Review of Considerations for Radiation Dose Rate Assessment of Plant Equipment Following Shutdown Chemistry

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1. Introduction

The purpose of reactor coolant water chemistry management is to maintain the integrity of the high-temperature, high-pressure system pressure boundaries and fuel cladding, ensure fuel performance, and minimize the generation of corrosion products to reduce radiation doses. Corrosion products generated within the system become activated and adhere to equipment such as the fuel surface and the water space of steam generators, leading to increased radiation dose rates. The nickel-iron oxides that deposit on the fuel surface are referred to as CRUD(Chalk River Unidentified Deposit), which constitutes the majority of activated corrosion products. CRUD adheres to the fuel surface through precipitation and deposition caused by coolant boiling and concentration differences on the fuel surface. CRUD adhering to the fuel surface, composed of nickel and iron oxides, is removed through the chemical decontamination process performed during power plant shutdowns. However, variations in radiation dose rates can occur due to various factors.

2. Shutdown Chemistry Result

Hydrogen peroxide is injected to remove CRUD from the fuel cladding surface during the period of power reduction and cooldown. When hydrogen peroxide is injected, CRUD dissolution reaches its peak; during this phase, changes in the radiation dose rates of nearby equipment were monitored.

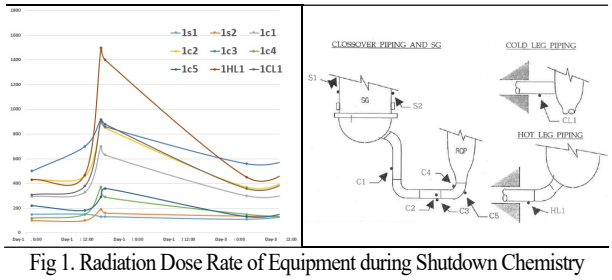


Fig 1. Radiation Dose Rate of Equipment during Shutdown Chemistry

Radiation dose rate measurements in the Reactor Coolant System (RCS) revealed that the dose rate peaked at the moment of hydrogen peroxide injection across all measurement points, with the maximum value observed at the RCP discharge point (1HL1). Although a decrease was noted at some locations before and after the injection, the majority showed an increase, resulting in an average increase rate of 10.7%.

The chemistry process during shutdown removes CRUD from the fuel surface by leaching radionuclides such as Co-58 and Co-60, which are then removed via ion exchange resins and filters. While the deposition of these radionuclides(Co-58 and Co-60) on metal surfaces can contribute to increased dose rates, the impact of Co-58 on long-term dose rates is limited due to its relatively short half-life of 70.88 days. However, caution is required regarding Co-60; with a half-life of 5.27 years, its deposition on piping can lead to prolonged increases in radiation dose rates.

3. Consideration Factor

Even if the shutdown chemistry process sufficiently removes CRUD from the fuel cladding surface, equipment radiation dose rates may still increase due to various factors. Among the potential influencing factors, this study reviewed the impacts of water chemistry management during plant normal operation, flexible operation, shut-down chemistry, zinc injection, and coast-down operations.

3.1 Normal plant operation and flexible operation

The pH of the reactor coolant(pH_T) is controlled by lithium concentration. The lithium concentration is maintained up to a maximum of 3.5ppm depending on the initial boron concentration of the cycle. Once the pH_T reaches 7.2, lithium is removed to maintain a constant pH.

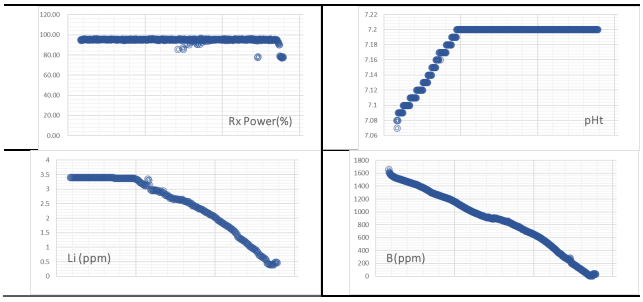


Fig 2. Trends of pH_T control for one period cycle

The pH management during operation is a key factor influencing the generation of corrosion products and was maintained normally throughout the operating

period. However, it appears that the trends in boron and lithium concentrations at the end of the cycle were affected by the shutdown operation.

No reactor shutdowns occurred during the operating period; however, three flexible operation events were executed, and no significant changes in water chemistry attributable to these flexible operations were observed. Low-concentration zinc injection was carried out for three months at levels below 5 ppb. During the zinc injection period, an increase in the Co-58 radionuclide was detected, which is believed to result from a displacement reaction as zinc penetrates metal surfaces. No anomalies were identified in fission products such as Cs-138 or Xe-135.

3.2 Shut-down chemistry

Shutdown chemistry was performed to remove radioactivity from CRUD on the fuel cladding surface. Hydrogen peroxide was utilized to identify the Co-58 peak, followed by purification. Subsequently, the conditions for reactor coolant draining and refilling were verified. Both the acidic-reducing and acidic-oxidizing environments were sufficiently purified over an adequate duration, making it unlikely that they are the cause of the increased radiation dose.

3.3 Zinc Injection

The power plant conducted low-concentration zinc injection operations for approximately three months. During this period, the concentration of the Co-58 radionuclide in the reactor coolant increased. Zinc incorporates into the internal structure of the oxide film on metal surfaces, and through a displacement reaction, it can cause the release of cobalt radionuclides into the reactor coolant, thereby increasing radioactivity concentrations. Several cases indicate that radioactivity concentrations tend to increase for about three cycles during zinc injection, which is attributed to the release from reused fuel surfaces and accumulated metal surfaces. Although radionuclide concentrations may increase in the short term, zinc injection contributes to long-term dose rate reduction by preventing the re-deposition of cobalt radionuclides onto metal surfaces.

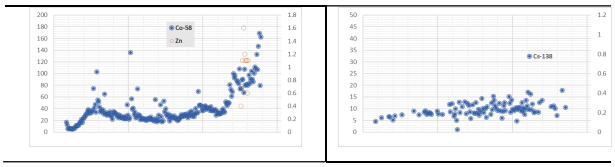


Fig 3. Trends of Co-58 and Cs-138 with Zinc Injection

Therefore, even with the observed increase in Co-58 concentration in the reactor coolant, the contribution to the current increase in dose rates is assessed to be low, as the mechanism primarily involves leaching from metal surfaces which reduces dose rates. Furthermore, considering the duration of the zinc injection, the potential dose rate reduction effect is also assessed to be limited.

3.4 Coast down Operation

The plant performed a coastdown operation at the end of the fuel cycle. Some plants have reported that low boron concentrations at the end of the cycle contribute to increased radiation dose rates. Although the exact cause of the dose rate increase remains unclear, it is anticipated that at boron concentrations below 100 ppm, pH fluctuations induced by temperature changes and variations in solubility may lead to the re-deposition of corrosion

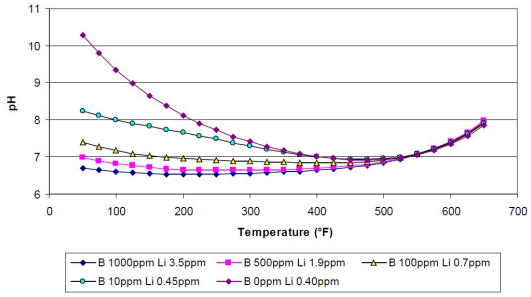


Fig 4. Relationship between pH and temp. for RCS chemistry[1]

As pH increases, the solubility of nickel and iron decreases, whereas their solubility increases as pH decreases. At low boron concentrations, larger fluctuations in pH amplify the temperature-dependent changes in solubility. It is believed that metal components dissolved in areas with high temperature and low pH (where solubility is high) re-deposit in areas with lower temperature and higher pH (where solubility is low). Consequently, significant impacts are expected in the CVCS sections where temperatures are lower.

4. Conclusion

To facilitate the end-of-cycle Coastdown Operation, a low boron concentration(10ppm) was maintained. Under such low boron conditions, significant fluctuations in pH_T can impact radiation dose rates. It is believed that the increase in activated corrosion products caused by zinc injection during the Coastdown Operation enhances deposition in low-temperature sections, potentially contributing to effects observed after the Plant shutdown. Although the specific mechanisms and influencing factors regarding re-deposition remain unclear, it is necessary to establish zinc injection operations and pH management strategies that account for the possibility of re-deposition driven by temperature effects in low boron concentration environments.

REFERENCES

[1] J. McElrath, Pressurized Water Reactor Primary Water Chemistry Guidelines, Rev.7, EPRI, TR-3002000505, 2014.