Evaluation of Acceptable pH Control Schemes Based on PWR Fuel Cladding Corrosion

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1. Introduction

In order to reduce the risk of axial offset anomaly (AOA), PWR operation with high pH coolants is desirable [1]. Operation at higher pH has been recognized by both EPRI and the industry as a promising initiative to reduce corrosion product generation and transport to the reactor core, which reduces the formation of crud on the fuel rod surface. Since AOA usually occurs when crud deposits on fuel rod surface reach sufficient thickness, less formation of crud eventually leads to the reduction of AOA risk. All domestic plants are currently adopting a Modified pH control scheme but maintaining a higher pH at the beginning of cycle (BOC) is more desirable to reduce the crud formation. The higher pH control scheme at BOC requires an increase in lithium concentration above 3.5 ppm, which is a maximum allowable value, during the first part of the cycle. Whereas this should produce significant improvements in preventing the crud formation, the practice has not been widely adopted because of concerns over the possible deleterious influence of these higher lithium levels on cladding corrosion and Primary Water SCC of steam generator tubes [2].

In addition, there is strong correlation between tin and corrosion rates. Reduced corrosion can be achieved by reduction of tin content [3,4], which enables to adopt higher pH control scheme.

Therefore, an acceptable pH control scheme from the viewpoint of fuel cladding corrosion is presented herein, based on the calculation results considering the effects of lithium concentration and tin content.

2. Methods and Results

In this section the effects of lithium concentration and tin (Sn) content on cladding corrosion are discussed. Corrosion thickness is calculated using two kinds of models. Each model is separately used for Advanced Cladding Material and Zircaloy-4 cladding under the conditions of various pH control schemes.

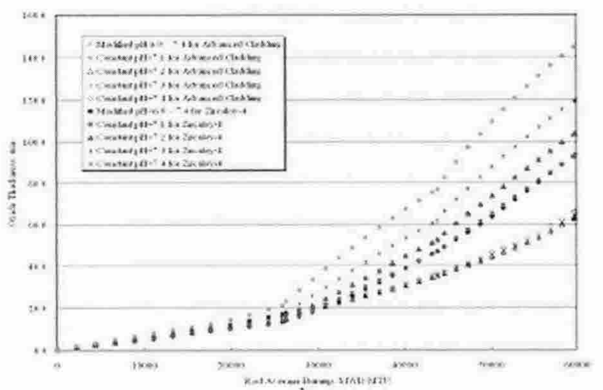
2.1 Fuel Geometry and Operating Conditions

The plant and fuel type considered in this study are 2,775 MWt Westinghouse type plant and 17x17 RFA. Nominal design values of Clad O.D (0.374"), I.D (0.329"), system pressure (2,250 psi), and coolant inlet temperature (556.5°F) are used in the evaluation. Mass flow rate of 2.39×10^6 (lb/hr-ft^2) is also used which is calculated based on thermal design flow (TDF). The core averaged linear power density and design $F_{\Delta H}$ are 5.44 kw/ft and 1.65, respectively. The rod power history used in the analyses is assumed to be 1.382, 0.958, 0.850 for each cycle which is the realistic power history based on the loading pattern (LP) with three 18 months cycle scheme. This rod power history makes the rod average burnup of nearly 60,000 MWD/MTU at end of life (EOL).

2.2 Lithium Concentration in RCS

The five types of pH control schemes are considered in order to evaluate the cladding corrosion for two types of cladding, Improved Zircaloy-4 and Advanced Cladding Material. The Modified pH control scheme is the most widely used control scheme around the world including Korea. However, as the operation conditions of the plant become more aggressive regarding to deposition of crud which causes the severe problems such as axial offset anomaly(AOA) and increase in out-of-core radioactivity, the higher pH control scheme is strongly recommended as one of the remedies. Currently, the Constant 7.1 and 7.2 pH control schemes are being used for many power plants in oversee countries. For this reason, the Modified pH control scheme, Constant 7.1 and 7.2 pH control schemes are investigated in this study. Additionally, the Constant 7.3 and 7.4 pH control schemes are accounted for the purpose of feasibility study even if they have not been implemented for plant operation.

The oxide thickness for Improved Zircaloy-4 cladding and Advanced Cladding Material under the five types of pH control schemes considered in this study is represented as a function of burnup in Figure 1. The Figure 1 shows that the oxide thickness is strongly dependent on pH control scheme of coolant for Improved Zirclaoy-4 cladding. On the other hand, the effects on oxide thickness for Advanced Cladding Material is negligibly small compared to Improved Zirclaoy-4 cladding. Based on the calculation results, it is judged that the Modified pH control scheme and Constant 7.1 pH control scheme are acceptable for Improved Zircaloy-4 cladding since the maximum oxide thickness at end of life (EOL) still meets the design limit of 100 um. On the contrary, all pH control schemes considered in this evaluation are acceptable for Advanced Cladding Material.



2.3 Tin (Sn) Content of Cladding

Figure 1. Peak Oxide Thickness vs. pH Control Scheme for Advanced Cladding Material and Improved Zircaloy-4 Cladding

2.3 Tin (Sn) Content in Cladding

For Improved Zircaloy-4 cladding, a plot of oxide thickness with various tin contents given in Figure 2 shows lower corrosion as tin concentration decreases from 1.45 to 1.20 wt%. Prior corrosion data on this cladding material along with its poor corrosion resistance in lithium environments indicate that tin is an important alloy addition in maintaining good in-reactor performance.

The observed tin effect in Advanced Cladding Material shown in Figure 2 is similar to that observed and well documented for Improved Zircaloy-4 cladding, where a reduced tin content provides the basis for the lower in-reactor corrosion of Improved Zircaloy-4 cladding over Conventional Zircaloy-4 cladding [5]. Figure 2 shows lower corrosion with decreased tin levels from 1.1 to 0.9 wt%. The implied effect of tin is consistent with the efforts that demonstrate lower corrosion with decreased tin levels [3,4,5].

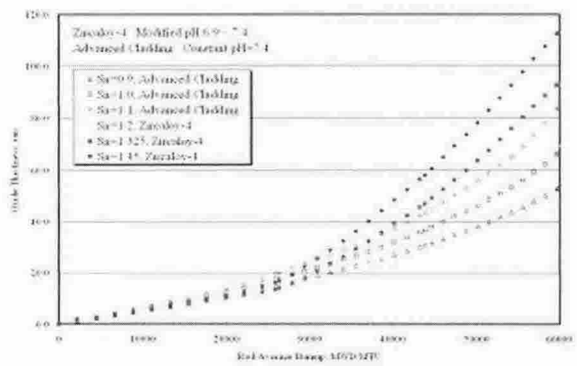


Figure 2. Peak Oxide Thickness vs. Sn Contents for Advanced Cladding Material and Improved Zircaloy-4 Cladding

3. Conclusion

The effects of RCS pH control scheme and tin content on cladding corrosion have been investigated for two types of cladding material, Improved Zircaloy-4 and Advanced Cladding Material.

Calculation results for Improved Zircaloy-4 cladding have shown that there is not enough margin of cladding oxidation if the plant is operating under Modified pH and Constant 7.1 pH. On the other hand, the corrosion thickness exceeds the maximum allowable value of 100 um if the plant adopts pH control strategies of the Constant 7.2, 7.3 or 7.4 pH. However, for Advanced Cladding Material, any kind of pH control scheme is acceptable for Westinghouse type plant loaded with 17x17 RFA based on the calculation results. This enables the domestic plants to adopt higher pH control scheme to reduce the risk of AOA.

Calculation results considering the effect of tin content have shown increased corrosion benefits with decreased tin content. Therefore, more reliability of the fuel and more flexibility in loading pattern (LP) can be attained and more design margin can be gained if Low Tin Advanced Cladding Material is developed and implemented.

REFERENCES

[1] PWR Axial Offset Anomaly (AOA) Guidelines, TR-110070, 1999.

[2] Wood C. J, Approaching Consensus on the Optimum pH for PWRs, Nuclear Eng. Int., 1990.

[3] Garde, A, M., Pati, S. R., Krammen, M. A., Smith, G. P., and Endter, R, K., Corrosion Behavior of Zircaloy-4 Cladding with Varying Tin Content in High-Temperature Pressurized Water Reactors, Zirconium in the Nuclear Industry : Tenth International Symposium, pp. 760-778, 1994.

[4] Robert J. Comstock, Gerald Schoenberger, and George P. Sabol, Influence of Processing Variables and Alloy Chemistry on the Corrosion Behavior of ZIRLO Nuclear Fuel Cladding, Zirconium in the Nuclear Industry : Eleventh International Symposium, pp. 710-723, 1996.

[5] Sabol. G. P., Comstock, R. J., Weiner, R. A., Larouere, P., and Stanutz, R, N., In-Reactor Corrosion Performance of ZIRLO and Zircaloy-4, Zirconium in the Nuclear Industry : Tenth International Symposium, pp. 724-744, 1994.