EPRI | ELECTRIC POWER RESEARCH INSTITUTE

NRC / SGMP Steam Generator Task Force Meeting

February 13, 2019

Agenda

9:00 am ***Introductions & Opening Remarks (NRC and Industry)***

SGMP Steam Generator Task Force Update (Industry)

- In-Plane Fluid Elastic Instability Project Status
- Anti Vibration Bar Insertion Depths
- Operational Assessment Process Could Safely Replace Existing Prescriptive Technical Specification Inspection Intervals
- Summary of Recently Issued SGMP Technical Reports
- Status of Industry Guidelines, Interim Guidance, and NEI 03-08 Deviations
- Recent Operating Experience

10:35 NRC items of discussion

10:45 Public comments/questions

In Plane Fluid Elastic Instability (IP FEI) Project Status

Helen Cothron

Status of SGMP Project

- All testing is complete and reports are published and have been reviewed by the Expert Panel
- Began collaboration efforts with MHI
  - Test results in agreement
- Presented test results to ASME Code Section III, Sub Committee for Appendix N 1300
  - Included information that provides general information about in plane fluid elastic instability
- Participated in conferences where world-wide research is presented
  - SGMP test rig and tests are the most realistic research to operating steam generator conditions
- Expert Panel meeting January 24th
  - All steam generator design organizations attended
  - Attempting to develop a simplified practical approach that will enable utilities to demonstrate that IP FEI is not a concern

Summary of Test Results

- Achieved IP FEI in both 2-Phase Freon tests
  - Expected in the first configuration because we set the gaps large (0.020”) enough to be able to observe the phenomena
  - Same gap, adding additional AVB and tube-to-AVB contact (without preload) in second configuration didn’t suppress IP FEI
- Collected amplitude, damping, work rate and void fraction data
  - Suitable for computer-code validation
- Important lessons learned from world-wide research
  - Preload, or tube-to-support contact interaction, is the most important parameter

Anti Vibration Bar Insertion Depths

Helen Cothron

SGMP Project

- SGMP funded work from 2012 – 2016
  - Provided the generic portions of a fatigue analysis for plant-specific fatigue analysis
  - Defined information necessary to complete the plant-specific analysis
  - Not applicable to steam generators manufactured after 1987
- Thermal hydraulic results provide an overview of the effects of tube support plate occlusion on the tube stability ratios across the bundle for tube rows of interest
- Each plant must adjust the results of this analysis for plant-specific operating conditions and as-built AVB configurations
- Survey in 2012 indicated that utilities were familiar with the issue and were taking actions as appropriate
  - Latest information indicates 15 plants have performed the analysis and 2 plants have plans to perform in the future

SGMP Deliverables

- SGMP Reports:
  - Generic Elements of U-Bend Tube Vibration Induced Fatigue Analysis for Westinghouse Model F Steam Generators, 3002001991, December 2013
  - Generic Elements of U-Bend Tube Vibration Induced Fatigue Analysis for Westinghouse Model D5 Steam Generators, 3002005424, September 2015
  - Generic Elements of U-Bend Tube Vibration Induced Fatigue Analysis for Westinghouse Model 44F Steam Generators, 3002007562, April 2016
  - Generic Elements of U-Bend Tube Vibration Induced Fatigue Analysis for Westinghouse Model 51F Steam Generators 3002007565, May 2016

Operational Assessment Process Could Safely Replace Existing Prescriptive Technical Specification Inspection Intervals

Overview/Background

Greg Kammerdeiner

Overview

- Current Technical Specification inspection frequencies are prescriptive and don't account for plant-specific operating experience
  - Some plants are inspecting more often than necessary due to the Technical Specification time/cycle limits
  - Some plants that would be able to skip inspections per the Technical Specifications must inspect every outage due to OA results
- No matter the time/cycle limits, the industry has a process that determines the safe operating interval
- Industry is requesting a revised steam generator Technical Specification to eliminate prescriptive inspection frequencies without compromising tube integrity requirements

Background

- TSTF 449 (2005)
  - Developed because original steam generator Technical Specifications were outdated
    - Didn’t focus on tube integrity
    - Applied inspection practices far exceeded Technical Specification requirements
- TSTF 510 (2011)
  - Extended periods due to more operating experience with improved materials, eliminated mid point requirements

SGMP Integrity Assessment Guidelines Provide a Robust Process for Ensuring SG Tube Integrity

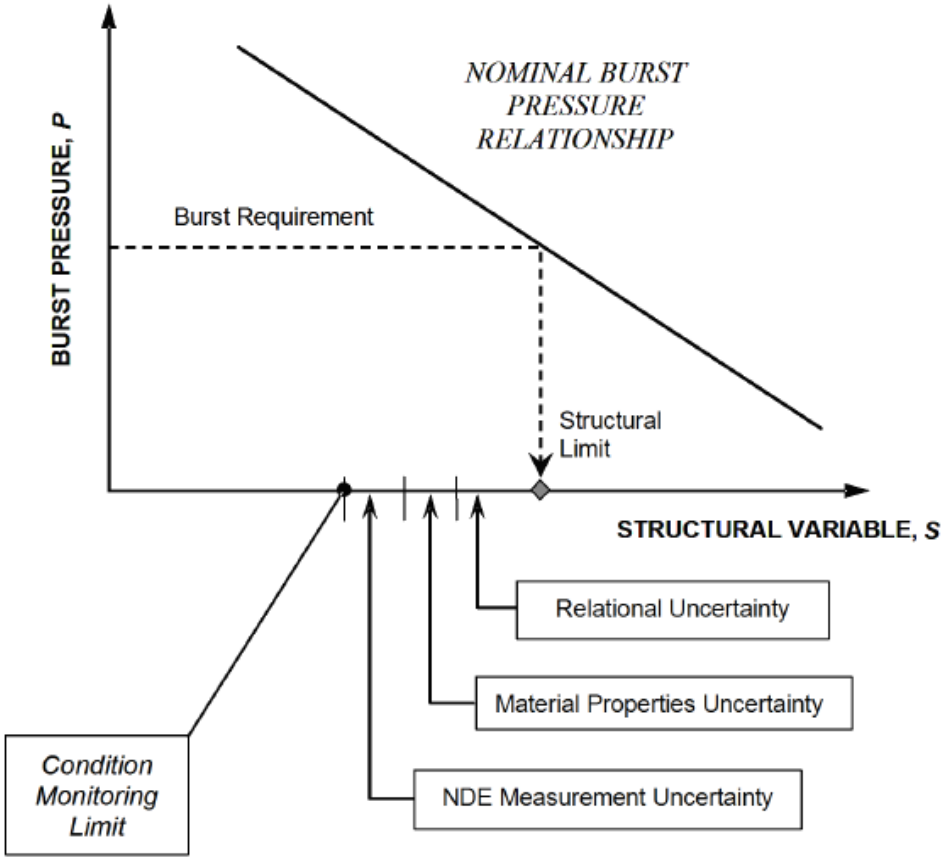
- Detailed industry guidance in place for completing necessary technical evaluations and for monitoring for leakage
  - Integrity Assessment Guidelines (3002007571)
  - Flaw Handbook (3002005426)
  - Burst and Leak Rate Testing (1006783)
  - Examination Guidelines (3002007572)
  - Primary-to-Secondary Leak Guidelines (1022832)
- Structural and leakage performance criteria developed with NRC's involvement are contained in Technical Specifications
- DA/CM/OA process is working effectively

Degradation Assessment

- Mandatory requirement in the Integrity Assessment Guidelines
- Existing and potential mechanisms must be determined
  - Existing mechanisms are those active in the steam generators
  - Potential mechanisms based on industry experience
- Examination techniques qualified through a standard process
- Industry operating experience
- Updated prior to each examination and reviewed along with the OA prior to any outage where steam generator inspections are not performed
  - Chemistry excursions
  - Operational events
  - Operating experience
  - Emergent regulatory issues

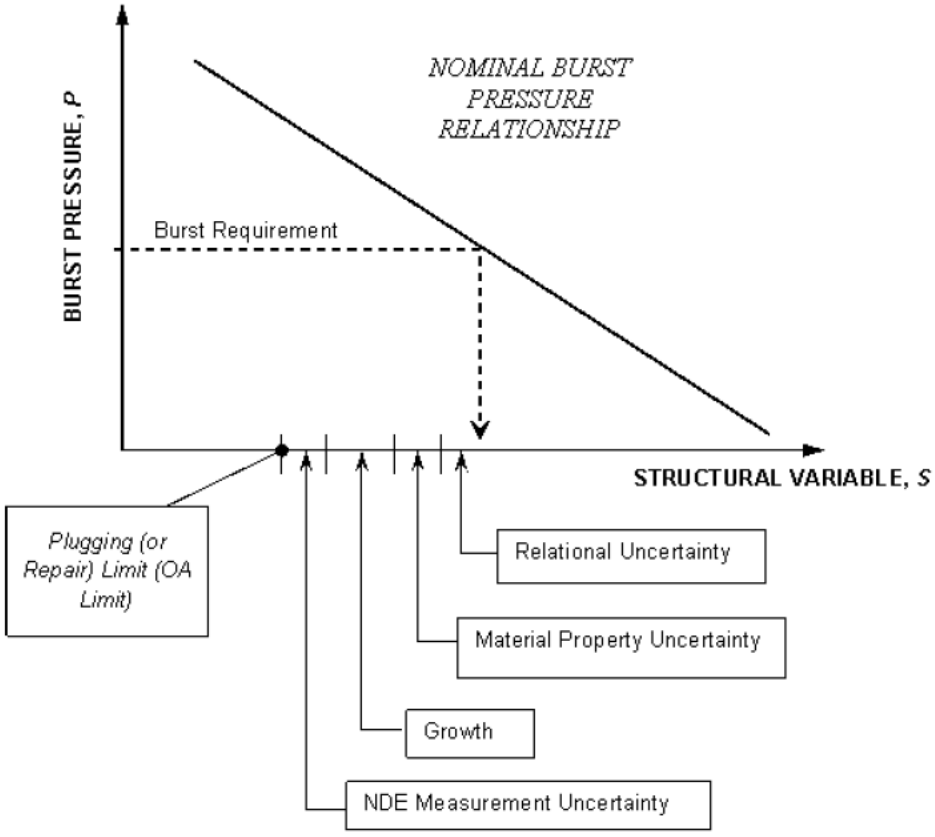
Condition Monitoring

- It is mandatory to perform this assessment after every steam generator inspection
- Evaluates the as-found condition compared to very conservative performance criteria
  - Goal is to verify end of cycle tube integrity and previous OA predictions
- Uncertainties included in calculations at 95th percentile



Operational Assessment

- It is mandatory to perform this assessment after every steam generator inspection to predict a safe operating interval
- Goal is to demonstrate that tube integrity will be maintained until the next inspection
- Very conservative structural and leakage performance criteria must be met using prescribed performance standards
- Defines the safe operating interval
  - Independent of Technical Specification inspection intervals
- Uncertainties at 95th percentile



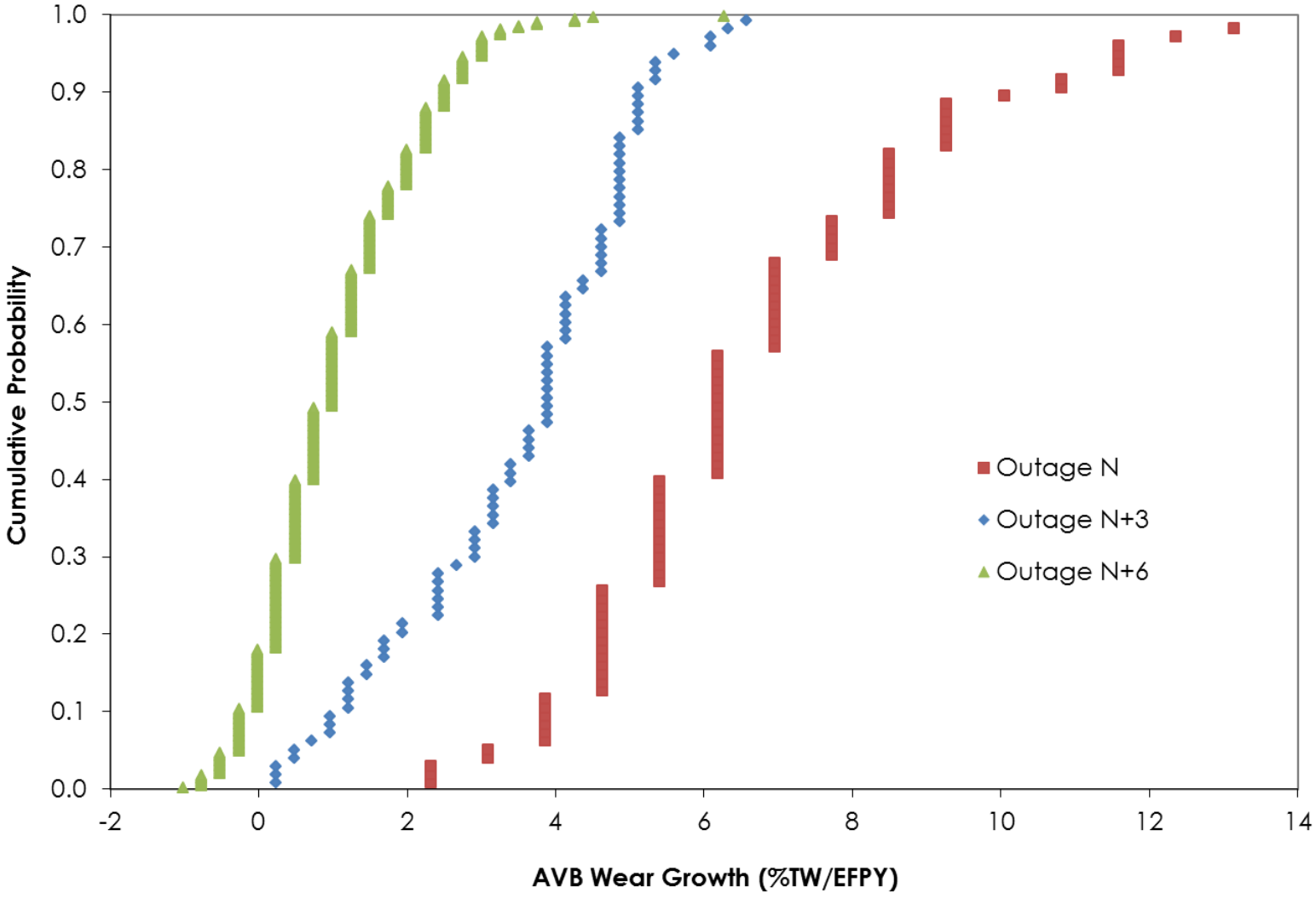
Alloy 690TT

Jeremy Mayo

Alloy 690TT Considerations for OA

- Alloy 690TT steam generator tube material has been in operating steam generators since 1989
  - No cracking has been reported
- Alloy 690TT tubing material has only been cracked in laboratories using non-prototypical conditions
  - Highly cold worked
  - Harsh chemistry conditions
- Tube wear is the only active mechanism
  - Beginning of cycle distribution is an important input
    - Excellent probability of detection for tube wear
  - Growth rate is the most important input to the OA to determine the operating interval
    - Excellent sizing capabilities

Typical Wear Growth Rate Distributions – Decreasing Over Time



Plant A Operational Assessment Example

Basic Design and Operating Info

- 4 loop plant
- Thot approx. 611°F
- Cumulative EFPY for replacement steam generators: 5.40
- ¾ inch, 0.043 inch wall, Alloy 690 TT tubing
- 4,983 tubes per steam generator
- 2nd ISI after replacement
- Zero tubes plugged in all four steam generators

Plant A Operational Assessment Example

Eddy Current Inspection Scope

- 100% full length inspection by bobbin coil
- 100% array probe inspection at top of tubesheet on the hot and cold leg periphery and no tube lane, 3 tubes deep.
- 100% array probe inspection of dings/dents ≥ 2 volts
- 100% array probe inspection of tubesheet tube expansion bulges
- Rotating coil for special interest of any non-resolved indications

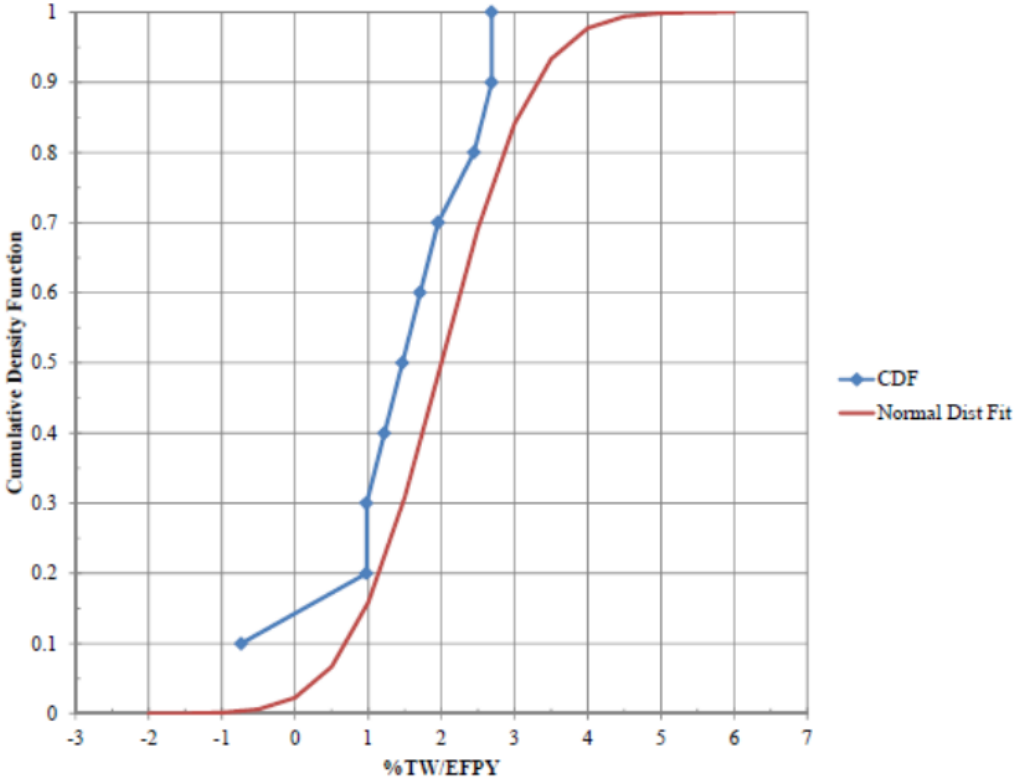
Plant A Operational Assessment Example

Existing Degradation Mechanisms

- Mechanical Wear at U-Bend Support Structures
- Mechanical Wear at Horizontal Advanced Tube Support Grids (ATSGs)
- Mechanical Wear due to Foreign Objects

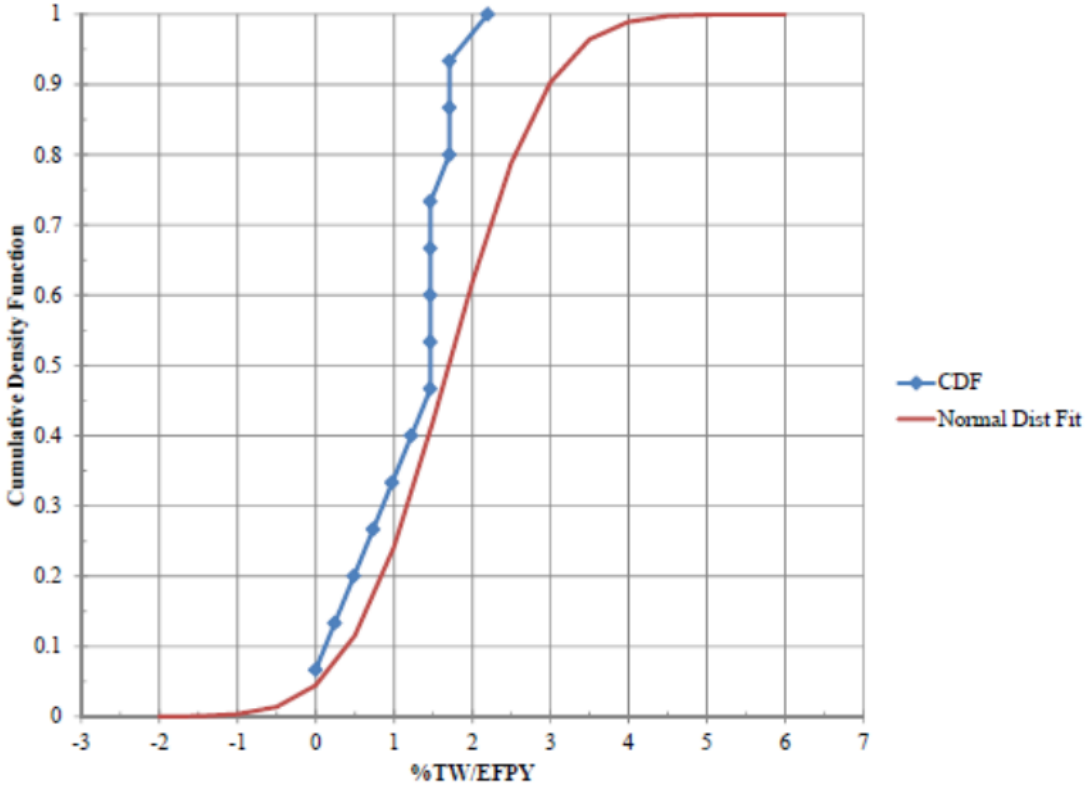
Plant A Operational Assessment Example

U-Bend Support Structure Wear Growth Rate					
# of Indications	Max Indication (%TW)	Max Remaining In-Service (%TW)	Max Growth (%TW/EFPY)	Avg Growth (%TW/EFPY)	Standard Deviation (%TW/EFPY)
10	24	24	2.69	1.54	1.03



Plant A Operational Assessment Example

Horizontal ATSG Support Structure Wear Growth Rate					
# of Indications	Max Indication (%TW)	Max Remaining In-Service (%TW)	Max Growth (%TW/EFPY)	Avg Growth (%TW/EFPY)	Standard Deviation (%TW/EFPY)
15	22	22	2.20	1.22	0.61



Plant A Operational Assessment Example

Operational Assessment Conclusions

- Monte Carlo analysis method was used for OA.
- Based on conservative wear growth rates OA was performed in support of three cycles of operation between inspections
  - Current limitation provided in the plant Technical Specification
  - Equivalent to no greater than 3 cycles of operation between inspections for this plant
- The longest operating duration between inspections was determined using Integrity Assessment Guideline methodology
  - Performance criteria satisfied up to 5 cycles

Technical Specification Overly Conservative for this Plant

Alloy 600TT

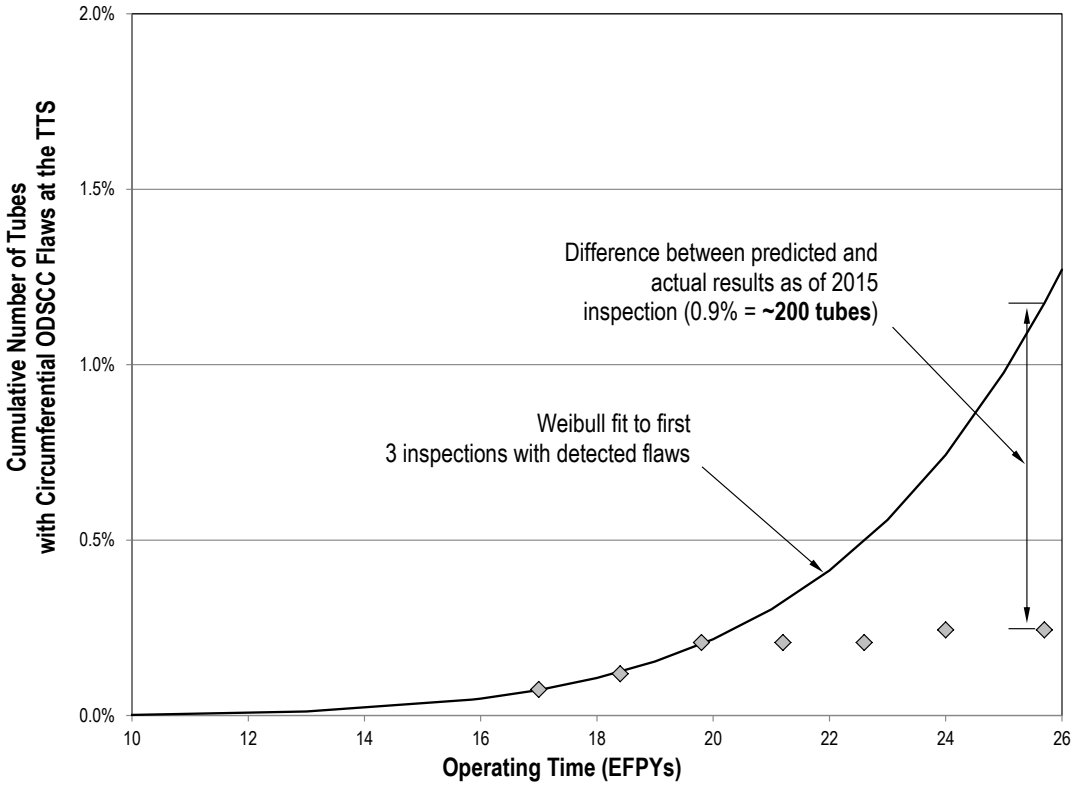
Kent Colgan

Alloy 600TT Considerations for OA

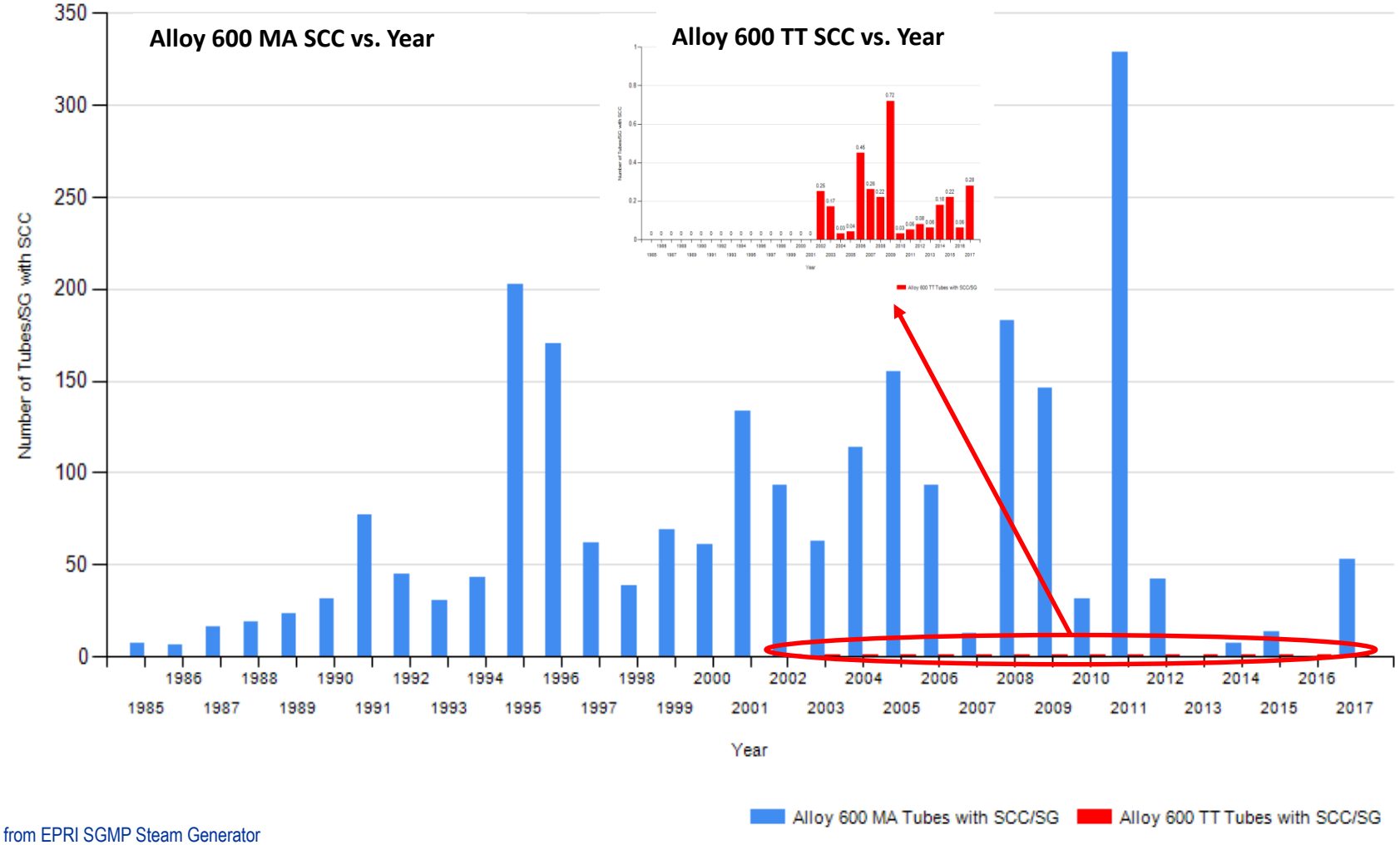
- SGs with Alloy 600TT tubing in the US have been operating reliably with little degradation for nearly 40 years
- Sporadic cracking in some 600TT units
  - Very few tubes affected (0.05% industry-wide as of 2018)
  - Unlike 600MA, small numbers of cracks have not led to widespread corrosion in any of 60+ SGs
- Expect that only a limited number of crack indications with minor severity will be occasionally observed in the future
- The guidelines include procedures that utilities are using that address operational assessments for cracking mechanisms
  - Safely and successfully justifying operating intervals

Operating Experience for Alloy 600TT Tubing

- Industry trends and plant OE show that cracking indications reflect flaws in small tube sub-populations
- Much larger numbers of defects would be detected if cracking were progressing through 600TT tube populations as with 600MA



SG Tube SCC Trends 600MA vs. 600TT Tubing – By Year



Data from EPRI SGMP Steam Generator Degradation Database (SGDD)

Plant B Operational Assessment Example

- Basic Design and Operating Info
  - 3 loop plant
  - Thot 604 degrees F
  - 7/8”, 0.050 inch wall, Alloy 600TT

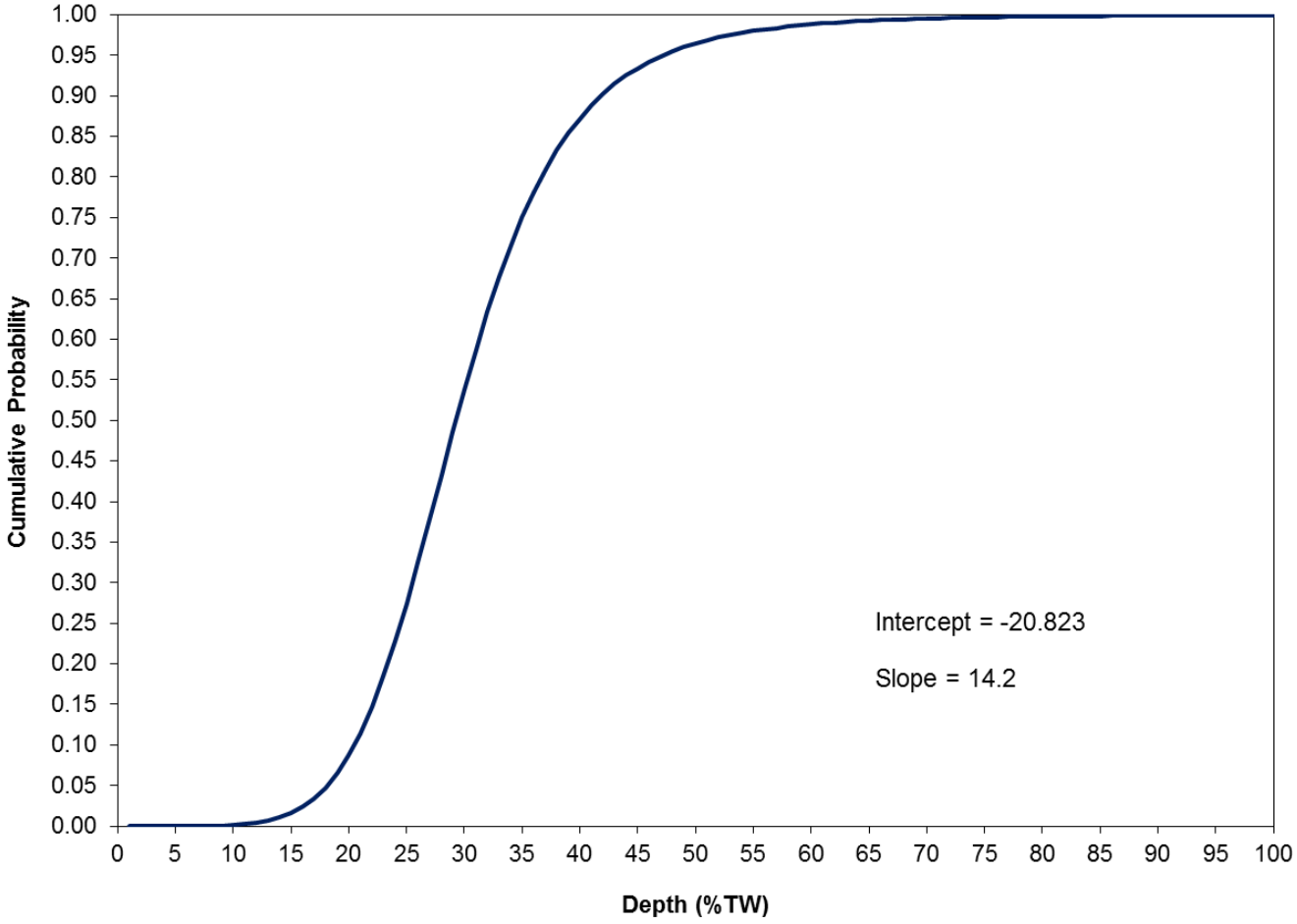
Plant B Operational Assessment Example

- Eddy Current Inspection Scope
  - 100% full length bobbin
  - 100% hot and cold leg top of tubesheet array in 2 steam generators
  - Low row U-Bends with rotating coil
- Existing Degradation Mechanisms
  - Axial PWSCC at the top of the tubesheet (one tube in prior inspection)
  - Circumferential ODSCC at the top of the tubesheet (one tube in prior inspection)
  - AVB wear
  - Foreign object wear
  - Broached support wear

Plant B Operational Assessment Example for Axial PWSCC

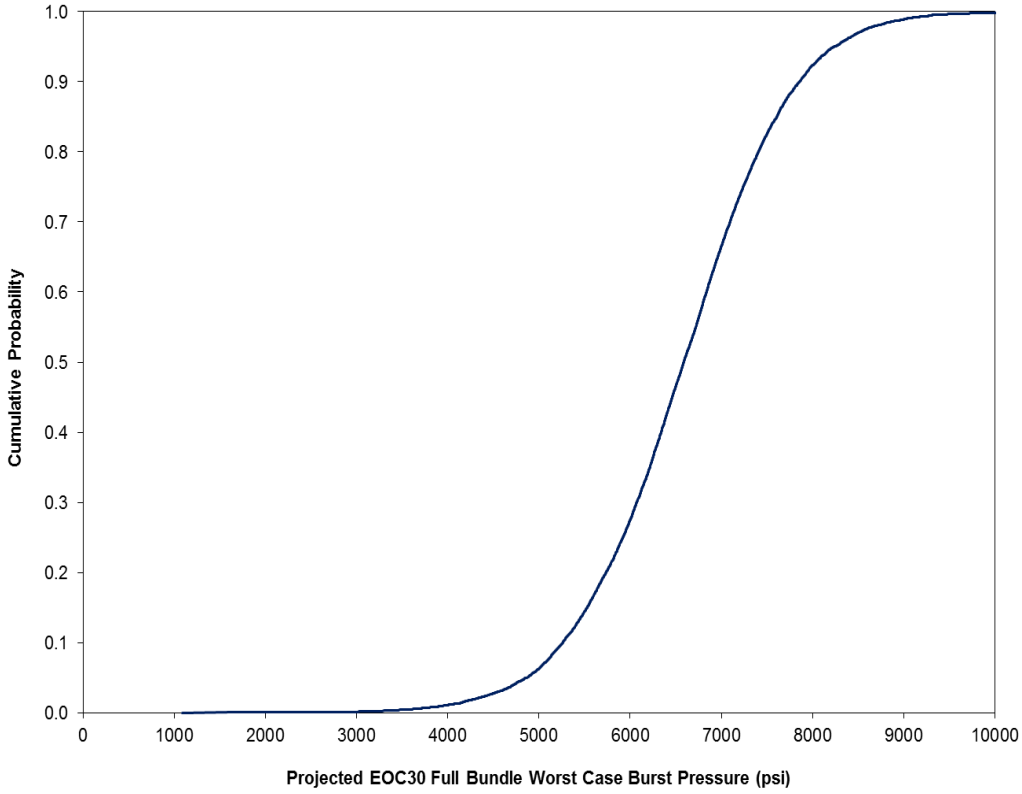
- Current outage no cracking
- OA evaluates the potential impact of axial PWSCC going forward with a two-cycle inspection interval.
  - Assumed PWSCC present in current inspection, even though none were detected
- Following the methodology described in the Integrity Assessment Guidelines, a fully probabilistic multi-cycle OA analysis was performed
  - Developed projections of both detected and undetected flaws for multiple cycles of operation
  - Considered POD, new flaw initiation, and growth to calculate burst probability and accident-induced leakage

Plant B Operational Assessment Example for Axial PWSCC



Projected EOC Tube Burst Pressures for TTS PWSCC

- The resulting distribution of future worst case degraded tube burst pressures
- Acceptable OA structural integrity is demonstrated if the 5th percentile value of this distribution meets or exceeds the SIPC limit



Plant B Operational Assessment Example for Axial PWSCC

- The projected worst case, degraded tube burst pressure after two cycles of operation based upon this very conservative evaluation for axial PWSCC flaws satisfies SIPC.
- Consequently, the structural integrity performance criteria will not be violated by axial PWSCC during the next two fuel cycles.
- The corresponding projected upper 95th percentile leak rate at MSLB conditions is zero.
- If one axial indication had been identified during the inspection, current Technical Specifications would require inspection after one operating cycle.
  - OA would have justified two operating cycles until next inspection

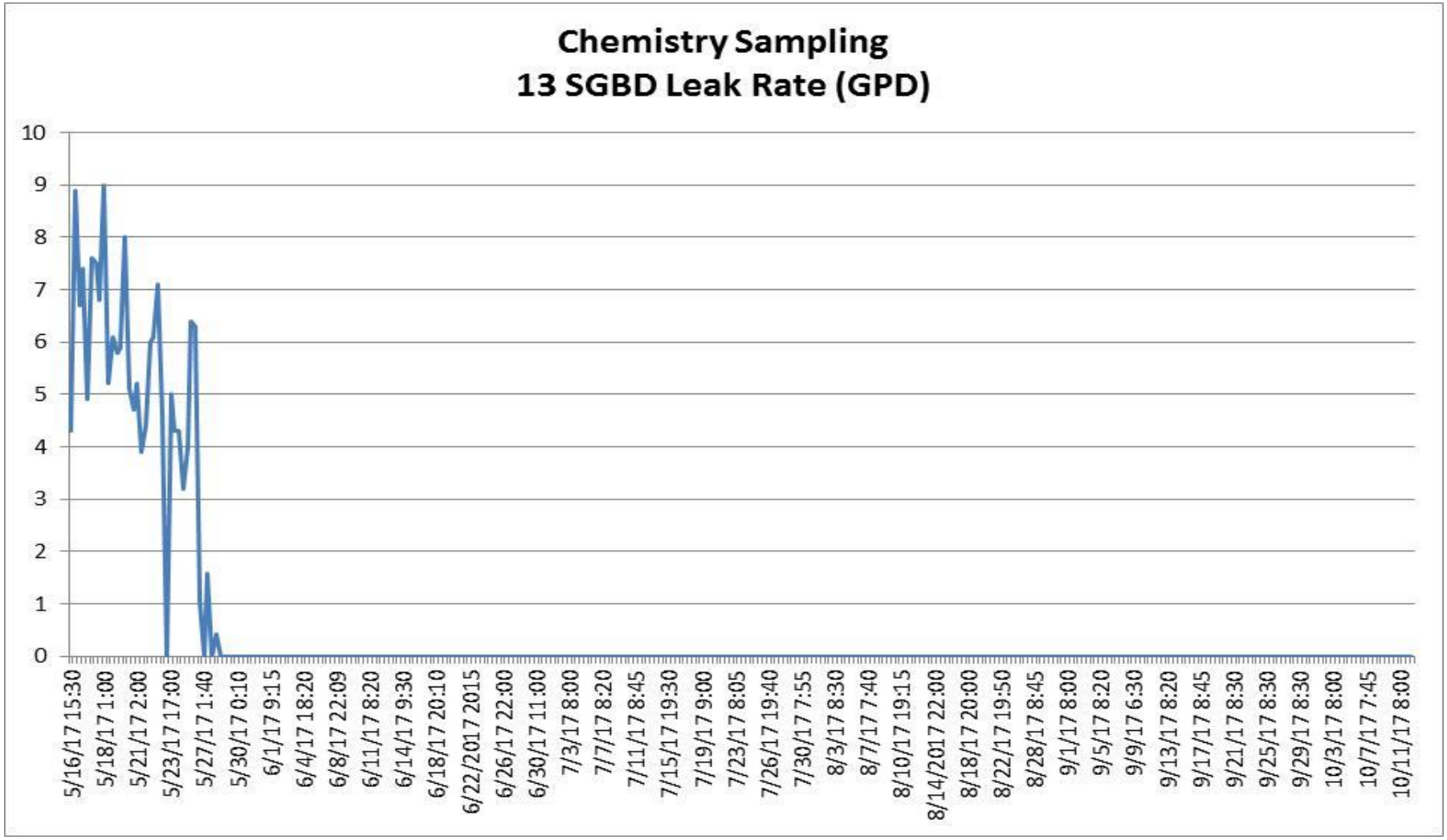
Foreign Objects

Lee Friant

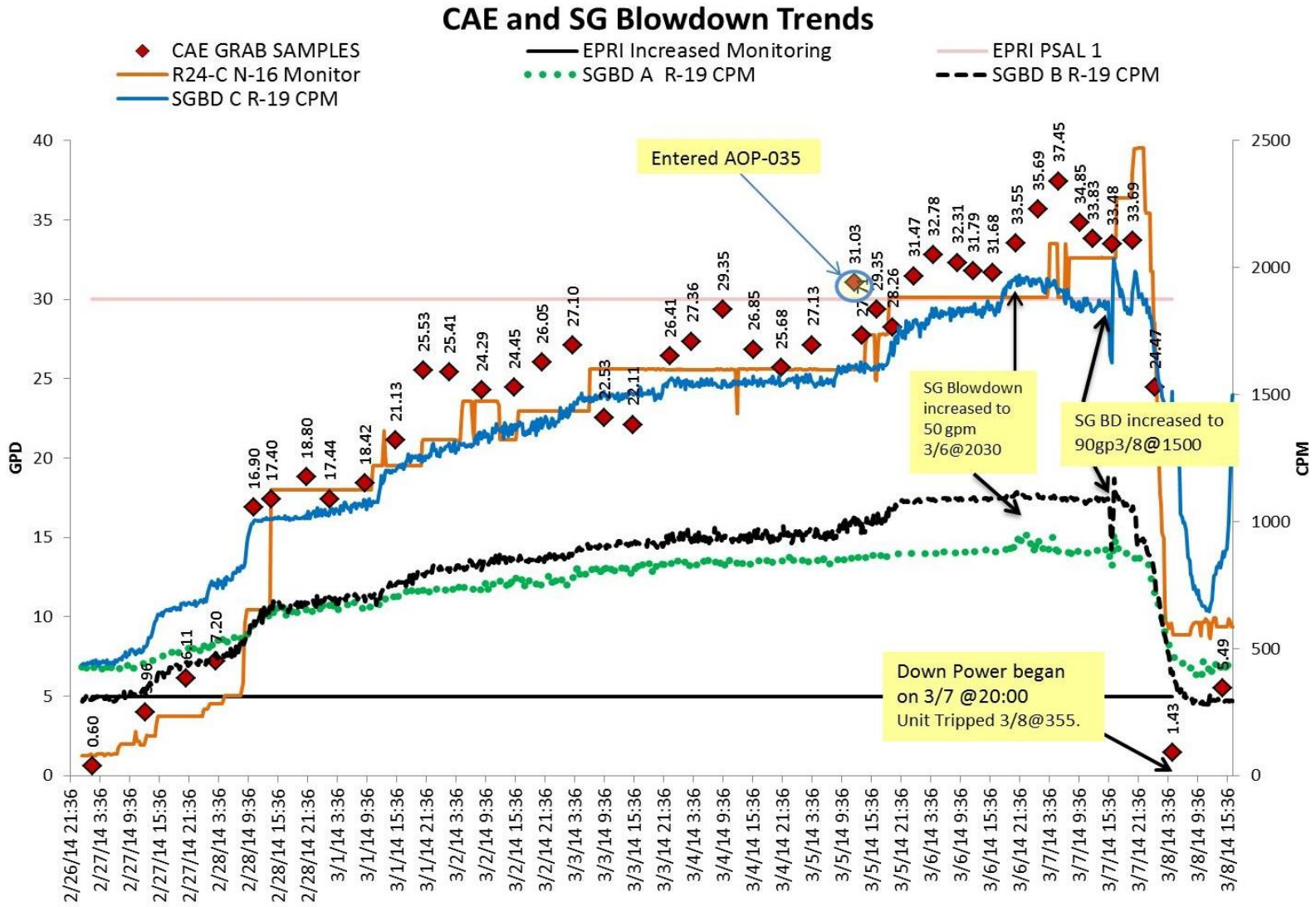
Foreign Objects

- The Integrity Assessment Guidelines require an OA to include aspects of secondary side conditions that could affect tube integrity such as foreign material remaining in the SGs and material degradation that could generate foreign objects during operation
- Foreign material exclusion practices have improved
- Some plants have installed foreign object trapping systems
- Typical foreign objects do not pose a threat of tube burst
  - Recent OE has been small objects and small leakage
- SGMP Primary-to-Secondary Leakage Guidelines require plants to monitor for leakage
  - The industry has been successful with identifying very small levels of primary-to-secondary leakage
  - The industry has a long history of being able to shut down the plants upon detecting leakage that could lead to tube burst

2017 - Plant with low level leakage monitored until planned shut down



2014 – Plant with leakage that increased until safe plant shutdown



Proposed Tech Spec Changes

Helen Cothron

Opportunity for Safely Using Performance-Based Criteria for Setting Inspection Intervals

- Alloy 690TT continues to perform well
  - No cracking has been observed in 30 years of operation
- Industry OE for Alloy 600TT indicates that performance will not be similar to 600MA
  - Small tube sub-populations are experiencing degradation
  - Risks of experiencing larger numbers of defects are likely not increased after finding small numbers of cracks
- Foreign objects are addressed in DA/CM/OA process and plant monitoring
- Indicates an opportunity for using operational assessment methodology for setting inspection intervals while continuing to operate safely
  - Established probabilistic methods have been used for this purpose previously for 600MA units
  - Integrity Assessment Guidelines provide guidance and requirements for using these methods

Proposed New Steam Generator Technical Specification Wording - Example

- In the Programs and Manuals Section 5.5.9, Steam Generator Program add a new paragraph c.
  - Provisions for operational assessments. Operational assessment means an evaluation that projects the condition of the steam generator tubes to the time of the next inspection and determines their acceptability with respect to the performance criteria for structural integrity and accident induced leakage. Operational assessments shall be conducted during each outage during which the SG tubes are inspected, plugged, [or repaired] to confirm that the performance criteria will be met at the end of the operating interval.
- In previous versions of Technical Specifications there is no mention of the operational assessments
- The current paragraph c would be changed to d

Proposed New Steam Generator Technical Specification Wording

- In the Programs and Manuals Section 5.5.9, Steam Generator Program section “d” has requirements for the different tubing material
- Changes for Section d.2 for Alloy 600MA
  - None
- Changes for Section d.2 for Alloy 600TT and Alloy 690TT
  - After the first refueling outage following SG installation, inspect each SG within the timeframe defined in the operational assessment.
  - Appropriately conservative “hard stops” to be determined
- The current section “d” would be changed to “e”

Proposed New Steam Generator Technical Specification Wording

- Section 5.6.8, Steam Generator Tube Inspection Report
  - Add a requirement to provide the Operational Assessment results and the maximum operating interval in the 180 day report

Proposed New Steam Generator Technical Specification Wording

- Changes to the rest of the Technical Specifications would have to be reworded to reflect these changes
- Industry proposes that we meet with the staff over the next months to agree on the specific wording

Summary

- Industry has conservative guidelines and procedures to maintain safe steam generator operations
- Alloy 600MA operating experience drove prescriptive Technical Specifications
- Alloy 600TT and 690TT are not following the Alloy 600MA trends
- Current operating experience proves that integrity assessments ensure safe operating intervals
- Industry proposes an effort with the NRC to develop more performance-based steam generator Technical Specifications

Summary of Recently Issued SGMP Technical Reports

Jim Benson

Investigation of Onset of In Plane Fluid-Elastic Instability (IP FEI) in Two-Phase Freon Flow, 3002012939, December 2018

- Multi-span U-bend (MSUB) tube bundle tests have been performed to investigate IP FEI.
- This work provided data that can be used to advance the understanding, prediction and mitigation of the mechanism for known support conditions
- Experiments described in this report were completed with refrigerant R-134a as the working fluid, with single-phase liquid flows and two-phase liquid/vapor flows generated by boiling
- Were successful in achieving IP FEI over a range of two-phase flow conditions with two well-characterized support conditions that involved flat-bar clearance supports at one and two positions along the U-bend, respectively
- Tests with a single flexible tube were also performed over a wide variety of conditions to characterize the in-plane vibration damping in the absence of the effects of vibration of neighboring tubes.
- The MSUB has produced a wealth of unique, high-quality data that are well suited for understanding IP FEI behavior, developing analytical correlations, and validating the different aspects of numerical models.
- The vibration, damping, work rate, pressure drop, visual, and void-fraction results of the MSUB tests are presented in this report.

Approach for Assigning a Confidence Measure to SG Auto Data Analysis Results, 3002013009, December 2018

- Assigning confidence measures to the classification of results from automated steam generator (SG) eddy current data analysis systems can provide significant benefits to utilities. Potential benefits may include the following:
  - Computing the reliability of signal classification from rotating probe coils and X-probe™ data by automated analysis systems.
  - Providing a quantitative confidence measure of each flaw detected, and flagging indications where operator intervention may be required (i.e., low confidence calls).
  - Utilizing a confidence measure to improve the performance of single party automated data analysis systems.
- This report provides the results of research on the development of algorithms for assigning a confidence value to the classification results from automated eddy current SG data analysis systems.
- The focus of this research is on the identification and quantification of uncertainties in the classification of bobbin probe, rotating probe and array probe analysis results into flaw and non-flaw categories.

Microstructure Characterization of Alloy 600TT Steam Generator Tubing, 3002012931, December 2018

- Historically, steam generators which used mill annealed Alloy 600 (Alloy 600MA) suffered from primary water stress corrosion cracking (PWSCC) and secondary side outer diameter stress corrosion cracking (ODSCC). Plants with Alloy 600MA were found to have PWSCC and ODSCC in large numbers after only a few years of operation.
- Thermally treated Alloy 600 (Alloy 600TT) was a modified version of Alloy 600 with an extra processing heat treatment to precipitate carbides along the grain boundaries.
- Laboratory testing suggested an improvement of Alloy 600TT over Alloy 600MA and in-service performance is greatly improved in Alloy 600TT compared to Alloy 600MA.
- Despite better performance of Alloy 600TT, some incidence of PWSCC and ODSCC have still been observed.
- This study is an attempt to help determine a nominal baseline microstructure for in-service material.

Performance Demonstration Database/Qualified Data Analyst v 4.5, 3002014412, November 2018

- The PDD/QDA software is a program for implementing a uniform industry-wide eddy current analyst qualification program meeting the requirements established in Pressure Water Reactor (PWR) Steam Generator Guidelines, Appendix G (3002007572).
- This new version incorporated array probe data

Effect of an Inhibitor for the Initiation of Lead Stress Corrosion Cracking, 3002012933, October 2018

- Alloys 690TT and 800 have demonstrated good performance in service
- Laboratory testing has demonstrated that both are susceptible to lead-induced stress corrosion cracking (PbSCC) in high pH conditions
- Inhibitors, which would reduce or eliminate PbSCC, could be employed as part of the secondary-side water chemistry program
- The testing described in this report used actively loaded, dog-bone tensile specimens with a blunt notch and direct current potential drop crack measurement with Alloy 690TT and 800 specimens with and without a candidate inhibitor.

Status of Industry Guidelines, Interim Guidance, NEI 03-08 Deviations

Jim Benson

SGMP Guideline Document Status

Guideline Title	Current Rev #	Report #	Last Pub Date	Imple-mentation Date(s)	Interim Guidance	Review Date	Comment
SG Integrity Assessment Guidelines	4	3002007571	June 2016	8/31/17	None	2020	
EPRI SG In Situ Pressure Test Guidelines	5	3002007856	Nov 2016	8/31/17	None	2020	
PWR SG Examination Guidelines	8	3002007572	June 2016	8/31/17	In Progress	2020	
PWR SG Primary-to-Secondary Leakage Guidelines	4	1022832	Sept 2011	4/11/2012 7/11/2012	None	2015	Rev 5 in progress – Target 2019 for publication

SGMP Guideline Document Status

Guideline Title	Current Rev #	Report #	Last Pub Date	Imple-mentation Date(s)	Interim Guidance	Review Date	Comments
PWR Primary Water Chemistry Guidelines	7	3002000505	April 2014	1/28/2015	None	2019	
PWR Secondary Water Chemistry Guidelines	8	3002010645	Sept 2017	6/27/2018	In Progress	2021	

One short-term deviation to Secondary Water Chemistry Guidelines was submitted (ML18306A444)

- Plant planned to perform an aux feed pump test, and during this time the hydrazine limit in the feed source would not have been met
- This is not a generic problem
- The deviation will be archived
- The deviation wasn't needed

Operating Experience

Jesse Baron

Westinghouse Nuclear Safety Advisory Letter 05-02, R1

- Some unreinforced secondary side closures 2.5” diameter or less have stress analyses that may be non compliant with ASME Code
- Initial conclusion is that it is not a safety issue
  - No Part 21
- SGMP investigating extent of condition and course of action for resolution
- NSAL has been provided to the other vendors

NRC Comments

Acronyms

Acronyms

- ASME — American Society of Mechanical Engineers
- AVB — Anti Vibration Bar
- BOC — Beginning of Cycle
- CAE — Condenser Air Ejector
- CM — Condition Monitoring
- CPM — Counts per Minute
- CNL — Canadian Nuclear Laboratories
- DG — Draft Guidance
- DA — Degradation Assessment
- EOC — End of Cycle
- EPRI — Electric Power Research Institute
- FIV — Flow Induced Vibration
- GPD — Gallons Per Day
- IP FEI — In Plane Fluid-Elastic Instability
- MA — Mill Annealed
- MHI — Mitsubishi Heavy Industries
- MSUB — Multi Span U-Bend
- NDE — Nondestructive Examination
- NEI — Nuclear Energy Institute
- NRC — Nuclear Regulatory Commission

Acronyms

- OA — Operational Assessment
- ODSCC — Outside Diameter Stress Corrosion Cracking
- OE — Operating Experience
- PDD — Performance Demonstration Database
- POD — Probability of Detection
- PbSCC — Lead-Induced Stress Corrosion Cracking
- PWR — Pressurized Water Reactor
- PWSCC — Primary Water Stress Corrosion Cracking
- QDA — Qualified Data Analyst
- SG — Steam Generator
- SGDD — Steam Generator Degradation Database
- SGMP — Steam Generator Management Program
- TSTF — Tech Spec Task Force
- TT — Thermally Treated
- US — United States

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