Effects of Zinc Injection on the Cladding Oxide Thickness in the Domestic Nuclear Power Plant

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1. Introduction

Injecting zinc into the primary coolant of PWR is effective method to reduce radiation fields. According to the research from 1989 to 1992 by Westinghouse and Westinghouse Owners Group, it was confirmed that zinc injection reduce the radiation fields and mitigate Primary Water Stress Corrosion Cracking (PWSCC). The first commercial plant for zinc injection demonstration was Farley-2 in 1994, and the effect of zinc injection was successfully demonstrated. Since then the PWR with zinc injection has been increased, there are about 80 PWR with zinc injection in the world in 2012 [1].

Zinc injection at the high duty plant has potential risk of increasing the cladding oxide thickness. Zinc injection doesn't affect the cladding corrosion directly but it may negatively affect crud deposit in the sub-cooled boiling region of the fuel [2]. So the effect of zinc injection on fuel integrity has been evaluated. For low duty plant it is confirmed that zinc injection doesn't affect the fuel integrity [3]. For high duty plant Callaway in U.S. and Vandellos II in Spain were successfully demonstrated [4] but the experience with zinc injection of high duty plant was still lacking. Thus EPRI recommend the fuel surveillance programs for the high duty plant to apply zinc [3].

The High Duty Core Index (HDCI) of most domestic nuclear power plant is above 150 Btu/ft^2-gal-^{o}F. Those plants with a HDCI of 150 Btu/ft^2-gal-^{o}F or greater may be considered as "high duty" [3]. As aforementioned, the experience with zinc injection of high duty plant was lacking. Thus to apply zinc injection in domestic plant with high duty, prudent approach is needed. In this study the effect of zinc injection in Hanul unit 1 with a HDCI of around 150 Btu/ft^2-gal-^{o}F was evaluated. And in the next study the effect of zinc injection in the plant of HDCI of around 200 Btu/ft^2-gal-^{o}F will be evaluated.

2. Operating Conditions

Hanul unit 1 served as demonstration plant for high duty core due to appropriate HDCI of about 150 Btu/ft^2-gal-^{o}F. Hanul unit 1 is Framatome-design PWRs and the reactor core consists of 157 RFA fuel assemblies with ZIRLO clad for cycle 17. Hanul unit 1 operates at a thermal nuclear power of 2775 MW and employs steam generators with Alloy 600 tubing.

Zinc was injected for 135 Effective Full Power Days (EFPD) during the second half of the cycle 17. The total cycle length for cycle 17 was around 540 EFPD and target zinc concentration was 5 ppb. Fig. 1 represents the reactor coolant pH and lithium levels during cycle 17 at Hanul unit 1. The unit was operated with a coolant pH_t 6.9 – 7.2 regime with a maximum allowable lithium concentration of 3.5 ppm. The coolant inlet temperature and coolant mass flow rate were 545.8 ^{o}F and 2.28 x 10^6 lb/hr-ft^2 respectively.

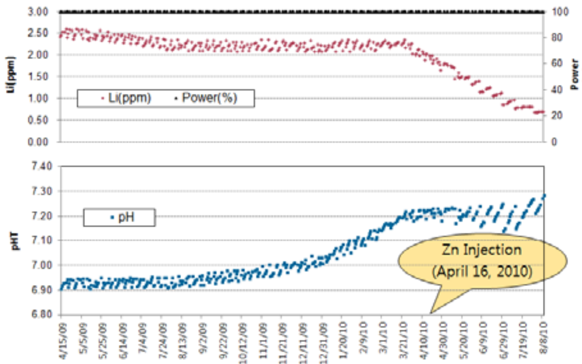

Fig. 1 Reactor Coolant pH and Lithium Concentration versus Time

During initial zinc cycle, the potential increase in the release of corrosion products to the primary coolant due to zinc incorporation into corrosion films is a concern. It may result in an enhancement of crud deposition on fuel rods, increasing the Axial Offset Anomaly (AOA) risk. Thus in order to reduce the available crud inventory in the primary coolant system before injecting zinc, Ultrasonic Fuel Cleaning (UFC) was applied at EOC 16.

After UFC it is confirmed that the crud was removed through the visual inspection. And before and after UFC the oxide thickness was measured and compared. Fig. 2 represents the measured oxide thickness of before and after UFC. The difference between before and after UFC oxide thickness is less than the uncertainty range of measurement. Thus, it can be judged that the impact of crud on the measured oxide thickness at EOC 17 is negligible.

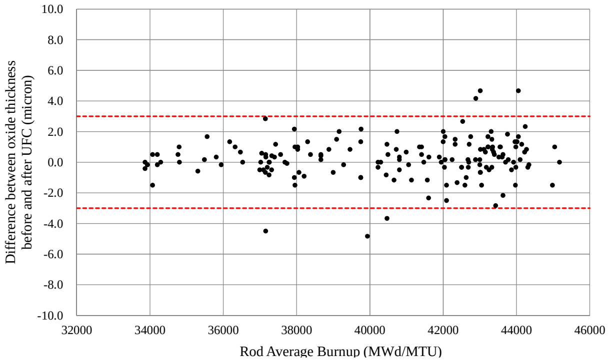

Fig. 2 Difference between oxide thickness before and after UFC (The red dash line means the measurement uncertainty)

3. Comparison of oxide measurements without and with Zinc injection

As a reference data to compare with oxide thickness without zinc injection, pre-zinc cladding corrosion measurements were obtained at EOC 16. Two thrice-burned and two twice-burned assemblies were measured. The selected assemblies have similar irradiation history to those with zinc injection.

Post-zinc corrosion measurements were performed at EOC 17 and the oxide thickness were taken from the middle of span 9 which is limiting axial location of fuel rod. Measurements were performed on high burn-up rod of two thrice-burned and two twice-burned assemblies. The oxide measurement data are averaged over a 1 inch interval.

Fig. 3 depicts the oxide thickness at EOC16 and EOC17, without and with zinc injection. The twice-burned assembly burn-up with zinc injection ranged from 45 to 46 GWd/MTU. And the thrice-burned assembly burn-up with zinc injection ranged from 48 to 55 GWd/MTU. Fig. 3 shows that most of the oxide thickness measurement data with zinc injection are well within those data without zinc injection.

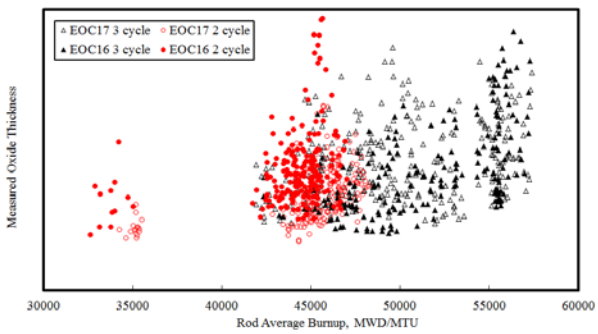

Fig. 3 Measured oxide thickness as a function of burn-up (closed symbol : without Zinc injection, open symbol : with Zinc injection)

4. Comparison of oxide measurements to predicted oxide thickness

Fig. 4 represents difference between measured oxide thickness and predicted oxide thickness with zinc injection. In this figure all measurements with zinc injection were bounded by upper bound predictions except 1 rod. And the average Measured and Predicted oxide thickness ratio (M/P) is 0.86 and the standard deviation is 0.26. Those mean the computer code well predicts oxide thickness for fuel rod with zinc injection. The computer code to predict oxide thickness was developed based on non-zinc injection database. Thus, it was confirmed that there are no significant differences in corrosion behavior of fuel exposed to zinc environment.

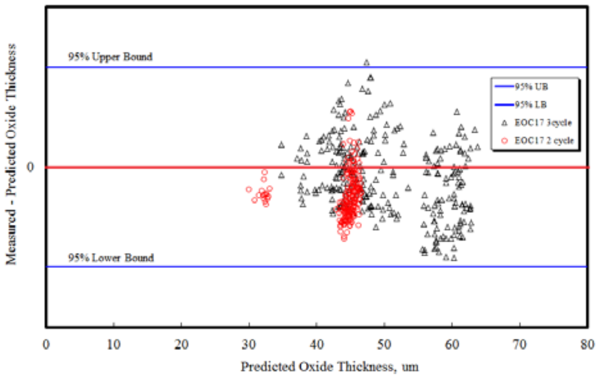

Fig. 4 Difference between measured oxide thickness and predicted oxide thickness as a function of burn-up with Zinc injection

5. Conclusions

Zinc injection had not caused any increase in oxide thickness in Hanul unit 1. Most of the oxide thickness measurement data with zinc injection are well within the non-zinc injection database. And the computer code which was developed based on non-zinc injection database well predicts oxide thickness for fuel rod with zinc injection. Thus, it can be concluded that zinc injection doesn't accelerate clad corrosion. Based on this result, plan is in place to continue with fuel surveillances in plants with HDCI of around 200 Btu/ft^2-gal-^{o}F.

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