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A study on the Effect of 62 GWD/MTU Fuel Rod Burnup Extension for Core Reactivity

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1. Introduction

Domestic light water reactor nuclear power plants are operating at a cycle of about 18-month under the condition of 60 GWD / MTU fuel rod burnup limit. On the other hand, the other countries including US have already allowed burnup of fuel rods up to 62 GWD / MTU, and 62 GWD / MTU licensing is also being carried out to mitigate design constraints and drive on 24-month cycle in Korea.

In the situation, this study began to go through the utilization for the extension of fuel rod burnup in terms of improving core reactivity (Cycle length).

This paper evaluated the impact of fuel rod burnup extension up to 62 GWD / MTU on the core reactivity from some perspectives for WEC (Westinghouse Electric Company) type 3-loop PWR (Pressurized Water Reactor) operating in Korea.

2. Analysis Method

2.1. Nuclear Design & Code System

General nuclear design methodologies for WEC type PWR were used for this analysis. With the WEC nodal code system PHOENIX-P and ANC that are being utilized in practice for nuclear design, the unit assembly calculations for each assembly and whole core calculations were conducted [1].

2.2. Economic Evaluation

Fuel cycle cost analysis method from OECD-NEA is adopted for this study. This method considers the worth of money at the reference time point, which is called present worth or levelization. And fixed cost and O&M (Operation and Maintenance) cost are calculated based on NASAP/INFCE methodology [2, 3].

3. Results and Discussion

3.1. Approaches for Utilization of Fuel Rod Burnup Extension from 60 GWD/MTU to 62 GWD/MTU in terms of Core Reactivity

It is expected that if the fuel rod burnup is a major design constraint in the increase of core reactivity, the fuel rod burnup extension could be directly contributed.

Meanwhile, the core reactivity can be increased by varying the amount of uranium loading and neutron leakage, which may result in the change of fuel rod burnup.

For this reason, the two different conditions of uranium loading (Flexible and Constant) were considered in order to investigate whether the fuel rod burnup is the restrictions for the increment of core reactivity.

3.2. Core Modeling

In addition to the domestic WEC type 3-loop PWR equilibrium core which has 18-month cycle with 65 feeds, the 21-month cycle equilibrium core with 77 feeds (77 Eq) and the 24-month cycle equilibrium core with 97 feeds (97 Eq) were modeled respectively.

The conditions applied to the core modeling are shown in the table below.

Table 1. Core Conditions for Nuclear Design

	65 Eq	77 Eq & 97 Eq
Fuel type	17ACE7-Gd_2O_3	
Thermal power	2900 MWth	
Enrichment (UO_2/ Gd_2O_3)	4.65/2.20 w/o	4.95/2.90 w/o
Code system	PHOENIX-P/ANC	

As shown in Table 1, it can be seen that in the longer cycle core of 18-month or more, the number of feed and the enrichment are increased as much as possible in order to achieve an appropriate total uranium loading.

3.2.1. 18-Month Cycle Core (65 Feeds)

The fundamental core characteristics including the peak rod burnup of the 18-month cycle are as follows.

Table 2. Core Characteristics for 65 Eq Model

	65 Eq	Design Criteria
Cycle length in EFPD (MWD/MTU)	473 (18,880)	-
HFP BOC CBC [ppm]	1,544	-
HZP BOC MTC [pcm/°F]	-0.78	≤ 5.0
Maximum FΔH	1.495	≤ 1.528
Maximum Fq	1.898	≤ 2.6
Peak rod burnup [MWD/MTU]	54,068	≤ 60,000

	1	2	3	4	5	6	7	8
1	X0	X1	X0	X1	X1	X1	X0	X2*
2	X1	X1	X1	X0	X1	X0	X0	X2
3	X0	X1	X0	X1	X1	X0	X1	
4	X1	X0	X1	X1	X0	X0	X2	
5	X1	X1	X1	X0	X0	X2		
6	X1	X0	X0	X0	X2			
7	X0	X0	X1	X2				
8	X2	X2						

Batch info
X0 (fresh)
X1 (once burned)
X2 (twice burned)

* peak rod burnup assembly

Fig. 1. Core Loading Pattern for 65 Eq Model

Table 2 represents that all design criteria including the current fuel rod burnup limit of 60 GWD / MTU are satisfied.

3.2.2. Longer Cycle Core (77 & 97 Feeds)

In order to evaluate the impact of changes in the total amount of uranium loading and the following effect of fuel rod burnup extension, 77 Eq and 97 Eq core were composed. The core characteristics are shown in the table below.

Table 3. Core Characteristics for 77 Eq & 97 Eq Model

	77 Eq	97 Eq	Design criteria
Cycle length in EFPD (MWD/MTU)	560 (22,460)	643 (25,790)	-
HFP BOC CBC [ppm]	1,562	1,548	-
HZP BOC MTC [pcm/°F]	-0.55	-0.50	≤ 5.0
Maximum FΔH	1.498	1.485	≤ 1.528
Maximum Fq	1.971	2.032	≤ 2.6
Peak rod burnup [MWD/MTU]	56,055	61,052	≤ 60,000

	1	2	3	4	5	6	7	8
1	X0	X1	X0	X1	X1	X1	X0	X0
2	X1	X1	X1	X0	X1	X0	X0	X2
3	X0	X1	X0	X1	X1	X0	X0	
4	X1	X0	X1	X1	X0	X0	X1	
5	X1	X1	X1	X0	X0	X1		
6	X1*	X0	X0	X0	X1			
7	X0	X0	X0	X1				
8	X0	X1						

Batch info
X0 (fresh)
X1 (once burned)
X2 (twice burned)

* peak rod burnup assembly

Fig. 2. Core Loading Pattern for 77 Eq Model

	1	2	3	4	5	6	7	8
1	X0	X1	X1	X0	X1	X0	X0	X1
2	X1	X1	X0	X0	X1	X0	X0	X1
3	X1	X0	X0	X1	X0	X0	X0	
4	X0	X0	X1*	X0	X0	X0	X1	
5	X1	X1	X0	X0	X0	X1		
6	X0	X0	X0	X0	X1			
7	X0	X0	X0	X1				
8	X1	X1						

Batch info
X0 (fresh)
X1 (once burned)

* peak rod burnup assembly

Fig. 3. Core Loading Pattern for 97 Eq Model

Above Table 3, the peak rod burnup and the cycle length tend to increase with higher enrichment and more number of feed, but the results are restrictive to some design criteria.

3.3. Flexible Uranium Loading Condition (Higher enrichment & More feeds)

The figure below shows the tendency of the peak rod burnup and the core reactivity depending on the increase of uranium loading.

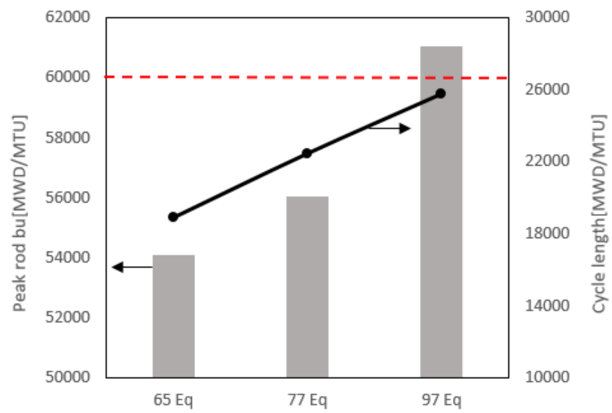

Fig. 4. Impact of U-loading Change on Peak Rod Burnup and Cycle Length

The peak rod burnup of the longer cycle core (97 Eq) obtained by increasing the uranium loading tends to be limited and exceeds the current burnup limit of 60 GWD / MTU. Therefore, it is essential to relax fuel rod burnup limit up to 62 GWD/MTU for 24-month core.

In addition, Table 4 shows the results of the economic evaluation with some assumptions, and it can be expected that a relatively large economic benefit can be gained when applying the 97 Eq core under the condition that the fuel rod burnup limit is relaxed, compared with 65 Eq and 77 Eq core.

Table 4. Economic Evaluation Results

	65 Eq	77 Eq	97 Eq
Avg. Capacity Factor [%]	91.32	92.56	93.46
Avg. Discharge Burnup [MWD/MTU]	45,699	45,795	41,743
U-loading [kg]	29,803	35,138	44,224
Fuel Cost [million $/yr]	59.44	64.02	69.72
Fixed Cost [million $/yr]	248.60	245.33	242.99
O&M Cost [million $/yr]	55.33	46.82	40.75
Relative Benefit [million $/yr]	Ref.	7.29	10.00

In other words, in the situation where the amount of uranium loading can be changed, the fuel rod burnup extension can enable longer cycle operation and contribute to the economic benefit by increasing cycle length.

3.4. Constant Uranium Loading Condition (Low Leakage Shuffle)

The effect of increase in the cycle length followed by the extension of the fuel rod burnup under the condition of fixed uranium amount was considered.

In the constant uranium loading condition, it can be obtained to improve the core reactivity by low leakage shuffle.

Firstly, in the case of 65 Eq core, as the feed is moved inside by the application of the low leakage shuffle (Fig. 5), the cycle length increases but inner power also increases. The peaking factor is violated, and the critical boron concentration, MTC (Moderator Temperature Coefficient) and other design criteria can be restrictive (Table. 5).

Also, the peak rod burnup which occurs at the peripheral (Fig. 1) may be even lower by low leakage shuffle compared to the original one. That is, the peak rod burnup is not a constraint in terms of improving the core reactivity.

Table 5. Core Characteristics of Low Leakage Shuffle Application Model for 65 Eq

	65 Eq	Design Criteria
Cycle length in EFPD (MWD/MTU)	478 (19,080)	-
HFP BOC CBC [ppm]	1,645	-
HZP BOC MTC [pcm/°F]	0.20	$\leq$ 5.0
Maximum FΔH	1.828	$\leq$ 1.528
Maximum Fq	2.302	$\leq$ 2.6
Peak rod burnup [MWD/MTU]	53,989	$\leq$ 60,000

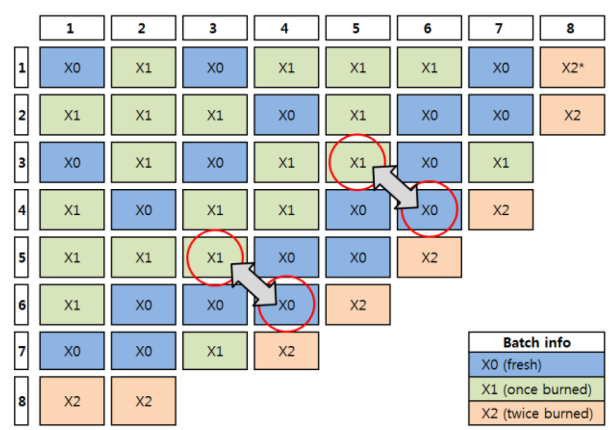

Fig. 5. Low Leakage Core Loading Pattern for 65 Eq Model

In addition, as shown in the above table, in the case of 65 Eq core, the maximum burnup of the fuel rod has a sufficient margin for the limit, which is not a constraint for design.

Secondly, in the 77 Eq and 97 Eq cores, the maximum fuel rod burnup exists inside the core (Fig. 2&3), and exceeds the limit of 62 GWD / MTU due to the increase of the cycle length by the low leakage shuffle (Fig. 6&7).

In these cases, however, the inner power of the core is increased as well, which causes unsatisfactory results in other design criteria such as peaking factor and critical boron concentration (Table 6).

Table 6. Core Characteristics of Low Leakage Shuffle Application Model for 77 Eq & 97 Eq

	77 Eq	97 Eq	Design Criteria
Cycle length in EFPD (MWD/MTU)	572 (22,930)	652 (26,170)	-
HFP BOC CBC [ppm]	1,627	1,675	-
HZP BOC MTC [pcm/°F]	0.15	0.61	≤ 5.0
Maximum FΔH	1.744	1.826	≤ 1.528
Maximum Fq	2.319	2.488	≤ 2.6
Peak rod burnup [MWD/MTU]	57,024	62,623	≤ 60,000

Fig. 6. Low Leakage Core Loading Pattern for 77 Eq Model

Fig. 7. Low Leakage Core Loading Pattern for 97 Eq Model

For the low leakage model for 77 Eq and 97 Eq, even though there would be extension of cycle length per the increment of fuel rod burnup, it is difficult to use the effect by extending the fuel rod burnup because the fuel loading pattern is unsatisfied with the basic design criteria.

4. Summary and Conclusion

This paper investigates the effect of fuel rod burnup extension in terms of improving core reactivity for domestic WEC type 3-loop PWR.

It was confirmed that fuel rod burnup limit extension can be utilized for longer cycle operation in the conditions of higher enrichment and more number of feed, which can increase uranium loading.

Otherwise, even if the low leakage shuffle is applied in the case of constant uranium loading condition, it is considered that the extension of fuel rod burnup cannot be utilized to improve core reactivity because of other design criteria constraints.

5. Future Plan

It is expected that the items reviewed in this paper based on the WEC type PWR condition can be referred to other domestic cores such as OPR1000 (Optimized Power Reactor 1000) and APR1400 (Advanced Power Reactor 1400).

REFERENCES

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