INTEGRATING CHEMISTRY WITH MAINTENANCE DURING CANDU REACTOR LAY-UP FOR RETUBING OUTAGES

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Abstract

CANDU® reactors were designed with a planned replacement of the horizontal zirconium alloy fuel channels midway through the operating life of the plant, i.e., following 25 to 30 years of service. The fuel channel includes the calandria tube, which isolates the primary coolant from the moderator, and the pressure tube, which contains the fuel and reactor coolant. At present, two of the units at Bruce A (in service 1977) and the CANDU-6 at Point Lepreau (in service 1982) are being retubed, and Wolsong Unit 1 (CANDU-6 in service 1983) and Gentilly-2 (CANDU-6 in service 1983) are preparing for retubing outages in 2009 and 2011, respectively.

A refurbishment outage is essentially an extended maintenance outage. The considerations for lay-up of some systems (e.g., the end shield cooling and liquid zone control systems) are the same as for regular maintenance outages. Other systems (e.g., the primary heat transport system) require more attention because the reactor will be defuelled and retubed in the refurbishment outage, and therefore it be impossible to lay-up these systems as during a regular maintenance outage.

It is essential to plan and maintain chemistry control during all phases of the ~18 month retubing outage, to manage the storage of the heavy water for the dismantled in-core systems and to minimize degradation of system components that are not being replaced, while allowing the maintenance activities to proceed. AECL is working closely with CANDU utilities to develop such lay-up chemistry guidelines. The coordination of chemistry control with planned maintenance is essential to minimize system degradation.

1 INTRODUCTION

The successful lay-up, and return to service, of CANDU systems requires effective coordination between all aspects of the retubing outage including maintenance and inspection plans, repair and replacement of components, and chemistry control. Retubing requires complete draining of the primary heat transport (PHT) and the main moderator systems for a significant portion of the outage because the pressure tubes and calandria tubes will be replaced. The guidelines and operating experience summarized in the present work have been developed with reference to available lay-up experience from the CANDU® industry (Bruce A and Pickering A), the Electric Power Research Institute (EPRI) guidelines as well as general good chemistry practices for minimizing corrosion. The guidelines provide strategies for chemistry control and inspection consistent with the changing plant state during the retubing outage. In certain cases, one or more alternative strategies have also been considered.

The requirements for chemistry control during a long-term retubing outage are not always the same as the requirements for maintenance. For example, the lowest risk for degradation is to maintain a system operational under normal chemistry, but this prohibits maintenance on the system. Conversely, opening a carbon steel system for maintenance and leaving it open may be most convenient for maintenance, but will be detrimental to system integrity. The coordination of chemistry control with planned maintenance is essential to minimize system degradation.

The aim of the work presented here is to review the lay-up phases during the long-term retubing outage, the techniques available for periodic inspection, and the strategies for selecting the optimal chemistry control and required inspection for each of the identified periods.

2 STRATEGY FOR CHEMISTRY CONTROL

For each of the normally water-filled systems there are several lay-up options for systems and components that could be used depending on the materials present and the maintenance requirements during the outage. Four general strategies have been identified and these are listed below along with the associated benefits and shortcomings:

1. System filled and circulating under normal operating and chemistry conditions.
   - This lay-up condition presents the lowest risk of materials degradation because the materials and water chemistry are known to be compatible.
   - This condition is not possible for many systems due to retubing and other maintenance activities.

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2. Wet lay-up under stagnant conditions (or minimal periodic circulation).
   - Isolating a system (or portion) and leaving it filled with water under optimum chemistry conditions can maintain material integrity provided the optimum chemistry conditions can be maintained and verified.
   - Maintaining chemistry control in an isolated system can be challenging, because it is difficult to obtain representative samples without recirculation. Chemistry adjustments (especially control of dissolved oxygen) are difficult because of the poor chemical mixing in a stagnant system.
3. Dry lay-up, blanketed by an oxygen-free cover gas
   - Draining the system of the working fluid and maintaining the exposed piping and components under an inert cover gas can minimize degradation. The cover gas should be sampled periodically to ensure that the concentration of oxygen is low. Dry lay-up under an oxygen-free cover gas may be appropriate when the system cannot be drained completely.
   - The use of an oxygen-free cover gas may create an unacceptable asphyxiation hazard.
4. Dry lay-up, air filled
   - The system is drained and dried, and left exposed to air or under a continuous dry air purge. This lay-up strategy should only be used if the materials are not susceptible to general corrosion or if it is possible to verify that the entire system has been drained completely (i.e., no dead legs) and the relative humidity of the dry air purge is maintained within specification and monitored continuously.
   - There is the potential risk of generation of nitrogen oxides (NO_x) and ozone through radiolysis under high radiation fields. In the presence of damp air (or stagnant wet areas) the nitrogen oxides can form nitric acid, leading to localized corrosion.

The materials in the system and the impact of the retubing activities on the system configuration were reviewed as summarized in Table 1 to determine the optimum lay-up chemistry for each system. When maintenance is not being performed on a component or system, all openings should be sealed with temporary covers as part of a strict Foreign Materials Exclusion (FME) program. This will avoid the need to recover or disposition material that has entered the system inadvertently during any phase of the lay-up.

3 SURVEILLANCE TECHNIQUES

It is important to monitor the effects of the outage or storage conditions on nuclear power plant components to check for corrosion and degradation. Surveillance is not unique to extended lay-ups; it is an ongoing part of plant operation and done regularly throughout the lifetime of the plant as part of a periodic inspection program. The techniques can be used to determine the effect of lay-up by comparing the condition of the plant at the beginning of the outage with the condition at the end of the outage and at intervals throughout the outage.

Commonly used surveillance techniques suggested by EPRI [1] are briefly described in this section, including recommended surveillance for extended lay-up.

3.1 Visual Inspections

Visual inspection is non-intrusive and is generally the most effective way to detect inoperative equipment, leaks, and to assess the general condition of components because many signs of degradation (or failure) are visible to experienced station staff.

Visual inspection applications include detection of:

- Surface degradation, i.e., general corrosion, wear, fracture, deposition, etc.
- Loose or missing parts.
- Leakage.
- Deterioration of applied coating or paint.
- Movement of supports.

Visual inspections may require the use of scopes to examine internal and external surfaces of systems and components that cannot be accessed readily or that are in high radiation fields of nuclear power plant systems. A colour chart provides a means to ensure the accuracy of colours when using cameras to collect an image under ambient lighting conditions.

During the retubing outage, facility walkdowns during all stages of lay-up (including video and/or photo records) and system (or component) maintenance provide a means for experienced personnel to identify degradation or an abnormal condition of the plant. Ensuring that the same person performs the same inspections or interprets the same data, where possible, will minimize the risk of differing interpretations because visual inspections can be subjective.

3.2 Chemical Analysis

Chemical analysis involves monitoring and controlling chemistry parameters (e.g., pH, chloride concentration, dissolved oxygen) within specified ranges for the wet lay-up of components and systems to minimize degradation.

During the refurbishment outage, whenever recirculating wet lay-up conditions are applied, chemical analysis surveillance techniques must be used as part of the process control program to ensure that specified lay-up conditions are being maintained. Chemistry parameters that are not within specification provide a warning that additional surveillance techniques may be required to check for degradation. Note that stations often define minimum monitoring frequencies during outages that are meant for long term monitoring once the system has reached a steady state. More frequent monitoring is required during chemistry transients or upsets.

The signals from the station digital control computer used during normal operation for chemistry monitoring may not be available during the long-term refurbishment outage. It is important, therefore, to ensure that critical parameters are trended (e.g., using a datalogger).

3.3 Relative Humidity

Relative humidity (RH), normally expressed as a percentage, is the ratio of the amount of water vapour in a given volume of air at a given temperature to the maximum amount of water vapour that would be present if the air were saturated with water at that temperature.

During the refurbishment outage, when a system is drained and dried, the RH should be monitored and controlled within a preset limit. Literature suggests that a relative humidity of <40% is adequate to protect carbon steel systems from excessive rates of corrosion, and two readings from two different meters is suggested [1]. RH should be coupled with other inspections to ensure that the dry lay-up condition is maintained.

3.4 Ultrasonic Testing

Ultrasonic Testing (UT) is a non-destructive method used to inspect components for welding or forging defects, fatigue cracks, porosity, inclusions, and stress corrosion cracks and can also be used for thickness measurements and bond testing.

During the refurbishment outage, any existing periodic wall-thickness monitoring program should be expanded to include UT of carbon steel piping and components in all critical systems, such as the steam cycle, reactor service water systems, end shield cooling system and the PHT and auxiliary systems to verify that degradation is not taking place during the refurbishment outage.

To ensure the effectiveness of the lay-up chemistry conditions, UT can be done at the beginning of the lay-up, at the end of the lay-up, and at regular intervals in between. Dead legs may present a significant corrosion risk, therefore these regions should be monitored at regular intervals during the outage by UT at the water line, i.e., the air water interface, and at a suitably representative location below the water line.

3.5 Eddy Current Testing

Eddy current testing (ECT) is a non-destructive technique used to determine material properties and integrity. The technique can be used to inspect components (e.g., tubing in the steam generators, heat exchangers and condensers) for cracks, fretting, pinholes, seams, porosity, welds, laps, pits and wastage.

During the refurbishment outage, the tubes of critical heat exchangers (e.g., SGs) should be examined (ideally at the beginning and end of the outage) using ECT to measure the tube wall thickness and to check for indications of localized corrosion, such as pitting or cracking.

3.6 Other

There are several other methods used for surveillance and non-destructive testing during retubing outage that are not mentioned explicitly in the present work. These are included here for completeness:

- Liquid Penetrant – to detect surface discontinuities in non-porous materials (e.g., tubes and welded surfaces).
- Magnetic Particle Testing – to detect surface and near surface discontinuities (e.g., cracks).
- Performance Monitoring – to trend system operating parameters (e.g., temperature, pressure, flow) to identify baseline operation and abnormal (degraded) operation.
- Pulled Tube Examination – to determine and quantify heat exchanger tube degradation.
- Radiographic Testing – to inspect internal and external surfaces for volumetric defects (e.g., at welds), locate foreign objects, and ensure proper installation of components.
- Sludge/Deposit/Scrape Analysis – to measure chemical composition of material removed from steam generators, and other heat exchangers, and vessels to identify quantity and source.

These surveillances methods also need to be scheduled within the retubing outage because some may be performed before, during and after required maintenance activities.

4 SYSTEM HIGHLIGHTS

4.1 Primary Heat Transport System

The primary heat transport (PHT) system is a closed recirculating heavy water loop, which transfers the heat generated by the nuclear fission of the uranium fuel to the steam cycle. In a CANDU reactor, the fuel bundles containing the uranium fuel are held in the reactor core inside horizontal zirconium alloy pressure tubes. The fission heat generated by the nuclear fuel is removed by the pressurized heavy water coolant, which is pumped through the fuel channels and past the fuel bundles. The hot coolant from each fuel channel is collected by the outlet feeders, one for each channel, combined in the outlet headers and passed through steam generators (SGs). In the SGs, the heat is transferred from the heavy water coolant on the primary side to the light water coolant on the secondary side of the SG tubes to generate steam. On exiting the SGs, the heavy water coolant is returned by the PHT pumps to the individual fuel channels through the inlet headers and feeders.

During retubing, the pressure tubes, end fittings and feeders will be replaced, necessitating the complete draining and drying of the PHT system following defuelling of the system. As there are several different system states during the retubing process, chemistry conditions have been defined for each state of the PHT and auxiliary systems during the retube outage.

4.1.1 Prior to System Draining

At the beginning of the outage, the PHT system will be operated under normal shutdown conditions with the heavy water circulating. This is the optimum lay-up state because it provides the lowest risk of materials degradation. This state will continue while the reactor is defuelled with the purification system in service and operational. At the end of the defuelling period, the chemistry of the PHT system will be within the normal shutdown chemistry specifications.

4.1.2 Drain and Dry

Once the reactor has been defuelled, the heavy water will be dosed with hydrazine and circulated throughout the system. This added hydrazine helps to protect areas that cannot be drained (‘dead legs’) prior to nitrogen blanketing. Hydrazine addition at Point Lepreau Generating Station successfully removed the oxygen introduced to the PHT system during the defuelling process and a residual hydrazine concentration within the target range was achieved prior to draining. When the oxygen concentration was low (<10 µg/kg), the heavy water in the PHT system was drained. Hydrazine decomposition produced ammonia maintaining the system alkaline during drying, reducing the radiolytic production of nitric acid, and reducing the risk of shutdown cooling heat exchanger corrosion.

It is important to monitor the drained portion of the PHT system for the build-up of radiolytically generated deuterium during draining. The cover gas deuterium concentration was monitored during the draining process at Point Lepreau and it was necessary to periodically purge the drained portion of the system with fresh nitrogen to avoid the build-up of flammable concentrations of deuterium.

Once the heavy water has been drained from the system, the main PHT auxiliary systems will be dried by vacuum drying. Cover gas monitoring and periodic purging with nitrogen gas will continue to ensure that the radiolytic generation of deuterium in these regions does not exceed 2 vol%.

4.1.3 Dry Lay-up

It is not possible to apply a cover gas to the PHT because the system will be disassembled for retubing and steam generator cleaning activities. Instead the relative humidity of the system will be maintained below 40% to minimize carbon steel corrosion by controlling the atmosphere within the reactor building.

For isolated auxiliary systems, a nitrogen-blanket will be applied and the oxygen content of the blanket will be monitored periodically. Pressurizing any isolated blanketed system to slightly more than the ambient pressure in containment and monitoring the pressure over time will provide further confidence in the integrity of the nitrogen blanket.

Certain portions of the PHT and auxiliaries (‘dead legs’) will not be completely dry even following vacuum drying. Regions where there are water-filled dead legs must be protected with nitrogen blanketing, along with the hydrazine treatment (achieved by dosing the whole PHT system with hydrazine prior to draining) to minimize oxygen ingress into the stagnant water. UT surveillance of these portions of the system is recommended in addition to these chemistry control methods.

4.1.4 Commissioning

Following the replacement of the feeder pipes and fuel channels, the PHT will be refuelled dry with new, unirradiated, fuel. The PHT and auxiliary systems will then be refilled with the stored heavy water. Prior to transfer to the PHT system, the chemistry of the stored water will be verified and hydrazine and lithium hydroxide added as appropriate to ensure that the oxygen concentration and pH_a are within specification.

Following transfer, the heavy water will be recirculated with the purification system operational as soon as the dissolved oxygen concentration is low to remove impurities in the water using filtration and ion exchange.

To ensure that optimal chemistry conditions are maintained during warm-up and initial operation, all chemistry specification for normal operation will be met prior to system warm-up. In particular, this means that the dissolved deuterium concentration will be maintained within specification through hydrogen addition early in the warm-up period.

4.2 Steam Cycle

The guidelines for lay-up are directed towards protecting the steam generators and the steam cycle piping because the carbon steel is the material most susceptible to degradation during a long-term lay-up, and the SGs are expensive and difficult to repair and replace. In particular, for long-term lay-up:

- The condensate, feedwater and steam piping, and associated drain lines should be protected from general corrosion.
- The steam generator tubes and internals, and other heat exchanger tubes, including the main condenser and moisture separators, should be protected from fouling, impurity ingress and corrosion.

Corrosion within these systems and the subsequent transport of the corrosion products into the SGs will be minimized by ensuring that high-quality demineralised water is used for all make-up to the system, by minimizing impurity ingress, and by ensuring that the pH and concentration of dissolved oxygen are controlled using all-volatile treatment (AVT) chemistry. In addition, the potential for developing oxidizing conditions must be minimized in both the feedwater and the SG during shutdown to reduce carbon steel corrosion and minimize the risk of pitting of the SG tubes. In particular, it is important to move the steam cycle and steam generators from normal full power operation to a lay-up state as quickly as possible.

Table 1:
Principle Materials and Recommended Lay-up States for CANDU Systems

System	Major Materials	Recommended Lay-Up State
Primary Heat Transport System	Carbon steel Stainless steel Zirconium alloys Incoloy 800	Wet recirculating initially with alkaline heavy water Hydrazine addition for oxygen removal Drained and dried during retubing
PHT Auxiliaries	Carbon steel Stainless steel	Wet recirculating initially Drained and dried with a nitrogen cover gas during retubing
Steam Cycle	Carbon steel Stainless steel Incoloy 800 Titanium	Wet lay-up with nitrogen blanket for steam generators Drained, and dried using dehumidified air flow for main steam, condensate and feedwater systems
Moderator and Auxiliaries	Stainless steel Zircaloy-2	Wet recirculating initially Drained and dried during retubing
End Shield Cooling	Carbon steel Stainless steel	Wet and recirculating with alkaline water Nitrogen cover gas Hydrazine addition for oxygen removal
Liquid Zone Controls	Stainless steel Zircaloy-2	Water filled with helium cover gas Periodic recirculation
Recirculated Cooling Water	Carbon steel Stainless steel Copper Brass Incoloy 800	Wet and recirculating with alkaline water System in-service for cooling purposes Partial drain may be required for maintenance

To achieve chemistry control in the steam cycle during the retubing outage requires management of a combination of three lay-up strategies:

1. Wet lay-up and recirculating – the system remains filled with chemically dosed water. Wet lay-up is the preferred method for lay-up of the steam generators. Wet lay-up may be used for the condensate and feedwater systems during a short (a few days) lay-up, but is not advisable for a retubing outage because it is not possible to exclude air from these water-filled carbon steel systems.
2. Lay-up with dried air – the system is drained, and dried air is circulated through the system. Lay-up with dried air is the preferred method for the condensate and feedwater systems for long-term lay-up. It may be necessary to place the steam generator under an atmosphere of air for a short period of time to support maintenance and inspection activities.
3. Lay-up under nitrogen – the system is drained, dried, filled with nitrogen gas and sealed. It is best to lay-up the steam generator wet and recirculating with a cover gas of nitrogen above the water line.

4.2.1 Steam Generator Lay-up

A boiler wet lay-up loop has been retrofitted at Canadian CANDU-6 reactors to isolate the SGs from the rest of the steam cycle following cooldown, during lay-up, and prior to start-up. Using this boiler wet lay-up loop, water is removed from each of the SGs through the blowdown lines and returned at a convenient location, i.e., feedwater or reheater drains line. The system permits chemical sampling, and addition of chemicals for pH and dissolved oxygen control. In general, valves need to be in maintained in good working condition to ensure that parts of systems can be isolated.

A combination of a nitrogen cover gas above the SG water line and dosing of the water with hydrazine maintains the concentration of dissolved oxygen below detection limits in the SG during lay-up. Sparging of nitrogen through the blowdown system provides an effective means to establish the cover gas and decrease the concentration of dissolved oxygen in the SG water.

It is anticipated that the steam generator may need to be drained, opened and exposed to air to facilitate inspection (e.g., visual), maintenance (e.g., lancing) and operational (e.g., PHT system drain) activities during the retube outage. Long-term dry lay-up of the steam generators is problematic because it is difficult to completely drain the water, therefore:

- The time that each steam generator is exposed to air should be minimized, e.g., work should be performed on a subset of the steam generators at one time, and the others will be protected to ensure that none are exposed to air except when being inspected or maintained.
- Efforts to completely drain the steam generator to avoid exposing the steam generator internals to moist air, e.g., vacuum out water that may remain on tubesheet and other internal surfaces would be beneficial.
- The water used for refilling the steam generators should be dosed appropriately.

4.2.2 Steam Cycle Dry Lay-up

The feedwater, condensate and steam systems will initially be open to the turbine-building atmosphere because it is not possible to seal the condenser, and other parts of the system. The steam cycle systems (e.g., condensate and feedwater including the tube and shell side of the low-pressure and high-pressure heaters) will be drained and water removed from any low spots or dead legs. Dryers will be used to maintain the carbon steel steam cycle components under an atmosphere of dried air during long-term lay-up, to enhance the removal of any residual water. It will be necessary to set up several systems to circulate dried dehumidified air through the entire steam cycle.

4.3 Moderator

The main moderator system is a low-pressure, low-temperature (~70ºC) closed heavy water circuit. The moderator heavy water is used to thermalize fast neutrons produced by nuclear fission. During normal reactor operation, heavy water is pumped continuously through heat exchangers to the calandria where it circulates and then exits via pump suction piping. During the outage, it will be necessary to drain the moderator because the zirconium alloy calandria tubes are being replaced as a part of the retube process.

For the initial portion of the lay-up outage, the moderator will be maintained under normal outage conditions to provide a guaranteed shutdown state. Following the removal of the fuel from the PHT system, the soluble neutron poisons will be removed from the moderator heavy water so that this heavy water is as free as possible of impurities prior to system draining.

Once the PHT system is drained and dried, the moderator can be prepared for draining. During the draining process, the area of the gas-liquid interface will increase significantly, as compared to the area when moderator level is above the top of the calandria. This will result in an increased rate of gas transfer from the moderator water, thereby requiring frequent cover gas monitoring as the water level is lowered.

During the retubing process, the moderator and auxiliary systems will be maintained under a dry atmosphere. The low moisture content is required to minimize the possibility of corrosion through the formation of nitric acid. If the surfaces are dry, any NO_x formed radiolytically is likely to be removed from the system rather than dissolve in any surface moisture. Normally the containment building air is maintained at a relative humidity significantly lower than 40%.

Following retubing, the moderator will be refilled with heavy water and recirculated through purification to remove any impurities. Prior to refill it is essential that the heavy water is either within the specifications required for normal operation or that performance of the moderator purification system will be sufficient to return the heavy water to the required quality without enhancing degradation of system components. Failure to achieve an adequate water quality could result in complications during the removal of the gadolinium nitrate to achieve reactor criticality.

Once the guaranteed shutdown state is established, fuelling of the PHT system will be started. The subsequent removal of the gadolinium poison and the addition of boron to control the reactivity in the refuelled core should be managed in the same way as for a newly constructed CANDU-6 reactor.

4.4 End Shield Cooling System

The calandria vault (shield tank) and the end shields protect the fuelling machine operating areas from direct radiation from the reactor and as a result, nuclear decay heats the water within these shields. The ESC system circulates alkaline demineralized light water separately through each end-shield, containing steel balls that provide additional shielding, and the calandria vault, and transfers the heat to the RCW system. During the extended outage for the retubing of CANDU-6 plants, the ESC system will be required to provide both temperature control and shielding functions and therefore it is anticipated that this system will remain water-filled and under normal operation for the majority of the outage.

Nitrogen gas is added as a vault cover gas, and occasionally as a purge, to reduce the concentration of H_2. Oxygen might be introduced into the system by air in-leakage, from the introduction of aerated make-up water, and from the radiolysis of water. Hydrogen is produced by water radiolysis and from the corrosion of carbon steel. Normally the small quantities of oxygen that enter this system are removed by the corrosion of the large surface area of carbon steel shielding balls.

Both Point Lepreau and Wolsong 1 have had periods of operation with significant addition of aerated make-up water that has resulted in oxidizing conditions in the system and enhanced radiolytic production of hydrogen. Therefore, the lay-up chemistry has been specified to include hydrazine addition as necessary to remove the oxygen and promote operation with the net radiolytic breakdown of water suppressed once the reactor is restarted.

While the addition of hydrazine during normal operation is not thought to be an effective means of oxygen removal due to the expected high rate of radiolytic breakdown of the added hydrazine, the lower radiation fields encountered during shutdown make the controlled addition more straightforward. If excess hydrazine is added, it can break down in the absence of oxygen to form ammonia, nitrogen and hydrogen.

Hydrazine has been used successfully at CANDU-6 plants to lower the ESC dissolved oxygen concentration during an outage. The shutdown radiation field was sufficient to radiolytically enhance the hydrazine oxygen reaction to rapidly remove the oxygen. Hydrazine addition has been used at Point Lepreau during the current lay-up outage (May-June 2008) to successfully reduce the dissolved oxygen to low concentrations. During the lay-up outage, hydrazine addition is recommended for whenever the oxygen concentration in this system is elevated (i.e., >100 μg/kg) so that reducing conditions are maintained during the majority of the outage.

Should it be necessary to partially drain the ESC system, the addition of hydrazine to remove oxygen will be necessary on refill. To avoid an excessive residual hydrazine concentration, the required quantity of hydrazine should be added in batches and the oxygen concentration monitored. Excess hydrazine could lead to hydrogen production during plant restart. Therefore a limit of 200 μg/kg of residual hydrazine has been specified for this system.

4.5 Liquid Zone Control System

The light water LZC system is a part of the reactor control system. It provides zonal reactivity control and short-term bulk reactivity control by varying the level of light water in 14 compartments within the reactor core as demanded by the reactor regulation system. The LZC system is filled with demineralized water, which is continuously circulated through a heat exchanger, cooled by water from the RCW system, and into the supply header for the liquid zone compartments. The cover gas is helium.

From a chemistry point of view, it is preferable to maintain this system under normal operating conditions for as long as possible during the retube outage to ensure that the water purity is maintained and the cover gas hydrogen concentration is controlled.

When it is required to shut this system down, the in-core portions will be completely filled with demineralized water and a helium blanket will be maintained in the out of core portions of the system. This strategy is intended to minimize both the formation of nitric acid and the production of hydrogen, especially during the early part of the outage when the radiation fields in-core will be highest. Maintaining the system in this state is intended to allow periodic circulation of both the liquid and cover gas systems, thereby allowing chemistry control to be maintained.

4.6 Recirculating Water System

The RCW system is a closed loop cooling system, which supplies water to station heat exchangers that are unsuitable for cooling with raw service water because of water quality requirements. Chemistry control within the RCW is necessarily a compromise because of the many different materials for the components of the interconnected systems. The carbon steel components, however, will be the most susceptible to general corrosion during all periods of operation and lay-up.

Chemistry control to minimize fouling within the RCW using minimally treated water primarily requires control of suspended solids within the system. This is accomplished in the RCW through feed and bleed to dilute the concentration of suspended solids.

Control of corrosion within the RCW is achieved by controlling the alkalinity (pH) using morpholine and by maintaining the concentration of dissolved oxygen below 50 μg/kg through the use of hydrazine. Hydrazine is used to remove dissolved oxygen from closed loop systems; however, hydrazine breaks down to form ammonia, which is known to be corrosive to copper and copper containing alloys. Therefore, it is advisable to maintain the concentration of hydrazine, and hence concentration of ammonia, as low as possible.

The RCW system will remain operational for part or all of the retubing outage because it is required to cool heat exchangers in systems that remain operational. Sufficient hydrazine is added to reduce the dissolved oxygen (entering via feed and bleed) and minimize the formation of ammonia.

During wet lay-up of the system, to accommodate short-term (i.e., less than 4 month) outages, the system will be dosed with sufficient hydrazine to maintain a residual hydrazine concentration in the system. Periodic recirculation of the water in the system will permit mixing, sampling and dosing of the system with chemical additives to maintain the water chemistry within specification.

If it is necessary to drain a part of the RCW system for maintenance or inspection, the rationale for long-term (i.e., longer than 4 months) dry lay-up of the RCW is similar to that for the steam cycle. During these periods dry lay-up using air is the only option as nitrogen presents an asphyxiation risk to workers. It is recommended to flow warmed dried (dehumidified) air through the portion of the system under dry lay-up such that the relative humidity at the exit from the system remains below the specification of 40%.

5 SUMMARY

This paper outlines the lay-up chemistry strategies selected for the major water-filled systems during CANDU-6 retubing outages and associated surveillance strategies. Coordination of the lay-up chemistry strategies with maintenance activities is important for effective planning and scheduling. Ensuring good chemistry and minimal foreign material ingress during the retubing outage will, in the long run, enable better chemistry control during future operation of the plant.

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7 REFERENCES

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