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A Neutronic Feasibility Study of an OPR-1000 Core Design with Boron-bearing Fuel

Kyung-Hoon Lee*, Sang-Yoon Park, Chung-Chan Lee, Yong-Sik Yang
Korea Atomic Energy Research Institute, Daedeok-daero 989-111, Yuseong-gu, Daejeon, 305-353, Republic of Korea
**Corresponding author: lkh@kaeri.re.kr*

1. Introduction

Burnable absorber is usually used to control excess reactivity and local power peaking, and to optimize fuel utilization. There are two significant burnable absorbing materials widely used in PWRs, such as boron and gadolinia (Gd_2O_3). In Westinghouse plants, boron is mainly used as a form of the integral fuel burnable absorber (IFBA) with a thin coating of zirconium diboride (ZrB_2) or wet annular burnable absorber (WABA) with a hollow Al_2O_3+B_4C pellet. In OPR-1000, on the other hand, gadolinia is currently employed as a form of an admixture which consists of Gd_2O_3 of 6~8 w/o and UO_2 of natural uranium.

Recently, boron-bearing UO_2 fuel (BBF) with the high density of greater than 94%TD has been developed by using a low temperature sintering technique [1]. In this paper, the feasibility of replacing conventional gadolinia-bearing UO_2 fuel (GBF) in OPR-1000 with newly developed boron-bearing fuel is evaluated.

2. Methods and Results

2.1 Design and Analysis Tools

The DeCART2D/MASTER two-step procedure is used as a reactor physics analysis tool for this study. The transport lattice calculations are performed by the DeCART2D [2] code to generate few-group cross sections, which are then tabularized as a function of burnups and temperatures by using the PROLOG code. Effective reflector cross sections are obtained by a 2-dimensional whole-core calculation using DeCART2D. A core physics analysis is carried out by the MASTER [3] code with these tabularized cross sections.

2.2 Fuel Assembly Design

Due to very high neutron absorption cross section of both ^{155}Gd and ^{157}Gd, the GBF is generally loaded in selected locations within an assembly. In the present study, the BBF with a small amount of boron is used in all rods due to relatively low neutron absorption cross section and helium production of ^{10}B. The BBF rods have same dimension as the GBF rods. The depletion characteristics of the BBF are quite different from those of the GBF. A single fuel assembly calculation was performed to identify the depletion characteristics of the BBF for which the DeCART2D calculations were done with the HELIOS [4] 47-group neutron and 18-group gamma libraries.

Fig. 1 shows the assembly k-infinity of the BBFs compared to those of the GBFs. The BBF has relatively larger initial reactivity hold-down than those of the GBF. But the k-infinity behavior of the BBF is similar to those of the GBF after 5 MWD/kgU. Thus, as shown in Fig. 1, three different assembly types divided into varied boron contents in ppm, which is defined as parts per million of additive boron weight to total uranium weight, were selected for core design.

Fig. 2 shows the depletion fraction of important burnable absorbing isotopes as a function of burnup. Both ^{155}Gd and ^{157}Gd were completely burned out at 15 MWD/kgU, while ^{10}B was depleted up to ~90%.

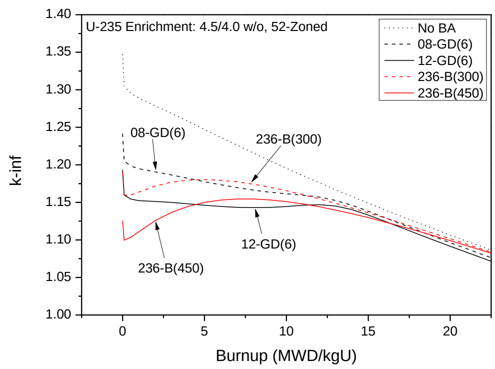


Fig. 1. Assembly k-infinity between GBFs and BBFs.

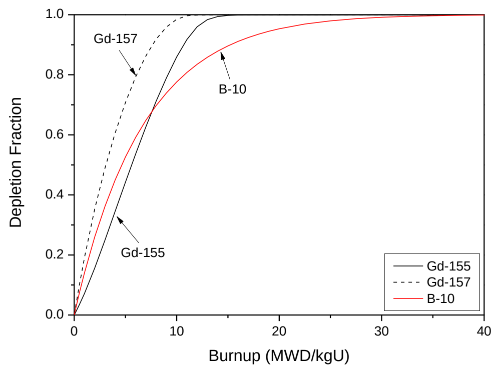


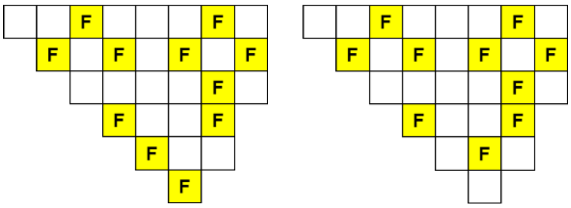
Fig. 2. Depletion fraction of burnable absorbing isotopes as a function of burnup.

2.3 Core Design and Analysis

Table I summarizes the fuel management scheme to describe a three-batch reload strategy from transition to equilibrium cycle. To explore the adequate power and burnup distributions for the equilibrium core, seven successive cycles from cycle 6 are investigated by using loading patterns as shown in Fig. 3. All cores consist of 64 fresh, 64 once-burned and 49 twice-burned fuel assemblies. Cycle 12 is chosen as the equilibrium core. The cycle-by-cycle MASTER core calculations were performed with the tabularized cross section library for the GBF and BBF assemblies shown in Fig. 1.

Table I: Fuel Management Scheme

FA Type	No. of Cycles						
	6	7	8	9	10	11	12
G	GBF						
H	GBF	GBF					
J	BBF	BBF	BBF				
K		BBF	BBF	BBF			
L			BBF	BBF	BBF		
M				BBF	BBF	BBF	
N					BBF	BBF	BBF
P						BBF	BBF
S							BBF
Cycle Length (EFPD)	460	467	472	465	468	467	467



Cycle 6 Cycle 7 and later

Fig. 3. Transition and equilibrium core loading pattern.

Table II: Comparison of neutronic parameters

Item	Reference	BBF
Cycle Length (EFPD)	470	467
Cycle Max. CBC (ppm)	1,479	1,294
AO Range (%)	-3.4~+6.7	-2.8~+3.5
Cycle Max. Peaking Factors		
Fq	1.814	1.756
Fr	1.499	1.482
Fz	1.213	1.225
Cycle Max. MTC (pcm/℃)		
HFP	-16.07	-21.59
HZP	+3.56	-0.35
Cycle Min. SDM (pcm)	7,447	7,132

Table II summarizes the typical core performance and safety parameters for cycle 12 of the BBF core and for cycle 6 of Hanbit Unit 3 as a reference core. The BBF core satisfies the cycle length requirement of 18-month, the BBF core has lower cycle maximum critical boron concentration (CBC) compared to the reference due to its large initial reactivity hold-down. The change of axial offset (AO) is similar and the peaking factors are slightly smaller in comparison to the reference. The MTC is more negative and the shutdown margin (SDM) is slightly smaller when compared to the reference. From these results, it is concluded that the BBF core has a comparable performance in typical OPR-1000 cores with the GBF.

Fig. 4 shows the burnable absorber worth versus cycle burnup. Although ~10% ^{10}B remains at the end of the first cycle of residence, the residual worth of the BBF is almost same as those of the GBF. This is attributed to the relatively large absorption cross section of remaining gadolinium isotopes such as ^{154}Gd (92 barns), ^{156}Gd (7 barns), ^{158}Gd (6 barns), and ^{160}Gd (5 barns) compared to ^{11}B (5 barns). Note that the value in parentheses indicates total cross section for each isotope.

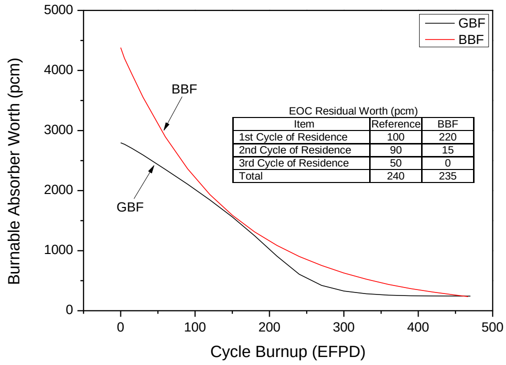


Fig. 4. Burnable absorber worth as a function of cycle burnup.

3. Conclusions

Neutronic feasibility study to utilize the BBF in OPR-1000 core has been performed. The results show that the OPR-1000 core design with the BBF is feasible and promising in neutronic aspects. Therefore, the use of the BBF in OPR-1000 can reduce the dependency on the rare material such as gadolinium. However, the burnout of the ^{10}B isotope results in helium gas, so fuel performance related study with respect to helium generation is needed.

ACKNOWLEDGEMENTS

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