Lessons Learned from the Management of Heat Transport System Materials Degradation at the Point Lepreau Generating Station

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ABSTRACT

New Brunswick Power Nuclear Corporation has been managing several serious degradation issues for the major components of the Point Lepreau Generating Station (PLGS) primary heat transport system. Self-assessments of the causes of decreasing performance indicators identified some underlying and common management process problems. Since 2003, the lessons learned from this experience have been implemented into an improved management approach. This paper gives a high-level overview of:

- The major degradation and materials degradation management issues
- The common underlying causes for inefficient materials management at PLGS
- An improved management approach to mitigate these causes and reduce the risks to the plant using the lessons learned.

1.0 INTRODUCTION

Since 1982, New Brunswick Power Nuclear (NBPN) has operated the Point Lepreau generating station (PLGS) with a life-time capacity factor of ~83%. PLGS is a CANDU®[1] pressurized heavy water design with 380 individual fuel channel assemblies running horizontally through the reactor core's cylindrical calandria vessel. Each fuel channel is comprised of two concentric zirconium alloy tubes. An inner pressure tube carries the fuel bundles and pressurized reactor coolant and an outer calandria tube separates the heavy water moderator in the calandria vessel from the pressure tube. Four loose garter springs in the annulus maintain separation between the two tubes in each channel. PLGS has four recirculating steam generators with alloy 800 tubing. Primary reactor coolant is carried between the fuel channels and the steam generating system by 380 SA 106B carbon steel feeder pipes and four headers, each for inlet and outlet flow. Figure 1 shows a schematic view of one reactor face and the general feeder piping system layout, with the insulation cabinet removed. In 2008, PLGS will begin an eighteen-month Refurbishment Outage when all fuel channels and feeder piping will be replaced. The current steam generators will remain in service for a total expected operating life of about 55 years.

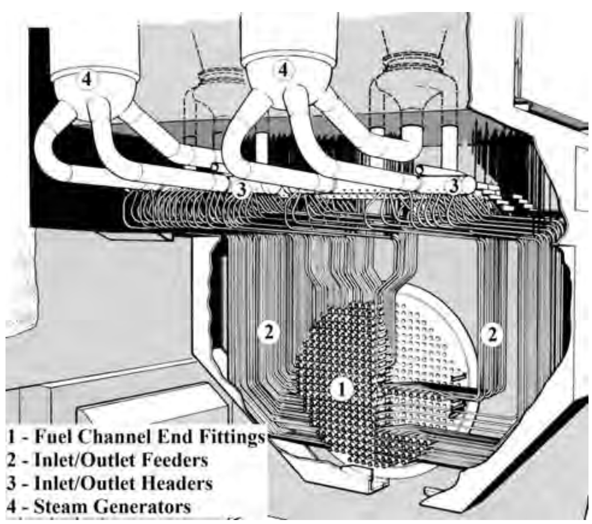

Figure 1: Layout of the CANDU® Reactor Coolant System.

[1] CANDU (CANadian Deuterium Uranium) is a registered trademark of Atomic Energy of Canada Ltd. (AECL)

A significant and fluctuating percentage of NBPN's operations and maintenance (O&M) budget has been directed at managing materials degradation issues for the three major primary heat transport system (HTS) components: feeders, fuel channels, and steam generators. Some of the major costs are due to:

- Lost production
- Planned and unplanned corrective maintenance
- Engineering to demonstrate safe operation
- Design changes
- Response to regulatory requirements
- Personnel radiation exposure
- Maintaining good public relations.

Changes in performance indicators such as the frequency of rework, unplanned maintenance, and emerging issues suggested that materials degradation management was not being as effective as it could be. Self-assessments identified some interesting management process issues and areas for improvement (AFI) that could be addressed to both reduce O&M costs as well as improve component safety and reliability. With these findings in hand, NBPN and AECL began developing a new approach to manage the degradation of the PLGS HTS major components in 2003. The purpose of this approach was to correct inefficient processes identified from the self-assessments and to make additional improvements that meet the intent of the US industry initiative following the Davis-Besse experience and outlined in NEI 03-08 [1]. The remainder of this paper provides an overview of the degradation issues for Point Lepreau's major HTS components, the lessons learned from the self-assessments, and the improvements NBPN has made to HTS materials degradation management using the lessons learned.

2.0 HTS MATERIALS DEGRADATION MANAGEMENT AT POINT LEPREAU

To appreciate the reasons why NBPN initiated self-assessments and a materials management improvement initiative, it is helpful to be acquainted with the PLGS major component degradation issues. First, PLGS materials degradation management is exacerbated in general by the following factors:

- NBPN is a relatively small Utility with limited technical resources with expertise in the area of materials degradation.
- Point Lepreau is physically remote from most of the industry from which it draws technical support.
- The nuclear industry in general is experiencing an increasing demand and decreasing supply of technical resources.
- There is an interrelationship between component and system-level degradation issues, namely:
  - Degradation of individual components can affect the performance of the full system,
  - Individual component management plans that use system-operating strategies could have a negative effect on other components.
- PLGS is a leading CANDU unit in terms of operating hours and has been the first to experience and manage some degradation mechanisms.
- PLGS has experienced an increasing severity of some degradation.

These general factors in combination with the complex nature of some of the specific degradation mechanisms placed an increased burden on the processes that were being used at PLGS to manage the risk. The degradation issues that were most problematic to manage and resulted in recurring risk concerns, such as unplanned maintenance, high rework, and forced Outages, are described in the following sections.

2.1 Feeder Piping

Since 1997, eighteen PLGS tight radius feeder bends downstream of the fuel channel outlets have been replaced because of flow accelerated corrosion and intergranular cracking initiated from both inside and outside surfaces. Details about the observed degradation and the strategies to manage it are provided in other publications [2-6]. Cracking from the outside surface has been the most challenging to manage. By 2003, it was becoming increasingly difficult to demonstrate safe, reliable operation for the following reasons:

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

Feeder cracking had also become a major economic risk for PLGS, causing:

- Two forced outages (90 days total)
- Extension of two planned outages (13 days total)
- Replacement energy costs ~ $50M
- Use of 3% of PLGS annual operations and maintenance budget
- Increased radiation exposure
  - ~30% of total Outage exposure on feeder inspection and replacement activities
  - Key inspection resources reach annual limit on feeders and are not available for other component inspections
- Increased Regulatory concern
- Loss of credibility with Owner & Public

2.2 Fuel Channels

There are many complex fuel channel degradation mechanisms, many of which are inter-related. The most problematic issue to manage at PLGS is the potential for pressure tube rupture resulting from contact with the calandria tube, subsequent zirconium hydride blister formation, and delayed hydride cracking [7]. The primary risk-reduction strategy is to locate and reposition (SLAR) spacers to remove or prevent contact for pressure tubes that have sufficient hydrogen concentration to form blisters. This requires onerous trending and tracking of critical parameters and a high reliance on sophisticated predictive models that are frequently updated to address industry operating experience and research results.

Predicting which channels are at-risk is complicated by the following features of the degradation and the assessment process:

- Radiation assisted creep causes the pressure tube to increase in diameter, elongate, and sag resulting in the need for complex finite element models to project contact with the calandria tube and to calculate the load on spacers, which is used to assess spacer movement.
- The criteria used to assess spacer movement are based on observations of previous movement and calculated loads for those spacers. Therefore, changes in the criteria used to postulate movement are very sensitive to observations of movement and model changes.
- Changes to the model used to predict pressure tube hydrogen concentration have had significant impact on the identification of channels at risk of blister formation.

The impact has been over ~$300M in consequential costs associated with inspection and maintenance activities with very high levels of unplanned work and rework. The risk reduction (benefit) in performing these activities was not quantified until very recently [5].

2.3 Steam Generators

During the first thirteen years of operation, PLGS 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.

Although by 2003, improvements in deposit management, chemistry control, foreign material exclusion, and other management activities had significantly improved steam generator reliability [8], stakeholders had lost confidence in the PLGS steam generator management program. This led to prescriptive inspection to address regulatory concerns that were not in alignment with PLGS management planning.

PLGS will continue to be a leading unit for the performance of steam generators with alloy 800 tubing during extended lay-up and for post-refurbishment operation. As a result, NBPN will be developing steam generator management plans that anticipate materials degradation issues out to 55 years service life, with relatively little relevant external operating experience to draw upon.

3.0 FINDINGS FROM THE SELF-ASSESSMENTS

Self-assessments of the processes used to manage HTS materials degradation identified some common underlying causal factors. These are described below.

3.1 Technical Information from R&D Programs is not always Considered in the Planning of Maintenance Activities

One reason why research results that may affect plant O&M do not reliably reach the system responsible engineer is that many R&D and engineering results are not reported in a format that can be easily used by station staff. For example, although it was well known in the research community that the PLGS feeder cracks were driven by residual stress, this information was not previously presented in a form that was practical for station staff responsible for developing feeder inspection scope to retrieve or use. As a result, early inspection scopes were not based on the key factors understood to cause cracking. Second, PLGS staff (being fewer in number and physically remote) are not able to participate fully on industry committees and at meetings, workshops, and conferences. The different perspectives of the two groups arising from differences in their training, experience, and company objectives, was found to aggravate these two factors by limiting effective communication.

3.2 Late Recognition of Material Degradation Issues

Many emerging issues that required unplanned maintenance and inspection were found to be anticipated or predictable. In some cases, this was caused by late recognition of regulatory concerns. In other cases, inadequate consideration of the consequences of R&D or engineering results to plant operation caused unplanned maintenance and inspection. For example, when a model that predicts spacer movement was updated, late recognition and communication of the impact the results would have on operations resulted in untimely, unplanned assessments and maintenance to demonstrate fitness for service of pressure tubes. For another utility, a forced shutdown was required for SLAR.

3.3 Lack of Consideration of Risk-Reduction for Maintenance Activities

In almost all cases, life management planning documents considered the risk of degradation, but not the risk reduction in performing inspection and maintenance activities. Some activities have a low chance of success or otherwise poor-risk reduction and other activities introduce additional risks. For example, the risk reduction from inspecting some steam generator internal components using an installed platform does not justify the increased risks associated with personnel safety hazards, introducing foreign materials, and inflicting mechanical damage to other components.

3.4 Practices Based on Industry Guidelines That Were Too Cumbersome and Resource Intensive

Many industry and station guidance documents, management plans, and assessment documents were too lengthy, did not contain key relevant information, or otherwise were not in a practical format for use by station staff. In many cases, staff simply were not using the documents.

3.5 Lack of Consideration of Positive Operating Experience

In several cases, condition and operating assessments did not consider inspection results or other operating experience that indicated no or limited degradation. This has led to overly pessimistic predictions of future condition and use of management activities with poor risk-reduction. For example, repeated SLAR of channels with no observed spacer movement has provided little risk reduction.

3.6 Potential for Imbalanced Distribution of O&M Resources between Components

The distribution of resources to manage HTS components and for the R&D program was not based on reduction of risk to the station.

3.7 Concern That Practices to Manage One Component May Not Be Compatible With Another

Recommendations for operations and chemistry changes meant to reduce the risk of one component were not always assessed for their impact on other components in the HTS.

3.8 Unclear Roles and Responsibilities

NBPN is responsible for managing the risks of HTS component degradation and generally hires service providers to identify and quantify the risks of degradation. However, it is not uncommon for service providers to recommend management activities (usually inspection) despite their lack of familiarity with the utility's general management strategy, other available management activities, implementation issues, and impact on other components and utility activities. Sometimes, recommendations or comments have been made based on a study of a single parameter. Disposition of unsolicited recommendations sometimes requires extensive effort to assess and they can create a false level of concern and unnecessary redistribution of recources away from high risk issues.

4.0 IMPROVEMENTS TO MANAGEMENT OF HTS MATERIALS DEGRADATION

NBPN recognized the need for an improvement initiative in response to the self-assessment findings. The overall objective of this initiative was to ensure that the level of risk for the HTS components was low and in line with other plant equipment. The general focus of the approach was to improve the implementation of technical information and to apply risk-based decision making into O&M plans. Specific goals were:

- Consistent and integrated approach for materials degradation management of the major HTS components.
- Materials degradation management plan formats that are similar for each component.
- HTS Materials Degradation Management Program to provide a formal interface between the feeder, fuel channel, and steam generator plans and other station processes (e.g. operations and chemistry control)
- Cost effective risk management to ensure safe, reliable operation.
- Prevent error-likely situations that could cause unplanned maintenance and forced outages.
- Provide basis for economic assessment of risk management strategies at the system level to ensure proper distribution of resources.
- Management of degradation issues that span multiple HTS components/functions.

To achieve these goals, improvements were made in the following areas.

4.1 Organizational Aspects

Since many of the causal factors are associated with how complex technical information is processed at the Station, it was recognized that alignment of staff competency with materials degradation management requirements was a key AFI. In general, the past practice at PLGS was to assign responsibility for management of materials degradation to staff that is responsible for the operational function of the system or components. NBPN made organizational changes as follows:

- Responsibility for management of degradation was assigned to staff with materials expertise
- Responsibility for implementation of management activities was assigned to staff with component/system expertise
- Staff augmentation to increase technical competency in the organization by adding contract staff with specific subject matter expertise

4.2 Implementation of Technical Information

The PLGS HTS component degradation is very technical and scientific in nature; therefore several AFIs related to how technical information is managed were identified. The primary intent of these AFIs was to both improve how scientific information was implemented into plant practices and also how research is planned to provide specific information for plant needs. The following activities were implemented to address these AFIs:

- A partnership approach was established with AECL to jointly develop management strategies. This improved the implementation of technical information by combining the strengths of operations and research perspectives into planning of both R&D and maintenance activities.
- It was important to define a clear division of responsibilities between the utility and contracted engineering and R&D services. The NBPN organization is responsible for operating the plant, maintaining plant equipment, developing risk management strategies, implementation of risk reduction activities, and system health monitoring. The R&D and engineering service provider's are contracted to provide technical support, design services, quantification of risk, and are expected to maintain high competency subject matter experts. With more clearly defined responsibilities, contractor organizations have been shifting towards the desired behaviors indicated in Table 1.
- NBPN has been increasing its collaboration with stations of similar design to share resources, operating experience, and to develop consistent management approaches. A good example is the collaboration with Hydro Quebec for feeder management. Gentilly-2 and PLGS feeder management plan documents are similar in format, logic, and content. R&D and engineering assessment results, operating experience are shared, as are technical and inspection specialists for planning and outage work.
- Recently, R&D and engineering programs have been designed to consider contingency planning for a range of anticipated operating conditions and outage inspection results. The results are used to prepare pre-planned activities or actions.
- Benchmarking visits are being used more extensively to take advantage of the best practices and lessons learned from other utilities. Materials degradation management issues and strategies are surprisingly applicable even for plants of different design.

Table 1: Desired shift in contractor behavior related to responsibilities for managing material degradation issues.

Observations Related to Understanding of Responsibilities	
Previously Observed ***"Unclear Responsibilities"***	**Desired Behavior** ***"Clear Responsibilities"***
Strongly worded recommendations about how the utility should manage risk	Identify and quantify the risks to the plant
Perspective that primary management strategy should be focused on the parameter under study	Appreciate the impact of possible study results as a contributing factor to the overall risk
Delaying implementation of results until a thorough data-set or mechanistic understanding is obtained	Use best available information and risk ranking of parameters to balance effort accordingly
Focus is on underlying mechanism and modeling	Consider impact on operations and know the acceptance criteria
Interfaces with other programs/end products is unclear and perception of use of results can be misleading	Establish clear links with how results will be used – especially operational assessments

4.3 System-Level Risk-Based Plan

AFIs associated with integration and consistency for the management of individual components is being addressed using a system-level HTS materials degradation management plan (MDMP). The concept is modeled after a mandatory requirement for an 'overarching' system-level plan in NEI 03-08 [1], with an emphasis on risk-based management. The MDMP also addresses system-level degradation such as increasing radiation fields and decreasing thermal efficiency, which was not addressed in individual component management plans. The MDMP includes the following elements:

- Clear interfaces between station work groups to ensure effective implementation of risk-reduction activities
- Defines the level of approval required for deviations from management plans.
- Identifies system-level operating requirements (e.g. more restrictive chemistry control) to protect specific components that have the potential to affect other components or system-level degradation mechanisms.
- A simple methodology to evaluate risk-reduction of management activities in a consistent manner for all components. The concept of risk-reduction considers the magnitude, probability, and consequence of the degradation, the likelihood that the activity will be successful, and consequential costs of performing the activity (worker hazards, expense, potential to introduce other degradation).
- Probabilistic safety evaluations to quantify the benefits of management activities to reduce nuclear safety risk
- Severe core damage frequency as a common unit to compare the risks of degradation between components in the system.

4.4 Concise Management Plan Documents

To address AFIs regarding management plan format, NBPN now uses a consistent and concise format developed by station staff, which follows station processes based on INPO AP-913 [9]. Individual management plans are kept to ~ 40 pages long and reference design and technical basis documents. In addition to the standard practical information, each plan is now required to include information critical to the operation of the station, such as:

- License requirements and regulatory commitments.
- Pre-determined response plans for inspection results.
- Clear acceptance criteria, e.g. for inspection results and chemistry excursions.
- Maintenance activities and outage schedules based on operational assessments.

4.5 Improved Communications with Stakeholders

Since 2003, NBPN has increased the frequency of meetings with the Regulator and has held several workshops and information meetings to discuss new degradation issues and management activities.

5.0 SUMMARY AND CONCLUSIONS

Increasingly challenging HTS materials degradation management issues and high levels of unplanned maintenance and re-work led NBPN to perform self-assessments. Lessons learned from this experience were applied to improve the PLGS materials degradation management program. NBPN have recognized many benefits from this improvement program to station reliability, O&M costs, and nuclear safety, such as:

- Improved credibility with stakeholders
- Resources focused on highest risk issues
- Significant reduction in unplanned maintenance
- Engineering effort is shifting from emerging issues to improvements

The biggest impacts have been from:

- Using a concise, practical management plan format that was developed by station staff who use them
- Improved implementation of technical information into station management plans
  - Ensure that all critical technical information is considered in planning maintenance activities
  - Consequence to plant operation is considered in the early planning stages of R&D and engineering work
- Clarifying the division of roles and responsibilities, based on organizational function and strengths
- Use of risk-based decision making to focus resources on activities that provide optimal risk-reduction

Because PLGS is a small and isolated station, a collaborative approach between NBPN and AECL was found to be an effective means to improve the implementation of technical and scientific information into plant management activities. The collaboration resolved many of the communication issues and took advantage of the operations strengths of PLGS staff and design and technical strengths of AECL staff to address most of the AFIs identified in the PLGS self-assessments.

NBPN is continuing to apply a high level of attention on the identified AFIs. Of particular interest is expanded collaboration with AECL and other utilities and in capturing best practices and lessons learned from elsewhere in the industry via activities such as benchmarking.

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