ELECTRIC POWER
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Steam Generator Management Program: Steam Generator In Situ Pressure Test Guidelines, Revision 4

2012 TECHNICAL REPORT

Steam Generator Management Program: Steam Generator In Situ Pressure Test Guidelines, Revision 4

This document does NOT meet the requirements of 10CFR50 Appendix B, 10CFR Part 21, ANSI N45.2-1977 and/or the intent of ISO-9001 (1994)

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1025132NP

Final Report, October 2012

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This publication is a corporate document that should be cited in the literature in the following manner:

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Information in this document provides guidance for the performance of in situ pressure testing of steam generator tubes. In situ pressure testing refers to hydrostatic pressure tests performed on installed tubing in the field. Such testing is considered a direct means of evaluating tube structural and leakage integrity. In situ pressure testing can be used to support condition monitoring of steam generator tube integrity.

This is a required document for a steam generator program developed in accordance with NEI 97-06 and reviewed for update every two years.

Background

Degradation of steam generator tubing can lead to a decrease in the load bearing capacity of the tubes and may compromise pressure boundary leak tightness. When such degradation is found during steam generator inspections, evaluations are performed to ensure that required structural margins are maintained and that leakage, if it occurs during normal operation or during design basis accident events, remains within allowable limits. Structural integrity and leak rate evaluations may be based on in situ proof and/or leak testing of tubing sections with eddy current indications of degradation. Since this testing allows for the direct measurement of structural and leakage conditions, the results provide a key element in the assessment of steam generator tubing structure and leakage integrity.

Objectives

- To document standard approaches and to provide requirements for the performance of in situ pressurization tests and the application of this test data. This document summarizes industry practices used successfully in the field via a recommended test protocol. Standardization will promote industry-wide consistency in test performance and the application of the results.

- To supplement the condition monitoring process as required by NEI 97-06, Steam Generator Program Guidelines and described in the EPRI report Steam Generator Integrity Assessment Guidelines.

Summary of Significant Changes

- For proof testing screening, volumetric degradation +Point probe threshold voltages were developed for initial screening of volumetric degradation to replace the conservative 0.5 volt screen.

- For leak test screening, +Point probe threshold voltages were developed for circumferential degradation under pressure and bending loads. These voltages supplement/replace the historic threshold voltages developed from in situ pressure test and destructive exam data.

- For leak test screening, +Point probe threshold voltages were developed for foreign object wear under pressure and bending loads.

- For leak test screening, +Point probe threshold voltages were developed to account for large break loss of coolant accident loads in once-through steam generators for circumferential degradation.

Results

This document includes information regarding tooling qualification, testing procedures, and the selection of tubes for testing. Appendices of this document provide details for a statistical approach for a selection of tubes for testing and supporting data for technical sections.

EPRI Perspective

Condition monitoring of steam generator tubing during a plant outage is a requirement of NEI 97-06. The application of in situ pressure test results is a useful tool in satisfying the requirements of condition monitoring of steam generator tube integrity. The publication of this document represents the best industry practices to date, and later revisions are expected as experience is gained through the use of this document.

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Condition monitoring

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A group of industry experts in structural and leakage integrity of steam generator tubing developed guidance for integrity verification by in situ pressure test. This document, together with the EPRI *Steam Generator Integrity Assessment Guidelines* [2], provide the tools for compliance with program elements contained in NEI 97-06, *Steam Generator Program Guidelines* [1]. This document contains requirements and guidance on test objectives, test conditions, post-test requirements, procedural specifications, and screening criteria for proof and leak testing.

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Section 1: Introduction

1.1 Background

Degradation of steam generator tubing can lead to decreases in load bearing capacity and may compromise pressure boundary leak tightness. When such degradation is observed, evaluations are performed to ensure that required structural margins are maintained and that leak rates, should leakage occur, will remain within allowable limits. NDE test results can be analyzed by a variety of methods to demonstrate that condition monitoring requirements are met:

- Analytical/semi-empirical calculations of burst pressures and leak rates. Procedures and equations for performing these evaluations are included in the Flaw Handbook [5] and the Integrity Assessment Guidelines [2].
- Laboratory burst and leak tests of pulled tubes with service-induced degradation
- In situ leak and/or proof testing of sections of tubing with eddy current indications of degradation

Figure 1-1 illustrates the relationship between the Integrity Assessment guidelines and the In Situ Pressure Test guidelines. The requirements of this guideline (i.e., shalls) apply when condition monitoring is performed by in situ screening per Figure 1-1.

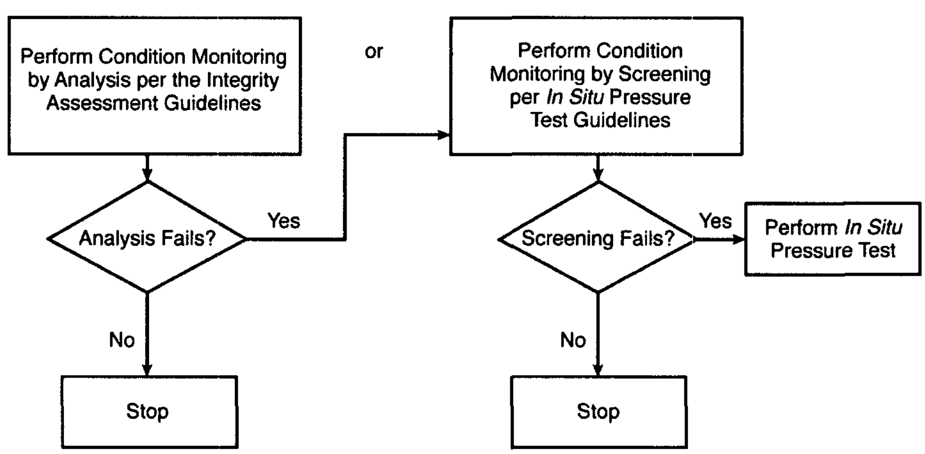

Figure 1-1
Relationship between Integrity Assessment and In Situ Pressure Test Guidelines

Since uncertainties vary from one method to another it is possible for one method to verify that condition monitoring requirements are met while another method fails to do so. If all relevant uncertainties are properly included, condition monitoring is met if any single method demonstrates that the worst case degraded tube meets structural and leakage performance criteria with a probability of 0.95 at 50% confidence.

Historically, some combination of the first two elements, inspection plus analysis and pulled tube examinations has formed the basis for structural integrity and leak rate evaluations. Testing of tubes removed from the steam generator provides an informative option with some uncertainty due to tube damage from the pulling operation. However, pulled tube examinations are expensive in terms of time, money and radiation exposure. Using eddy current inspection results to characterize the geometry of tube degradation coupled with analytical/semi-empirical calculations of burst pressures and leak rates is an economic, reliable option, but consideration of the uncertainties in sizing degraded regions can lead to overly conservative assessments of the severity of the detected degradation.

Since 1993, in situ pressure testing has been widely used in support of structural integrity and leak rate evaluations. In situ pressure testing refers to hydrostatic pressure tests performed on installed tubing in the field. The purpose of these tests is to demonstrate that the selected tubes satisfy specified structural and accident-induced leak rate performance criteria. For example, in situ testing has been used by many utilities to verify structural margins in instances where flaw NDE parameters have approached or exceeded minimum structural integrity threshold values (reduced for uncertainty). In situ pressure testing may be required to support the condition monitoring and operational assessment requirements of NEI 97-06, Steam Generator Program Guidelines [1] if other methods fail to do so.

The benefits of direct evaluation of the strength and leak rate properties of degraded sections of tubing can be realized with in situ testing. In situ testing allows for the measurement of structural and leakage margin without the inherent cost, schedule and potential uncertainties associated with pulling tubes for laboratory testing. For example, there has been documented evidence that the tube pulling operation can further degrade the flaw of interest (particularly if the flaw is circumferential in orientation) thereby introducing suspect leak and burst information. Additionally, pulled tube activities and subsequent laboratory time typically do not provide real time information to the user. As such, in situ testing has become a key element in the condition monitoring and operational assessment process.

The scope of this guideline includes tooling qualification, testing procedures, and information regarding the documentation and analysis of test results. This document also provides detailed protocols for the selection of tubes with various forms of degradation for in situ testing. Finally, the in situ testing guidelines, presented herein, are intended to complement the EPRI guidelines for laboratory burst and leak rate testing of steam generator tubing [3]. As such, the field test data may be used to support existing and future burst and leakage correlations.

1.2 Purpose

This document provides guidance and requirements for: (1) the conduct of in situ pressurization tests (2) the selection of steam generator tubes for structural integrity verification (3) the selection of tubes for in situ leak testing when leakage is present or has the potential to develop during normal operating or accident conditions and (4) engineering assessment of in situ results including necessary adjustments to relate room temperature test data with operating and accident conditions. If condition monitoring is proven by analytical/semi-empirical calculations of burst pressures and leak rates, the guidance in this document is not needed.

The information from in situ pressure testing is intended to support condition monitoring and operational assessments as required by NEI 97-06 [1] and described in the EPRI Steam Generator Integrity Assessment Guidelines [2]. The guidance provided in this document is experience-based, in that the protocol and desired output are achievable with available technology.

1.3 NEI 97-06 Requirements

The U.S. nuclear power industry established a framework for increasing the reliability of steam generators by adopting NEI-97-06 [1]. This initiative references the Steam Generator Integrity Assessment Guidelines as the basis for an industry consensus approach to demonstrating the condition of steam generators relative to the performance criteria. Specifically, the initiative requires that US nuclear power plant licensees meet the intent of the Steam Generator Integrity Assessment Guidelines [2]. The focus of the NEI initiative is steam generator integrity. All US plants have adopted Steam Generator Technical Specifications based on NEI 97-06 (TSTF 449 [26]).

The Steam Generator Management Program (SGMP) Administrative Procedures [4] and NEI 03-08 [27] include protocol that is to be followed by guideline revision committees with regard to establishing the level of implementation expected by a licensee. In particular, three categories or elements have been established: "Mandatory" requirements, "Needed" requirements (identified in SGMP documents as "Shall" requirements), and "Good Practice" elements (identified in SGMP documents as "Recommendations"). These categories are clearly defined in reference [27] and summarized below.

Mandatory – to be implemented by all plants where applicable

- Element substantively affects the ability of structures, systems and components to perform their intended safety function.
- Element would be highly risk significant if not implemented.
- Element poses a significant threat to continued operation of the affected plants, including economic threats that could reasonably lead to protracted plant shutdown or retirement.
- A consensus of the committee believes the element should be designated as "Mandatory

Needed (Shall) – to be implemented wherever possible, but alternative approaches are acceptable

- Element substantively affects the ability of structures, systems or components to reliably perform their economic function.
- Element would be moderately risk significant if not implemented.
- Element addresses a material degradation mechanism that has significant financial impact on the entire industry, especially where failure at one plant could affect many other plants.
- A consensus of the committee believes the element should be designated as "Needed"

Good Practice (Recommendations) – implementation is expected to provide significant operational and reliability benefits, but the extent of use is at the discretion of the individual utility.

- Element reflects an industry standard of performance or represents a consensus opinion of the committee.
- A consensus of the responsible committee believes the element should be designated as "Good Practice".

There are no mandatory requirements in this document. The "Shall" requirements and "Recommendations" appear throughout the document and are listed in Section 10.

The performance criteria address structural tube integrity, postulated accident leakage, and operational leakage, and are discussed in Section 2 of the Steam Generator Integrity Assessment Guidelines [2]. Internal and external documentation and reporting requirements are detailed in Section 7.

Section 2: Proof and Leak Test Objectives

NEI 97-06, Steam Generator Program Guidelines [1], requires that the utility assess tube integrity each time a steam generator tube is inspected, plugged, or repaired. The purpose of the assessment is to ensure that the performance criteria for structural and leakage integrity have been met for the previous operating period (e.g., condition monitoring) and will continue to be met for the next operating period (e.g., operational assessment). Meeting the structural criteria generally involves demonstrating that the burst pressure for the degraded tube meets a specified value containing a defined safety margin. In situ pressure testing to demonstrate structural integrity is referred to in this document as "proof testing." Satisfying leakage criteria requires demonstrating that the total leakage from all tubes with flaws meets the licensing basis limits for accident leakage. This is typically at a lower pressure than the proof test. In situ pressure testing to demonstrate leakage integrity is referred to in this document as "leak testing."

For damage mechanisms with alternate repair criteria approved by the NRC, portions of this document may not apply. For example, Generic Letter 95-05 Alternate Repair Criteria includes a methodology for structural and leakage assessments.

2.1 Test Objectives

- Demonstrate that structural and leakage integrity at end-of-cycle (EOC) satisfies the performance criteria in support of the condition monitoring assessment.
- Provide data to support a relationship between NDE data, proof test results, and calculated structural thresholds for use in condition monitoring and operational assessments.
- Establish an upper limit NDE threshold for indications that could exhibit large leak rates during postulated accident conditions.
- Obtain leak rate test data to support structural evaluations in cases where tube geometry does not support proof testing. Extrapolated leakage data combined with NDE results may characterize flaws as meeting structural requirements.

- Determine whether a relationship exists between indications that exceed the NDE based structural threshold and potential outlier leakage behavior.
- Obtain test data to support predictions of steam line break (SLB) leak rates from NDE data to be applied to condition monitoring and operational assessments.
- Obtain test data to demonstrate the leakage performance of leak limiting repairs.

Section 3: Compliance Responsibilities

3.1 Introduction

The objective of this section is to identify utility responsibilities for assuring that in situ testing activities achieve their full potential to enhance steam generator reliability.

3.2 Responsibilities

The responsibilities of the steam generator engineering organization include the planning, directing, and evaluation of in situ testing.

The steam generator engineering organization is responsible for all aspects of this guideline, including the requirements and recommendations summarized in Section 10.

NDE responsibilities performed by NDE personnel are described in the Section 3.3.

3.3 NDE Considerations

Supplemental NDE activities may be useful in supporting engineering evaluations of test results. These include:

- Conducting supplemental diagnostic NDE, as necessary, to characterize the critical flaw parameters. For example, ECT rotating pancake and/or +Point probe may be considered to further characterize the flaw, including the peak and average depth of penetration, peak voltage, total length and width, through-wall length (if applicable), and effective length above the threshold length recommended for testing.
- Using other NDE techniques (such as ultrasonics, liquid penetrant) to further characterize the flaw profile particularly the through-wall length/area.
- NDE data evaluation by sizing analysts in addition to the production analysts. The use of sizing analysts will provide added assurance that the NDE uncertainty numbers applied to the screening criteria are not encroached upon.
- Post testing NDE, including visual inspections, to evaluate changes in flaw characteristics.

Section 4: Screening Parameters/Tube Selection

4.1 Purpose

This section describes an acceptable method for screening indications for in situ leak and proof testing. There may be other acceptable methods; however, technically justifying their application would be the utilities' responsibility. The purpose of the in situ test screening is to identify indications requiring testing in order to assess the capability of the steam generator tubing to meet structural and leakage performance criteria. Indications that exceed the screening criteria shall be in situ pressure tested.

This section provides screening criteria for in situ leak testing and proof testing under several different scenarios:

- Screening criteria for proof testing when sizing capabilities are fully quantified. Quantified sizing is used in this document to refer to a sizing technique where uncertainties are known and documented for all necessary screening values. This sizing is typically performed by a small subset of the production analysts who are specifically trained.
- A ranking methodology for proof testing indications when sizing capabilities are not fully quantified. The basis for this methodology is included in Appendix C.
- Screening criteria for leak testing. This screen has steps that are applicable to techniques with and without quantified sizing techniques.
- Voltage thresholds for leak testing and proof testing. Appendix B provides the basis for development of voltage screening threshold values.
- Development of proof and leak test limit curves to screen indications, when sizing capabilities are fully quantified, using a statistical approach (Appendix A) applying methods from the EPRI Steam Generator Integrity Assessment Guidelines [2].
- Screening methodology for mixed mode flaws.

Figures 4-1 and 4-2 are flow charts depicting Section 4 screening.

Appendix D identifies indications and situations that are exempt from in situ testing (e.g., location of the flaw in surrounding support structures, physical limitations of the in situ test equipment due to the location of the flaw).

4.2 Nomenclature and Definitions

Except where noted otherwise in the following definitions, calculated plant-specific screening thresholds should include the effects of uncertainties, consistent with the condition monitoring requirements of EPRI Steam Generator Integrity Assessment Guidelines [2].

The terminology used in this section is defined as follows:

AD — *Average depth* – AD is the percent through-wall depth of an axially oriented flaw (crack-like or volumetric) which, when paired with the effective length of the flaw, is structurally equivalent to the measured flaw depth profile. The effective depth and length of an axial crack are the values consistent with segments of a partial depth crack that lead to the minimum estimate of the burst pressure (Flaw Handbook, [5]). AD may be calculated from the NDE-measured, depth profile (using the EPRI Flaw Handbook weak-link method), or may be estimated for a known flaw shape by applying an empirical max/avg depth ratio to the measured maximum depth.

AD_{THR-P} — *Average depth threshold for proof testing* – AD_{THR-P} is the length specific structural average depth threshold over the effective flaw length which satisfies the structural integrity performance criteria for condition monitoring. A partial through-wall depth burst model is used to develop AD_{THR-P}. AD_{THR-P} includes the effects of burst correlation, material property and NDE sizing uncertainties using the statistical criteria established in the Integrity Assessment Guidelines [2].

ARF — *Axial ranking factor* – A parameter used to rank the relative severity of axially oriented flaws when quantified sizing techniques are not available. ARF values are calculated from the NDE-measured maximum depth and length of the flaws. Flaws with larger values of ARF are considered in the ranking protocol to be more structurally challenging.

CRF — *Circumferential ranking factor* – A parameter used to rank the relative severity of circumferentially oriented flaws when quantified sizing techniques are not available. CRF values are calculated from the NDE-measured maximum depth and crack angle of the flaws. Flaws with larger values of CRF are considered in the ranking protocol to be more structurally challenging.

PDA *Percent degraded area* – PDA is a parameter that represents the size of circumferentially oriented degradation as a percentage of the cross-sectional area of the tube material. It may be calculated from the NDE throughwall depth and circumferential extent of the degradation, or may be measured directly by certain NDE techniques.

PDA_{THR-P} *Percent degraded area threshold for proof testing* – PDA_{THR-P} is the limiting calculated value of PDA which satisfies the structural integrity performance criteria for condition monitoring. PDA_{THR-P} includes the effects of burst correlation, material property and NDE sizing uncertainties using the statistical criteria established in the Integrity Assessment Guidelines [2].

L *Length* – Total axial flaw length in inches, as indicated by an NDE measurement.

L_{STR} *Length, structural* – The limiting calculated length of an axial crack which satisfies the structural integrity performance criteria regardless of its depth. L_{STR} includes the effects of burst correlation and material property uncertainties using the statistical criteria established in the Integrity Assessment Guidelines [2]. NDE uncertainties are not included since the crack is assumed to be through-wall and the length will be overestimated due to coil lead-in and lead-out effects.

L_{MIN} *Length, minimum* – The minimum physical length (inches) of a 100% through-wall axial crack that could result in leakage under limiting accident conditions (L_{MIN} = 0.1").

CA *Crack angle* - The total circumferential extent of a circumferential crack in degrees as determined by NDE measurement.

CA_{TWSL} *Crack angle structural threshold* – CA_{TWSL} is the limiting calculated angle of a 100% through-wall circumferential crack, which satisfies the structural integrity performance criteria. CA_{TWSL} is computed from PDA_{THR-P} where CA_{TWSL} is equal to 360 PDA_{THR-P}/100.

CA_{MIN} *Minimum crack angle for leakage* – CA_{MIN} is the minimum physical 100% through-wall angle in degrees for a circumferential crack that could result in leakage under limiting accident conditions (CA_{MIN} = 20 degrees).

CE *Circumferential extent of a volumetric indication* - CE is the total angle in degrees of a volumetric flaw in the circumferential direction as determined by NDE measurement.

MD *Maximum depth* – MD is the maximum depth in percent through-wall of an indicated flaw as determined by NDE measurement.

MD_{THR-L} *Maximum depth threshold for leakage testing* – MD_{THR-L} is the limiting calculated value of maximum degradation depth (percent through-wall) for the degradation length of concern that would leak under limiting accident conditions for pop-through. MD_{THR-L} includes the effects of the model correlation, material property and NDE sizing uncertainties using the statistical criteria established in the Integrity Assessment Guidelines [2].

MD_{THR-P} *Maximum depth threshold for proof testing* – MD_{THR-P} is the limiting calculated value of maximum degradation depth (percent through-wall) for the degradation length of concern which satisfies the structural integrity performance criteria for condition monitoring. The degradation length of concern could be the indication-specific length or a bounding length. Applicable burst equations are given in the EPRI Flaw Handbook [5]. MD_{THR-P} includes the effects of burst correlation, material property and NDE sizing uncertainties using the statistical criteria established in the Integrity Assessment Guidelines [2]. If MD_{THR-P} is used as AD_{THR-P} in the calculation, no NDE uncertainties are added.

VM *Maximum voltage* – The maximum peak-to-peak voltage indicated for the flaw. VM can be used for proof and leak test screening with or without quantified sizing techniques. Voltage calibrations are performed per the requirements of Section 4.4.

V_{CRIT} *Critical voltage for leakage* – Threshold peak-to-peak voltage that corresponds to a potential large leak and/or a high probability of leakage under limiting accident conditions for the detected degradation. V_{CRIT} is dependent on the degradation mechanism and tubing condition (see Table 4-1)

V_{THR-L} *Threshold Voltage for Leak Testing* – Threshold peak-to-peak voltage below which leakage under limiting accident conditions is unlikely to occur for the detected degradation. V_{THR-L} is a conservatively established threshold. V_{THR-L} is dependent on the degradation mechanism and tube condition (see Table 4-1).

Key terms or phrases used in this document are defined as follows:

Design Basis Accident Conditions Test Pressure

This test pressure demonstrates compliance with leakage integrity performance criteria of NEI 97-06 [1] associated with design basis accident.

Elevated Test Pressure

If it is desired to show that additional margin exists in the condition monitoring, assessment test pressures may be elevated beyond the required test pressures up to the maximum qualified pressure of the in situ system.

Intermediate Leak Test Pressure

If a leak is suspected, or occurs during performance of the test, an intermediate test pressure is intended to provide an additional leak rate point prior to the accident condition test pressure. This information may be helpful in case of a failure. Select a pressure approximately half way between NOPD and the estimated maximum achievable pressure up to the accident condition test pressure.

Intermediate Proof Test Pressure

Pressures with the minimum hold times at approximately every 500 psig or less, above the postulated accident conditions test pressure. Structural capability can only be related to the highest held test pressure.

Leak Test

A leak test is an in situ pressure test used to demonstrate leakage integrity. Satisfying leakage criteria requires demonstrating that the total leakage from all tubes with flaws meets the licensing basis limits for accident leakage. This is typically at a lower pressure than the proof test.

Proof Test Pressure

The proof test is defined as the pressure test demonstrating compliance with the structural integrity performance criteria of NEI 97-06 [1].

Proof Test

A proof test is an in situ pressure test used to demonstrate structural integrity. This involves demonstrating that the burst pressure for the degraded tube meets a specified value containing a defined safety margin.

Quantified Sizing

Quantified sizing is used in this document to refer to a sizing technique where uncertainties are known and documented for all necessary screening values. For example, if an axial crack indication is being screened, an applicable ETSS contains sizing uncertainties associated with length and depth. Sizing uncertainties are applied in accordance with the Integrity Assessment Guidelines [2].

4.3 General Guidance

The following general guidance applies to all types of indications:

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4.4 Probe and Voltage Normalization Requirements

As discussed in Appendix B, when applying the voltage threshold values of Table 4-1 for a specific plant application, it is important that the voltage calibration and analysis methods used to analyze field indications be consistent with the evaluation methods for prior in situ and destructive exam results. If the planned field voltage normalizations differ from the normalizations defined below, it may be necessary to reanalyze the more limiting prior in situ and destructive exam data to assure consistency with the field inspection voltage analysis methods.

For crack indications, the requirements to use the +Point voltage threshold values are:

- Analysis frequency: 300 kHz unless otherwise indicated in the section describing the correlation
- Voltage Normalization: The voltage values are set to 20 volts peak-to-peak on the appropriate 100% TW notch, at the maximum amplitude response near the center of the flaw, individually for each channel. Appropriate notch means a circumferential notch for a circumferential sensitive channel and an axial notch for axial sensitive and non directional channels.
- Voltage analysis: peak to peak volts
- Circumferential volts based upon axial lissajous analyses

For volumetric indications, the requirements to use the bobbin voltage threshold values are based on the following voltage normalization:

- Using the four 20% TW flat-bottom holes located on the ASME standard, set the peak-to-peak voltage to 4 volts for each channel and to 2.75 volts for the prime/quarter mix channel, or
- When using a repair criterion based on the correlation of a technique parameter to a structural parameter (for example, voltage versus burst pressure) normalized to a single reference standard, the transfer standard method of voltage correction, as defined by the alternate repair criteria, may be applied for NDE parameter normalization in the field to maintain consistency to that correlation, or

- Normalizing all standards to a single site-reference standard (the transfer standard method of correction, similar to the alternate repair criteria method) is acceptable, provided the single site-reference standard is normalized to 4 volts peak-to-peak on the four 20% TW flat-bottom holes to develop the transfer voltage.

For foreign object wear, the requirements to use the +Point voltage threshold values are based on the following voltage normalization:

- If +Point voltage screening values are applied to foreign object wear, the +Point 300 khz voltage is normalized to 20 volts peak-to-peak (Vpp) on 100%TW axial slots per the series of Eddy Current Technique Specification Sheet (ETSS) 2790X documents. NDE axial and NDE circumferential extent is determined using the goalpost method (null to null approach) also mentioned in the ETSS 2790X series documents.

4.5 Guidance on Tube Selection for Proof Testing

Figure 4-1 provides a flow chart depicting the proof test screening process for axial, circumferential, and volumetric flaws.

4.5.1 Initial Voltage Screening

The following are initial voltage screening values that can be used for the appropriate degradation mechanism for structural integrity. The quoted voltage values refer to + Point probe peak to peak values. The bases for the screens are in Appendix B.

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4.5.2 Guidance on Proof Test Tube Selection When Sizing Capabilities are Quantified

The selection process in this section should be utilized if NDE sizing capabilities are fully quantified. Where NDE uncertainties are required, use the statistical criteria established in the Integrity Assessment Guidelines [2].

The proof test selection process applies to pressure only loading. Although, axial defects are not affected by other contributing loads, circumferential and volumetric defects are affected by primary bending and axial membrane stresses. However the typical limiting structural integrity performance criterion (SIPC) is 3xNOPD. It is uncommon for accident loading with the appropriate safety factors to be the limiting SIPC.

One notable exception is circumferential and/or volumetric defects in once-through steam generator (OTSG) tubing under high axial loads during a large break loss of coolant accident (LBLOCA) event. When circumferential and/or volumetric degradation is present, determine the limiting SIPC. If contributing loads other than pressure must be considered condition monitoring should not be demonstrated by in situ pressure testing. Follow the guidance of the Integrity Assessment Guidelines. Examples are in Integrity Assessment Guidelines, Appendix E.

Compare NDE measurements of the as-found indications with plant-specific threshold values. Perform sequential screening, such that only indications that exceed a threshold value for the preceding screening parameter are evaluated against subsequent parameters. Screening protocols are included for axial SCC, circumferential SCC, volumetric flaws including foreign object wear, and mixed mode SCC flaws.

4.5.2.1 Axial Defects

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4.5.2.2 Circumferential Defects

In Section 4.5.1, a quick voltage screen was provided for proof testing of circumferential indications. If this screen was exceeded, continue screening the indications as follows.

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4.5.2.3 Volumetric Defects

Volumetric indications are characterized as degraded areas with measurable length, width and depth (i.e., three-dimensional degradation) in which essentially the complete volume of metal is degraded as opposed to localized degradation such as stress corrosion cracking (two-dimensional degradation). Volumetric degradation has been associated with corrosion (pitting, intergranular attack, wastage, and thinning) or with mechanical mechanisms (wear at tube supports and wear due to foreign object interaction). Pitting, IGA, wastage, and thinning have all but disappeared due to current secondary side chemistry control, steam generator replacement, and balance of plant heat exchanger replacement activities.

As explained in Appendix D, proof testing of pits for structural integrity assessment is not required, since documented evidence indicates that these defects do not significantly impact the burst strength of steam generator tubes.

4.5.2.3.1 Foreign Object Wear and Cold Leg Thinning

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4.5.2.3.2 Wear at Tube Support Plates and AVB/Straps

This screening methodology is based on +Pt 300/100 kHz mix, peak-to-peak signal characteristics.

In Section 4.5.1, quick voltage screens are provided for proof testing of wear at supports and AVB/Straps. If these screens were exceeded, continue screening the indications as follows.

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4.5.3 Guidance on Proof Test Tube Selection for When Sizing Capabilities are not Quantified

The selection process in this section should be utilized when NDE sizing capabilities are not fully quantified for the degradation being assessed. An example degradation mechanism is circumferential cracking at hard roll expansion transitions.

Appendix C provides the basis for a tube selection screening protocol for proof testing that is applicable for indications that do not have quantified NDE measurement uncertainties. The process begins with a quick screening and ends with a calculated relative ranking.

4.5.3.1 Axial Defects

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4.5.3.2 Circumferential Cracks

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4.5.4 Alternative Screening Methodology for Proof and Leak Testing

Appendix A provides an alternative tube selection process to Section 4.5.2. Similar to Section 4.5.2, Appendix A protocol is only applicable for indications that are sized with NDE techniques that have quantified measurement uncertainties. Appendix A process evaluates statistically the structural and leakage condition monitoring limits in terms of the material, NDE, and correlation uncertainties. Limit curves are developed and defined in terms of the indicated NDE measurement parameter. Inspection results can be plotted and compared to the limit curves to establish test candidates.

Appendix A applies the Integrity Assessment Guidelines and Flaw Handbook methods for determining tube integrity. If tube integrity is established using this methodology, in situ pressure test screening using the methodology in the earlier sections in this guideline is not necessary.

4.6 Leak Test Screening Criteria for Techniques with and without Quantified Sizing

Figure 4-2 provides a flow chart depicting the leak test screening process for axial, circumferential, and volumetric flaws.

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Table 4-1
Degradation Specific Leakage Screening Voltage Values (Pressure Only Loading)

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Table 4-1 (continued)
Degradation Specific Leakage Screening Voltage Values (Pressure Only Loading)

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Degradation Specific Leakage Screening Voltage Values

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Table 4-1 (continued)
Degradation Specific Leakage Screening Voltage Values

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Table 4-1 (continued)
Degradation Specific Leakage Screening Voltage Values

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Table 4-2
Degradation Specific Proof Test Screening Voltage Values

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4.7 Mixed Mode Defects – Guidelines for Selecting Flaws for Proof and Leak Testing

A mixed mode flaw for this section is defined as an axial indication and a circumferential indication located in general proximity to each other (e.g., at the same tube support plate (TSP) intersection). This section does not apply to other forms of interacting indications. Perform an in situ leak and proof test if degradation is determined to be interacting, and not applicable to WCAP 15574.

Westinghouse non-proprietary Class 3 report WCAP-15574, Rev. 1, "*Depth-Based SG Tube Repair for Axial PWSCC at Dented TSP Intersections – Alternate Burst Pressure Calculation,*" (ADAMS accession numbers ML013250021 and ML013250033) [8] provides burst test data for mixed mode indications and general guidance on mixed mode effects. With the exception of circumferential cracks having average depths near the axial crack > 75% and an axial crack having a through-wall length > 0.25 inch, a separation distance of 0.25 inch reduces mixed mode effects on burst pressures or leakage to negligible levels. Indications with an axial through-wall length > 0.25 inch would likely require in situ testing based on leakage evaluations independent of mixed mode considerations. For the purposes of in situ test screening, indications having separation distances < 0.25 inch are defined as interacting.

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A. Determine if either the circumferential or axial indication requires testing based on the individual crack sizes.

Refer to Sections 4.5.2.1 and 4.5.3.1 for axial cracks and 4.5.2.2 and 4.5.3.2 for circumferential cracks.

If no testing is required based on the size of the individual indications go to Step B.

B. Determine if the circumferential and axial indication are interacting.

WCAP-15574, Rev. 1 [8] provides test data supporting the use of an 80 mil high frequency coil to measure separation distances based on the null point distance between the axial and circumferential indications. In order to follow the guidance in this section, follow the technique defined in WCAP-15574, Rev. 1 [8].

Indications having separation distances < 0.25 inches are defined as interacting.

A separation distance of 0.25 inch is adequately demonstrated when the following are satisfied:

A ≥ 0.075 inch null point distance between the axial and circumferential indications is required to demonstrate acceptable separation for OD circumferential indications.

A ≥ 0.050 inch null point distance between the axial and circumferential indications is required to demonstrate acceptable separation for ID circumferential indications.

If the circumferential and axial indications are ≥ 0.25 inch apart, the indications are not considered interacting and are treated separately under Step A. If the circumferential and axial indications are < 0.25 inch apart, the indications are considered interacting, and further screening is required in Step C.

C. Determine the need for proof testing when the indications are interacting and go to Step D.

If interacting indications having either a circumferential average depth > 75% or an axial average depth > 80% or an axial through wall length > 0.25 inch perform a proof test due to the potential for mixed mode reductions in burst pressures.

D. Determine the need for leak testing when the indications are interacting.

If the circumferential average depth is > 50% and the axial indication could be expected to leak, perform a leak test due to the potential for the mixed mode effects increasing the axial indication leak rate.

4.8 Test Results

If all tested indications achieve pressures demonstrating that structural performance criteria are satisfied, proof testing is terminated. Similarly, if no leakage occurs at accident pressures demonstrating that leakage performance criteria are satisfied, leak testing is terminated. Observed test leakage does not directly imply failure of the leakage performance criteria. Moderate leakage would be expected for some of the indications that exhibit NDE characteristics exceeding the threshold values. If a fraction of the tested indications leak such that a bounding leak rate for the steam generator can be estimated from the leak rate data and this bounding leak rate is less than the allowable leakage limit, then performance criteria is satisfied.

If performance criteria are not satisfied or if leakage is observed during testing for a flaw at or below the screening values, the utility shall review the screening values. It may be necessary to revise the values, re-screen indications that did not require testing, and perform additional in situ testing.

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Figure 4-1
In Situ Proof Test Flowchart for Axial, Circumferential, and Volumetric Flaws

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Figure 4-1 (continued)
In Situ Proof Test Flowchart for Axial, Circumferential, and Volumetric Flaws

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Figure 4-2
In Situ Leak Test Flowchart for Axial, Circumferential, and Volumetric Flaws

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Figure 4-3
Foreign Object Wear Accident Leakage Thresholds with Bending Loads (see also Table 4-1)

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Section 5: In Situ Test Definitions (Deleted)

This section has been deleted.

Section 6: Test Procedure

6.1 Procedural Requirements

In situ testing shall be conducted in accordance with a utility approved procedure. Since the test results are used to support tube integrity assessments, the test apparatus, instrumentation and procedures comply with the requirements of 10CFR50 Appendix B.

The test procedure provides a test record identifying hold points, tooling, tube number, location, type of degradation to be tested, and the intended test sequence. The steps outlined below should be specified in the test procedures and include plant specific test pressures. These steps are not considered all inclusive and alternative plans may be acceptable depending on the test objectives (e.g., only leak testing may be necessary for indications restricted from burst – See Appendix D). Contingency plans are included in this guidance to address the event that measured leak rates exceed test system capacity, or excessive leakage terminates structural integrity pressure testing. In these cases a comparison of pressures, leak rate pressure differentials and tooling response provides a check to ensure that the full benefit of in situ testing will be realized.

No leakage is defined as a zero leak rate value as determined at the specified hold point. A minimum hold period of two (2) minutes shall be used to establish a zero leakage condition. If leakage occurs, continue testing until the leak rate stabilizes by remaining constant over a two (2) minute interval. A decreasing leak rate does not violate the stability of the crack. As an alternative to the two (2) minute stable leak rate requirement, the leak test pressure may be increased by two (2) percent with the leak rate then being measured over a single two (2) minute interval without demonstration of leak rate stability [28]. A valid leak rate measurement also requires a stable test pressure and a leak rate that remains within the test system measurement capability. If the leak test system exhibits a delay time in accurately measuring a constant leak rate the hold time period only begins after the delay time is exceeded.

Pressurization rates shall be maintained at less than 200 psi/sec, as averaged over the time interval for pressurization to each hold point.

The following information steps should be included in the test procedure:

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6.2 Post-Test Actions

The testing organization should provide a final test report with sufficient information to comply with the analytical and reporting requirements of Section 7.

The following actions are particularly important if the pressure test objectives were not satisfied or if leakage exceeded tooling capability. Post-test actions include:

- Consider profilometry to assess the extent of tube deformation after testing in the event of a possible tube structural failure or large leaker.
- Consider a visual examination to confirm the nature of the failure.
- Consider performing the same NDE exam as the pre-test NDE to determine what, if any, changes have occurred in the defect. This information may be useful in interpreting leak rate data and for implementing the ranking methodology in Appendix C.

Following in situ testing, evaluate the tube for plugging or repair. Tubes that are in situ tested to pressures that cause plastic deformation shall be plugged. If the tube is to remain in service, perform post in situ NDE to verify that the indication remains below applicable repair limits and appropriate ASME Section III over pressurization stress limits are not exceeded.

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Section 7: Documentation and Reporting

Utility specific technical specifications require NRC reporting if the condition of the steam generator tubes does not meet the specified performance criteria.

The protocol for SGMP metrics may include prompt utility reporting of in situ testing to SGMP, including but not limited to the following situations:

- If the test demonstrates that the condition of the steam generator tubes does not meet the specified performance criteria.
- If the test results in leakage or burst. This will also result in a review of the databases used as bases for voltage screening values.

Data obtained from in situ testing should be entered into the EPRI Steam Generator Degradation Database (SGDD) [10]. The database is on the EPRI web site at http://www.epri.com/sgdd. It is important that in situ data submittals be complete, correct and timely, as supporting information can result in more robust screening criteria.

It is recommended that the utility document essential steps of the in situ process, including but not limited to the following:

- Inspection in situ screening criteria developed in accordance with Section 4.
- Selection process and screening results, including tubes selected, not selected, and exempt.
- Results of in situ tests included in the condition monitoring assessment.

Section 8: Equipment Specification Requirements and Tool Qualification

8.1 Equipment Specifications

In situ tooling systems can pressurize either the full length of the steam generator tube or some smaller length containing the degraded region. In either case, system performance shall be qualified. The purpose of the qualification is to ensure that equipment and tooling will adequately validate tube integrity during the in situ pressure testing. System performance is influenced by the tooling capabilities, test objectives, conditions in the field environment and procedural adherence. Based on lessons learned, the following list of equipment specifications should be followed.

1. Demonstrate that the system is capable of applying the appropriate load and displacements to the tube commensurate with limiting accident conditions and pressure margins (i.e. axial, hoop).
2. Establish the maximum test pressure, as well as available pressurization rates, and the ability to hold reasonably constant pressures as a function of time. The entire in situ system should be capable, with acceptable factor of safety, to reach the maximum pressure that is specified in the qualification documentation.
3. Ensure the test system has adequate relief devices to protect personnel and equipment from over pressurization.
4. Ensure the system has a means of recording system pressure and leak rate as a function of time.
5. Ensure the system is designed to minimize the potential of entrained air in the test chamber.
6. Utilities may choose to conduct in situ testing for reasons other than condition monitoring and operational assessment requirements. Thus some tubes may be in situ tested and left in service. If tubes are to remain in service, ensure the in situ probe minimizes residual effects (i.e., grip marks). Quantify the maximum residual effect and ensure the maximum residual effect does not degrade a tested tube.

7. Determine the applied pressure at the defect site as a function of leak rate. The development or enlargement of through wall cracks during pressure testing can lead to large leak rates which prevent further pressurization. The pressure at the defect location could then be significantly less than the pressure at the supply location.

8. Ensure the leak testing system provides, at a minimum, the flow rate that equals the performance criterion during SLB conditions (typically 2-1/2 to 3 gallons per minute (gpm) at room temperature).

8.2 Tool Qualification

This section provides guidance for the qualification of the in situ pressurization test apparatus whose function is to provide information relative to the structural integrity and leakage properties of degraded sections of steam generator tubing. It is recognized that different tooling may be used for leak integrity verification versus structural integrity testing.

The fundamental goal for the qualification of in situ pressurization tooling is to provide assurance that such tooling will generate leak rate and burst pressure data comparable to conventional laboratory systems used for leak rate and burst testing of degraded sections of steam generator tubing. The following list should be followed:

1. Qualify the test process for the tubing geometry (diameter, wall thickness, expansion transitions, etc.) and location (top of tubesheet, freespan, U-bend, dent, etc.) for which it will be used.

2. Determine the maximum and minimum measurable leak rates as a function of applied pressure. Qualify the system for a specific range of leak rates at the limiting accident pressure condition (including correction factors). This includes the total uncertainty associated with the leak rate range and a system pressure drop vs. leak rate relationship such that the actual pressure at the flaw is known for leak rate correction. Any leakage below the range of qualification, for which the uncertainty is a significant portion of the measured flow, is considered non-measurable. Qualify the system for testing in the field to ensure pressure drop conditions do not change (e.g., length of tubing).

3. For local tests, specify the method for delivering the probe to the flaw and any tolerances associated with this method.

4. Determine the system pressure measurement uncertainty including pressure uncertainty in measuring the test pressure during leakage conditions.

5. If bladders are used, include the number of tests for which the bladders are qualified to minimize the potential for bladder failure during testing.

6. If pressure testing is performed with the bladder over the flaw, identify the effect of the bladder on burst pressure.

7. Identify any equipment related pressure adjustments needed to simulate axial loading.

8. Identify any additional pressure corrections to ensure that the tooling applies the necessary axial and hoop stresses to the tubes (i.e., temperature, head height, and/or locked tube correction factor for axial loading of circumferential flaws).
9. If there are changes in the system equipment, configuration or range of qualification, perform a re-qualification or an engineering evaluation which quantifies the effect on the previous qualification.
10. If bladders are used for securing the probe, identify the bladder pressures required to secure the probe and prevent slippage at the maximum design pressure.
11. If bladders are used to seal the hydro chamber, identify the bladder pressure required to ensure a leak tight seal.
12. Calibrate leak test equipment against a device traceable to the National Institute of Standards and Technology (NIST). At the leak rate equal to the performance criteria, repeatability should be within 5% and accuracy within 10% of the device. If pump cylinder volumes are to be used for measuring leak rates, determine the volume of the pump using calibrated standards traceable to NIST.
13. Record pressures and leak rates as a function of time.

8.3 Additional Considerations

The tooling application procedure should consider duty cycles of testing equipment to limit the potential for a tooling malfunction in the steam generator.

In situ tooling seal performance should be evaluated, both with respect to maximum pressure limitations and likely seal leak rates as a function of pressure. Low levels of seal leakage are of interest especially if substantial numbers of tubes exhibit leakage. It is important to determine if leakage observed during in situ testing is actually related to tubing degradation or is simply a reflection of seal leakage. Qualification testing of non-degraded sections of tubing is useful in this regard since the only leakage possible is system leakage.

For proof testing, it is sufficient to demonstrate that in situ tooling produces the same loads as a capped tube hydro-test. A strain gauged, virgin section of the tubing is a convenient qualification pressure test standard.

Pressure testing qualification may be degradation specific. If the degradation is uniformly axial, then the dominant load of interest is the hoop stress. In this instance an in situ tool which only develops a hoop stress in the degraded section of tubing is sufficient for both leak rate and structural integrity pressure testing. For circumferential degradation, which includes circumferential cracking and volumetric degradation with circumferential extent, axial loads and primary bending loads are accounted for by analysis or testing. See Section 9.3 for requirement and adjustments for contribution loads other than pressure.

In situ pressurization may be conducted on tubes that are effectively locked in place at intersections with tube support structures. It is sufficient to note here that qualification testing of in situ tooling in prototypic laboratory mock-ups of locked tube assemblies may be used either in place of or in conjunction with analytical evaluations.

Desired capacities relative to leak rate measurements and maximum applied pressure depend on tooling design goals. To demonstrate NEI 97-06 [1] performance criteria requirements with sufficient margin to allow flexible interpretation of test data, a test pressure capability on the order of 6000 psi or greater is advisable.

At pressures necessary to demonstrate NEI 97-06 [1] structural requirements, the development of through wall cracking and substantial leak rates may occur. In terms of leak rate measurement capacity, the maximum pressure differential of interest is the maximum steam line break pressure differential including test pressure corrections. Additional margin should be included in equipment design to provide a maximum leak test pressure differential of up to 500-800 psi above the target value. Leak test equipment with a capability of providing continuous flow of up to 2-3 gpm at these pressures is desirable for maximum flexibility. However, systems with lower capacities may be acceptable. In the case of applying results to circumstances where large numbers of degraded tubes are considered, a minimum measurement capacity of 0.001 gallons per minute would be useful. If the test objective is to assess cumulative leakage from a repair (plug or sleeve) even lower verification capabilities (as low as 0.001 gallons per day (gpd)) may be desired. It is desirable that the leak rate measurement system has the capability to provide real time feedback of very low leak rates. If a minimum volume of water needs to be displaced in order to identify leakage, the hold times for this test should be increased in order to identify the case of very low leakage.

Some additional considerations include: ease of use, reasonable setup and testing times, applicability to the locations of degradation of interest, radiation exposure involved in use, retrieval of all tooling materials, and low risk of damage to adjacent tubes should expected or unexpected tube bursts occur.

Section 9: Adjustments of In Situ Pressure Testing and Leak Rate Parameters

9.1 Introduction

Adjustments to simulate both normal and accident conditions shall be established for in situ testing. Consequently, an engineering assessment should be performed and maintained, or cited by reference, as part of the test record that demonstrates that the test is capable of producing loads at the flawed section of tubing which are equivalent to, or a conservative bound of, the actual loads during normal operation and postulated accident conditions, multiplied by the appropriate safety factor.

The purpose of this section is to provide information regarding the required adjustments to simulate the effect of a temperature or other difference between in situ and operating/accident conditions, including the effects of non-pressure loads during accident events.

Since tubing strength is higher for room temperature in situ tests compared to the elevated temperatures of normal operating and accident conditions, test pressures are adjusted upward to account for greater tubing strength. The required temperature adjustment factors are discussed and listed in Section 9.2.

Axial force and bending loads should be considered when evaluating tubing with circumferential degradation. This includes circumferential cracks and the circumferential extent and depths of volumetric degradation. In most cases, an increase of in situ test pressure can be used to simulate the effects of axial force and bending loads. Stress reports typically provide accident axial membrane and axial bending stresses. However these values are often worse case values and may be much higher than the stresses at flaw locations of interest. Section 9.3 provides the methodology to calculate an equivalent in situ test pressure corresponding to the sum of accident differential pressure, axial force and bending loads. Axial force can be generated by pressure, seismic loading and thermal expansion differences. Bending loads can be developed from seismic loading, LOCA shaking and high crossflow transients during MSLB and FLB events.

Section 9.4 presents post leakage adjustments to account for the differences in thermal hydraulic conditions for leak rates at normal operating and accident conditions versus test conditions. Section 9.4 provides an illustration of various required adjustments.

9.2 Adjustments for Temperature Effects

A correction for temperature effects on the flow stress of the tubing material is required to extrapolate proof test results from ambient in situ test conditions to service conditions. Burst pressure, axial strength and crack opening area depend on the flow strength of the tube material, taken as the average of the yield and ultimate tensile strengths. Burst pressure and axial strength decrease as the flow strength decreases. For most applications for Alloy 600, a bounding room temperature proof test pressure adjustment of 15% for mill annealed tubing is conservative. Alternatively, more specifically calculated temperature adjustments can be applied in lieu of the 15% bounding value (Table 9-1). Note that the temperature correction for Alloy 690 is significantly higher than for Alloy 600. Since flow strengths are lower at operating conditions, the target in situ test pressure at room temperature is increased by the ratio of flow strength at room temperature to the flow strength at operating and accident conditions. Table 9-1 lists these ratios for various tube sizes and material conditions. Test pressures are multiplied by the appropriate ratio.

9.3 Adjustments for Non-Pressure Loads for Circumferential Degradation

There are no adjustments required for non-pressure loads for axial degradation. Evaluate the presence of axial force and bending loads during accident scenarios for circumferential degradation (this term includes both circumferential cracking and the circumferential extent and depth of volumetric flaws). Such loads can affect both structural and leakage integrity. In some cases, the limiting structural integrity performance criterion is governed by accident conditions rather than a pressure loading of 3 times the normal operating pressure differential. Even for the typical case where 3ΔP is limiting, the effects of axial force and/or bending loads may be limiting for accident leakage integrity. Structural integrity is considered below followed by leakage integrity.

9.3.1 Structural Integrity

In general, the effects of axial force and bending loads on structural and leakage integrity can be simulated by an increase in the in situ test pressure. For structural integrity, non-pressure accident loads only have to be considered if they are limiting. The limiting structural integrity performance criteria is either 3 times the normal operating pressure differential, 3ΔP, 1.4 times the accident pressure differential, or a safety factor of 1.2 on combined accident pressure, primary axial force and primary bending loads. A safety factor of 1.0 is used for axial secondary loads. Axial secondary loads are usually only important in OTSG designs where differential thermal expansion during accidents can produce large secondary axial loads. The following assumes that combined accident loads are limiting and that calculated test pressures are further adjusted to account for temperature effects per Section 9.2 and by the instrument uncertainty correction per Section 9.6.

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9.3.2 Leakage Integrity

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9.4 Adjustment of In Situ Measured Leak Rates

In situ leak testing is performed at room temperature (~70°F) and the results are applied to operating and accident condition pressure differentials and temperatures documented in plant accident analyses. In situ leak rates may need to be adjusted for any density differences to be consistent with leakage assumed in accident analyses.

The extrapolation of room temperature test results to actual conditions of interest requires an understanding of the applicable phenomena and their governing parameters. For leakage these are the crack opening area, and the thermal hydraulic conditions for flow.

The temperature adjustment of the in situ test pressure leads to final crack opening areas that are essentially equal to those expected at the higher temperatures of interest. However, the thermal hydraulic flow conditions at room temperature are very much different than those at higher temperatures. Fortunately leak rate equations have been developed for axial and circumferential cracks and benchmarked versus laboratory leak rate measurements. Using these equations a leak rate measured at room temperature can be extrapolated to normal operating and accident conditions.

The approach to corrections for thermal hydraulic conditions of flow is as follows. The leak rate measured at room temperature at the temperature corrected differential pressure of interest identifies the leaking crack length through use of the leak rate equation for room temperature. Note that mechanical tearing can develop as the pressure differential increases from operating to accident conditions. The use of the temperature corrected differential test pressure ensures that the extent of tearing at room temperature will be the same as that which would have occurred at elevated temperature. Once the leaking crack length is determined, leak rates at operating and accident conditions are calculated using the appropriate leak rate equations as presented below.

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9.4.1 Circumferential Cracks

The crack opening area for a circumferential crack in a steam generator tube can be obtained from standard handbook solutions. The solution from the EPRI Ductile Fracture Handbook [13] is preferred. The solution of interest is that for a circumferential through-wall crack in a thin-walled cylinder under internal pressure, Vol. 1, Chapter 1, Section 7.3. This solution does not include a bending effect and in essence accounts for the presence of tube support structures in a steam generator. It is appropriate for total circumferential extents up to about 180 degrees.

The stress intensity factor of linear elastic fracture mechanics is:

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9.4.2 Axial Cracks

The general procedure for calculating the crack opening area of axial cracks in steam generator tubing is similar to that for circumferential cracks. A solution from the EPRI Ductile Fracture Handbook [13], Vol. 2, Chapter 6, Section 5 is employed. In this case, it is that for an axial through-wall crack in a thin-wall cylinder under internal pressure. A twice-iterated plastic zone correction is applied as discussed below.

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9.5 Example In Situ Adjustments

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9.6 Instrumentation Uncertainty Correction

Some additional margin is added to test pressures to cover pressure measurement uncertainty corresponding to the specific test instrumentation being used.

9.7 Locked Tube Correction

In situ pressurization may be conducted on tubes that are effectively locked in place at intersections with tube support structures. Since axial stresses are not a substantial consideration relative to the structural behavior of tubes with axial degradation, locking at tube support structure does not influence extrapolation of these test results. This is based on the position that the tube support structure does not influence radial displacements at the degraded section, and therefore the support locking and corresponding restriction of axial motion need not be considered for axial flaws.

In the pressure testing of tubes with certain circumferential and volumetric degradation, axial stresses should be applied across the degraded section. When axial tube displacements are hindered by locking at support structures, corrections to the in situ testing pressures are required to ensure test conditions are at least as severe as those expected during operating or accident conditions, or required by regulatory documents.

Note: Locked tube adjustment factors to be applied to in situ test pressures are tooling and generator design specific and should be provided by the in situ testing vendor. These additional corrections apply only to flaws with limiting circumferential extent. When evaluating the locked tube corrections, the tool design and operational characteristics, as well as the steam generator design and geometry can affect the correction to be applied. The user should verify with the vendor that the corrections are adequately modeled. The applied end cap load should equal the end cap load developed by the limiting loading condition or the leak test condition times the applicable cross sectional area of the tube. Section 8 contains more information.

9.8 Head Loss Correction

Qualification of in situ pressure testing techniques should address the system flow to ensure that the desired pressure difference is applied at the flaw. The applied pressure at the defect site, as a function of leak rate, when large leakage occurs should be known. For example, the development or enlargement of through wall cracks during pressure testing can lead to large leak rates which prevent further pressurization. The pressure at the defect location could then be significantly less than the pressure at the supply location. The in situ test pressure should be adjusted by the head loss at the corresponding leak rate for the type of flaw tested. Static head adjustments are not required since they are negligible compared to test pressures.

9.9 Material Properties

All threshold values related to structural and leakage integrity screening parameters are established using either lower tolerance limit (LTL) material property values or ASME Code minimum values in accordance with the Integrity Assessment Guidelines [2]. The material properties of tubes in situ tested can vary from tube-to-tube or steam generator-to-steam generator and therefore the proof and leak test results can be adjusted to account for these differences. If available, the actual material properties of the tube(s) at room temperature are documented on manufacturer's CMTRs. Refer to the EPRI Steam Generator Integrity Assessment Guideline for additional information on definition and calculation of structural limits.

9.10 Bladder Corrections

Un-reinforced bladder proof test results do not require adjustments. Correct the data if the tooling vendor utilizes a reinforced bladder.

Table 9-1
Ratio of Flow Strength at Room Temperature to Flow Strength at Elevated Temperature

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Table 9-2
Saturated Liquid Density

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Figure 9-1
Calculated and Measured Leak Rates (at Room Temperature Density) for Axial Cracks in Alloy 600 Tubing at Normal Operating Conditions

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Figure 9-2
Calculated and Measured Leak Rates (at Room Temperature Density) for Axial Cracks in Alloy 600 Tubing at SLB Conditions

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Section 10: Requirements

Needed Requirements	Section
Indications that exceed the screening criteria shall be in situ pressure tested.	4.1
Plant-specific length and depth threshold values shall be established for screening indications for in situ testing addressing plant specific integrity limits.	4.3
For each mode of degradation, NDE voltage, depth, and length shall be compared against the established threshold values to determine the need for in situ testing	4.3
All flaws shall be screened for both leakage and proof testing.	4.3
To use the voltage thresholds in Sections 4.5 and 4.6, voltage calibrations shall be performed per the requirements of Section 4.4.	4.3
All tubes with visible leakage as identified during the outage or during a secondary side leak test that are not associated with leak-limiting repairs or are not exempt by Appendix D shall be in situ tested unless a tube pull is planned.	4.3
All tubes that require proof testing shall also be leak tested.	4.3
All axial indications (indications where axial dimension is limiting) that require leak testing shall also be proof tested, except where Appendix D proof test exemptions are defined.	4.3
If circumferential or volumetric indications require leak testing and leakage occurs, proof testing shall be performed.	4.3
If performance criteria are not satisfied or if leakage is observed during testing for a flaw at or below the screening values, the utility shall review the screening values.	4.8
In situ testing shall be conducted in accordance with a utility approved procedure	6.1

Needed Requirements	Section
No leakage is defined as a zero leak rate value as determined at the specified hold point. A minimum hold period of two (2) minutes shall be used to establish a zero leakage condition.	6.1
Pressurization rates shall be maintained at less than 200 psi/sec, as averaged over the time interval for pressurization to each hold point.	6.1
Tubes that are in situ tested to pressures that cause plastic deformation shall be plugged.	6.2
In situ tooling systems can pressurize either the full length of the steam generator tube or some smaller length containing the degraded region. In either case, system performance shall be qualified.	8.1
Adjustments to simulate both normal and accident conditions shall be established for in situ testing.	9.1

Good Practices	Section
Per section 7, it is recommended that the utility document essential steps of the in situ process, including: In situ screening criteria developed in accordance with Section 4; selection process and screening results, including tubes selected, not selected, and exempted; and results of in situ tests included in the condition monitoring assessment.	4.3
If leakage was detected during operation, it is recommended that a reasonable effort be made to correlate the leak rate identified during the leak test to the leak rate detected during operation.	6.1.D

Section 11: References

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23. NRC Generic Letter 95-05, "Voltage-Based Repair Criteria for Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking," August 1995

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Appendix A: Statistical Approach to in Situ Test Selection

A.1 Introduction

The information contained in this appendix offers a more rigorous proof and leak test candidate selection process than the conservative quick screening process defined in Section 4, and illustrates two calculational approaches for selecting in situ pressure test leak test candidates. The methods described define the structural and leakage capacity of detected flaws based on NDE measurements and, by considering applicable uncertainties in accordance with the statistical criteria of the Steam Generator Integrity Assessment Guidelines, Revision 3 [2], determine compliance with NEI 97-06 [1] performance criteria regarding condition monitoring. This approach of satisfying condition monitoring requirements is sometimes referred to as condition monitoring via NDE sizing and analysis.

An evaluation strategy for in situ candidate selection may use any of the three unique methods described in reference [2] for combining the relevant uncertainties. In this appendix the proof test screening examples employ the Monte Carlo approach, and the leakage screening examples utilize the arithmetic approach. This appendix provides examples of these methods as applied to the evaluation of axial and circumferential cracking.

A.2 Tube Selection for Proof Testing

The sequential approach to in situ candidate selection outlined in Section 4 relies on the development of bounding evaluation parameters, with the expectation that each successive step in the sequence will reduce the number of test candidates. The Monte Carlo analysis approach to proof test candidate selection eliminates these intermediate steps. It consists of generating a distribution of burst pressures for the indicated flaw by drawing random values from the appropriate flaw component variables (material property, NDE and burst equation uncertainties) and calculating structural performance using valid burst strength models. The burst pressures resulting from this Monte Carlo simulation are then put in ascending order and the 5^{th} percentile value is identified (i.e., for N simulations, the 5^{th} percentile is the value of the $0.05 \cdot N^{th}$ entry). If this burst pressure value is higher than the performance criteria limit (e.g., 3NOPD), condition monitoring is met for structural integrity and no in situ pressure testing is necessary.

For flaw evaluations based on length and depth measurements, length-depth pairs whose 5th percentile burst pressure just meets the performance criteria limit are determined and are used to create a condition monitoring limit curve. With NDE-indicated length on the x-axis and NDE indicated depth on the y-axis, the condition monitoring limit curve provides a simple means of determining when a field-identified flaw requires in situ proof testing (i.e., when the flaw dimensions lie above the condition monitoring limit curve).

The EPRI Flaw Handbook Calculator (FHC) software [25] is a user-friendly application to perform a Monte Carlo analysis. One benefit of this approach is that the uncertainty effects are minimized while still meeting the required statistical acceptance criteria, thus ensuring appropriately conservative, but not excessively conservative, conclusions.

Detailed descriptions of Monte Carlo simulation methods and the equations used to evaluate various flaw morphologies are provided in the EPRI Flaw Handbook [5].

Axial Cracking

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Circumferential Cracking

This example illustrates the proof test screening process for an NDE-indicated OD circumferential crack measured as 60 PDA. As with the axial cracking example above, this example utilizes the FHC software and Monte Carlo methods.

The parameter used to assess the structural significance of this OD crack is the PDA, a physical characteristic which is based on the combination of the circumferential extent and the throughwall depth of the crack. For the purpose of this example, it is assumed that the cracked tube is subjected only to pressure loading and is laterally restrained by tube support structures. The applicable condition monitoring burst pressure equations (condition monitoring equations for Circumferential Cracking Under Pressure Loading with Restricted Lateral Tube Motion from the EPRI Flaw Handbook [5]) are discussed in detail in Reference [5] and are repeated below for convenience.

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A.3 Tube Selection for Leakage Testing – Pop Through Calculation

While voltage screening is the most direct method for determining if cracks require in situ leakage testing, there are situations when the use of a pop-through calculation may be beneficial, such as when the crack voltage lies between the screening threshold voltage and critical voltage values. The term pop-through refers to the event of a partial depth flaw under load that mechanically tears through the remaining wall thickness thus creating a leakage path.

Two examples of pop-through calculation are provided below; one for axial cracking and one for circumferential cracking. Both examples assume that pressure is the only significant source of loading during the limiting accident. Key input assumptions are identified below.

$t = 0.043$ inch	nominal tube wall thickness
$OD = 0.750$ inch	nominal tube outer diameter
$S_{YU} = 110{,}774$ psi	sum of yield and ultimate for Alloy 690TT @650°F (95%LCL) [5]
$\Delta p = 2{,}560$ psi	primary to secondary pressure differential for the limiting accident
$R_m = \frac{OD - t}{2} = 0.3535$	mid-wall tube radius (inch)

A.3.1 Axial Pop-Through

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A.3.2 Circumferential Pop-Through

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A.4 In Situ Candidate Selection

Neither conclusions that pop-through will occur, nor the presence of degradation which is 100% throughwall, proves that the Accident Induced Leakage Performance Criteria (AILPC) will be exceeded. The calculation of leak rate for identified degradation is an option which offers the potential to demonstrate that the AILPC is met even if those conditions exist. That said, this approach has limited practical benefit because of its tendency to produce overly conservative results due to the relatively large uncertainties involved.

Both of the leakage calculation examples described below are based upon the assumption that only one crack has been identified during an inspection. While this is useful to illustrate the calculation process it should be recognized that since the AILPC applies to an entire SG, the leakage contribution of all identified cracks should be considered, and the total tube bundle leakage from all identified degradation mechanisms should remain below the AILPC. Total bundle leakage may be found to exceed the AILPC even if no cracks individually exceed the AILPC. Under these circumstances, it would be necessary to perform in situ leak testing on enough of the cracks to prove that the total SG leakage would have remained below the AILPC during an accident. If, however, calculated leak rate for tube bundle is below the AILPC, leakage integrity is met and no in situ test is necessary.

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A.4.1 Axial Cracking

This example is made up of two parts. The first part steps through the calculation of crack opening area and leak rate for one value of crack length in order to illustrate the mechanics of the calculation. Although this is demonstrated for only one crack length, the same process is repeated for several different length values in order to construct a leak rate curve. The second part of the example applies the resulting leak rate curve to evaluate a field-identified axial crack.

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To demonstrate the calculational process, an arbitrary throughwall crack length of 0.4 inches is used. The crack opening area which results from exposure to the accident pressure, Δp, is calculated below by applying equations 9-17 through 9-29, defined earlier in this document[1].

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This example illustrates the limitation of this leakage calculation approach. Due to significant relational and NDE sizing uncertainties, the result may be too conservative to be practical for in situ screening. The use of Monte Carlo methods would reduce the effect of the uncertainties.

A.4.2 Circumferential Cracking

Similar to the axial cracking example above, this example is made up of two parts. The first part steps through the calculation for one value of circumferential crack extent in order to illustrate the mechanics of the calculation. Although the calculation is illustrated for only one crack extent value, this process is repeated for several different crack sizes in order to construct a leak rate curve. The second part of the example uses the leak rate curve to determine if a hypothetical, field-identified circumferential crack indication requires in situ leak testing.

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Table A-1
Part Through-wall Axial Cracking Example - FHC Input Data

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Table A-2
OD Circumferential Cracking Example - FHC Input Data

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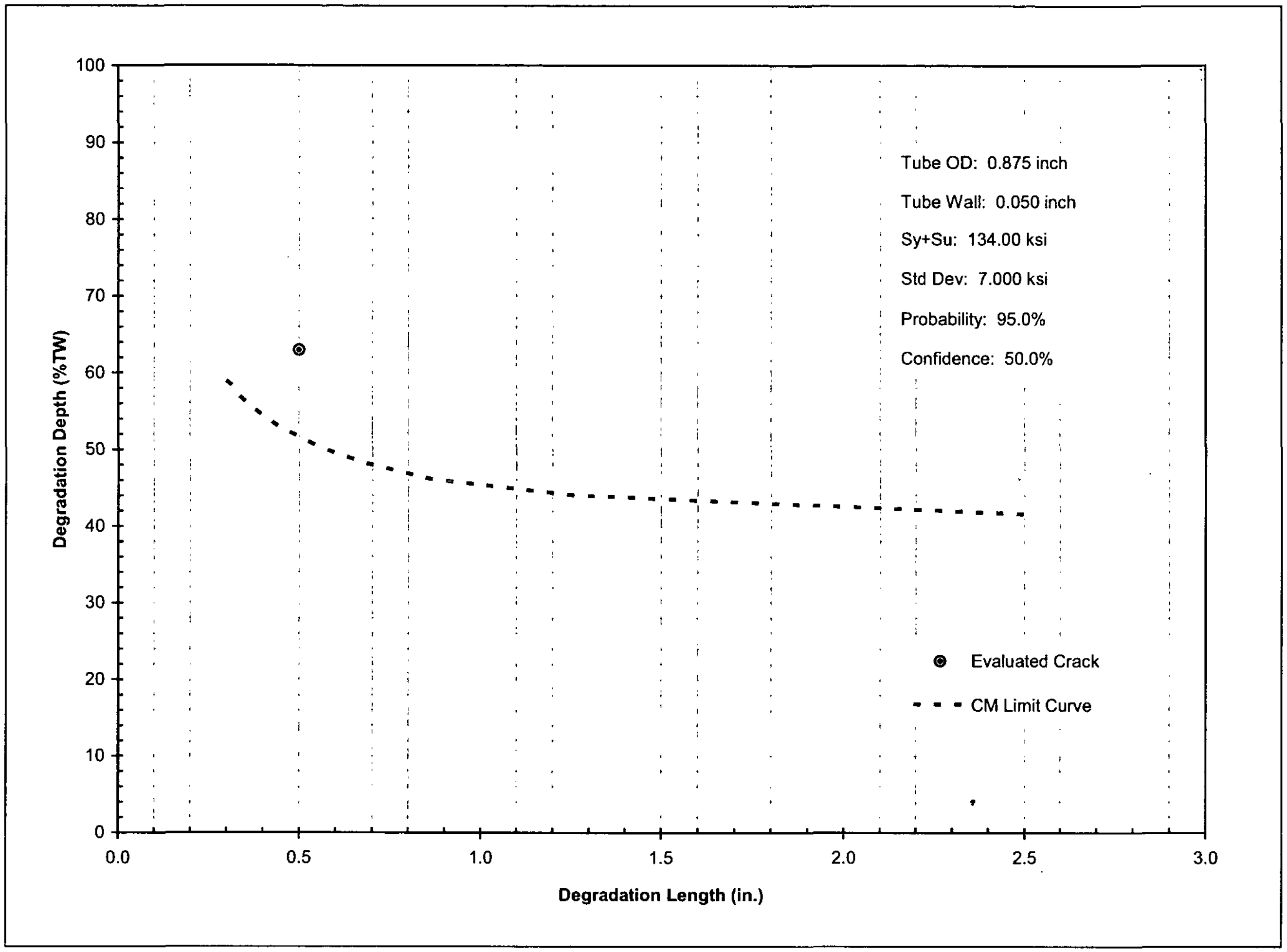

Figure A-1
In Situ Proof Test Screening for OD Part-Throughwall Axial Cracking
The indication being evaluated lies above the condition monitoring limit curve and therefore cannot be shown, using NDE measurements, to meet the structural integrity performance criteria.

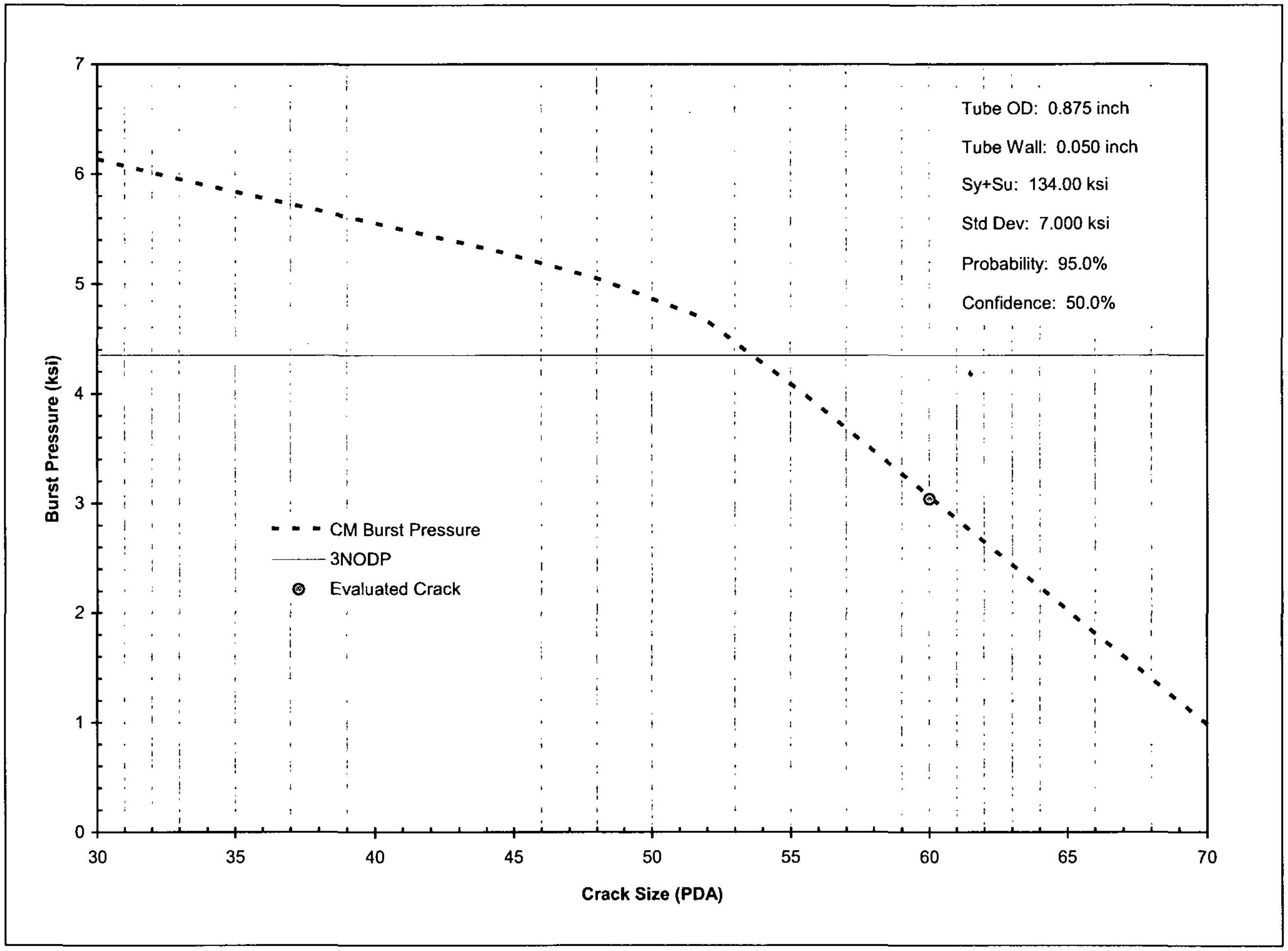

Figure A-2
In Situ Proof Test Screening for OD Circumferential Cracking
The indication being evaluated is below 3NOPD and therefore cannot be shown, using NDE measurements, to meet the structural integrity performance criteria.

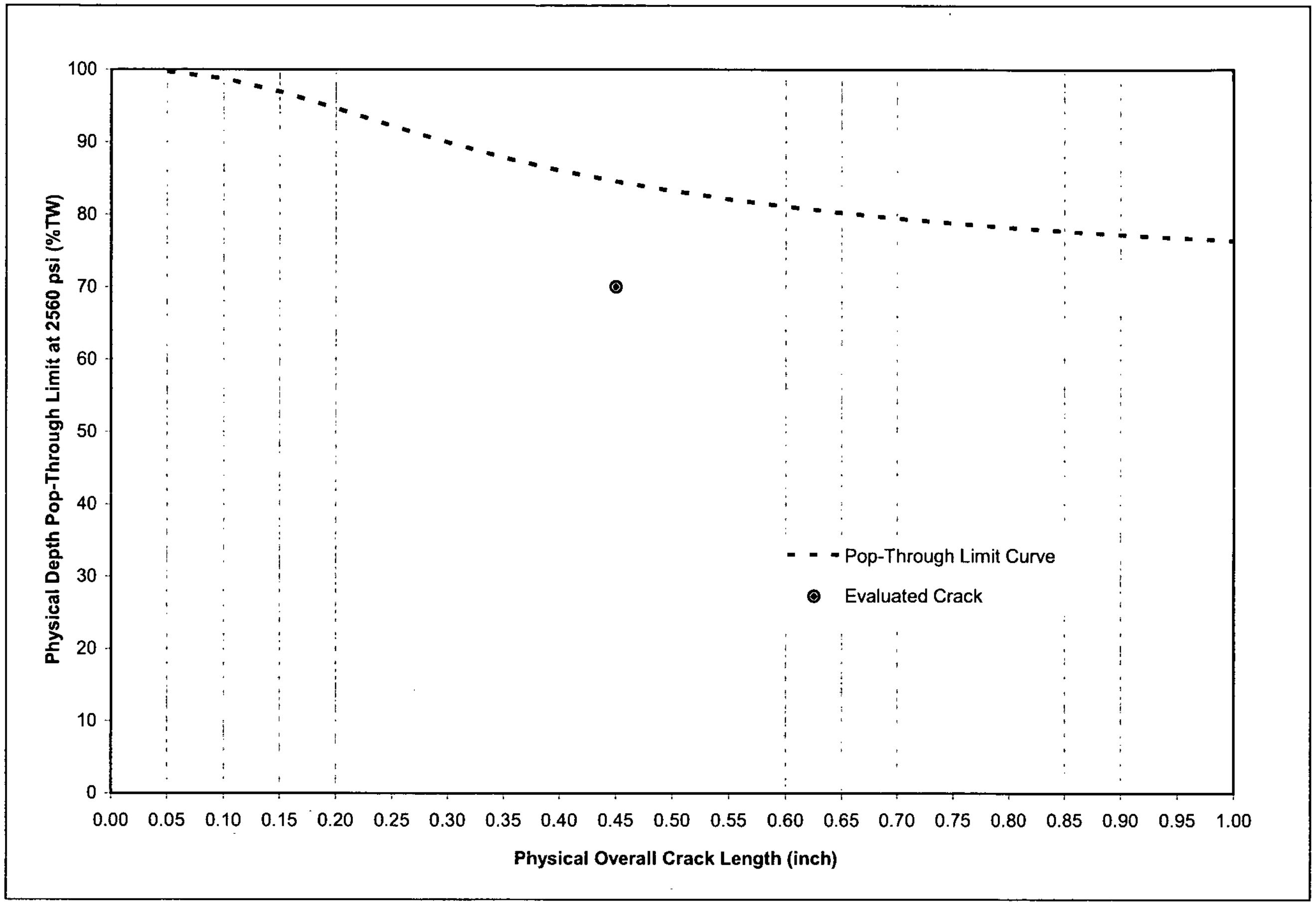

Figure A-3
In Situ Leakage Test Screening for OD Axial Cracking – Pop-Through
The indication being evaluated lies below the pop through limit curve and therefore would not require leak testing.

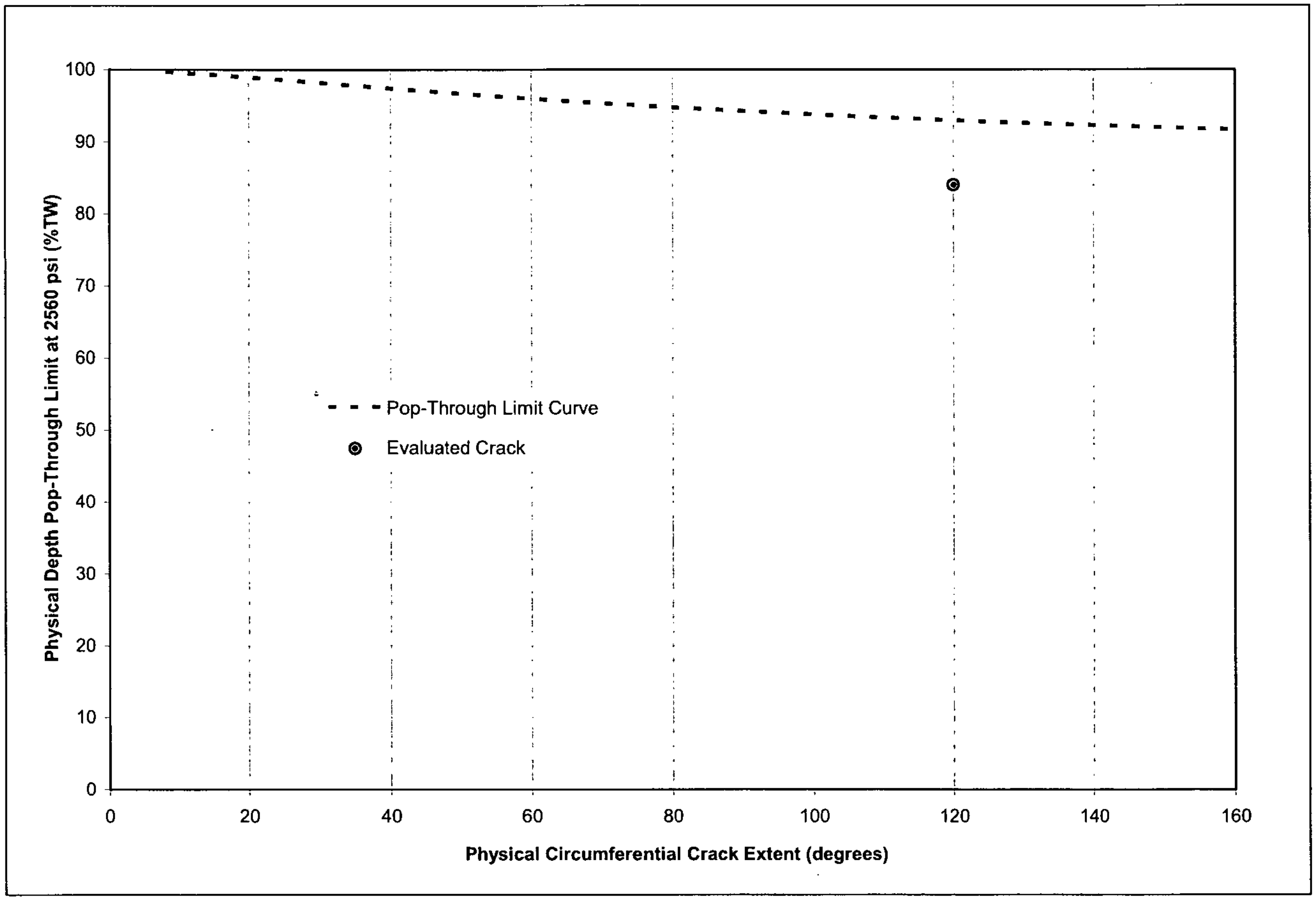

Figure A-4
In Situ Leakage Test Screening for OD Circumferential Cracking – Pop-Through
The indication being evaluated lies below the pop through limit curve and therefore would not require leak testing.

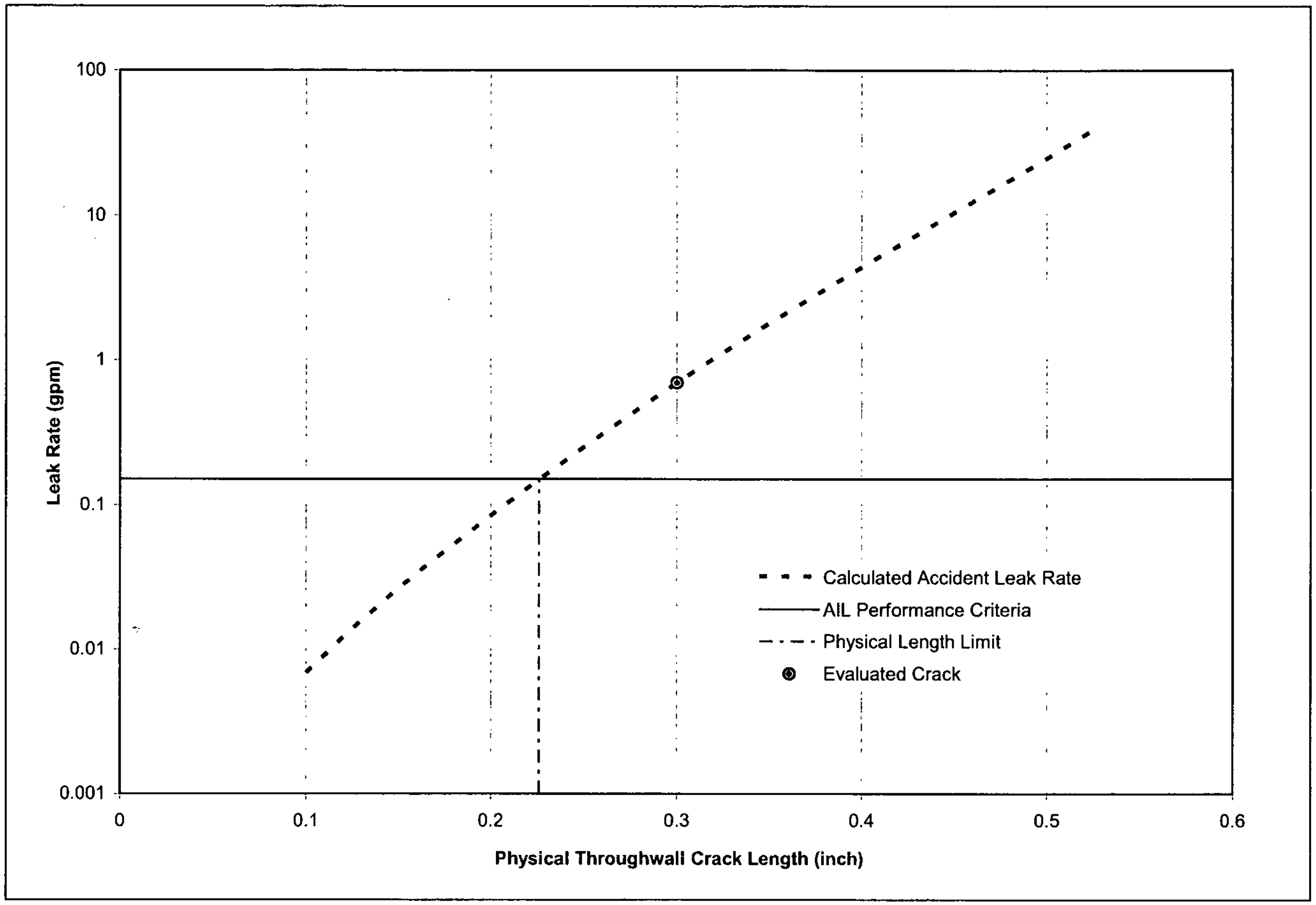

Figure A-5
In Situ Leak Test Screening for Throughwall Axial Cracking – Leak Rate
From the leak rate curve it is possible to identify the maximum physical crack length which would still meet the AILPC. In this example, that length is approximately 0.23 inches. The 0.3 inch long throughwall axial crack evaluated exceeds the accident induced leakage performance criteria. The tube would therefore require in situ leakage testing.

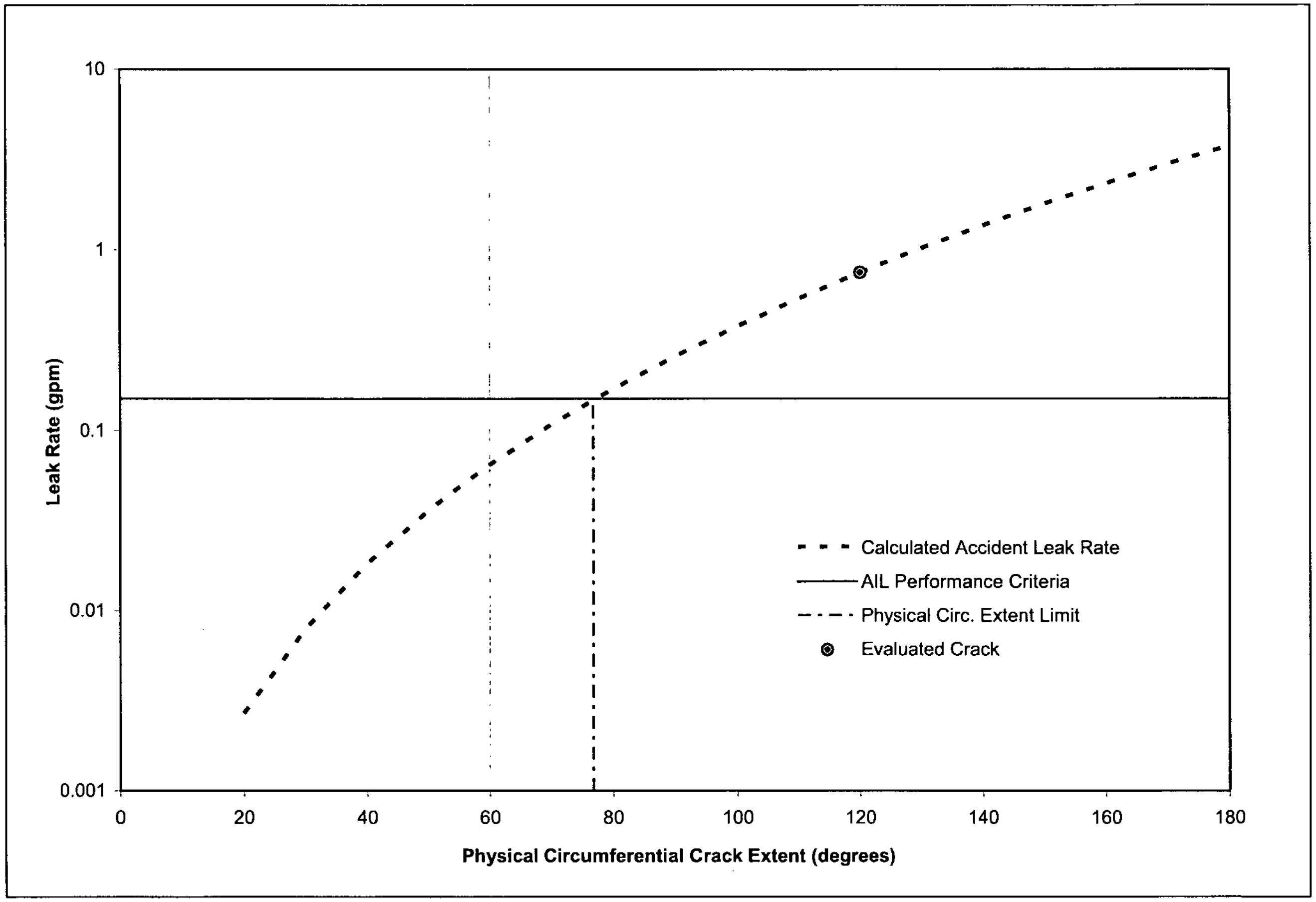

Figure A-6
In Situ Leak Test Screening for Throughwall Circumferential Cracking – Leak Rate
From this leak rate curve it is possible to determine the maximum physical throughwall crack angle which would still meet the AILPC. In this example, that length is approximately 77 degrees. The 120° throughwall circumferential crack evaluated exceeds the accident induced leakage performance criteria. The tube would therefore require in situ leakage testing.

Appendix B: Technical Basis for Voltage as Screening Parameter

B.1 Introduction

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B.2 Summary of Voltage Screening Values for Leakage Integrity

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Table B-1
Summary of Voltage Threshold Parameters for Leak Testing

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Table B-1 (continued)
Summary of Voltage Threshold Parameters for Leak Testing

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Table B-1 (continued)
Summary of Voltage Threshold Parameters for Leak Testing

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Summary of Voltage Threshold Parameters for Leak Testing

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Summary of Voltage Threshold Parameters for Leak Testing

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Table B-1 (continued)
Summary of Voltage Threshold Parameters for Leak Testing

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B.3 Methods for Developing Voltage Screening Values

B.3.1 Approach

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B.3.2 Voltage Screening Parameters from Prior In Situ Test and/or Destructive Exam Results

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B.3.3 Maximum Depth versus Voltage Correlation

B.3.3.1 Correlations used to Develop Information Only Threshold Voltages

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B.3.3.2 Correlations used to Develop 95/50 Threshold Voltages

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B.3.4 Lower Bound Voltages for Screening Indications for Pressure Testing

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B.3.5 Probe and Voltage Normalization Requirements

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B.4 Voltage Parameters for Axial PWSCC Indications

B.4.1 Database

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B.4.2 Maximum Depth to +Point Voltage Correlation and Parameters

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B.4.3 Voltage Screening Parameters from Prior In Situ Test Results

B.4.3.1 Axial PWSCC in Hardroll Expansion Transitions

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B.4.3.2 Axial PWSCC in Explosive and Hydraulic Expansion Transitions

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B.4.3.3 Axial PWSCC at Dented TSP and Eggcrate Intersections

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B.4.3.4 Axial PWSCC in U-Bends

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B.4.4 Summary

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Table B-2
Axial PWSCC in Hardroll Expansion Transitions: +Point Threshold Voltage Evaluation DE Data from Tube Exam Reports, NDE from EPRI SGDD Database and Westinghouse In Situ Test Records

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Table B-2 (continued)
Axial PWSCC in Hardroll Expansion Transitions: +Point Threshold Voltage Evaluation DE Data from Tube Exam Reports, NDE from EPRI SGDD Database and Westinghouse In Situ Test Records

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Table B-2 (continued)
Axial PWSCC in Hardroll Expansion Transitions: +Point Threshold Voltage Evaluation DE Data from Tube Exam Reports, NDE from EPRI SGDD Database and Westinghouse In Situ Test Records

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Table B-3
Explosive and Hydraulic Expansion Axial PWSCC: +Point Threshold Voltage Evaluation (Data from EPRI SGDD Database, 300 kHz, Volts Cal 20V for 100% EDM Axial Slot)

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Table B-3 (continued)
Explosive and Hydraulic Expansion Axial PWSCC: +Point Threshold Voltage Evaluation
(Data from EPRI SGDD Database, 300 kHz, Volts Cal 20V for 100% EDM Axial Slot)

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Table B-4
Axial PWSCC at Dented TSP and Eggcrate Intersections: +Point Threshold Voltage Evaluation (Data from EPRI SGDD Database and [20], 300 kHz, Volts Cal 20V for 100% EDM Axial Slot)

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Table B-4 (continued)
Axial PWSCC at Dented TSP and Eggcrate Intersections: +Point Threshold Voltage Evaluation
(Data from EPRI SGDD Database and [20], 300 kHz, Volts Cal 20V for 100% EDM Axial Slot)

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Table B-4 (continued)
Axial PWSCC at Dented TSP and Eggcrate Intersections: +Point Threshold Voltage Evaluation
(Data from EPRI SGDD Database and [20], 300 kHz, Volts Cal 20V for 100% EDM Axial Slot)

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Table B-4 (continued)
Axial PWSCC at Dented TSP and Eggcrate Intersections: +Point Threshold Voltage Evaluation
(Data from EPRI SGDD Database and [20], 300 kHz, Volts Cal 20V for 100% EDM Axial Slot

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Table B-4 (continued)
Axial PWSCC at Dented TSP and Eggcrate Intersections: +Point Threshold Voltage Evaluation
(Data from EPRI SGDD Database and [20], 300 kHz, Volts Cal 20V for 100% EDM Axial Slot)

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Table B-5
U-Bend Axial PWSCC: +Point Threshold Voltage Evaluation
(Data from EPRI SGDD Database, 300 kHz, Volts Cal 20V for 100% EDM Axial Slot)

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Table B-5 (continued)
U-Bend Axial PWSCC: +Point Threshold Voltage Evaluation
(Data from EPRI SGDD Database, 300 kHz, Volts Cal 20V for 100% EDM Axial Slot)

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Figure B-1
Axial PWSCC: Maximum Depth Versus Maximum +Point Volts

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Figure B-2
Axial PWSCC: Destructive Exam Max. Depth as Funtion of Max +Point Volts

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B.5 Voltage Parameters for Axial ODSCC Indications

B.5.1 Database

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B.5.2 Maximum Depth to +Point Voltage Correlation and Parameters

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B.5.3 Voltage Screening Parameters from Prior In Situ Test Results

B.5.3.1 Axial ODSCC at Eggcrate Intersections

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B.5.3.2 Freespan Axial ODSCC in Westinghouse SGs

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B.5.3.3 Freespan Axial ODSCC in CE SGs

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B.5.3.4 Freespan Axial ODSCC in OTSGs

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B.5.3.5 Axial ODSCC in Dings

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B.5.3.6 OTSG SG Freespan and Tubesheet Volumetric OD Indications (Probable OD IGA)

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B.5.3.7 Axial ODSCC in Sludge Pile

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B.5.3.8 Axial ODSCC in Hardroll, Explosive, and Hydraulic Expansion Transitions

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B.5.3.9 Axial ODSCC in U-Bends

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B.5.3.10 Axial ODSCC at OTSG Tube Supports

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B.5.4 Summary

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Table B-6
Eggcrate Axial ODSCC CE SG's: +Point Threshold Voltage Evaluation
(Data from EPRI SGDD Database and Supplemental ANO-2 Analyses, Volts Cal 20V for 100% EDM Axial Slot)

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Table B-6 (continued)
Eggcrate Axial ODSCC CE SG's: +Point Threshold Voltage Evaluation
(Data from EPRI SGDD Database and Supplemental ANO-2 Analyses, Volts Cal 20V for 100% EDM Axial Slot)

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Table B-6 (continued)
Eggcrate Axial ODSCC CE SG's: +Point Threshold Voltage Evaluation
(Data from EPRI SGDD Database and Supplemental ANO-2 Analyses, Volts Cal 20V for 100% EDM Axial Slot)

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Table B-6 (continued)
Eggcrate Axial ODSCC CE SG's: +Point Threshold Voltage Evaluation
(Data from EPRI SGDD Database and Supplemental ANO-2 Analyses, Volts Cal 20V for 100% EDM Axial Slot)

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Table B-6 (continued)
Eggcrate Axial ODSCC CE SG's: +Point Threshold Voltage Evaluation
(Data from EPRI SGDD Database and Supplemental ANO-2 Analyses, Volts Cal 20V for 100% EDM Axial Slot)

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Table B-7
Freespan Axial ODSCC in Westinghouse SGs: +Point Threshold Voltage Evaluation
(Data from EPRI SGDD Database and [15], 300 kHz, Volts Cal 20V for 100% EDM Axial Slot)

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Table B-7 (continued)
Freespan Axial ODSCC in Westinghouse SGs: +Point Threshold Voltage Evaluation
(Data from EPRI SGDD Database and [15], 300 kHz, Volts Cal 20V for 100% EDM Axial Slot)

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Table B-7 (continued)
Freespan Axial ODSCC in Westinghouse SGs: +Point Threshold Voltage Evaluation
(Data from EPRI SGDD Database and [15], 300 kHz, Volts Cal 20V for 100% EDM Axial Slot)

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Table B-7 (continued)
Freespan Axial ODSCC in Westinghouse SGs: +Point Threshold Voltage Evaluation
(Data from EPRI SGDD Database and [15], 300 kHz, Volts Cal 20V for 100% EDM Axial Slot)

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Table B-8
Freespan Axial ODSCC in CE SGs: +Point Threshold Voltage Evaluation
(Data from EPRI SGDD Database and Pulled Tube Data from Westinghouse Files)

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Table B-8 (continued)
Freespan Axial ODSCC in CE SGs: +Point Threshold Voltage Evaluation
(Data from EPRI SGDD Database and Pulled Tube Data from Westinghouse Files)

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Table B-8 (continued)
Freespan Axial ODSCC in CE SGs: +Point Threshold Voltage Evaluation
(Data from EPRI SGDD Database and Pulled Tube Data from Westinghouse Files)

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Table B-8 (continued)
Freespan Axial ODSCC in CE SGs: +Point Threshold Voltage Evaluation
(Data from EPRI SGDD Database and Pulled Tube Data from Westinghouse Files)

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Table B-8 (continued)
Freespan Axial ODSCC in CE SGs: +Point Threshold Voltage Evaluation
(Data from EPRI SGDD Database and Pulled Tube Data from Westinghouse Files)

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Table B-9
Freespan Axial ODSCC OTSG SGs: +Point Threshold Voltage Evaluation
(In Situ and NDE Data from Framatome and Pulled Tube Data from [18])

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Table B-9 (continued)
Freespan Axial ODSCC OTSG SGs: +Point Threshold Voltage Evaluation
(In Situ and NDE Data from Framatome and Pulled Tube Data from [18])

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Table B-9 (continued)
Freespan Axial ODSCC OTSG SGs: +Point Threshold Voltage Evaluation
(In Situ and NDE Data from Framatome and Pulled Tube Data from [18])

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Table B-9 (continued)
Freespan Axial ODSCC OTSG SGs: +Point Threshold Voltage Evaluation
(In Situ and NDE Data from Framatome and Pulled Tube Data from [18])

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Table B-9 (continued)
Freespan Axial ODSCC OTSG SGs: +Point Threshold Voltage Evaluation
(In Situ and NDE Data from Framatome and Pulled Tube Data from [18])

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Table B-9 (continued)
Freespan Axial ODSCC OTSG SGs: +Point Threshold Voltage Evaluation
(In Situ and NDE Data from Framatome and Pulled Tube Data from [18])

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Table B-9 (continued)
Freespan Axial ODSCC OTSG SGs: +Point Threshold Voltage Evaluation
(In Situ and NDE Data from Framatome and Pulled Tube Data from [18])

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Table B-9 (continued)
Freespan Axial ODSCC OTSG SGs: +Point Threshold Voltage Evaluation
(In Situ and NDE Data from Framatome and Pulled Tube Data from [18])

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Table B-10
Ding Axial ODSCC: +Point Voltage Evaluation
(DE Data from Westinghouse Report SG-99-03-005; Voltages from Westinghouse Analyses OTSG Data (5/8" OD) from Framatome)

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Table B-10 (continued)
Ding Axial ODSCC: +Point Voltage Evaluation
(DE Data from Westinghouse Report SG-99-03-005; Voltages from Westinghouse Analyses OTSG Data (5/8" OD) from Framatome)

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Table B-10 (continued)
Ding Axial ODSCC: +Point Voltage Evaluation
(DE Data from Westinghouse Report SG-99-03-005; Voltages from Westinghouse Analyses OTSG Data (5/8" OD) from Framatome)

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Table B-11
OTSG SG Freespan and Tubesheet Volumetric OD Indications (Probable OD IGA): +Point Threshold Voltage Evaluation (In Situ and NDE Data from Framatome)

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Table B-11 (continued)
OTSG SG Freespan and Tubesheet Volumetric OD Indications (Probable OD IGA): +Point Threshold Voltage Evaluation (In Situ and NDE Data from Framatome)

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Table B-11 (continued)
OTSG SG Freespan and Tubesheet Volumetric OD Indications (Probable OD IGA): +Point Threshold Voltage Evaluation (In Situ and NDE Data from Framatome)

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Table B-11 (continued)
OTSG SG Freespan and Tubesheet Volumetric OD Indications (Probable OD IGA): +Point Threshold Voltage Evaluation (In Situ and NDE Data from Framatome)

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Table B-11 (continued)
OTSG SG Freespan and Tubesheet Volumetric OD Indications (Probable OD IGA): +Point Threshold Voltage Evaluation (In Situ and NDE Data from Framatome)

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Table B-12
Sludge Pile Axial ODSCC W and CE SGs: +Point Threshold Voltage Evaluation
(Data from EPRI SGDD Database [10] and Westinghouse Files, 300 kHz, Volts Cal 20V for 100% EDM Axial Slot)

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Table B-12 (contiued)
Sludge Pile Axial ODSCC W and CE SGs: +Point Threshold Voltage Evaluation
(Data from EPRI SGDD Database [10] and Westinghouse Files, 300 kHz, Volts Cal 20V for 100% EDM Axial Slot)

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Table B-12 (contiued)
Sludge Pile Axial ODSCC W and CE SGs: +Point Threshold Voltage Evaluation
(Data from EPRI SGDD Database [10] and Westinghouse Files, 300 kHz, Volts Cal 20V for 100% EDM Axial Slot)

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Table B-12 (contiued)
Sludge Pile Axial ODSCC W and CE SGs: +Point Threshold Voltage Evaluation
(Data from EPRI SGDD Database [10] and Westinghouse Files, 300 kHz, Volts Cal 20V for 100% EDM Axial Slot)

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Table B-13
Expansion Transition and U-bend Axial ODSCC: +Point Threshold Voltage (Data from EPRI SGDD Database [10], 300 kHz, Volts Cal 20V for 100% EDM Axial Slot)

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Table B-14
OTSG Axial OD Indications at Tube Supports: +Point Threshold Voltage Evaluation (In Situ and NDE Data from Framatome)

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Figure B-3
Axial ODSCC All Data

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Figure B-4
Axial ODSCC CE Data

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Figure B-5
Westinghouse Axial ODSCC Data

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Figure B-6
W SG Axial ODSCC

B.6 Voltage Parameters for Circumferential PWSCC Indications

B.6.1 Database

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B.6.2 Maximum Depth to +Point Voltage Correlation and Parameters

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B.6.3 Voltage Screening Parameters from Prior In Situ Test Results

B.6.3.1 Circumferential PWSCC in Explosive Expansions

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B.6.3.2 Circumferential PWSCC in Hardroll Expansions

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B.6.3.3 Circumferential PWSCC in U-Bends

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B.6.4 +Point Voltage Screening Values

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B.6.5 Effects of Pressure and Bending Loads on +Point Voltage Screening Values

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B.6.6 +Point Voltage Screening Values for OTSG Tubing Under LBLOCA Loading

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Table B-15
Explosive Expansion Circumferential PWSCC: +Point Threshold Voltage Evaluation
(Data from EPRI SGDD Database [10] and [7], 300 kHz, Volts Cal 20V for 100% EDM Axial Slot)

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Table B-16
U-Bend Circumferential PWSCC Westinghouse SGs: +Point Threshold Voltage Evaluation
(Data from EPRI SGDD Database [10], 300 kHz, Volts Cal 20V for 100% EDM Axial Slot)

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Table B-16 (continued)
U-Bend Circumferential PWSCC Westinghouse SGs: +Point Threshold Voltage Evaluation
(Data from EPRI SGDD Database [10], 300 kHz, Volts Cal 20V for 100% EDM Axial Slot)

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Table B-16 (continued)
U-Bend Circumferential PWSCC Westinghouse SGs: +Point Threshold Voltage Evaluation
(Data from EPRI SGDD Database [10], 300 kHz, Volts Cal 20V for 100% EDM Axial Slot)

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Table B-16 (continued)
U-Bend Circumferential PWSCC Westinghouse SGs: +Point Threshold Voltage Evaluation
(Data from EPRI SGDD Database [10], 300 kHz, Volts Cal 20V for 100% EDM Axial Slot)

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Figure B-7
Maximum Depth versus +Point Voltage, Vpp, for Axial and Circumferential ODSCC

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Figure B-8
Maximum Depth versus +Point Voltage, Vpp, for Axial PWSCC also Applicable to Circumferential PWSCC

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Figure B-9
95/50 Accident Leakage Voltage Thresholds, V_{THR-L}, for Circumferential PWSCC as a Function of Outer Fiber Bending Stress, Alloy 600

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Figure B-10
95/50 Accident Leakage Voltage Thresholds, V_{THR-L}, for Circumferential PWSCC as a Function of Outer Fiber Bending Stress, Alloy 600, Large Radius U-Bends, R_B/R_m = > 122

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Figure B-11
95/50 Accident Leakage Voltage Thresholds, V_{THR-L}, for Circumferential PWSCC as a Function of Outer Fiber Bending Stress, Alloy 690

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Figure B-12
95/50 Accident Leakage Voltage Thresholds, V_{THRL}, for Circumferential PWSCC as a Function of Outer Fiber Bending Stress, Alloy 690, Large Radius U-Bends, R_B/R_m = > 122

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Figure B-13
95/50 Accident Leakage Voltage Thresholds, V_{THR-L}, for Circumferential PWSCC in OTSG Tubing Under Maximum Possible LBLOCA Axial Loads, Alloy 600 and 690 tubing

B.7 Voltage Parameters for Circumferential ODSCC Indications

B.7.1 Database

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B.7.2 Maximum Depth to +Point Voltage Correlation and Parameters

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B.7.3 Voltage Screening Parameters from Prior In Situ Test Results

B.7.3.1 Circumferential ODSCC in Hardroll Expansions

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B.7.3.2 Circumferential ODSCC in Explosive Expansions

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B.7.3.3 Circumferential ODSCC in U-Bends

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B.7.4 Summary of +Point Voltage Screening Values for Pressure Loading

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B.7.5 Effects of Pressure and Bending Loads on +Point Voltage Screening Values

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B.7.6 +Point Voltage Screening Values for OTSG Tubing Under LBLOCA Loading

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Table B-17
Hardroll Expansion Circumferential ODSCC: +Point Threshold Voltage Evaluation
(Data from EPRI TR-107197-P2, Table G-11 and EPRI SGDD Database)

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Table B-17 (continued)
Hardroll Expansion Circumferential ODSCC: +Point Threshold Voltage Evaluation
(Data from EPRI TR-107197-P2, Table G-11 and EPRI SGDD Database)

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Table B-17 (continued)
Hardroll Expansion Circumferential ODSCC: +Point Threshold Voltage Evaluation
(Data from EPRI TR-107197-P2, Table G-11 and EPRI SGDD Database)

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Table B-17 (continued)
Hardroll Expansion Circumferential ODSCC: +Point Threshold Voltage Evaluation
(Data from EPRI TR-107197-P2, Table G-11 and EPRI SGDD Database)

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Table B-17 (continued)
Hardroll Expansion Circumferential ODSCC: +Point Threshold Voltage Evaluation
(Data from EPRI TR-107197-P2, Table G-11 and EPRI SGDD Database)

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Table B-17 (continued)
Hardroll Expansion Circumferential ODSCC: +Point Threshold Voltage Evaluation
(Data from EPRI TR-107197-P2, Table G-11 and EPRI SGDD Database)

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Table B-18
Explosive Expansion Circumferential ODSCC: +Point Threshold Voltage Evaluation
(Data from EPRI SGDD Database and [7], Volts Cal 20V for 100% EDM Axial Slot)

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Table B-18 (continued)
Explosive Expansion Circumferential ODSCC: +Point Threshold Voltage Evaluation
(Data from EPRI SGDD Database and [7], Volts Cal 20V for 100% EDM Axial Slot)

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Figure B-14
Maximum Depth versus +Point Voltage, Circumferential ODSCC in OTSG Tubing Under Maximum Possible LBLOCA Axial Loads

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Figure B-15
95/50 Accident Leakage Voltage Thresholds, V_{THR-L}, for Circumferential ODSCC as a Function of Outer Fiber Bending Stress, Alloy 600 and Alloy 690

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Figure B-16
95/50 Accident Leakage Voltage Thresholds, V_{THR-L}, for Circumferential ODSCC as a Function of Outer Fiber Bending Stress, Large Radius U-bends, Alloy 600 and Alloy 690

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Figure B-17
95/50 Accident Leakage Voltage Thresholds, V_{THR-L}, for Circumferential ODSCC in OTSG Tubing Under Maximum Possible LBLOCA Loads, Alloy 600 and 690 tubing

B.8 Volumetric Indications

B.8.1 Approach

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B.8.2 Pitting

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B.8.3 Cold Leg Thinning

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B.8.4 Wear at TSP Intersections and AVB/Straps

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B.8.5 Wear from Foreign Objects Under Pressure Loading

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B.8.6 Wear from Foreign Objects Under Pressure and Bending Loads

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B.8.7 Wear from Foreign Objects Under LBLOCA Loads in OTSG Tubing

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B.8.8 Summary

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Table B-19
Pitting: Bobbin Coil Voltage Threshold Evaluation
(DE Data from EPRI ETSS 96005.2, Rev. 5; Bobbin Voltages from Westinghouse Analyses)

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Table B-19 (continued)
Pitting: Bobbin Coil Voltage Threshold Evaluation
(DE Data from EPRI ETSS 96005.2, Rev. 5; Bobbin Voltages from Westinghouse Analyses)

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Table B-20
Bobbin Coil Cold Leg Thinning (CLT): 7/8" Tube Diameter, 0.050" Wall (Westinghouse DE and NDE Data from [19]; Bobbin Voltages with Sludge in TSP Crevices)

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Table B-20 (continued)
Bobbin Coil Cold Leg Thinning: 7/8" Tube Diameter, 0.050" Wall (Westinghouse DE and NDE Data from [19]; Bobbin Voltages with Sludge in TSP Crevices)

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Table B-20 (continued)
Bobbin Coil Cold Leg Thinning: 7/8" Tube Diameter, 0.050" Wall (Westinghouse DE and NDE Data from [19]; Bobbin Voltages with Sludge in TSP Crevices)

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Table B-20 (continued)
Bobbin Coil Cold Leg Thinning: 7/8" Tube Diameter, 0.050" Wall (Westinghouse DE and NDE Data from [19]; Bobbin Voltages with Sludge in TSP Crevices)

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Table B-21
Bobbin Coil Wear at AVB/Straps and Tube Supports (DE Data from EPRI ETSS 96004.1, Rev. 7; Differential Bobbin Voltages from Westinghouse Analyses)

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Table B-21 (continued)
Bobbin Coil Wear at AVB/Straps and Tube Supports (DE Data from EPRI ETSS 96004.1, Rev. 7; Differential Bobbin Voltages from Westinghouse Analyses)

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Table B-21 (continued)
Bobbin Coil Wear at AVB/Straps and Tube Supports (DE Data from EPRI ETSS 96004.1, Rev. 7; Differential Bobbin Voltages from Westinghouse Analyses)

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Table B-22
Bobbin Coil Wear at AVB/Straps and Tube Supports (DE Data from EPRI ETSS 96004.2, Rev. 7; Absolute Bobbin Voltages from Westinghouse Analyses)

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Table B-22 (continued)
Bobbin Coil Wear at AVB/Straps and Tube Supports (DE Data from EPRI ETSS 96004.2, Rev. 7; Absolute Bobbin Voltages from Westinghouse Analyses)

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Table B-22 (continued)
Bobbin Coil Wear at AVB/Straps and Tube Supports (DE Data from EPRI ETSS 96004.2, Rev. 7; Absolute Bobbin Voltages from Westinghouse Analyses)

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Figure B-18
Pitting

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Figure B-19
Cold Leg Thinning

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Figure B-20
Wear at Tube Supports and AVB/Straps

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Figure B-21
Wear at Tube Supports and AVB/Straps

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Figure B-22
Limiting Allowable Depth for Accident Leakage Integrity versus Degradation Extent

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Figure B-23
+Point Voltage Thresholds, V_{THRL} for Accident Leakage Integrity, Foreign Object Wear

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Figure B-24
+Point Voltage, Vpp, versus EDM Slot Depth in Eddy Current Standards

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Figure B-25
Foreign Object Wear Degradation Geometries

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Figure B-26
Foreign Object Wear Degradation Geometries

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Figure B-27
+Point Voltage, Vpp, versus Axial Groove Depth

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Figure B-28
Bounding Leakage Integrity Pressure versus +Point Volts, Vpp, Circumferential Grooves

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Figure B-29
Bounding Leakage Integrity Pressure vs +Point Voltage, Vpp, All Test Geometries

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Figure B-30
In Situ Non Leakers at Accident Pressure

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Figure B-31
In Situ Leakers at Accident Pressure

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Figure B-32
+Point Voltage versus Maximum Depth, EDM Notches and Straight Across Circumferential Grooves

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Figure B-33
Maximum Depth Correlation with +Point Voltage, Straight Across Circumferential Grooves

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Figure B-34
Accident Leakage Threshold Voltage, V_{THR-L}, versus Outer Fiber Bending Stress, NDE Axial Extent ≤0.5", NDE Circumferential Extent > 90° and <= 180°

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Figure B-35
Accident Leakage Threshold Voltage, V_{THR-U} versus Outer Fiber Bending Stress, NDE axial Extent ≤ 0.5", NDE Circumferential Extent > 90° and <= 180°

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Figure B-36
+Point Voltage versus Maximum Depth, Axial and Circumferential Grooves

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Figure B-37
Maximum Depth Correlation with +Point Voltage, Axial Grooves

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Figure B-38
Accident Leakage Theshold Voltage, V_{THR-L}, versus Outer Fiber Bending Stress, NDE axial Extent > 0.5", NDE Circumferential Extent > 90° and <= 180°

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Figure B-39
Accident Leakage Theshold Voltage, V_{THR-L}, versus Outer Fiber Bending Stress, NDE axial Extent > 0.5", NDE Circumferential Extent > 90° and <= 180°

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Figure B-40
Effect of Bending Loads on Accident Leakage Thresholds for Foreign Object Wear

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Figure B-41
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In Situ Leakage Field Test Results at Accident Pressures

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In Situ Leakage Field Test Results at Accident Pressures

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B.9 Technical Basis for Volumetric Screening Methods for Proof Testing

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B.9.1 Burst Performance Comparison

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B.9.2 Geometric Sizing Performance

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B.9.3 Axial Length Screening Limit

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B.9.4 Integrity Assessment of 2 Volt Screening Threshold

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Wear Scar Library

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Circ ODSCC vs volumetric screening limits

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Figure B-48
Circ ODSCC vs volumetric screening limits

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B.10 Maximum Depth and +Point Voltage Data

Table B-25
Axial PWSCC Database for Maximum Depth and +Point Volts

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Table B-25 (continued)
Axial PWSCC Database for Maximum Depth and +Point Volts

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Table B-25 (continued)
Axial PWSCC Database for Maximum Depth and +Point Volts

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Table B-25 (continued)
Axial PWSCC Database for Maximum Depth and +Point Volts

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Table B-25 (continued)
Axial PWSCC Database for Maximum Depth and +Point Volts

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Table B-26
Axial ODSCC Database for Maximum Depth and +Point Volts

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Table B-26 (continued)
Axial ODSCC Database for Maximum Depth and +Point Volts

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Table B-26 (continued)
Axial ODSCC Database for Maximum Depth and +Point Volts

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Table B-26 (continued)
Axial ODSCC Database for Maximum Depth and +Point Volts

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Table B-26 (continued)
Axial ODSCC Database for Maximum Depth and +Point Volts

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Table B-26 (continued)
Axial ODSCC Database for Maximum Depth and +Point Volts

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Table B-26 (continued)
Axial ODSCC Database for Maximum Depth and +Point Volts

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Table B-27
Circumferential ODSCC +Point Maximum Volts and Destructive Exam Data

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Table B-27 (continued)
Circumferential ODSCC +Point Maximum Volts and Destructive Exam Data

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B.11 Voltage Ratios between Coils and Tube Sizes

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B.11.2 Ratio of +Point to 115 PC Voltages for Various Tube Sizes

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B.11.3 Ratio of +Point Voltages between Westinghouse and CE Steam Generator Tubing Size

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B.11.4 Ratios of +Point Voltages between Westinghouse Steam Generator Tubing Size

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B.11.5 Voltage Dependence on Throughwall Notch Length and Width

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Appendix C: Technical Basis for In Situ Pressure Test Screening Parameters when NDE Sizing is Not Quantified

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C.2 General Methods for Ranking and Selection of Indications for In Situ Pressure Testing

C.2.1 Issues to be Addressed

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C.2.2 Ranking and Selection of Indications for Pressure Testing

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C.3 Initial Screening Parameters

C.3.1 Throughwall Length as Initial Screen for Pressure Testing

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C.3.2 Requirements for Calculating Throughwall Length Limits

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C.3.3 Lower Bound Voltage Screening Values for Pressure Testing

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C.4 Calculation of Ranking Factors

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C.4.2 Calculation of Relative Ranking Factors

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C.4.2.1 Axial Indications

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C.4.2.2 Circumferential Indications

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C.4.3 Validation of Methods

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C.6.2 Expansion Guidelines

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C.7.2 Axial PWSCC NDE Sizing Evaluation for In Situ Testing

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C.7.3 Axial ODSCC NDE Sizing Evaluation for In Situ Testing

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C.7.4 Circumferential ODSCC NDE Sizing Evaluation for In Situ Testing

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C.7.4.1 Explosive Expansions

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C.7.4.2 Hardroll Expansions Data from EPRI Circumferential Crack Report

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C.7.4.3 Analysis using data from ETSS 21410.1, Rev. 0.

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C.7.5 Conclusions

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Table C-1
Relative Burst Pressure Ranking Sensitivity to NDE Uncertainties

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Table C-2
Axial PWSCC at Dented Eggcrate Intersections: Methods Evaluation for In Situ Test Selection (Data from [20]. +Point Data for 600 mil coil, 0.4 ips, 300 kHz, Volts Cal 20V for 100% EDM Axial Slot)

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Table C-3
Axial PWSCC at Dented Eggcrate Intersections: Methods Evaluation Assuming In Situ Test Failure
(Data from [20]. +Point Data for 600 mil coil, 0.4 ips, 300 kHz, Volts Cal 20V for 100% EDM Axial Slot)

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Table C-3 (continued)
Axial PWSCC at Dented Eggcrate Intersections: Methods Evaluation Assuming In Situ Test Failure
(Data from [20]. +Point Data for 600 mil coil, 0.4 ips, 300 kHz, Volts Cal 20V for 100% EDM Axial Slot)

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Table C-4
Axial ODSCC at Eggcrate Intersections: Methods Evaluation for In Situ Test Selection
(Data from EPRI SGDD Database and Sizing Performed for ANO-2 1/99 and 11/99 Outages)

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Table C-4 (continued)
Axial ODSCC at Eggcrate Intersections: Methods Evaluation for In Situ Test Selection
(Data from EPRI SGDD Database and Sizing Performed for ANO-2 1/99 and 11/99 Outages)

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Table C-4 (continued)
Axial ODSCC at Eggcrate Intersections: Methods Evaluation for In Situ Test Selection
(Data from EPRI SGDD Database and Sizing Performed for ANO-2 1/99 and 11/99 Outages)

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Table C-4 (continued)
Axial ODSCC at Eggcrate Intersections: Methods Evaluation for In Situ Test Selection
(Data from EPRI SGDD Database and Sizing Performed for ANO-2 1/99 and 11/99 Outages)

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Table C-5
Explosive Expansion Circumferential ODSCC: Methods Evaluation for In Situ Test Selection (Data from EPRI Report TR-107197-P2 [7])

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Table C-5 (continued)
Explosive Expansion Circumferential ODSCC: Methods Evaluation for In Situ Test Selection (Data from EPRI Report TR-107197-P2 [7])

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Table C-6
Hardroll Expansion Circumferential ODSCC: Methods Evaluation for In Situ Testing with Burst Test Failure (Data from EPRI Report TR-107197-P2 [7])

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Table C-6 (continued)
Hardroll Expansion Circumferential ODSCC: Methods Evaluation for In Situ Testing with Burst Test Failure
(Data from EPRI Report TR-107197-P2 [7])

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Table C-6 (continued)
Hardroll Expansion Circumferential ODSCC: Methods Evaluation for In Situ Testing with Burst Test Failure
(Data from EPRI Report TR-107197-P2 [7])

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Table C-7
Hardroll Expansion Circumferential ODSCC: Methods Evaluation for In Situ Testing with No Burst Test Failure (Data from EPRI Report TR-107197-P2 [7])

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Table C-7 (continued)
Hardroll Expansion Circumferential ODSCC: Methods Evaluation for In Situ Testing with No Burst Test Failure
(Data from EPRI Report TR-107197-P2 [7])

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Table C-7 (continued)
Hardroll Expansion Circumferential ODSCC: Methods Evaluation for In Situ Testing with No Burst Test Failure (Data from EPRI Report TR-107197-P2 [7])

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Table C-8
Hardroll Expansion Circumferential ODSCC: In Situ Evaluation Based on ETSS Data
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C.8 Example Rankings Based Upon Available In Situ and Destructive Exam Test Results

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C.8.1 Hardroll Circumferential ODSCC

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C.8.2 Axial ODSCC at Eggcrate Intersections

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Table C-9
Circumferential ODSCC Pulled Tube, Lab and In Situ Leak Test Data
(Data from EPRI TR-107197-P2, Table G-11, EPRI SGDD Database and ETSS 21410.1, Rev. 0)

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Table C-9 (continued)
Circumferential ODSCC Pulled Tube, Lab and In Situ Leak Test Data
(Data from EPRI TR-107197-P2, Table G-11, EPRI SGDD Database and ETSS 21410.1, Rev. 0)

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Table C-9 (continued)
Circumferential ODSCC Pulled Tube, Lab and In Situ Leak Test Data
(Data from EPRI TR-107197-P2, Table G-11, EPRI SGDD Database and ETSS 21410.1, Rev. 0)

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Table C-9 (continued)
Circumferential ODSCC Pulled Tube, Lab and In Situ Leak Test Data
(Data from EPRI TR-107197-P2, Table G-11, EPRI SGDD Database and ETSS 21410.1, Rev. 0)

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Table C-9 (continued)
Circumferential ODSCC Pulled Tube, Lab and In Situ Leak Test Data
(Data from EPRI TR-107197-P2, Table G-11, EPRI SGDD Database and ETSS 21410.1, Rev. 0)

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C.9 Technical Basis for Applying Maximum/Average Depth Ratio

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Figure C-1
Axial PWSCC Maximum to Average Depth Ratio – Burst Effective Data

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Figure C-2
Axial ODSCC Maximum to Average Depth Ratio – Burst Effective Average Depth

Appendix D: Indications Exempt from In Situ Testing

D.1 Introduction

The purpose of this appendix is to identify indications that are exempt from in situ testing because either the conduct of the test can not achieve the objectives, or integrity is inherently satisfied.

In order to comply with NEI 97-06 [1] requirements of assuring that the as-found tube condition complies with structural and leakage integrity requirements, this guideline requires that the user demonstrate that the test is capable of producing the stress state at the flawed section of tubing which is equivalent to, or a conservative bound of, the actual stress state during normal operation and postulated accident conditions multiplied by the appropriate factor of safety. In certain cases, this objective cannot be satisfied wholly through the conduct of in situ testing. For example:

- Indications in tubes with surrounding structures that would restrict leakage and/or burst during an in situ test render the results of an in situ test meaningless. Such defects include indications restricted from burst (IRB). In these cases, satisfaction of performance criteria may be demonstrated by analytical methods or by tube pull.
- Indications in locations that prohibit in situ testing due to physical limitations of the in situ test equipment. In these cases, satisfaction of performance criteria may be demonstrated by analytical methods or by tube pull.

There are also cases where proof testing is not required because structural integrity is inherently satisfied. For example:

- Surrounding structures (e.g., tubesheet) prevent tube burst during normal and accident conditions. Structural integrity is inherently satisfied, and in situ proof testing is not required. Leak testing may be necessary.
- Due to the nature of some damage mechanisms, the burst strength cannot be significantly degraded based on documented evidence. In situ proof testing is not required, however, leak testing may be necessary.

While not exempt from structural and leak rate testing, circumferentially cracked regions of a tube are inherently stronger than axial cracks (NUREG/ CR-6511) [22]. This is due to a combination of loading and geometry effects. The axial stress is only one-half of the hoop stress, the radial stiffness of the tube material is increased by the orientation of the crack, and the tube support structure results in the application of a load counter to the direction of deformation, i.e., bending of the tube is resisted.

D.2 Tubesheet Region

D.2.1 Proof Testing

For axial indications located within the tubesheet for tube/tubesheet expansions of any type (i.e., full depth or partial depth), burst cannot occur during normal operation and accident conditions due to the tubesheet constraint against radial deformation of the tube wall. As such, structural integrity is inherently provided, and proof testing is not required.

Circumferential flaws located within the tubesheet (e.g., within the star (*) distance) may have associated accident induced tubesheet pullout load issues that need to be addressed. However, these issues cannot be simulated by in situ pressure testing because the tube would be expected to become tighter in the tubesheet hole with the application of internal pressure. In addition, the discussion in the following section relative to the lack of efficacy of leak rate testing would also be expected to apply.

Any degradation below the * distance does not require proof testing.

Circumferential flaws located within the tubesheet in partial depth expansions should be tested if it can be confirmed that the degradation is somewhat uniform around the circumference of the tube. For degradation limited in circumferential extent it is likely that bending within the tubesheet would restrain the degraded section and make the interpretation of the test results very subjective.

For tubes with partial depth expansions, in situ testing is not recommended if the circumferential indication percent degraded area (PDA) is less than 75%. This is because the pressure required for such an indication to burst would be expected to be significantly greater that $3 \cdot \Delta P_{Nop}$, and significant plastic bending at the section with the crack is involved in the eventual failure. Contact with the inside of the tubesheet hole could provide an unquantified level of restraint against deformation and failure, thus making the result of questionable value. If the PDA is greater than 75%, failure by tensile overload in the axial direction is to be expected and the indication should be proof tested.

Note: For axial indications that extend above the TTS in full depth expansions (e.g., hydraulic, explosive, hardroll), only the flaw length above the TTS needs to be considered as freespan length for defect screening.

D.2.2 Leak Testing

Indications located within the tubesheet expansion may contribute to accident induced leakage; however in situ testing can not provide meaningful results. Technically justified leakage models may be used to assign leak rates to indications within the tubesheet.

For circumferential cracks within the tubesheet, it is doubtful that in situ testing of tubes with full-depth expansions would lead to meaningful results, even if the cracks were located very near the top of the tubesheet. The large differential pressure predicted to occur during a postulated accident causes the tubesheet to bow upward and loosen the tube-to-tubesheet joint, which would facilitate leakage. However, the difference in thermal expansion between the tube and the tubesheet material leads to a tightening of the tube-to-tubesheet joint. The effects may offset each other. When a tube is tested in situ, there is no bowing of the tubesheet nor is there any thermal expansion tightening of the joint. Thus, the measured leak rate could only be expected to be coincidentally representative of the actual value that would occur during a postulated accident. It is noted that this limitation should not be considered serious because it is quite improbable that such cracks would be sufficiently large as to challenge the applicable leak resistance criterion.

D.3 Drilled Tubes Support Plate (TSP) Region

D.3.1 Proof Testing

For axial flaws located entirely within a drilled TSP, burst cannot occur and structural integrity is inherently provided during normal operating and shutdown conditions due to the presence of the TSP constraint. Therefore, the 3xNOPD structural performance criterion does not apply to this mechanism. If it is assumed that the TSPs displace during a postulated SLB event, the SLB pressure is the structural performance criterion; however, in situ proof testing is not a valid test method because there is no means to displace the TSP during an in situ proof test. (Note: If it can be established that the TSPs remain adjacent to the flaw locations during a postulated SLB event, structural integrity is inherently provided during accident conditions and, once again, in situ proof testing is not required.).

Axial flaws that extend outside of the TSP are evaluated for in situ proof testing using the plant specific freespan parameters for integrity at 3NOPD conditions. Only the flaw extension outside of the TSP is considered in the screening methodology. Flaw extension beyond the TSP dictates the burst pressure of the indication at times when the TSP is adjacent to the flaw, as is the case during normal operation and shutdown conditions. The flaw length that extends outside the TSP is subject to the 3NOPD burst margin requirement while the total flaw length is subject to the 1.4SLBDP burst margin requirement. The length outside the TSP should be evaluated for pressure testing and tested if required. The total flaw length or a flaw totally inside the TSP cannot be meaningfully in situ proof tested relative to postulated accident loading criteria (assuming TSPs displace in a SLB event) due to the constraint provided by the TSP. In this case, in situ proof testing is not a valid test.

Proof testing of circumferential cracks which are located within a TSP hole does not approximate the conditions that would be in effect if the crack were located outside of the plate. If the flaw percent degraded area (PDA) is less than 75%, the expected failure mode involves significant plastic bending at the section of the crack. The presence of the TSP material may provide bending restraint in addition to that from the neighboring support plate. In this case, proof testing is not required.

If the PDA is greater than 75% the expected mode of failure will be tensile overload. The EPRI analysis of circumferential indications document, TR-107197 [7], presented a comparison of failure pressures of circumferentially cracked tubes relative to predictions developed from slit specimens. It was not unusual for specimens failing in axial tension to exhibit burst pressures significantly greater than the predictions (because of the presence of ligaments in actual cracks relative to EDM slit laboratory specimens). If the PDA for the indication is greater than 75%, including allowances for NDE uncertainties, the indication should be proof tested. Although, restraint from the interface with the support plate may elevate the failure pressure, it would not be expected to decrease it.

Note: Degradation at lattice type eggcrate TSPs is not exempt from in situ proof testing, as it has been shown that these supports provide little strengthening to regions with axial degradation. The same is true of broached TSP supports.

D.3.2 Leak Testing

For axial indications located entirely within a carbon steel drilled TSP (e.g., axial ODSCC GL [22] repair criteria, axial PWSCC repair criteria), associated packed or dented crevices will severely limit the leakage potential, and in situ leak testing of such indications at shutdown conditions will not model MSLB conditions. As such, in situ leak testing is not required, and leakage capability of the indication is determined analytically. For example, GL 95-05 repair criteria and axial PWSCC repair criteria require a Monte Carlo analysis to determine accident leakage. (Note: If it can be established that the TSPs remain adjacent to the flaw locations during a postulated SLB event, in situ leak testing of such indications may be performed to validate accident leakage assumptions.)

Circumferential cracks within the TSP may be considered as candidates for in situ leak testing with due consideration of the potential limitations associated with the testing results. As with proof testing, the results will not be truly representative of what may actually occur during a postulated accident condition, especially if some leakage occurs. For example, movement of the support relative to the crack would be expected to significantly affect the actual leak rate, a condition which cannot be duplicated by in situ testing. In addition, the leak path within a plate would be expected to be more restrictive during operation owing to the differences in thermal expansion characteristics, temperature and material, between the tube and the plate. There may also be a difference if the interface is such as to change the flashing characteristics of the leak path. This is not to say that information obtained will not be useful in all situations. The need for the test information should be considered relative to the unknowns associated with the results. If the unknowns cannot be quantified but can be demonstrated to constrain the leakage, then an in situ test that results in a positive outcome can be meaningful. It is to be expected that more often than not, in situ testing of circumferential indications with drilled support plates will not yield reliable results unless the test results in no leakage.

Indications that extend outside of the carbon steel drilled TSP are evaluated for in situ leak testing; however, only the flaw extension outside of the TSP is considered in the screening methodology.

D.4 Leak Limiting Sleeves

Certain sleeves with leak limiting expanded joints (e.g., roll joints, hydraulic joints) are termed leak limiting. Sleeving qualification approved by the NRC includes a leak rate methodology such that accident leakage is assigned to each sleeve joint. If degradation is subsequently detected in the sleeve joint, in situ leak testing of the flaw would not provide meaningful results. Leakage associated with the sleeve joint flaw cannot be determined because of potential combined leakage past the sleeve joint and the sleeve flaw.

D.5 Tube Ends

In cases where tube end cracking is detected and the tube end is considered part of pressure boundary, in situ pressure testing equipment may not be able to isolate the flawed tube end to allow a determination of accident leak rates. Rather, repair criteria approved by the NRC may account for accident leakage from the tube end flaw.

D.6 Tube Plugs

Mechanical plugs are designed to be leak limiting. In cases where plug degradation is detected, or plug leakage is suspected, in situ pressure testing equipment may not be able to isolate the plug to allow a determination of leak rates.

D.7 Pitting

Proof testing of pits for structural integrity assessment is not required, since documented evidence indicates that these defects do not significantly impact the burst strength of steam generator tubes. For example, a tube from a Millstone-2 steam generator had a band of numerous pits extending over an axial length of 1 1/2 inches. Post-burst test measurements indicated that some of these pits were at least 85 percent through-wall and 0.105 inch in diameter. The room temperature burst pressure for a specimen containing the band of pits was 9000 psi and the burst was through a gouge approximately 0.005 inch deep resulting from the tube pull. A non-defective section of the same tube burst at 10,250 psi. NUREG/CR-5117 [23] testing of tube from the Surry 2 steam generators supports this conclusion.

Operating history indicates that thousands of tubes in steam generators have developed pits but there have been essentially zero occurrences of through-wall pitting. Similarly, pits developed in laboratory test programs did not grow through-wall. In both the field and laboratory, deep pits developed in relatively short periods of time but subsequent exposure did not produce through-wall pits that leaked. However, none of these pits were exposed to accident conditions and thus the possibility they may leak under such conditions cannot be discounted. Therefore, in situ leak test screening of pits is required.

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