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Evaluation of Crud Induced Local Corrosion Using Falcon Code

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ABSTRACT: *AOA, the phenomenon of power shifting to bottom of axial power distribution because of boron deposition in CRUD chimney, affects safe operation of nuclear power plants. In particular, CRUD elevates cladding surface temperature by acting as local thermal resistance. This accelerates the cladding oxidation and degrades cladding integrity. So, it is important for fuel which experienced AOA to confirm the oxide thickness in terms of cladding integrity and reload core management. Therefore, CRUD induced local corrosion (CILC) caused by AOA was evaluated using FALCON code and we compared results with measured data. FALCON code which is the fuel performance code developed by EPRI containing can consider impacts of CRUD deposited on the cladding surface because it contains heat transfer equation about CRUD. Representative fuel assemblies (FA) were selected as followed cases. (i) Maximum power sharing FA, (ii) Maximum power sharing FA among once burned FA, (iii) Maximum CRUD thickness FA among once burned FA, (iv) Maximum burn-up FA. Rod power history and axial shape history were calculated by ANC code and CRUD thickness was calculated by EPRI's BOA code, respectively. Calculated CRUD thickness of each FA was evaluated up to 3.67mils. Following FALCON results, first case of FA had maximum oxide thickness with 61.69 microns. In contrast, measured oxide thickness was 36.75 microns which was lower than simulated results. Other measured values were also lower than calculated ones. In conclusive, FALCON overestimates the oxide thickness of CILC compared with measured data. Therefore, corrected methodology is needed to calculate the CILC problems using FALCON.*

KEYWORDS: *AOA, Crud, Corrosion Falcon*

I. Introduction

In recent, chalk river undefined deposit (Crud) deposit on cladding occurred various problems in PWRs. Crud is an oxide products (NiO, Fe_3O_4, $NiFe_2O_4$, etc) which is generated from pipe and steam generator tube of reactor coolant system. Metal ions dissolved from alloys of pipes to primary coolant, is migrated and deposit on the surface where sub-cooled nucleate boiling was occurred. Crud has porous structure. And axial offset anomaly (AOA) could be occurred when soluble boron was deposited in this porous. Also, severe cladding damage due to local corrosion like crud induced localized corrosion (CILC) because thermal conductivity of crud is very low.

In this research, oxidation acceleration of cladding such as CILC was predicted by code calculation and this prediction was compared with measured data. EPRI BOA v3.1 and FALCON v1.3.0 code was used in this study. BOA code can evaluate amount of crud in primary system, AOA prediction, crud deposition on cladding and boron deposition in crud. FALCON code can evaluate fuel performance, PCI prediction and oxide thickness of cladding, etc. Crud thickness was calculated by BOA code and oxide thickness was calculated by FALCON code. Then this results was compared with oxide thickness measured at nuclear power plant.

II. Code analysis methodology

In this study, we analyzed the effect of CILC on cladding oxidation. Selected fuel assemblies were experienced AOA, and was selected through conditions such as maximum power, maximum crud deposition, maximum oxide thickness. The oxide thickness of the selected nuclear fuel assemblies was measured by the ECT method in Over Haul. In addition, oxide thickness was evaluated by crud deposition using EPRI Falcon code v1.3.0 [ref], and the analytical results were compared with the measured results.

II.A. Crud thickness calculation

Because the thickness of the crud deposited in the cladding cannot be measured, the predicted value of the crud thickness was calculated through the code. EPRI BOA code was used to produce CRUD thickness input data. The BOA code was used for the AOA evaluation and the BOA model was set up to simulate the calculated ASI deviation and the actual ASI deviation of the plant. We then used the calculated crud thicknesses in the model.

II.B. Oxide thickness calculation

To generate the Falcon code input data, the LPD value and axial power shape data of the target fuel assemblies were extracted using ANC code. Crud thickness data which was calculated by BOA code was used. The thermal conductivity of the deposited CRUD was 1.18 W/m-K, as given in the EPRI report [3]. In the Falcon code, since the thermal conductivity of the crud cannot be input separately, the thermal conductivity of the oxide and crud composite layer was calculated by applying the lever rule. Oxide thickness of cladding was calculated by considering CRUD deposition, and fuel cycle. The previous cycle was calculated assuming no crud deposition. For the last period, the maximum oxide thickness of the previous cycle and the CRUD thickness were input.

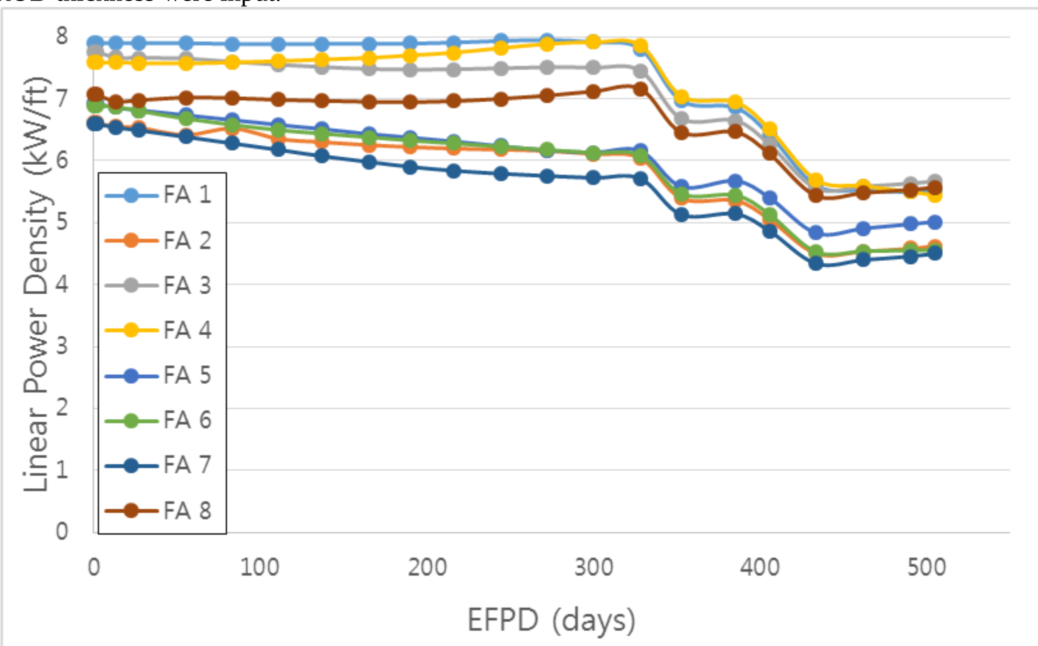

Fig. 1 LPD of each assemblies

II.C. Oxide thickness measurement

After the plant operation, eddy current test (ECT) was performed on the selected eight fuel assemblies. The ECT test was performed before and after crud cleaning. Crud did not have a significant effect on the ECT test. Oxide thickness was calculated by applying large measures to apply conservative results.

III. Results

Through the calculation of the BOA code, crud thickness was evaluated as shown in Fig. 2. It was estimated that the crud thickness of the FA 1 which was the thickest, and the four FAs of the selected assemblies were estimated that the crud was not deposited.

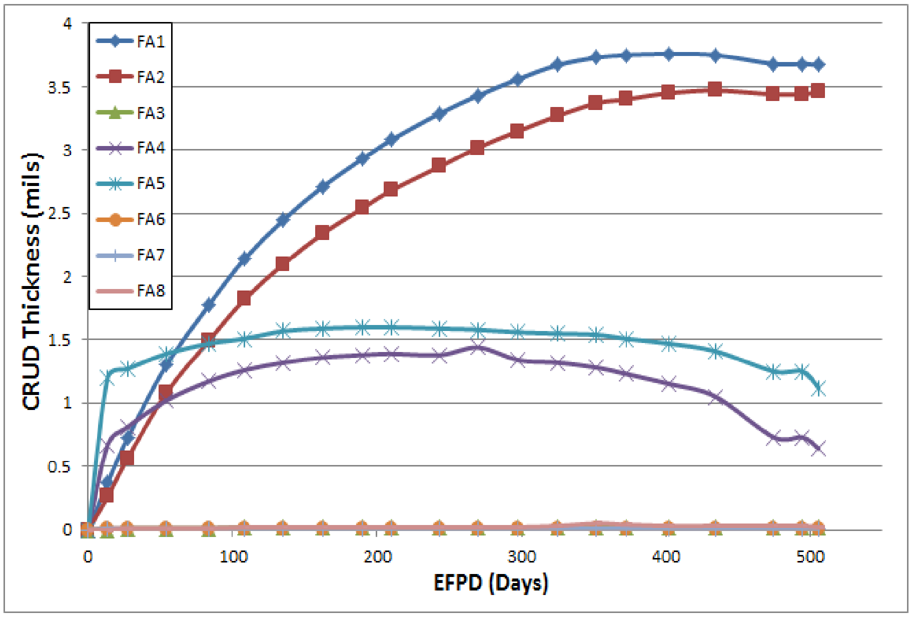

Fig. 2Crud thicknes calculated by BOA code

The following table compares the crud thickness, the calculated oxide thickness, and measured oxide thickness. Four of the eight selected nuclear fuel assemblies were estimated to have a significant amount of CRUD deposition and the other fuel assemblies were estimated to be almost free of crud. First, comparing the results of the code calculation and the measurement results of the fuel assembly without crud deposition, it can be seen that the results predicted by FALCON code were similar to those of the FALCON code except for the FA7. This showed that FALCON code predicts oxide thickness well if crud was not deposited.

Table 1 Maximum crud and oxide thickness of each fuel assemblies

FA Num	**Num of Cycle**	**Maximum CRUD Thickness (mils)**	**Oxide Calculation (microns)**	**Oxide Measurement (microns)**
1	1	3.76	77.35	36.75
2	1	3.47	71.96	29.50
3	1	0.02	9.23	10.33
4	2	1.44	54.82	39.01
5	2	1.6	54.09	33.00
6	2	0.01	24.60	24.39
7	3	0.01	50.56	16.75
8	1	0.01	9.53	11.67

However, calculated oxide thickness was overestimated compared to the measured value for the crud deposited fuel. This was considered to be a problem of choosing the thermal conductivity value of the crud. The thermal conductivity of the CRUD presented in the EPRI report is a measure of the thermal conductivity based on the non-boiling condition. However, the results of BOA code analysis showed that local boiling occurred near the crud. The heat transfer coefficient was enhanced by local boiling, and the thermal conductivity of the crud was also higher than expected. It is known that the thermal conductivity of the crud is 6.1W / m-K when the boiling occurs when the thermal conductivity of the crud is measured. Considering the oxide measurement results and the literature, it is considered that the acceleration of oxidation is caused by the thermal resistance due to the crud in the initial stage of crud deposition, but the heat transfer efficiency is increased due to local boiling when the crud thickness becomes sufficiently thick.

IV. CONCLUSIONS

This study conducted the accelerated oxidation by CILC. The thickness of the crud was calculated by EPRI BOA code, and the oxide thickness of the cladding was evaluated by EPRI FALCON code. The results were compared with the oxide thickness data measured by ECT in the power plant. Although oxidation accelerated due to low thermal conductivity of crud, it was evaluated that the degree of oxidation acceleration was not large due to the local boiling. Case analysis was lacking due to limited measured data. In the future, it is necessary to further optimize the CILC evaluation method by comparing the measurement results with the code calculation results.

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