MAINTENANCE AND LIFE ASSESSMENT OF STEAM GENERATORS AT EMBALSE NUCLEAR STATION

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ABSTRACT

The Embalse Nuclear Generating Station (ENGS) has four vertical I-800 U-tubes Steam Generators (SGs) manufactured by Babcock & Wilcox (B&W). They are one of the most important components from the point of view of safety and cost-related elements for potential life extensions in case of a replacement thereof. A Life Management program has been started covering the entire plant and starting with the Life Assessment (LA) of this component which consists in a systematic way to evaluate aging mechanisms focused on the plant refurbishment and life extension.

Because of this, maintenance-based ageing assessment from beginning of operation is analyzed and current LA-frame maintenance and inspections programs are carried out in order to maintain a high availability of the SGs. This will allow the planning for the plant life extension in the near future. The most important taken actions have been the Eddy Current (EC) In Service Inspection Program (ISI) which performs 100% of the tubes of two SG every 1.5 years started in 1992, the mechanical cleaning by blasting of the internal tube surface, the sludge removal from the secondary side tubesheet, the divider plate replacement, the installation of antivibration bars (AVB's), installation of TSP inspection ports and an exhaustive inspection of the secondary internals as a preliminary result of the LA.

The most relevant aging mechanism up to 2004 was the Flow Accelerated Corrosion (FAC) of U-bend supports and consequent fretting of tubes. The eddy current inspections allowed the fretting degradation to be detected and mitigated by installing AVB's. Currently, efficiency of this mitigating action is followed by vibration measurements and visual inspections. However, other degradation mechanism that could have origin due to the U-bend FAC like loose part damage (LPD) it is being analyzed since could be an issue in the future. At present, FAC degradation on the cold leg side and sludge deposition on the hot leg side of the carbon steel Tube Support Plates (TSP) are the main ageing issues at the point that SGs life extension could be compromised. During the LA-frame secondary side inspections of oct-nov 2005, many internals of SGs 2 and 4 were inspected for the first time and some important and minor degradation issues that are being assessed were found: possible crevice corrosion at the thermal plate-tube gap; incipient FAC at the steam separators and loose part/foreign object detection.

The results of the 2005 inspections and the conclusions of the TSP-related studies which include structural studies for accidents (Seismic and Steam Line Brake) and feed water chemical improvement to reduce FAC rate, will allow to complete the Life Assessment and the recommendations needed for refurbishment and life extension (repair/replacement of subcomponents, specific inspections, modifications of the In Service Inspection and Maintenance programs, etc)

The ENGS SGs shows a low percentage of exchange-surface area loss due to tube plugging, but they must be monitored continually and systematically if a life extension is intended. However, replacement-retubing options during the refurbishment outage should be being taken into consideration until the complete SG life prognosis is finished.

INTRODUCTION

As the Station reaches the end of its design life, the failures and problems resulting from aging may increase. In order to maintain a reliable, safe and economic operation of the plant, additional inspections must be performed and assessment of existing and new aging mechanisms must be carried out.

In this paper a general description of the SGs is presented. Then a summary of the most relevant aspects of the Embalse Steam Generator history (inspections, maintenance and design changes) is showed. A summary of the aging assessment performed up to date as well as the current state of the SGs Life Assessment is presented (additional inspections and their results) as well as the recommendations to preserve safe operation during the extended life. Finally, the conclusions related to the SGs operating experience and life prognosis related to the end of the design life and potential extension are included.

EMBALSE STEAM GENERATOR GENERAL DESCRIPTION

The Embalse SGs are B&W vertical-recirculating heat exchangers with alloy I-800 inverted U-tubes and internal preheater. The SGs uses the heat from the reactor to generate light water steam to move the turbine. The main parts of the SG are: the primary head, the tubesheet, the tube bundle, the preheater, the secondary side housing and the steam drum. In Figure 1 a general sketch of the SG is shown.

These have been designed pursuant to ASME Code Section III Class I to produce approximately 1033 kg/sec of dry steam. The designed circulation ratio (flow of total upwards mass in the tube bundle divided by the steam flow) is 5.9.

A summary of relevant SGs dimensional, materials and operational data is presented in Table 1.

Figure 1: Embalse SG Sketch

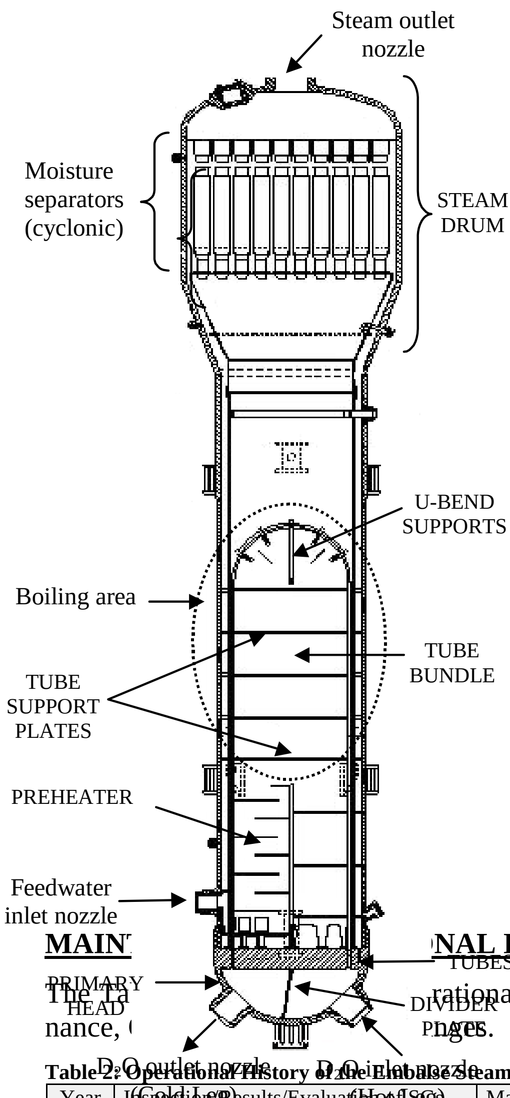


Table 1: Embalse SG characteristics

Dimensions	
Total Heat Exchange-Surface Area	2750 m^2
Number of Tubes (at initial operation)	3542
Tube Inner and Outer Diameter	15,87 / 13.67 mm
Tubesheet Diameter	2.76 m
Steam Drum Diameter	4 m
Steam Drum Length	6.35 m
Materials	
U-Tube Bundle	SB-163 Ni Cr Fe Alloy 800
Divider Plate	SA-516-Gr 70 (carbon steel)
Tubesheet	SA-508-C1 2 (carbon steel)
Tubesheet cladding	Alloy 600
Primary Head, Shell, Steam Drum.	SA-516-Gr 70 (carbon steel)
Tube Support Plates, Shroud.	SA-515-Gr 70 (carbon steel)
Drum Internals	SA-36 (carbon steel)
Nozzles	SA-541-C1 3 (carbon steel)
Design Operational Parameters	
Steam Flow Rate	1033 kg/sec
Steam Pressure at Outlet Nozzle	4.69 MPa
Steam Temperature at Outlet Nozzle	260 ºC
Feedwater Flow Rate	1033 kg/sec
Feedwater Inlet Temperature	157 ºC
Feedwater Pressure	4.826 MPa
D_2O Flow Rate	758 kg/sec
D_2O Inlet Temperature	309 ºC
D_2O Quality (by wt.) at Inlet	4.4 %
D_2O Inlet Pressure	9.88 MPa
D_2O Outlet Temperature	266.6 ºC
D_2O Outlet Pressure	9.63 MPa
Circulation Ratio	5 (min)
Continuous Purge Rate	1 kg/sec
Steam Quality	0.25 % (max)
Total Heat Transferred (4 SGs)	2061 Mwt

MAIN… NAL HISTORY SUMARY OF EMBALSE SG

The Ta… rational history of the Embalse SGs related to Inspections, Maintenance, … nges.

Table 2: Operational History of the Embalse Steam Generators

Year	Inspection/Results/Evaluation of SGs related issues	Maintenance SGs related actions	Operation SGs related issues	Design Changes SGs related actions

1980	Deformations in the tubes (DINGS) after the manufacturing thermal treatment by induced currents			Several Design changes during rebuilding. Re-placement of whole tube bundle
1983	In Service Inspection Program (ISI): - EC for 10% of the tubes in a SG of each unit every 5 years - Tube removal from a SG for metallur-gical examination once every 5 years - Welded joints and external supports inspection		Chemistry Design Manual: AVT: $pH_{25ºC}$ specified for secondary side 9,2 – 9,5 (morpholine controlled)	
1986	Tube removal from SG#3	Tube plugging due to leak in SG#3	Cold down & restart due to SG leak	
1987		Tube plugging due to leak in SG#2	Cold down & restart due to SG leak	
1991	First EC U-bend defects signals in SG#1	Tube plugging due to leak in SG#3	Cold down & restart due to SG leak	
1992	- Tube removal from SG#4 - In Service Inspection Program: EC inspection of 100% of the tubes every 3 years	Tube plugging due to leak in SG#1	Cold down & restart due to SG leak	
1995	Detection of superficial cracks in the anti-seismic lateral supports			
1996	Signs of rapid U-bend tube fretting degradation start to appear	Tube plugging due to leak in SG#2 & SG#3	Cold down & restart due to SG leak (twice)	
1997				Tubesheet inspec-tion port installation
1998	ISI Program: - Addition of Divider Plate visual inspection	Tube plugging due to leak in SG#3	Cold down & restart due to SG leak	
1999	- Sustained increase in PHTS inlet header temperature - Loss of heat transfer efficiency		- Secondary side pressure reduction (1 Kg/cm2) - Temperature reduction of the primary coolant at the reactor inlet header (1ºC)	
2000		Blasting cleaning of SG inner tube surface (SIVABLAST)	- Secondary side pressure recovery (1 Kg/cm2) - Temperature reduction of the primary coolant at the reactor inlet header (4ºC)	
2001		Tube plugging due to leak in SG#3	Cold down & restart due to SG leak	
2002	- Confirmation of U-bend supports FAC degradation and tube fretting - Sings of erosion at the gaps in the segmented divider plates - Sustained increase of the sludge pile above the tube sheet	- Increasing rate of tube plugging after an ISI EC inspection during a planned outage due to fretting in SG#1 & SG#3 - Tubesheet lancing mechanical cleaning	- Temperature reduction of the primary coolant at the reactor inlet header (3ºC)	Divider Plate re-placement
2003		Tube plugging due to leak in SG#1 & SG#2	Cold down & restart due to SG leak (twice)	
2004	Detection of Tube Support Plate FAC degradation at support 14C		$pH_{25ºC}$ specified for secondary side 9,5 – 9,6 due to U-bend support FAC degradation	Auxiliary U-bend support installation (antivibration bars)
2005	- Detection of Tube Support Plate FAC degradation at lower support plates in all SGs - History review of EC TSPs signals - Tube removal from SG#3 - Additional inspections of internals (Life Assessment frame inspections)			Tube Support Plate inspection port installation
2006	- TSP integrity evaluation (FIV analysis, seismic analysis, main steam line brake analysis)	Tube plugging due to leak in SG#1	- Cold down & restart due to SG leak - $pH_{25ºC}$ specified for secondary side 9,6 – 9,8 due to TSP FAC degradation	

MAINTENANCE-BASED AGEING ASSESSMENT

Aging Assessment has always been managed through the Maintenance Programs (Maintenance-based Ageing Assessment) at ENGS since the start of operation. In the following sections the main maintenance-related issues are presented.

Loss of heat transfer efficiency

Any reduction in SG thermal performance is reflected by an increase in the average temperature of the PHT system and in particular, an increase in the Reactor Inlet Header (RIH) temperature. Loss of heat transfer efficiency at Embalse SGs was caused mainly by three separate aging mechanisms which are described in the following paragraphs, *tube surfaces Fouling* (inner and outer), the pass trough between legs of primary coolant due to *erosion of the divider plates* (old design) and the *tubesheet sludge pile accumulation*.

The *fouling on the tube surfaces* is produced by the transport of corrosion products from systems of both circuits (primary and secondary) which concentrates in SGs and deposits on the tube surfaces because the temperature conditions. Due to the sustained increase in the temperature of the primary coolant at the reactor inlet header because of PHTS aging, the operative trips margins are reduced with regard to the initial design conditions. To recover the initial design trip margins the SGs operating pressure was reduced in 1999 in order to diminish the coolant's temperature at the outlet so that the station could get to the 2000 scheduled outage without exceeding the temperature limit of 270ºC. The pressure was reduced by 1 kg/cm^2, thus obtaining a temperature reduction of approximately 1ºC (Figure 2). During the 2000 scheduled outage the internal cleaning of the SGs tubes was performed using the system designed by SIEMENS called SIVABLAST. It consisted of blasting the tube inner surface, with 0.2 mm diameter stainless steel balls with air at a pressure of 6 kg/cm^2 through the injection nozzles. The amount of magnetite removed was 2,602 kg from 10,387 blasted tubes. After the start-up of the station it was observed that the thermal-hydraulic conditions of the Primary Heat Transport system appreciably improved and that the live steam pressure that had been reduced previously could be normalized. The reactor inlet temperature decreased approximately 4.5ºC (Figure 2), the PHTS flow increased 4% and the steam quality at the channels outlet dropped from 3% to 1.3%.

To assess *erosion of the divider plates*, during the 2002 scheduled outage the divider plate replacement in the four Embalse SGs was performed. The existing plates formed by 13 bolted segments, bolted and fixed to the head, were dismantled and a new one made up of 4 segments was installed and welded in-situ, forming finally one single floating piece convex towards the hot side. Three main improvements were attained:

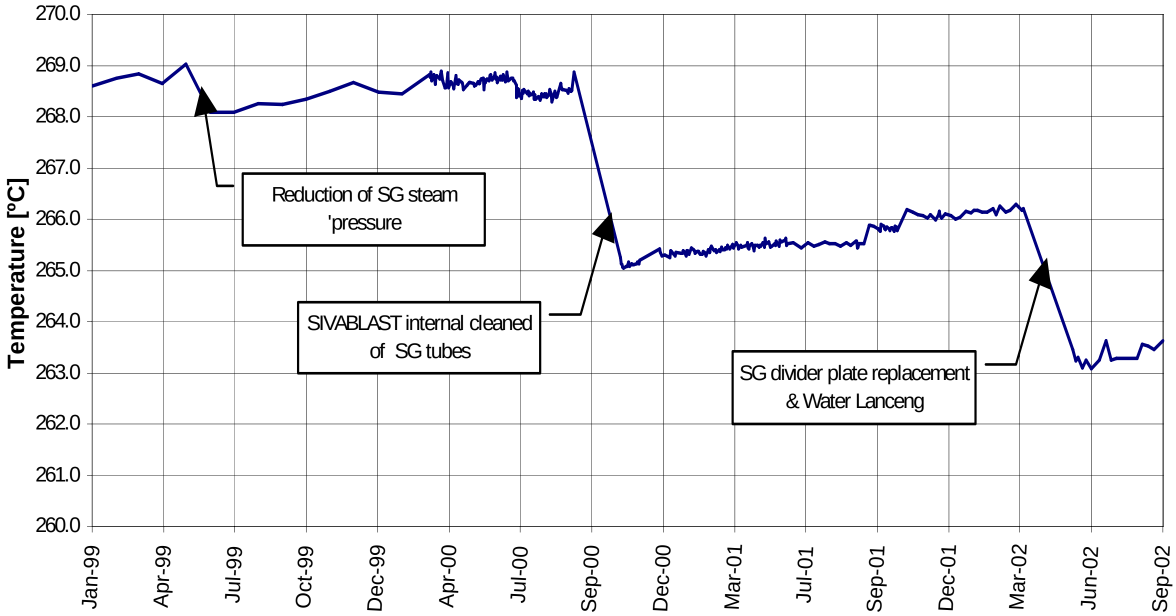
- The undesired passage of water between the cold and hot legs and through the existing tracks between plates and bolts joints produced by erosion was eliminated, thus obtaining a substantial improvement of the heat transfer efficiency and a decrease of the primary coolant temperature at the RIH of about 3ºC jointly with the tubesheet waterlancing activity (Figure 2)
- A better coverage of the trip is attained in the slow loss of regulation events. The lowering of the RIH temperature and quality at the outlet of the channels makes more difficult to reach the critical channel power at the moment of shutdown system trip due to high neutron power.
- The probability of loose parts due to a detachment of components of the segmented DP caused by erosion corrosion was minimized.

The *tubesheet sludge pile accumulation* was detected in the Embalse SGs secondary side from the eddy current inspections of tubes. The sludge pile reached approximately 38 cm high above the tubesheet in the center of the hot leg. The presence of this sludge has several negative effects for the plant. Among these, the more important ones are the tube outer surface corrosion that could occur in this area and the loss of the SGs efficiency.

These sludge piles were eliminated almost completely by means of a tubesheet inspection port installation in 1997 and the thereafter mechanical cleaning with pressurized water jets "Waterlancing" performed during the 2002 scheduled outage. About 320 Kg of sludge were removed (wet weight). After washing, visual inspections were carried out to determine the level of remaining sludge. In SG#2 and #4 localized piles less than 2" high remained, and in SG#1 and SG#3 only flakes were observed in the places where supposedly the pile was located, but no other accumulation of sludge in the tubesheet was detected. The tasks were performed and supervised by B&W the coordination of works was carried out by NASA along with the rest of the activities on the SGs.

The tubesheet sludge pile accumulation is currently included in the In Service Inspection Program for monitoring.

Figure 2: Average Reactor Inlet Header Temperature



Micro cracks in lateral supports welded joints

During the 1995 scheduled outage the presence of superficial cracks in the anti-seismic lateral supports of the SGs was confirmed and they underwent a further careful examination. During the 1998 and 2000 scheduled outages these defects were again inspected by means of the particle technique. Then they were ground and the cracks did not reappear. A root cause and fracture mechanics studies were performed and the following observations were pointed:

i) The problem was probably caused by a combination of a deficiency in the welding process as well as in the material selection. The low alloy steels with low contents of elements that increase the resistance, as the one used in the supports (ASTM A-508 GR II), are susceptible to the two phenomena that may have originated the intergranular micro cracks. These two phenomena are the stress relieve cracking which is generated in the coarse grain heat-affected zone (HAZ) during the post-welding thermal treatment, or the cold cracking caused by hydrogen that enters during the welding.

ii) The fracture mechanics study performed confirms that the defects could not propagate by fatigue unless due to a very large number of cycles.

The cracks of lateral supports are currently included in the In Service Inspection Program for inspection and tracking.

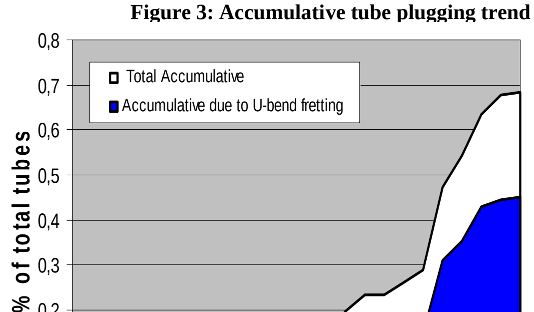
Flow-Accelerated Corrosion (FAC) of Supports and Tube fretting at the U-bend

The first signs of U-bend defects on tubes were detected by EC inspections in 1991 in SG#1 but rapid fretting damage in the cold leg side of the U-bend region has been experienced by SG#1 and SG#3 since 1996. The fretting damage is the main cause of tube plugging and has caused several tube leaks and forced outages (Table 3 and Figure 3)

Table 3: Current state of Embalse SG tube plugging

	PRE SERVICE	REMOVED	LEAKS	PREVENTIVE		TOTAL
				Other	U-bend fretting	
SG#1	-	-	3	5	22	**30**
SG#2	-	-	3	12	9	**24**

Figure 3: Accumulative tube plugging trend



SG#3	1	2	5	1	26	**35**
SG#4	-	1	-	-	7	**8**
TOTAL	**1**	**3**	**11**	**19**	**64**	**97**

*Removed after plugged

The root cause of the U-bend fretting damage was the FAC degradation of the cold leg side U-bend supports (scallop bars) The corroded supports cause wear in two ways:

- The openings around the tubes in the scallop bars are enlarged, the tube to support clearance increases, reducing the effectiveness of the support. As a result the tube vibrates, causing wear.
- If corrosion of the scallop bars is very severe, the bars brakes at the ligaments (Figure 4). The broken bar may have a sharp edge that contacts the tube causing a small deep fret.

Figure 4: Broken scallop bar

The main factors affecting FAC rates in the SGs were:

i) *Material Composition*: FAC rates are reduced in materials containing chromium, and to a lesser extent, Molybdenum. Scallop bars are made of plain carbon steel.

ii) *Water Chemistry*: FAC rates are generally reduced at high pH levels (within the typical SG operating range), and increase when there is very little oxygen or aggressive scavenging (high hydrazine). In ENGS the upper limit for the feedtrain pH range is limited because of the brass of the tube condenser material.

iii) *Flow Fields*: FAC is larger in regions where there is a disruption of the flow (and the resulting high turbulence), such as turns or obstructions. The U-bend support of the Embalse SGs has a complex geometry and then the susceptibility to create high turbulence regions.

Two strategies to mitigate the U-bend supports FAC and tube fretting were taken:

- Increasing the specified pH value for the secondary side water chemistry to the range 9.5-9.6 in order to arrest the FAC. Studies in this matter (Ref. 1) were requested to the National Nuclear Energy Commission (CNEA) in 2002 and were implemented in 2004 (see Table 2)
- Restrain the vibration of tubes by adding additional supports at the U-bend (antivibration bars).

The *antivibration bars* (AVBs) were installed in the four SGs during the 2004 scheduled outage. Each auxiliary support consists in flat bars (AVBs) inserted between the tube lanes and mounted on a slotted bar which is fixed to the existing tie rods. Each SG has three auxiliary supports at the U-bend, two on the cold leg side and one on the hot leg side.

The efficiency of the new supports is currently being monitored by vibration measurements on the shell of the SGs at the U-bend height and by tracking of tube plugging. Currently, vibration condition was reduced by 40% in average and an incipient decrease of the exchange-surface area loss rate due to U-bend degradation tube plugging in SG#1 has been detected (Figure 11)

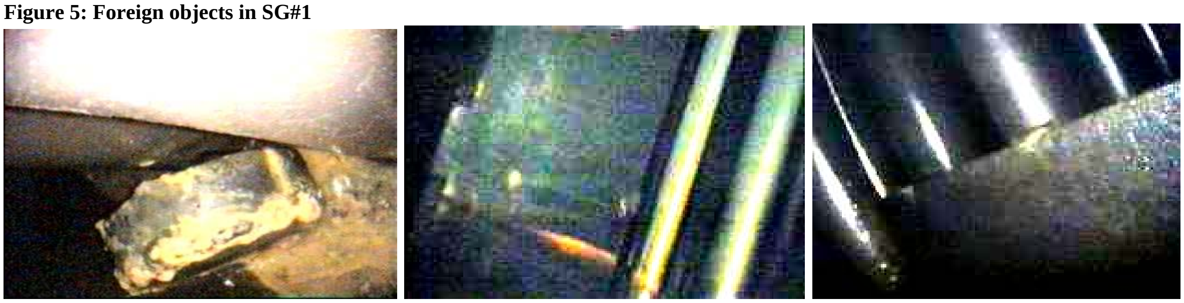
Foreign Object Damage (FOD)

After 20 years of operation just two cases of FOD only in SG#1 have been confirmed.
The first sign of FOD (that was later confirmed) was detected during the ISI of 2002 scheduled outage when the tube X48-Y07 in SG#1 had to be preventively plugged because an EC indication

of 74% on the cold leg side near the tubesheet appeared and developed during a three years operation period. Later on in 2004 an indication in tube X51-Y06 also on the cold leg near the tubesheet was detected and still being monitored. The LA-frame visual inspections performed in 2005 (described in later section) confirmed that those indications were caused by a foreign object deposited on the cold leg side of the tubesheet adjacent to tubes X17-Y24 and X51-Y06 (Figure 5, a) At present the origin of the object is unknown and actions have been taken to extract the object during the next scheduled outage.

The second confirmed case occurred in 2003 when the plant had to be shut down because a leak in SG#1. The damaged was in tube X03-Y56 and the EC inspection detected the defect on the hot leg side near the tubesheet, also tubes X02-Y57 and X02-Y55 were preventively plugged due to indications in the same region. Visual inspections performed in 2004 confirmed a metal-sheet-type foreign object of about 8”x 8”x1/8” jammed between the damaged tubes (Figure 5, b and c). At present the origin of the object is also unknown and an extraction procedure that will be implemented in the next scheduled outage has been developed. Because its size, extraction of this object is complicated because requires cutting-off operation inside the SG but is no urgent because it seems to be stacked between plugged tubes only.

Figure 5: Foreign objects in SG#1



a) **b)** **c)**

There are more EC indications of possible FOD that remain unanalyzed (mainly on the feedwater region of the SGs) and were not yet assessed due to unavailability of access for visual inspections.

The LA-frame additional visual inspections (explained in a later section) are trying to cover these indications that remain unassisted.

It is also believed that loose part damage (LPD) from the U-bend degradation and TSP FAC (next section) could be an issue in the near future, but at present no damage has been confirmed due to this phenomenon.

TSP FAC degradation and fouling

During the scheduled outage of 2004 visual inspection of the U-bend region of the four SGs was performed after the AVBs installation in order to detect any foreign object from the activity. Because of TSP FAC degradation noticed trough COG, an unplanned visual inspection of the upper TSP (14C-22H) was carried out. The results showed signs of advanced FAC degradation and even ligament breach on the periphery of the Cold Leg side (Figure 6)

In early 2005 the SGs Life Assessment was initiated. Knowing that the life extension of SGs could be compromised, the following activities focused on TSP FAC degradation were performed for the scheduled outage of 2005:

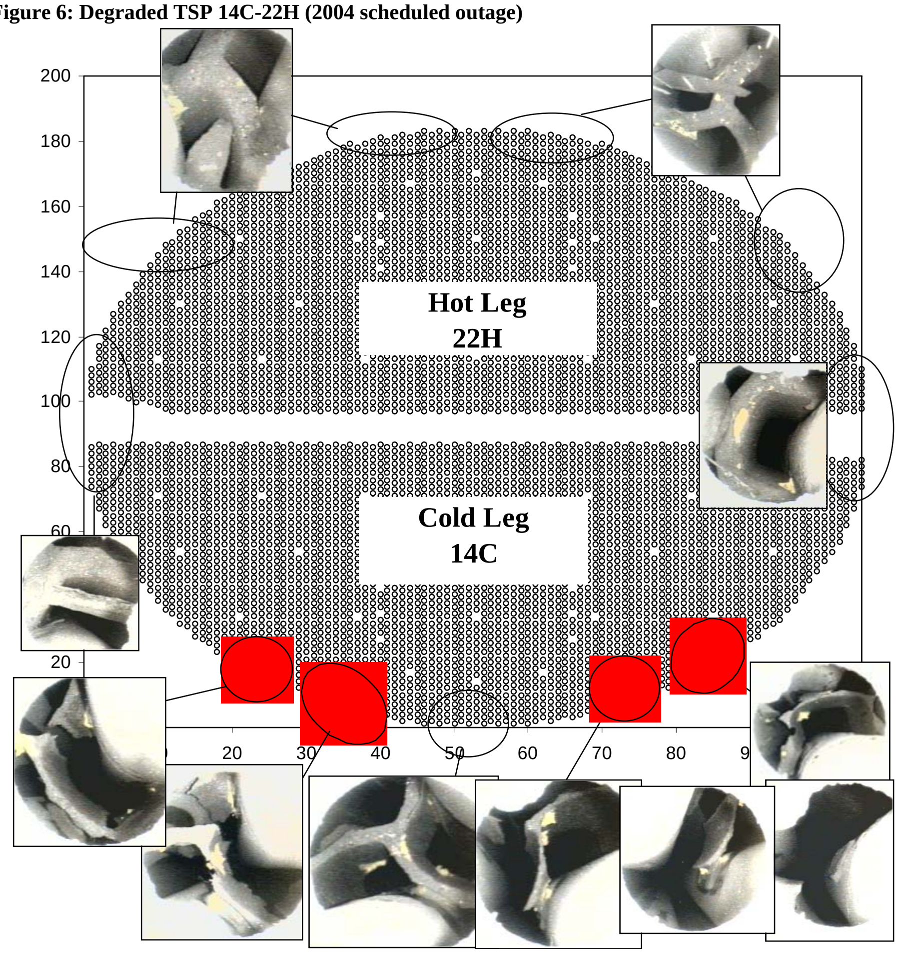
- *TSP Inspection port installation*: non reinforced inspection ports were installed on the shell to permit the access to most of TSPs (Figure 7)
- *TSP visual inspections*: in all SGs TSPs 14C-22H, 13C-23H, 12C-24H, 11C-25H, 10C-26H and 09C-27H were inspected through the new ports. TSPs 29H in all SGs were inspected through the tubesheet inspection port.
- *100% EC inspections for SG#1 and SG#3*: this activity was planned according to the existing In Service Inspection Program but the results were later used for the TSP FAC assessment.

- *EC-FAC related historical data evaluation*: available EC inspection data were analyzed and the TSPs FAC maps were obtained for all SGs.

The inspections showed that the TSPs are degraded. In particular, the ligaments between the broach plates are thinned and in some cases breached in the cold leg region (Figure 8 a, b and c). Material is missing from the TSPs, particularly at supports 14C (most severe degradation), 13C, 12C, 11C, and 10C (progressively less degraded). The TSP conditions in terms of thinning and breaching has been characterized jointly by Atomic Energy of Canada Limited (AECL) and NASA from the EC data (Ref. 2).

At the same time, fouling deposits were observed on the hot leg TSPs. At some locations, sufficient deposits were present to classify the broach holes to be partially or completely blocked, e.g., in supports 29H, 27H, 26H, 25H, and 24H (Figure 8 d, e and f).

Figure 6: Degraded TSP 14C-22H (2004 scheduled outage)



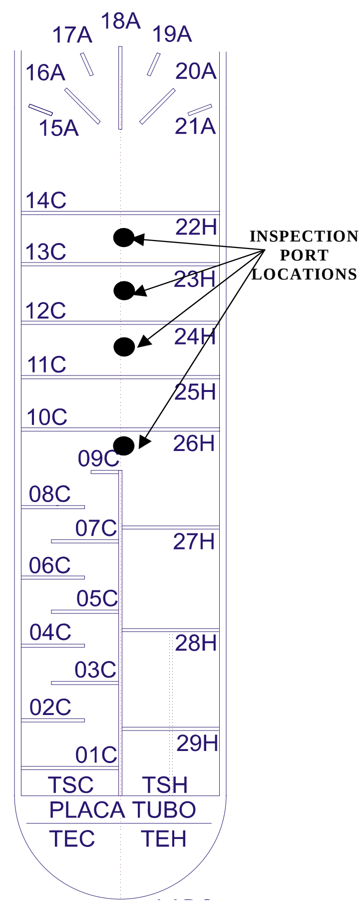


Figure 7: TSP inspection ports Locations (2005 scheduled outage9

To assure the safe operation of SGs, a set of engineering analysis were requested to AECL including: *TSPs Condition Assessment, Thermal hydraulic Analysis, Steam Generator Fretting and Fatigue Analysis, TSPs Seismic Analysis, Root Cause Analysis of the TSP FAC Degradation* and the *TSP Life Assessment*. Most of these studies are under development and review but some preliminary conclusions can already be analyzed in the following paragraphs.

Again, as we mentioned for the U-band FAC case, the three factors for FAC to occur were analyzed for root cause identification (Ref. 3):

i) *Susceptible material:* broach plates of carbon steel with low but not negligible Cr content of 0.07 to 0.08 mass % Cr.

ii) *Water chemistry conducive to FAC*: Specification for the pH-controlling amine concentration was low; MPH, the amine used for pH control is suboptimal (another amine could provide a higher pH_T in the SG);

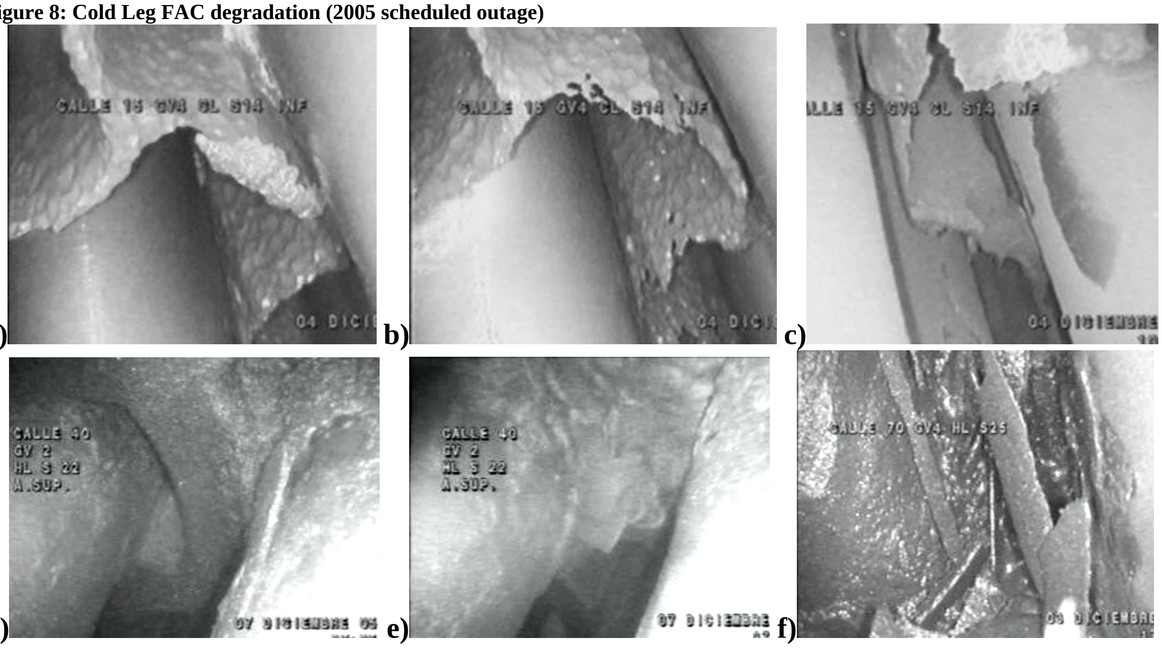
iii) *Suitable thermo-hydraulic conditions*: relatively high flow velocity on the SG cold leg, caused by a partial blockage of the broach holes by fouling deposits at the SG hot leg, due to heavy localized fouling of TSPs.

At present urgent corrective actions to assess TSPs FAC in order to keep safe operation and minimize degradation up to the end of the design life are being to be implemented and considered:

- Increase pH_T in the SGs by increasing the concentration of morpholine in the SG final feedwater to about 20 mg/kg in order to operate as close to the upper end of the specified $pH_{25ºC}$ concentration range of 9.6-9.8 has been implemented from early 2006 (see Table 2)
- Clean the SG deposits blocking the broach holes on the SG hot leg during the next scheduled outage.
- Use ethanolamine (ETA) in place of morpholine (MPH) for steam-cycle pH control is planned for early next year.
- Ensure that no significant amount of any acid forming anion is present in the SG blowdown.
- Ensure that cation conductivity in the SG blowdown does not exceed 0.2 mS/m at any time. Monitor the cation conductivity continuously using an on-line monitor.

Because of this degradation mechanism is compromising the life extension of the Embalse SGs other actions are being considered regarding TSP FAC degradation from the point of view of Life Assessment (explained in following section)

Figure 8: Cold Leg FAC degradation (2005 scheduled outage)



a) b) c) d) e) f)

STEAM GENERATORS LIFE ASSESSMENT

The end of the design life for ENGS is foreseen for beginning 2011 based on the fuel channel creep limitation. However, a political decision about the intention for a Life Extension has been taken and a possibility of increase power in about 5% is under study. During the first part of a Life Extension Project, the aging mechanisms of components will be assessed and a remaining service life prognosis has to be determined in order to assure the ability to perform their functions safely and economically during a determined period of time.

In year 2002 a systematic Aging Assessment of the SGs and some other components according to IAEA guidance recommendations (Ref. 4) was initiated. Later on in early 2005, the first part of a more detailed study began following the methodology given by AECL (Ref. 5) named Life Assessment (LA), in which the work previously done matched very well. These two stages have permitted to understand and give a more thorough treatment to the aging mechanisms existing from the beginning of operation and allow an early detection of the recently discovered ageing effects, aiming to the life extension.

A Plant Life Extension Project (PLEX), in its first stage, involves the performance of aging assessment studies of the *Systems-Structures-Components* (SSC). These studies are executed to define the lifetime of the SSC, as well as the modifications and recommendations required to allow an economic and safely operation conditions within of the Plant extension life (Ref. 6) These studies use different methods of systematic analysis like the *Life Assessment* (LA) for an early detection of the aging consequences on the SSC and the optimization of its performance for the extended life. In following sections the LA process used for Embalse SGs is shown.

Gathering of information

The Life Assessment of Embalse SGs began in 2005. During the first part of the study a collection of information was performed, this included a documentation revision related to:

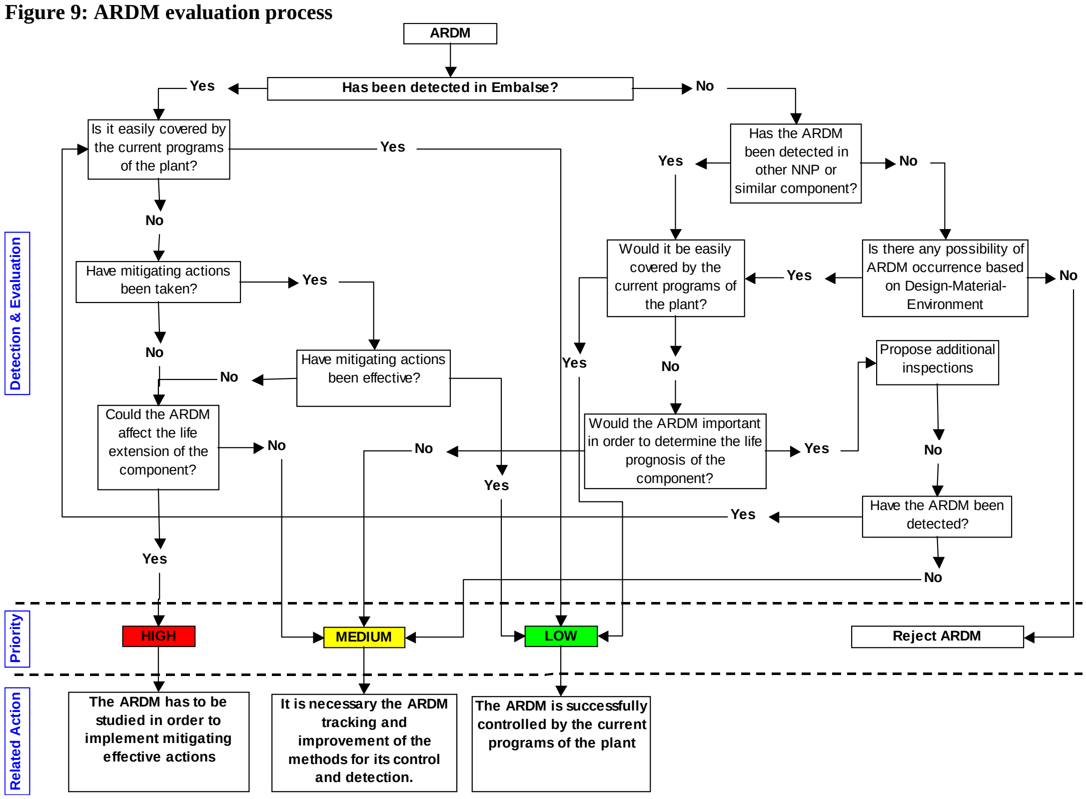
- Design requirements (codes, specifications, functions, design changes)
- Operational history (chemistry control, events, transients)
- Maintenance and Inspections (Corrective-Preventive-Predictive maintenances, inspections programs)

Age-Related Degradation Mechanism evaluation

Based on the world experience and the previous maintenance-based aging assessment analysis performed at ENGS, all the possible (ARDM) for the SGs were defined and an evaluation according to the ENGS Maintenance-Inspection Programs was performed. This permitted to define a priority for each ARDM in order to focus the corrective actions and recommendations in those that the effects could compromise the life of the SGs. The ARDM evaluation process is showed in the flow chart of Figure 9.

As a result of the first stage of this process additional inspections were proposed and implemented during the 2005 scheduled outage, the most relevant findings are presented in the following section.

Figure 9: ARDM evaluation process



LA-frame additional inspections (2005 scheduled outage)

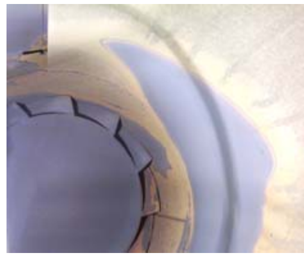
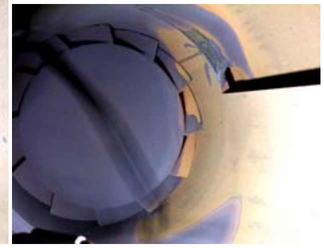
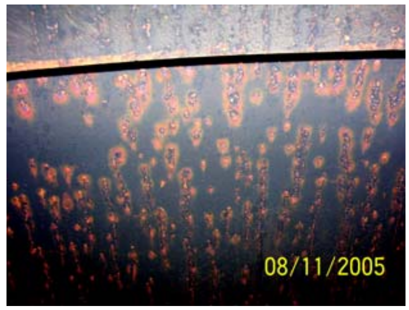
As a partial result of the process from Figure 9 additional inspection plans of many sub-components were proposed and some of them implemented during the 2005 scheduled outage. Into the scope of the inspection plans the following sub-components were included:

- *Primary side:* tube plugs welds, divider plate joint welds and components, tubesheet cladding, primary head inner surface.
- *Secondary side:* cyclonic moist separators, upper and lower deck components, U-bend region and components, shroud, down comer annulus, tube support plates, tubesheet, feedwater header (outer surface), and thermal plate.
- *External sub-components:* shell, welds, supports.

The most important findings are summarized in Table 4.

Table 4: Major findings of the LA-frame additional inspections (2005 scheduled outage)

ARDM	Comment on corrective actions	Morphology
Pore indication in an old tube plug weld	A 100% of the tube plug welds are being included for leak inspection and monitoring.	
Possible corrosion at the thermal plate-tube gap	In depth X-probe EC inspections are planned for the next scheduled outage in order to determine if there is any degradation on the tube surface.	
Foreign object damage at tubesheet level	Extraction is planned for the next outage and to include a Foreign Object Exclusion program in the ISI is recommended in the SG LA report.	Figure 5, a

ARDM	Comment on corrective actions	Morphology
Possible FAC in primary cyclones	Thickness measurements and metallographic surface characterization are planned for the next outage in order to identify the degradation.	 
Possible pitting at the EWS header level region	This ARDM doesn't seem to be a critical issue, but samples for chemical composition analysis have been taken anyway.	 

The ARDM matrix

The result of the ARDM evaluation process (Figure 9) is shown in Table 5and it represents the current state of the Embalse SGs from the point of view of ageing.

Table 5: Embalse SGs ARDM matrix

ARDM Matrix	General Corrosion	Pitting	Crevice Corrosion	SCC	FAC	Fretting	Denting	Fatigue	FOD/LPD	IGA	Fouling	Gasket Face Damage	Welds defects
Tubes		**B**	**M**	**B**		**A**[1]	**B**	**M**	**A**[2]		**M**		**M**
Old tube plugs													**M**
Tubesheet									**M**		**M**		
TSPs					**A**[3]				**A**[7]		**A**[4]		
Preheater Baffle Plates					**M**						**M**		
Thermal Plate			**M**		**M**				**M**		**M**		
U-bend Supports (Scallop Bars)					**A**[5]				**A**[6]				
Shell	**M**							**B**					
Tie Rods	**M**				**M**								
Primary Head									**M**				
Divider Plate (primary side)									**M**				**B**
Feedwater Header Region & Thermal Sleeve			**M**		**M**			**B**	**M**				
EWS Header		**B**			**M**								
Cyclonic Moist Separators (primary & secondary)					**M**								
Column Support	**B**							**B**					**B**
Lateral Supports	**B**							**M**					**B**
Back-up Supports	**M**												
Manways (primary side)								**B**				**M**	
Manway (secondary side)								**B**				**M**	
TSP Inspection Ports												**M**	
Angle Tubesheet Inspection Ports								**B**				**M**	**B**
Tubesheet Inspection Ports (Waterlancing)												**M**	
D_2O inlet and outlet nozzles								**B**					**B**
Main Steam Outlet Nozzle								**B**					**B**
Small Nozzles												**M**	

[1]Fretting of tubes at the U-bend still occurring but in minor degree (see Life Prognosis section) and is about to switch from **A** to **M.**

[2]A global Foreign Object Exclusion still incomplete and a risk of tube damage and plant unavailability still remind.

[3]Some of the major corrective actions have been implemented but no effectiveness has been confirmed yet.

[4]TSP broached holes cleaning has not been performed yet.

[5]Corrective actions are related to note ([3])

[6 & 7] There is some signs that Loos Part Damage (LPD) could be occurring due to the broken scallop bars and TSPs but has not been confirmed yet, if not, this could be an issue in the near future.

The SGs Life Prognosis

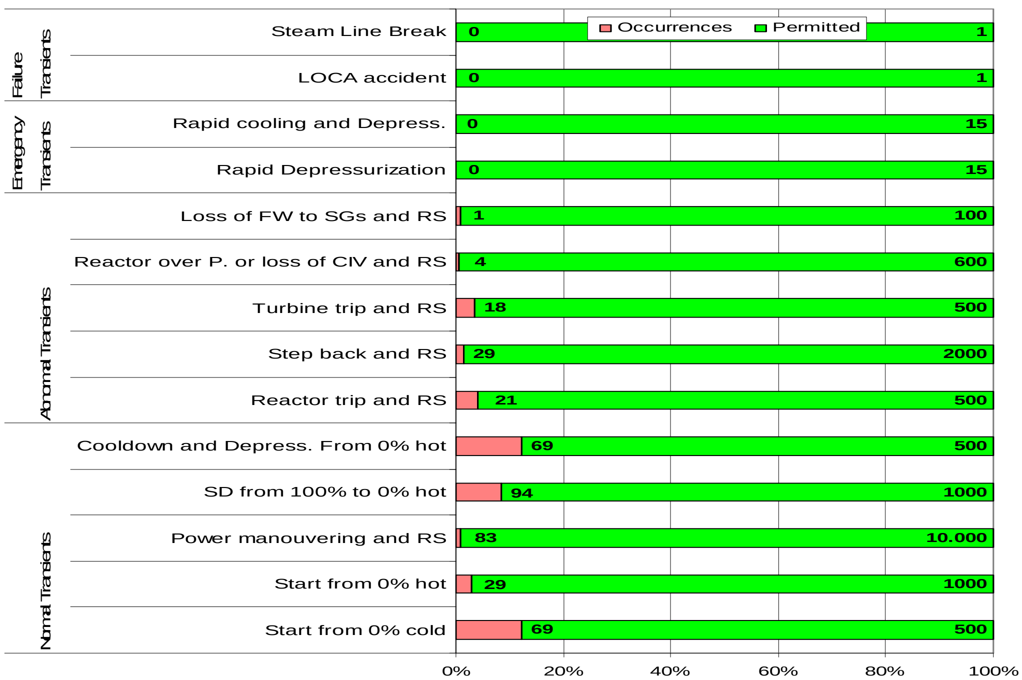
There are two main aspects that are being considered in order to estimate the life prognosis of the SGs, the *design-based degradation issues* (operating transients and loss of the pressure limit boundary), and the *loss of surface-exchange area and consequent efficiency loss caused by ARDMs* (ageing-related degradation mechanisms that are out of design)

The rate of pressure limit boundary loss cannot be accurately determined because no periodic shell thickness measurements were taken, but some shell thickness measurements performed during the TSP inspection port installation showed values even higher than the design nominal thickness. Some additional thickness measurements are recommended but it is concluded that the pressure limit boundary loss due to general corrosion will be neither a design-life limiting nor life-extension limiting.

The permitted operating transients is another limit for SG life-extension even design-life attainment. Embalse SGs transients have always been tracked and there is no evidence that this could be a limitation for the extended life operation. Figure 10 shows a comparison between the occurred operating transients and the specified permitted transients.

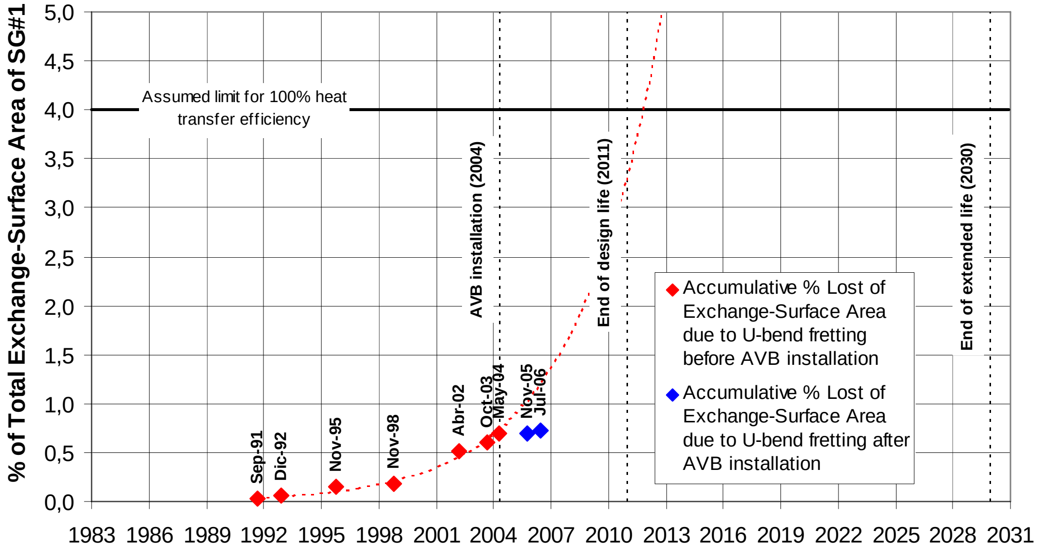
The ageing-related degradation mechanisms that are out of design and affect in some way the exchange-surface area are currently the most concerning SGs life limiting.

Figure 10: Comparison between the occurred operating transients and the specified permitted transients.



The scallop bar FAC and tube fretting at the U-bend is one of the important ARDM that caused most of the tube plugging. The exchange-surface area loss due to this mechanism has been tracked, and showed a critical rate from the point of view of life extension in SG#1 (Figure 11). Fortunately since the corrective action has been implemented (AVB installation) an average improvement of 40% of the vibration condition has been obtained and an incipient decrease of the exchange-surface area loss rate has been detected in SG#1(Figure 11) It is preliminary concluded that the rate will still decrease allowing to postulate that this ARDM wouldn't be a life-extension limiting. Have to be taken into account that Loose Part Damage due to broken scallop bars could compromise this conclusion if it becomes an issue and more EC inspections have to be performed before to confirm the mitigation of the U-bend fretting.

Figure 11: Tube U-bend fretting evolution in SG#1



The TSPs FAC degradation is with no doubt the most critical ARDM at the moment and is compromising the SGs life extension. Some water chemistry-related corrective actions have been already taken and some others (broached hole cleaning) will be implemented in the next outage, but more EC inspection data related to TSPs FAC have to be determined in order to estimate the FAC rate, then to perform an accurate life prognosis and the corrective actions effectiveness determination. Studies recently performed by AECL (Ref. 3) states that altogether, implementation of these corrective actions is expected to result in an approximately up to threefold reduction of the FAC rate at the cold leg compared to the current one. This reduction is due to the more alkaline pH_T (reduction of FAC rate by a factor of 0.5) and cleaning of broach holes (reduction of FAC rate by a factor of 0.67)

The fact is that life extension of SGs cannot be confirmed at this point and even alternative options like replacement-retubing have to be taken into consideration.

The SGs Life Assessment recommendations

All the considerations related to the Life Prognosis estimations mentioned in the previous section are valid only if all the recommendations resulting from the Life Assessment process is being to be implemented in the near future.

The recommendations resulted from the Embalse SGs LA includes modifications and proposed actions of different areas such maintenance programs, inspection programs, design changes, operation practises and engineering analysis. Some of the issues to be considered are:

- A systematic Predictive Maintenance program for an early detection of SG loss of heat exchange efficiency due to fouling is needed. Such a program should include the analysis of the reactor inlet header temperature tracking, tubesheet sludge pile accumulation and tube fouling (primary and secondary side) as well as the blowdown efficiency. The Program should be able to propose the corrective actions when a specified limit is reached. The SG pressure drop in the PHTS could be also analyzed.
- Improvement of the vibration measurement program and its scope extension to the tubesheet region and feedwater header region for foreign object detection. This program should be also included in the Predictive Maintenance Program.
- Improve the Work Plans and maintenance practices in order to minimize the risk of foreign object inclusion into a system. A Foreign Exclusion Program from the point of view of system and not only component should be considered.

- Performance of the water chemistry changes on the secondary side has to be tracked in order to determine its efficiency against FAC in SGs.
- EC inspections procedures from the point of view of TSPs FAC and fouling have to be developed and qualified, then TSPs FAC and fouling rates have to be determined.
- Add more inspection ports for visual inspections of secondary side internals as feedwater header (for foreign object detection and exclusion) and rest of the tube support plates (for fouling and FAC degradation characterization)
- An accurate exchange-surface area margin has to be determined for Embalse SGs.
- Once all the TSP analysis is concluded, life extension of SGs has to be evaluated and defined.

CONCLUDING REMARKS

- In general for the first period of operation (1983-2002), maintenance of the Embalse SGs has been good although it was not in a systematic way for heat exchange efficiency loss. Maintenance-based ageing assessment has been effective after the ARDM has been detected and the component affected in some degree (secondary and primary side fouling, divider plate erosion) In the adverse sense, the ISI EC inspection program has always permitted an early detection of tube localized defects allowing the preventive plugging and minimizing the risk of SG leaks, although not always good defect characterization has been obtained nor detailed tracking been performed in some cases.
- ENGS end of life is estimated for beginning of 2011. During the second period of SGs operation (2002-2006) many actions have been taken thinking in the SGs life extension. Some design changes have been performed (divider plate replacement, additional U-bend supports, inspection port installation) The Life Assessment methodology has been an useful tool to understand the ageing effects on the component and allow an early detection, tracking and mitigation of some of them (U-bend supports FAC and tube fretting). However, the state-of-the-art in relation to TSPs FAC by the time it started, it couldn't permit an early assessment of the phenomenon. As a result of the LA process and regarding the current SGs ARDMs, a preliminary SG life prognosis was performed and is being to be analyzed jointly with a set of recommendations.
- The current total loss of SG exchange-surface area of about 0.7% after 21 years of operation doesn't seems to be critical for life extension compared against an assumed limit of 4%. In addition and related to the limiting operating transients, 15% of occurrences has not been reached in each case even for normal transients. These are good attainments, but recently appeared ageing issues have to be considered since they could compromise exchange-surface area and/or safe operation in the near future. Currently, SGs life prognosis depend mainly on the TSP FAC corrective actions effectiveness and engineering analysis results as well on the strategic decision if whether the plant power will be increased or not for the extended life.
- If power increasing is decided for the future, the most realistic scenario is the replacement-retubing of SGs despite de TSP structure analysis. Because the ENGS Reactor Building lay out, replacement of entire SGs is very difficult then retubing options have to be considered for the refurbishment outage of 18 months. In this case different strategies could be analyzed:
  - *Entire SGs replacement* implies high costs for new SG fabrication and difficulties in handling inside the reactor building; tube bundle-steam drum assembling could be analyzed.
  - *In site rebuilding* involves tube replacement and an in-site bundle assembling. Similar work has been previously done during construction then the experience obtained could be an advantage, but in-site tube assembling implies a long outage (refurbishment outage to be consider)
  - The whole *tube bundle and tubesheet replacement* could be another option, it saves assembling time and fabrication costs, but an in-situ tubesheet-primary head cut-off and weld procedure has to be developed.

- If the TSP structure analysis results are acceptable for safe operation of SGs for 30 more years (conditional based on fitness for service) and power increasing is not decided, then an economic evaluation should be performed in order to compare the benefits of a fitness for extended service life versus SG retubing.

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