EVOLUTION OF MANAGEMENT ACTIVITIES AND PERFORMANCE OF THE POINT LEPREAU STEAM GENERATORS

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ABSTRACT

The Point Lepreau steam generators have been in service since 1983 when the plant was commissioned. During the first thirteen years of operation, Point Lepreau steam generator maintenance issues led to 3-4% unplanned plant incapability. Steam generator fouling, corrosion, and the introduction of foreign materials during maintenance led to six tube leaks, two unplanned outages, two lengthy extended outages, and degraded thermal performance during this period.

In recognition of the link between steam generator maintenance activities and plant performance, improvements to steam generator management activities have been continuously implemented since 1987. This paper reviews the evolution of steam generator management activities at Point Lepreau and the resulting improved trends in performance. Plant incapability from unplanned steam generator maintenance has been close to zero since 1996. The positive trends have provided a strong basis for the management strategies developed for post-refurbishment operation.

1.0 INTRODUCTION

The steam generators at the Point Lepreau Generating Station (PLGS) have been in service since 1983 when the plant was commissioned. During the first thirteen years of operation, steam generator degradation and maintenance issues led to 3-4% unplanned plant incapability. Steam generator fouling, corrosion, and the introduction of foreign materials during maintenance led to six tube leaks, two unplanned outages, two lengthy extended outages, and degraded thermal performance during this period.

In recognition of the link between steam generator maintenance activities and plant performance, improvements to steam generator management activities have been continuously implemented since 1987. This paper reviews the evolution of steam generator management activities at Point Lepreau and the resulting improved trends in performance. Plant incapability from unplanned steam generator maintenance has been close to zero since 1996. The positive performance trends provide support for the decision not to replace steam generators during the eighteen-month plant refurbishment outage beginning in 2008. The post refurbishment design life is 30 years at 80% capacity factor.

PLGS has four recirculating steam generators configured in a two-loop heat transport system with two steam generators in each loop. The steam generators are a Babcock and Wilcox Canada design with an integral steam drum and preheater. The design features that have most relevance to the steam generator management at PLGS are:

- Alloy 800 tube material
- Stainless steel (type 410) tube supports (tube support plates, U-Bend scallop bars, preheater upper baffle plates)
- Carbon steel components in the feedwater box/preheater section (e.g. thermal sleeve, plates, lower baffle plates)
- Emergency Water Supply (EWS) header (with J-tubes) is also used for reheater drains return flow and is made of a combination of carbon steel and Co-Mo
- Seawater cooled condensers

Additional details of the PLGS steam generator design and operating conditions are provided in Figure 1.

Babcock & Wilcox Steam Generators

Design:

- 4 Steam Generators, 2 per reactor loop
- Vertical U-tube
- Integral steam drum and preheater
- 18.9m high
- 4.01m Steam Drum OD
- 3550 tubes, triangular pitch (0.950”)
- Alloy 800 Tubes (5/8” OD, 0.0445” WT)
- 410 SS broached hole support plates
- 410 SS U-bend scallop bar supports
- 410 SS preheater upper baffles
- Carbon steel preheater section
- Carbon steel shell, drum, internals
- Inconel clad tubesheet
- Heat Transfer Area: 3177m^2
- Heat Transfer: 515MW
- Design T and P (Primary/Secondary side):
  - 318/266°C
  - 11MPa/5.07 MPa

Operational Data:

- Coolant Information:
  - Volume – 10.8m^3
  - Inlet T - 309°C
  - Outlet T - 266°C
  - Inlet P – 9.89MPa
  - Outlet P – 9.61MPa
  - Inlet Quality – 4.4%
  - Flow – 1.9Mg/s
- Steam Information:
  - Output – 262kg/s
  - Exit P - 4.55MPa (original)
  - Exit T - 260°C
  - Exit Quality – 99.75%
- Feedwater Information:
  - Flow – 258kg/s
  - T (Full Power) - 187°C
- Reheat Information:
  - Flow ~ 20kg/s
  - Temp - 242°C

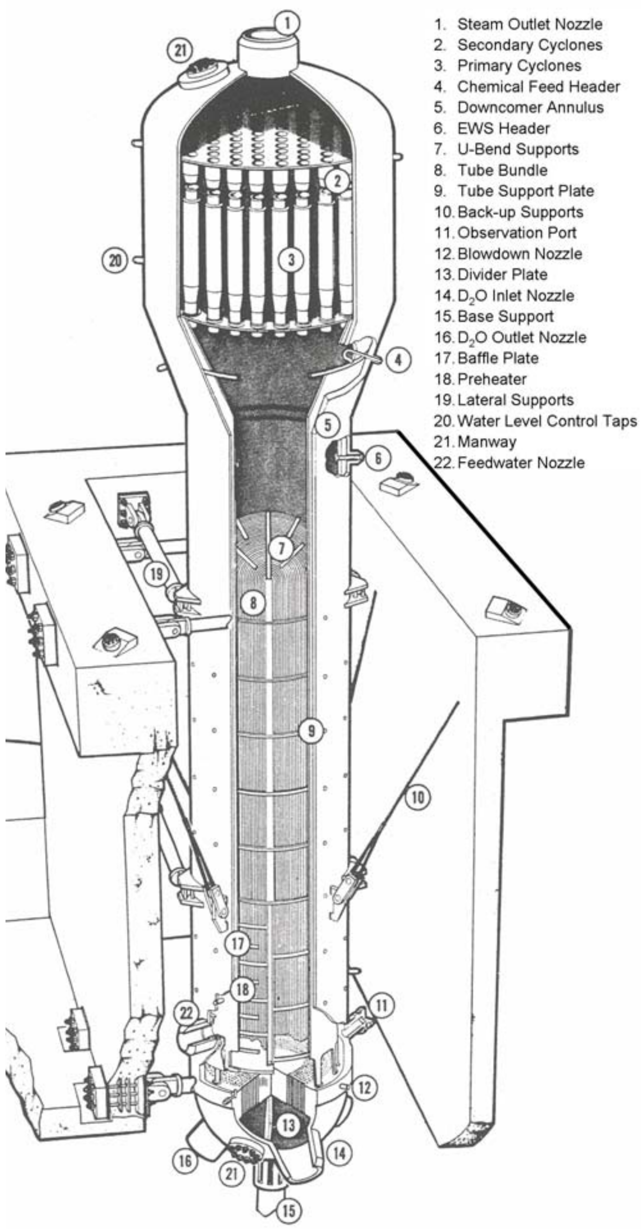


Figure 1: PLGS Steam Generator Design and Operating Conditions

2.0 DEGRADATION MECHANISMS AND POTENTIALLY AFFECTED LOCATIONS AT PLGS

Numerous components of the steam generators can be susceptible to different degradation, by mechanisms that are interrelated. This section briefly describes these degradation mechanisms and the locations potentially affected, according to their likelihood of occurrence. For the PLGS design, there is no anticipated degradation with unmanageable failure rate or safety significance. The characteristics of each degradation mechanism require different management strategies and maintenance activities that are discussed later in this paper. Table 1 provides a summary of this information.

Table 1: Summary of Management Plan Elements for Credible Degradation

Potentially Affected Components	**Primary Strategy to Manage Degradation**	
	Plan Elements	**Management Activities**
Expected Degradation Under Normal Operating Conditions		
Flow Accelerated Corrosion		
EWS header and J-tubes, Bolted divider plate, bowl ear gap, Secondary and primary separator vanes, Feedwater box, head, nozzle, and lower baffle supports	Inspection	Wall thickness, Eddy current of tubes (adjacent to baffle plates), Visual inspection
	Repair & Replace	Repair/Replace thinned components
	Chemistry control	Control alkalinity
Fouling		
Tubing inside surface, particularly hot leg side, Secondary side horizontal surfaces, particularly the hot leg of the tube sheet, also tube supports, separator decks, Tubing outside surface	Deposit Removal	PHT: Mechanical cleaning Secondary: Waterlancing, Chemical Cleaning
	Chemistry control	PHT: Control alkalinity Secondary: Alkalinity, impurities and particulate, oxidizing potential during shutdown and startup
Credible Degradation Under Common Operating Conditions		
Fretting		
Debris fretting of tube outside surface at the tubesheet, mainly at the bundle periphery, along the tube-free lane & near the feedwater inlet. Support fretting of tube outside surface at U-bend scallop bar supports	Configuration Management	Foreign materials exclusion program Loose parts detection and retrieval
	Deposit Removal	Waterlancing
	Inspection	Volumetric
	Repair	Tube plugging
Localized Corrosion		
Wastage and pitting of tubing outside surface, primarily under deposits Wastage of tie rods under the sludge pile	Deposit Removal	Waterlancing
	Chemistry Control	Impurities, oxidizing potential
	Inspection	Volumetric inspection Visual inspection
	Repair	Tube plugging
Credible Degradation Under Rare Conditions		
Fatigue, Tube Denting, Plugged Tube Failure, Environmental Cracking		
Fatigue of feedwater nozzles and distribution box, seismic restraint lugs, and tie rods. Tube denting under heavy deposits. Failure of tube plugs. Environmental	Deposit Removal	Waterlancing
	Chemistry Control	Impurities, oxidizing potential
	Inspection	Volumetric inspection Visual inspection Material surveillance

cracking of tubing in locations of residual stress and fouling.	Operating Guideline	Heat up and cool down limits

2.1 Expected Degradation under Normal Operating Conditions

Based on the PLGS steam generator design and external operating experience, flow accelerated corrosion (FAC) and fouling are expected to occur to various degrees on some components during normal operating conditions. Mitigation activities can be performed to minimize the severity of these mechanisms, but it is not economical to completely prevent them.

2.1.1 Flow Accelerated Corrosion

Carbon and low alloy steel components can be susceptible to flow accelerated corrosion under normal steam generator chemistry and operating conditions in locations of high coolant flow rate and turbulence and under-saturation in dissolved iron. Steels with very low chromium content (0.01%) are particularly susceptible. The components considered most susceptible to FAC, based on operating experience and knowledge of operating conditions are listed in Table 1.

2.1.2 Fouling

The primary side of the steam generator tube bundle is susceptible to magnetite fouling, increasing from just beyond the entrance of the hot leg to the preheater. Primary side tube fouling is caused by the precipitation of dissolved iron generated by FAC of outlet feeders.

Secondary side fouling is caused by deposition of solid particles entrained in the coolant during normal operation and from crud bursts during reactor startup. The (mainly magnetite) particles are generated from corrosion of feedtrain materials under normal operating conditions as well as impurities that enter the secondary system under off-design conditions (condenser leakage, resin ingress, contaminated make-up). On the secondary side, horizontal surfaces and locations with a high local heat flux are most susceptible to deposit buildup, the hot leg side of the tube sheet, in particular.

2.2 Credible Degradation Under Common Operating Conditions

Fretting and localized corrosion are degradation mechanisms that have been known to occur in materials used in the PLGS steam generator design, as a result of common operating conditions that are not optimal.

2.2.1 Fretting

Debris fretting of tubing can occur from damage by loose parts that have inadvertently entered the system as a consequence of manufacture and installation, maintenance activities or degradation of steam generator internals. Fretting is most likely at the tubesheet, in tubes on the bundle periphery, along the tube-free lane and near the feedwater inlet.

External operating experience indicates that fretting of tubing at supports can sometimes occur under design conditions. The incidence and severity is known to increase if tube supports become degraded or flow patterns change because of deposit buildup.

2.2.2 Localized Corrosion

The outside surface of alloy 800 tubing is susceptible to localized corrosion if aggressive local chemistry is permitted to develop. Crevice regions or locations under deposits are most susceptible. Oxidizing chloride conditions from air ingress and condenser leaks can lead to tube pitting whereas acidic-sulfate or -phosphate from aggressive hideout conditions or incorrect phosphate-to-sodium ratios during phosphate treatment can lead to wastage. External operating experience indicates that carbon steel tie rods can also suffer wastage under deposits if aggressive local chemistries develop.

2.3 Credible Degradation Under Rare Conditions

Plugged tube failure and other degradation mechanisms of specific components have been identified as less likely but credible either based on rare external operating experience, laboratory data under abnormal operating chemistries, or other postulated operating conditions.

2.3.1 Fatigue

Low cycle or thermal fatigue has been postulated at defects in the seismic restraint lug-to-shell weld heat affected zone during heat up and cool down transients and at the feedwater pipe to nozzle weld, feedwater distribution box, and at the tie rods at the thermal plate due to thermal stratification when cold water is added during zero power hot conditions. The most likely susceptible locations for high cycle fatigue would be at defects in the upper tube bundle if subjected to flow induced vibration because of inadequate support or tube lockup from heavy fouling.

2.3.2 Tube Denting

The outside surface of tubing can be mechanically deformed (dented) if it is physically restrained and subject to forces caused by the volume expansion of magnetite from the rapid oxidation of iron, usually under acidic conditions. Heavily fouled tubing adjacent to carbon steel components (tie rods, supports) is most susceptible; denting in the hard sludge pile region has also been reported.

2.3.3 Environmental Cracking

PLGS steam generator materials are not considered susceptible to environmental cracking under normal operating and anticipated transient conditions. Cracking would require high tensile stresses from mechanical damage or sub-optimal fabrication practices and the development of a highly aggressive environment (highly caustic or acidic, particularly when Pb present) most likely within an occluded region (e.g. beneath heavy fouling, within a tubesheet crevice) and/or from a severe chemistry transient. The likelihood of cracking will be reassessed once the cause of crack-like indications observed within the tubesheet crevice below the upper expansion in four German plants has been identified.

3.0 PLGS STEAM GENERATOR DEGRADATION – OPERATING EXPERIENCE

This section briefly describes the degradation observed in the PLGS steam generators that has had the greatest influence on the evolution of management activities. The most significant degradation has been fretting and localized corrosion of tubing, FAC of internal components, and fouling.

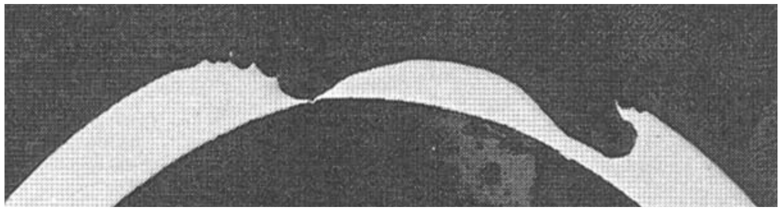
3.1 Fouling

During the first decade of PLGS operation, secondary side deposits accumulated to a degree that promoted localized corrosion of tubing, some broach-hole blockage, and decreased thermal efficiency of the steam generators. All surfaces were covered with deposits, including the primary and secondary separator decks and steam generator tubing. Deposits grew about 5cm high on the hot leg lower support plates, blocking some of the trefoil broached holes of the first and second tube support plates and beginning to block some of the holes in the top support plates. Accumulation of sludge in the center of the hot leg tubesheet covered about 10% of tubes in each steam generator to a maximum height of about 15cm with a 5cm hard core.

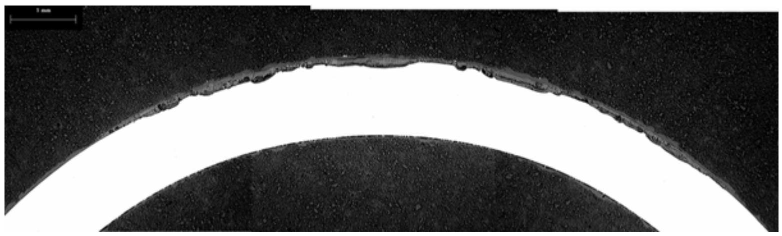
Magnetite has deposited on the tube inside surfaces at a rate of about 50kg per steam generator per year. Deposits can reach about 150μm in thickness on the cold leg. These deposits interfere with tube inspection (damage probe heads and create signal noise), reduce heat transfer efficiency, and increase local radiation fields.

3.2 Tube Degradation

In the early years of operation, there was a significant amount of unplanned maintenance resulting from steam generator tube degradation. Fretting and localized corrosion has led to six tube leaks (1985, 1987, 1992, 1994, two in 1996), two unplanned outages (1994, 1996), and plugging of about eighty tubes. Pitting or phosphate wastage has occurred in thirty-one tubes caused by aggressive chemistries developing beneath fouling deposits and exacerbated by aggressive impurities introduced during condenser leaks. Figure 2 (top) shows a metallographic cross section through the pitted region that caused the tube leak in 1987. This pit was under fouling at the hot leg first support plate and was associated with mechanical damage on the tube surface. PLGS pitting has often shown undercutting as in Figure 2, and has been attributed to the local presence of copper and chloride ion.



1987 Tube leak



2002 Surveillance Tube

Figure 2: Tube Pitting at Fouled First Support Plate that Led to 1987 Leak (top) and Tube Removed for Surveillance in 2002 showing an Indication of Arrested Phosphate Wastage (bottom)

Thirty-seven tubes have been plugged because of debris from foreign materials left in the secondary system during maintenance or by the generation of loose parts from degradation of internal components. Some of these tubes had debris-frets and other tubes surrounding irretrievable debris were plugged in case of debris-fretting. The two leaks in 1996 were attributed to debris fretting. Seven tubes have also been plugged because of U-bend fretting at Anti-Vibration Bars. These are randomly distributed across the tube bundle above row 50.

3.3 Flow Accelerated Corrosion

Severe FAC degradation of the EWS header and J-tubes led to their replacement with more resistant Cr-Mo steel in 1996. FAC from the inside surface caused perforation at the T-joint and several J-tubes to break off. FAC on the outside surface at the low clearance gap with the thermal sleeve also led to perforation. Figure 3 shows this FAC damage to the original header in 1996 and the good condition of the same locations of the replacement header in 2002.

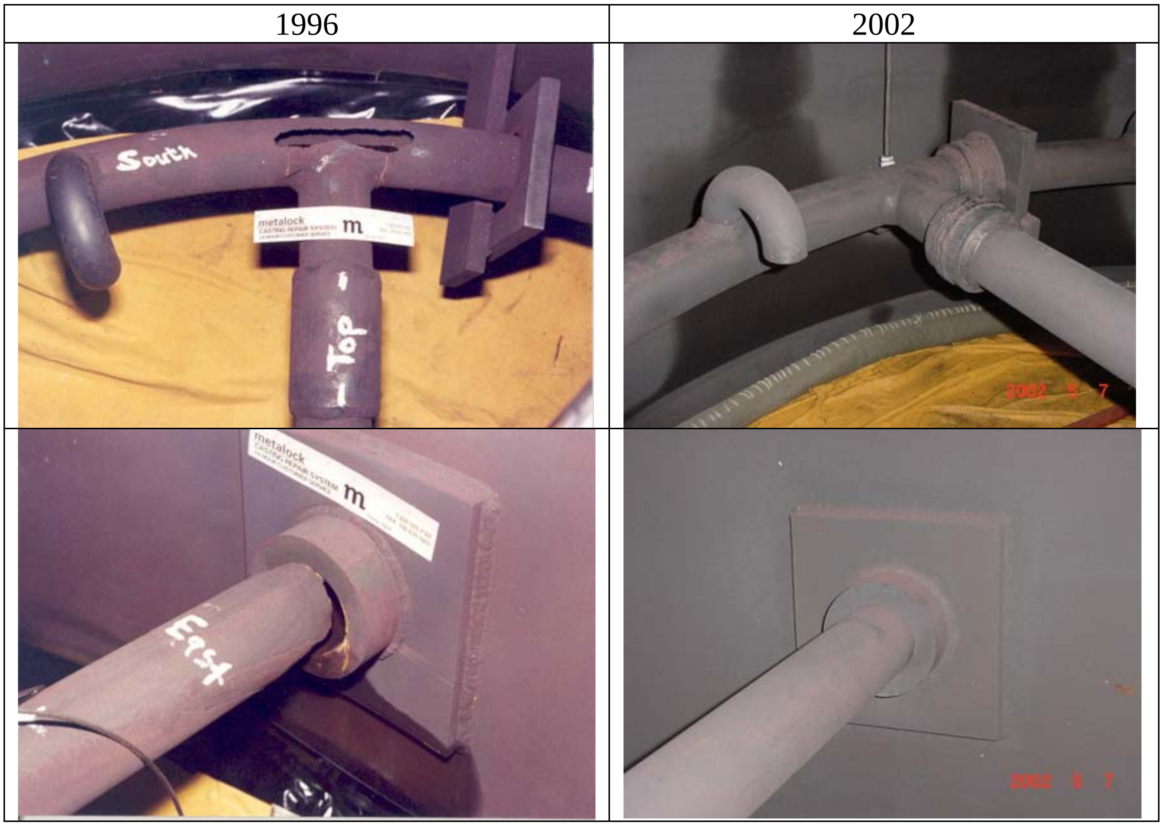


Figure 3: FAC Damage to the EWS Header T-joint (top) and Thermal Sleeve Connection (bottom) in 1996 and the Good Condition of the Replacement Header in 2002

In 1994, FAC damage of some divider plates was observed due to leakage between the plates and some bolts holding the divider plates to the upper seat bar were found sheared. As a result, the primary side divider plate panels and bolts were replaced with a more resistant one-piece floating design in 1995. This design included FAC-resistant materials for the tubesheet seat bar, liner welded directly to the SG head seat bar, and material buildup on the sealing faces of the divider plate rim.

FAC that is not currently life-limiting has been observed at other locations. Visual inspection of the primary head at the intersection with the divider plate and the seat bar has shown some minor indications of FAC in what is known as the “ear gap”. FAC is also occurring at a low rate in the PLGS removable secondary separators at the vane edges and in shallow circular patterns on the inside of the top surface of the base plate. Wall thickness measurements in 2006 on the baseplates from B02 and B04 indicated maximum wall losses of between 0.002 to 0.022” from a nominal thickness of 0.125”. B02 and B04 inspections in 2006 indicated that FAC is not active in the primary separators. Locations considered susceptible (vanes and scoops) showed no signs of FAC degradation. Limited inspection of the PLGS feedwater boxes and inlet locations has indicated some FAC of the stay bolts around the feedwater inlet, the feedwater box top plate, and the thermal sleeve. FAC has not been observed at the friction-fit retaining ring location.

4.0 IMPROVEMENTS TO STEAM GENERATOR MANAGEMENT

Improvements to steam generator management activities have been continuously implemented since 1987 to minimize degradation of system components, optimize plant performance, and prolong steam generator life. These activities form part of the formal Steam Generator Life Management Plan issued in 2006. The major improvements are briefly described below under the management plan elements shown in Table 1:

4.1 Chemistry Control

The control of secondary side chemistry has been continually improving since early operation. The objectives are to minimize fouling, corrosion, and the development of aggressive crevice or underdeposit chemistries. Many of these improvements are described in an Optimization Plan for the Steam Cycle and are summarized below:

- 1986 – A full flow condensate polishing plant was put into service to remove impurities in the feedwater that are introduced as a result of condenser tube failures.
- 1988 - Switched from ammonia to morpholine as the pH control agent to increase the pH in the steam condensate regions throughout the turbine. The purpose was to reduce FAC and iron transport from carbon steel surfaces wetted by steam condensate.
- Early 1990’s - The sodium/phosphate ratio was optimized to minimize the development of the aggressive underdeposit environment that was considered to be the primary cause of the observed tube wastage.
- 2000 - Changed from congruent phosphate treatment to all-volatile treatment (AVT) due to concerns over continuing phosphate wastage.
- 2000- Full flow condensate polishing was suspended and only put in service during full power operation in the event of condenser leakage. Condensate polishing is still performed during start-up to remove feedwater impurities and to reduce iron transport.
- 2000 – A recirculation loop was retrofitted to permit the feedwater to by-pass the steam generators and return to the condenser for the purpose of conditioning the feedwater during preparations for start-up. During recirculation of the feedwater, the pH is brought into specification, the condensate polisher removes corrosion products, and hydrazine is added to remove dissolved oxygen.
- 2004 – Minor modifications to the blowdown system were completed to achieve maximum design blowdown flowrate (OM36310 states a maximum of 6.2 kg/s or 1.55 kg/s per boiler) when impurity levels in the steam generator are unusually high. This can occur during shutdown when hideout return occurs (release of species from occluded sites where they accumulated during operation), periods of startup, or after condenser leaks. Boilers are drained and refilled prior to startup

to remove hideout return impurities. Boiler blowdown is not utilized for this purpose prior to warmup.

- 2004 – Improvements to condensate polisher resin reduced feedwater contaminants from resin slippage during startups (e.g. a two stage regeneration process was implemented to reduce chloride loading on regenerated anion resin).

4.2 Deposit Removal

In recognition of the need to minimize the development of aggressive underdeposit chemistries, prevent tube lockup and flow instabilitlies, maintain tube inspection tool passage, and restore loss of thermal efficiency, deposit removal activities have been implemented since 1987.

- Secondary side tubesheet water lancing has been performed on one or more steam generators during outages in 1987, 1991, 1992, 1993, 1995, 1999, and 2004. Figure 4 shows an the deposit removed from the steam generator 3 tubesheet hot leg by water lancing in 2004, after five years accumulation. Water lancing of all four steam generators is planned every four years in future.

2004 Before Water Lancing	2004 After Water Lancing
	

Figure 4: Hot Leg Tubesheet Deposits Before and After Water Lancing in 2004

- In 1995, a primary side mechanical clean of ~60% of tubes (8209) in all four steam generators removed a total deposit mass of 789kg. A second primary side clean of all four steam generators is planned during the 2008-09 refurbishment outage.
- In 1995, a secondary side high temperature chemical cleaning of all four steam generators was performed. Deposits were effectively removed from all surfaces; tubes were cleaned, almost all broached holes were completely cleaned, and only a small amount of hard sludge remained on the tubesheet. A total of 1236kg material was removed, including 70kg of phosphates and 54kg of other salt impurities. It should be noted that a copper step was not performed so residual copper may remain, particularly on carbon steel surfaces.

4.3 Repair and Replace

Repair or replacement of components is performed primarily to prevent tube failure (tube plugging), replace degraded components with a more corrosion resistant material or design, and to maintain component design function. The examples below have the added benefits of restoring lost thermal efficiency (divider plate), preventing loose parts (EWS header), and reducing corrosion product transport to the steam generators (secondary side piping).

- As discussed in section 3.3, steam generator internals that have experienced severe FAC (EWS header and primary side divider plate) have been replaced with a more corrosion resistant design. Subsequent inspections have shown no significant degradation of the replaced components.
- Between 1986 and 1990, secondary side carbon steel piping significantly affected by FAC was replaced. Those components with the highest FAC rates in the extraction steam, heater drains and vents, reheater steam, and steam drain systems were replaced with austenitic stainless steel or in a few cases, Cr-Mo steel.

4.4 Configuration Management

Configuration management of components is generally performed to identify and prevent its own damage and to maintain its own design function. The three examples given below also improve the protection of steam generator components against environmental cracking, debris fretting, and localized corrosion.

- Early 1990's – Restricted use of Pb-containing leak suppressants by selecting products low in Pb and also by controlling the use of excess leak suppressant.
- 1996 – Implemented steam generator foreign materials exclusion processes to monitor for loose parts and control foreign objects. The main elements are:
  - Increased visual inspection of secondary side internal components. Loose parts or foreign objects are removed unless it is shown by evaluation that these objects will not cause unacceptable tube damage or the tubes are removed from service.
  - A plant-wide foreign materials exclusion (FME) program was implemented. This program includes procedures to preclude the introduction of foreign objects into the primary or secondary side of the steam generators. The main elements of the program are increased awareness of maintenance staff, formal procedures to control access to open systems and equipment, cleanliness requirements, accountability of all materials and tooling used for maintenance inside the system, and accountability for components and parts removed from internals of systems.
- 1999 - Preventative maintenance on the condensers was increased to reduce the risk of seawater impurities and air ingress into the condensate water. This included:
  - Increased frequency and extent of condenser tube inspection and repair

- Improved the condenser tubesheet coating (SPECOAT) to protect it from corrosion and galvanic attack at the tube/tubesheet rolled joint
- Located and sealed likely sources of air leaks
- Increased frequency of condenser tube cleaning
- Upgraded condenser leak detection system to indicate condenser hotwell contamination
- Replacement of condensate extraction pump restriction bushings with lead free material

At PLGS, condenser leak searches and maintenance can be performed on-line by isolating condenser half shells. No significant condenser leaks have occurred since these improvements were implemented with the exception of occasional leakage in condenser CD01B from July 2005 until it was repaired January 2006.

4.5 Inspection

Figure 5 shows history of tube inspections. In response to the tube fretting and localized corrosion observed in the first decade of operation, tube inspection was substantially increased. 100% of tubes were inspected in 1999 and 2002. In 2006, a risk-based inspection program was introduced which focuses on regular inspection of highest risk tubes. These tubes were identified based on an understanding of the steam generator operating conditions and key factors driving degradation, and also from internal and external operating experience. At the same time, a risk-based inspection scope for the internal components was also implemented. As a result, for example, after 2006, inspection of the EWS header will decrease to levels that satisfy the minimum requirements of CSA N285.4-05, whereas inspection of the feedwater box and nozzles is raised in priority in upcoming outages.

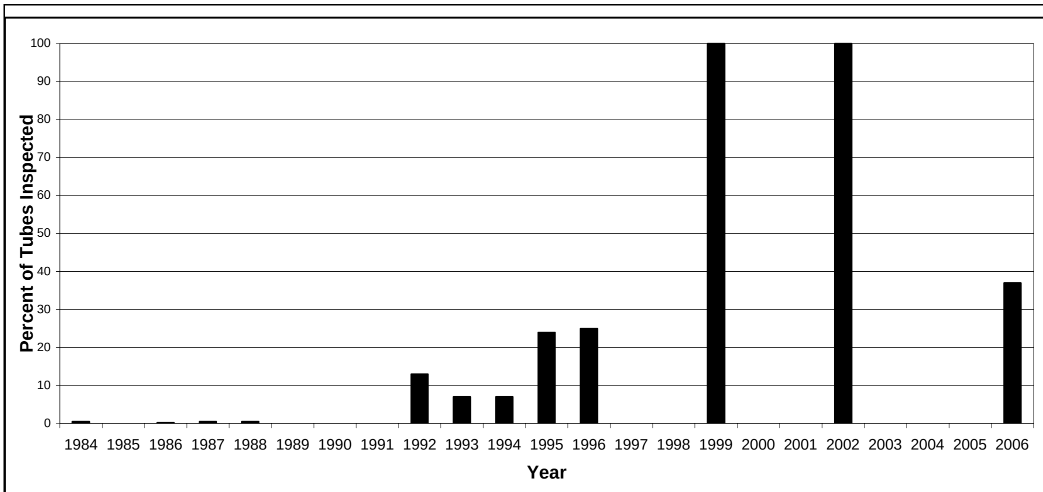


Figure 5: PLGS Steam Generator Tube Inspection History

5.0 RELATIONSHIP BETWEEN STEAM GENERATOR MANAGEMENT ACTIVITIES AND MATERIALS DEGRADATION

This section reviews the expected and credible steam generator degradation identified in section 2 and discusses how the incidence of observed degradation (section 3) has changed as a result of the management activities introduced at PLGS (section 4).

Flow accelerated corrosion of some carbon steel components is expected during normal operating conditions. Replacement of those with life-limiting degradation (EWS header, primary divider plate) with more resistant materials and design has been effective at preventing further FAC. For example, figure 3 shows the degraded condition of the original EWS header in 1996 after 13 years service. Inspection of the replaced headers in steam generators 2 and 4 in 2006 after 10 years service, showed no appreciable degradation. The condition of other steam generator components identified as susceptible to FAC is being monitored.

Fouling is also expected during normal operating conditions but several management activities have been successful at minimizing and removing secondary side deposit accumulation. Since 1995 when chemical cleaning practically restored the secondary side to its original condition (with the exception of a ~5cm hard core within the tubesheet sludge pile), several activities have been successful in preventing corrosion products from entering the steam generator and water lancing has been used to regularly remove those that have accumulated on the tubesheet.

The replacement of secondary carbon steel piping that was undergoing high FAC rates with corrosion resistant materials; improvements in pH control, and improved processes to prevent crud bursts and remove corrosion products from the feedwater have been effective at minimizing corrosion products entering the steam generators. Corrosion product sampling indicates that the concentration of iron in the final feedwater is about 2μg/kg under full power operating conditions and 40-60 μg/kg in blowdown. The mass of deposits removed during water lancing indicates that these activities have been effective at minimizing accumulation of deposits on the tubesheet. In 1995, ~10 kg was removed whereas in 1999 a total of only 1.1kg was removed from all four steam generators. In 2002, the total mass removed was even lower, 0.7kg. The sludge pile height is currently 40-50mm high, reduced from a maximum height of 200mm in 1987 prior to water lancing, and 80mm in 1995 prior to deposit removal activities.

Eddy current inspections of tubing and secondary side visual inspections indicate that the fouling rate of upper tube supports has also been reduced by these activities. Tube inspections in 2006 continue to show that broached hole blockage has not re-occurred. The visual inspection images in Figure 6 shows how clean the hot leg broached holes and upper tube supports were in 2004 and 2006, respectively, a decade after chemical cleaning.

Figure 6: Visual Inspection Images Showing Lack of Fouling in the Upper Bundle
Left) hot leg broached holes in support 9 in steam generator 3 in 2004
Right) U-bend scallop bar supports in steam generator 4 in 2006

As a result of the 1995 divider plate replacement and the primary and secondary side cleaning, the reactor inlet header temperature (RIHT) was reduced from 267.6ºC to 264ºC (4.4MPa boiler pressure). In the decade of operation since that time, the RIHT has only risen about 1ºC.

The tube plugging history illustrated in Figure 7 indicates a clear reduction in tube degradation since 1999. Pitting and phosphate-wastage has been practically arrested. There have been no tubes plugged because of localized corrosion since 1999 and eddy current results show for existing defects indicate minimal growth (~1% through-wall per year). This good performance is attributed mainly to the significant reduction in deposit loading since 1995, reductions in impurity ingress to the steam generators by elimination of condenser leaks, and suspension of phosphate chemistry. Condensate polishing and improved blowdown are also believed to contribute.

Following the debris-fret leaks in 1996, the risk associated with debris was reduced by implementing improvements to the steam generator foreign material exclusion program in 1996, by inspecting 100% of tubing in 1999 and plugging those at high risk of debris fretting, implementing a plant wide foreign material exclusion program and a more rigorous secondary side inspection and loose parts/foreign object removal program. Since 1999, there have been no additional tubes plugged because of debris. Figure 6 (right image) illustrates the effectiveness of video inspection to identify locations with foreign material.

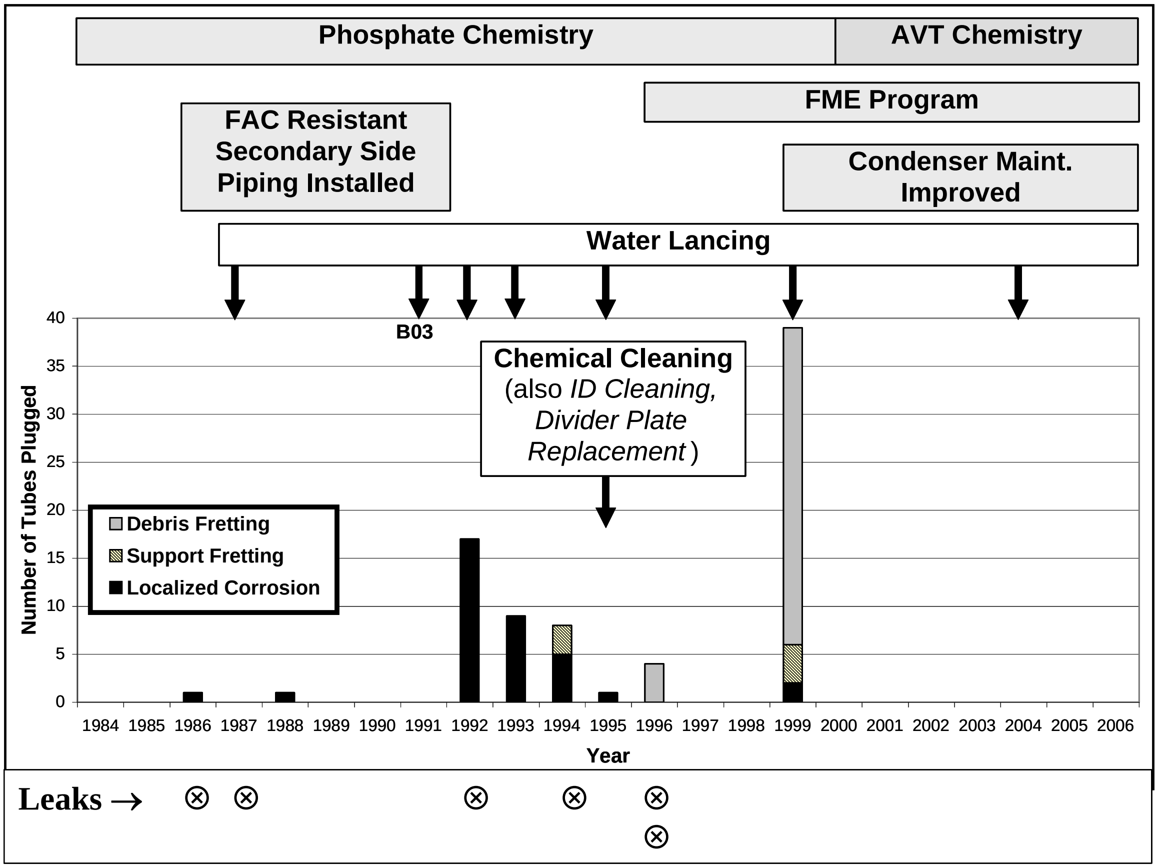


Figure 7: PLGS Steam Generator Tube Plugging and Management Activity History

6.0 CONCLUDING REMARKS

Selected maintenance activities have significantly reduced PLGS steam generator degradation and unplanned shutdowns. Localized corrosion and fretting of tubing has been practically arrested. Existing defects are growing at only ~1% through-wall per year and no new indications have been found. The management activities considered to have made the greatest improvements are feedwater impurity control (including condenser maintenance and chemistry control), suspension of phosphate chemistry, rigorous deposit management (including chemistry control, deposit removal, and replacing piping that generated corrosion products), and risk-based inspection of tubing and internal components.

Currently, the PLGS steam generators are in good condition. Good performance is expected to continue during post refurbishment operation with continued attention to the management activities described above and effective layup during refurbishment. As a result of external operating experience, NBPN is also paying attention to possibility of FAC of secondary separators and feedwater inlet/boxes, wastage of tie rods, and environmental cracking of tubing in tubesheet crevices.