Axial Region Optimization for Cycle Length Extension of Small Modular PWR

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1. Introduction

Soluble boron-free small modular pressurized water reactor (SMPWR) can be a transportable size core due to the absence of the chemical volume control system (CVCS) and the amount of liquid radioactive waste, and further remove the corrosion problem caused by boric acid [1]. The SMPWR needs large amount of burnable absorber (BA) instead of soluble boron, but the more the amount of BA is, the shorter the fuel cycle length is. Therefore, this paper studies axial region sensitivity test to make fuel cycle length of SMWPR longer. The procedure of axial region sensitivity test is as follows: cutback sensitivity tests, material and height sensitivity tests in the axial region. CASMO-4E/SIMULATE-3, which is Studsvik's reactor core design code system, has been used for these simulation [2-4].

2. Small Modular PWR Design

2.1 SMPWR Specification

Core design parameters of SMPWRS are summarized in Table I. The thermal power is 200 MWt, and its power density is 58.4 kW/L. A fuel assembly (FA) is based on 17 pins by 17 pins Westinghouse type. The fuel material is UO_2 and BA material is an R-BA, which is a thin layer of Zr-^{167}Er coated in the cladding as shown in Fig. 1 [5]. The target maximum reactivity is within 1,000 pcm to secure stable excess reactivity control. There is no soluble boron in the moderator due to boron-free SMPWR.

Table I: Core Design Parameters of SMPWR

Parameters	Target Value
Thermal power	200 MWt
Power density	58.4 kW/L
Fuel cycle length	36 months
FA type	17x17 Westinghouse
Fuel material	UO_2
BA material	R-BA
Fuel enrichment	4.90 w/o ^{235}U
Number of FAs	37
Active core height	2.0 m
Maximum Reactivity	< 1,000 pcm
Boron concentration	0 ppm
3D pin peaking factor	< 4.4
Axial Offset	-0.4 < AO < +0.4

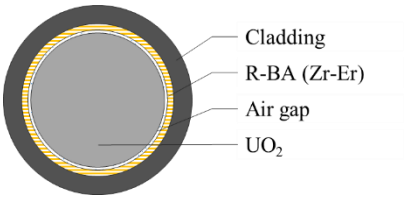

Fig. 1. R-BA Cross Sectional View.

The loading pattern with 37 FAs is as shown in Fig. 2. The core consists of 12 FAs of Type 01 and 25 FAs of Type 02. Type 01 uses 1 mm of ^{167}Er5 w/o R-BA for 88 pins, and Type 02 use 2 mm of ^{167}Er 15 w/o R-BA for 216 pins as shown in Fig. 3. The maximum reactivity of this reference core is 548 pcm. The cycle length is 798 effective full power days (EFPD, 26.6 months), so its cycle length is shorter than targetvalue, 36 months.

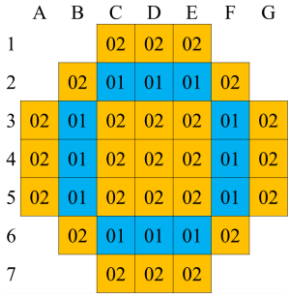

Fig. 2. Two-batch Loading Pattern for SMPWR.

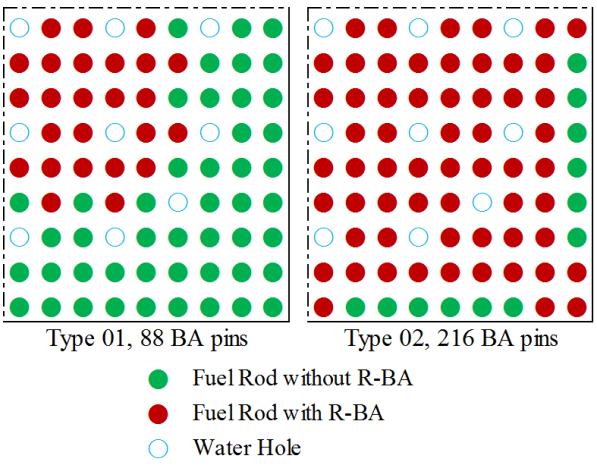

Fig. 3. Fuel Assembly Pattern for Type 01 and Type 02.

The procedure of axial region sensitivity test is as follows: cutback sensitivity tests, material and height

sensitivity tests in axial region except cutback region. The Fig. 4 shows the geometry of test cases.

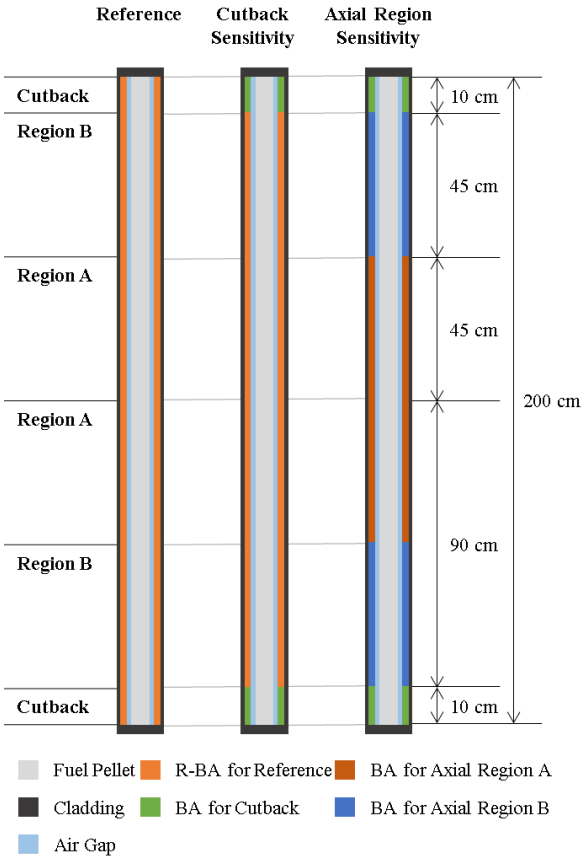

Fig. 4. Axial View of BA Rods for Test Cases.

2.2 Cutback Sensitivity Test

The cutback sensitivity test is performed at the top and bottom regions. The relative power at the top and bottom regions is low, thus those regions may not need to load much BA. The reference core does not have cutback region. The height of cutback changes from 2 cm to 10 cm by 2 cm steps from both the top and bottom. There are three sensitivity cases are carried out:

- One is UO_2 enrichment change without BA from 2.2 w/o to 4.9 w/o by 0.5 w/o steps.
- Another is Zr-B instead of Zr-^{167}Er, and content of B in Zr-B has been changed from 5 w/o to 10 w/o. The ^{235}U enrichment is fixed as 4.9 w/o.
- The other is Zr-Gd instead of Zr-^{167}Er and Gd content in Zr-Gd has been changed from 5 w/o to 20 w/o by 5 w/o steps. The ^{235}U enrichment is fixed as 4.9 w/o.

Three cases of the longest fuel cycle length are summarized in Table II. Those cases have 10 cm of cutback height. 10 cm of the cutback with Gd 10 w/o of Zr-Gd is the best test case, because its reactivity is satisfied the limit only.

Table II: Cutback Sensitivity Results

Test cases, height	Cycle Length [EFPD]	Max. Δρ [pcm]
Reference (No Cutback)	798	548
Gd 5 w/o of Zr-Gd (^{235}U 4.9 w/o)	951	1029
Gd 10 w/o of Zr-Gd (^{235}U 4.9 w/o)	942	934
^{235}U 4.9 % (No BA)	959	1132

2.3 Axial Region Sensitivity Test

The reference cutback has been decided as 10 cm of cutback with Gd 10 w/o in Zr-Gd. The axial region sensitivity has been calculated in the rest 180 cm except cutback. There are two regions, A and B, as shown in Fig. 4. The center region is called as Region A from the center to 45 cm. The Region B is from 45 cm (Region A) to 90 cm (cutback). The height of Region A is as same as that of Region B as 45 cm. Zr-^{167}Er, Zr-B and Zr-Gd are used as BA material, and its content has been changed from 5 w/o to 20 w/o by 5 w/o steps.

Table III: BA content in Zr-BA

BA Content	TYPE 01	TYPE02
Region A	^{167}Er 2 %	^{167}Er 12 %
Region B	B 8 %	B 8 %

The height of axial region has been changed by 5 cm steps. When the height of Region A is 40 cm in both Type 01 and Type 02 and the BA content is as shown in Table III, the reactivity swing decreases around 400 pcm and the cycle length increases to 1027 EFPD (34.2 months). k_{eff} change as burnup is as shown in Fig. 5. The axial region sensitivity result gives the longest fuel cycle length, but The AO and the Fq are not satisfied as shown in Fig. 6 and 7. Table IV shows the summary of sensitivity test through the reference case, cutback sensitivity test and axial region test.

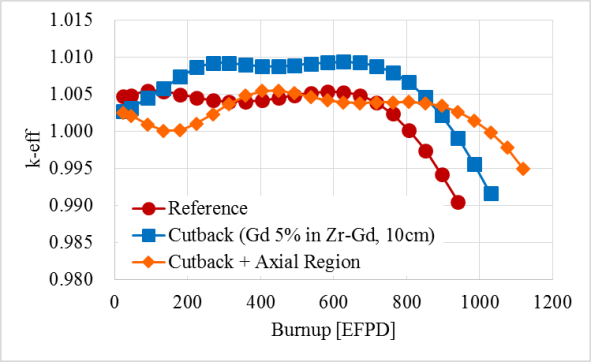

Fig. 5. k_{eff} change as burnup

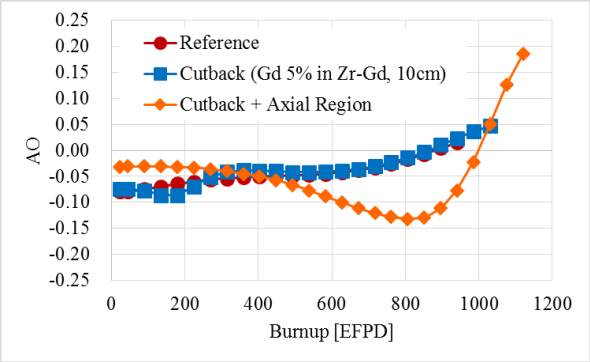

Fig. 6. AO change as burnup

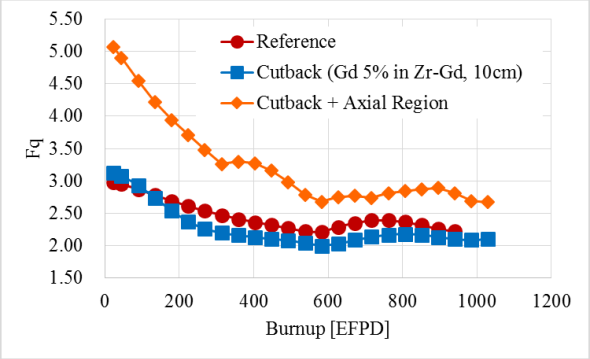

Fig. 7. Fq change as burnup

Table IV: Summary of Sensitivity Tests

	Reference	Cutback	Cutback + Axial Region
Height Each Region			
Cutback	-	10 cm	10 cm
01-A	50 cm	45 cm	40 cm
01-B	50 cm	45 cm	50 cm
02-A	50 cm	45 cm	40 cm
02-B	50 cm	45 cm	50 cm
BA Content in Zr-BA			
Cutback	-	Gd 10%	Gd 10%
01-A	^{167}Er 5%	^{167}Er 5%	^{167}Er 2%
01-B	^{167}Er 5%	^{167}Er 5%	B 8%
02-A	^{167}Er 5%	^{167}Er 15%	^{167}Er 12%
02-B	^{167}Er 5%	^{167}Er 15%	B 8%
Result			
EFPD	798 days	942 days	1026 days
Δρ Swing	548 pcm	934 pcm	547 pcm

3. Conclusions

This paper studied axial region sensitivity test in SMPWR to extend the cycle length. Zr-^{167}Er, Zr-B and Zr-Gd are used for BA material, the height of cutback and axial region has been changed. The cycle length of the reference core is 798 EFPD (26.6 EFPM), and there is no cutback and only ^{167}Er-Zr is used in R-BA. The optimal BA for cutback region is 10 cm of cutback with natural Gd 10 % in Zr-Gd, and the cycle length increases to 942 EFPD (31.4 months). Through the axial region sensitivity test, the cycle length becomes 1026 EFPD (34.2 months), but the peaking factors were not satisfied their limits. The 4.8-month increases compared with the reference core through the cutback sensitivity test. The possibility to excess reactivity with control rods in this core should verify.

REFERENCES

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