Experience of Axial Offset Anomaly (AOA) Risk Assessment for Reload Core after Steam Generator Replacement

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1. Introduction

Ulchin Unit 2 replaced Steam Generators in 2011 and 2012. Replacement of Steam Generator may have an effect on core operation and nuclear fuel reliability in aspect of CRUD deposition on fuel rod surface and consequently increased AOA risk of reload core.

AOA is defined as a significant negative axial offset deviation from prediction of the core design.[2] AOA causes negative impacts which hindrance effective core control during normal and transient core operation such as an erosion of shutdown margin, loss of operation flexibility during transient.[2] To evaluate effect of Steam Generator Replacement on fuel and core operation prior to SGR, KHNP-CRI performed AOA risk assessment with EPRI's AOA risk assessment tool BOA and provided recommendation to reduce AOA risk of the post SGR core operation.

2. Methods and Results

2.1 BOA Modeling

BOA (Boron-induced Offset Anomaly) Risk Assessment code is developed by EPRI to provide AOA (CIPS) risk assessment. Axial Offset Anomaly (AOA, also referred to as CIPS, Crud Induced Power Shift) is caused by the Boron incorporated into the thick crud deposited especially on the upper span of the fuel assembly.

Core boron deposited on the fuel rod absorbs thermal neutrons of the upper span of the core and causes a depression of flux distribution. This phenomenon is called as CIPS or AOA. Threshold values of core boron are shown in Table-I.

Table I: Boron Threshold Mass Target Range

Core Size (# of Fuel Assemblies)*	Boron Threshold (lbm)	Upper Limit (+10%)
241	0.37	0.41
217	0.34	0.37
193	0.30	0.33
177	0.28	0.31
157	0.24	0.26
121	0.19	0.21

*(For core sizes not listed, boron lbm threshold is determined by: Threshold = (# of Fuel Assemblies) * (0.30/193).

Crud deposition is driven by SNB (Subcooled Nucleate Boiling) on hot assemblies and corrosion products in the RCS.

Subcooled Nucleate Boiling area and mass of the core boron are calculated from the Core node power distribution data of core design and CFD modeling.

Final BOA model is adjusted through benchmarking process for the previously operated cycles and measured data

The effect of Steam Generator Replacement on core is based on increased Ni and Fe release rate from the Steam Generator tube surface. The first three cycles, Ni and Fe release rate of Steam Generator are relatively high. In addition, second cycle after Steam Generator Replacement is at higher risk of AOA because the crud mass carried over from the first cycle. [1]

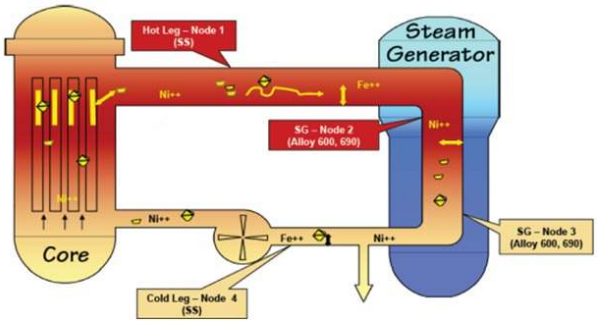

Fig. 1 Schematic Diagram of BOA model

2.2 Ulchin Unit 2 AOA assessment

Ulchin Unit 2 cycle 18 is the target cycle of AOA risk analysis after Steam Generator Replacement(Alloy 600→Alloy 690). Also, new fuel design (ACE7) which incorporates increased IFM (Intermediate Flow Mixer) grids feature is implemented as fresh fuels of Ulchin Unit2 cycle 18.

The mixed effects of Steam Generator change, new fuel design feature and Ultrasonic fuel cleaning were encountered in Ulchin Unit 2 cycle 18 AOA risk assessment.

Maximum boron mass deposited in the core is calculated as 0.35lbm at 459 EFPD (Effective Full Power Day) of Ulchin Unit 2 cycle 18. It is greater than the threshold value 0.24lbm and less than twice the threshold. The increased potential for mild and manageable AOA(less than -5% of axial offset deviation) is expected.

Maximum Core Boron mass of cycle18 is 1.75 times greater than that of cycle 17. Main contributors of core boron mass increase were increased Ni release from the new Steam Generator surface and increased local boiling and crud thickness.

Ultrasonic Fuel Cleaning is modeled to decrease the core boron mass, and the result showed that the maximum core boron mass is decreased to 0.27lbm. It is slightly above the threshold value 0.24lbm but AOA susceptibility is remarkably decreased.

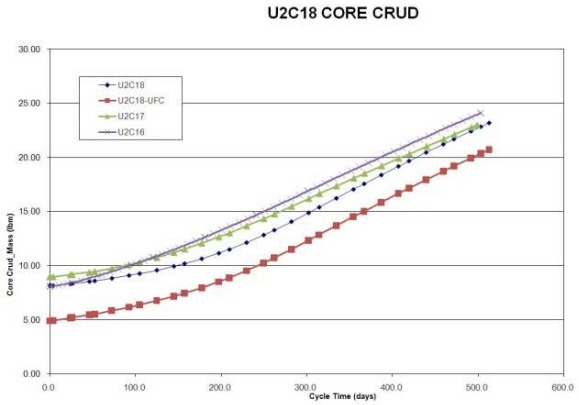

Fig. 2 Core CRUD mass: Cycle 16 – 18

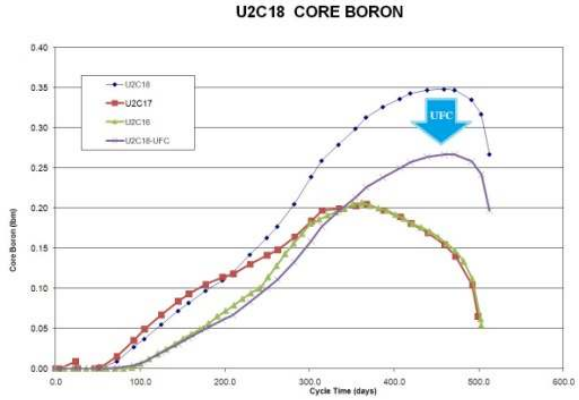

Fig. 3 Core BORON mass: Cycle 16 - 18

2.3 Ulchin Unit 1 AOA assessment

Ulchin Unit 1 cycle 19 is the target cycle of AOA risk analysis after Steam Generator Replacement. New fuel design (ACE7) feature is implemented as Ulchin Unit 2. Ulchin Unit 1 has been implementing Zn injection (5ppb) since cycle 17 to reduce exposure during outage. There is possibility that Zn injection could give a negative impact on core in aspect of AOA risk in the initial cycles of Zn injection, Zn injection with Steam Generator replacement is modeled for AOA risk analysis. Also, Ultrasonic Fuel Cleaning performed during O/H after cycle 16 and 17 was encountered as well. In cycle 18, core boron mass is calculated as 0.247lbm at 360 EFPD due to increased core power peaking factor of reload core design. It is slightly exceeds boron threshold value 0.24lbm (Table 1.).
In cycle 19, maximum core boron mass is 0.31lbm at 370 EFPD and it exceeds threshold value of 0.24lbm.
Mild AOA is expected with 0.31lbm of core boron.

If Ultrasonic Fuel Cleaning is performed for the reloaded fuels in cycle19, core boron mass can be decreased to 0.185lbm and it is below the threshold value.

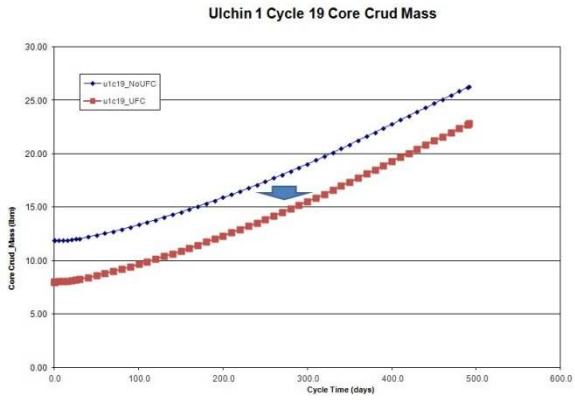

Fig. 4 Core CRUD mass: Cycle 19

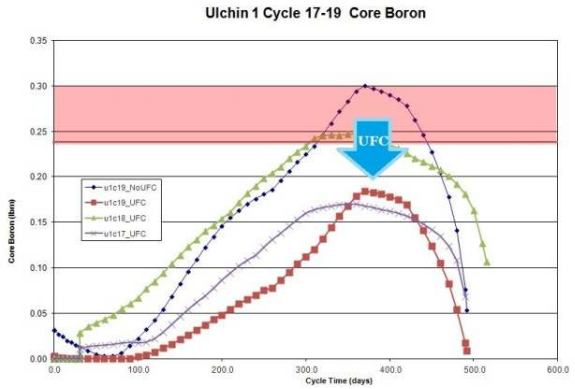

Fig. 5 Core BORON mass: Cycle 17- 19

4. Conclusions

With the results of AOA risk assessment using BOA, KHNP-CRI suggested Ultrasonic Fuel Cleaning to Ulchin Site and Ulchin Unit 1,2 performed and planed UFC to reduce AOA risk. AOA risk assessment is strongly required to every reload core design verification process and all plant configuration changes that have potential to have an impact on core operation.

Unit 1, 2 experienced AOA at several cycles in the past. Also, a series of scheduled changes in Ulchin Unit 1, 2 could aggravate AOA risk of following cycles after change. AOA risk assessment will be applied to planned core related changes such as Power Optimization, Zinc Injection, New Fuel Design, Extended Cycle operation, Reload Core Design, etc.

REFERENCES

[1] Boron-Induced Offset Anomaly (BOA) Risk Assessment Tool, Version 3.0, EPRI, Palo Alto, CA: 2010
[2] PWR Axial Offset Anomaly (AOA) Guidelines, [3] Revision 1, EPRI, Palo Alto, CA: 2004.