EMBALSE REFURBISHMENT – AGING, SAFETY ASSESSMENT, AND THE PATH FORWARD

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Abstract

The Embalse Nuclear Power Station has been engaged in Pre-refurbishment activities for two years. The primary focus has been on the first phase Pre-Project Condition Assessment Program (PCAP). This phase of the Refurbishment and Life Extension (RLE) project consists of all preparatory activities that are required to define the refurbishment scope and costs, and for input into the utility business case for the RLE project.

As part of an overall Plant Life Management (PLiM) program, the following activities have been performed:

1. Systematic and rigorous condition assessments / life assessments (including Health Prognosis and Recommendations)
2. Assessment of design and safety analysis features at Embalse, relative to current technology and licensing practices
3. Pre-Project activities related to: Retube, Steam Generator replacement, and Digital Control Computer (DCC) replacement

The program has been a joint effort of Embalse NPS-NASA, AECL, ANSALDO and several other support organizations. Details of the planned program were addressed previously in a paper presented at the 28th CNS Conference (2007), entitled "Embalse Refurbishment – Pre-Project Condition Assessment Phase 1". Since that time, significant progress has been made towards completing the assessment program and planning for the next steps.

This paper presents the progress of Refurbishment and Life Extension (RLE) Program at Embalse Nuclear Power Station with specific emphasis on the PCAP efforts. This includes a discussion of the benefits and lessons learned from RLE project's perspective, and an overview of some key conclusions of the aging assessments. Finally, this paper outlines the path forward.

It should be noted that results of assessments presented in this paper are very conservative. This is driven largely by the fact that there are currently uncertainties in equipment condition that can be addressed through the activities recommended as an outcome of these assessments.

1. Introduction

The Embalse Nuclear Power Station (NPS) has been engaged in Pre-refurbishment activities for two years. The primary focus has been on the first phase Pre-Project Condition Assessment Program (PCAP) that consists of all preparatory activities required to define the refurbishment scope and costs, and for input into the utility business case for the Refurbishment and Life Extension (RLE) project.

As part of an overall Plant Life Management (PLiM) program, the following activities have been performed:

1. Systematic and rigorous condition assessments / life assessments (including Health Prognosis and Recommendations)
2. Assessment of design and safety analysis features at Embalse, relative to current technology and licensing practices
3. Pre-Project Activities Related to: Retube, Steam Generator Replacement, and Digital Control Computer (DCC) replacement

Each of the above will be briefly discussed within this paper. The methodology applied in conducting this type of work was the topic of a previous paper Ref. [1].

1.1 General Considerations About Embalse NPS

The Embalse NPS is located on the shores of the Embalse lake in the Córdoba province, Argentina and is operated by Nucleoélectrica Argentina Sociedad Anónima (NASA) who also operate Atucha I (C.N.A.I, a PHWVR designed by SIEMENS-KWU).

Embalse NPS is a CANDU®[1]6 type reactor with 648 MWe output. The plant achieved first criticality in March 1983 and commercial operation began in January 1984. In the last 10 years it has shown an excellent performance with an average 88.25 % Capacity Factor (CF). Since 1992, planned outage programs at 18-month operation intervals have been implemented.

Embalse NPS was designed (as with other early CANDU® 6 reactors) with a 30-year design life at an average CF of 80%. Due to its very good performance in the last ten years at CFs well over 80%, the plant design life will be reached before the 30-year design life, and it is now estimated to be in 2011.

An extended outage tentatively scheduled to begin in the year 2011 (known as the 'Refurbishment Outage') provides a unique opportunity for replacement and/or refurbishment activities recommended to extend the life of the reactor (by an additional 30 years beyond the end of Design Life).

[1] "CANDU" is a registered trade-mark of Atomic Energy of Canada Limited

2. Condition Assessment (CA) / Life Assessment (LA)

CA and LA are two techniques being used to assess aging degradation of the Embalse plant, and to assess the health/life prognosis of equipment for service life extension. The aging assessment portion of the PCAP is comprised of 118 CA or LA studies in total for which the responsibility is shared among NASA, AECL and other organizations as follows (refer also to Figure 1):

- CAs and LAs performed by NASA with final review by AECL
- CAs and LAs performed by NASA with AECL's assistance
- CAs and LAs performed by AECL with final review by NASA
- CAs and LAs performed by NASA and others (e.g. ANSALDO for turbine generator and Balance Of Plant). On these studies, NASA is cooperating with suppliers and other consultants.

AECL's scope of work is focused mainly on system studies, and major nuclear equipment such as nuclear piping, nuclear vessels, the reactor structure, etc. NASA is completing the balance of work with support on specific studies from AECL or other consultants.

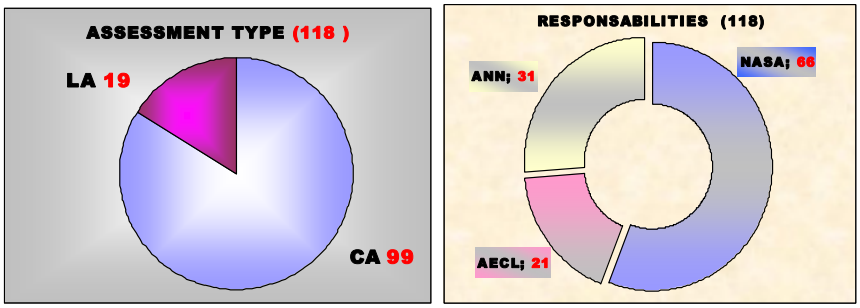


Figure 1 Distribution of Responsibility for Aging Assessment

2.1 Some Key Aging Assessment Results

At the time when the previous paper was presented, most of the assessments were started, but few were completed. Now as the project nears completion, aging assessment results of many of the significant plant Systems, Components, and Commodities (SCCs) can be discussed; some are briefly described below.

It should be noted that results of assessments presented in this paper are very conservative. This is driven largely by the fact that there are currently uncertainties in equipment condition that can be addressed through the additional activities recommended as an outcome of these assessments. Using such a conservative approach implies that once recommendations are implemented to address the uncertainties, component condition will not be worse than was predicted.

Civil Structures (Reactor Building, Internal Structures, Liner) – Civil structures will continue to meet their intended functional requirements for reliable operation with implementation of the following recommendations:

- Replace joint sealant (Thiokol)
- Develop and implement an Aging Management Program (AMP) for civil structures
- Incorporate enhancements/improvements to specific procedures (e.g. concrete repair)
- Partially reline Dousing Tank

Figure 2 which depicts signs of degradation observed at joints and in the Dousing tank, lends support to the above noted recommendations.

Joint Deterioration

Bubble in Tank Liner

Figure 2 Observations of Degradation Related to Civil Structures

Nuclear Piping (Primary Heat Transport, Moderator, Other Systems) – For assessment the nuclear piping systems were divided into three:

1. Primary Heat Transport (PHT) and Auxiliary Systems
2. Moderator and Auxiliary Systems
3. Other Systems – Emergency Core Cooling (ECC), Dousing, Emergency Water Supply (EWS), Liquid Injection Shutdown System (LISS) and Liquid Zone Control (LZC)

Overall the nuclear piping and supports will continue to meet their intended functional requirements for continued reliable operation with implementation of the following recommendations:

- Execute recommendations made during field walk downs conducted in December 2005 and April 2007. Refer to Figure 3.
- Include small-bore piping in station inspection programs.
- Inspect sections of buried piping.
- Include pipe supports in piping inspection programs.
- Implement improvements to existing maintenance programs for consistency with what other stations are doing.

Large Nuclear Vessels - Nuclear vessels including the pressurizer, degasser condenser, ECC gas tank, ECC water tanks, and various ion exchange columns and their associated supports will continue to meet their intended functional requirements for reliable operation with the implementation of recommendations to address the following: laminations detected in the ECC gas tank (assessed as manufacturing defect that has not progressed), a high Cumulative Usage Factor (CUF) in the degasser condenser supports, and the potential for fatigue of pressurizer spray nozzles and thermal sleeve.

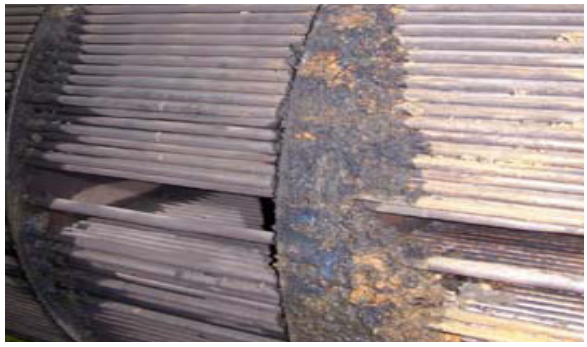
Large Nuclear Heat Exchangers – Included Shutdown Coolers, PHT Purification Interchangers, PHT Purification Cooler, Main Moderator Heat Exchangers, and the ECC Heat Exchanger. Each of these heat exchangers will continue to meet it's intended functional requirements for reliable operation with the implementation of recommendations to address the following: Flow Induced Vibration (FIV) of tubes, thinning of heat exchanger shells, and the effects of Microbially Influenced Corrosion (MIC) due to cooling with raw service water (refer to Figure 4).

Enhancements to the existing preventive maintenance and chemistry programs are generally recommended to manage these aging mechanisms.

Supports Not Taking Loads

Other Signs of Degradation

Figure 3 Pictures Showing Condition of Select Nuclear Pipelines



Deposits on Tube Bundle

Mussels in Tube Bundle

Figure 4 Deposits In Heat Exchangers Cooled with Lake Water

Feeders - The feeders are planned to be replaced as part of refurbishment activities. Refer to Section 4.1 for more details.

Steam Generators - The steam generators are planned to be replaced as part of refurbishment activities . Refer to Section 4.2 for more details.

Digital Control Computers – Replacement of the computers is planned to address current obsolescence issues. Refer to Section 4.3 for more details.

I&C Commodities – Transmitters, Relays, Solenoid Operated Valves (SOVs), Panels, Power Supplies, Resistance Temperature Detectors (RTDs), Junction Boxes, etc., were evaluated as commodity groups. The primary issues addressed via these assessments include: the potential for

common mode failure when the same models are employed in large numbers throughout the station, the availability of spares, and obsolescence.

Process Systems **–** Systematic screening was employed in system CAs in order to identify components that require further aging evaluation with the project. One of the primary goals was to establish the scope of related commodity CAs where many of the components requiring further evaluation would be assessed. Those components not covered by commodity CAs were dispositioned as not requiring further evaluation or were evaluated within the system CA.

2.2 Factors Influencing Aging Assessment Results

Some of the factors influencing aging assessment results are:

- Raw service water system used for cooling – unlike other stations which employ a closed circuit demineralised cooling water circuit
- Existing maintenance programs could benefit from improvements, e.g. the addition of new activities, tailoring existing activities to deal with aging, optimization of frequencies, etc.
- Uncertainty in equipment condition – in many cases the current condition is unknown and inspections may be needed to confirm current condition.

All of the above, and in particular the last bullet, contribute to a more conservative evaluation. Often such a conservative approach results in a less than good health prognosis[2] being assigned, which may be augmented to good if recommended actions are taken to reduce uncertainties.

3. Safety Assessment

The main objective of the safety assessment portion of the PCAP is to assess the design and safety analysis features at Embalse NPS, relative to current technology and licensing practices. AECL has been assisting NASA in this activity through the preparation of various documents on the topics of CANDU® 6 safety design related changes, review of Embalse plant trip parameters, input for the licensing basis, and others, through technical support.

3.1. Main Elements of Embalse Safety Assessment Program

Overall the Safety Assessment Program for Embalse NPS covers a wide range of activities, the most relevant being:

A) Consolidation of Level 1 Probabilistic Safety Assessment (PSA) (e.g. for the review of system reliability, which is based on PSA models).
B) Definition and execution of new Deterministic Studies
C) General up-dating of Embalse´s Safety Report
D) Analysis of plant compliance with Canadian Nuclear Safety Commission (CNSC) Standards
E) Analysis of plant compliance with Autoridad Regulatoria Nuclear (ARN) Standards
F) Analysis of Reactor Trip Coverage
G) Review of Site Seismic Conditions
H) Seismic Margin Assessment

[2] The Condition Assessment methodology provides for very specific Health Prognosis definitions, which takes into account a number of factors including uncertainties.

I) Provision and review of a Generic Level 2 PSA
J) Severe Accident simulations and analyses
K) Severe Accident Management
L) Simplified verification of plant compliance with general AR 3.1.3 Standard
M) Licensing Basis Document (LBD)
N) Planning of Periodic Safety Review (PSR)

3.1.2 Tasks Completed

- Item "A" above - fully completed with the present issue of Fire PSA Final Report, together with the consolidation of the Final CDF value.
- Item "D" above - verification of compliance with CNSC Standards R-7, R-8, R-9, R-10 and R-77.
- Item "E" above - verification of compliance with ARN Standard 3.4.2
- Items "M" and "N" above – preliminary drafts completed

3.1.3 On-Going Tasks

- Elaboration of Embalse´s Safety Analysis Plan, as a technical specification to AECL for the execution of Item "B" Deterministic Studies
- Initiating survey of all ARN Standards required to be in-compliance
- Analysis of Events Catalogues for Reactor Trip Coverage, based on Embalse PSA, CNSC R-8/10 Standards and AECL´s proposal.
- Elaboration of reviewed versions of LBD and PSR Program documents
- Item "G" above - under discussion with AECL and the University of Cordoba

3.1.4 Planned Activities in the Short-Term

- Discussions with AECL leading to a contract for the execution of New Deterministic Studies
- Discussions with AECL leading to a draft scope of supply for other major safety assessment activities

4. Retube, Steam Generator Replacement, and DCC Replacement

A significant outcome of the Embalse PCAP is that retubing, steam generator replacement, and DCC replacement are planned to extend the life of the plant. Each of these activities is briefly described in the subsections that follow.

4.1 Retubing

Retubing involves the large-scale replacement of all fuel channels, calandria tubes and feeder piping components. This entails replacement of portions of the pressure boundary of the primary heat transport system and the calandria vessel, which is part of the moderator system. Other systems affected by retubing are the annulus gas system and those instrumentation systems in which tubing in the upper feeder cabinet is removed to provide access for upper feeder replacement. The work associated with retubing is complex and will be executed by a diverse workforce made up of AECL, NASA and contractor staff.

Following planning, training, and other pre-outage activities, retubing will generally be comprised of the following key steps:

1. Placing the reactor into guaranteed shutdown state. After shutdown reactor systems must be laid up in a state that allows replacement of the required components, e.g. the primary heat transport system must be de-fuelled and then the heavy water drained and stored for the duration of the retube outage, installation of reactivity mechanism deck cover, etc.
2. Preparation activities such as removing obstructions from the work areas within the reactor building, preparing the fuelling machine bridge for retubing, installing and commissioning support equipment in the reactor building work areas, removing reactor face insulation and portions of the feeder cabinet.
3. Removal of feeder components, fuel channels and calandria tubes. All feeders, end fittings (end fitting body, liner tube, shield plug, closure seal insert, outboard bearing sleeve and inboard journal ring), channel closures, calandria tubes, pressure tubes and positioning assemblies will be replaced with new components.
4. New feeder installation commences with the installation of upper feeder piping, followed by the installation of calandria tubes and fuel channels.
5. New fuel is loaded into the reactor and new channel closures and shield plugs are installed.
6. Finally close out support activities are done, i.e. removing temporary retubing support equipment, etc.

A Qualification Program for the local supply of reactor components is in place. This has two phases:

- Phase 1 – an initial assessment of the supplier's capability; and
- Phase 2 – an in-depth qualification program after which the successful supplier would be qualified to provide replacement reactor components for CANDU® reactors and be eligible to bid for the Embalse retubing program and the new build project. Phase 2 includes the qualification of Comision Nacional Energia Atomica (CNEA) laboratories in Argentina.

Phase 1 has already been finished and NASA with AECL's assistance is currently involved in Phase 2. CONUAR has been identified as the supplier of reactor components with CNEA as an independent agency performing sample qualification tests.

4.2 Steam Generator Replacement

NASA and AECL has commenced engineering activities related to the replacement of the Embalse steam generators in order to support continued operation of the Embalse NPS for an extended period.

Two options for the steam generator replacement were evaluated:

1. Steam Generator Cartridge (SG portion below the drum) replacement
2. In situ retubing (Significant degradation of the tube support plate has been identified, which cannot be replaced without removal of the tube bundle)

The evaluation conducted showed that the in situ option has higher risk and there are no industry precedents for in situ retubing of steam generators in an operating plant. Hence the steam generator cartridge replacement option was selected.

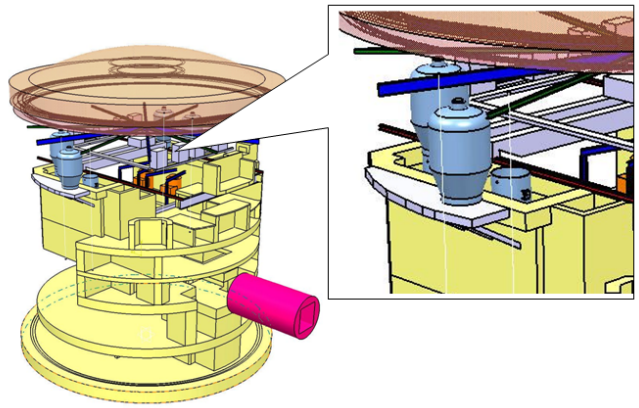


Figure 5 Steam Drum Removal

Figure 5 shows how the steam drum will be cut and moved aside in order to remove the cartridge.

A project implementation plan has been outlined identifying NASA as the project manager with AECL and IMPSA (a local manufacturer) in cooperation with B&W Canada on design transfer and technical / procurement support. The impact on the Reactor Retube schedule was assessed. The potential extent of local supply of materials and services has also been factored into the plan. Two local companies IMPSA (SG main supplier) and FAE / CONNUAR (potential SG tubing supplier) have been evaluated and accepted (with conditions) by AECL.

For the steam generator cartridge replacement Qinshan SG design has been assumed as the reference design. Since the replacement tube bundle is larger than the old Embalse SG tube bundle, a system analysis is being conducted to upgrade the overall station performance. The biggest challenge to meet the cartridge delivery for 2011 Retube Outage is coming from sourcing long lead items like the tubesheet forging and the tubing due to high world wide demands for the same items or their constituent materials.

A preliminary installation study was performed and indicated that the SG Cartridge replacement option is feasible and can be implemented using the Equipment Airlock. Temporary material handling equipment, structural steel for temporary structures and shoring of some floors would be required for the transporting the cartridges out of and into the Reactor Building. Although some challenges are expected since this would be a First of A Kind procedure for a CANDU® 6 plant, sufficient industry experience exists to draw upon to reduce the risk of the implementation.

The replacement plan includes the re-use of all the SG supports (except for the backup) with minor modification to the lower lateral support. Also the steam drum will be re-used, and as such, is undergoing inspection and an assessment of the remaining life.

4.3 Digital Control Computer Replacement

The DCCs are obsolete and are planned to be replaced for life extension. Two alternatives for replacement were assessed by CANDU Owners Group (COG) Joint Project Phase 1:

1. Change to a Distributed Control System
2. Replace the existing Varian V-70 with a SSCI-890 emulator

The second alternative was selected. This is a similar system to that currently used by AECL in newer CANDU® stations. The same system has also been selected by other CANDU® utilities such as Wolsong in Korea and Gentilly II in Canada.

The following activities were conducted (May 2007):

- Acquire Intellectual Property rights from SSCI
- Design solutions for obsolescence issues
- Manufacture of prototype DCCZ
- Acceptance of prototype
- Training
- Long Term Support
- Find a suitable company to perform the above

Policies of the DCC replacement are:

- To maximize NASA's participation in the development and implementation of the project (to build NASA's experience in this area)
- To use AECL as the main contractor responsible for the project management for all phases of the project.

Contractual details are under discussion with AECL for the supply of the required hardware and software. The assembly and commissioning of the new DCCs will be under NASA responsibility.

5. Other Areas of Interest for Plant Life Extension (PLEx)

Related to extending plant life, there are also a number of other activities that are already in place or are planned to be implemented in the near future.

Two major programs are:

1. Obsolescence Program
2. EQ Program

Other modifications and corrective actions include:

- Retubing the Main condenser
- Painting the inner surfaces of the Condenser Cooling Water piping
- Implementing improvements to the In Service Inspection (ISI) Program
- Changing the last stage Low Pressure Turbines blades
- Installing a new inverter Class II for BUC installation
- Refurbishment of the Reactor Building and Turbine Building cranes
- Replacement of transformers containing PolyChlorinated Biphenyls (PCBs)
- Replacement of Turbine electro hydraulic controls
- Replacement of all equipment related to Chilled Water Supply to the Local Air Coolers (LACs) of the RB.
- Replacement of the Service Water rotating filters

- Piping and supports inspections
- Circuit Breaker replacement (2GG)
- Installation of a Recirculating Cooling Water (RCW) system
- Replacement of many obsolete I&C components
- Up-rating related modification on Nuclear Steam Plant (NSP) and Balance of Plant (BOP)
- Modifying electrical equipment due to new configuration and equipment
- Performing seismic related modifications
- Informing the public about the project

6. Conclusions

The Embalse NPS has been engaged in Pre-refurbishment activities for two years. As the project nears completion, results are available which provide input to the business case, help to define the scope of the refurbishment outage, help to identify improvements or enhancements to existing plant maintenance and inspection programs, and can be used to develop an ongoing Aging Management Program.

For life extension three major pieces of equipment will be replaced during the refurbishment outage. These are the feeders, steam generators, and DCCs. Other major systems and components should be able to continue to operate to the end of design life, but may require that mitigating actions be taken to extend their life further, e.g. repairs to civil structures, heat exchangers, and select nuclear pipelines, or that improvements be made to the existing maintenance programs. To further support extending the life of the plant an Obsolescence Program, an EQ Program and other modifications or corrective actions are already in place or planned to be implemented in the near future.

Beyond pre-refurbishment activities, engineering, procurement and other preparatory activities are needed to proceed with reactor refurbishment. Implementation will follow including all field activities carried out during the outage. The work associated with refurbishment is complex and a diverse workforce will be needed to plan, prepare and execute reactor refurbishment activities needed to extend the life of the Embalse NPS for an additional 30 years beyond the end of it's current design life of 2011.

7. Acronyms

AECL	Atomic Energy of Canada Limited
AMP	Aging Management Program
ARN	Autoridad Regulatoria Nuclear
B&W	Babcock and Wilcox
BOP	Balance of Plant
CA	Condition Assessment
CANDU®	CANada Deuterium Uranium, registered trademark of AECL
CF	Capacity Factor
CNEA	Comision Nacional Energia Atomica
CNSC	Canadian Nuclear Safety Commission
CNS	Canadian Nuclear Society
COG	CANDU Owners Group
CUF	Cumulative Usage Factor

DCC	Digital Control Computer
ECC	Emergency Core Cooling
EQ	Environmental Qualification
EWS	Emergency Water Supply
FIV	Flow Induced Vibration
I&C	Instrumentation and Controls
ISI	In Service Inspection
LA	Life Assessment
LAC	Local Air Cooler
LBD	Licensing Basis Document
LISS	Liquid Injection Shutdown System
LZC	Liquid Zone Control
MHTS	Main Heat Transport System
MIC	Microbially Influenced Corrosion
MW	Mega Watt
NASA	Nucleoeléctrica Argentina Sociedad Anónima
NPS	Nuclear Power Station
NSP	Nuclear Steam Plant
P&IC	Pressure and Inventory Control
PCAP	Pre-Project Condition Assessment Program
PCB	PolyChlorinated Biphenyls
PSA	Probabilistic Safety Assessment
PSR	Periodic Safety Review
PHT	Primary Heat Transport
PLEx	Plant Life Extension
PLiM	Plant Life Management
RB	Reactor Building
RCW	Recirculating Cooling Water
RLE	Refurbishment and Life Extension
RTD	Resistance Temperature Detector
SCC	Systems, Components, and Commodities
SG	Steam Generator
SOV	Solenoid Operated Valve

8. References

[1] G. Diaz, R. Sainz, R. Gold, R. Dam, J. Nickerson, “Embalse Refurbishment – Pre-Project Condition Assessment”, presented at 28th CNS Annual Conference & 31st Annual CNS/CNA Student Conference, *S*aint John, New Brunswick, 2007 June.