LESSONS LEARNED IN PREPARING FOR A PRIMARY HEAT TRANSPORT SYSTEM CHEMICAL DECONTAMINATION

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Abstract

As a global market leader in chemical decontamination technology, Westinghouse has experienced the lessons learned associated with preparing for the chemical decontamination of the Primary Heat Transfer System in a CANDU® reactor. This paper presents those lessons learned, and the challenges found in performing studies for design considerations.

When a decision is made to refurbish a CANDU® reactor, the owner faces constraints in dose, schedule, cost, and quality. This paper examines the effects of these constraints, and the developments made to improve results in areas such as: existing and post decontamination system capabilities, solvent selection criteria for optimum results, process methodology efficiency gains, selection of systems for retention or replacement and cost-benefit analysis for dose reduction goals.

1. Introduction

Hydro Quebec (HQ) planned to complete a chemical decontamination of the Primary Heat Transport System (PHTS) at the Gentilly-2 nuclear station at the beginning of a rehabilitation outage that was scheduled for the spring of 2011. The decontamination would have included the pressure tubes, end fittings, feeder pipes, headers, and associated piping connected to main pumps and steam generators, but excluded the steam generators themselves. The chemical decontamination was required in order to reduce the radiation exposure to staff who would have been involved in the replacement of the above PHTS components.

The decontamination was to be performed two (2) quadrants at a time, connected in parallel, with solvent flowing through the system in the normal forward direction. Hydraulic subdivision of the quadrants would be accomplished by arrangement of the Gentilly-2 PHTS by HQ.

In preparation, engineering work and artifact testing were performed in 2008 and 2009. The engineering phase was nearing completion and equipment procurement and fabrication had commenced when the decision was made to decommission the plant rather than rehabilitate it, so the decontamination project was cancelled. This report contains a brief description of the artifact testing and some of the challenges, planning considerations, and lessons learned encountered in the engineering and testing that was performed prior to cancellation.

2. Artifact testing

Pilot scale artifact testing was performed in 2009 to confirm results from testing in 2008 and to compare the CAN-DEREM™ Plus and CITROX processes in preparation for the planned PHTSdecontamination at Gentilly-2. The testing consisted of three-step processes for both solvents, with an Alkaline Permanganate (AP) treatment as an intermediary step.

The test equipment included a pump, a mix tank, a heater, a filter, ion exchange (IX) columns, a process monitor containing corrosion coupons, a sock filter containing magnetite to represent system iron loading, a container with steel shot to mimic system surface area, carbon steel and stainless steel pipe artifacts taken from Gentilly-2 and Point Lepreau, and interconnecting hoses and instrumentation. The system was designed to replicate the expected PHTS flow Reynolds numbers (Re) over the surface of the artifacts. Figure1 is a simplified Pump and Instrument Diagram (P&ID) showing a configuration of the test equipment.

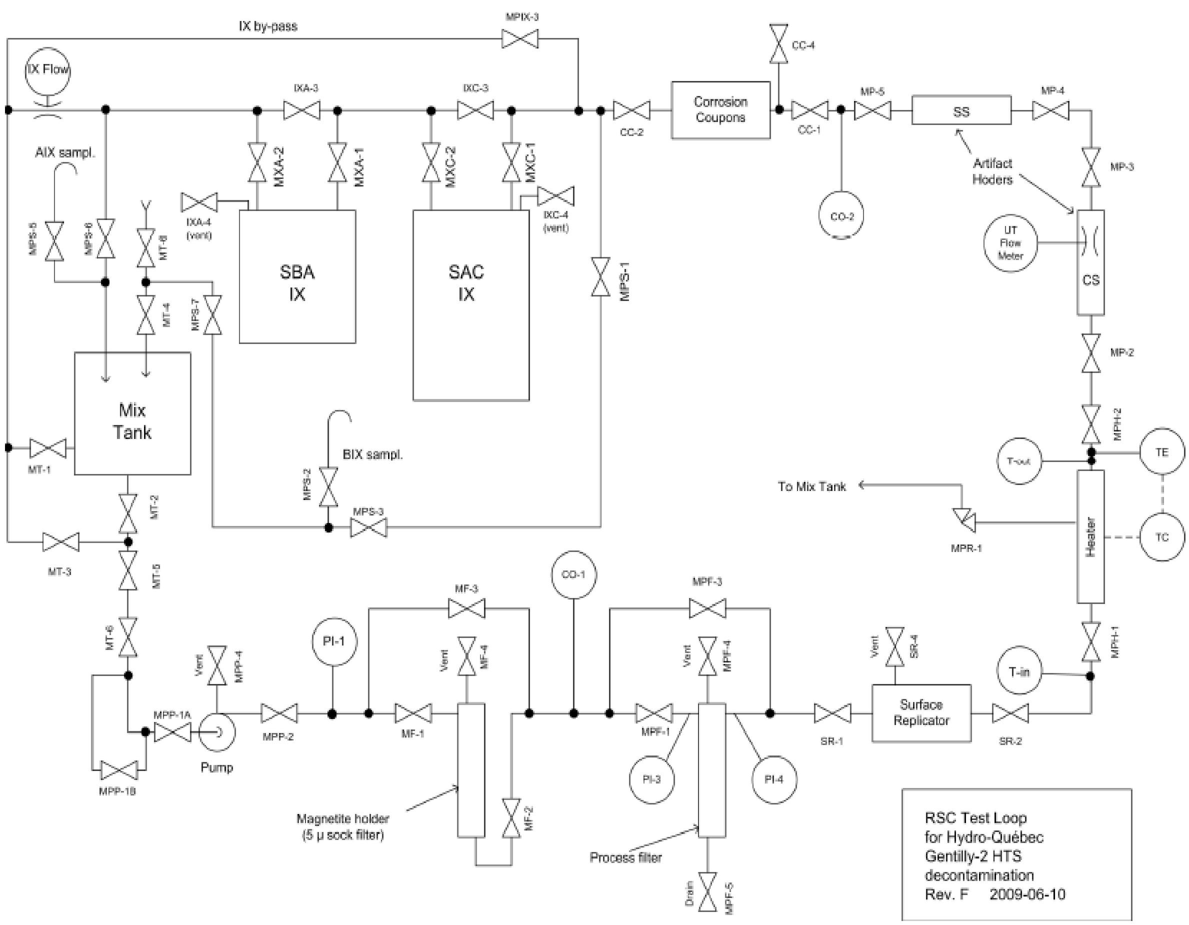

Figure 1 Test Loop P&ID

The testing demonstrated that both CAN-DEREM™ Plus and CITROX were successful at removing the oxide film and achieving the desired dose reduction goal of at least a Decontamination Factor (DF) of 5 on the carbon steel feeder pipe (DFs >50 achieved for both solvents).

3. Lessons Learned/Planning Considerations

1. The estimated magnetite loading was over 2000 kg. A significant portion of the deposit was expected to release as particulate. There was a concern that the particulate would settle out in low flow regions or potentially plug small orifices. To mitigate, aflow of 4,000 gpm (with an average 125,000 Re in the feeder pipes) was chosen to suspend particles withincorporation of full flow through the filters to capture the particulate. While no attempt was made to verify the release of particulate from the film, magnetite particulate that was introduced to the artifact test system was successfully transported past the artifacts (which were subject to 125,000 Re) to the filter.

2. The magnetite deposit loading was similar in scope to boiler secondary loading. Although EPRI had developed a Steam Generator (SG) cleaning process, which had been applied many times for removal of secondary side magnetite deposits in boilers,the process creates a large volume of liquid waste. Gentilly-2 was set up to handle large quantities of IX resin waste, so consideration of dilute regenerative solvents which result in a solid waste form of ion exchange resin was desired.

3. After much discussion, the decision was made not to completely remove the heavy water in the PHTS (via drying) prior to the decontamination as it would require too much time. This would not impact the chemical process, but it would have an impact on the Temporary Decontamination Equipment (TDE) installation and operation. The project did not reach this phase, but it was estimated to take twice as long to install the TDE with personnel required to work in bubble hoods. Gentilly-2 did not want to extend the schedule; therefore the plan was to work double shifts as the crew size could not just be doubleddue to building and room size constraints. The presence of tritium and its associated required safety precautions have a significant impact on schedule that needs to be considered during planning.

4. In order to monitor the flow rate in selected feeder pipes, ultrasonic flowmeters were planned to be incorporated in the design as this type of flow meter can be mounted outside the pipe. However, this presented a few challenges.
   a. Locations with sufficient space to mount the transducers needed to be found.
   b. The transducer selected would be required to withstand the process temperature of up to 100 ^{o}C.
   c. Since the feeder pipes are inside a single insulated vault, the transducer signal wires would need to pass through a penetration to outside the vault.
   d. Ultrasonic flowmeters don’t work well with high particulate loading. However, it was determined that it would be of value to at least know the flowrate in the selected feeder pipes, even if it was only during the initial cool water recirculation phase of the process.

5. Monitoring the dose rate on selected feeder pipes presented many of the same challenges as monitoring the flow rate, due to the high temperatures inside the vault. Dose monitoring equipment needs to be able to withstand temperatures of up to 100 °C.

6. A semi-remote filter cartridge change out system was selectedfor ALARA. It was planned to do several change outs throughout the process.

7. Normal connection for a Full System Decontamination (FSD) would use the boiler primary manways. Since the boilers were not in the flow path, the Emergency Core Cooling (ECC) system was to be used to make connections to the plant.

8. In order to place the TDE in locations to reduce impact on other outage activities, the TDE was placed on three different levels. This required the design of a temporary structural floor to support the equipment and meet the floor loading limits.

9. Due to the presence of heavy water in the process, all TDE vents needed to be routed to the active ventilation system.

10. Process selection considered flowing through some plant systems that were not planned for replacement. Therefore, the process needed to be a qualified process that would remove the deposits and activity but have acceptable corrosion rates to allow continued plant operation.

11. In the artifact testing, it was shown that while CAN-DEREM™ Plus was faster at dissolving the surrogate particulate magnetite, CITROX was a little faster at dissolving the actual oxide film. CAN-DEREM™ Plus had higher general corrosion rates and galvanic corrosion at the weld interface between carbon steel and stainless steel. For these reasons, and for ease of application, CITROX was selected to be the solvent used at Gentilly-2. However, it was soon learned that the environmental impact statement had already been performed assuming that CAN-DEREM™ Plus would be the solvent used. It was determined to be unfeasible to redo the statement with CITROX, so CAN-DEREM™ Plus was ultimately chosen. Solvent choice needs to be considered early in the planning stages.

12. Since CAN-DEREM™ Plus promoted galvanic attack of carbon steel, the boilers were to be bypassed during the decontamination, to protect the welds in the channel head. The boiler Hot Leg (HL) and Cold Leg (CL) nozzles were to be isolated with bungs.

13. Ethylenediaminetetraacetic Acid (EDTA) is only slightly soluble in acidic conditions. The EDTA concentration in CAN-DEREM™ Plus is near the solubility limit. This makes batching for a large system challenging. The entire solvent can't be dissolved in the volume of a mix tank then injected into the system. Repetitive injections of the portion that will dissolve would take far too long. Injecting the solvent as a slurry is undesirable as it could lead to excessive localized corrosion in low flow areas where the EDTA particulate would collect. A compromise was planned using two mix tanks in series with a continuous "feed and bleed". This would allow for more EDTA to be dissolved in the mix tanks, while moderating the size and amount of particulate that would dissolve in the system.

14. When using EDTA, some of the EDTA will adhere to cation resin, reducing the concentration of EDTA in solution. Furthermore, EDTA is such a good chelating agent that the resin cannot easily strip away trivalent iron and much of it will pass through the resin, also reducing the amount of available free EDTA. Additional EDTA should not be added to the system to compensate, for as the cation column becomes depleted with iron, the EDTA that was captured on the column will begin to elute out, increasing the EDTA concentration. If the concentration of EDTA exceeds the solubility limit, the EDTA will precipitate out of solution, potentially redepositing activity.

15. The solubility of EDTA decreases with decreasing temperature. The concentration of EDTA in CAN-DEREM™ Plus reaches the solubility limit when the temperature drops to around 60°C. Thus, if the system is allowed to cool too much during the process, due to equipment failure, loss of power, or other off-normal incident, the EDTA will begin to precipitate out of solution. Mitigation strategies of multiple heaters, pumps (or ability to rebuild), and power supplies should be considered during risk assessment.

16. Gentilly-2 had primary pump seals and bearings that generated antimony (^{125}Sb) deposits in the PHTS film. Antimony dissolves in oxidizing conditions and can be removed usingan anion resin. An Alkaline Permanganate (AP) step was planned specifically for removal of the antimony at Gentilly-2. Antimony is not expected to be as prevalent in other CANDU® plants. However, the antimony loading should be evaluated at each plant to determine if an AP step is warranted.

17. There are several regulatory and administrative challenges to performing work at CANDU® plants, including performing a Hazard and Operability Study (HAZOP), obtaining a Canadian Registration Number (CRN) for each piece of equipment, verifying code compliance, and performing Job Safety Analysis (JSA). Sufficient time, 6 months or more, in the planning/engineering phase needs to be reserved for meeting these challenges.Much of this can be performed concurrently with engineering efforts.

18. The following are historical operating experience from decontaminations at CANDU® plants and mitigation solutions that were performed/proposed for Gentilly-2:
    a. Inadequate amount of resin planned led to early termination of decontamination, reducing the achievable benefit.
        i. Film characterizationwas performed to determine oxide loading.
        ii. Large amount of contingency resin was planned.
    b. Slow solvent regeneration led to longer application times, higher corrosion, and re-deposition of activity.
        i. Large pumps and ion exchange columns were planned to allow for high flow and short solvent regeneration time.
        ii. System broken into ½ loop decontaminations.
    c. Large magnetite loading in Steam Generators (SG) slows decontamination of feeder piping.
        i. Steam Generators were to be bypassed.
        ii. If SG included, mechanical pre-cleaning is an option.
    d. Iron oxalate precipitation from CAN-DECON™ applications re-deposited activity.

   i. CAN-DEREM™ Plus does not contain oxalic acid.
   ii. If CITROX used, lower concentration of oxalic acid in CITROX and lower iron concentration due to faster ion exchange regeneration prevent oxalate precipitation.

e. Antimony activity was not removed and was then re-deposited.
   i. Standard antimony pre-cleaning performed by Gentilly-2.
   ii. AP step performed to remove antimony.
f. Crud was re-deposited.
   i. Fast regeneration flow prevents solvent saturation.
   ii. Optional reverse flow through core to go from cleaner side to more contaminated side, lowering the risk of moving particulate from a high dose area to a low dose area.

4. Conclusion

The artifact testing and system design engineering performed in preparation for the full system chemical decontamination of the Gentilly-2 PHTS provided valuable experience and lessons learned that laid the foundation for streamlining the effort required for future CANDU®applications.