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Impact of UO_2 Enrichment of Fuel Zoning Rods in Long Cycle Operation of PWR

Ho Cheol Shin [a], Eun Jeong [b], Jiwon Choe [b], Deokjung Lee [a*]
[a]*Core and Fuel Analysis Group, KHNP-CRI, 70, Yuseong-daero, Yuseong-gu, Daejeon 34101*
[b]*School of Mechanical and Nuclear Engineering, UNIST, 50, UNIST-gil, Ulju-gun, Ulsan 44919*
[*]*Corresponding author: deokjung@unist.ac.kr*

1. Introduction

There are two primary utility requirements for GEN III+ Pressurized Water Reactors (PWR) [1]: the first one is a long-cycle operation and the second one is low-boron operation. Extending the cycle length can not only increase the energy production, but also bring down outage costs by reducing the number of refueling outages during the lifetime of a nuclear power plant. It is reasonable that more fresh fuels are loaded for long cycle operation. However, minimizing the number of fresh fuels is essential in aspect of fuel economics.

One CE type fuel assembly (FA) has 5 water holes whose diameter is greater than the diameter of fuel rods as shown in Fig.1. This can cause high power peaking near the water holes, due to increased thermalization of neutrons in those regions. To prevent this, special fuel zoning rods are used and surround the water holes. These rods use lower-enriched uranium (they have an enrichment rate lower than the other fuel rods). If we adjust the enrichment rate of fuel zoning rods, we can reduce power peaking and moreover increase cycle length.

Therefore, in this paper we design a core suitable for long cycle operation and we perform sensitivity tests of fuel cycle length on UO_2 enrichment in fuel zoning region. This way, we hope to extend the cycle length while using the same number of fresh fuels. The correlations between the fuel zoning enrichment and cycle length, peaking factor, critical boron concentration and shutdown margin are analyzed. CASMO-4E/SIMULATE-3, which is Studsvik's reactor core design code system, has been used for these simulations [2-4].

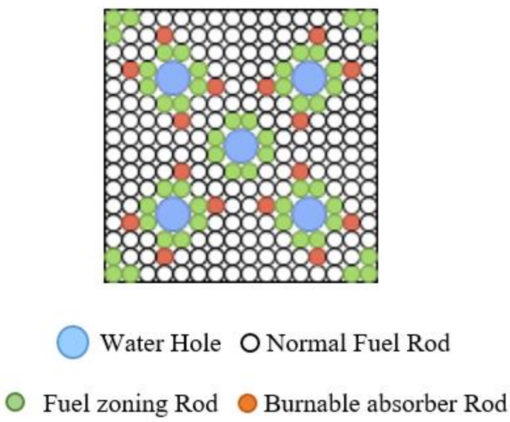

Fig. 1. CE type fuel assembly.

2. Design Long-cycle PWR with Different UO_2 Enrichment High of Fuel Zoning Rods

2.1 24-month cycle equilibrium core

An equilibrium core with 24-month cycle length was designed as a reference core. This reference core was designed for 24-month cycle length including overhaul time. The quarter loading pattern (LP) of this core is as shown in Fig. 2. Gadolinia (Gd_2O_3) is used as burnable absorber (BA) in the reference core. This LP follows checker board pattern using once burned fuels and fresh fuels so as to fulfill core design parameters.

The reference core performance results are summarized in Table I. This core uses 4.95 w/o ^{235}U UO_2 fuels, 4.45 w/o ^{235}U UO_2 in fuel zoning and 105 fresh fuel assemblies for an extended cycle length. The core design parameters, which are initial critical boron concentration (CBC), 3D pin peaking factor (Fq), maximum pin burnup and MTC at hot zero power (HZP) BOC, MTC at hot full power (HFP) BOC, middle of cycle (MOC) and End of Cycle (EOC), are all within design limits. Since the core parameters satisfy the design limits, the reference core is well designed for 24-month long cycle operation.

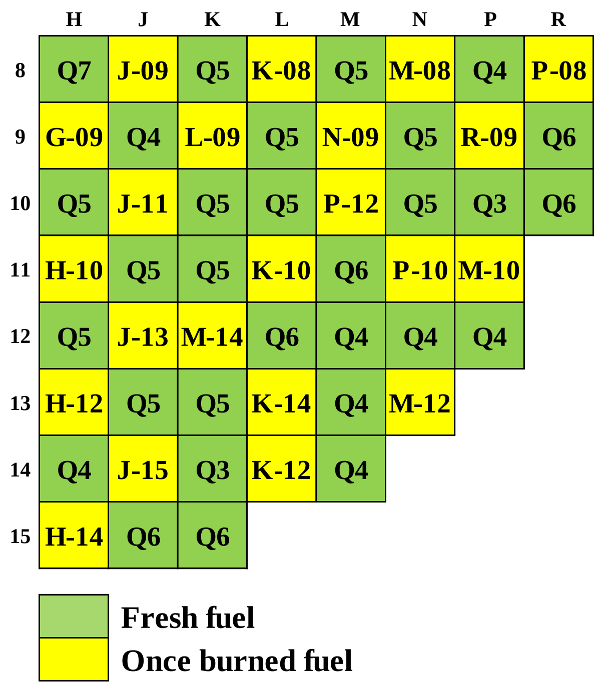

Fig. 2. Loading pattern of the reference core.

Table I: Summary of core results for the reference core

Parameters	Values
Enrichment [w/o ^{235}U] (Normal/Fuel Zoning)	4.95/4.45
Number of Batch	2
Number of FA (Fresh/Once/Twice)	105/72/0
Initial CBC [ppm]	1693
Fuel Cycle Length [EFPD]	650.40
Fuel Cycle Length [EFPM]	21.68
Fuel Cycle Burnup [GWd/MT]	23.80
3D Pin Peaking Factor (Fq)	1.86
Max. Pin Burnup [GWd/MT]	59.91
MTC at HZP BOC [pcm/°F]	3.33
MTC at HFP BOC [pcm/°F]	-6.77
MTC at HFP MOC [pcm/°F]	-14.43
MTC at HFP EOC [pcm/°F]	-38.94

2.2 Loading fuel zoning rods with different UO_2 enrichment

To obtain a longer cycle equilibrium core using the same number of fresh fuels, we study the dependence of fuel cycle length on UO_2 enrichment in fuel zoning region. 4.50 w/o and 4.60 w/o ^{235}U in UO_2 are used for sensitivity test. UO_2 enrichment sensitivity test results are shown in Table II. Reference core uses 4.45 w/o ^{235}U in UO_2 in fuel zoning region. We observe that the fuel cycle length increases as the enrichment rate in fuel zoning region increases.

Fig. 3 shows boron letdown curve for different fuel zoning enrichments. Fig. 4 presents the variation of Fq during one cycle. Fq changes very slightly for different fuel zoning enrichments, but it remains at all times within the design limit (Fqmax=2.568) as shown in Fig. 4. From Fig. 3 and Fig. 4, we observe that the CBC and Fq values do not change significantly for the tested fuel zoning enrichments. Correlation of shutdown margin and fuel zoning enrichment is shown in Table III. Even for higher values of fuel zoning enrichment rate than in the reference case, shutdown margin is maintained. This property is a very important characteristic in terms of safety margin.

When we increase fuel zoning enrichment, we can increase the fuel cycle length (which is beneficial) without causing a significant change in CBC, Fq and shutdown margin. These results show that increasing the uranium enrichment rate in fuel zoning rods can be used to extend the cycle length for long cycle operation, while using the same number of fresh fuels and maintaining the core parameters within their design limits.

Table II: CBC and Fuel Cycle Length Comparison

Test Cases	Initial CBC [ppm]	Fuel Cycle Length [EFPD]
Reference	1693	650.40
FZ 4.50w/o	1701	652.30
FZ 4.60w/o	1720	655.60

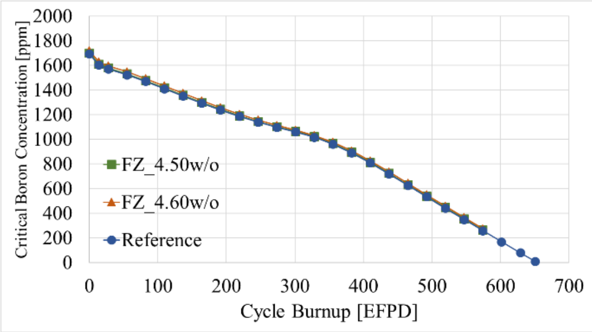

Fig. 3. Boron letdown curve Comparison.

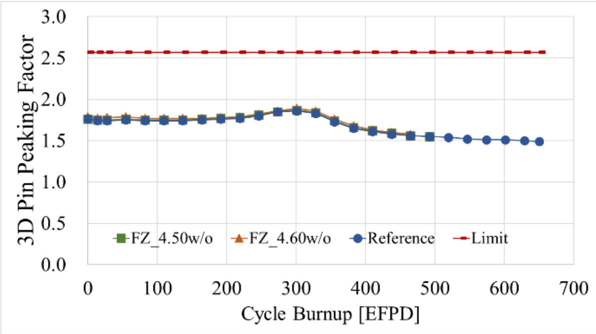

Fig. 4. 3D Pin Peaking Factor (Fq) Comparison.

Table III: Shutdown margin at BOC Comparison

Reactivity(pcm)	Reference	FZ 4.50w/o	FZ 4.60w/o
All rods in (ARI)	12823	12813	12615
Stock Rod Worth	923	924	821
Uncertainty of rod worth	1190	1189	1179
Rod worth for criticality	0	0	0
Engineering error	100	100	100
Real worth	10610	10600	10515
HFP to HZP	3916	3912	3914
Uncertainty of core	80	80	80
Engineering error	100	100	100
Total power defect	4096	4092	4094
Shutdown margin	6514	6508	6421

3. Conclusions

In this paper, we designed a core suitable for long cycle operation and we conducted sensitivity tests of fuel cycle length on UO_2 enrichment rate in fuel zoning region in order to extend the cycle length while using the same number of fresh fuels. The correlations between the fuel zoning enrichment and cycle length, peaking factor, CBC and shutdown margin were analyzed. The more the enrichment rate in fuel zoning region increases, the more the fuel cycle length increases. At the same time, CBC, Fq and shutdown margin do not change significantly. Increasing the fuel zoning enrichment rate presents the right property of increasing the fuel cycle length without causing a large change to CBC, Fq and shutdown margin.

In conclusion, by increasing the uranium enrichment rate in fuel zoning region, fuel cycle length can be increased and the safety margins can be maintained for long cycle operation of cores.

REFERENCES

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