Effect of Axial Power Distributions of Fuel Assemblies on Axial Offset Anomaly

*SeoJeong Lee, Ji-Eun Jung
Korea Hydro & Nuclear Power Co. Ltd., 70, 1312-gil, Yuseong-daero, Yuseong-gu, Daejeon, Korea
*Corresponding author: s.jeong2@khnp.co.kr

1. Introduction

The deviation of the power of the upper and lower part of the reactor core is referred to as Axial Offset(AO, WH type) or Axial Shape Index(ASI, CE Type). If the difference between its design value and its measured value is more than 0.03, it is called an Axial Offset Anomaly(AOA). The process of occurrence of this is in order of CRUD(Chalk River Unidentified Deposits) precipitation on the cladding surface where boiling occurs, boron deposition in the CRUD and change of the axial power distribution due to neutron absorption of boron[1].

1/4 assembly-wise radial power distribution and core average axial power distribution are used to produce the thermal-hydraulic data of the core for the CRUD precipitation calculation in the above process. To improve the accuracy of the AOA risk evaluation, however, this study tried to apply the axial power distribution of each fuel assembly instead of the core averaged. A change in the shape of the axial power distribution may alter the location and amount of the boiling and the CRUD precipitation, which may result in a change in boron deposition characteristics that directly affect the AOA risk. In this paper, the axial power distribution effects on AOA was analyzed.

2. Methods and Results

Figure 1 shows the AOA risk assessment methodology used for this analysis. The core average axial and radial power distributions calculated by the nuclear design code (ANC) are used to produce thermal hydraulic data of the core, such as pressure, temperature, heat flux and coolant density by axial node using subchannel analysis code (VIPRE). These data are provided to BOA(Boron-induced Offset Anomaly) that is water chemistry analysis code[2].

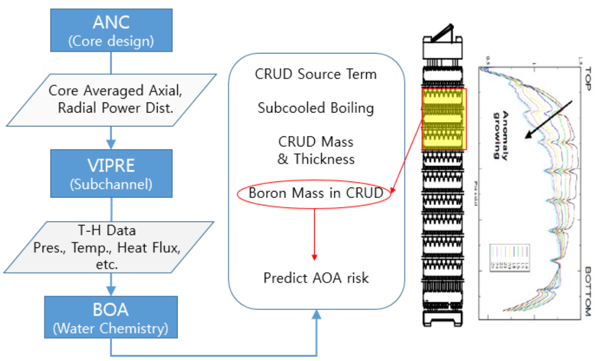

Fig. 1. Flow chart of AOA risk assessment[2]

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 AOA risk. In this methodology, axial power distributions for each fuel assembly are extracted from the ANC and used for VIPRE calculation. A 1/4 assembly is one channel, and the four channels in one assembly have the same axial power distribution.

2.1 Subject of Evaluation

The specific cycle of OPR1000 was targeted. As shown in Figure 2, based on the 1/4 symmetric core design, the BOA results of the case of applying the core average axial power distribution were compared to the case of applying each axial power distribution of 52 fuel assemblies. Figure 3 shows the power distributions of core average and each assembly.

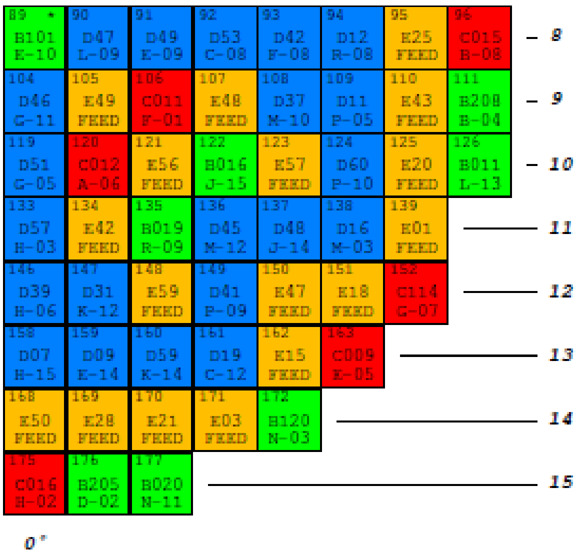

Fig. 2. 1/4 core loading pattern of the OPR1000 specific cycle

2.2 BOA Results

Comparing the amount of core boron deposition that can determine the degree of AOA risk, it is smaller in the case of applying the 52 axial power distributions as shown in Figure 4. And the amount of CRUD precipitation was compared for a specific assembly selection for detailed analysis. In Figure 5, the red positions are the fuels in which the CRUD is much deposited, and these positions are the fresh fuel(FEED) position in Figure 2. Since the fuel number of 19 had the largest amount of CRUD precipitation, detailed analysis of the fuel was conducted.

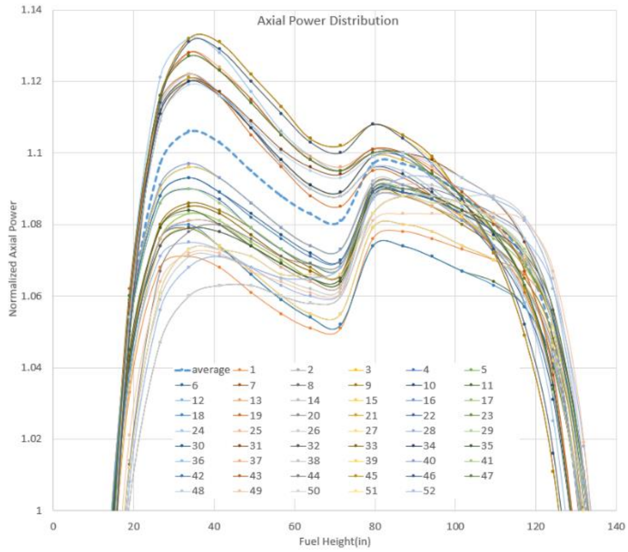

Fig. 3. Axial power distributions of core average and each assembly

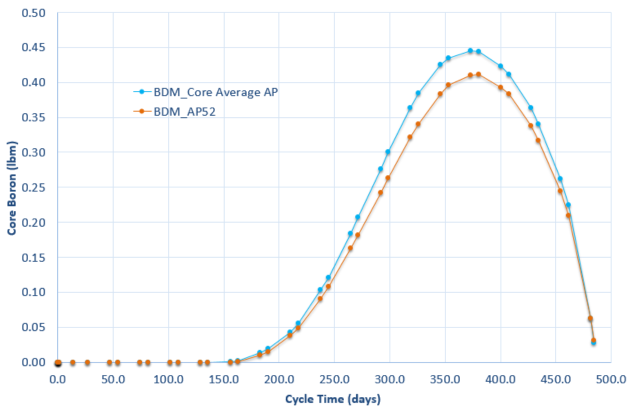

Fig. 4. Core boron deposition mass

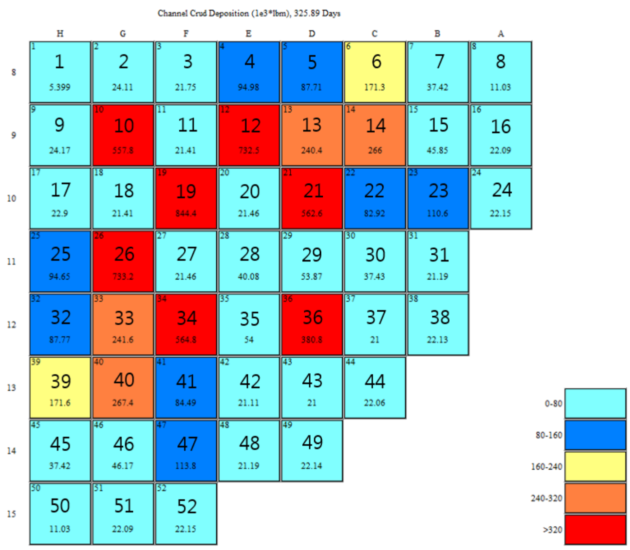

Fig. 5. CRUD precipitation mass by each assembly

2.3 Detailed Analysis

The power distribution of the fuel No.19 is more concentrated in the lower part compared with the core average case. The reason for this is that the fresh fuel having a constant burnup in the axial direction has a higher power at the lower part of the core due to reactivity feedback where the coolant temperature is relatively low.

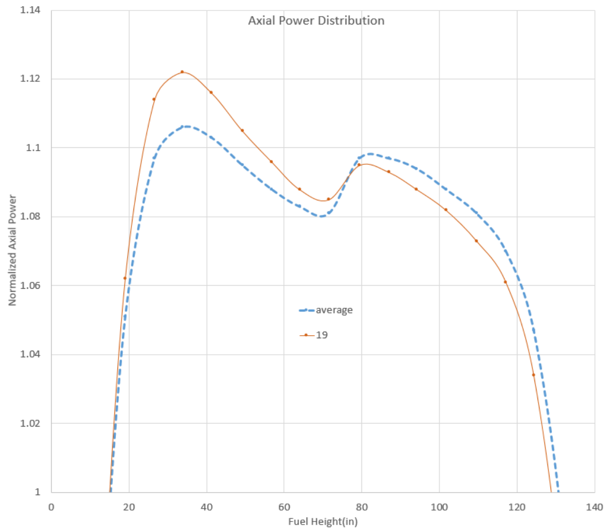

Fig. 6. Axial power distributions of core average and fuel No.19

If CRUD is present on a boiling surface of a cladding, the boron concentration at the surface is determined considering diffusion through the CRUD layer. A concentration factor(Eq.1) is calculated for each axial node and used to determine the concentration of a particular species at the cladding surface from the bulk coolant boron concentration[3]

$$CF_i = \frac{C_{clad}}{C_{coolant}} = Exp\left[\frac{\dot{m}_e \delta_c}{\rho_{liq} D_k P}\right] \qquad (1)$$

where

C_{clad} = concentration at clad surface,
$C_{coolant}$ = concentration of bulk fluid,
$\dot{m}_e$ = mass evaporation rate,
δ_c = CRUD thickness,
ρ_{liq} = saturated liquid density,
D_k = diffusion coefficient of species k, and
P = CRUD porosity.

If the denominator variables of the exponent of Equation 1 are constant, the amount of boron deposition becomes exponentially increase as the CRUD thickness and mass evaporation rate are increase. Therefore, the effect of the applying the power distribution of each assembly was analyzed for these two variables.

As a results of analysis of Figure 7 and 8, the boiling starts to occur at the fuel height of 100 inches or more, and the CRUD is also precipitated in a region where boiling occurs. The CRUD thicknesses are very similar in both cases, but the mass evaporation rate is larger in case of the core average power distribution in the region of about 130 inches above the fuel height because in that case the boiling is more likely to occur at the cladding surface due to higher power at the upper region as shown in Figure 6. Therefore, as shown in Figure 9, the boron deposition mass of fuel No. 19 is larger when the core average axial power distribution is applied.

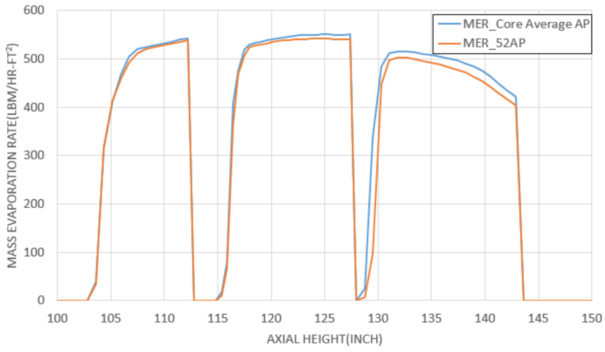

Fig. 7. Mass evaporation rate

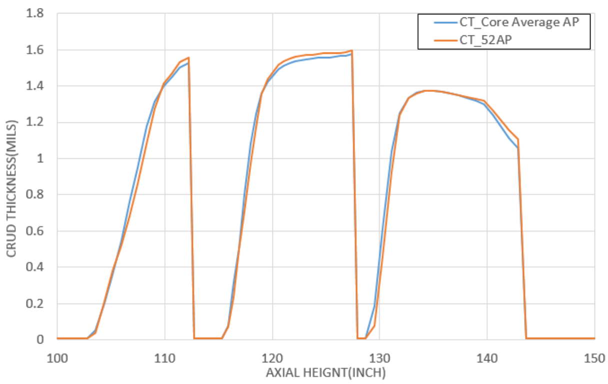

Fig. 8. CRUD thickness

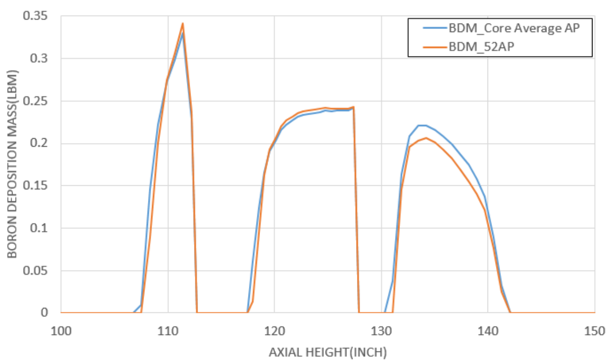

Fig. 9. Boron deposition mass

3. Conclusions

The effects of axial power distributions were compared through the BOA results by selecting the fuel in which the CRUD is most deposited among the fresh fuels.

The axial power distribution of fresh fuel has a larger power at the bottom region of the core and a lower power at the top region compare with the core average axial power distribution. Due to this factor, the latter application increases the amount of boiling at the top region and overestimates the core boron deposition mass. Therefore, applying the axial power distribution of each fuel assembly is a way to predict more accurate AOA results.

REFERENCES

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[2] S. J. Lee, et al., A Study for prediction Accuracy Improvement of Axial Offset Anomaly Risk, Transaction of the KNS autumn meeting, 2018.

[3] 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