STEAM GENERATOR LIFE CYCLE MANAGEMENT - B&W PERSPECTIVE

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ABSTRACT

This paper is an effort towards the B&W perspective about the effective life cycle management plan (LCMP) of the CANDU Steam Generators (SGs) based on the proactive identification of active and plausible degradation mechanisms for various SG components and the need to achieve a safe and economic operating interval for the station.

The objective of this paper is to provide the guidelines for the near-term and long-term effective strategy for inspections, maintenance and design modifications as necessary for the safe and reliable operation of the SGs during the plant design life and beyond. The derived activities of this strategy need to be integrated with the station outage specific work scope plan for an effective life cycle management.

The technical basis for these activities is based on the review of SG components for any life limiting factors, review of previous field inspection records, maintenance work and modifications at the station and operational experience (OPEX) from other steam generators operating worldwide with similar design. These activities need to be performed in order to ensure that the SGs perform within an acceptable level of safety and reliability as per the licensing bases, while optimizing station production and cost effectiveness.

INTRODUCTION

In order to ensure that the steam generators (SGs) will operate effectively during their entire service life, a proactive program of inspection and maintenance is required, along with adherence to good water chemistry control (Ref. 6). Such a program is the best defense to ensure that unacceptable degradation is identified as early as possible. In some cases, steam generators are planned to operate beyond their original design life and it is considered prudent to gain assurance of the continued good health of the steam generator by implementation of inspections and cleaning (Ref. 4 and Ref. 7) operations from time to time. Such inspections relate to ongoing monitoring that may give an insight regarding any specific degradation mechanisms.

LIFE CYCLE MANAGEMENT OF STEAM GENERATORS (AN OVERVIEW)

The purpose of the life cycle management plan (LCMP) is to provide both the near-term and the long-term strategy for inspections, cleaning and modifications as necessary for safe operation of SGs during the design life and, if possible, beyond the original design life (i.e., life extension). The derived activities of this strategy are required to be integrated with the outage specific work scope plan.

This life cycle management plan (LCMP) establishes the requirements for an optimized in-service inspection, testing, surveillance and maintenance of steam generator (SG) components. The technical basis for these activities is based on the review of SG components for any life limiting factors, review of previous field inspection records, maintenance work and modifications at the utility and operational experience from steam generators worldwide with similar design. These activities need to be performed in order to ensure that the steam generators perform safely and reliably, within the documented design bases, licensing bases and the safe operating envelope, while optimizing station reliability, production and cost effectiveness.

LCMP OBJECTIVES AND STRATEGY

An LCMP must address both the near-term and long-term requirements to meet the following general objectives:

- To minimize safety risk due to a component degradation or failure.
- To minimize station incapability due to SG performance.
- To meet or exceed regulatory requirements (CSA Standard N285.4, Ref. 1).

Monitoring, timely detection and characterization of SG component degradations are essential to the management of SG component integrity over the station life.

This information is used to:

- Assess component degradation and integrity relative to the safety and performance criteria.
- Assess needed improvements in measures being taken to mitigate active degradation mechanisms.

STEAM GENERATOR SURVEILLANCE

The first step in building an LCMP is the steam generator surveillance that requires identification of components susceptible to aging and is done as follows:

i) general listing;
ii) identification of potential mechanisms (Ref. 2 and Ref. 3); and
iii) screening of components against basic criteria.

In this identification phase, essentially all SG components are listed. This is done to avoid overlooking problems in obscure parts that may prove significant. In the screening step, this long list is reduced substantially.

This initial screening step is required to narrow down the list of possible components requiring further consideration and uses extremely conservative and general criteria. In most cases, these criteria are based on an extended steam generator life of 40 years, being a bounding assumption, with a substantial margin intended to allow for the effects of potential manufacturing defects, corrosion, and any other forms of degradation that may not have been accounted for in the original design. The basis for assessment makes reference to design, existing analysis, operating and inspection data, and in some cases it may be necessary to reintroduce components to the listing based on inspection findings.

First, all of the components, welds and features in the steam generator are identified from original manufacturing assembly drawings, modification assembly drawings and records of shop and site repair, design documents, procedures, and correspondence. These are subdivided into four basic groups, namely: primary side pressure boundary components and attachments, secondary side pressure boundary components and attachments, primary side internals, and secondary side internals.

Secondly, known aging issues and their impact on the components in general are reviewed. In most cases where an aging issue was understood at the time that the steam generator was designed, it is only expected to become significant for life extension activities (for example, operating cycles and fatigue). In some cases, where aging issues are not known or quantified at the time of the design, these mechanisms may be significant, even for the short-term operation of the steam generators (for example, manufacturing anomalies and degradation mechanisms). In each case, criteria are set for initial screening of the component.

Thirdly, these criteria are applied to the components, through reference to existing analyses, design drawings, and design experience, thus arriving at a list of critical components.

BUILD AN LCMP AND BASIS FOR INSPECTION INTERVAL AND SCOPE

The steam generator surveillance streamlines the life cycle management objectives and strategies for SG components that are based on the following criteria, depending on the probability of degradation.

- i) Component safety and performance,
- ii) Consequential cost to remedy unacceptable condition,
- iii) Probability of new or continuing degradation,
- iv) Accessibility.

The selection of strategies is based on verifying component structural integrity and minimizing the risk of forced outages due to component failure. The evaluation of risk and risk reduction is based on probability of degradation and the magnitude of the consequences of such degradation in terms of safety and performance of the steam generators. Since the risks of SG component degradation vary due to local flow conditions, differences in geometry, material composition, loadings, location, a composite of the criteria outlined above should be established to set up the basis for the inspection interval that also establishes the risk management levels used for decision-making for risk-based inspection and maintenance of SG components. These risk levels are used to detect degradation that can challenge the structural integrity of the components, impacting the safety and performance of the SGs.

The strategy requires frequent inspection of safety significant (H) or structurally at risk (M) components that have a high (H) probability of new or continuing degradation

For the components that have low consequence of failure (L), or components that are safety significant (H) or structurally at risk (M), but have medium (M) or low (L) probability of new degradation or rapid degradation growth, the strategy requires a routine general inspection, as mandated by CSA N285.4 (Ref. 1).

The limiting components that set the SG inspection interval and scope (number of boilers) should be identified. Inspections of other components (along with general overview inspection) should be performed on an opportunity basis to the extent practical by station outage schedule and resource availability.

Table 1 - Risk Management Levels Used for Decision-Making for Risk-Based Inspection and Maintenance of SG Components

Factors	Criteria
Component Safety/Performance	
Safety (H)	Safety significant component whose failure relates directly to safety risk
Structural (M)	Structural component whose failure impacts the economic risk such as forced outage
Non-Structural (L)	Non-structural component whose failure does not impact a forced outage (economic) or a safety risk
Consequential Cost to Remedy Unacceptable Condition	
High (H)	High consequential cost
Medium (M)	Medium consequential cost
Low (L)	Low consequential cost
Probability of New or Continuing Degradation	
High (H)	Relatively high probability of new degradation or rapid degradation growth
Medium (M)	Lower probability of new degradation or rapid degradation growth
Low (L)	Very low or low probability of new degradation or rapid degradation growth
Accessibility	
Inaccessible (I)	No maintenance access/High radiation fields
Difficult (D)	Difficult maintenance access
Readily Accessible (A)	Relatively easy maintenance access.

The inspection interval and scope (number of boilers and extent) is set by the limiting components.

PERSONNEL TRAINING AND QUALIFICATION REQUIREMENTS

The steam generator expertise and development requires technical data acquisition, surveillance result interpretation, personnel training and development. The technical data acquisition requires acquiring information about degradation mechanisms based on SG surveillance, degradation mechanisms known to occur elsewhere, and a predictive database of SG behavior based on SG surveillance. This also requires personnel training and developing the capability of interpreting the surveillance results. To summarize, the LCMP program should also include;

Training and Skills Management - to ensure that responsible engineering staff have the skills necessary to perform the day to day, long range and extraordinary tasks and planning necessary to maintain the SGs in good condition. The objective of the program is to provide the engineer with knowledge needed to:

i) direct reliable operation of the equipment
ii) direct investigation of operation reliability/compliance issues
iii) plan for and deal with the results of outage, inspection and maintenance work

The areas of training may include the following items:

i) Working knowledge of internal structures/design features, SG materials of the various components
ii) Working knowledge of operation of the SG, including thermal hydraulics

iii) Review of SG history dockets and design reports
iv) Recommendations about water chemistry
v) Preventive program regarding proper maintenance of the SG during its service life
vi) Knowledge of inspection processes, inspection planning and interpretation of findings
vii) Knowledge of maintenance procedures, including outage planning for inspection and maintenance, opening and closing of steam generators, leak detection and tube plugging
viii) Data Systems – for managing records and data relating to
   a. Design and Engineering of SGs Including Records of Configuration and Configuration Changes (Modifications)
   b. Records of Operation of the SGs Including Operating Cycles and Thermal Transients, Operating Water Chemistry including Feedwater and Blowdown Chemistry, CPT (Corrosion Product Transport), Layup, Startup, etc.
   c. Inspection Observations and Cleaning and Maintenance Records.

FITNESS FOR SERVICE ASSESSMENT

Fitness-for-service assessments, including structural integrity and operational assessments should be performed at the completion of each inspection campaign to demonstrate the ability of the SGs to function safely for the next operating period. The purpose of the integrity assessment is to ensure that the performance criteria have been met for the previous operating period (i.e., condition monitoring) and will continue to be met for the next operating period (i.e., operational assessment).

As per CSA N285.4 (Ref. 1), Clause 14.2.5.2.2 and Clause 14.3.5.2.2, conditions from previous and current inspections that do not comply with the acceptance criteria shall be acceptable, provided that it has been demonstrated to the regulatory authority that the structural integrity of the component is predicted to be adequate at the end of the next periodic inspection interval. In general, the analysis used to demonstrate structural integrity shall be performed in accordance with the Fitness for Service Guidelines.

When inspections identify any non-standard condition (such as unretrieved foreign objects or degradation in excess of what was previously observed in the specific SG), the condition should be dispositioned prior to vessel closure as per Clause 14.2.5.3, Clause 14.3.5.3 and Clause 14.4.5.3 of CSA N285.4 (Ref. 1). Disposition may require additional inspections in the affected or other SGs, or engineering analysis. An assessment shall be completed to demonstrate that the structural integrity of the SG and tubes will be adequate at the end of the next periodic inspection interval. In general, the analysis used to demonstrate structural integrity shall be performed in accordance with the Fitness for Service Guidelines.

Inspection records and issuance of reports shall comply with the requirements of Clause 14.2.6, Clause 14.3.6, Clause 14.4.6 and Clause 11 of CSA N285.4 (Ref. 1).

CONCLUSION

LCMP is the most valuable tool for nuclear SG asset management that helps the utilities make informed technical and business decisions in a deliberate and organized way. The utilities can use it is an effective near-term and long-term planning method for optimizing unplanned generation loss in a systematic way, forecast the maintenance/replacement costs and capital investments required to achieve that mandate ensuring the plant safety and a pre-determined plant operating period. It addresses issues as systematic component aging management, scheduled maintenance, technical obsolescence, refurbishment, replacement or redesign of equipment that are critical for the safe and productive plant operation, schedule of these activities and projections of long-term expenditures involved. LCMP helps utilities engage in more sustainable production and clearly defines and measures the business value they are gaining by the application of this tool (Ref. 8).

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