Steam Generator Integrity Assessment Guidelines

Revision 2

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REPORT SUMMARY

This report provides guidance for evaluating the condition of steam generator (SG) tubes based on nondestructive examination (NDE) or in situ pressure testing. This integrity assessment is normally performed during a reactor refueling outage. Nuclear power plant licensees who follow this document's guidelines will have satisfied their requirements for condition monitoring and operational assessment as defined in the Nuclear Energy Institute (NEI) initiative, *Steam Generator Program Guidelines*, NEI 97-06.

Background

Damage to steam generator tubing can impair its ability to adequately perform required safety functions in terms of both structural integrity and leakage integrity. Therefore, assessing tube integrity is an important component of a steam generator program, which is required by NEI-97-06. This program establishes a framework for structuring and strengthening existing steam generator programs. The fundamental elements that are needed represent a balance of prevention, inspection, evaluation, repair, and leakage monitoring measures.

Objectives

- To help licensees support implementation of NEI 97-06.
- To help licensees meet the integrity assessment performance criteria described in NEI 97-06.
- To define requirements and describe in detail implementation procedures for a successful steam generator integrity assessment.

Approach

An ad-hoc committee of licensee experts and additional industry specialists developed these integrity assessment guidelines. This document presents common industry practices for integrity assessment that are achievable with current technology. Any revisions to these guidelines are implemented through the Steam Generator Management Program consensus process, which requires adherence to a formal industry review, comment, and approval protocol. Interim guidance will be provided to the industry whenever necessary between guideline revisions.

Results

This document describes acceptable methods for degradation assessments, condition monitoring, operational assessments, and secondary-side assessments. Condition monitoring refers to assessing the status of steam generator tubes during an outage to ensure that they maintained adequate safety margins for the previous operating period. Operational assessment is intended to ensure that steam generator tubes will maintain adequate safety margins during the upcoming

operating period. There are other acceptable methods for integrity assessment; however, they require technical justification for their application.

This document is a major rewrite of Revision 1 of the integrity assessment guidelines. The report has been completely reorganized. There is more detail in each chapter, there are many fewer appendices, and much new material is included. A great deal of emphasis is placed on providing examples of how to carry out the essential steps of an integrity assessment. Methods for determining probability of detection (POD) of flaws are provided, as are methods for estimating flaw sizes and how large they might grow over an operating interval. There also is a new chapter on secondary-side integrity.

Since Revision 1 was published, there have been five occasions when interim guidance was issued. These are as follows:

- *Interim Guidance on New Degradation Mechanisms*, August 31, 2001;
- *Interim Guidance on Three Mile Island Tube Sever Event*, August 18, 2003;
- *Interim Guidance on Revised Structural Performance Criteria*, SGMP-IG-05-001, January 17, 2005;
- *Interim Guidance to Communicate Issuance of NEI 97-06 R2 and Gaps Between Revision 2 and Current Guidelines*, SGMP-IG-05-002, October 10, 2005; and
- *Interim Guidance Regarding Adverse Trend of Foreign Objects in Steam Generators*, SGMP-IG-05-04, November 18, 2005.

This document incorporates guidance for these occasions, although the wording may be slightly different. In any case, interim guidance is now superseded by this document.

EPRI Perspective

NEI 97-06 requires condition monitoring and operational assessment of steam generator tubing. These integrity assessment guidelines provide a useful description of how steam generator tubing can be shown to meet required performance criteria. Using a standard approach facilitates acceptance and review by regulatory authorities.

This document reflects current industry practices and represents an acceptable method for integrity assessment. Revisions can be expected as the industry accumulates experience with this guideline.

Keywords

Nuclear steam generators
Degradation assessment
Condition monitoring
Operational assessment
Secondary-side integrity assessment
Integrity assessment

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INTRODUCTION

1.1 Objective

These guidelines present requirements and implementation procedures for meeting the objectives of steam generator tube integrity assessments including:

1. Identification and characterization of degradation forms within steam generators that require assessment,
2. Application of appropriate NDE technology, consistent with the expected degradation and in accordance with the EPRI Steam Generator Examination Guidelines [1].
3. Application of integrity assessment methods, consistent with the expected degradation and required safety factor, for use in evaluating integrity at the end of an inspection interval and to ensure integrity during the subsequent inspection interval.

Successful implementation of the above objectives will help ensure that steam generator integrity will be maintained for each degradation form during operation and applicable design basis accidents.

Licensees should use this document to demonstrate the condition of their steam generators relative to performance criteria used for condition monitoring and operational assessment as defined in the NEI initiative, Steam Generator Program Guidelines NEI 97-06 [2].

1.2 Scope

As required by NEI 97-06, this document offers guidance and requirements for the evaluation methods, margin, and uncertainty considerations used to determine tube integrity. It also provides guidance for performing steam generator degradation assessment (DA), condition monitoring (CM), operational assessment (OA), and secondary side assessment. Assessment of steam generator tube integrity requires an evaluation of both burst and leakage throughout an operational plant cycle. Information on how to carry out these assessments is provided in the body of this document with supplemental examples in the appendices. Other approaches may be used with technical justification.

1.3 Basic Methodology of Steam Generator Integrity Assessment

This section summarizes the details of steam generator integrity assessment. This assessment applies to steam generator components which are part of the primary pressure boundary (e.g., tubing, tube plugs, sleeves and other repairs). It also applies to foreign objects and secondary side structural supports (e.g., tube support plates) that may, if severely degraded, compromise pressure-retaining components of the steam generator.

Figure 1-1
Steam Generator RCS Pressure Boundary Assessment; Condition Monitoring and Operational Assessment

1.4 Compliance Responsibilities

This document presents a general approach and examples for demonstrating steam generator tube integrity. Plant specific programs should consider plant design, materials, steam generator corrosion experience, and operating philosophy. Performing the assessments herein will help plant personnel understand what inspections and repairs are necessary and the appropriate length of operation between inspections. To meet this goal, an effective corporate policy and monitoring program are essential and should be based on the following:

1.5 Contractor Oversight

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TUBE INTEGRITY CRITERIA

2.1 Introduction

This chapter presents analysis margins and acceptance criteria for structural integrity and through-wall leakage associated with degraded steam generator tubing.

2.2 Structural Integrity Performance Criterion

The SIPC provides the margins for tube integrity against tube burst or collapse. The structural integrity performance criterion is:

Figure 2-1
SIPC Implementation Logic

2.3 Leakage Integrity Performance Criteria

The leakage integrity performance criteria provide requirements for both operational and accident leakage.

2.4 Performance Acceptance Standards

The performance acceptance standards for assessing tube integrity to the structural integrity and accident leakage performance criteria apply to both condition monitoring and operational assessments. The acceptance standard for structural integrity is:

The acceptance standard for accident leakage integrity is:

2.5 Discussion of Structural Margins and Bases

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Steam generator tubes exhibit a low probability of burst under normal operating conditions and accident conditions. The definition of tube burst is:

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2.5.4 Limits on Yield Strength

2.6 Pressure Load Definitions

Normal steady-state full power operation as defined in NEI 97-06 [2], and discussed in Appendix A, is:

> The conditions existing during MODE 1 operation at the maximum steady state reactor power as defined in the design or equipment specification. Changes in design parameters such as plugging or sleeving levels, primary or secondary modifications, or T_{hot} should be assessed and their effects on differential pressure included if significant.

The limiting accident pressure differential is the maximum or largest pressure differential across the tube wall for the design basis accidents (Service Levels C and D). For most plants, this is the pressure differential during a main steam line break. Apart from pressure loading, other contributing loads that can occur during the postulated accidents shall be evaluated to determine if these loads contribute significantly to tube burst. Such loads are discussed in Section 2.5.1, Section 3.7.2, and in Appendix A.

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TUBE INTEGRITY ASSESSMENT LIMITS

3.1 Introduction

This chapter presents the general requirements for establishing the tube integrity and repair limits associated with steam generator tubing, such that the tube integrity performance criteria and the performance acceptance standards defined in Chapter 2 are satisfied during operation. Tube integrity limits are defined for each degradation mechanism.

3.2 Tube Integrity Limits

3.2.1 Condition Monitoring Limit

Condition monitoring is the assessment of the current state of the steam generator tubing, and is performed at the conclusion of each steam generator inspection. The purpose of condition monitoring is to confirm that both the structural integrity and accident-induced leakage performance criteria were satisfied during the past inspection interval.

3.2.2 Operational Assessment Limit

An operational assessment is a forward-looking prediction of the steam generator tube conditions at the next inspection.

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4.1 Introduction

This chapter addresses NDE system performance measures and their uncertainties associated with tube bundle examination for tube integrity applications. Two aspects of performance are considered: 1) degradation detection, quantified by Probability of Detection (POD), and 2) degradation sizing, quantified by linear correlations of true-versus-measured values of structural quantities of interest, such as length and depth of degradation.

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In this chapter methods are presented to determine degradation growth rates from NDE inspection information. This chapter also provides specific growth rate information from industry service experience that may be used when plant-specific data are limited.

5.2 Background

5.3 Data Evaluation Procedures

The following procedures can be used to characterize distributions of growth rates for use in Operational Assessments. Two methods are presented. The first method is a simplified approach that provides a conservative estimate for growth since it includes sizing uncertainties. In some situations, this method may result in a very conservative value for growth rate distribution, in which case a second, more refined method, may be used to give a more realistic estimate for growth rate by explicitly accounting for sizing uncertainties.

5.3.1 Conservative Estimate of the Growth Rate Distribution

5.3.2 Realistic Estimate of the Growth Rate Distribution

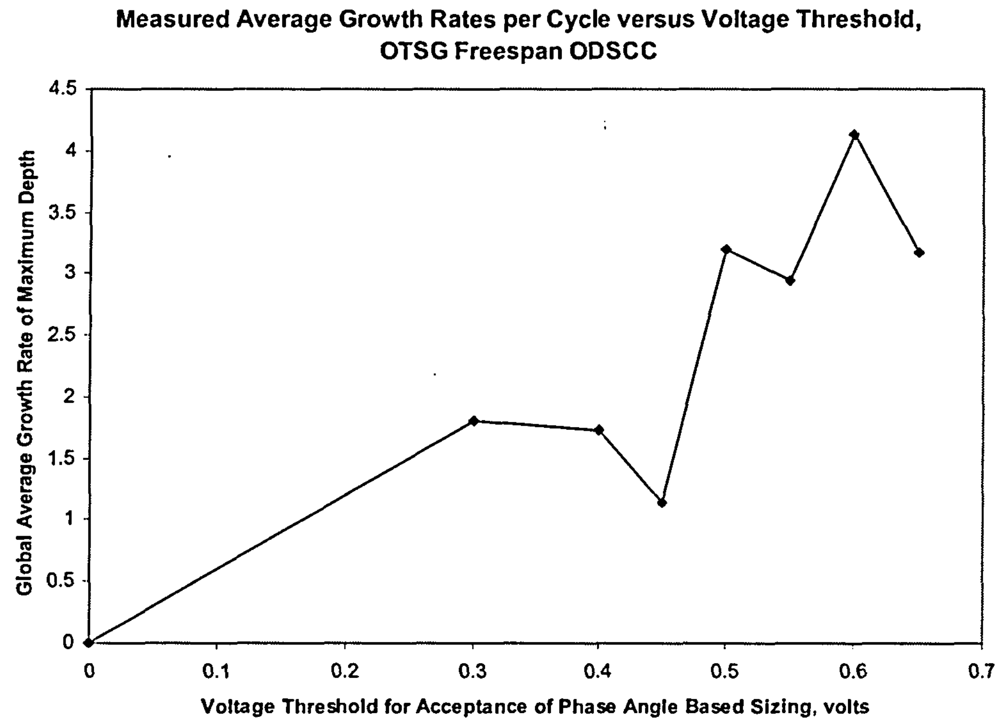

Figure 5-1
Global Average Growth rate of Maximum Depth as Voltage Threshold of Acceptable Sizing Data is Increased

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Three examples of estimating actual physical growth rates from NDE measurements of degradation growth are presented below. The first two examples are for plug on sizing repair scenarios and the third is for a plug-on-detection degradation mechanism.

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DEGRADATION ASSESSMENT

6.1 Introduction

Degradation assessment is the process of identifying and documenting existing and potential degradation in planning for an upcoming outage, including inspection plans and related actions for the primary and secondary sides of the steam generator.

6.2 Purpose

The overall purpose of the degradation assessment is to ensure that appropriate inspections are performed during the upcoming outage, and that the requisite information for integrity assessment is provided.

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Condition monitoring (CM) involves the evaluation of inspection results at the end of the inspection interval to determine the state of the steam generator tubing for the most recent period of operation relative to structural and leakage integrity performance criteria. This chapter provides guidance on performing structural assessments.

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Required reporting to the NRC is addressed in each licensee's technical specification and in NEI 97-06. The NRC report includes the results of the condition monitoring performed during a SG inspection.

Required reporting to the industry is addressed in NEI 97-06. It is important the licensees share experiences with the industry in a timely manner through the SGMP and/or the INPO OE process. If a performance criterion is exceeded or if a new industry degradation mechanism is identified, this information should be sent to appropriate SGMP representatives as soon as possible via e-mail so that lessons learned can be disseminated quickly to the industry. All appropriate tables in the EPRI Steam Generator Database shall be completed within 120 days after startup.

11.2 Internal Reporting

The reporting discussed in this section is not meant to cover all required internal reporting or documentation. This section is concerned with required reporting for integrity assessments. Refer to other EPRI Guidelines for additional internal reporting requirements.

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11.2.2 The Condition Monitoring Report

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LIST OF ABBREVIATIONS AND ACRONYMS

AILPC	Accident-Induced Leakage Performance Criterion
ARC	Alternate Repair Criteria
ASL	Axial Secondary Loads
ASME	American Society of Mechanical Engineers
AVB	Anti-Vibration Bar
AVT	All Volatile Treatment
BOC	Beginning of Cycle
BP	Burst Pressure
B&W	Babcock and Wilcox
CAF	Corrosion-Assisted Fatigue (High Cycle Fatigue)
CDF	Cumulative Distribution Function
CE	Combustion Engineering
CEOG	Combustion Engineering Owners' Group
CFR	Code of Federal Regulations
CLT	Cold Leg Thinning
CM	Condition Monitoring
CMTR	Certified Mill Test Report
DA	Degradation Assessment
ECT	Eddy Current Testing
EDF	Empirical Distribution Function
EFPY	Equivalent Full-Power Years
EOC	End of Cycle
EPRI	Electric Power Research Institute
ETSS	Examination Technique Specification Sheet
FDA	Fractional Degraded Area
FLB	Feed Line Break
FME	Foreign Material Exclusion
FOSAR	Foreign Object Search and Retrieval
FS	Free Span
FSAR	Final Safety Analysis Report

GDC	General Design Criteria
GLM	Generalized Linear Modeling
GPD	Gallons Per Day
GR	Growth Rate
IAGL	Integrity Assessment Guidelines
ICC	Intergranular Cellular Corrosion
ID	Inside Diameter
IGA	Intergranular Attack
IDIGA	Inside Diameter Intergranular Attack
IGSCC	Intergranular Stress Corrosion Cracking
INPO	Institute for Nuclear Power Operations
ISI	In-Service Inspection
LAPD	Limiting Accident Pressure Differential
LCO	Limiting Condition Operation
LOCA	Loss of Coolant Accident
LR	Leak Rate
LTL	Lower Tolerance Limit
MAPOD	Model-Assisted Probability of Detection
MD	Maximum Depth
MSLB	Main Steam Line Break
NDE	Nondestructive Examination
NEI	Nuclear Energy Institute
NMP	NDE Measurement Parameter
NOP	Normal Operating Pressure
NOPD	Normal Operating Pressure Differential
NRC	United States Nuclear Regulatory Commission
NSSS	Nuclear Steam Supply System
OA	Operational Assessment
OD	Outside Diameter
ODSCC	Outside Diameter Stress Corrosion Cracking
OE	Operating Experience
OI	Operating Interval
OTSG	Once Through Steam Generator
PDA	Percent Degraded Area
Pdf	Probability Density Function
PICEP	Pipe Crack Evaluation Program (a computer program)

PL	Primary Load
POB	Probability of Burst
POD	Probability of Detection
POL	Probability of Leak
PWR	Pressurized Water Reactor
PWSCC	Primary Water Stress Corrosion Cracking
RCPB	Reactor Coolant Pressure Boundary
RFC	Retirement for Cause
RG	Regulatory Guide
RPC	Rotating Pancake Coil
RSG	Recirculating Steam Generators
SF	Safety Factor
SG	Steam Generator
SGDD	Steam Generator Degradation Database
SGMP	Steam Generator Management Program
SGPB	Steam Generator Pressure Boundary
SGTR	Steam Generator Tube Rupture
SIPC	Structural Integrity Performance Criterion
SL	Structural Limit
SLB	Steam Line Break
SR	Stability Ratio
SRP	Standard Review Plan
SSE	Safe Shutdown Earthquake
STP	Standard Temperature and Pressure (60°F, 760 mm Hg)
S/N	Signal-to-Noise Ratio
TRM	Technical Requirements Manual
TS	Tubesheet
TSP	Tube Support Plate
TSPC	Tube Support Plate Center
TSPE	Tube Support Plate Edge
TW	Through Wall
UTS	Upper Tubesheet (in OTSGs)
W	Westinghouse

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A

APPENDIX A: INDUSTRY TECHNICAL BASES FOR STRUCTURAL INTEGRITY ASSESSMENT

A.1 Introduction

A.2 Definition of Burst

A.2.1 Burst Condition

A.2.2 Technical Discussion

A.2.3 Application - Condition Monitoring

A.3 Deterministic Structural Performance Criterion Pressure Loading Definition

A.3.1 Background

A.3.2 Statement of Structural Performance

Figure A-1
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A.3.5 Limits on Yield Strength

A.4 ASME Code Review

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A.6.4 Treatment of Axial Thermal Loads

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A.7.1 Tube Burst Condition

A.7.2 Plastic Collapse Under Tension and Bending

A.7.3 Circumferential Degradation

A.7.4 Axial Degradation

A.8 Summary and Conclusions

A.9 References

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B
APPENDIX B: MODEL-ASSISTED POD DEVELOPMENT

B.1 Model-Assisted POD (MAPOD)

B.1.1 Ahat Modeling

Figure B-1
Ahat POD Modelling

Figure B-2
Excel™ Implementation of Ahat POD Modeling for Cold-Leg Thinning ETSS Data

Figure B-3
Excel™ Implementation of Ahat POD Modeling for Cold-Leg Thinning ETSS Data

Figure B-4
Excel™ Implementation of Ahat POD Modeling for Cold-Leg Thinning ETSS Data

B.1.2 Noise-Dependent Structural POD Modeling

B.1.2.1 Ahat (S/N) Modeling

B.1.2 2 Monte Carlo Ahat (S/N) Simulation

Figure B-5
Monte Carlo Simulation of Ahat (S/N) Data

B.1.2.3 Incorporating Human Factor or Personnel Effects

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Monte Carlo Generated Noise Dependent Structural POD Model

B.1.2.4 Illustrating the Dependency of POD on (S/N)

Figure B-8
Cumulative Noise Distributions Used for Noise-Dependent Monte Carlo POD Simulations

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Figure B-9
Monte Carlo Simulated Noise-Dependent Structural Detection Probabilities Showing the Effects of Increasing and Decreasing Noise

Figure B-10
Monte Carlo Predicted POD Compared with Technique Limit and Weighted Average POD for one the Performance Demonstration Datasets

B.1.2.6 Applications

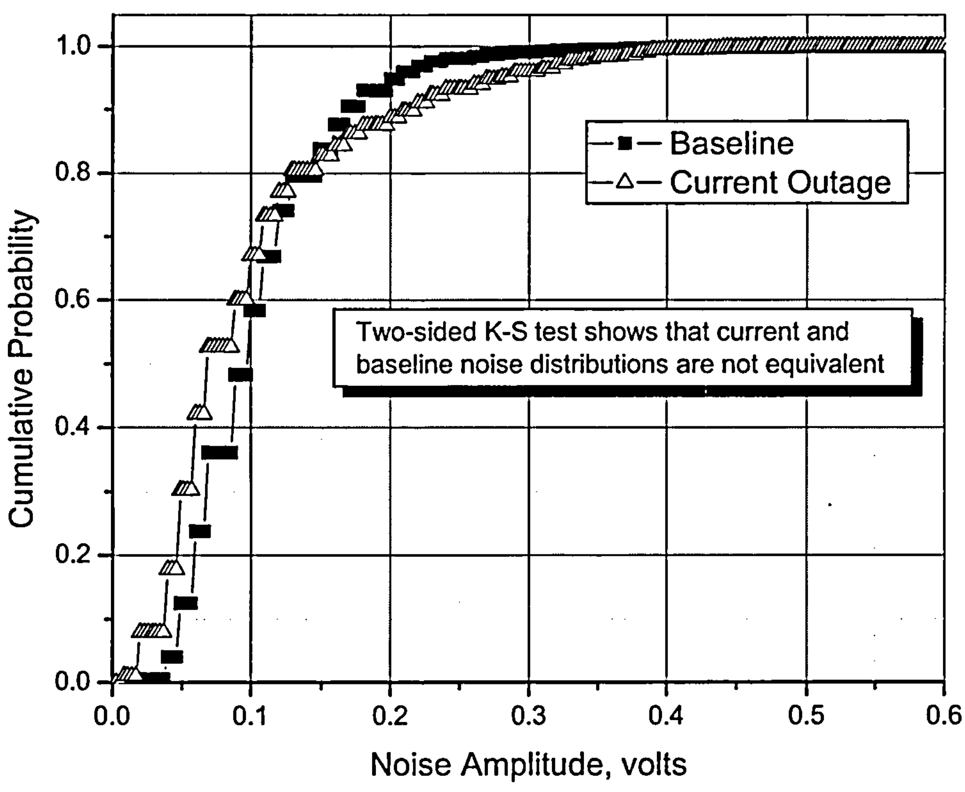

Figure B-11
Kolmogorov-Smirnov Comparison of Two Noise Distributions

Figure B-12
Kolmogorov-Smirnov Comparison of Two Noise Distributions

Figure B-13
Simulation Logic for Deriving Effective POD

Figure B-14
Simulation Outputs for +Pt Confirmation

Figure B-15
Comparison of Effective POD with Bobbin and +Pt coil PODs (+Pt Confirmation)

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C

APPENDIX C: EXAMPLES OF CONDITION MONITORING AND OPERATIONAL ASSESSMENT LIMIT DETERMINATION

C.1 Axial Cracking Examples

C.1.1 Example of Freespan, Through-wall Axial Crack

C.1.2 Condition Monitoring Limit Using Arithmetic Method

C.1.3 Condition Monitoring Limit Using Simplified Statistical Method

C.1.4 Growth

C.1.5 Monte Carlo Analysis

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Burst Pressure as a Function of Critical Crack Length for the Three Methods

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C.2.5.2 Arithmetic Method, Pressure Only

C.2.5.3 Simplified Statistical Analysis, Pressure Only

C.2.5.4 Monte Carlo Analysis, Pressure Only

C.2.6 Pressure Plus External Bending and Axial Loads

C.2.6.1 Calculation of the Structural Limit, Pressure Plus Bending & Axial Loads

C.2.6.2 Condition Monitoring Limit, Pressure Plus Bending & Axial Loads

C.2.6.3 Arithmetic Method, Pressure Plus Bending & Axial Loads

C.2.6.4 Simplified Statistical Analysis, Pressure Plus Bending & Axial Loads

C.2.6.5 Monte Carlo Analysis, Pressure Plus Bending & Axial Loads

C.2.7 Conclusions

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C.3.1 Example of Uniform 360° Thinning Over a Given Axial Length

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Figure C-4
Comparison of CM solutions for a burst pressure of 4.473 ksi

Figure C-5
Distribution of simulated burst pressures for a sample depth and length

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