Life Extension at the Point Lepreau Generating Station - Powering the Future

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Abstract. The Point Lepreau Generating Station operated safely for 25 years with a lifetime capacity factor of 82%. Equipment ageing issues (predominately fuel channels and feeders) challenged the station's reliability in the last ten years. Because of the importance of the station to the economy of the province of New Brunswick, refurbishment of the station was investigated. In 2008 refurbishment of the station began with the intention to enable safe operation for another 25 to 30 years at high capacity factor.

1. INTRODUCTION

The Point Lepreau Generation Station (PLGS) is a CANDU®[1] 6 pressurized heavy water design that went into service in February 1983 in the province of New Brunswick, Canada. It is rated at 680 MWe. It was the first CANDU 6 to go operational. Today there are 11 CANDU 6 units operating in 5 countries.

PLGS is located in the province of New Brunswick, Canada on the Bay of Fundy. PLGS is the single nuclear unit owned and operated by the New Brunswick Power Nuclear Corporation (NBPN). PLGS supplies nearly one-third of the New Brunswick electrical load; hence, its safe reliable operation is of major importance to the people of New Brunswick.

In keeping with the theme of this conference, this paper describes the challenges facing the station late in its life, the assessment of feasibility for life extension, and execution of the Refurbishment Outage.

2. PLGS DESIGN

The CANDU 6 is a pressurized heavy water design with 380 individual fuel channel assemblies running horizontally through the reactor core's cylindrical calandria vessel. Each fuel channel is comprised of two concentric zirconium alloy tubes. An inner pressure tube carries the fuel bundles and pressurized reactor coolant and an outer calandria tube separates the heavy water moderator in the calandria vessel from the pressure tube. Four loose spacer springs in the annulus maintain separation between the two tubes in each channel. PLGS has four recirculating steam generators with alloy 800 tubing. Primary reactor coolant is carried between the fuel channels and the steam generating system by 380 SA 106B carbon steel feeder pipes and four headers, each for inlet and outlet flow. Figure 1 shows a schematic view of one reactor face and the general feeder piping system layout, with the insulation cabinet removed. Figure 2 is a schematic of the reactor assembly showing the fuel channel configuration. The current steam generators will remain in service for a total expected operating life of about 55 years.

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[1] CANDU (<u>CAN</u>adian <u>D</u>euterium <u>U</u>ranium) is a registered trademark of Atomic Energy of Canada Ltd. (AECL)

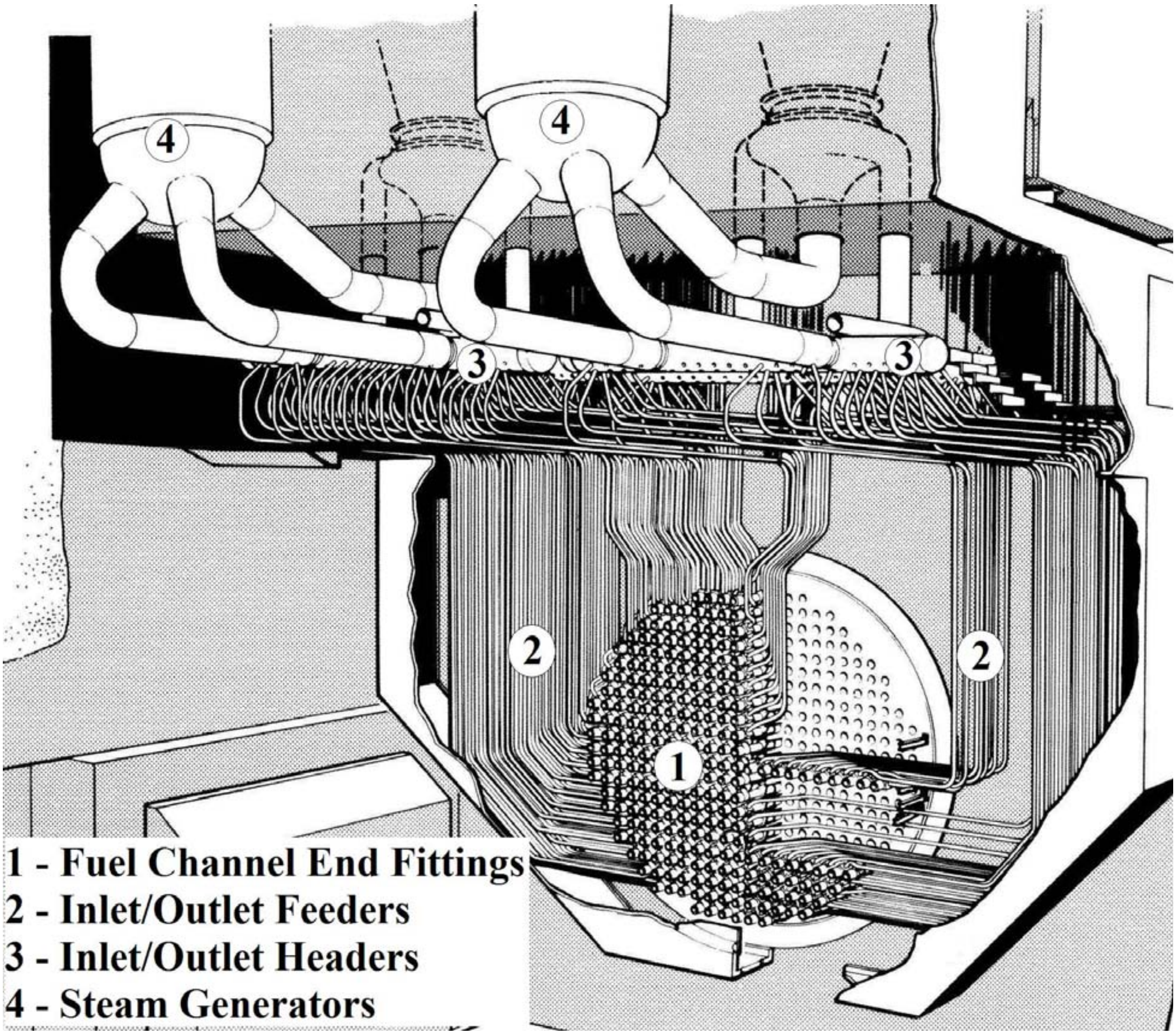

Fig. 1. Layout of the CANDU® Reactor Coolant System.

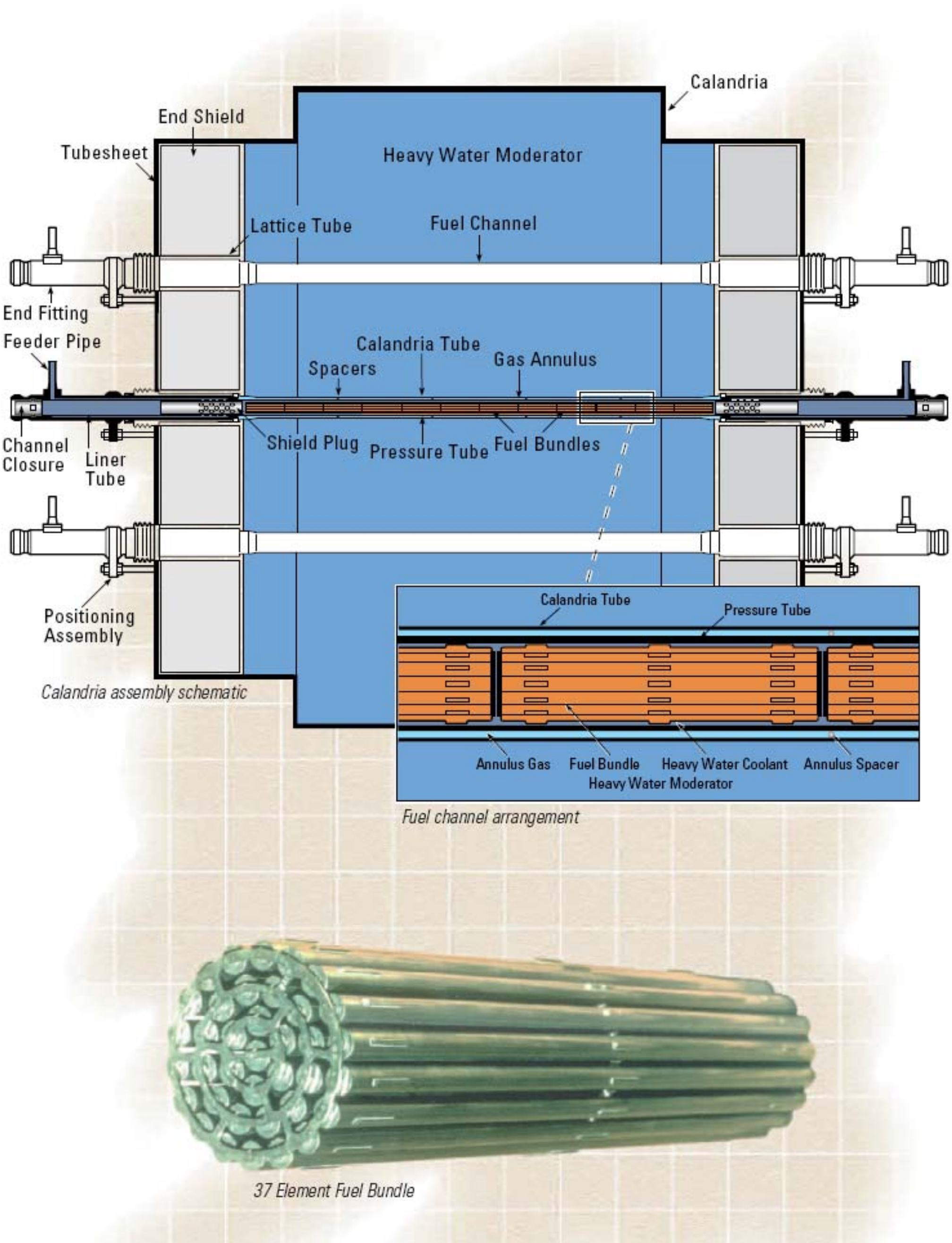

Fig. 2. CANDU® Reactor assemly

3. EARLY PERFORMANCE (FIRST HALF OF LIFE)

Early operation of the station can be characterized as operating at high capacity factors and short annual outages (<30 days) up to 1994 (average capacity factor = 93.4%). Inspection programs were mainly in compliance with mandated Periodic Inspection Programs and In-service inspections of turbines and steam generators.

4. LATER PERFORMANCE (SECOND HALF OF LIFE) - ONSET OF RELIABILITY ISSUES

4.1. Operating challenge

The decision to Refurbishment PLGS was not made until 2005. Economic end of life was determined to be 2010 (limited by fuel channels and feeders). Consequently, until a refurbishment decision was made, the station had to manage several operational issues to maintain adequate safety margins and preserve economic viability. Operational safety was not compromised and conservative decisions were made to maintain safety margins. Lifetime capacity factor to 2008 was 82%.

The following sections describe the primary reliability and capacity risks that the station had to manage since 2000.

4.2. Fuel channels

4.2.1. Spacer relocation

By the early 1990s inspections and research indicated that the loose fitting spacer springs were susceptible to movement. Radiation assisted creep causes the pressure tube to increase in diameter, elongate, and sag. Should contact between the pressure tubes and the corresponding calandria tubes occur, the potential for pressure tube rupture increased because of resultant hydride blister formation and hydride cracking. In 1995 a 6 month outage was planned to reposition the fuel channel spacers to prevent contact between the pressure tubes and the calandria tubes.

Because of refinements in the fuel channel sag algorithim and because not all spacers were relocated optimally in 1995, smaller spacer relocation campaigns were required in a couple of subsequent outages. The impact has been over ~$300M in consequential costs associated with inspection and maintenance activities with very high levels of unplanned work and rework [1].

4.2.2. Effects of diametral creep

As the pressure tube diameter increases, the coolant flow patterns through the fuel bundles change because of the increasing gap between the top of the fuel bundles and the top of the pressure tubes. Consequently, the margin to fuel sheath dryout reduces in some bundle sub-channels. To maintain adequate dryout margin, reactor power was reduced beginning in 1998 with additional deratings in the following years in accordance with the predicted pressure tube diaametral creep rate. Pressure tube diameters were measured periodically and the creep model adjusted accodingly. By 2008 reactor power had been reduced by 12%.

4.3. Feeders

4.3.1. Thinning

As would be expected, the original intent was that PHT feeder piping would last for the design life of the station, 30 years at an 80 % capacity factor. A corrosion allowance was built into the pipe wall thickness specifications to meet this objective based on an anticipated rate of wall thinning.

Since the plant was commissioned in 1982, feeder piping was included in the Periodic Inspection Program (PIP) and ultrasonic (U/T) wall thickness measurement readings were routinely taken at specified locations during planned station maintenance outages. Generally, these sites were located on accessible sections of feeder pipe away from the reactor face to minimize radiation exposure to inspectors. The results of these inspections indicated that wall thinning rates were within design limits. However, cleaning and inspections carried out on the primary side of PHT boilers provided some evidence that there could exist a feeder-thinning problem. Heavy deposits of magnetite (Fe3O4) were discovered in the steam generator cold leg. This discovery coupled with the lack of any observations of thinning in straight sections of feeder piping raised concerns that there might be localized degradation along the feeder. More focused inspections carried out during the 1995 Outage at PLGS established that feeders were indeed thinning excessively at bends on outlet feeders directly downstream of the Grayloc® hubs on the channel end fitting. Consequently, some feeders would not meet their design life because of insufficient corrosion allowance.

An aggressive inspection program was instituted in the annual outages to track the thinning to ensure no feeders operated below the minmum wall thickness and to plan timely replacement. In 2005 the bends of six outlet feeders were replaced.

The mechanism of wall thinning was identified as Flow Accelerated Corrosion (FAC) caused by coolant flow and chemistry conditions that remove the magnetite film that normally protects the feeders from corrosion, and promote a high transport rate of corrosion reactants and products to and from the surface, respectively. [2]

Feeder bend replacement is a complex task because of the difficult access, the ovality of the pipe from cold bending and the radiation fields.

4.3.2. Cracking

In 1997 a leak from a crack that originated from the inside of an outlet feeder pipe elbow resulted in a long forced outage. The root cause of the crack initiation was thought to be mechanically driven because the associated fuel channel was not configured as per the design.

In 2001 another leak from a crack that originated from the inside of an outlet feeder pipe elbow resulted in another forced outage. Inspection of other feeders revealed the presence of two with cracks. There were no configuration issues; clearly, there was a serious unkown cracking phenomenom underway.

A significant R&D program through the Candu Owners Group was initiated to understand the cracking mechanism and to develop inspection techniques. By 2003, it was becoming increasingly difficult to demonstrate safe, reliable operation for the following reasons:

- A large percentage of removed tight radius bends were found to contain incipient outside surface cracks (50-200μm deep), suggesting that a large population of in-service bends may be susceptible to deeper cracking;
- Cracks have been observed to develop from an un-detectable size to ~75% through-wall within one year of operation;
- Outside surface cracks occur at the bend extradoses where the margins on crack stability are lowest because of the lower wall thickness, reduced fracture toughness, and the potential to develop longer partial-through-wall cracks.

To prevent further forced outages, all high risk bends and a selection of those of less risk were inspected annually. Bends with discovered cracks were replaced. Outages were designed with the expectation of finding two cracks; however, the particular feeders could not be pre-determined and the number would only be known on completion of the inspection program. Consequently, outage length and costs could not be confidently predicted. From 1997 to 2007 two feeder bends were replaced because of leaks and sixteen were replaced because of cracks identified by inspection (post removal metallugical examination revealed that six of the sixteen were falsely indentified as having cracks).

Although it has not been possible to conclusively determine the cracking mechanism, two likely and possibly inter-related candidates are Stress Corrosion Cracking (SCC) caused by exposure to mildly oxidizing hot coolant and Low Temperature Creep Cracking (LTCC), possibly exacerbated by atomic hydrogen flux from FAC. [3]

Feeder cracking was a significant challenge because of:

- Two forced outages (90 days total)

- Extension of two planned outages (13 days total)
- Replacement energy costs ~ $50M
- Use of 3% of PLGS annual operations and maintenance budget
- Increased radiation exposure:
- ~30% of total Outage exposure on feeder inspection and replacement activities
- Key inspection resources reach annual limit on feeders and are not available for other component inspections
- Increased Regulatory concern
- Loss of credibility with Owner & Public

4.4. Safety System Trip Logic Reliability

There are two independent shut down systems in a Candu 6. Shut Down System 1 (SDS1) consists of 28 spring loaded cadmium absorber rods suspended above the core by energized magnetic clutches. Shut Down System 2 (SDS2) consists of six tanks filled with gadolinium nitrate that can be injected into the core by helium pressure. The helium tank is connected, through six quick-opening valves arranged in a triplicated array, to a helium header which services the helium tanks.

Each shut down system has a triplicated logic system (programmable digital comparators (PDC)) that will de-energize the clutches to release the rods into the core (in the case of SDS1) or will open the quick-actuating valves to inject the gadolinium nitrate into the core (in the case of SDS2) when any two of three independent trip channels are actuated. SDS1 and SDS2 have independent trip channels. The selection of trip parameters is such that there are adequate measurements for all identified process failures. Protection is designed for each identified process failure, using two separate parameters where practicable.

Each shut down system has a design unavailability target of less than 10^{-3} years per year. Thus, to demonstrate the reliability of the shut down systems the trip channels must be logic tested often while the reactor is at power. This is done by deliberately placing the channel in the tripped state (known as “rejected”); thus, a trip signal on either of the other two channels will result in a completed reactor trip.

A trip signal can come from the process or from a failed PDC. As the PDCs aged, there were seven to twelve electronic board failures per year that if there had been a channel rejected for testing at the time, there would have been a completed reactor trip. There were two such spurious trips since 2001. The PDCs were obsolete so obtaining spare parts was a challenge. An aggressive campaign of changing out high failure rate components (e.g. capacitors) reduced the board failure rate to five to seven per year. Operations managed the testing very effectively to keep the time the channels were rejected to a minimum.

4.5. Station Control Computers

Reliability of the Station Control Computers was reduced because of aging of obsolete electronic components and degradation of cabling. While there were no forced outages as a result, the effort required to maintain the components was extensive.

A strategy for maintenance and spares was established in 2002 that was designed to enable operation to 2015 with the current computers if necessary. The long-range plan has Station Control Computer replacement scheduled for 2013.

4.6. Uninterruptable Power Supply

Reliability of the Uninterruptable Power Supply System (UPS) was a significant issue because of aging of obsolete electronic components. There have been significant problems with failures of inverter components; a few resulted in plant upsets. In addition there were quality control problems with parts supplied by and work done by the manufacturer.

The challenge was to get to Refurbishment or end of life without major failures. The main thrust was to repair failed components and to insure the components were adequately tested before installation. With the replenished stock and the improved maintenance strategy, major UPS issues were averted.

4.7. Turbine Supervisory

There were several incidents of turbine supervisory upsets that could not be resolved; one resulted in a forced outage in 2002. Much of the electronics was obsolete. Diagnostic equipment was added in 2004 to help identify faults.

5. REFURBISHMENT

5.1. Planning

A study on the long-term economic life of Pt. Lepreau GS was conducted in 1997 and 1998. The study concluded that refurbishment may be economically desirable. It addressed the capital investment required to replace the reactor fuel channel assemblies and to refurbish other equipment. Also, it recommended that NBPN conduct a more detailed technical and financial assessment prior to committing such investment. In February 2000, the necessary funds were committed to conduct the assessment to refurbish the Point Lepreau GS with a target date for refurbishment in 2006.

The project had three phases:

- Project Definition Phase 1

The Definition Phase evaluated the risks associated with proceeding with a major refurbishment of PLGS, including regulatory, financial, performance and schedule, and market risks. The product of the Definition Phase was a business case establishing the economic viability of the project and a Project Execution Plan (PEP) that defined scope, cost, and schedule, along with a plan for execution and an objective analysis of the risks involved.

A comprehensive Condition Assessment process of the station’s structures, systems and components was conducted to determine the other issues that would have to be addressed to life extend the station. An Integrated Safety Review (addressed the safety factors covered in a Periodic Safety Review) was done based on IAEA NS-R-1, IAEA NS-G-2.10 and CNSC RD-360 (draft) to determine gaps with international Safety Goals, modern codes and standards and regulatory requirements. The outputs from these analyses determined the scope of a Refurbishment Outage.

- Project Execution Phase 2 Pre-Outage

The Project Execution Phase commenced on approval of the NB Power Board of Directors and other authorities in 2005. Activities in this phase were detailed design, preparation of work packages and completion of the deterministic and probabilistic safety analyses (Level 2 PSA).

- Project Execution Phase 3 Refurbishment Outage

At the end of March 2008, PLGS was shut down to commence the Refurbishment Outage. That outage is in progress. The Refurbishment Outage has three phases (see 5.3 Status):

- Station shutdown, defuelling and dewatering
- Execute the modifications, replacements and repairs

- Commission and return to service

5.2. Refurbishment Outage Scope

5.2.1. General

Approximately 230 design changes will be implemented and more than 9000 maintenance orders will be performed. The work can be roughly categorized as improve safety (regulatory commitments and improvements in severe core damage frequency and large release frequency), improve reliability (address ageing issues and fix deficiencies), and increase output. The more significant scope items are listed in the following sections.

5.2.2. Improve Safety

- Install a reactor building filtered vent system and calandria vault make up system (required to meet Large Release Frequency target) [complete]
- Broaden Shutdown System trip coverage for moderator related events involving leak, loss of circulation or loss of cooling and to provide improved coverage for loss of flow events in the heat transport system.
- Modify moderator heat exchangers to improve the moderator sub-cooling margin [complete]
- Improve Shield Cooling System pressure relief capability (install a rupture disc on the calandria vault) [complete]
- Add a 4th Recirculated Water Cooling Pump
- Add a heat transport system pump trip on high thrust bearing temperature [complete]
- Add a filtering system to the main control room ventilation system to protect the main control room operators enabling them to mitigate a postulated severe accident event.
- Modify in-core start-up counters to enable independent movement [complete]
- Upgrade fire detection, suppression and egress.
- Replace the underground diesel fuel storage tank for the emergency power system [complete]

5.2.3. Improve Reliability

- Replace all fuel channels (critical path)
- Replace all feeders
- Replace Shutdown System trip comparators
- Replace Uninterruptable Power Supplies (inverters and rectifiers) [complete]
- Replace turbine supervisory, electro-hydraulic governor system and turbine over-speed system
- Install a third Class III power standby diesel system
- Expand the solid radioactive waste management facility [complete]
- Inspect internal reactor components [complete]
- Clean the primary side of the steam generators
- Continue with Station Control Computer maintenance plan
- Replace Condenser Cooling Water (CCW) isolation valves
- Rewind the main generator and stator and replace associated auxillaries (excitation system (including voltage regulators, stabilizers and rectifiers) and hydrogen system dryer)
- Replace safety related resistance temperature (RTD) cables [complete]
- Replace moderator system primary isolation valves [complete]
- Refurbish raw service water system components
- Refurbish re-circulated cooling water system components [complete]
- Remove heat transport storage tank liner [complete]
- Repair dousing tank liner

5.2.4. Increase output

Advantage of the long outage to replace fuel channels and feeders was taken by replacing the low pressure turbines with high efficiency turbines. Electrical output is expected to increase by 25 MWe.

5.3. Status

5.3.1. Station shutdown and dewatering

The first phase was completed on schedule in May 2008. The reactor core was defuelled using the Fuelling Machines (12 bundles in each of 380 channels). Following defuelling, heavy water was drained from the heat transport and moderator systems and a vacuum drying system installed to reduce the tritium hazard. In addition, the secondary side of the steam generators were cleaned and other water systems were laid-up. The local air coolers in the vicinity of the reactor faces were removed to provide space for the reactor fuel channel replacements.

5.3.2. Execute the modifications, replacements and repairs

5.3.2.1. Fuel channels and feeders

The second phase is well underway. The critical path remains through the replacement of the fuel channels and the feeders. Replacing the fuel channels and feeders consists of the following steps: remove feeders, remove end fittings, remove pressure tubes, remove calandria tubes, inspect the internals of the reactor, install calandria tubes, install pressure tubes, install end fittings and install feeders.

At the time of writing this paper (September 10, 2009), diasassembly of the reactors components (i.e. removal of the fuel channels and feeders) is complete and inspection of the reactor internal components is complete (no significant findings). Preparation of the calandria tubesheet is in progress for calandria tube installation. Installation of upper feeders is in progress.

Custom-designed, automated electro-mechanical tooling is used to limit manual activities to keep the radiation exposure low. Local trades were trained to operate the tooling. Production rates for dismantling the fuel channels and feeders, inspection of the calandria internals and preparation of the calandria tubesheet have been less than initially predicted. Contributing factors are complex processes requiring high precision, first time useage, space restrictions, and unexpected impact on the mechanisims from the cutting and shearing operations. For example, tooling designed to shear the feeders did not perform as expected; consequently, the feeders were removed manually. This presented contamination problems that were difficult to resolve.

Despite the equipment problems, actual radiation exposure is tracking below predicted.

Significant effort is being expended in the review of the re-assembly procedures and verification on mock-ups. Safety and quality remain paramount.

5.3.2.2. Remaining scope

Installation of several of the non-critical path scope items is complete (see 5.2.2 and 5.2.3) and the remainder (other than fire upgrades) are expected to be complete by year end.

Execution of the non-critical path work and non-turbine work was negatively impacted by intereference with this high profile work. For example; heavy lifts of turbine rotors required evacuation of the Turbine Hall as a safety precaution.

5.3.2.3. Discoveries

Two significant discoveries were the deterioration of raw service water piping encased in concrete and hydride embrittlement of the titanium condenser tubes.

Inspection of the raw service water piping from the heat exchangers to the condenser cooling water ducts revealed significant erosion/corrosion of the piping that is encased in concrete. Modifications are underway to reroute the discharge from the heat exchangers to the ducts.

Early in the outage, a couple of condenser tube leaks occurred following cleaning. Inspection revealed wide spread hydride embrittlement of the condenser tubes at the outlets. The cause was attributed to improper setting of the cathodic protection system. Sleeves will be installed in the tubes at the ends to enable reliable operation to the next planned outage (2012). Replacement of the tubes will be done during that outage.

Another discovery was the degraded condition of a moderator pump wear ring and bearings. Routine vibration monitoring had not indicated a problem. The second moderator pump will be examined.

5.3.3. Commission and return to service

Commissioning and restart preparations are nearly complete and the restart schedule is being refined. Sixty of the 230 design changes require formal commissioning (85% of the 400 procedures are drafted or complete). Approximately 50% of the construction packages have been accepted by Commissioning and commissioning is underway where plant state permits and in some cases is complete (E.g. Uninterruptable Power Supplies).

6. CONCLUSION

Despite the schedule challenges, daily progress is being made to complete the outage and have a successful restart. Subsequent refurbishment of other Candu 6s will benefit greatly from the OPEX gained in New Brunswick. We are confident that the Point Lepreau Generating Station will restart and operate safely and reliably for the next 25 to 30 years for the people of New Brunswick.

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