Evaluation of Zinc Addition to the Primary Coolant of the Korean PWRs

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1. Introduction

Zinc is typically added to the reactor coolant of PWRs as a solution of zinc acetate at a concentration of 5 to 40 ppb. Lower concentrations (5-10 ppb) are typically used at plants primarily interested in reducing radiation fields, while higher concentrations (20+ ppb) are used for both PWSCC mitigation and radiation field reduction. In this study, technical issues related to zinc addition are reviewed and implementation plan is discussed for the Korean PWR plants.

2. Discussion

This section discusses fuel rod corrosion product deposition risk, and provides recommendations for implementing zinc addition at Korean PWR plant.

2.1 RCS Nickel Concentration

Nickel in the form of nickel oxide has proven to be a primary constituent of fuel rod corrosion product deposits leading to AOA (Axial Offset Anomaly). AOA occurs when lithium metaborate is adsorbed into a thick corrosion product layer that has formed on the surface of the fuel rods. The boron in the lithium metaborate is a neutron absorber and causes a local power suppression in the affected fuel assembly or assemblies. When zinc is added to the RCS, additional nickel will be released into the primary coolant due to substitution of zinc for the nickel in primary system metals. Therefore, it is important to ensure that steady-state RCS nickel levels are low prior to zinc addition to prevent excessive crud deposition rates.

2.2 Risk of Crud Deposition

A portion of the total heat transfer from the fuel to the coolant at plants with high fluid temperatures and high surface heat flux at the fuel clad occurs through sub-cooled nucleate boiling (SNB). Surface boiling is known to enhance the rate of formation of corrosion product deposits (crud) on the cladding surface. Because of this greater risk of high crud deposition rates, changes in coolant chemistry (such as zinc addition) must be approached more cautiously than at plants with cores that exhibit minimal or no SNB.

EPRI has recently developed the "High Duty Core Index" (HDCI) to quantify the risk of high crud deposition rates in PWRs [1]. This term was developed to allow a simple determination of whether or not a plant is a "high duty plant".

Most Korean PWR plants are currently operating well above the "high duty plant" cutoff value of 150. Consequently, Korean PWR plants are susceptible to high corrosion product deposition rates. Based on the potential of increased corrosion product deposition rates, it will be important to sample the RCS regularly for nickel concentration and measure the core axial power distribution on a regular basis to ensure the absence of AOA. Also, zinc addition should not begin until after the point in the fuel cycle of highest fuel thermal duty has been reached.

2.3 Zinc Addition Plan

A careful, step wise, conservative plan for implementation of zinc addition is recommended for Korean PWR plants since most Korean PWR plants is classified into high duty plant. Given this situation, the following actions are recommended:

- Consider applying ultrasonic fuel cleaning prior to zinc addition to lower the total RCS inventory of corrosion products.
- Begin zinc addition during the second half of a fuel cycle after stable chemistry trends are established and the core is past the point of peak sub-cooled nucleate boiling. Lower boiling (or lower thermal duty) will reduce the risk of AOA initiation and, should AOA occur, reduce the chance of losing Technical Specification required shutdown margin during the latter half of the cycle.
- Begin at a low zinc concentration and increase zinc levels cautiously. There is a potential for short-term local increases in dose rate due to displacement and relocation of existing radiocobalt inventories as a result of zinc substitution. Additionally, increased RCS corrosion product mobility may lead to thicker crud deposits on the fuel. The interaction of zinc with primary system materials results in higher nickel levels in the RCS. It is known that nickel contributes to core crud that causes AOA [2]. Also, thick crud has the potential to increase fuel cladding corrosion rates due to higher clad surface temperatures. Experience with zinc addition at high duty plant is limited, and the core crud characteristics in the presence of zinc addition at high duty plants are not well known.
- Secure zinc addition prior to a planned load reduction or maintenance shutdown in order to limit the peak zinc concentration experienced as the plant reduces power. This is a conservative measure to avoid any approach to zinc solubility limits. Experience at Farley and Diablo Canyon demonstrates that very large increases in zinc concentration can occur during shutdown evolutions. This is primarily caused by the coolant

temperature decrease during the shutdown coupled with the retrograde solubility of zinc [3].

3. Conclusion

Zinc addition at Korean PWR plants is expected to provide the benefits observed at other PWRs where zinc addition has previously been implemented; 1) reduction in radiation fields, 2) reduction in PWSCC crack initiation rates, and 3) improved primary system material integrity.

Because of the high duty nature of Korean PWR plants, it is necessary to take conservative, cautious [4] approach recommended herein for the first two or three cycles.

REFERENCES

[1] PWR Primary Water Chemistry Guidelines: Volume 1, Revision 5, EPRI, Palo Alto, CA: 2003. TR-105714-V1R5.

[2] Overview Report on Zinc Addition in PWRs, EPRI, Palo Alto, CA: 2001. 1001020.

[3] Evaluation of Zinc Addition to the primary Coolant of PWRs, EPRI, Palo Alto, CA: October 1996, TR-106358, Vol. 4.