STEAM GENERATOR TUBE INSPECTION SPECIFICATION

L.S. Obrutsky, B.A. Lepine and R. Lakhan

UNRESTRICTED / ILLIMITÉ
Presentation Agenda

• Background
• Rationale
• Approach
• Inspection Specification Content
• Target Flaw Size
• Performance Requirements
• Limitations
• Future
Steam Generator Inspection
Specification Background

- CAN/CSA N285.4 requires the owner, or licensee, to engage in performance demonstration of NDE activities, Clause 3.6(e).
- This non-specific clause applies to any NDE method or technique and any component covered by the standard.
- The USA comparable code – ASME XI, Appendix VIII - is limited to the reactor pressure vessel, piping and bolting and refers only to ultrasonic's as the inspection method.
- However, the US NRC, accepts the application of the EPRI Steam Generator Examination Guidelines (SGEG) as meeting the performance demonstration requirements equivalent to ASME XI, App. VIII.
- The Inspection Qualification Joint Program (IQJP) accepted the European Network for Qualification (ENIQ) as more effective for CANDU plants, especially for fuel channels and related components, piping and vessel inspection.
Should the system adopt ENIQ, the EPRI SGEG, a hybrid of ENIQ/EPRI or a different process?

The overall objective was to construct an inspection qualification process for steam generators which was:

• Acceptable to the utilities and also consistent for the industry
  – Historically, CANDU utilities had applied Appendix H of EPRI guidelines for qualification of SG inspection technologies
  – EPRI uses generic flaw types and sizes, i.e. 60% structural integrity limit.

• Acceptable to the inspection service providers

• Acceptable to the regulator
  – ENIQ requires the formulation of the Inspection Specifications (Engineering document which must state target flaw size).
  – ENIQ calls for an independent qualification organization
Recommendation was to proceed with a hybrid system, taking the most appropriate aspects from both ENIQ and EPRI SGEG.

- Two documents were produced:
    - Scope: to establish a condition monitoring limit (CML) to ensure that inspections will detect all structurally significant flaws, which will bound all (or almost all) known and plausible flaw types encountered in CANDU steam generator tubes. This document provided the inputs to the development of the second document
In accordance with the CIQB guidelines, the Steam Generator Tube Inspection Specification COG-JP-4027-V11 provides the following information:

- Component description
- Component environment
- Observed or postulated degradation mechanisms
- Inspection requirements
- Performance demonstration technique requirements
- Target flaw size
- Inspection personnel qualification requirements
• The utility is responsible for specifying station-specific degradation mechanisms and conditions for which inspection qualification is required.

• For a given degradation mechanism, the utility should indicate whether the minimum qualification requirements prescribed in this specification apply, and provide any supplemental requirements that need to be addressed in the qualification.

• Therefore, to review and accept a qualification package, the CIQB requires:
  – The station-specific engineering requirements,
  – the Steam Generator Tube Inspection Specification, and
  – the Technical Justification including a training program.
**Target Flaw Size**

- Is defined as the specific flaw (character, shape and dimensions) for which it is necessary to demonstrate a high assurance of detection and the ability to accurately size.
  - Is the input into the Inspection Specification to be used in designing the inspection system.
  - Is the basis of the process for qualifying the inspection procedure and inspection personnel.

- **As a minimum**, the industry practice (based on EPRI) of using a 60% TW bounding generic target flaw size for demonstrating detection with 0.80 POD at a 90% CL **shall be met**.

- However, for each active or postulated degradation mechanism in any given steam generator the utility may define additional structural limits or condition monitoring limits, NDE detection and sizing capability, and plugging criteria.
### Target Flaw Size for CML

#### CML for Axial and Volumetric Flaws (Axial Length ≥ 5 mm)

<table>
<thead>
<tr>
<th>Axial Length</th>
<th>Limited Circumferential Extent*</th>
<th>Unlimited Circumferential Extent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15.9 mm (0.625&quot;) OD</td>
<td>12.95 mm (0.500&quot;) OD</td>
</tr>
<tr>
<td>5 mm &lt; 2(L_{eff}) ≤ 13 mm</td>
<td>65%TW</td>
<td>75%TW</td>
</tr>
<tr>
<td>13 mm &lt; 2(L_{eff}) ≤ 25 mm</td>
<td>59%TW</td>
<td>69%TW</td>
</tr>
<tr>
<td>25 mm &lt; 2(L_{eff})</td>
<td>55%TW</td>
<td>64%TW</td>
</tr>
</tbody>
</table>

\(2L_{eff}\) is the effective axial length of the flaw

#### CML for Circumferential and volumetric Flaws (Axial Length<5 mm)

<table>
<thead>
<tr>
<th>Axial Length</th>
<th>15.9 mm (0.625&quot;) OD</th>
<th>12.95 mm (0.500&quot;) OD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>76%da</td>
<td>82%da</td>
</tr>
</tbody>
</table>
### Detection Performance Requirements by Flaw Depth and Related FFS Assessment Range

<table>
<thead>
<tr>
<th>Category</th>
<th>Applies to</th>
<th>Generic Requirement to Qualify for Detection (Depth-based)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Flaws over CML (i.e. &gt;60%TW generic Target Flaw Size or CML per Tables 4 &amp; 5).</td>
<td>Shall have high POD and shall be demonstrated (needed to support Condition Monitoring (CM)).</td>
</tr>
<tr>
<td>2</td>
<td>Flaws over 40%TW CSA N285.4 Acceptance Criteria (or &gt;CML minus Growth)</td>
<td>Should have high POD; however, for certain flaw types/conditions this may not be achievable. In these cases, actual POD performance in this range shall be documented (needed to support Operational Assessment (OA)).</td>
</tr>
<tr>
<td>3</td>
<td>Flaws over 20%TW CSA N285.4 Reporting Criteria</td>
<td>Should have good POD; however, for certain flaw types/conditions, this may not be achievable. In these cases, actual POD performance in this range shall be documented (needed to support OA).</td>
</tr>
</tbody>
</table>

**Notes:**
Appendix A provides non-mandatory guidance for basic performance demonstration of Category 1 flaws. Appendix B provides non-mandatory guidance for augmented performance demonstration for flaws in all Categories (if additional information on NDE performance is required by utility engineering). An Appendix A approach (which may include selected elements of Appendix B) may be used as non-mandatory guidance to demonstrate POD performance for Category 2 and 3 flaws.
• Utility Engineering should provide the organization producing the qualification with the degradation mechanisms to be addressed, generic default requirements and targets, and any supplemental requirements before qualification work proceeds.

• In addition, Utility Engineering may also specify augmented requirements and targets specific to their station and flaw types that are not addressed in this table.
### Summary of Qualification Requirements for the Inspection of SG Tubing for Given Flaw Type

<table>
<thead>
<tr>
<th>NDE Performance criteria to be addressed</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Flaw Detection</strong></td>
<td>5.6, 5.7</td>
</tr>
<tr>
<td>POD: To qualify for detection, as a minimum, high POD at and above the target flaw size (60% TW or CML) shall be demonstrated, and actual performance below 60% TW/CML shall be demonstrated. Non-mandatory guidance is provided in Appendix A and B.</td>
<td></td>
</tr>
<tr>
<td><strong>Depth Sizing</strong></td>
<td>5.6, 5.7</td>
</tr>
<tr>
<td>Sizing accuracy: No target for depth sizing has been set. Actual sizing performance should be demonstrated over the full range of flaw detection. Non-mandatory guidance is provided in Appendix A and B.</td>
<td></td>
</tr>
<tr>
<td><strong>Length Sizing</strong></td>
<td>5.6, 5.7</td>
</tr>
<tr>
<td>Sizing accuracy: No target for length sizing performance has been set. When required, actual sizing performance should be demonstrated based on site-specific engineering requirements.</td>
<td></td>
</tr>
<tr>
<td><strong>Circumferential Extent Sizing</strong></td>
<td>5.6, 5.7</td>
</tr>
<tr>
<td>Sizing accuracy: No target for circ. extent sizing performance has been set. When required, actual sizing performance should be demonstrated based on site-specific engineering requirements.</td>
<td></td>
</tr>
<tr>
<td><strong>Flaw Location</strong></td>
<td>4, 5.2.2, Appendix C</td>
</tr>
<tr>
<td>Reliable locating of flaws relative to support structures or tube features (e.g., free span vs. supports, TTS, Expansion etc).</td>
<td></td>
</tr>
<tr>
<td><strong>Flaw Characterization</strong></td>
<td>5.2, 5.5.1, Appendix C</td>
</tr>
<tr>
<td>Flaws should be correctly characterized as ID or OD, and as Axial, Circumferential, or Volumetric.</td>
<td></td>
</tr>
<tr>
<td><strong>Flaw Resolution</strong></td>
<td></td>
</tr>
<tr>
<td>No performance requirement has been set for this parameter. Flaw resolution targets, when required, to be based on site-specific engineering requirements (e.g., minimal discernable distance between flaws).</td>
<td></td>
</tr>
</tbody>
</table>
## Summary of Qualification Requirements for the Inspection of SG Tubing for Given Flaw Type

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Description</th>
<th>TJ Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ID Magnetite</strong></td>
<td>Effect of ID deposits on POD and sizing should be addressed in the TJ.</td>
<td>3, 5.4.1, 5.4.2</td>
</tr>
<tr>
<td><strong>Tube Restrictions and geometries</strong></td>
<td>Limitations related to tube access shall be identified. Tube geometric effects on POD and sizing should be addressed in the TJ. Use of alternative probes should be considered.</td>
<td>5.4.1, 5.6, 5.7</td>
</tr>
<tr>
<td><strong>OD Deposits</strong></td>
<td>Effect of OD deposits on POD and sizing should be addressed in the TJ.</td>
<td>3, 5.4.1, 5.4.2</td>
</tr>
<tr>
<td><strong>Inspection Speed</strong></td>
<td>Inspection speed shall be addressed in the TJ. Sampling and digitizing rates for digital instruments should meet or exceed applicable industry standards (e.g., for ET, requirements of ASME Section V)</td>
<td>5.3.1, 5.4.3</td>
</tr>
<tr>
<td><strong>Probe Wear</strong></td>
<td>NDE probe wear and its effect on POD shall be addressed in the TJ, for probes susceptible to wear. ET-specific issues to consider include tolerance for probe centring, fill factor or lift-off (e.g., three-hole test, concentric-groove centring test) and criteria for signal quality (e.g., excessive spiking, signal drift).</td>
<td>5.4.2</td>
</tr>
<tr>
<td><strong>Noise</strong></td>
<td>Noise shall be addressed in TJ. No performance requirement has been set for this parameter. However, methods used to measure noise levels should be documented (see non-mandatory guidance in Appendices A, B)</td>
<td>5.8.2</td>
</tr>
<tr>
<td><strong>Training and Testing Program</strong></td>
<td>The NDE service provider shall have an effective training and testing program, and be addressed in the TJ. Recommended personnel training and testing program elements are provided in non-mandatory Appendix C</td>
<td>5.9</td>
</tr>
<tr>
<td><strong>False Calls</strong></td>
<td>False Call rates should be considered to maintain the effectiveness of personnel qualification tests. Non-mandatory guidance is provided in Appendix C.</td>
<td>Appendix C</td>
</tr>
</tbody>
</table>
Data set requirements include (similar for Appendix B):

- Data-set grading units be based on steam generator operating experience as inferred from tube pulls.
- Flaws should produce signals similar in terms of signal characteristics, signal amplitude, and S/N ratio, to those being observed in the field.
- Data sets generated using validated theoretical models may be used provided signals are similar to those being observed in the field in terms of signal characteristics, signal amplitude, and S/N ratio.
- Supplemental NDE techniques may be used to determine the flaw dimensions provided they are independent techniques and have been previously qualified for sizing in accordance with Appendix B.
- Where applicable, the influence of extraneous test variables associated with each of the damage mechanisms (e.g., denting, dings, OD and ID deposits, tube geometry changes, support structures) should be assessed.

UNRESTRICTED / ILLIMITÉ
Appendix A: POD Requirements

• Minimum detection data set is 11 flawed grading units.
  – For Category 1 flaws:
    – Data set shall be uniformly distributed over the depth range of 60% to 100% TW, or a range based on CML.
    – Minimum 0.80 POD @ 90% CL to be demonstrated. Uses decision threshold of 2/1 Calculates POD from Binomial distribution.
  – For Category 2 and 3 flaws:
    – Actual POD for Category 2 and 3 flaw ranges can be demonstrated, as outlined in Slide 9 for the ranges between 40% to 60% TW and 20% to 40% TW respectively. Target detection performance provided by the utility’s site-specific engineering requirements.

• POD calculations shall include the use of undetectable flaws; i.e., reported as no detectable degradation (NDD).
Appendix A: Sizing Requirements

Demonstrated for each damage mechanism/extraneous test variable combination, such as depth, length, circumferential extent.

- Minimum sizing data set is 16 grading units, including the detection set.
  - Sizing data set include samples with maximum measured size smaller than target flaw size.
  - For depth sizing, data set should be uniformly distributed over the depth range of 20% TW to target flaw size.
  - Calculated by using the standard error of regression and the correlation coefficient formulas. For the standard error of regression, it is recommended to use the 90/50-confidence level.
  - Also recommends to calculate root-mean-square error (RMSE) and mean error to evaluate sizing accuracy and the systematic inaccuracies in the NDE predictions, respectively.
Appendix B: Augmented Requirements for Performance Demonstration (non-mandatory)

POD requirements:

- Recommends that performance demonstration be based on generating NDE system performance data in accordance with the methods described in MIL-HDBK-1823A (Hit/Miss or à vs. a)
- Demonstrated by flaw category as per the requirements outlined in Slide 9, which can be demonstrated from a single calculated POD curve.
  - The data set shall be uniformly distributed over the depth range of interest.
  - Minimum detection data set is 20 flawed grading units, Recommended ≥40.
  - Noise levels should be measured from field data, and treated as outlined in MIL-HDBK-1823A. The methods used to measure these noise levels should be clearly explained and justified in the Technical Justification.
  - Different decision thresholds can be used, however, it is acceptable to base the decision threshold on a signal-to-noise ratio criterion of 2:1.
Appendix B: Sizing Requirements

Demonstrated for each damage mechanism/extraneous test variable combination, such as depth, length, circumferential extent.

• Minimum sizing data set requires a specific number of samples for each depth range (0-35% TW, 36-65% TW and 66-100% TW), including the detection set as follows:
  – When the sizing correlation is used for flaws left in service per the CSA acceptance criteria (e.g., 40% depth): >30 samples, composed of 10 samples per range.
  – Supporting fitness-for-service assessments only (OA & CM), >20 samples composed of >7, >6 and >7 samples for each depth range, respectively.
  – Calculated by using the standard error of regression and the correlation coefficient formulas. For the standard error of regression, it is recommended to use the 90/50-confidence level.
  – For tube integrity assessments, sizing performance should have a correlation coefficient at 95% confidence level for a positive correlation.
  – Calculate RMSE and mean error to evaluate sizing accuracy and the systematic inaccuracies in the NDE predictions, respectively.
Appendix C: Personnel Training and Qualification Guidelines (non-mandatory)

The purpose is to ensure a uniform knowledge base and skill level for data analysis, and knowledge of the procedures, techniques and instructions relevant to the work.

- Site Specific Performance Demonstration (SSPD) prior to each inspection campaign includes
  - Steam generator design, layout, and structures.
  - Existing and postulated degradation mechanisms.
  - Procedures, techniques and instructions relevant to the work.
  - Expected typical flaw responses and non-flaw responses (graphics and/or raw data with evaluated results).
Appendix C: Personnel Examination Requirements

- Trainers should be at least CAN/CGSB Level II certified individuals, written and practical final examinations should be reviewed CAN/CGSB Level III certified individuals.
- Written examinations on the procedures, techniques and instructions open book, minimum 10 questions and 80% passing grade.
- Practical: Grade each individual based on randomly selected data sets for each degradation mechanism.
  - Minimum acceptance criterion for flaws detection $\geq 0.80$ POD at a 90% CL 11 minimum number of gradable flaws (based on expert opinion).
  - False call rate: Unflawed grading units should be two times that of the flawed grading units. If 11-17 sample set: no false calls accepted. If >17 sample set, then <10% of unflawed grading units.
  - Two re-attempts permitted.
Issues not Addressed by the Inspection Specifications

Subjects of a current COG R&D Work Package
• Noise measurements methods and effect on POD.
• Minimum number of noise measurements.
• In-situ noise assessment.
• Effect of false call rate on POD.

Subjects of future work
• Calibration tube quality requirements.
• Data analysis and documentation of results requirements for qualification exercises.
• Effect of tube geometry, deformations, denting.