ATTACHMENT 6

Byron Station, Units 1 and 2

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Byron Unit 2 Operational Assessment Addressing Deferment of B2R22 Steam Generator Tube Examinations to B2R23, April 2022

EXELON GENERATION COMPANY
Attn: Mr. Patrick Creegan
Corporate Steam Generator Engineer, Asset Protection,
Fleet Engineering Programs
Byron Nuclear Generating Station
4450 North German Church Road
Byron, IL 61010
patrick.creegan@exeloncorp.com

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PREPARED BY
William K. Cullen
412-951-5001
william.k.cullen@intertek.com

Russell C. Cipolla
408-636-5322
russell.cipolla@intertek.com

Michael C. Liu
408-636-5324
Michael.C.Liu@intertek.com

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Issuing Office
Intertek AIM
3510 Bassett Street
Santa Clara, CA 95054
408-745-7000

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Executive Summary

Exelon Generation Company has submitted a one-time Technical Specification change to defer the Byron Unit 2 B2R22, October 2020 steam generator (SG) tube eddy current inspection to the B2R23 outage, April 2022. The objective of this Operational Assessment (OA) is to provide the technical justification for deferring the B2R22 SG tube examination by one operating cycle. The evaluation is performed in accordance with EPRI Steam Generator Integrity Assessment Guidelines. This OA evaluates the predicted condition of the SGs after three cycles of operation (Cycles 21, 22, and 23).

The most recent examination at the B2R20 outage (fall 2017) identified SG tube fretting wear at anti-vibration bar intersections, at tube support plate intersections, and at preheater drilled hole support plates. Stress corrosion cracking was not reported within the pressure boundary portion of the tubes at the B2R20 inspection or at any prior Byron Unit 2 inspection. Additionally, as a Technical Specification change is required to implement the deferment, potential degradation mechanisms, mechanisms which have not been reported at Byron Unit 2 but judged to have a meaningful likelihood of initiation based on operating experience from similar units or laboratory testing were assumed to have initiated and also evaluated.

The results of these analyses demonstrate that extending the inspection interval by one cycle is fully supported by the industry performance standards for tube integrity. The structural integrity performance criterion margin requirement of three times normal operating pressure (3xNOPD) on tube burst will be satisfied at B2R23 for the existing and potential degradation. Also, the accident-induced leakage performance criteria for the limiting accident condition will be satisfied for the cumulative leakage requirement for any one SG and for all four SGs for the operating period to B2R23 (end-of-cycle (EOC) 23).

It has been concluded that given the examination scope implemented at B2R20 (EOC 20), all structural and accident leakage performance criteria in NEI 97-06 are predicted to be met through the EOC 23 for the existing and potential degradation mechanisms.

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1 | Introduction

Exelon Generating Company has submitted a license amendment request for a one-cycle extension to the current inspection interval for the Byron Unit 2 steam generators (SGs). This request will defer the Byron Unit 2 SG tube examinations from end-of-cycle (EOC) 22 (B2R22 outage) to EOC 23 (B2R23 outage) in April 2022. The objective of this assessment is to provide the technical justification for deferring the SG tube examination by one operating cycle while maintaining the requirements in NEI 97-06 [1]. This operational assessment (OA) is performed in accordance with EPRI Steam Generator Integrity Assessment Guidelines (IAGL) described in [2], and, evaluates the predicted condition of the SGs after three cycles of operation (Cycles 21, 22, and 23).

Throughout this OA process, conservative stress corrosion cracking (SCC) growth rates and detection capabilities have been incorporated to ensure that a robust analysis was performed. To date, SCC mechanisms have not been reported within the pressure boundary portion of the Byron Unit 2 SGs. This OA evaluates potential SCC degradation mechanisms (mechanisms not observed at Byron Unit 2 but observed at similar units or judged to have a meaningful likelihood of occurrence) even though evaluation of such mechanisms is not typically considered in the OA process.

The two most recent examinations at B2R18 (EOC 18) and B2R20 (EOC 20) identified wear at anti-vibration bar (AVB) intersections, at tube support plate (TSP) intersections, and wear at drilled hold support plates (DSP) intersections as the only existing degradation modes directly related to SG design. Tube wear due to foreign object interaction was also reported at B2R20 as well as several prior inspections. Evaluation of foreign object wear/foreign material remaining within the SGs is being evaluated by another vendor and Exelon in a separate document. To date, corrosion degradation has not been observed within the pressure boundary region of the Byron Unit 2 SG tubing.

Section 4 develops key inputs to the analysis; degradation growth rates, Weibull initiation functions for SCC mechanisms, and identification of the SCC susceptible population sizes. The results of these analyses are presented in Section 5 for the existing degradation mechanisms; Section 6 presents the OA results for the potential mechanisms.

2 | Current State of Byron Unit 2 Tube Bundles

2.1 Background

The Byron Unit 2 SGs are Westinghouse Model D5 type, utilizing Alloy 600 thermally treated (A600TT) tube material, full depth hydraulic expansion in the tubesheet region, and stainless steel tube support structures. A schematic illustration of the Byron Unit 2 SGs is shown in Figure 2-1. The tube hole style at TSPs is a quatrefoil broached lobe design. These SGs utilize a preheater design which introduces the majority of the feedwater to the lower region of the cold leg side of the tube bundle. Within the preheater region, the tube baffle support plate hole style is a simple drilled hole.

To date, Byron Unit 2 has experienced fretting wear at tube supports (AVBs, TSPs, and preheater baffles) and tube wear due to interaction with foreign objects. SCC indications have also been reported near the tube end; however, the location of these degradation modes is outside of the pressure boundary as defined by application of the H* alternate tube repair criterion and is not evaluated herein. Per the H* alternate repair criteria, degradation identified below the H* distance is not required to be removed from service. Foreign object wear, while observed within the SGs, is usually not an artifact of SG design or manufacture and is dependent on ingress of material from the balance-of-plant. Evaluation of foreign object wear/foreign material remaining within the SGs for the extended operating period was performed by Exelon and another vendor.

In general, there are several corrosion-related degradation mechanisms that are classified as potential for the A600TT tube material utilized in the Byron Unit 2 SGs. These mechanisms involve forms of SCC either on the primary side or steam-side, oriented either axial or circumferential to the tube axis, and occurring at different locations in the tube bundle. For SGs utilizing A600TT tubing, these potential mechanisms ordered according to their judged risk level, from highest to lowest are:

- Axial ODSCC at TSP intersections on known high residual stress tubes
- Circumferential ODSCC at the hot leg top-of-tubesheet (TTS) expansion transition
- Axial ODSCC at tube dings and dents (both high stress and non-high stress tubes)
- Axial ODSCC at TSP intersections on non-high residual stress tubes (including indications which may extend beyond the edge of the TSP)
- Axial ODSCC at the hot leg TTS expansion transition
- Axial primary water stress corrosion cracking (PWSCC) in small radius U-bends
- Axial and circumferential PWSCC at the TTS (generally bounded by ODSCC analyses)
- Circumferential PWSCC at bulges (BLG) and over-expansions (OXP) within the expanded tube-in-tubesheet region
- OD pitting

The mechanisms judged most challenging to establishing that the OA satisfies the tube integrity criteria are:

- Axial ODSCC at TSP intersections on known high residual stress tubes
- Circumferential ODSCC at the hot leg TTS expansion transition

- Axial ODSCC at tube dings and dents (both high residual stress and non-high residual stress tubes)

2.2 Examination Scope at Last Inspections

The applied eddy current examination scopes from the B2R18 [3] and B2R20 [4] inspections are summarized below. Visual inspections of the channelhead and secondary side were also performed in both outage but are not discussed herein.

2.2.1 B2R18 (2014)

Bobbin Probe Inspections

- 100% full length bobbin inspection except Row 1 and Row 2 U-bends
- Monitoring of hot leg tubes for slippage

+Point™ Probe Inspections

- 50% inspection of Row 1 and Row 2 U-bends (TSP 11H to 11C) including all 9 tubes with identified manufacturing anomalies ("Blairsville Bump")
- 50% inspection of hot leg bulges (≥18V) and over-expansion (≥1.5 mils) within the H* distance
- 100% inspection of >5V dings in the U-bend of all SGs
- 50% inspection >5V dents and dings in the hot and cold legs of all SGs
- All tubes with historical foreign object wear
- +Point special interest testing of bobbin and X-Probe I-codes and tubes surrounding possible loose part signals
- 100% inspection of >2V hot leg dents and >5V hot leg dings on high residual stress tubes
- 100% quatrefoil and baffle plate mix residuals >0.4 vertical maximum volts

X-Probe Inspections

- 50% inspection of hot leg tubesheet region from 3 inches above TTS to the H* distance*
- Inspection of three-tube deep pattern around the periphery, no tube lane, and T-slot from TTS to TSP 01H/01C*
- 100% inspection of high residual stress tubes from 3 inches above TTS to the H* distance plus 100% of high residual stress tubes at hot and cold leg TSP intersections and preheater baffle intersections
- 50% inspection of expanded preheater baffles at 02C and 03C plus expanded preheater baffles at 02C near the flow blocking region

* The total percentage of hot leg tubes inspected at the expansion transition, which is the most likely location SCC initiation for the tubesheet region; therefore exceeds the nominal 50% specification when the peripheral, tube lane, and T-slot programs are combined with the 50% nominal inspection program.

2.2.2 B2R20 (2017)

Bobbin Probe Inspections

- 100% full length bobbin inspection except Row 1 and Row 2 U-bends
- Monitoring of hot leg tubes for slippage

+Point Probe Inspections

- 50% inspection of Row 1 and Row 2 U-bends (TSP 11H to 11C) including all tubes with identified manufacturing anomalies ("Blairsville Bump")
- 50% >5V dings and dents in the hot leg, cold leg, and U-bend
- 50% 2-5V dents at 01H, 01C, 02C, 03C, 04C, 05C, and 06C
- 50% 2-5V dings below 01H and 06C
- All existing and new TSP wear indications
- 100% quatrefoil and baffle plate mix residuals >0.4 vertical maximum volts
- 100% ≥2V dings and dents on high residual stress tubes
- Special interest testing including Bobbin I-codes, historic foreign object wear locations, tubes surrounding foreign object signals

X-Probe Inspections

- 50% hot leg tubesheet region from 3 inches above TTS to the H* distance*
- 50% inspection of hot leg bulges and over-expansion within the H* distance
- 50% inspection of expanded preheater baffles at 02C and 03C plus 100% of expanded preheater baffles at 02C near the flow blocking region
- Inspection of two-to-three tube deep pattern around the periphery from 01C/01H to 3 inches below the TTS*
- 100% inspection of high residual stress tubes from 3 inches above TTS to the H* distance, plus 100% of high residual stress tubes at hot and cold leg TSP intersections and preheater baffle intersections

* The total percentage of hot leg tubes inspected at the expansion transition, which is the most likely location of SCC initiation for the tubesheet region; therefore exceeds the nominal 50% specification when the peripheral, tube lane, and T-slot programs are combined with the 50% nominal inspection program.

The applied inspection programs at B2R18 and B2R20 have aggressively addressed axial ODSCC at TSP intersections on high residual stress tubes and axial ODSCC at dents and freespan dings. These inspection programs are judged the most conservative within the industry when compared with other units. The inspection programs performed for the hot leg tubesheet region (from several inches above the TTS down to the H* distance) suggest that SCC mechanisms in this region either have not initiated or that initiation is consistent with the current accumulated operating exposure. If the latter is accurate, the analyses contained herein conservatively evaluate such degradation.

2.3 Summary of Inspection Results

Consistent with B2R18 inspections, the B2R20 examination indicated that the following tube degradation mechanisms were present:

- Wear at AVB tube contacts
- Wear at TSP tube contacts
- Wear at drilled support plate tube contacts
- Wear due to foreign objects

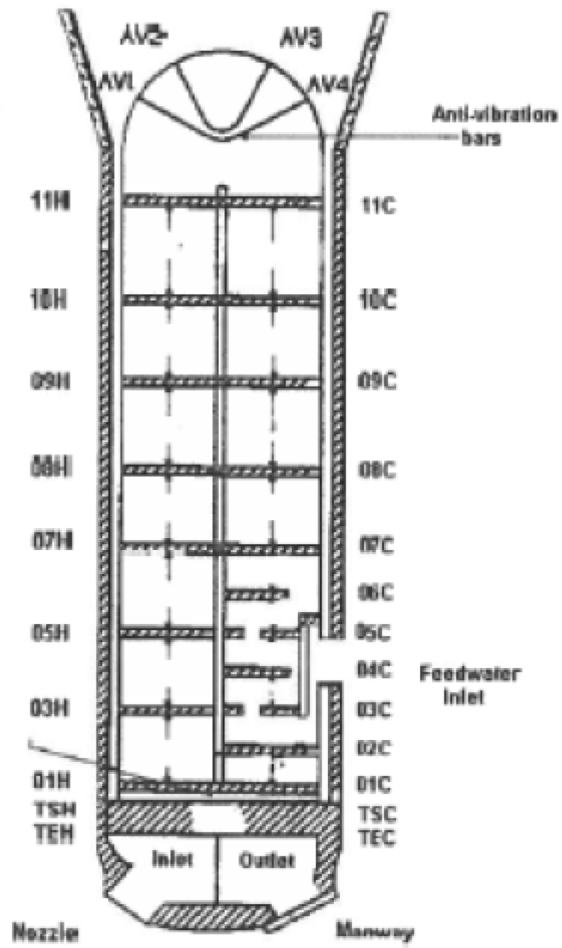
There was no corrosion-related degradation detected within the defined tubing pressure boundary.

2.4 Tube Plugging

At B2R20, 96 tubes were removed from service by plugging: 3 in SG 2A, 92 in SG 2C, and 1 in SG 2D [4].

Two tubes were plugged due to AVB wear with depth greater than or equal to the Technical Specification repair limit of 40%TW, both in SG 2A. One tube was preventively plugged due to TSP wear that was projected to exceed the Technical Specification repair limit of 40%TW in SG 2C. Two tubes were preventively plugged due to foreign object wear with the presence of a possible loose part (PLP) signal: one each in SG 2A and 2D.

A loose backing bar was discovered at 02C in the waterbox region at the feedwater inlet for SG 2C; 91 tubes were preventively plugged in SG 2C to prevent damage if other backing bars or cut-out plates become loose. The backing bar issue also has previously occurred in SG 2A, resulting in 91 tubes preventively plugged at B2R11.



Note: AVB bars are denoted as AV in the figure

Figure 2-1 — Schematic Illustration of Byron Unit 2 Model D-5 SG Tube Bundle [4].

3 | Operational Assessment Methodology

3.1 General Approach of This Operational Assessment

The typical OA purpose is to evaluate as-found degradation during an inspection and to project forward to the next scheduled inspection, the severity of this degradation, and evaluate the degradation against the performance criteria. Per the IAGL, the OA typically only considers existing degradation observed in the SGs. The existing degradation mechanisms for Byron Unit 2 and evaluated in this OA are:

- Tube wear at AVB intersections, at TSP intersections, and at preheater baffle plates

However, this OA is unique as it is used to support the Exelon license amendment supporting deferment of the B2R22 scheduled SG eddy current inspections to B2R23. As the inspection period between inspections is now proposed to exceed the prior interval established by the plant technical specifications, several potential degradation mechanisms are considered. The purpose of these additional evaluations is to provide to the Nuclear Regulatory Commission, a high level of confidence that the extended operating interval will not increase the risk of release of radioactivity to the environment.

The potential mechanisms for which full rigor OA analyses are performed are:

- Axial ODSCC at TSP intersections on high residual stress tubes
- Axial ODSCC at freespan dings on high residual stress tubes
- Axial and circumferential ODSCC at the hot leg TTS expansion transition
- Axial ODSCC at dents and at freespan dings on non-high residual stress tubes

Additional potential mechanisms considered in the evaluation which are judged to be bounded by one of the above analyses include:

- Axial and circumferential PWSCC at the hot leg TTS expansion transition
- Axial PWSCC at small radius U-bends
- Axial ODSCC at TSP intersections on non-high residual stress tubes (including indications which may beyond the edge of the TSP)

3.2 Tube Integrity Requirements

The OA is forward-looking and provides an estimate of the operational period wherein the steam generators will maintain the CM performance criteria. The performance criteria were established for structural integrity and accident-induced leakage in [1]. The structural integrity performance criterion (SIPC) and accident-induced leakage performance criteria (AILPC) are as follows:

- Structural Integrity — "All in-service steam generator tubes shall retain structural integrity over the full range of normal operating conditions (including startup, operation in the power range, hot standby, and cool down), all anticipated transients included in the design specification, and design basis accidents. This includes retaining a safety factor of 3.0 against burst under normal steady state full power operation primary-to-secondary pressure differential and a safety factor of 1.4 against burst applied to the design basis accident primary-to-secondary pressure differentials. Apart from the above requirements, additional loading conditions associated with the design basis accidents, or combination of accidents in accordance with the design and licensing basis, shall also be evaluated to determine if the associated loads contribute significantly to burst or collapse. In the assessment of tube integrity, those loads that do significantly affect burst or collapse shall be determined and assessed in combination with the loads due to pressure with a safety factor of 1.2 on the combined primary loads and 1.0 on axial secondary loads."

- Accident-Induced Leakage — "Accident induced leakage performance criterion: The primary-to-secondary accident induced leakage rate for any design basis accident, other than SG tube rupture, shall not exceed the leakage rate assumed in the accident analysis in terms of total leakage rate for all SGs and leakage rate for an individual SG. Leakage is not to exceed 1.0 gpm total through all SGs and 0.5 gpm through any one SG."

Guidelines for performing the integrity assessment of SG tubing are given in [2]. It has been established that the limiting criterion for tube structural integrity for Byron Unit 2 is maintaining the margin of 3.0 against burst under normal steady state full power operation primary-to-secondary pressure differential.

3.3 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 OAs. The acceptance standard for structural integrity is:

- The worst-case degraded tube shall meet the SIPC margin requirements with at least a probability of 0.95 at 50% confidence.

The worst-case degraded tube is established from the estimation of lower extreme values of structural performance parameters (e.g., burst pressure) representative of all degraded tubes in the bundle.

The acceptance standard for accident leakage integrity is:

- The probability for satisfying the limit requirements of the AILPC shall be at least 0.95 at 50% confidence.

The analysis technique for assessing the above conditions may be either deterministic or fully probabilistic in calculation format. The different analysis methods and input assumptions for these assessments are discussed in the EPRI IAGL [2].

3.4 Structural Models

The calculation of burst capability is performed using the degradation specific equation from the EPRI Flaw Handbook [5]. The equations listed below are taken from [5].

Burst pressure of AVB wear and TSP wear indications uses Equation 5-62. This equation is applicable to volumetric degradation with circumferential arc length <135 degrees.

Wear at preheater baffles could have extended circumferential arc lengths; thus Eq. 5-60 is utilized.

Equation 5-11 is applied for part-through-wall axial ODSCC. Equation 5-12 is used to define the adjustment factor which allows Equation 5-11 to be applied to part-through-wall axial PWSCC.

Equations 5-20 and 5-21 are applied for circumferential ODSCC. Equation 5-22 is used to define the adjustment factor which allows Equation 5-11 to be applied to part-through-wall circumferential PWSCC.

The burst models are developed from regression analysis of burst test data on actual tube specimens. The structural parameters which control tube burst for axial degradation are the structural equivalent depth and structural equivalent length (SEL). Thus, as axial degradation is truly two-dimensional many combinations of structural equivalent depth and SEL can represent the burst pressure consistent with the performance criteria. For circumferential degradation, the controlling structural parameter is the percent degraded area (PDA) of the flaw based on the tube cross-section.

3.5 Leak Rate Models

As described in [6, 7], a two-phase flow algorithm can be used to compute flow rates through cracks as a function of pressure differential (p), temperature (T), crack opening area (A), and total through-wall crack length (L). Friction effects and crack surface roughness were included in the model. Calculated main steam line break, room temperature, and normal operating condition leak rates were fitted to regression equations. The leak rate regression equation for main steam line break conditions is given as:

$$Q = \{a + b\exp[c(A/L)^n + d(A/L)]\}\, Ap^m \qquad (3\text{-}1)$$

where a, b, c, d, n, and m are regression coefficients as determined by analysis results. The leak rate Q is expressed in terms of gpm at room temperature (70°F). To convert to gpm at any other temperature, the calculated Q is multiplied by the ratio of the specific volume of water at temperature (T) to the specific volume of water at 70°F. The pressure, p, is in units of psi, A is in $inches^2$, and L (equivalently L_{leak} as defined above) is in inches. The crack opening area is calculated using appropriate methods discussed in [6].

Equation 3-1 is appropriate for computing accident-induced leak rates for SCC degradation. The validity of the leak rate equations is provided by a comparison of calculated leak rates versus measured leak rates as discussed in [6, 7].

For wear-type degradation, the likelihood of through-wall leakage is determined from the projected maximum wear depth that would lead to a pop-through or through-wall penetration. A specific leak rate value is not directly computed but it is conservatively assumed that if a wall penetration occurs, the accident-induced leak limit will be exceeded.

3.6 Inspection Interval Analysis

The primary objective of an OA is to determine the allowable operating period between inspections. This can be accomplished by either deterministic analysis methods or by fully probabilistic modeling of the input variables.

3.6.1 Deterministic Analysis

A deterministic analysis approach was applied for the existing wear mechanisms to establish an allowable cycle or multi-cycle run time in accordance with EPRI IAGL. A plug on NDE sizing strategy is used for calculating the allowable inspection interval for these mechanisms. A deterministic OA for calculating cycle run times requires conservative estimates for indication size at beginning-of-cycle (BOC), limiting size at EOC, and degradation growth rate. For each wear degradation mechanism, the projected maximum worst-case depth at the next scheduled examination is calculated from:

$$d_{EOC} = d_{BOC} + (WR)\,t_{INSP} \qquad (3\text{-}2)$$

where d_{BOC} is the depth in percent through-wall (% TW) at the BOC, d_{EOC} is the depth in % TW at EOC, WR is the growth rate due to wear (% TW/ effective full power year (EFPY)), and t_{INSP} is the operational period in EFPY until the next scheduled examination. Equation 3-2 is later used in the OA (Section 5) for the three detected wear mechanisms for three-cycle inspection interval.

3.6.2 Probabilistic Multi-Cycle Analysis

The analysis method used for the potential SCC mechanisms for the Byron Unit 2 OA is a fully probabilistic analysis of the full tube bundle in accordance with Section 8.3 of the EPRI IAGL [2]. This level of analysis is required because the deterministic approach is not capable in accurately evaluating the potential mechanisms. A plug-on-detection repair strategy is applied for all crack-like indications found within the tube pressure boundary.

The probabilistic model consists of a Monte Carlo simulation of the processes of initiation, degradation growth, eddy current (ECT) inspection, and the removal of degraded tubes. A schematic illustration showing the simulation process on how the distribution of worst case calculated burst pressures are established is shown in Figure 3-1. The state of degradation of the SG tubing is simulated in the model by the total flaw population that is defined by several attributes. These attributes include the population size and the distributions of length, structural depth, maximum depth, and material properties. Given a randomized set of these attributes for each flaw indication in the simulated population, an estimate of burst pressure and leakage can be made for each indication in the flaw population. From these estimates, population attributes, such as the distribution of minimum burst pressure and accident-induced leakage are determined.

The probabilistic computations were performed using Intertek AIM's OPCON Version 3.03 program [8]. The logic flowchart of the multi-cycle method is shown in Figure 3-2. A time-to-flaw-initiation (Weibull) function is applied. The physical processes of flaw initiation, flaw growth. and simulated inspections (via use of a probability of detection (POD) function) are modeled for several past and future cycles. Benchmarking of results to the observed information obtained from past inspections for units which have reported SCC provides assurance of the accuracy of predictions over the operating interval to the next inspection.

The OPCON program simulates up to about 15,000 individual initiation sites over several operating cycles. The overall simulation process consists of many thousands of individual Monte Carlo trials, each of which simulates the degradation state of a complete SG, or composite SG for a given degradation mechanism. The Monte Carlo simulation involves many trials to obtain a converged solution.

The simulation process is shown in Figure 3-2, which illustrates the Monte Carlo process. There are three major steps in the process:

a

a

For the evaluation of the potential mechanisms at Byron Unit 2, it is conservative to assume for the BOC distribution of flaws following the last inspection that at least one SCC indication had initiated sometime in the prior operating period (N-1), with at least two initiations present at the end-of-cycle N inspection and that the initiated indication(s) were not reported. Specifically, for this type of OA analysis, the model may produce detectable indications at the most recent inspection, but the model was configured to ignore these simulated detections (i.e., an NDE process "miss"). This model configuration assures a conservative analysis as well as simulating the plant experience, which is that no SCC was detected during the most recent inspection. As the model configuration permits any simulated detections to be allowed to remain in-service, the POD at the last inspection has a negligible impact on the calculated burst and leakage probabilities at B2R23. The POD only has the impact of estimating the number of detected indications at B2R23. During model development, the distribution of non-detected depths at the most recent inspection is reviewed. This is done to produce a conservative but realistic model. If the distribution of non-detected depths is too small, the model is not conservative. If the applied growth rates produce too large a distribution of non-detected depths, the model is not realistic as detections would have been expected during the outage. Additionally, the model would produce an excessive number of predicted detections which is not consistent with plant experience. This would suggest that either the applied growth is not prototypic or the assumed initiation point for the evaluated degradation is too early in the lifecycle of the unit.

The simulation process generates a record of the results of all trials performed from which overall burst and leakage probabilities may be inferred and appropriate distributional information obtained. This process is carried over the past operational cycles and current/future operational cycles.

The actual structural dimensions of each flaw, d_{ST} and L_{ST}, are tracked for the complete trial. Growth is applied to the structural depth. The shape factor for each flaw is applied at the beginning of each trial prior to inspection and the POD determines whether the flaw is detected or not detected. The final output contains the individual cumulative distributions for actual structural depths, detected actual structural depths, and measured maximum depths. The measured depth distribution is created by applying the measurement uncertainty to each flaw by random sampling from the linear regression model on depth sizing.

3.7 Measurement Uncertainty

Measurement uncertainty for sizing of wear indications was applied to the calculation of CM limits. This allows direct comparison of projected flaw depths, based on the most recent inspection results depth estimates plus a growth allowance, against the CM limit. The source of these (measurement uncertainty) data is the EPRI Examination Technique Specification Sheet (ETSS) document. A linearized relationship between actual size and NDE size was assumed. For relating actual sizes from NDE results:

$$X_{Actual} = A_0 + A_1 X_{NDE} + \varepsilon_{Error} \quad (3\text{-}3)$$

where X_{Actual} and X_{NDE} are the indication sizes for actual and NDE bases, and A_0, A_1, and ε_{Error} are regression fit constants (intercept, slope, and random error which include the standard error of estimate, ε_e, for the technique and analyst's error, ε_a). For relating measured sizes from predicted actual sizes:

$$X_{NDE} = B_0 + B_1 X_{Actual} + \varepsilon_{Error} \quad (3\text{-}4)$$

where B_0, B_1, and ε_{error} are again regression constants derived from fitting sizing data.

Industry data (ETSS) were used to define the parameters in Eqs. 3-3 and 3-4 from standard linear regression data analysis [9]. A summary of sizing uncertainties for the mechanisms applicable to Byron Unit 2 is given in Table 3-1. The scatter in actual data about the regression fit is assumed to be normally distributed with a standard deviation equal to the standard error of estimate.

Measurement uncertainty was applied to the repair-on-NDE sizing calculations for the existing wear degradation mechanisms. For the probabilistic analyses, OPCON tracks the progression of the actual flaw sizes (depth and length), so measurement uncertainty was not relevant in the OA for the potential mechanisms in this situation of a one cycle extension.

Table 3-1 — Relationships for Measurement Uncertainty for Byron Unit 2 – B2R20

Mechanism/ Location	Eddy Current Probe	Sizing	ETSS Reference	Condition Monitoring[1]			Operational Assessment[1]		
				Intercept	Slope	Std Error	Intercept	Slope	Std Error
Wear at AVB Supports	Bobbin	Depth (%TW)	96004.3 Rev 13	a, c					
Wear at Broached Tube Support Plates[2]	+Point	Depth (%TW)	21998.1 Rev 4						
	+Point	Depth (%TW)	96910.1 Rev 11						
Wear at Drilled Support Plates	+Point	Depth (%TW)	96910.1 Rev 11						
Foreign Object Wear[3]	+Point	Depth (%TW)	21998.1 Rev 4						
	+Point	Depth (%TW)	96910.1 Rev 11						

NOTES:

1. Condition monitoring sizing is Actual versus NDE. OA sizing is NDE versus Actual. The parameters A_0, A_1 and ε_e are obtained from ETSS measurement uncertainty correlations. The parameters B_0, B_1 and its corresponding ε_e were calculated from a regression fit of the ETSS sizing data.
2. ETSS 96910.1 Rev. 11 was used to size volumetric wear indications (tapered) at broached TSP lands. ETSS 21998.1 Rev. 4 is used for sizing indications at point wear at edges of TSP lands.
3. For foreign object wear, ETSS 21998.1 Rev. 4 is extended for use with PLP present within a structure or freespan because the mix suppresses structures and/or loose part signals. ETSS 96910.1 Rev. 11 is extended for sizing freespan foreign object wear because signal characteristics resemble tube wear from a broached TSP.

c

Figure 3-1 — Aspects of Monte Carlo Simulation to Calculate Probability of Tube Burst [2].

a

Figure 3-2 — Probabilistic Simulation to Determine Worst-Case Degraded Tube – Full Bundle Analysis.

4 | Input Variables and Distribution Functions

The input variables and the statistical distributions representing the uncertainties in these inputs in the OA to determine structural and leakage integrity are given in this section. These include the mechanical strength, flaw characterization (flaw sizes and shapes), and more importantly, the POD functions and degradation (wear) growth rates.

4.1 Tubing Properties and Operating Conditions

The SGs utilized at Byron Unit 2 are Model D5 SGs. The tubing material is A600TT. The TSP design is a broached style with quatrefoil flow lobes; the TSP material is 405 stainless steel. Pertinent inputs relevant to the integrity analysis include:

- Tube material — A600TT
- Tube OD — 0.75 inch
- Tube wall thickness — 0.043 inch
- Mean $S_y + S_u$ at 650°F — 137,370 psi [10]
- Standard deviation of $S_y + S_u$ — 7,242 psi [10]
- T-hot — 611°F [11]
- Normal operating pressure differential — 1,385 psi [11]*
- Performance criteria — 4,155 psi
- Number of original tubes per SG — 4,570

*Current average steam pressure for Cycle 22 results in a normal operating pressure differential of 1,377 psi. A conservative value of 1,385 psi was used for the OA analyses.

4.2 Operating Cycle History

The operational history for all cycles was provided by Exelon [12]. The following presents the operational history information from B2R10.

EOC	Outage	Outage Date	Inspection	SCC Detected?	Cycle Length (EFPY)	Cumulative EFPY
10	B2R10	Fall 2002	Yes	No	1.397	12.823
11	B2R11	Spring 2004	Yes	No	1.462	14.285
12	B2R12	Fall 2005	Yes	No	1.453	15.738
13	B2R13	Spring 2007	Yes	No	1.453	17.191
14	B2R14	Fall 2008	Yes	No	1.387	18.578
15	B2R15	Spring 2010	Yes	No	1.474	20.052
16	B2R16	Fall 2011	Yes	No	1.345	21.397
17	B2R17	Spring 2013	Skip	N/A	1.434	22.831
18	B2R18	Fall 2014	Yes	No	1.403	24.234
19	B2R19	Spring 2016	Skip	N/A	1.460	25.694
20	B2R20	Fall 2017	Yes	No	1.360	27.054
21	B2R21	Spring 2019	Skip	N/A	1.449	28.503
22	B2R22	Fall 2020	Skip*	N/A	1.451 (est.)	29.954 (est.)
23	B2R23	Spring 2022	Yes	N/A	1.451 (est.)	31.405 (est.)

*Note: Proposed to defer B2R22 inspection to B2R23.

4.3 Probability of Detection (POD)

The POD for the examination technique used in the inspection process is an important input to the probabilistic OA because it establishes the size and number of indications that can remain undetected in the tube bundle. When assuming at the start of a cycle that indications are postulated to exist after an inspection, the largest missed postulated flaw(s) generally defines the worst-case EOC flaw at the next inspection. For Monte Carlo simulation shown in Figure 3-2, when plug-on-detection inspection strategy is used, the BOC flaw population is, by definition, the population of undetected after inspection.

The POD for the inspection technique can be developed in one of three ways:

1. Performance demonstration process (PDP) using analyst data on degraded tubes with known number and sizes of the mechanism of concern. A specialized nonlinear regression process is then used to establish the probability of detecting an indication of a given depth.
2. An analytically based A-hat methodology or the similar EPRI MAPOD methodology which uses a signal processing approach dealing primarily with flaw signal amplitude and noise amplitudes. These methods permit the quantification of POD function behavioral changes with various levels of interfering signal (noise) such as may be present.
3. An empirical approach that relies on a benchmarking process to observed inspection data over several cycles of operation. The cumulative distribution of predicted flaw depths is closely related to the system POD function present. In addition, the absence of flaws below a threshold depth precludes a POD function with a non-zero POD below that depth. This eliminates a significant portion of possible POD function candidates obtained by other means.

In practice, a combination of two or more of these methods is often used to obtain a robust estimate of the POD function parameters.

The POD was established from industry data resulting from PDP. The bobbin probe POD as a function of wear depth is derived from manufactured specimens and provided by EPRI ETSS 96004.1. The POD parameters for logistic and log-logistic model used in the Monte Carlo Simulation are shown below:

$$\mathrm{POD(X)} = \left[\frac{1}{1+\exp[A+B(X)]}\right] \qquad \text{(Logistic)} \qquad (4\text{-}1)$$

$$\mathrm{POD(X)} = \left[\frac{1}{1+\exp[A+B\,\mathrm{Log}_{10}(X)]}\right] \qquad \text{(Log-Logistic)} \qquad (4\text{-}2)$$

where "X" is the depth in %TW, and the parameters A and B are obtained by logistic regression analysis of hit-miss data from PDP or EPRI Model Assisted POD (MAPOD) simulations.

The log-logistic model was used in the OA for Byron Unit 2. The model parameters for the ECT technique were obtained from qualified industry data or derived from evaluations of the inspection process to obtain the systematic POD including the effect of signal noise at the tube location of interest. For comparative purposes, the +Point and Bobbin PODs for detection of axial ODSCC at broached TSPs are shown in Figure 4-1 [9, 13]. This figure shows the relative detection performance of the +Point versus the Bobbin coil for detecting SCC.

Due to the manner in which the OA models were developed (assumed non-detection at the most recent inspection), the POD plays a minor role in the OA model. As the OA models were setup to ignore simulated detections at prior outages the POD curve applied only influences the number of predicted detections at the next eddy current inspection.

For each of the mechanisms judged most challenging to the completion of an OA which supports deferment of the B2R22 inspection to B2R23, an initiation analysis was performed (Appendix A). The PODs used in the initiation analysis may use the POD curve from an ETSS or developed from POD simulation methods, such as the EPRI MAPOD methodology. In some cases, the industry POD may have been manually adjusted to provide a conservative estimation of detection at prior inspections.

4.4 Degradation Growth Rates

4.4.1 Wear Degradation

Degradation growth rates for tube wear at support structures and drilled support baffles were developed by comparing the B2R20 with B2R18 and B2R18 with B2R16 inspection results and normalizing the growth rates to a per-EFPY basis. Growth rates are based on repeat measurements. ECT data results were provided by Exelon in [12, 14, 15, 16].

Because wear rates vary between steam generators, each steam generator's performance was considered, and the most limiting case was reported. For the AVB wear rates, the average and 95th percentile values were based on a statistical analysis of the population. There were 348 repeat measurements in SG 2B (the limiting steam generator at B2R18) for AVB indications. There were 179 repeat measurements in SG 2D (the limiting steam generator at B2R20) for AVB indications.

For all four steam generators, there were only five repeat measurements for DSP wear in both outages. Similarly, for all four steam generators, there were only seven repeat measurements for TSP wear in both outages. It is not meaningful to determine average or 95th percentile DSP and TSP wear rates with such a small population.

Wear Mechanism	B2R18 Wear Growth (%TW/EFPY)			B2R20 Wear Growth (%TW/EFPY)		
	Average	95/50 (1)	Max	Average	95/50 (1)	Max
AVBs	0.5 (2)	2.19 (2)	3.5 (2)	0.4 (3)	2.1 (3)	4.3 (4)
TSPs (5)			2.5 (2)			3.2 (6)
DSPs (5)			1.1 (6)			2.5 (7)

Notes:

(1) Determined by a fitted lognormal distribution for the limiting steam generator.
(2) Limiting case, observed in SG 2B.
(3) Limiting case, observed in SG 2D.
(4) Limiting case, observed in SG 2A. The maximum observed wear rate in SG 2D was 3.2%TW/EFPY. The average and 95/50 wear rates in SG 2A were slightly negative (assumed to be zero) and 1.8%TW/EFPY, respectively.
(5) Insufficient data for development of a distribution.
(6) Limiting case, observed in SG 2A.
(7) Limiting case, observed in SG 2B and SG 2D

The application of the wear rates used in the OA is described in more detail in Section 5.

4.4.2 Corrosion Degradation

The only active corrosion degradation in the Byron Unit 2 SGs is PWSCC at the hot leg tube ends in the heat affected region of the tube-to-tubesheet weld. This area is outside of the pressure boundary portion of the tube, justified by application of the H* alternate repair criteria, and thus not subject to tube plugging or inspection requirements.

As SCC degradation has not been reported in the pressure boundary portion of the tubes, there is no plant specific growth rate data applicable to Byron Unit 2. SCC growth rates utilized in this OA are taken from the EPRI IAGL default functions. Comparison with growth data from other A600TT units will be used for comparison purposes to show the conservatism of the IAGL default growth functions.

Axial ODSCC at TSP Intersections on High Residual Stress Tubes:

The approach for application of growth is to apply the IAGL default upper bound growth rate to known high residual stress tubes at TSP intersections. Axial ODSCC at freespan dings and at dents is not specifically addressed by the IAGL recommendations but any such initiations would be captured by the axial ODSCC at TSP intersections on known high residual stress tubes; low Weibull slope initiation model discussed later. Additionally, industry experience has shown that depth growth rates for axial ODSCC at dings, even on A600 mill annealed (MA) tubing, has been shown to be bounded by the IAGL typical default growth, not the upper bound IAGL default growth.

For all other SCC mechanisms considered, the IAGL typical default growth will be applied. Application of the IAGL typical default growth is considered conservative for the other SCC mechanisms.

Specifically, for the Braidwood Unit 2 OA (completed May 2020), the historic bobbin data for SG C R44 C47 were reviewed to assess the presence of precursor signals for the 03H TSP elevation and the ding crack at 03H +33.9 inches. The evaluation of growth rates for these indications is discussed below. Although no SCC has been reported at Byron, the Braidwood SCC experience can be considered applicable. Inclusion of the Braidwood R44 C47 growth discussion is relevant and an integral part of the Byron analysis.

A review of the SG C R44 C47 2011 bobbin data for the 03H TSP shows a precursor signal is present; however, it has been generally accepted throughout the industry that the 2011 P1 mix channel signal would not be readily reported by production analysis. But a precursor signal is present which establishes that the bobbin signal did not progress from a purely NDD (no detectable degradation) condition in 2011 to the flaw reported in 2012.

The 2011 bobbin data for the freespan ding crack show a precursor signal is present with a phase angle of 144 degrees, which, based on the ding ODSCC reporting criteria of ETSS 24013, meets the reporting criteria as flaw-like. But as the ding signal amplitude, as evidenced in the 2008 data is only 1.06 volts, the analyst may not recognize that this was a ding location, and thus may have evaluated the signal using non-ding evaluation logic. Thus, it can be established that precursor signals were present for both the 03H TSP elevation and for the freespan ding in the 2011 bobbin probe data. Further review of earlier outages (2009 and 2008) was also performed.

a,
b

a,
b

Circumferential ODSCC at the Hot Leg TTS Expansion Transition:

For the potential mechanisms applicable to the Byron Unit 2 SGs, the EPRI IAGL typical default distribution had been shown to be conservative for A600TT based on the analyses of the available data [13]. The number of tubes with SCC indications in the A600TT fleet is not sufficient to develop robust, reliable growth rates with the exception of circumferential ODSCC at the TTS expansion transition. Prior analyses have utilized the IAGL default distribution in the respective OAs. For circumferential ODSCC at the TTS, both the IAGL typical default and a recommended PDA growth function are used. The recommended PDA growth function well bounds the Plant G1 growth data and bounds the PDA growth function for an operating plant which uses original vintage, A600MA tubing. Thus, either of these growth functions will produce conservative results of the evaluation of circumferential ODSCC at the TTS for Byron Unit 2. The "typical" and "bounding" distributions recommended in the EPRI IAGL are plotted in Figure 4-3.

For circumferential degradation, a review of SCC data was performed and compared with the EPRI default rates. Figure 4-4 presents a plot of PDA and maximum depth growth for the EOC 14 and EOC 15 indications from Plant G1, which is the lead A600TT industry plant with regards to the number of circumferential ODSCC indications. These data were provided by the licensee. This plot includes the IAGL typical default PDA growth function for comparison (the solid red line). As shown on this plot, the IAGL typical default function is judged very conservative for this mechanism. Given the conservatism of this function compared to the Plant G1 growth data, the OA for circumferential ODSCC represents an extremely conservative assessment.

Circumferential ODSCC PDA growth rate for an operating plant with original vintage SGs using A600MA tubing was also compared with the IAGL default growth. These data were provided by the licensee and are also plotted on Figure 4-4. The data were adjusted to an operating temperature of 611F (from 609^{o}F) for comparison with the IAGL default PDA growth rate. Circumferential ODSCC is the dominant mechanism at this plant, having affected approximately 800 tubes. The method of tube expansion used in this plant (mechanical roll expansion) will produce higher residual stresses compared to hydraulically expanded tubes. This growth data were based entirely on +Point probe inspection data whereas the default circumferential ODSCC growth rate data may include many data points based on pancake coil inspection data. Thus, this A600MA plant data were judged more reliable, and thus a better approximation of current circumferential ODSCC PDA growth rate defined by the IAGL typical default PDA growth rate. These growth data are bounded by the IAGL default value.

Thus, two sources, the A600TT lead plant for circumferential ODSCC and an A600MA plant with an aggressive circumferential ODSCC PDA initiation function and large circumferential ODSCC database, support the conservatism of the IAGL typical default growth rate.

Figure 4-4 also shows an adjusted PDA growth function developed by applying an adjustment factor of 1.25 to the IAGL default PDA growth. The selection of an adjustment factor of 1.25 is somewhat arbitrary but is used as a shape factor adjustment when estimating maximum depth growth from PDA growth. The adjusted PDA growth function is shown by the dashed red line. The EPRI IAGL recommends the use of a shape factor of 1.25 to estimate maximum depth growth from structural average growth. In this case, the shape factor is used to estimate a more realistic PDA growth which can be used in a sensitivity case for the evaluation of circumferential ODSCC. This adjusted PDA growth curve remains bounding for both growth data sets discussed above. This further supports the assumption that the EPRI default growth rates are conservative for the potential mechanisms in Byron Unit 2. Additionally, the EPRI Feasibility Study [13] includes discussion related to the apparent PDA growth determined from

NDE data for Plant G1 and true PDA growth which includes both detected and non-detected portions of postulated circumferential ODSCC flaw profiles. This discussion concludes that IAGL default growth remains bounding for all plant conditions.

Axial ODSCC and Axial PWSCC at the Hot Leg TTS Expansion Transition:

The axial ODSCC database for A600TT tubing is significantly smaller than that of circumferential ODSCC. There are only 8 indications for the TTS region; six from Plant G1 and two from Plant S.

For six of these eight, the EPRI Feasibility Study [13] concludes that the depth growth rates are bounded by the IAGL typical default growth rate.

The other two indications, reported at the 1R13 and 1R14 outages of Plant G1, could have experienced maximum depth growth rates of up to 24%TW/EFPY, however, the details surrounding these indications suggest that these growth rates should not be applied for other plants, especially those which have not reported axial ODSCC at the TTS to date.

The first of these (reported in the 1R13 outage) may be associated with an incomplete hydraulic expansion at the TTS based on the +Point probe terrain plot. An improper chemical addition several cycles earlier could have allowed highly corrosive species to concentrate in this region. A precursor signal was present in the 1R12 data, but the signal amplitude is small (0.1 volt).

The second of these (reported in the 1R14 outage) also contains a precursor signal in the prior inspections' data, but the signal amplitude is not available. This tube was pulled for destructive examination however the tube was not completely cut and was damaged during the tube pull. The maximum corrosion depth of 100%TW was confirmed in the destructive examination. Using the rule from the Feasibility Study [13] of assuming initiation two cycles prior to the earliest precursor, the averaged maximum depth growth over the life cycle of this indication can support a growth of ~18%TW/EFPY. Due to the applied inspection program of 50% in two SGs on a rotating basis, the next prior inspection was at the 1R08 outage, which review concludes was NDD. Thus, it is plausible that a precursor could have been present in the 1R12 inspection, but this tube was not inspected in this outage.

Considering these details and that the remaining indications were bounded by the IAGL typical default growth rate, it is recommended that the IAGL typical default growth rate, adjusted to the Byron 2 operating temperature, be applied.

Another conclusion from the EPRI Feasibility Study [13] is that the PWSCC growth rates are bounded by ODSCC growth rates for the same SCC orientation. This observation is used to apply the OA results from the ODSCC to bound the behavior of PWSCC (Section 6).

Axial ODSCC at Freespan Dings and Dents at Quatrefoil TSP Intersections:

The EPRI Feasibility Study [13] concludes that the IAGL typical default growth rates can be applied to axial ODSCC at dings and dents. This conclusion was developed prior to the spring 2020 inspections. In the spring of 2020 at Plant S, 15 axial ODSCC indications were reported on 11 tubes. Fourteen of these were reported at the top hot leg TSP (08H) and one was reported at the top cold leg TSP (08C). The general observation of axial ODSCC maximum depth growth at freespan dings on A600MA tubing is that the growth rates are bounded by the IAGL typical default growth function.

A history review of the Plant S, 2020 indications was performed by the inspection vendor. Based on an extensive history of addressing this and similar (freespan ding ODSCC) mechanisms, Intertek assisted the inspection vendor in their review of these signals. The following presents the results of this review.

Plant S History Review of 2020 ODSCC Indications					
Row/Col	**Locn**	**TSP Elevation**	**2018 Result**	**2015 Result**	**2012 Result**
R16 C5	08H	Bottom	DDI (1)	Distorted (2)	Not Reviewed
R16 C5	08H	Top	DDI (1)	Distorted (2)	Not Reviewed
R42 C102	08C	Bottom	SAI	SAI	Not Reviewed
R14 C119	08H	Top	Not Tested	SAI	Distorted (3)
R15 C119	08H	Top	Distorted (3)	NDF	Not Reviewed
R16 C119	08H	Bottom	SAI	Distorted (3)	Not Reviewed
R16 C119	08H	Top	SAI	SAI	Not Reviewed
R13 C120	08H	Bottom	SAI	SAI	Not Reviewed
R14 C120	08H	Bottom	SAI	SAI	Not Reviewed
R14 C120	08H	Top	SAI	SAI	Not Reviewed
R15 C120	08H	Bottom	Not Tested	SAI	Distorted (3)
R16 C120	08H	Bottom	Not Tested	SAI	SAI
R16 C120	08H	Top	Not Tested	SAI	SAI
R10 C121 (4)	08H	Top	Not Tested (4)	Not Tested (4)	Not Tested
R11 C121	08H	Top	Not Tested	SAI	Distorted (3)

Notes:

(1): Only bobbin coil data is available. Reanalysis indicates that a distorted dent with indication (DDI) report should have been made in 2018. Phase change of >20 degrees is observed compared to the 2000 bobbin data.

(2): Only bobbin coil data are available. Phase rotation of 16 degrees for the indication at the bottom of the TSP and 21 degrees for the indication at the top of the TSP compared to the 2000 bobbin data is observed, indicating that the SCC was present in 2015 and of a sufficient depth to influence the bobbin phase angle response.

(3): Distortion of the signal is apparent when compared with 2000 +Pt data, suggesting presence of SCC. However, signal definition is not sufficient to estimate flaw amplitude or depth.

(4): Dent voltage is ~4V thus this location was not sampled with +Point in prior inspections. Review of the 2018 and 2015 bobbin data suggests presence of signal distortion suggesting ODSCC presence.

Due to the combination of the dent residual and flaw, assessment of depth is not as straightforward as for axial SCC at the TTS expansion transition or at TSP intersections.

The methodology for maximum depth assessment at the 2020 inspection utilized the amplitude-based depth sizing regression from ETSS I28432. Phase based depth assessment was also included however the phase-based depth assessment is primarily used as a method of validation of the amplitude-based depth assessment. Due to the combination of the dent residual and flaw, phase based depth assessment can be unreliable thus development of growth rate should be based on the amplitude-sizing results. A best judgment approach was used for selection of the portion of the resultant signal used for phase-based depth assessments. This judgment was based on prior experience with this mechanism. Intertek collaborated with the inspection vendor to aid in accurate sizing performance for these indications. Table 4-1 provides the maximum depths for the 2020 and historical data and the maximum depth growth rate data.

The data in column "%TW Growth/EFPY Most Recent Inspection Period" is the growth for the 2018 to 2020 or 2015 to 2020 period, depending upon the date of the most recent inspection.

The data in column “Averaged %TW Growth/EFPY History Review Period” is the growth for the period from the earliest history review data used to 2020. For some indications this period is from 2012 to 2020, for others this review period is from 2015 to 2020.

a, b

The EPRI Feasibility Study [13] utilized a methodology to identify SCC growth by assuming initiation occurs two cycle prior to the earliest precursor signal. The growth rate is then determined by dividing the depth at time of reporting by the total EFPY for the period from initiation to observation. This process could develop artificially large growth rates if the history review includes only the most recent inspection. However, in the case of the Plant S dent ODSCC indications the history review was conducted over many inspections which then increases the confidence in the identified upper bound growth rate. This process was applied to the Plant S indications and the upper bound growth was determined to be 11%TW/EFPY, which is bounded by the IAGL typical default maximum depth growth rate for an operating temperature of 611°F of 16.1%TW/EFPY.

Table 4-1 — Plant S Maximum Depth of 2020 ODSCC Indications with History Depth

Row/Col	Locn	TSP Elevation	2020 %TW Amplitude-Based	2020 %TW Phase-Based	2018 %TW Amplitude Based	2015 %TW Amplitude Based	2012 %TW Amplitude Based	%TW Growth/EFPY Most Recent Inspection Period	Averaged %TW Growth/EFPY History Review Period
R16 C5	08H	Bottom	61	50	56 (1)	46 (2)	N/A	3.57	3.57
R16 C5	08H	Top	67	2	56 (1)	46 (2)	N/A	7.86	5.0
R42 C102	08C	Bottom	71	95	58	55	No Data	9.3	3.81
R14 C119	08H	Top	63	74	No Data	49	51	3.3	3.33
R15 C119	08H	Top	46	41	50 (3)	NDF	N/A	-2.86	
R16 C119	08H	Bottom	73	96	72	50 (3)	No Data	0.7	5.48
R16 C119	08H	Top	66	65	64	59	No Data	1.4	-0.48
R13 C120	08H	Bottom	48	33	52	55	No Data	-2.86	5.24
R14 C120	08H	Bottom	63	52	45	65	No Data	12.9	1.43
R14 C120	08H	Top	61	50	50	57	No Data	7.86	0.95
R15 C120	08H	Bottom	56	65	No Data	50	50 (3)	1.4	1.43
R16 C120	08H	Bottom	61	62	No Data	60	58	1.19	1.19
R16 C120	08H	Top	75	84	No Data	69	65	-0.48	-0.48
R10 C121	08H	Top	61	66	No Data	No Data	No Data		
R11 C121	08H	Top	55	64	No Data	50 (3)	50 (3)	1.2	0.71

(1): +Point was not performed. History review of the bobbin data indicates that a distorted dent with indication should have been reported. The applied 2018 depth estimate of 56%TW is based on the bobbin probe POD curve at POD = 0.50.

(2): +Point was not performed. History review of the bobbin data indicates that phase rotation of 16 to 21 degrees from horizontal is observed which implies SCC is present. A distorted dent with indication should have been reported. The applied 2015 depth estimate of 46%TW is based on the bobbin probe POD curve at POD = 0.25.

(3): +Point data shows signal is clearly distorted but not of sufficient clarity to reliably depth size. Applied depth estimate of 50%TW is based on the +Point probe POD curve at POD = 0.50.

4.5 Susceptible Population

The susceptible population size combined with a two-parameter Weibull function can be used with the Weibull failure equation to describe the introduction of initiated flaws into the model. This section describes the development of the susceptible population sizes. The SCC performance of A600TT tubing to date indicates that very small percentages of the fleet wide tube count have been affected. As such, it can be difficult to define the susceptible population. Not all tubes within the tube bundle will experience SCC. SCC experience from A600MA tubing SGs suggests that the highest percentage of tubes affected within permanent, hardened deposit regions is approximately 50%.

4.5.1 Circumferential ODSCC

a,
b

a,
b

4.5.2 Axial ODSCC at TSP Intersections on High Residual Stress Tubes

The axial ODSCC at TSP intersections on high residual stress tube mechanisms includes two OA models; an acute model, which initiates a discrete number of indications in a short period of time, and a low Weibull slope model, which initiates indications on a nearly constant frequency.

This mechanism has not been reported at Byron Unit 2. The history of this mechanism at Braidwood Unit 2 shows that in the A2R10 (2003) inspection, four indications were reported on three tubes; two tubes were in SG C and one in SG A. Indications were not reported again until A2R15 (2011) when three indications were reported on one tube in SG D. At A2R16 (2012), one tube in SG C was reported to contain two indications at TSP intersections and one indication at a freespan ding. No indications were reported in the A2R17 (2014) or A2R19 (2017) inspections.

At Plant D in 2009, three tubes (two in SG D and one in SG B) were reported with this mechanism; this was the first reporting of this mechanism at Plant D. Indications were again reported in 2015 when two indications were reported on one tube in SG D.

The susceptible population size for the axial ODSCC at TSP intersections on high residual stress tubes acute model is selected as four initiation sites. The largest number of indications reported in any Braidwood inspection is four. The Braidwood experience and Plant D experience show that the most recent observations show a reduction in the indication count from prior inspections, supporting the judgment that the tubes with the least resistance to ODSCC initiation would be the first to be detected and leaving in service tubes with increased ODSCC initiation resistance.

If future initiations at Byron mimic the pattern of prior inspections at Braidwood, the acute model represents a conservative assessment of potential initiation sites up to the B2R23 inspection. If the ODSCC initiation of future affected tubes is truly improved over the prior observations, the low Weibull slope model is anticipated to represent future performance.

a,
b

4.5.3 Axial ODSCC at Dented TSP Intersections and Freespan Dings

<u>Freespan Dings:</u>

a,
b

There is one non-high residual stress tube in the A600TT fleet with axial ODSCC at freespan dings. This experience is from Plant S in 2012 when three indications were reported on one tube in SGC; the ding amplitudes were ~1 volt. In SGC at Plant S there are 139 dings >2V located on the hot leg and in the U-bend. Since these three indications were reported on <2V dings, using the reported >2V ding population to assess the affected percentage is conservative as the number of non-reported <2V dings is likely much larger than 139 locations. Thus, the affected percentage is established to be <0.7% (1 out of 139 reported >2V dings).

For Byron Unit 2, the number of <5V dings (actually 2V to <5V since the reporting threshold is 2V) is substantially larger than the number of <5V dents. The largest <5V ding population is found in SG 2C and is 1321 locations. The next largest total is found in SG 2D and is 1101 locations. As <5V dings and dents would be expected to have similar initiation functions and similar bobbin probe detection performance, the OA model will combine the <5V ding and <5V dent populations for the limiting SG, which is SG 2D with a <5V ding/dent population of 1844 locations based on the B2R20 data. A susceptible population size of 1850 for the limiting SG will be applied.

Dents at Quatrefoil TSPs:

In the A600TT fleet, up to the spring 2020 inspections, there was only one non-high stress tube with a dent crack. The dent amplitude was ~11 volts. In spring 2020, Plant S reported 15 axial ODSCC indications on 11 tubes, all in SG B. Fourteen (14) of these were reported at the 08H TSP (top hot leg TSP), and one was reported at 08C (top cold leg TSP). Of the 11 affected tubes, the SCC was reported at >9V dents on eight of these tubes. For the 2020 inspection, 3 axial ODSCC indications were reported on <5V dents, 1 was reported on a 5 to 9V dent, and 11 were reported on >9V dents. Eleven of these 15 indications were reported at locations with dents ranging from 9 to 17 volts. The other 4 indications were located at dents ranging from 1.1 to 4 to 5.1 volts (depending on the inspection data used). Total accumulated EFPY at the spring 2020 inspection is approximately 26.0 EFPY.

For plants with A600TT tubing and stainless steel, quatrefoil style tube hole TSPs, dents at TSPs have been considered to exhibit an ODSCC initiation potential similar to that of freespan dings since the dent is not formed from the carbon steel corrosion product, as is the case with carbon steel drilled hole style TSPs. Additionally, experience from plants with A600MA tubing indicates that there is no discernable difference in initiation potential as a function of ding voltage for freespan dings which experienced axial ODSCC.

However, in the case of the Plant S, spring 2020 experience, the ODSCC incidence rate for large voltage dents (>9V) is dramatically larger than for other dent voltage ranges and ODSCC was not reported at dings. The table below provides the number of hot leg and U-bend dings and 08H/08C dents in various voltage ranges for SGB of Plant S. Only SGB hot leg data will be used since all 2020 SCC indications were reported in SGB. Data for both the ECO19 and EOC15 outages are provided in this table. The EOC15 dent population is substantially larger than the EOC19 dent population; this difference in counts can be attributed to change of the bobbin analysis result from DNT (2015) to DDS (2019) for many locations.

Plant S, SGB 2020 ODSCC Incidence Rates for Various Ding and Dent Voltage Levels				
Location	**Voltage Range**	**Number of Ding/Dent Locations**	**Number of Indications**	**Affected Percentage**
Ding (hot leg and U-bend)	<5V	156	0	0%
	5 to 10V	14	0	0%
	>10V	3	0	0%
Dent	<5V (1)	18 (EOC19) 311 (EOC15)	3 3	16.7% 0.96%
	5 to 9V (1)	154 (EOC19) 177 (EOC15)	1 1	0.64% 0.56%
	>9V (1)	89 (EOC19) 102 (EOC15)	11 11	12.35% (2) 10.78% (3)

(1): Dent counts based on 08H and 08C locations.

(2): If only 08H SCC and 08H dent count is used, affected percentage = 33.33%.

(3): If only 08H SCC and 08H dent count is used, affected percentage = 27.0%.

a, b

Thus, the affected percentage of <5V dents and 5 to 9V dents is similar to the A600MA plant experience. However, the affected percentage of >9V dents from Plant S is 27 times that of >9V dings from the Comanche Peak 1 original SGs if only the 08H and 08C SCC and dent counts are used.

What then could account for the difference in susceptibility of the Plant S, SGB, >10V dents?

Of the 253 >9V dings in Comanche Peak SG1 (the only SG with >9V ding cracks at Comanche Peak 1), 232 are found in the U-bend. These dings were a result of tube bundle repair while the SGs were in fabrication. The flexibility of the tube in the U-bend region would not be expected to introduce additional operating stresses resultant from binding or lockup of the tubes at an adjacent structure.

a,
b

But in Plant S, SGB, the peripheral tubes in Rows 13 through 30 contain dents at both 08H and 07H, however, axial ODSCC was reported on tubes in Rows 13 through 16 (and dents at both 08H and 07H). Further scrutiny of the 08H dents shows that while the average dent amplitude for the tubes with >9V dents and SCC is 12 volts, the average dent amplitude at 08H for SGB, Row 13 to Row 16 is 9.2 volts, and the average dent amplitude at 08H for SGB, Row 17 through Row 30 is only 5.3 volts. Note that the dent amplitudes for the tubes with SCC in Rows 10 and 11, and for R16 C5, are <5V.

Dents at the top TSP are reported in the other SGs but by far, the largest number of dents and largest dent amplitudes are found in SGB. The following table presents descriptive characteristics of the 08H dent populations at Plant S.

Plant S Dent Amplitude Statistics for the Top Hot Leg TSP				
	SGA	SGB	SGC	SGD
Number Dents	66	233	203	42
Average Dent Voltage	3.5	5.3	3.6	4.0
95th Percentile Dent Voltage	7.15	12.38	7.05	8.22
Max Dent Voltage	11.25	16.52	12.88	8.44

a, b

In conclusion, while not a quantitative evaluation, the anecdotal evidence surrounding the Plant S experience suggests that the following prerequisites are necessary for atypical axial ODSCC initiation at hot leg dents:

a, b

With regard to the above prerequisites judged necessary for development of axial ODSCC in large voltage dents, a review of the Byron 2 bobbin data was performed. The following presents the results of this review:

SG 2A:

a, b

SG 2B:

a, b

SG 2C:

a,
b

SG 2D:

There are no tubes in SG 2D which satisfy the above criteria. The average dent amplitude at 11H in SG 2D is 4.4 volts.

Thus, only three tubes in Byron 2, all in SG 2B, are judged susceptible to the same mechanism as at Plant S for large voltage dents.

Therefore, the OA model for SG 2B addressing dents at 11H will utilize an acute initiation model. Three tubes are judged to be susceptible; the OA model will conservatively assume 10 susceptible tubes. Since the dent amplitudes at 11H for these tubes are <5V they have not been inspected with a +Point probe. Due to the potential for increased ODSCC susceptibility, it is recommended that these three tubes be inspected with a +Point probe at B2R23.

The following table presents the breakdown of dents by location based on the B2R18 bobbin data.

Byron 2 Dent Statistics								
	All Locations		Hot Leg Straight Section		U-bend		Cold Leg Straight Section	
SG	Total	>5V	Total	>5V	Total	>5V	Total	>5v
2A	395	125	148	43	12	2	235	80
2B	621	125	228	37	24	0	369	88
2C	503	107	295	71	44	0	164	36
2D	945	211	386	103	134	18	425	90

The number of >10V dents is 32 for SG 2A, 18 for SG 2B, 16 for SG 2C, and 43 for SG 2D.

4.6 Initiation Function

The Weibull statistical distribution is used to model the initiation of SCC in A600TT tubes. The Weibull distribution is a well-known model for representing time to failure in various forms of aging mechanisms, such as fatigue, cracking, etc. The Weibull model has been effectively used to predict the behavior of A600MA tubing for many of the original SGs. The initiation function is a critical input to the multi-cycle model as it introduces flaw initiation to the analysis stream as a function of time (EFPY). The EPRI Feasibility study concludes that a Weibull initiation slope of 1.5 is appropriate for modeling of SCC degradation mechanisms that have not been reported in a particular plant.

For each SCC mechanism evaluated, with the exception of the axial ODSCC at TSP intersection on high residual stress tubes acute model (discussed later), a consistent methodology was applied for estimation of the first initiation. This methodology assigns the first initiation one cycle prior to the most recent inspection of each portion inspected. If less than 100% inspection was applied at the area of interest, the susceptible population size was adjusted to allot half of the indications to the earlier inspected population and half to the later inspection. For example, at B2R18, 50% of the hot leg tubesheet region was inspected and at B2R20, the other 50% of the hot leg tubes were inspected. The defined susceptible population size for the SG was allotted half to the tubes inspected at B2R18 and half at B2R20.

a,
b

For SCC mechanisms addressed by <100% sampling programs, as the total susceptible population size was allotted between the two inspections, the CL was adjusted to produce two initiations in the 50% population inspected at B2R18, and two initiations in the 50% population inspected at B2R20.

4.7 SCC Length Distributions

4.7.1 Axial ODSCC and PWSCC at the TTS

All US plant A600TT axial ODSCC and axial PWSCC indications at the TTS and axial ODSCC at dings and dents (excluding the 2020 Plant S experience), were combined into one bounding distribution. An additional length allowance was included to account for potential influence of the expansion transition geometry and is discussed below.

a,
b

In 2012, axial ODSCC was reported at three ding sites on one tube, located about 3 inches above the lowest hot leg TSP. The ding voltages were all about 1V. The reported crack length is uncharacteristic for this ding amplitude, and, is substantially longer than the reported lengths of the other two cracks. The flaw lengths reported in the ECT data management report were 0.23 inch, 0.18 inch, and 0.20 inch. The flaw lengths reported in the 180-day report were 0.52 inch, 0.15 inch, and 0.18 inch. As the 180-day report lengths for the other two flaws were slightly reduced from the data management report but the other crack increased in length, the possibility exists that the 0.52 inch report is a typographical error. Additionally, ding crack length estimation is more complex than for non-ding locations and requires consideration of signal amplitude and phase angle responses for each profiled line. Thus, the potential exists that the 180-day report length of 0.52 inch may be an overestimate.

a,

b

Figure 4-8 also plots separately the as-reported lengths of the axial PWSCC indications reported in the A600TT fleet. As seen on this figure, the axial PWSCC lengths are significantly bounded by the ODSCC lengths. Thus, application of the SEL distribution shown on Figure 4-8 will provide for a conservative assessment and the OA results for axial PWSCC which can be considered to be bounded by the axial ODSCC at TTS OA results.

4.7.2 Upper Bound Axial ODSCC Length Distribution for Freespan Dings

The total number of ding/dent axial ODSCC indications for the A600TT fleet was five prior to the 2020 Plant S experience. Four come from Plant S (three freespan ding axial ODSCC cracks on one tube and one axial ODSCC at a dent), plus one freespan ding axial ODSCC crack found on a high residual stress tube at Braidwood Unit 2. Thus, while the above length distribution is judged applicable to A600TT for dings and dents, in the event that an upper bound analysis is required, an alternate ding axial ODSCC length distribution can be applied.

This distribution is taken from a plant with Model D4 SGs which used A600MA tubing, Plant C1 OSG. During manufacture of the SGs, after tube insertion and tack expansion, approximately 1100 tubes per SG were removed and replaced after the repair. During removal/replacement of these tubes, the first adjacent columns of tubes experienced significant ding impacts in the U-bend. Consequently, approximately half of the ding axial ODSCC indications at this plant were located in the U-bend. The length distribution of these cracks bounds the combined axial SCC length distribution discussed above. The total length distribution was adjusted in the same manner as discussed above. Note that use of this A600MA plant length distribution could be considered overly conservative for all other plants due to the tube bundle repair performed.

For plants using stainless steel tube support structures, denting in the classical sense (i.e., deformation of the tube due to volumetric expansion of the carbon steel corrosion product in the tube-to-drilled hole TSP crevice) cannot occur. Thus, for A600TT, axial ODSCC on dings and dents would be expected to have similar initiation and growth characteristics.

a,
b

4.7.3 Axial ODSCC at TSP Intersections on High Residual Stress Tubes

For the evaluation of axial ODSCC at TSP intersections on high residual stress tubes described in Section 5, a conservative length distribution was applied. This distribution is developed by combining all axial ODSCC at TSP intersection indications from Plant S, which was the first plant to experience this mechanism, all Braidwood Unit 2 indications, and all indications from Plant D. It should be noted that the Plant S length distribution bounds the Braidwood and Plant D lengths. This total length distribution was adjusted using the same uniform distribution range discussed above.

a,
b

4.7.4 Circumferential ODSCC at the TTS Expansion Transition

The circumferential ODSCC length distribution only influences the OA analysis when considering leakage. The PDA controls burst while arc length and maximum depth are used in the leakage calculation. The leakage analysis uses a conservative methodology to first assess pop-through or tearing of the flaw. This calculation assumes the flaw will exhibit a uniform depth equal to the maximum depth along the entire reported arc length. By applying the as-reported arc of the flaw in the leakage calculation, a large amount of conservatism is included as pulled tube experience has shown that circumferential ODSCC is *not* described by a uniformly deep depth profile.

Figure 4-9 plots the cumulative probability distribution of circumferential ODSCC arc lengths from the lead plant, Plant G1. Of the 65 A600TT industry indications, 62 have come from Plant G1. The EPRI Feasibility Study included an additional arc length allowance to account for future crack growth which was intended to support four-cycle operation between inspections. The original leakage assessment provided in the Braidwood Unit 2 Phase 1 report [20] also utilized the adjusted arc length distribution intended for four-cycle analyses.

a,
b

4.7.5 Axial ODSCC at Freespan Dings and at Dents at Quatrefoil TSPs

Earlier evaluations, as well as the EPRI Feasibility Study [13] concluded that the axial ODSCC length distribution for dings and dents would be bounded by the TTS SCC distribution. The Plant S experience from 2020 supports this judgment. Section 4.7.2 discusses an upper bound ding/dent length distribution developed from an A600MA plant. The majority of these indications are located in the U-bend and are associated with tube damage due to tube removal and replacement during manufacture. The ding ODSCC indications located in the vertical straight section of tubing for this plant show a nearly uniform length distribution from 0.1 to 0.55 inch. This distribution is similar to the TTS distribution and has a similar upper bound length, which also supports the judgment that the axial SCC distribution for the TTS can be applied to dings and dents in A600TT plants.

a,
b

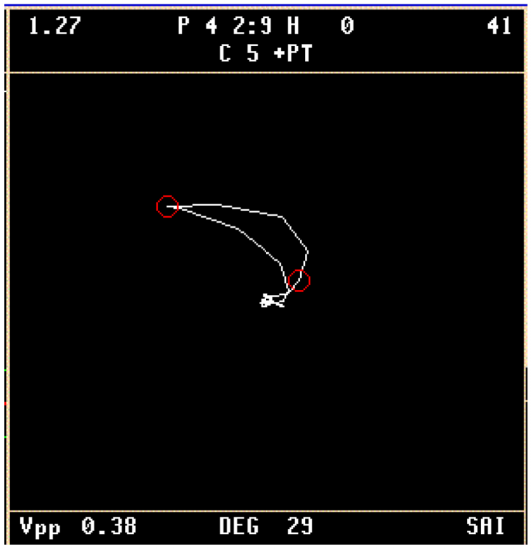
To assess the dent SCC length for the Byron assessment, approximately 100 dents were characterized using the B2R20 and B2R18 +Point data. The dents used for this assessment ranged from 2 to 17 volts.

Separate length distributions were developed for all data, for dents <5V, for dents <9V, and for dents >9V. The length distributions for the <5V and <9V populations are essentially identical, with the <9V population slightly bounding the <5V population. The length distribution for the >9V population bounds the others. For the <9V dents, the dent length range is from 0.19 to 0.55 inch with an average of 0.29 inch. For the >9V dents, the dent length range is from 0.31 to 0.59 inch with an average of 0.44 inch.

a,
b

a,
b,
c

Figure 4-1 — Comparison of Probability of Detection Functions for Axial ODSCC.



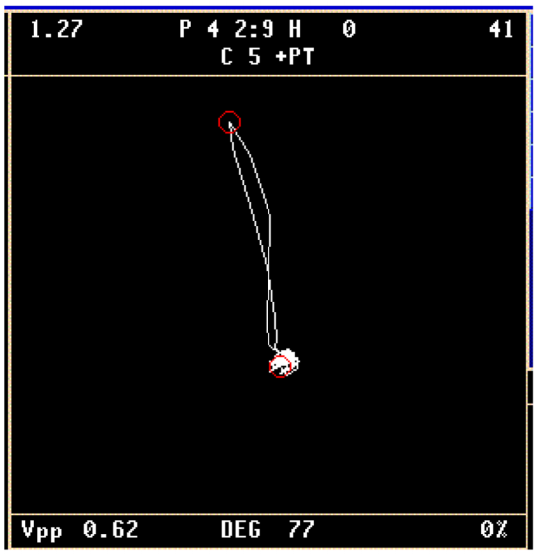


Figure 4-2 — Comparison of Ding ODSCC (top) and TSP ODSCC (bottom) +Point Lissajous Responses.

c

Figure 4-3 — Default Crack Growth Rates for A600TT Tubing at 611°F.

a,

b,

c

Figure 4-4 — Comparison of Various Crack Growth Rate Functions from Operating Data.

a,
b

Figure 4-5 — Plant S Axial ODSCC at Dented Quatrefoils Maximum Depth Growth Rate per EFPY.

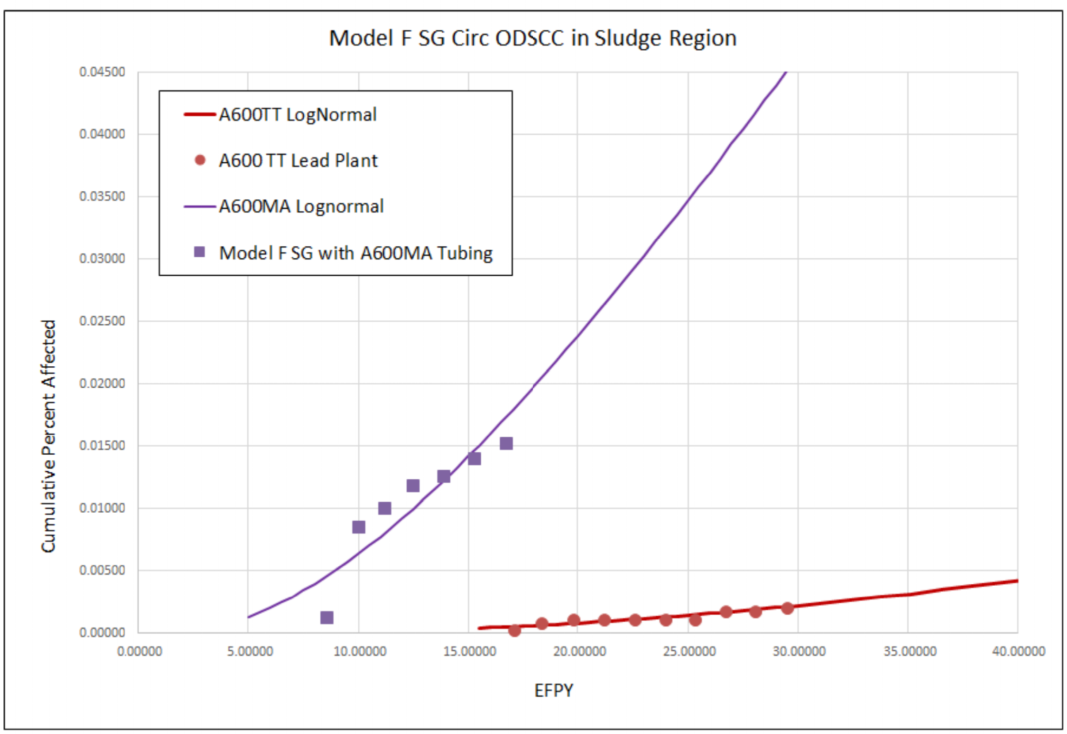


Figure 4-6 — Prediction of Circumferential ODSCC in A600TT Lead Plant and A600MA Plant with Model F SGs.

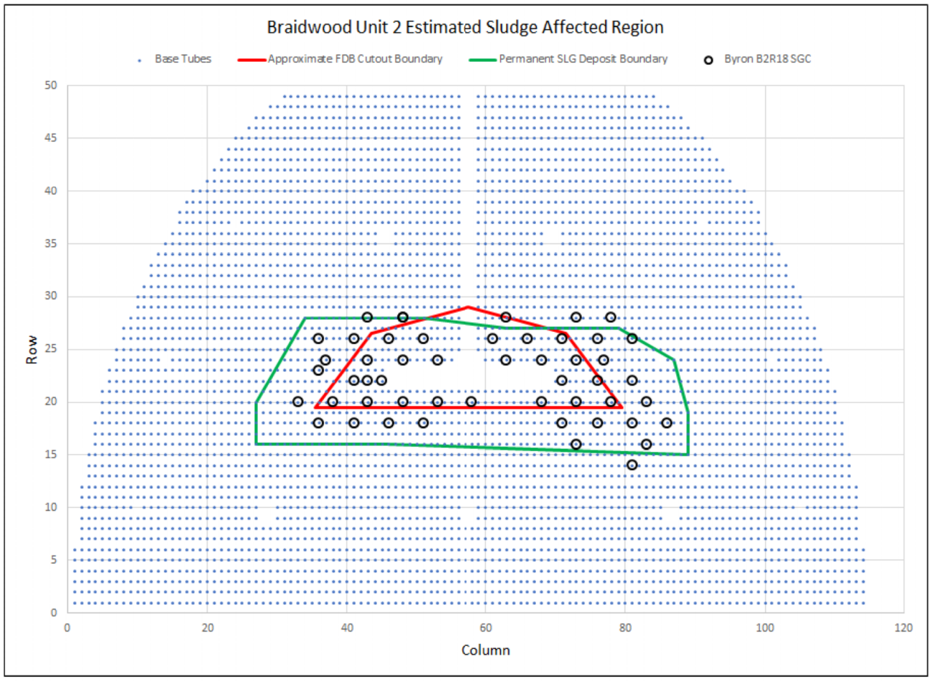


Figure 4-7 — Braidwood Unit 2 SGD Sludge Deposition and Definition of ODSCC Susceptible Region.

a,
b

Figure 4-8 — Axial SCC Length Distribution for A600TT Tubing.

a,
b

Figure 4-9 — Circumferential ODSCC Arc Length Distribution for A600TT Tubing.

a,
b

Figure 4-10 — Axial ODSCC Length Distribution at Dents for A600TT Tubing.

5 | Operational Assessment for Existing Mechanisms

5.1 Assessment Method

A deterministic OA methodology consistent with the EPRI IAGL was completed to address the wear at tube support structure mechanisms observed at B2R20 extended to B2R23. Section 3.6.1 and the following discussion briefly describes the deterministic OA methodology. Table 5-1 presents a summary of the deterministic OA results for wear at structures mechanisms. A fully probabilistic methodology (Section 3) was utilized for the assessment of SCC mechanisms.

The existing mechanisms evaluated using a deterministic methodology are wear degradation due to tube contact points at AVBs, TSP intersections, and at DSP locations. Wear degradation from known foreign objects in each SG were evaluated by Exelon. The deterministic calculations for AVB wear, wear at TSPs, and wear at DSPs is based on the guidance contained in [2].

Plug (or repair) on NDE sizing strategy is used in the OA for the existing mechanisms. The basic analysis steps for each degradation mechanism are:

1. Identify the largest flaw indication which could potentially remain in service at BOC.
2. Calculate the projected largest flaw at EOC for each scheduled outage by applying the upper 95th percentile growth rate or maximum growth rate for small growth populations for the next operating period to the largest flaw at BOC.
3. Compare the projected largest flaw size at future EOC inspections to the condition monitoring limit size.
4. Compare the projected largest flaw size at future EOC inspections to leakage size.

A successful deterministic OA for three-cycles must demonstrate that the performance criteria for tube integrity (burst and leakage) will be satisfied at the acceptance probability of occurrence level of 95-50 for all input conditions. Compliance with the structural performance criterion is indicated when:

$$d_{EOC} < d_{CM} \qquad (5\text{-}1)$$

where d_{EOC} is the limiting defect depth at the next tube examination, and d_{CM} is the condition monitoring limit. NDE sizing uncertainty is applied in the calculation of d_{CM}.

Table 5-1 — Summary of Wear at Structures OA Results

	AVB	TSP	DSP
OA Methodology	Deterministic	Deterministic	Deterministic
Uncertainty treatment	Arithmetic	Arithmetic	Arithmetic
Largest indication returned to service after B2R20 (%TW, NDE)	39%TW	34%TW	26%TW
Applicable ETSS	96004.3 r13	96910.1r11	96910.1r11
Bounding degradation growth rate (%TW/EFPY)	2.1	3.2	2.5
Basis for growth rate selection	(Note 1)	(Note 2)	(Note 2)
Projected size at B2R23, 52 EFPM (%TW, NDE)	48%TW	48%TW	37%TW
Bounding degradation geometry	(Note 3)	(Note 3)	(Note 4)
Burst pressure at projected actual B2R23 size (psi)	5741	4545	5773
Condition Monitoring limit at 3xNOPD, 4155 psi (%TW, NDE)	68%TW	52%TW (Note 5)	53%TW
Approximate margin (%TW)	~20%TW	~4%TW	~16%TW

Notes:

(1) Basis for selection: 95th percentile of paired AVB wear indications at B2R18 and B2R20 for limiting steam generator.
(2) Basis for selection: largest observed growth rate for paired wear indications at TSP (or DSP). Total population of thirteen TSP paired indications and ten DSP paired indications, for both outages combined.
(3) Volumetric with limited circumferential and axial extent
(4) Volumetric uniform thinning with limited axial extent
(5) CM Limit calculated using uniformly deep flaw profile. Experience suggests TSP wear will exhibit a tapered profile. For assumed taper angle of 1 degree the CM limit is 68%TW.

5.2 Anti-Vibration Bar Wear

A full-length bobbin probe examination covered 100% of all active tubes at the B2R20 examination. The 1,145 detected indications at B2R20 for wear associated with AVBs ranged in depth from 9 to 42%TW, sized by an EPRI-qualified examination technique (ETSS 96004.3 rev 13). Two of these indications were at or exceeded the technical specification tube plugging limit of 40%TW and were repaired by plugging; both of these indications were in SG 2A, so a total of two tubes were plugged in SG 2A at B2R20 for AVB wear. This means the deepest indications associated with AVB wear that were returned to service is 39%TW (NDE depth). There were two such 39%TW AVB wear indications: one each in SG 2A and 2B.

The shape of AVB wear caused by a tube interacting with a flat bar support is bounded by the physical model of volumetric wear with limited circumferential and axial extent. The width of the AVB is 0.29 inches; however, since not all tubes intersect orthogonally with AVBs, a 20% allowance is used for degradation length, and the assumed axial length of the AVB wear scar is 0.35 inch. 3×NOPD pressure (4,155 psi) is the limiting condition for structural integrity performance, and the condition monitoring limit for AVB wear at this pressure is 68%TW (NDE depth).

Observed AVB wear rates at Byron Unit 2 were calculated by comparing the change in depth of AVB wear indications from the three most recent examinations at B2R20, B2R18, and B2R16. There were more than 1,000 paired AVB wear indication data in each outage for both B2R20 and B2R18. When considered as an aggregated population (i.e., combining results from all four steam generators), more than half of the paired indications in both outages showed no growth. As an aggregated population, the observed wear rates at B2R20 are bounded by the observed wear rates at B2R18, indicating that wear rates have attenuated.

However, since results vary by steam generator and by outage, a limiting case was determined by evaluating the wear rates in each steam generator individually, as noted in Section 4.4.1. For B2R18 (comparing paired inspection data with B2R16), the limiting case steam generator wear rates were in 2B, which had a higher average, upper 95th percentile, and maximum wear rate than the wear rates in the other three steam generators, individually considered. For B2R20 (comparing data with B2R18), the limiting case steam generator wear rates were in 2D. In B2R20, although 2D had a higher average and upper 95th percentile wear rate than any of the other three steam generators, 2A had a slightly higher observed maximum wear rate. Coincidentally, the observed upper 95th percentile wear rate for SG 2B (limiting SG at B2R18) was the same as the observed upper 95th percentile wear rate for SG 2D (limiting SG at B2R20), so the applied bounding wear rate for the upcoming inspection interval was selected to be 2.1%TW/EFPY (Section 4.4.1).

The projected size of the deepest AVB wear indication that was returned to service over the three-cycle operating period (4.38 EFPY, Section 4.2) based on this bounding wear rate is 48%TW (NDE depth). This is less than the 3×NOPD condition monitoring limit of 68%TW (NDE depth) at B2R23. Therefore, the structural performance criteria of NEI 97-06 will be satisfied, with a margin of approximately 20%TW. The cumulative projected accident leakage contribution from wear mechanisms over the operational period from B2R20 to B2R23 is zero. Newly reported indication depths were also examined, and it is concluded that the B2R23 depth of the limiting newly reported indication at B2R20 will be bounded by the 48%TW condition developed above.

5.3 Wear at Tube Support Plates

For Byron Unit 2, the broached TSPs are the supports ranging between 02H – 11H and 11C – 07C, inclusive. The full-length bobbin probe examination also detected wear at broached TSPs during the B2R20 examination. There were fourteen detected indications for wear associated with broached TSPs at B2R20 with depths ranging from 11%TW to 39%TW (NDE depth), sized with ETSS 96910.1 rev 11; this maximum occurred at R49 C65, TSP 07C, in SG 2C. This tube was repaired by plugging. Of these 14 indications, ten of these were paired and had a history of TSP wear at B2R18 while four of these were newly detected. The deepest indication returned to service at B2R20 was 34%TW (NDE depth) at R49 C64, TSP 07C, in SG 2C.

The broached TSPs in the Byron Unit 2 SGs are 1.125 inches thick, and are quatrefoil, with four lands spaced evenly around the circumference of the tube. The shape of single-land TSP wear is also bounded by the physical model of volumetric wear with limited circumferential and axial extent. A uniformly deep depth profile is applied, and the length of the indication is assumed to be equal to the width of the full TSP. For this morphology the condition monitoring limit for broached TSP wear at 3×NOPD is 52%TW (NDE depth). Byron experience, as well as the majority of the TSP wear indications in Westinghouse SGs have been shown to exhibit a tapered depth profile over the length of the indication. The tapered wear depth profile significantly increased the condition monitoring depth limit.

Observed TSP wear rates at Byron Unit 2 were calculated again by comparing the change in depth of TSP wear indications from the three most recent examinations (B2R20, B2R18, and B2R16). There were few paired TSP wear data, so the data from both inspection periods (B2R18 to B2R20, and B2R16 to B2R18) were combined to calculate broached TSP wear rates; there were a total of thirteen paired TSP wear rates obtained in this manner. All observed wear rates were bounded by a maximum observed wear rate of 3.2%TW/EFPY (Section 4.4.1); this occurred at R49 C64, TSP 07C, in SG 2C.

The projected size of the deepest TSP wear indication that was returned to service over the three-cycle operating period (4.38 EFPY) is 48%TW (34%TW largest return to service depth + 14%TW growth) using the bounding wear rate. This is less than the 3×NOPD condition monitoring limit of 52%TW (NDE depth) at B2R23. Therefore, the structural performance criteria of NEI 97-06 will be satisfied, with a margin of approximately 4%TW. It should be noted that the reported lengths of the observed hot leg TSP wear indications suggest a tapered wear condition. The +Point data for R49 C65 were reviewed to confirm a tapered wear shape. Two indications were reported by +Point. The deeper indication extends the entire width of the TSP but suggests a tapered depth profile. The shallower indication has a length of approximately 0.25 inch, which also suggests a tapered depth profile. For an assumed taper angle of 1 degree the associated maximum depth consistent with the performance criterion is approximately 68%TW which then bounds the maximum projected TSP wear depth of 48%TW. The cumulative projected accident leakage will be zero over the next operational period based on the projected limiting depth sizes for this mechanism. Newly reported indication depths were also examined, and it is concluded that the B2R23 depth of the limiting newly reported indication at B2R20 will be bounded by the 48%TW condition developed above.

5.4 Wear at Drilled Tube Hole Support Plates

For Byron Unit 2, the DSPs refer to the lowermost flow baffle plate (01H and 01C) and the drilled hole style support plates in the preheater section (ranging between 06C – 02C, inclusive). The full-length bobbin probe examination also detected wear at DSPs during the B2R20 examination. There were five detected indications for wear associated with DSPs (four paired and one new), with depths ranging from 9%TW to 26%TW, sized with ETSS 96910.1 rev 11. Because none of these indications were repaired by plugging, the largest indication associated with DSP wear that was returned to service is 26%TW (NDE depth), which occurred at R48 C35, DSP 02C in SG 2C.

The DSPs in the Byron Unit 2 SGs are 0.75 inch thick and have round holes with relatively small radial clearance for the tubes they support, so the shape of DSP wear is bounded by the physical model of volumetric wear with uniform (full-circumference) thinning over a limited axial extent. The length of DSP wear is assumed to be limited to the thickness of the DSP, 0.75 inch. The condition monitoring limit for DSP wear at 3×NOPD is 53%TW (NDE depth).

Observed DSP wear rates at Byron Unit 2 were calculated again by comparing the change in depth of DSP wear indications from the three most recent examinations (B2R20, B2R18, and B2R16). There were few paired DSP wear data, so the data from both outages (B2R20 from B2R18, and B2R18 from B2R16) were combined to calculate DSP wear rates; there were a total of ten paired DSP wear rates obtained in this manner. The resulting largest observed wear rate was 7.1%TW/EFPY; this occurred at R48 C35, DSP 02C in SG 2C (which is also the deepest DSP wear indication returned to service) for B2R18 to B2R20. However, the sizing basis for the B2R18 inspection is the bobbin probe, whereas sizing basis for B2R20 for DSP wear was +Point. The inspection history of this location shows essentially no change in the bobbin- based depth estimates (6 to 8%TW) from 2005 to 2014. The +Point based depth estimate at B2R20 was 26%TW, which then infers a growth rate of 7.1%TW/EFPY. As this growth rate is atypical for DSP wear at Byron Unit 2, the B2R18 and B2R20 bobbin data for this location were reviewed and it is determined that there is no change in the bobbin signals between these inspections thus it can be concluded that the B2R20 +Point based depth is an inspection transient. Therefore, as the indication on R49 C65 had no change based on the bobbin data, the largest valid DSP wear growth rate is then 2.5%TW/EFPY, found on two tubes, one in SG B and one in SG D.

The projected size of the deepest DSP wear indication that was returned to service over the three-cycle operating period (4.38 EFPY) is then 37%TW (R48 C35 in SG C, 26%TW largest return to service depth + 11%TW growth). This is less than the 3×NOPD condition monitoring limit of 53%TW (NDE depth) at B2R23. Therefore, the structural performance criteria of NEI 97-06 will be satisfied, with a margin of approximately 16%TW. The cumulative projected accident leakage will be zero over the next operational period based on the projected limiting depth sizes for this mechanism. Newly reported indication depths were also examined, and it is concluded that the B2R23 depth of the limiting newly reported indication at B2R20 will be bounded by the 37%TW condition developed above.

5.5 Foreign Object Evaluation

Foreign object wear time analyses are not part of this OA. The foreign object wear time evaluation was performed by another vendor.

6 | Operational Assessment for Potential Mechanisms

6.1 Assessment Method

The potential corrosion-related mechanisms have been proactively monitored by performing additional qualified ECT examinations in past outages. To date, Byron Unit 2 has not experienced (reported by NDE) any corrosion degradation of the pressure boundary portion of the tubing (as defined by the H* alternate repair criteria) on either non-high residual stress tubes or on high residual stress tubes.. In earlier outages, SCC degradation at tube-ends was reported; however, with application of the H* Alternate Repair Criteria, inspection below the H* depth is not required.

For the OA of potential SCC mechanisms, the following methodology was applied. Specifically:

1. All potential mechanisms are assumed to be existing and evaluated in the OA.
2. It is assumed that prior to the most recent tube examination, SCC had initiated and was missed (not detected) by ECT during the inspection. This assumption will create a population of undetected flaws that will exist at the start of the cycle following the inspection.
3. The IAGL typical default crack growth rates were conservatively applied.
4. For SCC mechanisms (other than axial ODSCC at dings and dents) that were sampled at the last inspection, the tube population was divided into two groupings per the implemented sampling plan (inspected and non-inspected) in accordance with Section 8.6 of EPRI IAGL. The POB and POL assessment was individually computed for each partially inspected group and later numerically combined to give the total probabilities for the mechanism.
5. For axial ODSCC at dings and dents the assumed first initiation point was assumed earlier in the plant operating history than for other SCC mechanisms due to the NDE detection challenges at these locations. Additionally, the susceptible population was not divided between the two most recent inspections. These practices provide a very conservative assessment of this mechanism.

In support of the probabilistic OA for the potential mechanism, a lead-plant evaluation was performed where the operating history of Byron Unit 2 was compared with those plants that have experienced SCC to estimate equivalent initiation times for each mechanism. This information was primarily used to establish when initiation at Byron Unit 2 would have occurred, or could occur, and to help to define the range of Weibull parameters appropriate for OA.

6.2 Potential Degradation Mechanisms

There are several corrosion-related degradation mechanisms that are generally classified as potential for A600TT tube material (including the A600TT tubing utilized in the Byron Unit 2 SGs). These mechanisms involve forms of SCC on the primary or steam-side, oriented either axial or circumferential to the tube axis, and occurring at different locations in the tube bundle. For SGs utilizing A600TT tubing, these potential mechanisms ordered according to their judged risk level, from highest to lowest, are:

- Axial ODSCC at TSP intersections on known high residual stress tubes
- Circumferential ODSCC at the hot leg TTS expansion transition
- Axial ODSCC at tube dings and dents (both high stress and non-high stress tubes)
- Axial ODSCC at TSP intersections on non-high residual stress tubes

- Axial ODSCC at the hot leg TTS expansion transition
- Axial ODSCC in the freespan, immediately above TSPs[1]
- Axial PWSCC in small radius U-bends
- Axial and circumferential PWSCC at the TTS (generally bounded by ODSCC analyses)
- OD Pitting on the cold leg in the sludge pile region

As stated in Section 3, the potential mechanisms for which a full rigor OA was also performed are axial and circumferential ODSCC at the hot leg TTS expansion transition and axial ODSCC at freespan dings and at dents.

Postulated axial ODSCC at TSP intersections on non-high residual stress tubes is addressed by the axial ODSCC at TSP intersections on high residual stress tubes, low Weibull slope model. This analysis case applies the IAGL upper bound default growth rate and as such, can be considered conservative for this potential mechanism for Byron Unit 2.

6.3 Axial ODSCC at TSP Intersection on High Residual Stress Tubes

The tube population affected by ODSCC at TSP includes normal non-residual stress tubes and those tubes that have been identified as having high residual stresses from fabrication [18]. At B2R18 and B2R20, all tubes (in the SG) were inspected in the straight length region using a bobbin probe and all high residual stress tubes were tested at all hot leg and cold leg TSP intersections using an X-Probe. The combination of bobbin inspection with subsequent X-Probe inspection is based on Design of Experiments Theory and Monte Carlo simulation of POD for the combined inspection processes. In essence, the initial screening with the bobbin probe produces a theoretical set of simulated detections and non-detections as a result of processing a uniform input depth distribution through the bobbin probe POD. The non-detected depths then are used as the input distribution to the processing of the X-Probe POD curve. The resulting simulated non-detected distribution after X-Probe POD application then results in a non-detected depth distribution which then is improved for application of each individual probe [19].

The total number of high residual stress tubes is 39 (7 in SG A, 12 in SG B, 11 in SG C, and 9 in SG D). Axial ODSCC at TSP intersections on high residual stress tubes has not been reported at Byron Unit 2. Axial ODSCC at TSP intersections on high stress tubes has been reported at Braidwood Unit 2; the data trending from Braidwood will be conservatively applied as a bounding analysis case for Byron.

Axial ODSCC at TSP intersections on high residual stress tubes was first reported at Braidwood Unit 2 (sister plant to Byron) in 2003 (A2R10) when two affected tubes were reported in SG C and one in SG A. These three tubes were 2-sigma tubes (located in Rows 10 or higher). Indications were not reported again until 2011 (A2R15) when one tube in SG D was reported with indications. This tube was a Seabrook Signature tube (located in Row 9 or lower). In 2012 (A2R16), one tube in SG C was affected; this tube was a 2-sigma tube. This tube, R44 C47, contained indications at the 03H and 05H TSPs as well as a freespan ding crack located just below 05H.

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[1] This mechanism was reported for the first time in the A600TT fleet during the fall of 2019. The indication was reported on a non-high stress tube. Characterizing probe data suggest the presence of significant deposits both within the TSP flow lobes and above/below the TSP. At B2R20 a “soft” chemical cleaning process was applied at Byron Unit 2. This maintenance activity should proactively address this mechanism by removing contaminants which could affect ODSCC initiation. Based on information provided by the licensee [21] the maximum depth growth of the indication from 2016 to 2019 is bounded by the IAGL typical default growth rate.

The OA model used considers two different initiation functions to model two possible predicted behaviors. Based on the Braidwood Unit 2 performance, as well as the performance of the other units with this mechanism, the initiation most resembles an acute initiation model which initiates some discrete number of indications within a short operating period. These indications then grow and eventually are detected. At some point(s) in the future, another acute initiation event is experienced. However, as logic would dictate, those tubes with the highest susceptibility to axial ODSCC would be expected to experience initiation first. Going forward, the initiation model may then follow that of a low Weibull slope, which is the expected initiation model for non-high residual stress tubes. Therefore, two initiation models were evaluated, one with rapid initiation of SCC in a short operating period (acute model), and the other having a gradual evolution of SCC over a time (low Weibull slope model) as observed with other SCC mechanisms.

In the acute model, four indications are assumed to initiate within a very short operating window. This value represents the largest number of indications reported on high residual stress tubes at any prior Braidwood inspection. In the low Weibull slope model, the Weibull initiation function introduces flaws to the model as a function of time. The integrity models are setup as relative models. That is, the EFPY values used in the model (which are based on the Weibull initiation function and time) represent specific points in time in the Byron operating history. As the mechanism has not been reported at Byron Unit 2, there is an obvious delay in the first initiation point. The model then projects forward from this first initiation point.

As indications were not detected in B2R18 or B2R20, this strongly implies that had initiations been postulated prior to B2R18 that indications would have been detected at B2R20. The model then uses an initiation point consistent with the EPRI feasibility study which results in the first initiation a minimum of one cycle prior to the most recent inspection. In the model, the first initiation occurs at approximately 4.76 relative EFPY which is during Cycle 19. At 6.12 relative EFPY, which represents B2R20, all four susceptible indications have initiated. The actual EFPYs for Cycle 21 and Cycle 22 are used in the model, a conservative Cycle 23 length of 1.50 EFPY is applied. In the low Weibull slope model, two indications have initiated at the point equivalent to B2R20.

The software used for the integrity analysis can predict the number of initiations and number of predicted detections at any point in time. The model can also be setup to ignore any potential detections for a particular inspection. Thus, as no indications were detected at B2R20, the model is configured such that any potential detections (internal to the model) are returned to service (kept in the simulated indication distribution), mimicking the inspection result of no-detectable-degradation condition. These indications are tracked and grown by the model up to B2R23. The structural average growth rate used is the IAGL upper bound default function with a LogNormal mean of 1.95.

The EOC SEL distribution is also an important input to the analysis as the SEL is used in the burst and leakage calculations.

a, b

The structural average depth growth rate applied in both models is the upper bound default growth value; this function has a LogNormal mean of 1.95 and standard deviation of 0.65. This growth rate is judged conservative for this mechanism. Section 4 provides discussion of the developed growth rate for the indication at 03H on R44 C47, which was in situ pressure tested at A2R16. This discussion indicates that the IAGL upper bound default growth rate is conservative.

6.3.1 Acute Initiation Model Results

The model predictions for number of initiated indications and bobbin detections for the plant outages are shown in Table 6-1. In the model, for an EFPY equivalent to B2R23, the calculated probability of burst (POB) is 3.74%, which is less than the limit of 5%, and the probability of leakage (POL) exceeding the AILPC of 0.5 gpm is 1.20%, which is less that the limit of 5% for this mechanism. Thus, the analysis results for the acute model satisfy the performance criteria at B2R23. Table 6-1 provides key inputs to the OA model and results of the analysis.

Table 6-1 — Acute Model Results for 100% Bobbin/X-Probe Examination at B2R20 — Axial ODSCC at TSP Intersections on High Residual Stress Tubes

a,
b
c

Section 4 presents an analysis of maximum depth growth rate for the axial ODSCC on Braidwood tube R44 C47 at 03H. This indication was reported to have progressed from an NDD condition to a significant depth at the following outage and is generally considered to represent the bounding growth rate for high residual stress tubes. The growth rate analysis of Section 4 indicates that the IAGL typical default growth rate remains bounding for this indication. The acute initiation case was rerun using the IAGL typical default growth rate instead of the upper bound default growth rate to assess the sensitivity to growth rate in the analysis. At B2R23 the POB is reduced to 0.1% and the POL is reduced to 0.0%. One to two indications are predicted to be detected at B2R23 for this growth rate condition.

6.3.2 Low-Weibull Slope Initiation Model

The low slope model uses a Weibull slope of 1.5. The susceptible population size is defined in Section 4. The Weibull CL used produces one initiated indication at least one cycle prior to B2R20. The model predictions for number of initiated indications and Bobbin detections for the plant outages are shown in Table 6-2. In the model EFPY equivalent to B2R23, the calculated POB is 3.18%, which is less than the limit of 5% for this mechanism, and the POL exceeding the AILPC of 0.5 gpm is 1.87%, which is less that the limit of 5% for this mechanism. Thus, the analysis results for the low Weibull slope model satisfy the performance criteria at B2R23.

Given the conservative number of susceptible sites utilized in the model, any postulated initiations on non-high stress tubes are also considered to be addressed by this model (see Section 6.7). This analysis is conservative for the non-high residual stress tubes as the IAGL typical default growth (LogNormal mean of 1.50) is expected to be conservative for non-high residual stress tubes. Table 6-2 provides key inputs to the OA model and results of the analysis.

Table 6-2 — Low Weibull Slope Model Results for 100% Bobbin/X-Probe Examination at B2R20 — Axial ODSCC at TSP Intersections on High Residual Stress Tubes

a, b c

6.4 Circumferential ODSCC at TTS Expansion Transitions

Sampling inspections have been performed at Byron Unit 2 for detecting the onset of SCC at the TTS. SCC has not been reported to date at the TTS expansion transition or at bulge or over-expansion locations within the tubesheet. The following provides the tubesheet +Point or X-Probe sampling in the hot leg since 2007 (B2R13):

- At B2R13, 30% Point sampling in each SG was performed.
- At B2R14, 40% +Point sampling in each SG was performed (20% from +/-3 inch about TTS plus 20% TSH +3 inches down to the H* distance).
- At B2R15, 50% +Point sampling in each SG was performed (25% from +/-3 inch about TTS plus 25% TSH +3 inches down to the H* distance).
- At B2R16, 25% +Point sampling in each SG was performed (25% from +/-3 inch about TTS plus 25% TSH +3 inches down to the H* distance).
- At B2R18, nominal 50% X-Probe sampling in each SG was performed from +3 inch above the hot leg TTS down to the H* distance plus X-Probe testing from +/-3 inch about TTS of high flow regions (thus total X-Probe testing of the expansion transition region exceeded 50%).
- At B2R20, nominal 50% X-Probe sampling in each SG was performed from +3 inch above the hot leg TTS down to the H* distance plus X-Probe testing from +/-3 inch about TTS of high flow regions (thus total X-Probe testing of the expansion transition region exceeded 50%).

Eddy current inspections were not performed at B2R17 or B2R19.

Since complimentary 50% sampling was applied at B2R18 and B2R20, each inspection subset was evaluated independently with regard to initiation. The circumferential ODSCC models were developed consistent with the other OA models in that since SCC has not been reported to date, initiation was assumed at least one cycle prior to the most recent inspection and two initiates are assumed at present at the time of the most recent inspection and not detected by the X-Probe. It should be noted that the model is configured to ignore any potential detections at the most recent inspection. This ensures a conservative assessment as all initiated flaws are allowed to remain in-service. The susceptible population was divided between the 50% inspection programs. That is, 50% of the susceptible population is assumed to exist within the tubes last inspected in B2R18 and 50% of the susceptible population is assumed to exist within the tubes last inspected in B2R20. The configuration of the model conservatively neglects the additional X-Probe testing of high secondary flow regions at the hot leg TTS at B2R18 and B2R20, which includes the expansion transition region.

<u>Population Last Inspected at B2R18 – Default Growth Rate</u>

For initiation behavior, a Weibull slope of 1.5 for circumferential ODSCC at units which have not reported SCC has been estimated in [13]. Unless otherwise noted, the applied PDA growth rate is the IAGL typical default growth rate. The characteristic life is adjusted to produce the desired number of initiates for each inspected population. For the population of tubes last inspected at B2R18, the POB is 2.75% and POL is 0.21%, with five predicted detections at B2R23. Table 6-3 provides key inputs to the OA model and results of the analysis. Section 4 describes the arc length distribution data review.

Table 6-3 — Model Results for 50% X-Probe TTS Examination at B2R18 — Circ ODSCC

a,
b
c

Population Last Inspected at B2R18 – Recommended Growth Rate

Section 4 includes discussion of PDA growth which identifies a recommended PDA growth rate. If this growth rate is used in the above OA model, the POB at B2R23 is reduced to 0.31% and POL is 0.0%. Even with this reduced PDA growth rate, the number of predicted detections at B2R23 is still 4 to 5 indications, implying that the reduced PDA growth rate does not significantly influence the number of predicted detected indications. Note that the recommended PDA growth rate bounds the A600TT lead plant PDA growth data and the A600MA plant PDA growth data discussed in Section 4.

Table 6-3a provides results of the reanalysis of the case described by Table 6-3 using the recommended PDA growth rate. Since this analysis uses a more realistic but still conservative PDA growth rate, this analysis represents the recommended OA result for this mechanism.

Table 6-3a — Model Results for 50% X-Probe TTS Examination at B2R18 — Circ ODSCC Recommended PDA Growth Rate

a,
b
c

Population Last Inspected at B2R20 – Default Growth Rate

For the 50% tube examination at B2R20, the same approach is followed except that the assumption that one indication initiates in the operating period prior to B2R20 and two initiates are assumed present at the B2R20 inspection and not detected by X-Probe.

For initiation behavior, a Weibull slope of 1.5 for circumferential ODSCC at units which have not reported SCC has been estimated in [13]. The characteristic life is adjusted to produce the desired number of initiates for each inspected population. For the population of tubes last inspected at B2R20, the POB is 0.64% and POL is 0.30%, with three to four predicted detections at B2R23. Table 6-4 provides results of the analysis and key inputs to the OA model. Note that the calculated POL of 0.30% is based on the recommended arc length distribution. Note that the recommended arc length distribution bounds the arc length reports of all industry (A600TT) indications.

Table 6-4 — Model Results for 50% X-Probe TTS Examination at B2R20 — Circ ODSCC

a, b

Population Last Inspected at B2R20 – Recommended Growth Rate

As with the population last inspected at B2R18, the same reanalysis methodology using the recommended PDA growth rate was performed. The POB at B2R23 is 0.03% and POL is 0.0%.

Table 6-4a provides results of the reanalysis of the case described by Table 6-3 using the recommended PDA growth rate. Since this analysis uses a more realistic but still conservative PDA growth rate, this analysis represents the recommended OA result for this mechanism.

Table 6-4a — Model Results for 50% X-Probe TTS Examination at B2R20 — Circ ODSCC with Recommended PDA Growth Rate

a,
b

The total POB for this mechanism for comparing with the performance standard of < 5% is calculated using a Boolean summation of the two probabilities:

POB = 1-(1-0.0031)(1-0.0003) = 0.34%

The total POB for this mechanism satisfies the SIPC margin requirement performance standard. POL is 0.03%.

6.5 Axial ODSCC at TTS Expansion Transitions

The OA for axial ODSCC at TTS is configured in a similar manner as for circumferential ODSCC at the TTS expansion transition. The only difference between the two models is that the initiation function [13] uses the susceptible population size determined in Section 4. As with circumferential ODSCC, the CL is adjusted to produce one initiation at least one cycle prior to the most recent inspection with two initiates at the most recent inspection. The model is configured to ignore any potential detections at the most recent inspection. This is conservative as all initiated flaws remain in-service.

<u>Population Last Inspected at B2R18 – Default Growth Rate</u>

The same approach is taken with regard to distribution of the susceptible population between the two inspections (i.e., B2R18 and B2R20).

The length distribution applied is the SEL developed from the distribution of all TTS (ODSCC and PWSCC) and ding/dent SCC indications reported prior to spring 2020. Section 4 describes this distribution and its development.

For initiation behavior, a Weibull slope of 1.5 for axial ODSCC at units which have not reported SCC has been estimated in [13]. The characteristic life is adjusted to produce the desired number of initiates for each inspected population. For the population of tubes last inspected at B2R18, the POB is 0.20% and POL is 0.12%, with two to three predicted detections at B2R23. For such low probabilities of burst and leakage for the population that was last inspected at B2R18, there is no reason to perform the same analysis for the population last inspected at B2R20 since these flaws will be in-service for two fewer cycles. The POB and POL for the population last inspected at B2R20 are conservatively assumed to be half the corresponding value computed for B2R18 when the combined probabilities are evaluated below. Table 6-5 provides results of the analysis and key inputs to the B2R18 OA model. The applied growth rate is the IAGL typical default growth rate.

Table 6-5 — Model Results for 50% X-Probe TTS Examination at B2R18 — Axial ODSCC

a,
b
c

The total POB for this mechanism for comparing with the performance standard of ≤5% is calculated using a Boolean summation of the two probabilities:

POB = 1-(1-0.0020)(1-0.0010) = 0.30%

POL = 1 – (1-0.0012)(1-0.0006) = 0.18%

The total POB for this mechanism satisfies the SIPC margin requirement performance standard.

As a sensitivity study, a lognormal length distribution describing the as-reported total flaw length was used (i.e., total reported flaw length equals SEL). The POB at B2R23 is only increased to 1.1% and the POL is only increased to 0.43%.

6.6 Axial ODSCC at Dings and Dents

Tube dings in the freespan and dents at support structures have been tested in past outages with ECT including 100% bobbin coil testing of dings/dent signals < 5 volts, and with a sampling program using the +Point probe for dent signal voltages as low as 2 volts.

At B2R18 (fall 2014), the ding/dent +Point inspection program included 100% dings/dents >5V in the U-bend region and 50% +Point inspection of >5V hot leg and cold dings/dents. Even though the hot leg would be expected to lead the cold leg with regard to ding/dent ODSCC initiation, the B2R18 program conservatively addressed cold leg locations.

At B2R20 (fall 2017) the +Point scope included 50% of all (hot leg, cold leg, and U-bend) >5V dings/dents, 50% of 2 to 5V dents at 01H and 01C through 06C, plus, 50% of 2 to 5V dings below 01H and below 06C. These location specific ding /dent programs were implemented to address the hottest region of tube temperatures (01H and below) and areas where the SG design (within the preheater) could potentially introduce a manufacturing related anomaly associated with the number of drilled hole style plates within the preheater.

Exelon has aggressively sampled hot leg dings and dents for many inspections. At B2R16 (2011), B2R15 (2010), and B2R14 (2008), the program included 25% of hot leg dings and dents >3V while at B2R13 (2007), the program included 25% of hot leg dings/dents >5V and 50% of hot leg dings/dents >3 but <5V.

The following table presents the breakdown of dings by location based on the B2R18 bobbin data.

Byron 2 Ding Statistics								
	All Locations		**Hot Leg Straight Section**		**U-bend**		**Cold Leg Straight Section**	
SG	Total	>5V	Total	>5V	Total	>5V	Total	>5v
A	803	162	428	92	54	13	321	57
B	580	98	267	46	46	8	267	44
C	1698	397	854	210	92	17	752	170
D	1410	283	704	156	81	22	625	105
Total	4491	940	2253	504	273	60	1965	376

The number of >10V dings is 33 for SG 2A, 16 for SG 2B, 62 for SG 2C, and 35 for SG 2D, or 146 for the plant. In comparison, Plant S contains 23 dings >10V.

The following table presents the breakdown of dents by location based on the B2R18 bobbin data.

Byron 2 Dent Statistics								
	All Locations		**Hot Leg Straight Section**		**U-bend**		**Cold Leg Straight Section**	
SG	Total	>5V	Total	>5V	Total	>5V	Total	>5v
2A	295	71	148	41	13	1	134	29
2B	622	114	230	32	22	0	370	82
2C	510	108	300	75	44	1	166	32
2D	959	216	389	108	142	17	428	91
Total	2386	509	1067	256	221	19	1098	234

The number of >10V dents is 32 for SG 2A, 18 for SG 2B, 24 for SG 2C, and 43 for SG 2D, or 117 for the plant. In comparison, Plant S contains 147 >10V dents.

6.6.1 Axial ODSCC at <5V Dings and <5V Dents

Byron Unit 2 has performed 100% full length bobbin inspection in each SG for at least 10 successive inspections; the bobbin probe is qualified for axial ODSCC detection in <5V dings and <5V dents. As stated above, the aggressive +Point inspection program applied at B2R20 and earlier inspections effectively improved the overall bobbin detection program at hot leg dings and dents since the +Point probe was also applied to <5V dings and dents. The bobbin detection technique for <5V dings forms the basis for the bobbin detection technique at <5V dents. As such, the POD curves are essentially identical. Since the POD curves are essentially identical, for simplicity, this OA case combines the total number of <5V dings and <5V dents in the limiting SG of 1850 locations into one OA analysis case. The SEL distribution applied is the SEL distribution for the <9V dent assessment described in Section 4. The protocol for the other mechanisms evaluated forced at least one initiation in the cycle prior to the most recent inspection. However, those analyses involved either the use of improved detection performance probes or bobbin probes in non-dented/ding locations. Given the difficulties associated with bobbin probe detection and recent plant performance, the OA model forces the first initiation at B2R16, or four cycles prior to B2R20. This model is quite conservative as it produces 8 initiates by the B2R18 outage. Using the previously applied methodology a minimum of 2 initiates would be modeled at the B2R18 outage.

This case, and the >5V ding and >5V but <9V dent cases, differ in philosophy from the cases utilized in the Braidwood Unit 2 1-cycle extension OA. The Braidwood analyses were performed prior to the Plant S, spring 2020 experience. The axial ODSCC SEL distribution applied in the Braidwood analyses utilized the SEL distribution based on the axial ODSCC at dings experience from an A600MA plant; the ding cracks at this plant were primarily located in the U-bend region and resultant from tube bundle repair during manufacture. Since the reporting of the Plant S experience and the observation of the limited lengths associated with these flaws, significant effort has been expended to more accurately estimate the axial ODSCC flaw lengths in the OA prediction. Additionally, it was decided to utilize a more conservative assessment of first initiation which emphasizes the negligible impact that these degradation mechanisms (axial ODSCC at dings and dents) have upon satisfaction of the performance criteria.

At B2R23, the POB is 0.08% and the POL exceeding the AILPC is 0.05% for this sub-population. There are four predicted detections at B2R23. For the inspection at B2R23, the evolution of the assumed number of initiations predicted by the model is shown in Table 6-6. It should be noted that the predicted number of detections at B2R23 (4) is consistent with the Plant S, spring 2020 experience (4 indications) reported on ≤5V dents. This case was not intended to recreate the Plant S, spring 2020 experience for ≤5V dents and can be considered coincidental.

Table 6-6 — Model Results for 100% Bobbin Inspection at B2R20 — <5V Ding and <5V Dents

a,
b
c

As an upper bound sensitivity case, the OA model was configured to provide for a predicted number of detections at B2R23 of approximately 19 indications, which is 1% of the total number of <5V dings and dents in SG 2D. The value of 1% is conservative compared with the limiting A600MA plant experience and bounds the A600TT experience when detection becomes “alerted.” The applied growth rate is the

IAGL typical default, which is conservative given the Plant S growth rate analysis described in Section 4. In order to produce this number of indications at B2R23 with a near uniform Weibull slope of 1.5, the first initiation is during Cycle 13. For a Weibull slope of 1.5 the associated CL is then 135 EFPY in order to produce 19 detections at B2R23.

At B2R23, the POB is 0.8% and the POL exceeding the AILPC is 1.7% for this sub-population. For the inspection at B2R23, the evolution of the number of initiations predicted by the model is shown in Table 6-7. Note that for 19 postulated predicted detections at B2R23, if the model is configured to allow the POD to function at B2R18 the likelihood of detection is judged high and the likelihood of detection at B2R20 is judged very high.

Table 6-7 — Model Results for 100% Bobbin Inspection at B2R20 — <5V Ding and <5V Dents

a,
b
c

6.6.2 Axial ODSCC at >5V Dings

The OA methodology for this sub-population will follow a similar methodology as for the <5V population; based on the inherent issues associated with dings and dents, first initiation is assumed four cycles prior to B2R20. Additionally, the susceptible population was not divided between the B2R18 and B2R20 inspections. This approach is more conservative than the approach applied in previous analyses. The only functional difference between this case and the <5V ding and <5V dent case will be the susceptible population size and the associated Weibull initiation function.

The A600MA plant experience shows no discernable difference in the affected percentage as a function of ding amplitude. SG 2C has the largest >5V ding population of 400 locations. A large portion of these dings, 243, are located in the span between 10H and 11H and 10C and 11C, suggesting tube insertion difficulty as the cause of the dings. As for the <5V ding and dent case, first initiation is assumed at B2R16. The SEL distribution applied is the SEL distribution for the >9V dent assessment described in Section 4 since this population includes all >5V dings (maximum ding voltage in SG 2C is approximately 24 volts). The growth rate applied is the IAGL typical default.

At B2R23, the POB is 0.6% and the POL exceeding the AILPC is 0.3% for this sub-population. For the inspection at B2R23, the evolution of the number of initiations predicted by the model is shown in Table 6-8.

Table 6-8 — Model Results for 50% +Point Inspection at B2R18 and B2R20 — >5V Dings

a,
b
c

This case, and the <5V ding/dent cases, differs in structure from the cases utilized in the Braidwood Unit 2, 1-cycle extension OA. The Braidwood analyses were performed prior to the Plant S, spring 2020 experience. The axial ODSCC SEL distribution applied in the Braidwood analyses utilized the SEL distribution based on the axial ODSCC at dings experience from an A600MA plant; the ding cracks at this plant were primarily located in the U-bend region and resultant from tube bundle repair during manufacture. Since the reporting of the Plant S experience and the observation of the very limited flaw lengths, significant effort has been expended to more accurately estimate the axial ODSCC flaw lengths. It was decided to utilize a more conservative assessment of first initiation to emphasize the negligible impact that these degradation mechanisms (axial ODSCC at dings and dents) could have upon satisfaction of the performance criteria.

a,
b
c

6.6.3 Axial ODSCC at >5V but <9V Dents

The OA methodology for this sub-population will follow a similar methodology as for the <5V ding/dent population; based on the inherent issues associated with dings and dents, first initiation is assumed four cycles prior to B2R20. Additionally, the susceptible population was not divided between the B2R18 and

B2R20 inspections. This approach is more conservative than the approach applied in previous analyses. The only functional difference will be the susceptible population size and the associated Weibull initiation function. The A600MA plant experience shows no discernable difference in the affected percentage as a function of ding amplitude. SG 2D has the largest >5V but <9V dent population of 166 locations. As for the <5V ding and dent case, first initiation is assumed at B2R16. The SEL distribution applied is the SEL distribution for the <9V dent assessment described in Section 4. The growth rate applied is the IAGL typical default.

At B2R23, the POB is 0.08% and the POL exceeding the AILPC is 0.08% for this sub-population. For the inspection at B2R23, the evolution of the number of initiations predicted by the model is shown in Table 6-9.

Table 6-9 — Model Results for 50% +Point Inspection at B2R18 and B2R20 — >5V and <9V Dents

a,
b
c

The total POB for this mechanism (axial ODSCC at <5V dings and dents, >5V dings, and 5 to 9V dents) for comparing with the performance standard of ≤5% is calculated using a Boolean summation of the three probabilities (i.e., <5V dings/dent, >5V dings, and >5V and <9V dents):

$$POB = 1-(1-0.0008)(1-0.0008)(1-0.006) = 0.76\%$$

$$POL = 1-(1-0.0005)(1-0.003)(1-0.0008) = 0.43\%$$

The total POB for this mechanism satisfies the SIPC margin requirement performance standard.

6.6.4 Axial ODSCC at >9V Dents

Section 4 presents an argument related to the performance of this sub-population and identifies a susceptible population for Byron Unit 2 of three tubes. An acute initiation model was developed which uses a conservative susceptible population size of 10 locations. The characteristic life was selected to produce initiation of all 10 indications prior to the B2R20 inspection. The SEL distribution applied is the SEL distribution for the >9V dent assessment described in Section 4. The applied growth rate is the IAGL typical default. Note that growth rate assessment of the Plant S, 2020 indications concludes that the IAGL typical default growth rate bounds the Plant S, 2020 experience.

For this case, the POB at B2R23 is 1.1% and the POL exceeding the AILPC is 0.5%. For the inspection at B2R23, the evolution of the number of initiations predicted by the model is shown on Table 6-10.

Table 6-10 — Model Results for 50% +Point Examination at B2R18 and B2R20 — >9V Dents

a,
b
c

Note that if the growth rate developed in Section 4 for the Plant S 2020 experience is used, the POB is reduced to 0.55% and the POL exceeding the AILPC is reduced to 0.2%.

a,
b
c

6.7 PWSCC at TTS Expansion Transitions

6.7.1 Axial PWSCC at TTS Expansion Transition

It has been shown that PWSCC growth rates are bounded by ODSCC growth rates and that the developed axial ODSCC growth rates are bounded by the EPRI IAGL typical default curve [13]. Axial PWSCC reported lengths are bounded by the Axial SCC length distribution provided by Figure 4-8.

Therefore, as the axial ODSCC at TTS OA shows POB and POL are acceptable, the axial PWSCC OA will also therefore be acceptable. Given the very low POB and POL for axial ODSCC at the TTS, if this mechanism is detected at B2R23, the judgment that the POB and POL for axial PWSCC are zero is not unrealistic.

6.7.2 Circumferential PWSCC at TTS Expansion Transition

It has been shown that PWSCC growth rates are bounded by ODSCC growth rates and that the developed circumferential ODSCC growth rates are bounded by the IAGL typical default growth rates [13]. Circumferential PWSCC reported lengths are bounded by the circumferential ODSCC length distribution. Therefore, as the circumferential ODSCC at TTS OA shows POB and POL are acceptable, the circumferential PWSCC OA will also therefore be acceptable. Given the limited arc length of the circumferential PWSCC indications reported for the fleet and that the growth rates are bounded by ODSCC, if this mechanism is detected at B2R23, the judgment that the POB and POL for circumferential PWSCC are zero is not unrealistic.

6.8 Axial ODSCC at TSP Intersections on Non-High Residual Stress Tubes

The tube population affected by axial ODSCC at TSP intersections includes normal non-residual stress tubes and those tubes that have been identified as having high residual stresses from fabrication [18]. All tubes at TSP intersections have received 100% bobbin coil examination. In addition, the 39, 2-sigma tubes received a 100% sample inspection by X-Probe at all hot leg and cold leg TSP intersections at B2R18 and B2R20. At both B2R18 and B2R20, a supplemental inspection program was applied which proactively addresses high noise conditions on non-high residual stress tubes. Under this program, any TSP mix residual noise component of >0.4 volt is tested with a +Point probe. This methodology was originally developed for enhanced detection of axial ODSCC at eggcrate intersections in original vintage C-E SGs. The 0.4 volt vertical maximum noise value is established using standard tube integrity analysis techniques with application of the IAGL typical default growth rates.

The first A600TT fleet reporting of this mechanism on non-high residual stress tubes was reported during the Fall 2019 inspection at a plant with Model D5 SGs. Section 6.2 provides additional discussion of this experience.

A prior study [19] which investigated the SCC initiation potential in A600TT tubing estimated that 0.1% of the tube bundle would be affected by axial ODSCC at TSP intersections up to the end of the original license. This evaluation was performed prior to the observation of axial ODSCC on high residual stress tubes, thus this estimate can be assumed to apply to the non-high residual stress tube population. For a Model D5 SG, 0.1% of the tube population is five tubes per SG. As the average accumulated operating time for the A600TT fleet is approximately 25 to 30 EFPY, and only three indications on two tubes (one affected tube per SG) has been reported for the A600TT fleet, the prior study has been shown to provide a reasonable estimate. The low Weibull slope model for axial ODSCC at TSP intersections on high residual stress tubes applies a very conservative susceptible population size (100 locations per SG). The model results (Table 6-2) predict a conservative number of initiated indications at B2R23 which when compared with the observed industry inspection results represent a bounding assessment and also are conservative compared to the 0.1% affected value discussed above. Thus, it can be concluded that the axial ODSCC at high residual stress tube low Weibull slope model accounts for any postulated initiates on non-high residual stress tubes. The high residual stress tube model uses the IAGL upper bound default growth which will represent a bounding analysis for non-high residual stress tubes.

6.9 Other Mechanisms

Axial ODSCC in the freespan without the presence of a ding has been reported on one tube during a fall 2019 inspection (two aligned indications, one slightly above the TSP, suspected to have been affected by heavy deposits and one within the TSP) across the entire A600TT tubing fleet. This mechanism has been reported at numerous plants using A600MA tubing. In one instance, pulled tube examination showed the presence of axial scratches or gouges associated with the observed degradation. Such scratches or gouges, believed to be associated with the tube insertion process in SGs using drilled hole TSPs, would not be expected in SGs using quatrefoil design TSP tube holes. Information provided in [21] suggests that significant deposit accumulation may have contributed to this event. The soft chemical cleaning applied at Byron Unit 2 at B2R20 can only positively affect the initiation of this mechanism. Additionally, information presented in [21] can be used to establish that the applied growth rate for this tube is bounded by the IAGL typical default growth function. Thus, in the unlikely event that this mechanism is observed at B2R23, the results of the low Weibull slope model would be considered a very conservative bounding analysis.

Axial PWSCC has been reported on one tube at a Row 1 U-bend at Plant G1. This indication was located slightly above the bend tangent. Bobbin data from the pre-service inspection (PSI) showed the presence of a geometric anomaly at the eventual location of the degradation. It can be hypothesized that this anomaly contributed the development of PWSCC and that the anomaly was associated with manufacture of the SG as the post bend thermal treatment would have reduced any residual stresses associated with the anomaly to a level which would not support SCC development. This indication can also be traced to +Point inspections four cycles prior to its eventual reporting. Thus, it can be concluded growth rates are bounded by the IAGL typical default values. Exelon has performed 50% +Point inspection of Row 1 and Row 2 U-bends each outage. In addition, Exelon has proactively addressed this industry experience by inspecting those tubes with identified anomalies in the U-bend at each inspection. Lessons learned from the inspection history surrounding this indication have been implemented at Byron Unit 2. Therefore, it can be concluded that these mechanisms would not affect the ability of the SGs to maintain their intended safety function after one additional operating cycle.

Circumferential PWSCC at bulges or over-expansions below the TTS are not evaluated. The maximum arc length of these indications from the A600TT fleet is approximately 60 degrees arc. Such indications cannot contribute to burst and will not contribute to leakage.

OD pitting has been reported at one plant with A600TT tubing. The SGs in this plant were replaced in the early 1980's. Secondary side chemistry control has greatly improved compared to the timeframe these SGs were installed. Pitting generally is not considered a mechanism that will challenge structural or leakage integrity. Pitting has also been strongly associated with high copper concentrations in the secondary side deposits. Byron Unit 2 does not contain any copper bearing tube materials in the balance-of-plant system. Additionally, the design of the preheater inherently involves higher secondary side fluid cross-flow velocities than feedring style units thus the likelihood that pitting is present in the Byron Unit 2 SGs is judged extremely low.

7 | Summary and Conclusions

Exelon has submitted a one-time license amendment request (LAR) to allow deferring the Byron Unit 2 B2R22 SG tube examinations to the next scheduled outage, B2R23, in Spring 2022. In support of the LAR, this OA was prepared and provides the technical basis for deferring the B2R22 SG inspections to B2R23. The OA conservatively evaluated the existing degradation mechanisms as well as several potential SCC degradation mechanisms. In addition, recent inspection results from Plant S regarding axial ODSCC at dents at the top TSP have considered.

It should be recognized that the EPRI IAGL due not require potential mechanisms to be evaluated in the OA. It was judged that these additional evaluations were required to support the license amendment request.

The following conclusions were drawn from the revised OA:

1. The results from the revised OA fully support the deferment of SG ECT inspection to B2R23.
2. Structural integrity performance criterion margin requirement of three times normal operating pressure (3xNOPD) on tube burst will be satisfied at EOC 23 for the existing and potential degradation.
3. AILPC for the limiting accident condition will be satisfied for the cumulative leakage requirement for any one SG and for all four SGs for the operating period to EOC 23.

Therefore, given the examination scope implemented at the Byron Unit 2 B2R18 and B2R20 outages, all structural and accident leakage performance criteria in NEI 97-06 are predicted to be met through the EOC 23 for the existing and potential degradation mechanisms.

Table 7-1 presents a summary of the POB and POL exceeding the AILPC limit of 0.5 gpm at B2R23 for the existing and potential degradation mechanisms evaluated in this OA. If the respective probabilities require combinations due to existence of sub-populations, the combined probability values are provided.

Table 7-1 — Summary of OA Results for Potential Mechanisms

Mechanism	Probe Type	B2R20 Exam Scope	Probability of Burst	Margin to SIPC	Probability of Leakage Exceeding Accident-Induced Leak Limit	Margin to AILPC Limit	Calculated 95/50 Leakage (gpm)
Axial ODSCC at TSP Intersections: HRS Tubes – Acute Model	Bobbin and X-Probe	100%	3.74%	1.26%	1.20%	3.8%	0.0100
Axial ODSCC at TSP Intersections: HRS Tubes – Low Weibull Slope Model (Includes Non-HRS Tubes)	Bobbin and X-Probe	100%	3.18%	1.82%	1.87%	3.13%	0.0427
Circ ODSCC at TTS Expansion Transitions(4)	X-Probe	55%	0.34%	4.66%	0.03%	4.97%	0.0146
Axial ODSCC at <5V Dings/Dents(4) Axial ODSCC at >5V Dings(4) Axial ODSCC at >5V but <9V Dents(4)	Bobbin +Point +Point	100% 50% 50%	0.76%	4.24%	0.43%	4.57%	0.0082
Axial ODSCC at >9V Dents	+Point	50%	1.10%	3.90%	0.5%	4.50%	0.0102
Axial ODSCC at TTS Expansion Transitions	X-Probe	50%	0.30%	4.70%	0.18%	4.82%	~0
Circ PWSCC at TTS Exp. Transitions (1)	X-Probe	50%	<0.34%	>4.66%	~0%	~5%	~0
Axial PWSCC at TTS Exp. Transitions (1)	X-Probe	50%	<0.30%	>4.70%	~0%	~5%	~0
PWSCC in Small Radius U-Bends (1)	+Point	50%	<0.30%	>4.70%	~0%	~5%	~0
Total Summed Leak Rate for All Mechanisms: AILPC Limit = 0.5 gpm							0.0757 (2, 3)

Notes:

1. PWSCC at TTS and at U-bends is bounded by ODSCC at TTS cases
2. Leak rate from axial ODSCC at TSP intersections on high residual stress tubes is taken from the maximum of the two cases. These cases are independent and are not combined.
3. No primary-to-secondary leakage was reported during Cycle 21 and is not expected for Cycle 22. Therefore, there is no contribution from indications below H*.
4. Identified probability of burst and leakage and combined by Boolean sum of all contributing sub populations.

8 | References

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[4] B2R20 180 day report, "Byron Station, Unit 2 Steam Generator Tube Inspection Report for Refueling Outage 20," April 6, 2018

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[18] Exelon document EC 617170 DA, "B2R20 Steam Generator Degradation Assessment," transmitted to Intertek (W. Cullen) from Exelon (P. Creegan) dated 5/15/2020," dated 3/27/2020

[19] 35th EPRI NDE Conference; “A600TT Inspection Strategy for an Aging Fleet: ODSCC Growth Rate and POD Update, Bill Cullen, Westinghouse Electric, 2016

[20] Intertek AIM 200310778-2-1, “Braidwood Unit 2 Operating Cycle Extension to A2R22,” April 5, 2020

[21] Duke Power, “Catawba 2R23 September 2019 Operating Experience,” December 2019 SGMP-RIC Meeting

Appendix A | Lead Plant Initiation Analysis

In support of the probabilistic OA, a lead-plant evaluation was performed where the Byron Unit 2 operating history was compared with those plants that have experienced SCC to estimate equivalent initiation times for each of the mechanisms judged most challenging to satisfaction of the performance criteria at B2R23 based on similar analyses performed for Braidwood Unit 2. This information was primarily used to establish when, or if, initiation at Byron Unit 2 would have occurred, or will occur, and to help to define the range of Weibull parameters appropriate used in the OA. An Arrhenius equation with ODSCC activation energy equal to 30 kcal/mole was applied when estimating the equivalent initiation point for Byron Unit 2.

Circumferential Outside Diameter Stress Corrosion Cracking at Hot Leg Top-of-Tubesheet

The lead A600TT plant reported indications at 17.1 effective full power year (EFPY) (1R13); T-hot = 618°F. The prior inspection included only 50% +Point inspection in two of the four steam generators (SG), thus limited history lookback information is available; however, some indications had precursors at 1R12. The initiation point has been estimated to be 11.57 EFPY. The equivalent initiation point for Byron Unit 2 is then 13.65 EFPY.

An "initiation analysis" model was developed which generated the first initiation at 13.6 EFPY, which is the approximate mid-point of Cycle 11. The susceptible population size identified in Section 4 was used with a Weibull slope of 1.5 and characteristic life to produce one initiate at B2R11. At B2R14, detection is plausible, limited only by the scope of the top-of-tubesheet region +Point inspection (40%). Note that 20% of the tubes were inspected from +3 to -3 inches about the TTS and 20% were inspected from +3 inches above TTS down to the H* depth using a +Point probe. Even with the limited +Point inspection scope of 40% at B2R14, detection is likely. If the inspection scope at B2R14 were 100%, detection would essentially be ensured as the model predicts two detected indications. If the model is configured to ignore POD effects for all inspections prior to B2R18, at B2R18 4 to 6 indications are predicted to have been detected. Thus, it can be concluded that initiation did not occur at 13.6 EFPY.

Axial Outside Diameter Stress Corrosion Cracking at Tube Support Plate Intersections on High Residual Stress Tubes

This mechanism is comprised of two sub-populations; Seabrook Signature tubes, or tubes of a row size and below that could fit into the thermal treatment furnace (Row 8 for 0.875-inch outside diameter tubes, Row 9 for 0.75 inch outside diameter tubes, and Row 10 for 0.688 inch outside diameter tubes), and 2-sigma tubes, or high residual stress tubes which could not fit into the thermal treatment furnace.

The first observation was at Plant S (618°F T-hot) involving Seabrook Signature tubes at 9.7 EFPY (OR08 outage) with an estimated initiation point between 4.2 to 5.6 EFPY. About half of the OR08 indications had precursors in OR06 (7.06 EFPY). All indications were reported in SG D. SG D was not inspected at OR07 or OR05. No precursors were observed in the OR04 data (4.2 EFPY). If 4.2 EFPY is used for the first initiation at Plant S, the equivalent initiation at Byron Unit 2 is 5 EFPY, and if 5.6 EFPY is used for the first initiation at Plant S, the equivalent initiation at Byron Unit 2 is 6.61 EFPY. However, Byron Unit 2 does not contain any Seabrook Signature tubes.

The first industry reporting of axial ODSCC on 2-sigma tubes was at Braidwood at A2R10 (12.78 EFPY). Three indications were reported on one tube; all had precursors in A2R09, thus placing the first initiation point at A2R07 or 8.57 EFPY. Byron Unit 2 contains 39 2-sigma tubes. Since both plants operate at the same temperature, if the susceptibility of both plants were equal, then indications would have been reported at an earlier Byron Unit 2 inspection.

Axial Outside Diameter Stress Corrosion Cracking at Dents and Freespan Dings

The lead A600TT plant reported indications at OR15 (18.96 EFPY); with T-hot = 618°F[2]. One tube was reported to contain three indications at three different dings. At the same outage, one tube was reported to contain an axial ODSCC indication at an 11V dent at the top hot leg TSP in the same inspection. Based on the presence of precursor signals, the first initiation point for each was 12.4 EFPY. The equivalent initiation point for Byron Unit 2 is 14.63 EFPY.

Two initiation analysis models were developed which generated the first initiation at 14.63 EFPY, which is during Cycle 12. Both models used the susceptible population size identified in Section 4 with a Weibull slope of 1.5 and characteristic life to produce one initiate at 14.63 EFPY. A similar analysis performed for Braidwood used the >5V ding/dent population. That analysis was performed prior to the 2020 Plant S experience. Since the >9V dent population is small, the initiation analysis for Byron considered all >5V dings and dents in the limiting SG (600 location in SG 2D). The applied growth rate is the IAGL typical default.

Since no indications have been reported the model was configured to ignore potential simulated detections for inspections prior to B2R18. For the >5V dings/dents, the likelihood that an indication would be reported by B2R18 is judged high. The model was then modified to ignore potential simulated detections at B2R18 to assess the likelihood of detection at B2R20. For the >5V dings/dents, the likelihood that an indication would be reported by B2R20 is judged very high (2 simulated detected indications). Thus, if this mechanism initiated at the equivalent EFPY with the lead plant, it is reasonable to assume that indications would have been reported. As a sensitivity the growth rate developed from the Plant S 2020 experience was applied with the model setup to ignore postulated simulated detections prior to B2R20. Even with this reduced growth rate, the likelihood that at least one indication would have been detected is judged high.

For the <5V ding/dent population the likelihood that an indication would be reported by B2R18 is judged modest; even though the susceptible population is larger, the bobbin detection capability is reduced compared to the +Point probe. For the <5V ding/dent population the likelihood that an indication would be reported by B2R20 is judged high (1 to 2 reported indications).

Thus, these analyses support that these mechanisms either have not initiated or that the growth rate is so low that the performance criteria would not be infringed at B2R23. These analyses also support the selection of the first initiation point at least one cycle prior to the most recent inspection.

[2] At the time of reporting of this mechanism, T-hot had been raised from 618°F to 621°F due to implementation of an uprating. The estimated initiation point is prior to the T-hot increase associated with uprating.

ATTACHMENT 9

Byron Station, Units 1 and 2

NRC Docket Nos. STN 50-454 and STN 50-455

Westinghouse Letter LTR-CECO-20-043-NP, Revision 0, "Engineering Re-Evaluation of Byron Unit 2 Steam Generator C Waterbox Cap Plate and Potential Loose Parts in Support of Steam Generator Inspection Deferral for B2R22 (Fall 2020) Outage," June 2020 (NON-PROPRIETARY)

Westinghouse

To: Tracy D. Roots (Exelon)
cc: Timothy J. Heindl (Exelon)
Patrick M. Creegan (Exelon)
Jay R. Smith
Logan T. Clark
Daniel Merkovsky
Gary W. Whiteman

Date: June 22, 2020

From: Joshua R. Phillips
Ext: (724) 722-5302

Your ref:
Our ref: LTR-CECO-20-043-NP, Revision 0

Subject: **Engineering Re-Evaluation of Byron Unit 2 Steam Generator C Waterbox Cap Plate and Potential Loose Parts in Support of Steam Generator Inspection Deferral for B2R22 (Fall 2020) Outage**

References:

1. Westinghouse Transmittal Letter CAE-17-37, Revision 0, “Transmittal of LTR-CECO-17-022, ‘Engineering Assessment of the As-Found Condition of Byron Unit 2 Steam Generator 2C Waterbox Cap Plate during the B2R20 Outage’ and LTR-CECO-17-023, ‘Tube Plugging and Stabilization Recommendations for Byron Unit 2 Steam Generator C Waterbox Potential Loose Parts’,” October 2017. (Westinghouse Proprietary Class 2)
2. Westinghouse Calculation Note CN-CECO-17-004, Revision 1, “Evaluation of Foreign Objects in the Secondary Side of Byron Unit 2 Steam Generator 2C - Fall 2017 Outage B2R20,” June 2020. (Westinghouse Proprietary Class 2)
3. Westinghouse Safety Evaluation EVAL-17-27, Revision 0, “Preventive Tube Plugging and Stabilization for Operation with Potential Loose Parts in Byron Unit 2 Steam Generator C Waterbox (Exelon Screening No. 6E-17-068 Rev. 0),” October 2017. (Westinghouse Proprietary Class 2)
4. Westinghouse Safety Evaluation EVAL-04-33, Revision 1, “Steam Generator Preheater Waterbox Cap Plate Loose Parts Evaluation,” April 2004. (Westinghouse Proprietary Class 2)

EXECUTIVE SUMMARY

During the B2R20 refueling outage at Byron Unit 2, a visual inspection of the preheater region of Steam Generator 2C (SG 2C) found that a cut-out plate backing bar was missing from the steam generator's waterbox cap plate. The backing bar was subsequently located and retrieved from the tube bundle at the '02C' tube support plate.

The purpose of the original evaluation performed in 2017 was to assess the impact of the as-found condition of the SG 2C waterbox cap plate on the steam generator's structural integrity, thermal-hydraulic performance, and tube integrity as well as assess the planned approach for mitigating risks to the steam generator's structural integrity, thermal-hydraulic performance, and tube integrity during future operation of the steam generator. Based on visual inspections of the as-found condition of the cap plate, Westinghouse performed an initial evaluation (contained in Reference 1) and concluded that ninety-one (91) tubes within the steam generator should be plugged and stabilized. Following the plugging and stabilizing of these tubes, Westinghouse concluded that operation of Steam Generator 2C for the next two (2) 18-month fuel cycles was acceptable and that a very low risk existed that any potential degradation of the cap plate during the two operating cycles will have an impact on the steam generator's structural integrity, thermal performance as it relates to the waterbox, or nuclear safety. A 50.59 screening in accordance with 10 CFR 50.59 was performed by Westinghouse and is documented in EVAL-17-27 (Reference 3).

This letter report summarizes the evaluation performed in 2017 and further, contains a re-assessment of the waterbox cut-out plate region for extended operation in order to support a deferral of steam generator inspection activities during the B2R22 outage until B2R23, or an additional 1.5 years of operation. The evaluations in this letter support the conclusion that the waterbox cut-out plate and potential loose parts are acceptable for an additional 1.5 years of operation, and there are no inspection or remedial actions recommended by Westinghouse for the B2R22 outage. Further, wear time calculations show an acceptability for the remaining bars/tabs still attached to the waterbox cut-out plate for at least six (6) years of operation as concluded in Reference 2 (should the backing bars become loose) and summarized in this letter report.

INTRODUCTION

During the B2R20 refueling outage at Byron Unit 2, a visual inspection of the preheater region of SG 2C (a Westinghouse Model D5 steam generator) found a loose part that was subsequently determined to have been generated from the steam generator's waterbox. The loose part, which was located within the tube bundle at the '02C' tube support plate (commonly referred to as the 'B' plate), was subsequently removed from the steam generator.

Based on a visual inspection of SG 2C's waterbox, it was determined that the source of the loose part was one of the two cut-outs made in the central locations of the waterbox's cap plate.[1] These cut-outs were made in the cap plate during manufacturing of the steam generator to generate 'windows' in the cap plate to permit access to the inside of the waterbox. Following the completion of work internal to the waterbox, the

[1] The waterbox of the Model D5 steam generator is located on the cold leg side of the steam generator's tube bundle at the feedwater nozzle.

cut-out plates created from cutting out the two access windows were designed to be reinstalled in the cap plate by full-penetration groove welds on three sides of each cut-out plate. During the reinstallation welding of these cut-out plates, backing bars were used to 'frame' the three sides of the cut-out plates where the full-penetration groove welds would be located in order to provide backing for the root passes of the welds. Each cut-out plate possessed three backing bars, with one backing bar being approximately 10.5 inches long and spanning the length of the cut-out plate and the other two backing bars being approximately 2.5 inches long and approximately 4 inches long and located on the ends of the cut-out plates. Thus, a total of six backing bars were utilized to re-install the two cut-out plates during steam generator manufacture. These backing bars were intended to be fused to the full penetration groove welds and permanently remain in place in the steam generator.

Visual examination during the B2R20 outage determined that all three backing bars were in place on the right cut-out plate while only two backing bars were in place on the left cut-out plate.[2] It was visually confirmed that the loose part removed from the '02C' tube support plate was the third and missing backing bar from the left cut-out plate. Thus, it was determined that the backing bar came loose from the underside of the waterbox's cap plate during plant operation and subsequently exited the waterbox via the waterbox's bottom opening. The backing bar then migrated to an area within the tube bundle on the '02C' tube support plate.

Finally, it is critical to note that backing bars were found to have come loose from a cap plate cut-out plate in SG 2A during the B2R11 outage in Spring 2004. In SG 2A, each cap plate cut-out plate was designed to utilize four backing bars during re-installation of the cut-out plates via full penetration groove welds. For one cut-out plate, it was found during the B2R11 outage that three of the four backing bars had become loose within the steam generator, while all four backing bars were in place on the other cut-out plate. Two of the three loose backing bars were removed from the steam generator while the third backing bar has yet to be removed from the steam generator. Evaluations were performed by Westinghouse at the time of discovery of the loose backing bars. A 50.59 screening in accordance with 10 CFR 50.59 was performed by Westinghouse and is documented in EVAL-04-33 (Reference 4).

EVALUATION OF AS-FOUND CONDITIONS

Based on a review of the as-found conditions of the waterbox cap plate in SG 2C during the B2R20 outage, Westinghouse performed the following evaluations in 2017 (transmitted in Reference 1) to determine the potential impact that the as-found conditions could have on the steam generator's structural integrity, thermal-hydraulic performance, or tube integrity. These evaluations are considered to still be applicable for an additional cycle of operation until the B2R23 outage.

<u>Evaluation of Missing Backing Bar</u>

As stated earlier, the cut-out plates' backing bars were used to 'frame' the three sides of the cut-out plates in order to provide backing for the root passes of the cut-out plates' full penetration groove welds. [

]a,c,e

[2] The left and right orientations are based on a view from outside of the steam generator looking inward through the steam generator's feedwater nozzle.

[

]a,c,e.

Therefore, it can be concluded that the missing backing bar from the cap plate's left cut-out plate in SG 2C has no impact on the steam generator's structural integrity or thermal-hydraulic performance. In addition, since the missing backing bar was removed from the steam generator, the backing bar poses no threat to the steam generator's tube integrity. Thus, continued steam generator operation with the missing backing bar was deemed acceptable.

Evaluation of Cap Plate Cut-out Plate

During the loose cap plate backing bar event in SG 2A during the B2R11 outage, Westinghouse deemed that a risk existed that the cap plate cut-out plate's full penetration groove welds could potentially degrade to the extent that a cap plate cut-out plate could separate from the cap plate and become loose within the steam generator, potentially leading to tube contact/wear. For the missing backing bar event in SG 2C, Westinghouse has determined that the risk of a cut-out plate becoming loose within the steam generator is extremely low during the three operating cycles following the B2R20 outage. This determination is based on the following reasons:

- During the B2R11 outage, visual inspections of the visible portions of one cap plate cut-out plate's full penetration groove weld (i.e., the portions of the groove weld that became visible from the underside of the cap plate due to the three missing backing bars) showed severe degradation to the groove weld. This degradation was observed as loss of weld filler material, with gaps existing in the groove welds where one could see completely through the welds (i.e., no weld material existed in the joint between the cut-out plate and cap plate). During the B2R20 outage, visual inspection of the portions of the full penetration groove weld between the left cut-out plate and the cap plate that were exposed due to the missing backing bar shows a complete groove weld (i.e., no gaps) in the joint between the cut-out plate and the cap plates. While the depth of the groove weld cannot be determined based on the visual inspections performed from the underside of the cap plate, it was concluded that the exposed portion of the groove weld was a continuous weld (i.e., no gaps), unlike the condition of the exposed groove welds in SG 2A during the B2R11 outage. Also, no degradation to the exposed weld joint could be visually observed from the underside of the cap plate.

- For the left cut-out plate during the B2R20 outage, two of the three backing bars are in place and attached to their respective full penetration groove welds from the underside of the cap plate; whereas all three of the backing bars for the right cut-out plate are in place and attached to their respective full penetration groove welds from the underside of the cap plate. Thus, there is no reason to believe that the full penetration groove welds on the backsides of the backing bars (when viewed from the underside of the cap plate) have degraded in any manner as the backing bars are still in place and shielding the weld joint from any flow at the underside of the waterbox's cap plate. Therefore, it is reasonable to conclude that all three full penetration groove welds for the right cut-out plate are not degraded and will fully support the cut-out plate per the original design. Also, it is reasonable to conclude that the two full penetration groove welds with backing bars in place for the left cut-out plate are not degraded and will fully support the cut-out plate per the original design. Based on the visual inspection results, it is also reasonable to conclude that since the area of groove weld for the left cut-out plate that was exposed by the missing backing bar shows no visible signs of degradation, it too will also provide support to the cut-out plate per the original design. Thus, the designed structural integrity of the cut-out plates, cap plate, and waterbox is satisfied.

- Upon discovery of the degraded cut-out plate full penetration groove welds in SG 2A during the B2R11 outage, no actions were taken in the steam generator to secure the cut-out plate. Rather, the cut-out plate was left in its as-found condition and the plant was operated for one operating cycle. During the subsequent B2R12 outage, a visual inspection of the waterbox revealed that the cut-out plate was still intact and had not become loose within the steam generator. In addition, the visual inspection showed that while additional degradation to the cut-out plate welds may have occurred during the operating cycle between the B2R11 outage and the B2R12 outage, this degradation was not considered to be significant. Thus, the as-found conditions of the cut-out plate welds during the B2R12 outage were not significantly different than the as-found conditions of the cut-out plate welds during the B2R11 outage. [

  ][a,c,e]. It should be noted that a repair was performed on the SG 2A waterbox cap plate during the B2R12 outage to permanently secure both cut-out plates as well as their respective backing bars.

Given the fact that the exposed portion of the left cut-out plate's full penetration welds in SG 2C visually showed no signs of degradation during the B2R20 outage and all other portions of the full penetration welds can be assumed to not be degraded based on the fact that their respective backing bars are still in place, there is no evidence to suggest that the full penetration groove welds of either cut-out plate in SG 2C possess any degradation. [

][a,c,e]. Thus, Westinghouse concludes that there is no evidence to suggest that either cut-out plate could become loose after an additional operating cycle until B2R23.

Finally, it should be noted that due to the severely degraded as-found conditions of the cut-out plate welds in SG 2A, evaluations were performed by Westinghouse during the B2R11 outage to assess the potential impact of a cap plate cut-out plate becoming loose within the steam generator. The results of these evaluations, which are provided in Reference 3, were used to support start-up and subsequent operation of the plant with the as-found, degraded conditions.

Evaluation of Potential for Additional Loose Backing Bars

Due to the geometry of the cut-out plate's full penetration groove weld joint, visual inspection of the weld joint could not provide evidence of the state of fusion between the groove welds' filler material and the backing bars (i.e., the point of fusion is located on the sides of the backing bars that are interfacing with the underside of the cap plate and cut-out plates). While other nondestructive examination (NDE) techniques (e.g., ultrasonic examination, radiographic examination) may be utilized to determine the state of fusion between the groove welds' filler material and the backing bars, it was concluded that these NDE techniques were not feasible options during the B2R20 outage due to the location of the cut-out plate within the steam generator, the geometry of the waterbox, and the available access openings in the steam generator's shell. Based on these limitations, Westinghouse could not conclusively determine that the full penetration welds attaching the cut-out plates properly fused with the five remaining backing bars in SG 2C. Thus, Westinghouse cannot conclusively determine that the five remaining backing bars in SG 2C will not become loose during future plant operation. Note that this same conclusion was drawn by Westinghouse with regard to the backing bars in SG 2A during the B2R11 outage.

Since the potential for backing bars to become loose within the steam generator during subsequent operating cycles could not be excluded, Westinghouse determined that actions were required during the B2R20 outage to mitigate the risk of potential tube contact (and subsequent wear) by a loose backing bar following plant startup. Thus, per Westinghouse Letter LTR-CECO-17-023 (transmitted in Reference 1), Westinghouse developed a strategy for the plugging of ninety-one (91) tubes within the steam generator. This plugging strategy addressed the possibility of any of the five remaining backing bars becoming loose within the steam generator. Note that Westinghouse advised that all ninety-one (91) tubes recommended for plugging be stabilized as well.

TUBE PLUGGING AND STABILIZATION

Consideration of potential migration locations for the backing bars led to the identification of ninety-one (91) tube locations that were to be preventively plugged and stabilized in SG 2C at Byron Unit 2. The following factors were considered in the development of the plugging and stabilization list.

Original Wear Evaluation

The original wear calculations from Reference 2 showed that the presence of the potential backing bars or backing end tabs as loose parts resulted in wear times greater than two full cycles of operation during potential contact with non-peripheral tubes. [

]^{a,c,e}. Wear calculations showed that the presence of the cutout tabs supported two full cycles of operation at any potential wear site in SG 2C, excepting the list of plugging and stabilizer locations in Reference 1.
[

]^{a,c,e}.

[

]^{a,c,e}.

The backing end tab loose part that was retrieved from the baffle plate during B2R20 contained a small raised tack weld remnant [ ]^{a,c,e}. If the tack weld remnant were to be positioned in a configuration where it was contacting a tube within the tube bundle, it may cause unacceptable wear exceeding the tube structural limit within one operating cycle. Westinghouse judges that in order for a raised tack weld remnant of a loose backing bar to cause significant tube degradation, a series of events would have to occur concurrently, these being:

1. A backing bar has to separate from the waterbox cutout plate.
2. A remnant of the tack weld attaching the backing bar to the cutout plate must be present on the bar.
3. The tack weld remnant has to be a small enough size to allow the bar to enter the tube bundle. If the tack weld remnant size is too large, it would remain in contact with a peripheral tube that is plugged and stabilized and prevent the bar from completely entering the tube bundle.
4. The backing bar with the tack weld remnant must come to rest with the tack weld against the tube, as opposed to the opposite flat face of the backing bar which would not have a tack weld remnant.

Westinghouse judges that this sequence of events is unlikely and has a remote possibility of occurring. Additionally, Exelon has a robust Primary to Secondary Leakage Monitoring Program which would detect any occurrence of leakage should a through-wall penetration of an in-service tube be caused by a tack weld remnant. [ ]^{a,c,e}.

Therefore, the possibility of tube rupture is remote and [ ]^{a,c,e} will only result in a leakage wear that would be identified by Exelon's Primary to Secondary Leakage Monitoring Program, which requires progressive monitoring and actions up to and including plant shutdown before plant operational leakage limits are exceeded. This is a standard treatment of hypothetical loose parts in steam generators, i.e., the speculative risk of a leakage event due to a large, severe foreign object is mitigated by a Leakage Monitoring Program such as the one in place at Byron Unit 2.

It was therefore recommended that the tubes identified in Reference 1 be plugged and stabilized in SG 2C at Byron Unit 2. Row and column locations in Reference 1 were plugged with a Westinghouse ribbed mechanical plug on both the hot and cold leg sides and stabilized with a Westinghouse 86-inch bare cable stabilizer in the cold leg. Both the Westinghouse ribbed mechanical plug and 86-inch bare cable stabilizer are qualified for use in the Model D5 steam generators at Byron Unit 2.

Revised Wear Evaluation

As part of the re-analysis effort performed in the current revision of Reference 2, credit was taken for the tubes already plugged and stabilized. Tubes that had wear times less than two operating cycles were preventatively plugged and stabilized, therefore, are acceptable for the life of the steam generator. The remainder of the tubes were re-evaluated for a longer operating period to determine acceptability for a one-cycle deferral of steam generator inspection activities during B2R22.

There were two main configurations evaluated for wear [

]a,c,e.

When considering this realistic wear configuration of the bars, wear times were calculated as greater than 6 effective full power years or 4 full cycles of operation with condition monitoring being met.

[

]a,c,e. Therefore, all calculated wear times for tubes remaining in-service were shown to be in excess of four full operational cycles and these results support the conclusion that an additional cycle of operation after B2R22 and a deferral of steam generator inspections until B2R23 is acceptable.

RECOMMENDED ACTIONS DURING B2R20 OUTAGE

Based on the evaluations performed in 2017 (Reference 1) and summarized in the previous sections, Westinghouse determined that there was no need to perform any actions on the SG 2C waterbox cap plate to re-install the missing backing bar or install a new (i.e., replacement) backing bar. In addition, Westinghouse determined that there was no need to perform any actions to permanently secure either of the cap plate cut-out plates (similar to what was done in SG 2A during the B2R12 outage) during the B2R20 outage. The only action that Westinghouse recommended was the plugging/stabilizing of the ninety-one (91) tubes per LTR-CECO-17-023 (Reference 1) in order to create a defense against the possibility of another backing bar becoming loose within the steam generator. This was subsequently completed during the B2R20 outage in accordance with Westinghouse recommendations.

RECOMMENDED ACTIONS DURING B2R23 OUTAGE

During the next scheduled inspection outage in B2R23, Westinghouse recommends that the following actions be performed in SG 2C:

- A visual inspection of the SG 2C waterbox cap plate should be performed. This visual inspection should be performed to determine if the five remaining cut-out plate backing bars have remained in place during the subsequent operating cycles following the B2R20 outage. This visual inspection should also be performed to determine if any degradation has occurred to the visible portions of the cut-out plates' full penetration groove welds.

- If any backing bars are found to be loose within the steam generator, the backing bars should be removed from the steam generator.

- In order to support operation of the plant following the B2R23 outage, one of the two following actions should be performed:

  - Perform repairs on the cap plate to remove all remaining backing bars from the steam generator or permanently secure all remaining backing bars to the cut-out plates, thus eliminating the possibility of future loose backing bars. These repairs should also permanently secure the cut-out plates to the cap plate if visual inspections performed during the B2R23 outage determine that there is a threat that a cut-out plate could become loose within the steam generator during subsequent plant operating cycles. Note that successful completion of repairs to eliminate the possibility of future loose backing bars would permit the de-plugging of the ninety-one (91) tubes recommended for plugging in Reference 1, thus allowing the tubes to be returned to service if desired.

  - Perform an evaluation of the as-found conditions of the B2R23 outage's visual inspection to support plant start-up following the B2R23 outage and subsequent operation of the plant.

EXTENT OF CONDITION AT BYRON UNIT 2

The following provides the extent of condition for the cut-out plate backing bars in the other three steam generators at Byron Unit 2:

- As stated earlier, loose cut-out plate backing bars were discovered in SG 2A during the B2R11 outage. During the B2R12 outage, repairs were performed on the SG 2A waterbox cap plate to permanently secure all cut-out plate backing bars remaining in the waterbox. Thus, the risk of loose cut-out plate backing bars does not exist in SG 2A.

- During the B2R11 and B2R20 outages, visual inspections of the waterbox cap plate in SG 2B were performed. Based on a review of the digital images taken during these inspections, it has been concluded that no backing bars are present on the SG 2B waterbox cap plate. Thus, the risk of loose cut-out plate backing bars does not exist in SG 2B.

- Based on a review of the manufacturing records for SG 2D in 2004, Westinghouse determined that while cut-outs had been made in the waterbox's cap plate, the cut-outs in SG 2D were markedly different from those performed in SG 2A and that the welding of the cutout plates during re-installation did not involve the use of permanent backing bars. Thus, the risk of loose cut-out plate backing bars does not exist in SG 2D.

SUMMARY

Westinghouse originally performed an evaluation of the as-found conditions of the waterbox cap plate in SG 2C at Byron Unit 2 during the B2R20 outage as contained in Reference 1. Based on that evaluation, Westinghouse concluded that ninety-one (91) tubes within the steam generator should be plugged and stabilized. Following the plugging and stabilizing of these tubes, Westinghouse concluded that operation of SG 2C for the following two (2) 18-month fuel cycles was acceptable and that a very low risk existed that any potential degradation of the cap plate during the two operating cycles would have an impact on the steam generator's structural integrity, thermal performance as it relates to the waterbox, or nuclear safety.

According to this letter report, the conclusions of Reference 1 are updated after a re-evaluation of the waterbox cut-out plate region. Wear time results from Reference 2 conclude that if any of the backing bars or backing end tabs were to become loose, the postulated wear configurations for each of the backing bars or backing end tabs lead to acceptable wear times in excess of six effective full power years or four full operational cycles. Further, a review of the as-found conditions affirmed that the original conclusions are still applicable for an additional cycle of operation and there is no additional risk that the as-found conditions could have an impact on the steam generator's structural integrity, thermal-hydraulic performance, or tube integrity. Therefore, this re-evaluation supports deferral of steam generator inspection activities during the B2R22 outage until B2R23, or an additional 1.5 years of operation.

If any additional information is needed or requested on this issue, please contact the undersigned.

Author: *__Electronically Approved__
Joshua R. Phillips
Component Engineering & Chemistry Operations

Verifier: *__Electronically Approved__
John S. Rees
Component Engineering & Chemistry Operations

Approved: *__Electronically Approved__
Nicole D. Vitale, Manager
Component Engineering & Chemistry Operations

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