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Axial Offset Biasing with Burnup Dependent Albedo Constants

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1. Introduction

The axial offset in the beginning of cycle has been under predicted by about 2~3% for 3-loop WH type domestic plants. This phenomenon is also quite common in plants abroad and known as Axial Offset Deviation compared to Axial Offset Anomaly or Crud Induced Power Shift. It could result in the inaccuracy of Fq surveillance results by affecting the W(Z) parameter which accounts for transient behavior of axial offset and increase the operator burden for reactor control. In this paper, the axial offset biasing methodology using the burnup dependent albedo in top/bottom reflector region is proposed and the comparison to the measured AO value was made for some domestic plants.

2. Methods and Results

The Axial Offset(AO) is the power sharing percentage of the top and bottom halves of the core and represents the degree of skewness about axial power shape. It is an essential parameter for the surveillance, monitoring and control of core power distribution. APA code system[1] is used for the core design of domestic WH-type plants. The axial offset has been under predicted by about 2~ 3% in the beginning of a cycle and slightly over predicted after the middle of a cycle for 3-loop plants. The AO difference could result in the inaccuracy of Fq surveillance results since the W(Z) parameter which accounts for the transient behavior of AO is based on predicted AOs. Also it increases the burden of operator for reactor control.

2.1 AO Biasing by Albedo Constants

Major factors affecting AO difference are cross sections, burnup shadowing of control rod and power history, inlet temperature variation, and boundary condition on top/bottom of the core. Recently, the amount of AO difference has been increased by more than 3% for some plants and various approaches to reduce the difference have been tried, such as axial burnup correction, inlet temperature adjustment, imaginary control rod insertion all without any significant improvement. Although the measured AO could be followed via imaginary control rod insertion[2], it affects the local axial power distribution drastically and heavily depends on the loading pattern thus AO prediction is not consistent cycle by cycle. Therefore, it is not appropriate to use imaginary control rod for the AO difference relaxation. AO prediction could be improved by the cross section treatment which is quite hard to achieve and requires a huge amount of effort. In this paper, AO biasing based on time dependent albedo boundary condition was proposed and the effects on safety related parameters were evaluated.

2.2 Albedo Models in APA code system

The albedo boundary condition is applied to the outer surface of the problem in ANC code[3] which is a nodal depletion code in WEC APA code package. The net current albedo is defined as the ratio of the net current out of the reflecting region to the flux of the reflection region as shown in Fig. 1. Since the outermost node is a reflector in axial direction in ANC, top/bottom albedos are applied at the outer surface of the reflector nodes as a boundary condition. No upscattering is assumed, so the albedo boundary condition has the general form of Eq (1). For the geometry of Fig. 1, 2-group diffusion equation(Eq.(2)) in reflector region gives flux solution of the Eq. (3). which represents the reflection coefficient.

$$\begin{bmatrix} J_1 \\ J_2 \end{bmatrix} = \begin{bmatrix} a_{11} & 0 \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} \phi_1 \\ \phi_2 \end{bmatrix} \quad (1)$$

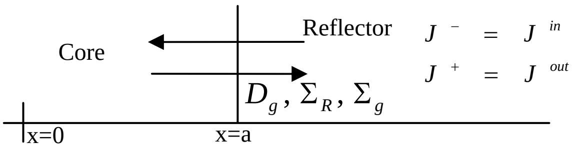

Figure 1. Geometry for Reflector Boundary Modeling

$$\begin{aligned} &-D_1\nabla^2\phi_1 + (\Sigma_1 + \Sigma_R)\phi_1 = 0 \\ &-D_2\nabla^2\phi_2 + \Sigma_2\phi_2 = \Sigma_R\phi_1 \end{aligned} \quad (2)$$

$$\begin{aligned} &\phi_1(x) = A_1\sinh(\tau x) \\ &\phi_2(x) = A_1\beta\sinh(\tau x) + A_2\sinh(Lx) = \phi_{2p}(x) + \phi_{2h}(x) \\ &where, \quad \tau^2 = \frac{\Sigma_1+\Sigma_R}{D_1}, \quad L^2 = \frac{\Sigma_2}{D_2}, \quad \beta = \frac{\Sigma_R}{(L^2-\tau^2)D_2} \end{aligned} \quad (3)$$

Since partial current densities are approximated in diffusion theory as Eq (4) by the P1 approximation, the albedo coefficients a_{11},a_{22},a_{21} can be obtained as Eq. (5) [4,5].

$$J^{\pm}(r,t) = \frac{\phi(r,t)}{4} \mp \frac{D}{2}\hat{e}\cdot\nabla\phi(r,t) \quad (4)$$

$$a_{11} = D_1\tau, \quad a_{22} = D_2L, \quad a_{21} = -\frac{\Sigma_R}{(L+\tau)} \quad (5)$$

2.3 Burnup Dependent albedo correction

As shown in Eq. (5) albedo coefficients a_{11},a_{22},a_{21} are functions of cross sections of reflector region, thus albedo constants can be modified by adjusting diffusion coefficients, absorption cross section and removal cross section input for reflector region to bias the predicted to the measured AO. That is, they are modified to reduce neutron leakage at the top and result in more top skewed axial power shape, or positive AO. Albedo coefficients which give the best AO prediction were determined by heuristic approach and bottom reflector albedos are also adjusted to conserve the core reactivity. Since AO prediction is reversed around in the second half of the cycle, the original albedos are retained for those period for both the top and bottom reflectors. The top reflector node albedo coefficients are summarized in Table 1.

Table 1. Summary of Albedo Coefficients

Top Albedo Coefficients	Biased Albedo		Original Albedo
	0~10000 MWD/MTU	10000 ~ EOL	0~EOL
a_{11}	0.3359	0.2144	0.2144
a_{22}	-0.1202	-0.0585	-0.0585
a_{21}	0.2283	0.1031	0.1031

2.4 Results and Discussion

Burnup dependent albedo was applied to two of the 6 domestic WH 3-loop plants for several cycles in order to bias the AO prediction, where single sets of albedo coefficients are used for these plants. The predicted AO generally matches to the measured AO within 1% of AO difference with slight discontinuity at the albedo transition point as shown in Fig. 2 and 3. The overall core reactivity is evaluated based on critical boron and there is a slight increase at BOL (~5 ppm) and almost no change at EOL. The axial power profile comparison results show that the axial power profile is skewed reasonably reflecting AO bias. For the safety evaluation, nominal Fq was increased slightly (3.5%) after MOL for biased model and the Fdh remained almost the same. MTC and DTC were also compared to find that they were almost the same with maximum differences of 0.16 pcm/°F for MTC and 0.02 pcm/°F for DTC.

3. Conclusions

Burnup dependent albedo for the top/bottom reflector was applied to WH type 3-loop plants in order to bias the AO to the measured AO. The biased AO is in good agreement with the measured AO with slight discontinuity at the albedo transition point. The albedo bias effects on core reactivity, Fdh, MTC, DTC were found to be negligible while there was a minor increase in Fq and the axial power profile was transformed reasonably reflecting the AO change. AO bias by burnup dependent albedo was found to be a very good approach for the best prediction of AO in domestic WH type 3-loop plants. Since the albedo was determined by heuristic approach, more detailed analysis of burnup dependent cross section behavior in the reflector node is necessary for further study.

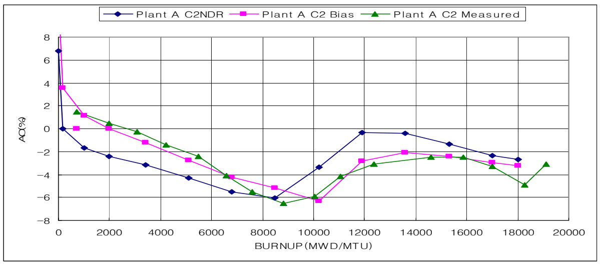

Fig. 2. AO Bias with 2nd Cycle Application for Plant A

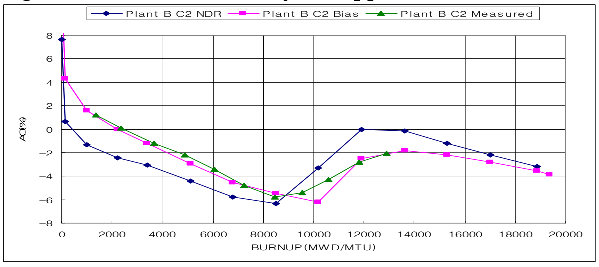

Fig. 3. AO Bias with 2nd Cycle Application for Plant B

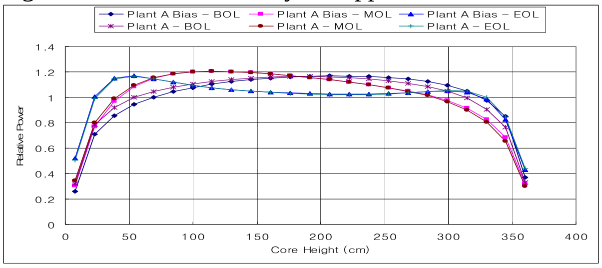

Figure 4. Axial Power Profile Comparison

Table 2. Core Reactivity Comparison with AO Biasing

Core Reactivity	Average Delta Critical Boron (ppm)	
	Plant A	Plant B
BOL	+5	+5
EOL	0.33	0

Table 3. MTC Comparison Results with AO Biasing

MTC(pcm/°F)	Plant A NDR	Plant A Bias	Bias-NDR
BOL HZP ARO	-0.096	0.062	0.158
BOL HFP ARO	-12.276	-12.265	0.011
EOL HFP ARO	-38.938	-38.905	0.033

Table 4. DTC Comparison Results with AO Biasing

DTC(pcm/°F)		Plant A NDR	Plant A Bias	Bias-NDR
B	HZP ARO	-1.906	-1.928	-0.022
	HFP ARO	-1.420	-1.422	-0.002
E	HZP ARO	-2.070	-2.066	0.004
	HFP ARO	-1.586	-1.586	0.0

REFERENCES

[1]Nguyen, T.Q., et. al., Qualification of the PHOENIX-P/ANC Nuclear Design System for Pressurized Water Reactor Cores, WCAP-11596-P-A, June 1988

[2] Secker, J. R., et al, 'Methods for Evaluating Crud Induced Axial Power Shift,' ANS Annual Meeting, June 17-21, 2001, Milwaukee, WI.

[3]Liu, Y. S., et. al., ANC-A Westinghouse Advanced Nodal Computer Code, WCAP-10965-P-A, September 1986

[4]James J. Duderstadt, Louis J. Hamilton, Nuclear Reactor Theory

[5]The Feasibility study on the nuclear design code domestication, K.J. Lee, et. al., KNFC-TR-041-97, 1997