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

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Contents

Objective

▣ To achieve Soluble Boron Free (SBF) Small Modular Reactor (SMR)

- New Burnable Absorber (BA) is designed to have a flat reactivity profile
- To achieve the core excess reactivity lower than 1%$\Delta\rho$ for the whole cycle

Background of study

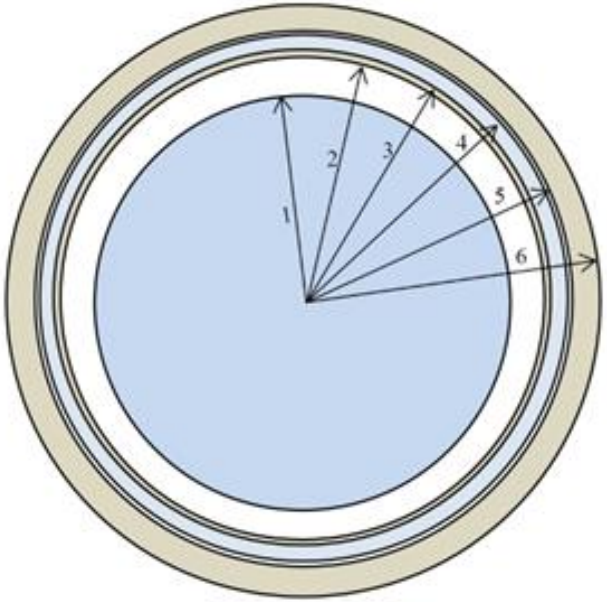
- Soluble boron is effective and reliable to control excess reactivity. However, Soluble Boron causes some negative effects such as corrosion, positive Moderator Temperature Coefficient (MTC), radwaste production and the requirement of Chemical and Volume Control System (CVCS).
- For SBF core, BA and control rods are possible methods to control excess reactivity.
- In general, three types of BA have been used in commercial nuclear design such as integral type (Gadolinia, Erbia), discrete type (WABA, Pyrex), and IFBA (Integral Fuel Burnable Absorber) (BA coated around the fuel pellet).

Core Design Requirements

Nuclear Design Requirements	Value
Thermal Power	180 MWth
Uranium enrichment	4.95 w/o
Cycle length	> 3 years
Excess reactivity control	Soluble-Boron-free
Fuel composition	UO_2 fuel
Assembly type	17x17 array
Number of fuel assemblies in core	37 FAs
Height of active core	200 cm

Methodology

▣ The new BA named SLOBA (SLOw Burnable Absorber) which is designed with the double-layers BA (B_4C/Al_2O_3) structure is introduced to achieve SBF core. The purpose of double-layers BA structure is to increase BA loading as well as burnout time.



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

Methodology

▣ The parametric study of inner and outer SLOBA radius were analyzed

- Inner radius of SLOBA (R1 is varied while R4 is kept constant)
- Outer radius of SLOBA (R4 is varied while R1 is kept constant)
- With fixed boron weight fraction of 15 w/o.

Methodology

▣ the optimum range of SLOBA rod size having minimum reactivity swing will be selected to perform the loading pattern search.

▣ the equation below is represented the minimum reactivity swing:

$$\Delta\rho_{swing} = k_{high,35} - k_{low,35}$$

Where $\Delta\rho_{swing}$: Minimum reactivity swing

$k_{high,35}$: k-infinite, highest value between ranges 0.5 to 35 GWD/MTU

$k_{low,35}$: k-infinite, lowest value between ranges 0.5 to 35 GWD/MTU

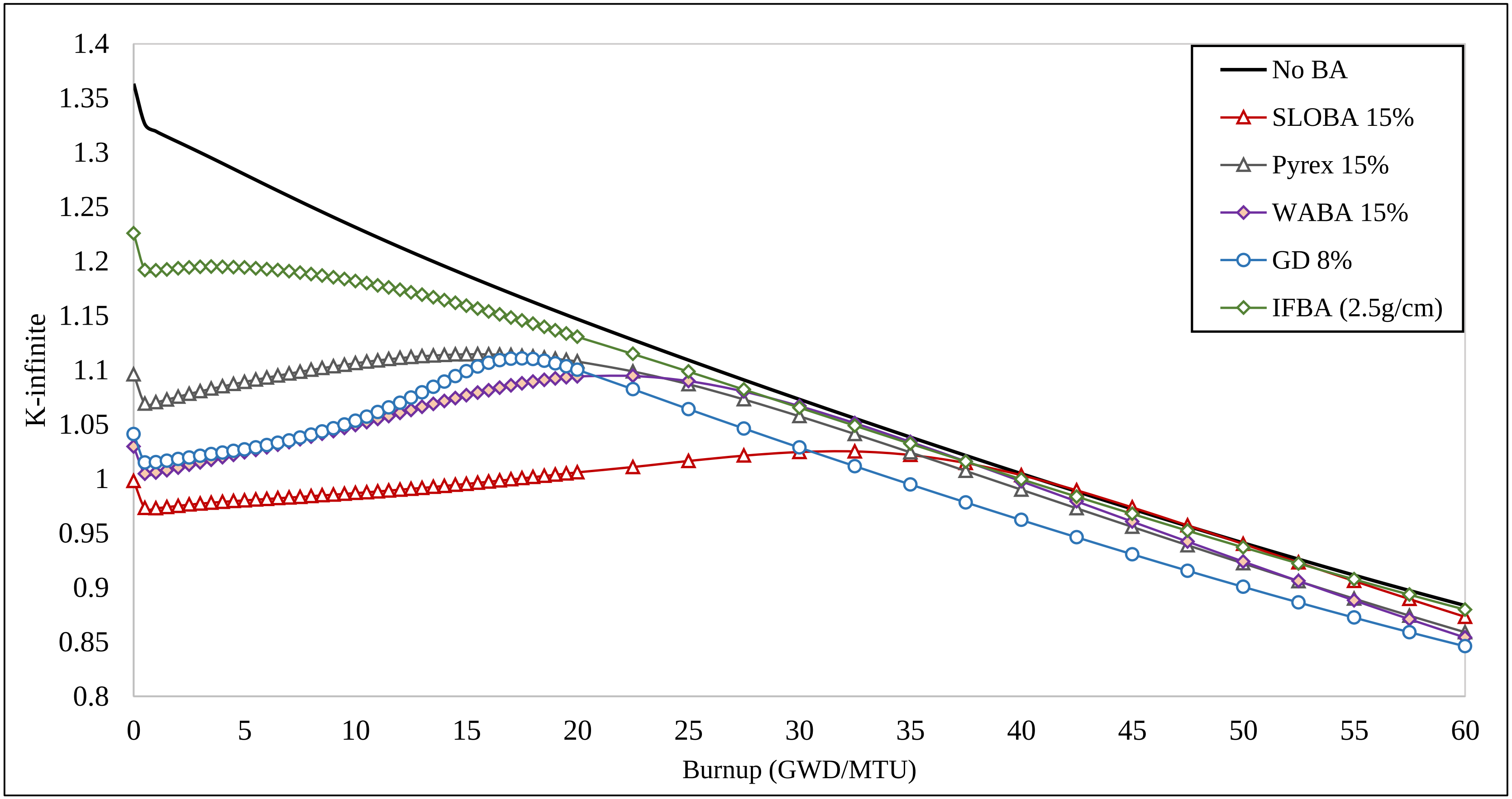
▣ The depleted result of Gadolinia loaded LP is used as a reference and compared to SLOBA loaded LP

▣ Computer Tools

- CASMO-3 and MASTER-3.0 is used to perform the calculation.

Result

▣ The comparison of k-infinite for assemblies with difference types of 32 BA rods in 17x17 FA.



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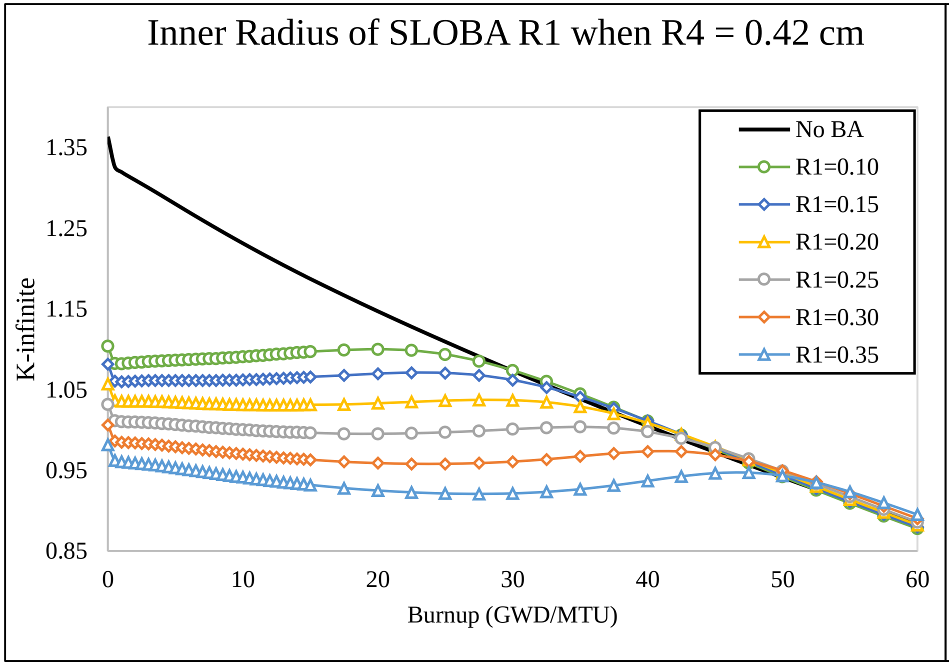
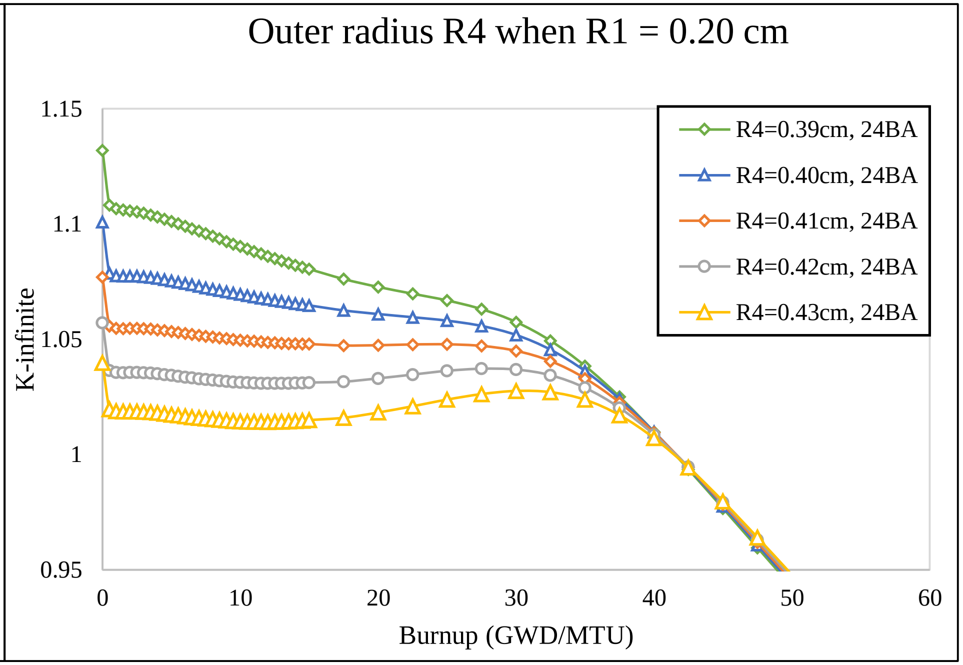
Result

▣ SLOBA inner and outer radius fuel depletion characteristic





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Result

▣ The determination of Inner and outer radius having minimum reactivity swing

R1 (cm)	Min. Reactivity Swing	R4 (cm)	Min. Reactivity Swing
0.10	0.05549	0.39	0.69860
0.15	0.30110	0.40	0.42500
0.20	0.00829	0.41	0.02267
0.25	0.01622	0.42	0.00829
0.30	0.02839	0.43	0.13410
0.35	0.04153		

▣ The optimum range of SLOBA radius with minimum reactivity swing

- R1 is range between 0.18 cm to 0.23 cm
- R4 is range between 0.41 cm to 0.43 cm

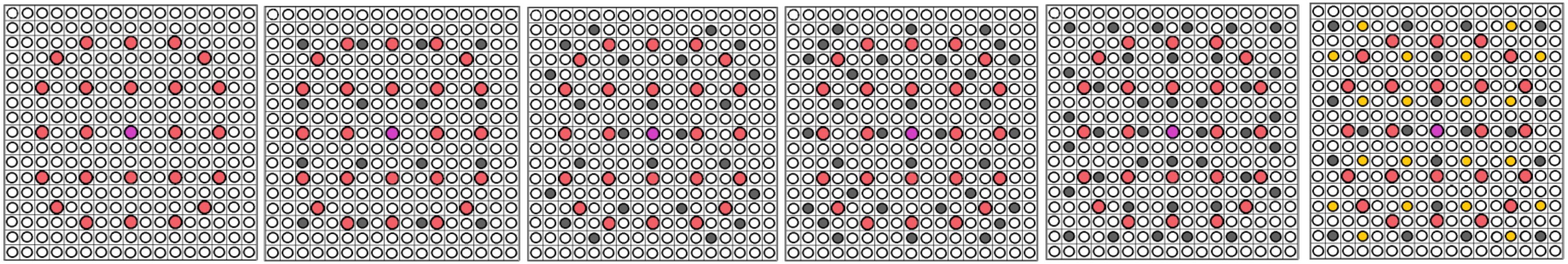
▣ R1 = 0.20 cm and R4 = 0.41 cm of SLOBA rod sizes will be used to perform the loading pattern search

Result

▣FA types and FA Loading Pattern

FA Type	N0	S0	S2	S4	S6*	M6** (SLOBA/Gd)
Number of fuel rods	264	248	240	232	224	224
Number of BA rods	0	16	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 S2 S4 S6 M6

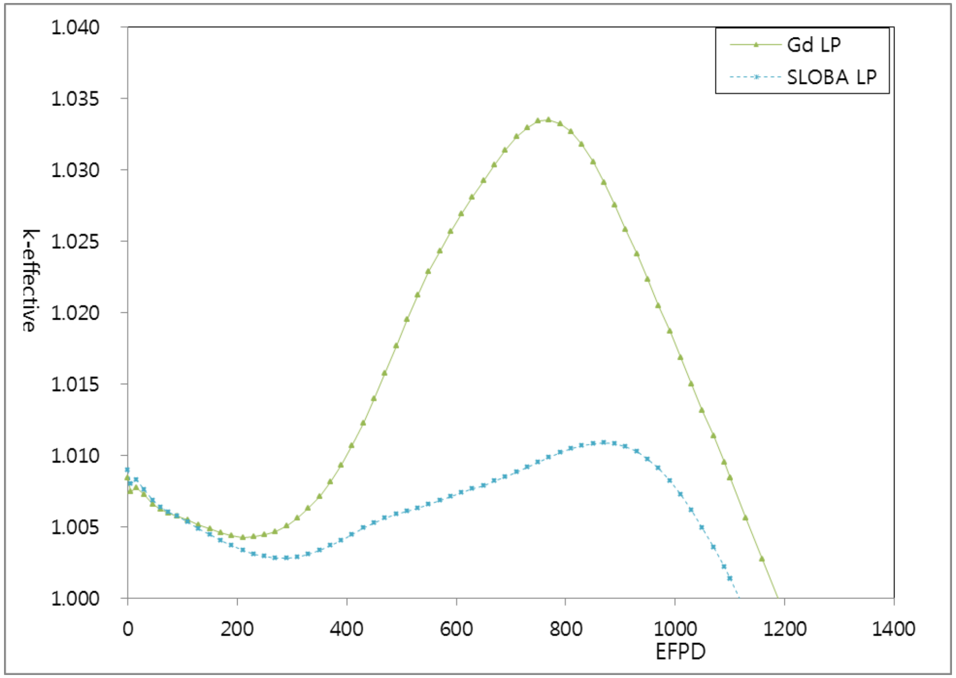
- ○ : Fuel Rod
- ● (red) : Guide Tube
- ● (purple) : Instrumentation Tube
- ● (black) : SLOw Burnable Absorber
- ● (yellow) : Gadolinia

Result

▣ Core Loading Pattern of SLOBA loaded LP

		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		

Result and conclusion



- Gadolinia loaded LP shows a maximum k-effective of 1.033539 (excess reactivity of 3.25%$\Delta\rho$) and SLOBA loaded LP shows a maximum k-effective of 1.009868 (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.
- SBF core can be achieved by utilizing the SLOBA rod to control excess reactivity less than 1%$\Delta\rho$ with the maximum three-years cycle lengths.

Reference

[1] J. H. Park, J. K. Kang, and C. J. Hah, Reactivity Flattening for a Soluble-Boron-Free Small Modular Reactor, KNS, Gyeongju, Korea, 2015.

[2] Electric Power Research Institute, “Elimination of Soluable Boron for a New PWR Design”, EPRI-NP-6536, 1989.

[3] M. Edenius, B. H. Forssen, “CASMO-3: A Fuel Assembly Burnup Program, User’s Manual 3”, Studsvik Nuclear, Version 4.4, 2004.

[4] Korea Atomic Energy Research Institute, “MASTER 3.0 User’s Manual”, Version 3, 2004.

Thank You for your attention

Q & A