Economic Evaluation of Primary Zinc Addition at Yonggwang Unit 1

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1. Introduction

Laboratory testing and industry experience, particularly at US plants, have established that addition of zinc to the primary system in PWRs reduces the rate of initiation of primary-side cracking (SCC) in Alloy 600 components and also lowers radiation fields in the environment in which plant personnel work during refueling outages. In addition to these benefits, however, a significant economic investment is required in order to qualify and implement a zinc addition program. Consequently, it is appropriate to evaluate quantitatively whether the economic benefits of zinc addition can be expected to outweigh the costs before making a final decision to add zinc to the RCS. This study discusses such a cost-benefit evaluation for zinc addition at Yonggwang unit 1.

2. Methodology

In order to evaluate the economic attractiveness of zinc addition at Yonggwang unit 1, the estimated costs associated with implementing primary zinc addition are projected until the end of the expected operating period. These costs are evaluated on a net present value (NPV) basis (2004 year) in order to facilitate fair comparisons with no-zinc option. The basic approach used is as follows:

- Predict the corrosion rates of Alloy 600 components, including steam generator tubes, piping butt welds, control rod drive mechanism (CRDM) J-groove welds, and bottom-mounted instrument (BMI) nozzle J-groove welds using appropriate statistical techniques. Predictions are carried out for both the zinc addition and the no-zinc options.
- Estimate the total plant dose and the expected reduction in dose with zinc addition. The degree of dose reduction depends on whether natural zinc or depleted zinc acetate (DZA) is used.
- Estimate the relevant economic inputs, such as the cost of chemicals, equipment, inspections, and analyses associated with zinc addition; the costs of inspections and repairs associated with PWSCC; the cost of personnel dose; and others.
- Quantify the uncertainties in key inputs. However, the inherent uncertainties in these inputs can have a significant impact on the economics of zinc use. Therefore, the key parameters are modeled with statistical distributions that facilitate probabilistic analysis.
- Specify a procedure for calculating the total NPV of relevant cost factors for operation at Yonggwang unit 1 with and without zinc addition. Costs are calculated over the remainder of a 40-year operating life.
- Perform a probabilistic analysis that calculates the cumulative NPV cost associated with each scenario during the remaining operating period. The following are all analyzed: use of natural zinc at 5, 20, and 40 ppb; use of depleted zinc at 5, 20, and 40 ppb; and no zinc addition. It is assumed that Yonggwang unit 1 first injects zinc at the start of cycle 17 (17.2 EFPY) and does so for 80 % of all operation after this time.
- These analyses are carried out using Monte Carlo simulation technique, which inherently quantifies the variability associated with all of the input parameters.
- Asses the economic attractiveness of zinc addition for each of the chosen scenarios relative to the no-zinc option based on the probabilistic economic results.

3. Result

Monte Carlo simulations, each consisting of 50,000 trials, were completed for Yonggwang unit 1. For all cases, the cumulative NPV costs are shown in Figure 1, which plots the cost as a function of the probabilities of occurrence predicted by the Monte Carlo simulations at the time the current operating period expires in 2027.

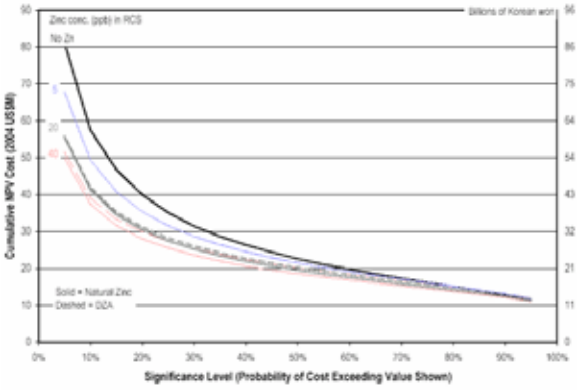

Figure 1. Cumulative NPV Cost Results for Operation through EOL (2027) from Monte Carlo Simulation.

For example, in the absence of zinc (top curve), there is a 50 % chance that NPV cost will be greater than

about US$23M, while there is a 90 % chance it will exceed US$13M and only a 10 % chance it will be as large as US$57M. It is clear that there is a high probability that zinc usage at any level will lead to some economic savings. The NPV savings expected with each zinc strategy analyzed are quantified directly in Figure 2. This plot reveals the following regarding the expected NPV savings by 2027.

- 20 ppb:
  - 50 % chance of at least US$3M with natural zinc and US$2M with DZA
  - 95 % chance of savings greater than zero with natural zinc
  - 20 % chance of savings greater than US$10M with natural zinc
- 2 ppb:
  - 50 % chance of at least US$1M with both natural zinc and DZA
  - 80 % chance of savings greater than zero with natural zinc
  - 8 % chance of savings greater than US$10M with natural zinc
- 40 ppb:
  - 50 % chance of at least US$4M with natural zinc and US$2M with DZA
  - 98 % chance of savings greater than zero with natural zinc
  - 24 % chance of savings greater than US$10M with natural zinc

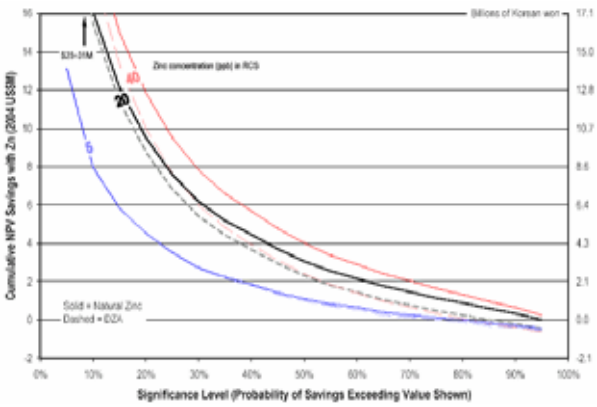

Figure 2. Cumulative NPV Savings Predicted for Operation through EOL (2027).

Higher target zinc concentrations correlate with increase NPV savings, although the economic difference between 5 ppb and 20 ppb is substantially larger than the difference between 20 ppb and 40 ppb. This result suggests that a target concentration close to this middle value of 20 ppb will yield the bulk of the savings that might be achieved with higher concentrations while remaining well within the range of concentrations for which substantial US plant experience has already been established. This plot also shows that for concentrations between 5 and 40 ppb in the RCS, natural zinc is always predicted to be more economical than DZA.

Figure 3 shows the three individual cost factors which are primarily responsible for the predicted savings associated with natural zinc addition at 20 ppb: 1) reduction in personnel radiation exposure (~US$0.5M), 2) reduction in lost production time due to CRDM nozzle repairs (~US$0.5M), and 3) reduction in lost production time due to BMI nozzle repairs (~US$1M).

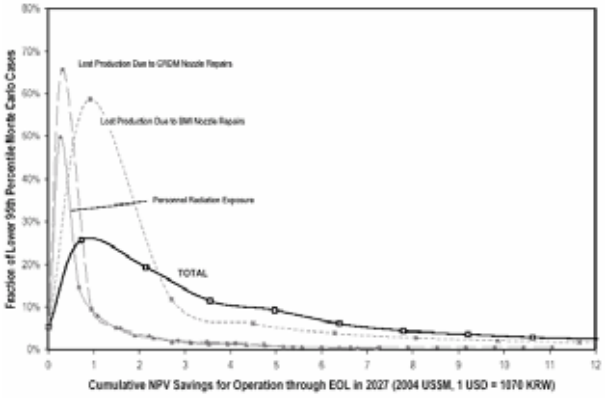

Figure 3. Impact of Chief Cost-Saving Factors on Cumulative NPV Savings Levels as Predicted by Monte Carlo Simulations for Natural Zinc Addition at 20 ppb.

4. Conclusion

In summary, the following conclusions can be drawn from Monte Carlo simulation results.

- For a wide rang of target zinc concentrations (5-40 ppb), natural zinc is predicted to be more cost-effective than DZA. Although the economic benefit with natural zinc compared DZA is not very large(~US$1M), it is consistently present in all cases and for all significance levels and therefore has a very high probability of being realized. This difference indicates that the higher cost of DZA compared to natural zinc outweighs the relatively small additional dose savings provided by DZA.
- The NPV savings that are likely to be achieved with zinc at Yonggwang unit 1 are approximately US$2-7M for operation with 20 ppb zinc during the current expected operating life (2027). However, there is a small but appreciable probability of larger savings (20 % chance of >US$10M) as well as very little probability (<5 %) of not at least breaking even.