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Effect of Reactor Coolant Flow Rate on Axial Offset Anomaly Risk Assessment

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1. Introduction

The AOA(Axial Offset Anomaly) is also called CIPS(CRUD-Induced Power Shift). As the name implies, the cause of AOA is that boron compounds are deposited on the CRUD(Chalk River Unidentified Deposits) precipitated on the upper core, which causes the axial power distribution to differ from the design value. To predict a next cycle's AOA risk, the AO(Axial Offset) measurements from N-3 cycle to the current N cycle are benchmarked to set the CRUD-related variables then the next cycle's AOA risk is evaluated using the variables[2]. However, as a result of analyzing the cause of the specific cycle which was difficult to benchmark in the CRUD analysis, it was judged that the flow rate difference was the cause. In this paper, how the difference in a flow rate affects AO deviation and AOA prediction was analyzed.

2. Methods and Results

The possibility of AOA occurrence is predicted by the BOA(Boron-induced Offset Anomaly) code. BOA calculates the CRUD source term, subcooled nucleate boiling, CRUD precipitation mass and thickness, and produces the mass of boron deposited in CRUD to predict the degree of AO deviation(|Measured AO – design AO|). Benchmarking the AO deviation means adjusting this boron mass to the AO deviation degree. The amount of boron deposit capable of generating 3% AO deviation depending on the size of the core is listed in Reference [2]. This paper is based on 0.24 lbm of boron in the 157 fuel assembly core.

2.1 Benchmarking of AO Deviation

Figure 1 shows the AO design and measured values from N-3 cycle to the N cycle currently in operation. N-3 and N-1 cycles had AO deviations of nearly 3%, and N-2 cycle resulted in AOA. What is unusual is that the measured AO was biased upward at the beginning of the cycles before the N cycle. This means that the power at the top of the core is greater than the design value at the period.

Figure 2 shows the results of the BOA calculation using the measured flow rate. It is similar to the actual trend that the N-2 cycle has the worst evaluation result before N cycle. However, in all cycles, the amount of boron deposition is far less than the threshold value at which AOA can occur. This result is not considered to be benchmarked. For benchmarking, CRUD variables need to be adjusted in such a way as to increase the amount of the CRUD and boron deposition, or to review the thermal hydraulic data.

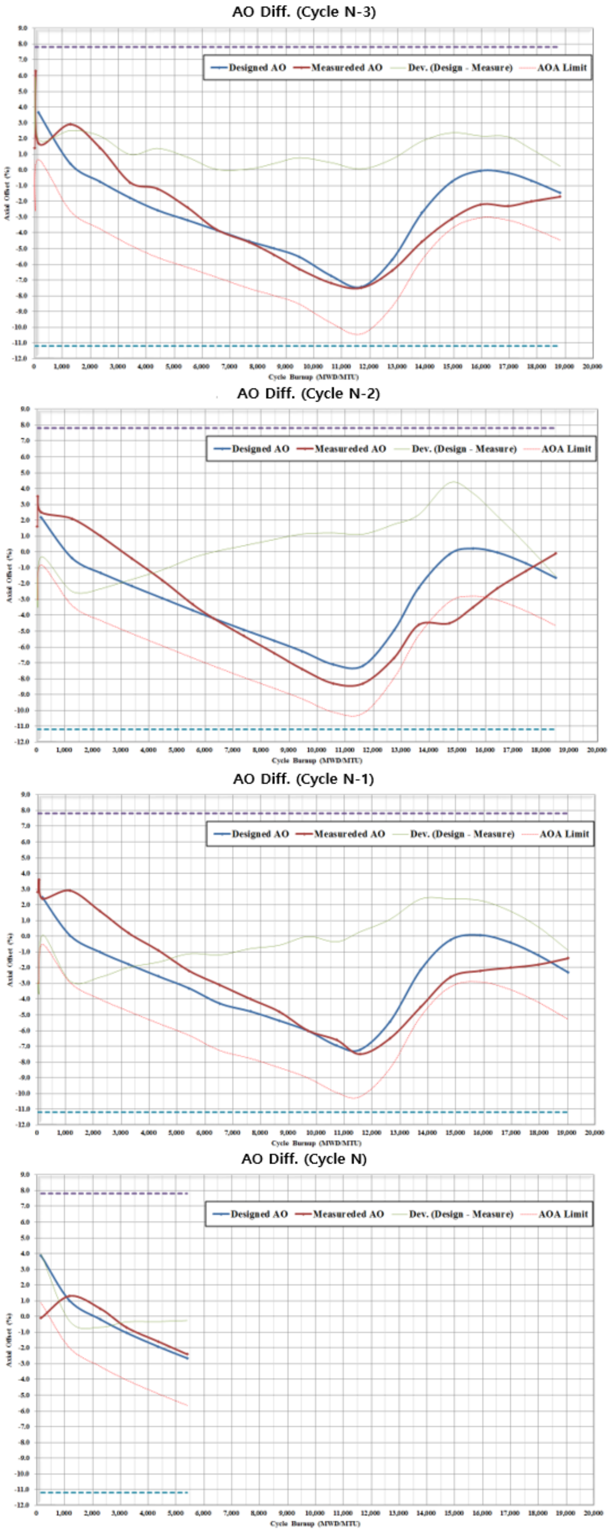

Fig. 1. Design and Measured values of AO from N-3 to N cycle

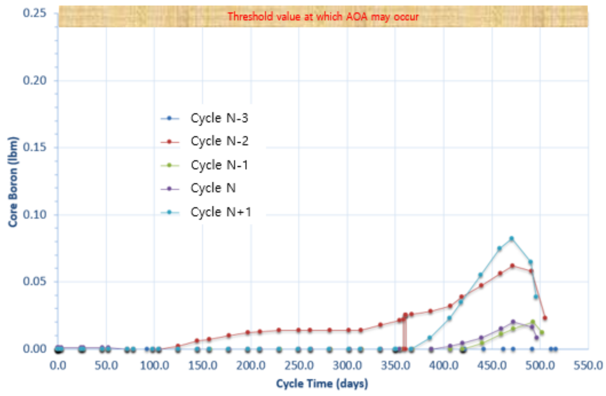

Fig. 2. Core boron mass with measured flow rate

2.2 Change of Flow Rate for Benchmarking

Since benchmarking is not possible with the variables of BOA, the thermal hydraulic data for BOA input was reproduced by changing the flow rate. The thermal hydraulic calculation was performed through the VIPRE-01 code. The flow rate reduced by 5 % compared to the measured value was applied(Table 1).

Table 1. Flow chart of AOA risk assessment

Cycle	Flow Rate(GPM)	
	Measured Value	5% Reduction
N-3	304782	289543
N-2	299870	284877
N-1	304480	289256
N	301801	286711

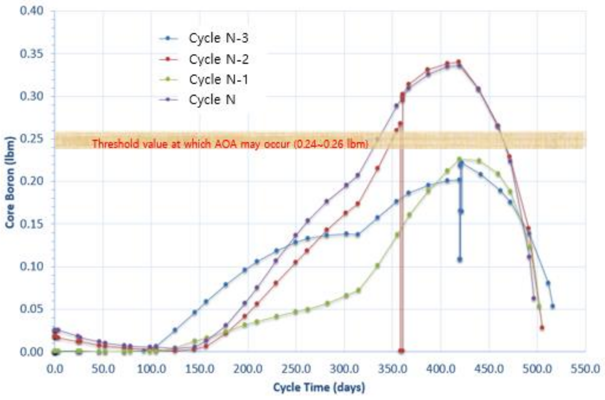

Fig. 3. Core boron mass with 5% reduced measured flow rate

Table 2. Benchmark results

Cycle	Max. Boron Deposition Mass(lbm)	Max. Predicted Diff.	Max. Measured Diff.
		(%), (0.24lbm, 3% criterion)	
N-3	0.2222	2.78	2.36
N-2	0.3397	4.25	4.36
N-1	0.2257	2.82	2.37
N	0.3361	4.20	-

The results of the assessment are summarized in Figure 3 and Table 2. The benchmark results from N-3 to N-1 cycles were similar to the measurements. The AO deviations of the N-3 and N-1 cycle were estimated to be close to 3%, and the N-2 cycle was estimated to have a value at which AOA could occur. However, benchmarking was impossible for the N cycle. Although N cycle was estimated to be very similar to N-2, N cycle in Figure 1 is very similar to the measured value and the design value up to now and is different from the trend in N-2 cycle.

To analyze the cause of these phenomena, the design flow rate and the measured flow rate are compared in Table 3. The flow rates used in the design from N-3 cycles to N-1 cycles are 6-8% lower than the measured values. However, the N cycle design value is almost the same as the measured value because it was determined by taking into account the previous cycle's measured values. Table 4 compares the channel outlet temperatures when the flow rate was adjusted by 5%. At 5% increase in flow rate, the outlet temperatures decreased by about 3°F and more than 3.5°F decreased in the fresh fuel channels.

As the measured flow rate is larger than the design value, the effect on AO deviation is the increase in the upper power due to the MTC(Moderator Temperature Coefficient). If the upper power is higher at the beginning of cycle, the lower power naturally increases after the middle of the cycle. In this case, even if the core boron mass is small as shown in Figure 2, the AOA risk may increase because the AO deviation increases to the bottom as shown in Figure 1. In N cycle, the AO is similar from the beginning of the cycle because the design and measured value of the flow rate are very similar.

Table 3. Comparison of designs value and measured values of flow rate

Cycle	Flow Rate(GPM)		(c-a)/a (%)
	Design Value, c	Measured Value, a	
N-3	281100	304782	-7.8
N-2	281100	299870	-6.3
N-1	281100	304480	-7.7
N	302439	301801	0.2

Table 4. Temperature variation of subchannel outlet by flow rate change

Channel No.		Channel Outlet Temp.(°F)		Diff.(a-b), °F
		a	b	
Fresh Fuel	49	627.20	630.96	-3.76
	55	627.33	631.07	-3.74
	105	623.39	627.00	-3.61
	122	628.51	632.29	-3.78
Reloading Fuel	17	611.14	614.26	-3.12
	57	596.40	598.88	-2.48
	77	615.93	619.24	-3.31
	153	573.38	574.78	-1.4

a: Design flow rate was applied.
b: Measured flow rate was applied.

The reason for the increase of boron deposit amount when the flow rate decreased by 5% similar to the design value is that the temperature and boiling of the upper part of the core increase resulting in the high amount of CRUD precipitation. On the other hand, the AOA risk in N cycle seems to be overestimated because the flow rate is lower than the design value.

3. Conclusions

The flow rate affects AOA risk by changing the temperature of upper core. If the measured flow rate is greater than the design value, the AO deviation may increase without boron deposition in CRUD due to the MTC. If the measured value is smaller than the design value, the AOA risk may increase due to the increase in CRUD and boron deposition. Therefore, the measured flow rate should be used in the AOA risk assessment. Also the flow rate reflecting measured values of previous cycles should be used for core design because AOA will be evaluated using the design value in case of AOA prediction cycle(N+1) that does not have a measured flow rate.

REFERENCES

[1] Frattini, P. L., et al., Axial Offset Anomaly: Coupling PWR Primary Chemistry with Core Design, Water Chemistry for Nuclear Reactor Systems, 1, BNES, Bournemouth, 2000
[2] J. L. Westacott, et al., Boron-induced Offset Anomaly (BOA) Risk Assessment Tool version 3.1, EPRI technical report 3002000831, 2013.