Application of B_4C/Al_2O_3 Burnable Absorber Rod to Control Excess Reactivity of SMR

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1. Introduction

Soluble boron in a nuclear reactor coolant is one of the methods to control excess reactivity of the reactor. However, the use of soluble boron also causes some negative effects such as corrosion, more-positive-tendency of Moderator Temperature Coefficient (MTC) and the requirement of Chemical Volume Control System (CVCS). One of the conceptual design features of SMR having been developed in Korea is soluble-boron-free reactor to eliminate those drawbacks. Control rods and Burnable Absorber (BA) rods can be other methods than soluble to control excess reactivity.

In general, three types of BA rods have been used in commercial nuclear design. The first type is integral type of BA which is a uniform mixture of fuel with burnable absorber material such as gadolinium and erbium. The second type is discrete type of BA which contains only BA. Discrete type of BA commonly uses boron. WABA (Wet Annular Burnable Absorber) and PYREX are such type. The other type is IFBA (Integral Fuel Burnable Absorber) in which fuel pellet surface is coated with BA.

This paper compares nuclear characteristics of three types of BA as well as SLOBA in terms of k-infinite vs. burnup and explain design basis of SLOBA. This paper also presents the application of SLOBA rods to control long-term excess reactivity of SMR. The SMR loaded with SLOBA rods has been developed for the past few years in Korean. It is named as Bandi-50 with design features of 180 MWth, 37 FAs, fuel assembly height of 200 cm. Soluble-boron-free is one of nuclear design requirements of Bandi-50 and is achieved by controlling excess reactivity of the SMR using BAs and control rods only. To achieve this design requirement, LP is carefully determined in such way that CBC should be as low as possible. Final LP loaded with SLOBAs shows maximum CBC lower than 1 $\%\Delta\rho$ and maintain flatter CBC variation during entire cycle than LP loaded with other BAs. CASMO-3 and MASTER-3 are used for cross-section generation and depletion calculation.

2. Nuclear Design characteristics of SMR

Three types of BA materials are widely used in commercial core design and they are gadolinium, boron and erbium in order of magnitude of absorption cross-section. Figure 1 shows burnup characteristics of BAs. The legend in Figure 1 shows types of BA rods and weight percent of BA. A total of 32 BA rods are loaded in 17x17 FA. Gadolinium absorption cross-section is highest so that it's burn-out slop is steepest among them. IFBA shows smallest hold-down power of excess reactivity and burns out in shortest time among them. WABA, PYREX and SLOBA show similar slop of burn-out and SLOBA has longest burn-out and slowest burn-out slop among them. This kind of trend of each BA is repeatedly observed for various numbers of BA rods per FA.

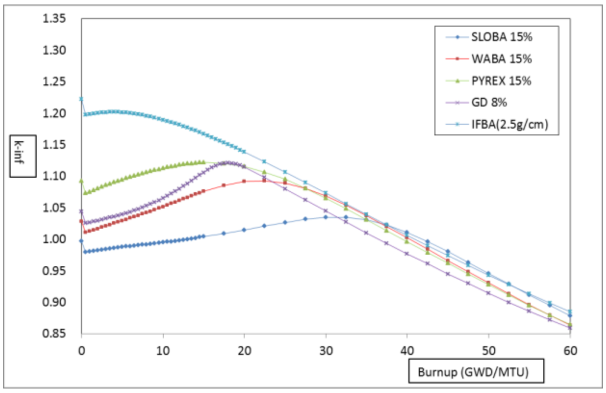
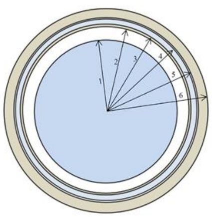


Fig. 1. K-inf vs Burnup of BAs

2.1. SLOBA design

Unlike WABA and PYREX, SLOBA has double-layered BA structure to increase loading of BA as well as burn-out time. Figure 2 shows the structure of SLOBA [1]. Outer layer of BA shows spatial self-shielding effect so that it help inner layer of BA burn out slow. Boron weight percent in SLOBA is 15 %.



Layer	Radius (cm)	Material
0 – 1	R1	B_4C/Al_2O_3
1 – 2	0.3750	Air
2 – 3	0.3800	Zr-4
3 – 4	R4	B_4C/Al_2O_3
4 – 5	0.4316	Air
5 – 6	0.4760	Zr-4

Fig. 2. Double layered structure of SLOBA

Variables are inner layer radius, outer layer radius to investigate optimum SLOBA structure and design basis for SLOBA is to have flatter and longer-lasting k-infinite of FA loaded with SLOBA. In Figure 3, burn-out slope of others than R4=0.42 cm runs faster as outer layer radius increases or decrease whereas burn-out time of each case is almost same. Figure 4 shows that burn-out time of BA increases as inner layer radius, R2, increases. This is because BA loading increases.

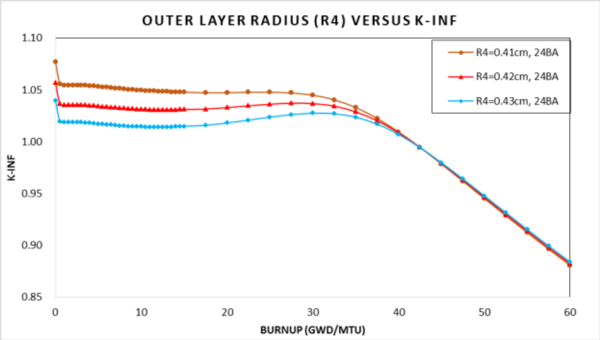


Fig. 3. Outer layer radius (R4) vs. k-infinite

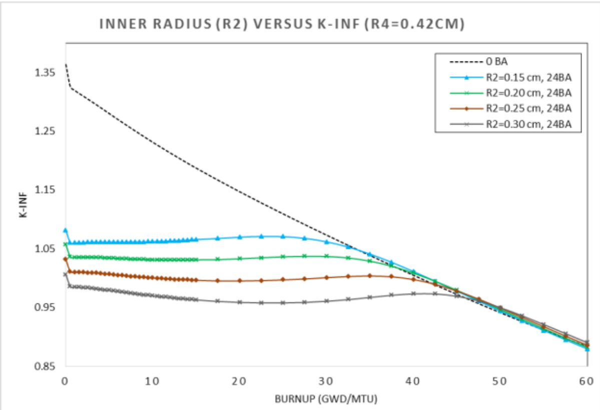


Fig. 4. Inner layer radius (R2) vs. k-infinite

2.2. Nuclear Design Requirements of Bandi-50

Bandi-50 design is a system-integrated modular-type, light water cooling reactor. It employs passive safety design concepts with natural circulation. The reactor is designed with a rated electric power of 50 MWe. Top tier nuclear design requirements imposed to Bandi-50 are presented in Table 1. Complying with the requirements, BA loaded LP needs to be determined in such way that excess reactivity during core burnout stays less than 1 $\%\Delta\rho$. This value of the excess reactivity means the maximum allowable minimum insertion of control rod groups to maintain the core critical.

In this paper, the depletion results of SLOBA loaded LP is compared with those of gadolinia loaded LP. SLOBA loaded LP is same as gadolinia loaded LP except type of BA and total loading of uranium. Gadolinia loaded LP has more uranium loading by about 742 kg because gadolinia BA rod is integral type mixed with UO2. SLOBA loaded LP aims to achieve excess reactivity of less than 1 $\%\Delta\rho$ [2].

Table 1 Nuclear Design Requirements

Nuclear Design Requirements	Value
Uranium enrichment	< 5.0 w/o
Cycle length	> 3 years
Excess reactivity control	Soluble-Boron-free
Fuel composition	UO_2 fuel
Assembly type	17x17
Number of fuel assemblies	37
Height of active core	200 cm

3. Results and Conclusions

Fuel assembly cross-sections are generated by CASMO-3[3], and core depletion calculations are performed by MASTER [4]. Table 2 shows fuel types loaded in the LP in Figure 5. The total number of FAs is 37 and fuel enrichment is 4.95 w/o. Figure 6 compares depletion characteristics of SLOBA loaded LP with gadolinia loaded LP. Gadolinia loaded core has the same LP of SLOBA loaded LP and shows a maximum k-effective of 1.033539 (excess reactivity of 3.25 $\%\Delta\rho$) whereas SLOBA loaded LP has a maximum k-effective of 1.00 9868 (excess reactivity of 0.98 $\%\Delta\rho$). There is noticeable reduction of excess reactivity from 400 EFPD to 800 EFPD as we expected from the design of SLOBA, which requires to have flatter and longer burn-out characteristics.

Table 2 FA types used for SLOBA loaded LP

FA Type	S0	N0	S2	S4	S6*	M6** (SLOBA /Gd)
Enrichment (w/o)	4.95	4.95	4.95	4.95	4.95	4.95
Number of fuel rods	248	264	240	232	224	224
Number of BA rods	16	0	24	32	40	20/20
Number of FA	8	8	8	8	1	4

S6* has 40 SLOBA rods.
M6** has 20 gadolinia rods and 20 SLOBA rods.

		N0	S0	N0		
	S0	S2	M6	S2	S0	
N0	S2	S4	S4	S4	S2	N0
S0	M6	S4	S6	S4	M6	S0
N0	S2	S4	S4	S4	S2	N0
	S0	S2	M6	S2	S0	
		N0	S0	N0		

Fig. 5. SLOBA loaded LP

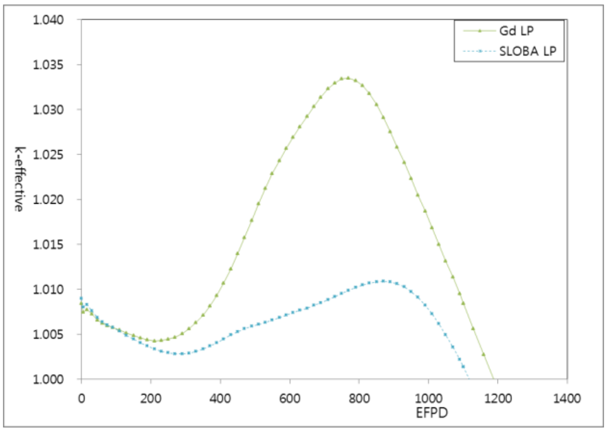


Fig. 6. Depletion characteristics of SLOBA loaded LP

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