresh fuel
O : Once burn
T : Twice burn

(F,O,T)
burnup(MWD/MTU)
# of BA rods

Figure 2. 1/4 radial configuration of a test core

Figure 3 shows the result of calculations. 13inch axial blanket for BA rod, i.e.,7 inch longer than that of normal fuel rod, seems to be optimal in this test core.

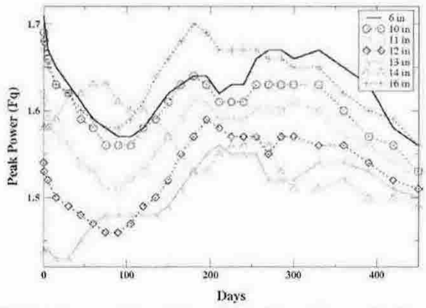


Figure 3. Total assembly peak power along the cycle for various lengths of axial blanket in BA rod

We produced several safety parameters with 6 inch/13 inch length axial blanket. Figure 4 shows the critical boron concentration and that this test core maintains criticality until the end of cycle. The excess reactivity at beginning of cycle is reduced about 750 ppm of the boric acid. The moderator and fuel temperature coefficients (MTC and FTC) are negative throughout the whole cycle as shown in Figures 5 and 6. Additionally, Figure 7 shows the radial peaking factor.

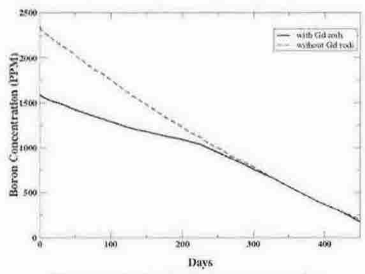


Figure 4. Critical boron concentration

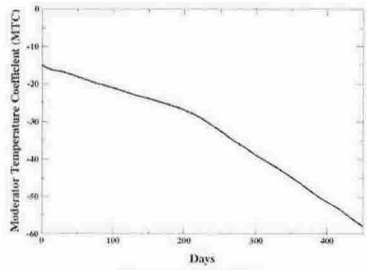


Figure 5. MTC

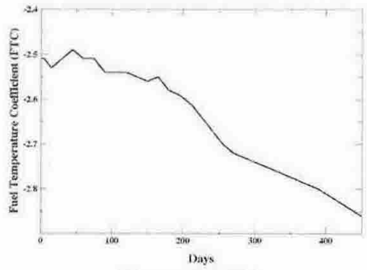


Figure 6. FTC

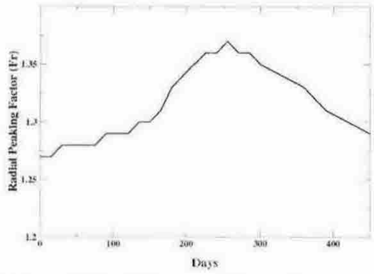


Figure 7. Radial assembly peak power

4. Conclusions

Several configurations of BA rod positions are suggested as optimal BA rod placement and shown in Figure 1. With the resulting fuel assemblies, 3-D burnup calculations have been performed to determine the optimal length of axial blanket. The peak power shows minimum when 13 inch axial blanket is used in BA rods. The results of burnup calculations with fuel assembly types and axial blanket determined show that safety parameters are satisfactory for 16 month-cycle operation and the neutron absorbing effect of BA rods is about 750 ppm boron at BOC. The results of this paper would be useful for design of a reactor core for long-term cycle operation.

REFERENCES

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