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RS-20-058 | 10 CFR 50.90
April 16, 2020

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555-0001

Braidwood Station, Units 1 and 2
Renewed Facility Operating License No. NPF-77
NRC Docket No. STN 50-457

Subject: Supplement to License Amendment Request for a One-Time Extension of the Steam Generator Tube Inspections

References:

1) Letter from D. Murray (Exelon Generation Company, LLC) to U.S. Nuclear Regulatory Commission, "Emergency License Amendment for a One-Time extension of the Steam Generator Tube Inspections," dated April 6, 2020 (ADAMS Accession No. ML20097J188)

2) Email from J. Wiebe (U.S. Nuclear Regulatory Commission) to L. Zurawski (Exelon Generation Company, LLC), "Preliminary RAIs for Exelon's April 6, 2020, Application to Defer Braidwood, Unit 2, Steam Generator Inspections," dated April 10, 2020

In Exelon Generation Company, LLC (EGC) letter dated April 6, 2020 (Reference 1), EGC requested an amendment to the Technical Specifications (TS) for Renewed Facility Operating License No. NPF-77 for Braidwood Station, Unit 2 (Braidwood). The proposed amendment request revises TS 5.5.9, "Steam Generator (SG) Program," for a one-time revision to the frequency for Steam Generator Tube Inspections.

In Reference 1, EGC stated that the final Operational Assessment (OA) would be submitted to the NRC by April 17, 2020. Attachments 2 and 3 to this letter provide the final OA which addresses all degradation mechanisms. The final OA does not invalidate the conclusions made in Reference 1 to justify the deferral of the Steam Generator inspections until the next Unit 2 refueling outage.

In NRC email dated April 10, 2020 (Reference 2), the NRC determined that additional information is needed to complete its review. During the clarification call held with the NRC on April 10, 2020, the NRC requested for the Foreign Object analysis to be submitted to the NRC. Attachments 5 and 6 to this letter provide the Foreign Object analysis.

EGC has reviewed the information supporting the no significant hazards consideration and the environmental consideration that was previously provided to the NRC in Attachment 1 of the Reference 1 letter. The additional information provided in this submittal does not affect the

conclusion that the proposed license amendment does not involve a significant hazards consideration. This additional information also does not affect the conclusion that there is no need for an environmental assessment to be prepared in support of the proposed amendment.

Attachment 2 is the proprietary version of Braidwood Unit 2 Operational Assessment Addressing Deferment of A2R21 Steam Generator Tube Examinations to A2R22, October 2021, Report Number AIM 200310778-2-2. Attachment 5 is the proprietary version of the Evaluation of Braidwood Unit 2 Steam Generators for Deferral of Secondary Side Foreign Object Inspection in the Spring 2020 Outage (A2R21), LTR-CECO-20-027, Rev. 1. Attachments 2 and 5 contain information proprietary to Intertek USA, Inc. and Westinghouse Electric Company, LLC respectively. Intertek USA, Inc., Westinghouse Electric Company, LLC and EGC request that the contents of Attachments 2 and 5 be withheld from public disclosure in accordance with 10 CFR 2.390(a)(4). Attachments 3 and 6 provide the non-proprietary versions of Braidwood Unit 2 Operational Assessment Addressing Deferment of A2R21 Steam Generator Tube Examinations to A2R22, October 2021, Report Number AIM 200310778-2-2 and Evaluation of Braidwood Unit 2 Steam Generators for Deferral of Secondary Side Foreign Object Inspection in the Spring 2020 Outage (A2R21), LTR-CECO-20-027, Rev. 1, respectively.

There are no regulatory commitments contained within this submittal. Should you have any questions concerning this submittal, please contact Ms. Lisa Zurawski at (630) 657-2816.

I declare under penalty of perjury that the foregoing is true and correct. Executed on the 16th day of April 2020.

Respectfully,

Dwi Murray
Sr. Manager – Licensing
Exelon Generation Company, LLC

Attachments:
1) Affidavit of Withholding – Intertek USA, Inc.
2) Proprietary Braidwood Unit 2 Operational Assessment Addressing Deferment of A2R21 Steam Generator Tube Examinations to A2R22, October 2021, Report Number AIM 200310778-2-2
3) Non-Proprietary Braidwood Unit 2 Operational Assessment Addressing Deferment of A2R21 Steam Generator Tube Examinations to A2R22, October 2021, Report Number AIM 200310778-2-2
4) Affidavit of Withholding – Westinghouse Electric Company, LLC
5) Proprietary Evaluation of Braidwood Unit 2 Steam Generators for Deferral of Secondary Side Foreign Object Inspection in the Spring 2020 Outage (A2R21), LTR-CECO-20-027, Rev. 1
6) Non-Proprietary Evaluation of Braidwood Unit 2 Steam Generators for Deferral of Secondary Side Foreign Object Inspection in the Spring 2020 Outage (A2R21), LTR-CECO-20-027, Rev. 1

cc: NRC Regional Administrator – Region III
NRC Senior Resident Inspector – Braidwood Station
NRC Project Manager, NRR – Braidwood Station

ATTACHMENT 1

Affidavit of Withholding – Intertek USA, Inc.

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AFFIDAVIT for AIM 200310778-2-2

State of California, County of Santa Clara:

(1) I, Michael T. Cronin, have been specifically delegated and authorized to apply for withholding and execute this Affidavit on behalf of Intertek USA, Inc. dba Intertek AIM (Intertek).

(2) I am requesting the proprietary portions of Intertek report AIM 200310778-2-2 be withheld from public disclosure under 10 CFR 2.390(a)(4), and for the following reasons to be considered pursuant to 10 CFR 2.390(b)(4).

(3) In making this application for withholding of proprietary and confidential information, I have personal knowledge of the engineering practices and procedures utilized by Intertek, and the ability in designating specific information and data that are considered trade secrets, privileged, confidential, commercial, or financial information.

(4) Pursuant to 10 CFR 2.390, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld.

a. The information sought to be withheld from public disclosure is owned and has been held in confidence by Intertek and is not customarily disclosed to the public.

b. Public disclosure of this proprietary information is likely to cause substantial harm to the competitive position of Intertek because it would enhance the ability of competitors to provide similar technical evaluation justifications and licensing defense services for commercial power reactors without commensurate expenses. Also, public disclosure of the information would enable others to use the information to meet NRC requirements for licensing documentation without purchasing the right to use the information.

c. The information sought to be withheld from public disclosure has been provided to Intertek under a license and/or non-disclosure agreement by a third party and may not be customarily disclosed unless the third party waives its rights to the information.

(5) Intertek does not publicly release or disclose proprietary or confidential information in the course of business. Information is held in confidence if its release might result in the loss of an existing or potential competitive advantage, or discloses client proprietary information, as listed below:

a. The information reveals details of proprietary practices or procedures used by Intertek to include analytical methods or processes, where its disclosure to any of Intertek's competitors without license from Intertek will be harmful to Intertek's business.

b. It consists of supporting data, including test data, relative to an analytical procedure or process, the use of such would give Intertek's competitors an economic advantage.

c. It reveals procedures, methods, or data which are proprietary to a third party, for which Intertek is obligated to protect.

d. Its use by a competitor would reduce that competitor's expenditure of resources or improve that competitor's competitive position.

e. It contains patentable methods for which patent protection may be desirable.

f. It reveals cost or price information, production capacities, budget levels, or commercial strategies of Intertek, its customers, or its suppliers.

g. It reveals aspects of past, present, or future Intertek or customer funded development plans and programs of potential commercial value to Intertek.

(6) The attached documents are bracketed and marked to indicate the bases for withholding. The justification for withholding is indicated by means of lower case letters (a) through (g) located in the upper left corner within the bracketed area enclosing each item of information being identified as proprietary. These lower-case letters refer to the types of information Intertek customarily holds in confidence identified in Sections (5)(a) through (g) of this Affidavit.

I declare that the averments of fact set forth in this Affidavit are true and correct to the best of my knowledge, information, and belief.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on: 15 APR 2020

Michael T. Cronin
Director of Engineering

JURAT

A notary public or other officer completing this certificate verifies only the identity of the individual who signed the document to which this certificate is attached, and not the truthfulness, accuracy, or validity of that document.

State of California

County of Santa Clara

Subscribed and sworn to (or affirmed) before me on this 15 day of April, 2020 by Michael Thomas Cronin,

proved to me on the basis of satisfactory evidence to be the person(~~s~~) who appeared before me.

[signature]

Signature (Seal)

MICHELLE RING
COMM. # 2259218
NOTARY PUBLIC - CALIFORNIA
SANTA CLARA COUNTY
COMM. EXPIRES OCT. 17, 2022

OPTIONAL INFORMATION

DESCRIPTION OF THE ATTACHED DOCUMENT

(Title or description of attached document)

(Title or description of attached document continued)

Number of Pages ____ Document Date________

Additional information

INSTRUCTIONS

The wording of all Jurats completed in California after January 1, 2015 must be in the form as set forth within this Jurat. There are no exceptions. If a Jurat to be completed does not follow this form, the notary must correct the verbiage by using a jurat stamp containing the correct wording or attaching a separate jurat form such as this one with does contain the proper wording. In addition, the notary must require an oath or affirmation from the document signer regarding the truthfulness of the contents of the document. The document must be signed AFTER the oath or affirmation. If the document was previously signed, it must be re-signed in front of the notary public during the jurat process.

- State and county information must be the state and county where the document signer(s) personally appeared before the notary public.
- Date of notarization must be the date the signer(s) personally appeared which must also be the same date the jurat process is completed.
- Print the name(s) of the document signer(s) who personally appear at the time of notarization.
- Signature of the notary public must match the signature on file with the office of the county clerk.
- The notary seal impression must be clear and photographically reproducible. Impression must not cover text or lines. If seal impression smudges, re-seal if a sufficient area permits, otherwise complete a different jurat form.
  - ❖ Additional information Is not required but could help to ensure this jurat is not misused or attached to a different document.
  - ❖ Indicate title or type of attached document, number of pages and date.
- Securely attach this document to the signed document with a staple.

ATTACHMENT 3

Non-Proprietary Braidwood Unit 2 Operational Assessment Addressing Deferment of A2R21 Steam Generator Tube Examinations to A2R22, October 2021, Report Number AIM 200310778-2-2

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NON-PROPRIETARY

Braidwood Unit 2 Operational Assessment Addressing Deferment of A2R21 Steam Generator Tube Examinations to A2R22, October 2021

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REPORT NO
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15 April 2020

List of Revisions

Rev.	Date	Revision Details	Authors
0	15 April 2020	Initial Issue	W. K. Cullen R. C. Cipolla M.C. Liu

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Executive Summary

Exelon Generation Company has submitted a one-time Technical Specification change to defer the Braidwood Unit 2 A2R21, April 2020 steam generator (SG) tube eddy current inspection to the A2R22 outage, October 2021. The objective of this Operational Assessment (OA) is to provide the technical justification for deferring the A2R21 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 20, 21, and 22).

The immediately prior examination at the A2R19 outage (spring 2017) identified SG tube fretting wear at anti-vibration bar intersections, at tube support plate (TSP) intersections, and at preheater baffle plates. Stress corrosion cracking was not reported at the A2R19 inspection or at the A2R17 inspection. The only stress corrosion cracking mechanisms reported at Braidwood Unit 2 in prior outages was axial outside diameter stress corrosion cracking (ODSCC) at TSP intersections on known high residual stress tubes and axial ODSCC at a freespan ding on a known high residual stress tube. The axial ODSCC at a freespan ding was reported on a tube which also had axial ODSCC indications at TSP intersections. Axial ODSCC was reported at the A2R10, A2R15, and A2R16 inspections. This OA evaluates these previously observed degradation mechanisms. Additionally, as a Technical Specification change is required to implement the deferment, potential degradation mechanisms, mechanisms which have not been reported at Braidwood 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 A2R22 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 A2R22 (end-of-cycle (EOC) 22).

It has been concluded that given the examination scope implemented at A2R19 (EOC 19), all structural and accident leakage performance criteria in NEI 97-06 are predicted to be met through the EOC 22 for the existing and potential degradation mechanisms.

Contents

List of Tables and Figures

1 | Introduction

Exelon Generating Company has submitted a license amendment request for a one-cycle extension to the current inspection interval for the Braidwood Unit 2 steam generators (SGs). This request will defer the Braidwood Unit 2 SG tube examinations from end-of-cycle (EOC) 21 (A2R21 outage) to EOC 22 (A2R22 outage) in October 2021. 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 20, 21, and 22).

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. All existing SCC mechanisms (previously observed in the Braidwood Unit 2 SGs) have conservatively been modeled. Additionally, this OA evaluates potential SCC degradation mechanisms (mechanisms not observed at Braidwood 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 A2R17 (EOC 17) and A2R19 (EOC 19) identified wear at anti-vibration bar (AVB) locations, wear at tube support plate (TSP) tube intersections, and wear at drilled tube hole style support plates as the only existing degradation modes directly related to SG design. Tube wear due to foreign object interaction was also reported at A2R19 as well as several prior inspections. Evaluation of foreign object wear is being evaluated by another vendor in a separate document. There was no corrosion degradation observed at A2R17 or at A2R19.

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 Braidwood Unit 2 Tube Bundles

2.1 Background

The Braidwood 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 Braidwood 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 hole style is a simple drilled hole.

To date, Braidwood Unit 2 has experienced fretting wear at tube supports (AVBs, TSPs, and preheater baffles), axial outside diameter stress corrosion cracking (ODSCC) at TSP intersections on high residual stress tubes (five affected tubes to date), axial ODSCC at a freespan ding on one high residual stress tube (this tube also contained ODSCC at a TSP intersection), 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 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 for the extended operating period was performed by another vendor.

Generally speaking, there are several corrosion-related degradation mechanisms that are classified as potential for the A600TT tube material utilized in the Braidwood 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 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
- 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)
- Tube wear mechanisms

Of this list of SCC degradation mechanisms, only axial ODSCC at TSP intersections and at a freespan ding on high residual stress tubes has been reported at Braidwood Unit 2.

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 A2R17 [3] and A2R19 [4] inspections are summarized below. Visual inspections of the channelhead and secondary side are not included.

2.2.1 A2R17

Bobbin Probe Inspections

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

+Point^{TM} Probe Inspections

- 50% inspection of Row 1 and Row 2 U-bends including all 39 tubes with identified manufacturing anomalies ("Blairsville Bump")
- 50% inspection of hot leg bulges and over-expansion with the H* distance
- SGs 2A, 2B, and 2D — 50% inspection at >2V hot leg dents, 100% >5V dings (hot leg, cold leg, and U-bend), 100% >5V cold leg dents, 100% >2V dents at AV1 and AV2, 50% >2V dents at AV3, AV4, and 11C
- SG 2C — 100% inspection at >2V hot leg dents, 100% >5V dings (hot leg, cold leg, and U-bend), 100% >5V cold leg dents, 100% >2V dents at AV1, AV2, AV3, AV4, and 11C
- All tubes with historical foreign object wear
- +Point special interest testing of bobbin 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 4 inches above TTS to the H* distance*
- Inspection of three-tube deep pattern around the periphery, no tube lane, and T-slot from 3 inches above TTS to the H* distance*
- Inspection of high residual stress tubes from 4 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 tubes inspected from 3 to 4 inches above the hot leg TTS to the H distance is 63% when the peripheral, tube lance, and T-slot program is combined with the 50% inspection of the remainder of the hot leg tubesheet region.

2.2.2 A2R19

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 including all tubes with identified manufacturing anomalies ("Blairsville Bump")
- 50% >5V dings and dents in the hot leg, cold leg, and U-bend
- 50% >2V and >5V dents at 01H, 02C, 03C, 04C, 05C, and 06C
- 50% >2V and >5V dings below 01H and 06C
- 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 with the H* distance
- 50% inspection of expanded preheater baffles at 02C and 03C plus expanded preheater baffles at 02C near the flow blocking region
- Inspection of three-tube deep pattern around the hot leg periphery, no tube lane, and T-slot from 4 inches above TTS to the H* distance*
- Inspection of three-tube deep pattern around the cold leg periphery and T-slot from 01C to 3 inches below the TTS
- 100% inspection of high residual stress tubes from 3 inches above to 3 inches below TTS plus 100% of high residual stress tubes at hot and cold leg TSP intersections and preheater baffle intersections

The total percentage of tubes inspected from 3 inches above the hot leg TTS to the H distance is 63% when the peripheral, tube lance, and T-slot program is combined with the 50% inspection of the remainder of the hot leg tubesheet region.

The applied inspection programs at A2R17 and A2R19 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 A2R17 inspections, the A2R19 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 (DSP) tube contacts
- Wear due to foreign objects

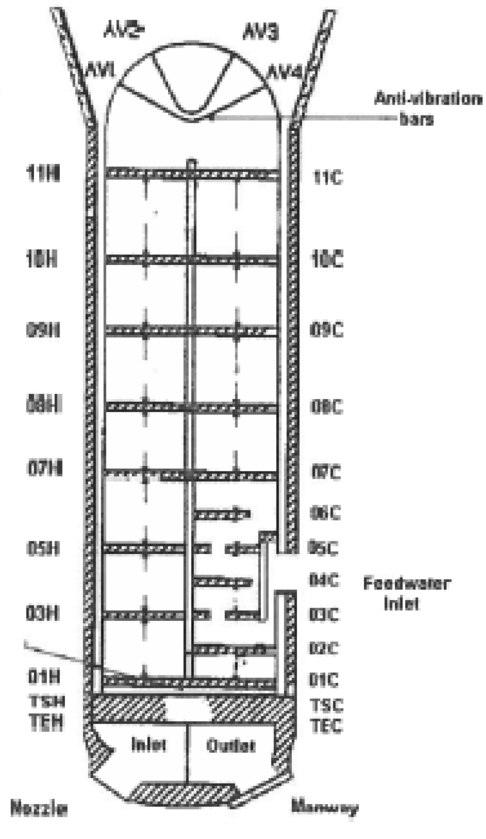
There was no corrosion-related degradation detected within the defined tubing pressure boundary.

2.4 Tube Plugging

At A2R19, 11 tubes were removed from service by plugging: 7 in SG 2A and 4 in SG 2D [4].

Seven tubes were plugged due to AVB wear with depth greater than or equal to the Technical Specification repair limit of 40%TW. One tube was conservatively plugged due to foreign object wear without the presence of a possible loose part (PLP). Three tubes with PLP signals were plugged due to their proximity to foreign object wear locations reported in A2R17.

Westinghouse Model D-5 TSP and AVB Configuration



Note: AVB bars are denoted as AV in the figure

Figure 2-1 — Schematic Illustration of Braidwood Unit 2 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 Braidwood Unit 2 and evaluated in this OA are:

- Axial ODSCC at TSP intersections on high residual stress tubes
- Axial ODSCC at freespan dings on high residual stress tubes
- 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 A2R21 scheduled SG eddy current inspections to A2R22. 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 and circumferential ODSCC at the hot leg TTS expansion transition
- Axial ODSCC at dents and at freespan dings on non-high residual stress tubes (includes axial ODSCC at freespan dings on 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

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 Braidwood 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 existing SCC and potential SCC mechanisms for the Braidwood 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 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 of the flaw population. From these estimates, population attributes, such 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 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 Braidwood Unit 2, it is conservative to assume for the BOC distribution of flaws following the last inspection that at least one SCC indication had initiation sometime in the prior operating period (N-1), with 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 A2R22. The POD only has the impact of estimating the number of detected indications at A2R22. 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 nondestructive examination (NDE) results based on the mechanism and ECT probe. The source of these 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 Braidwood 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 Braidwood Unit 2 – April 2020

Mechanism/ Location	Eddy Current Probe	Sizing	ETSS Reference
Wear at AVB Supports	Bobbin	Depth (%TW)	96004.3 Rev 13
Wear at Broached Tube Support Plates[(2)]	+Point	Depth (%TW)	21998.1 Rev 4
	+Point	Depth (%TW)	96910.1 Rev 10
Wear at Drilled Support Plates	Bobbin	Depth (%TW)	96004.3 Rev 13
	+Point	Depth (%TW)	96910.1 Rev 10
Wear in Freespan (volumetric)[(3)]	+Point	Depth (%TW)	21998.1 Rev 4
	+Point	Depth (%TW)	96910.1 Rev 10
Foreign Object Wear[(3)]	+Point	Depth (%TW)	21998.1 Rev 4
	+Point	Depth (%TW)	96910.1 Rev 10

a, c

NOTES:

1. Condition monitoring sizing is Actual versus ECT. 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. 10 was used to size volumetric wear indications (tapered) at broached TSP lands. ETSS 21998.1 Rev. 4 was used for sizing indications at point wear within 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. 10 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 Braidwood 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 — 1370 psi [11]*
- Performance criteria — 4110 psi
- Number of original tubes per SG — 4570

*Current average steam pressure for Cycle 21 results in a normal operating pressure differential of 1360 psi. A conservative value of 1370 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 A2R10, which was the first outage that SCC degradation outside of the tube ends was reported.

EOC	Outage	Outage Date	Inspection	SCC Detected?	Cycle Length (EFPY)	Cumulative EFPY
10	A2R10	Fall 2003	Yes	Yes	1.448	12.781
11	A2R11	Spring 2005	Yes	No	1.379	14.160
12	A2R12	Fall 2006	Yes	No	1.441	15.601
13	A2R13	Spring 2008	Yes	No	1.446	17.047
14	A2R14	Fall 2009	Yes	No	1.370	18.417
15	A2R15	Spring 2011	Yes	Yes	1.434	19.851
16	A2R16	Fall 2012	Yes	Yes	1.412	21.263
17	A2R17	Spring 2014	Yes	No	1.451	22.714
18	A2R18	Fall 2015	Skip	N/A	1.361	24.075
19	A2R19	Spring 2017	Yes	No	1.485	25.560
20	A2R20	Fall 2018	Skip	N/A	1.438	26.998
21	A2R21	Spring 2020	Skip*		1.40 (est.)	28.398 (est.)
22	A2R22	Fall 2021	Yes		1.45 (est.)	29.848 (est.)

*Note: Proposed to defer A2R21 inspection to A2R22.

4.3 Probability of Detection

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:

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

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

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 Braidwood 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.

For each of the mechanisms judged most challenging to the completion of an OA which supports deferment of the A2R21 to A2R22, 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 A2R16 and A2R17 and A2R17 and A2R19 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].

The DSP wear rate listed below is correct; there was no growth of the DSP wear indications.

Wear Mechanism	A2R17 Wear Growth (%TW/EFPY)			A2R19 Wear Growth (%TW/EFPY)		
	Average	95/50 (1)	Max	Average	95/50 (1)	Max
AVBs	0.0 (2)	2.9	5.5	0.5	2.6	4.6
TSPs (3)			2.1			0.7
DSPs (3)			0.0			0.0

Notes:
(1): Determined by a fitted normal distribution.
(2): Observed average wear rate for AVB wear indications was negative.
(3): Insufficient data for development of a distribution.

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 Braidwood Unit 2 SGs is axial ODSCC at TSP intersections on high residual stress tubes and axial ODSCC at a freespan ding on a high residual stress tube. The single tube with axial ODSCC at a freespan ding also had axial ODSCC indications at TSP intersections.

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. The axial ODSCC at freespan ding is not specifically addressed 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. 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 Braidwood Unit 2, the historic bobbin data for SG C R44 C47 was reviewed to assess the presence of precursor signals for the 03H TSP elevation and the ding crack at 03H +33.9 inches.

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 shows 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

For the potential mechanisms applicable to the Braidwood 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. Therefore, the default distributions are used in the OA for the potential degradation mechanisms at Braidwood 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 G, which is the lead industry plant with regard 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 G growth data, the OA for circumferential ODSCC represents an extremely conservative assessment.

Circumferential ODSCC PDA growth rates for a plant with original vintage SGs using A600MA tubing were also compared with the IAGL default growth. These data were provided by the licensee. Circumferential ODSCC is the dominant mechanism at this plant, having affected approximately 800 tubes; these SGs are still in operation. 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, support the conservatism of the IAGL typical default growth rate.

Figure 4-4 also shows an adjusted PDA growth function developed by applying a shape factor of 1.25 to the IAGL default PDA growth. The adjusted PDA growth 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 Braidwood Unit 2.

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).

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 initiation 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.

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 mimic the pattern of prior inspections, the acute model represents a conservative assessment of potential initiation sites up to the A2R22 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

4.6 Initiation Function

The Weibull statistical distribution is used to model the initiation of SCC in A600TT tubes. The Weibull distribution is a well know 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 A2R17, 50% of the hot leg tubesheet region was inspected and at A2R19, 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 A2R17 and half at A2R19.

a,

b

4.7 SCC Length Distributions

4.7.1 Axial ODSCC and PWSCC at the TTS and Dings and Dents

All A600TT axial ODSCC and PWSCC indications at the TTS and axial ODSCC at dings and dents 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

a,

b

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 is five. Four come from Plant S (three freespan ding axial ODSCC cracks 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 expansion, approximately 1100 tubes per SG had to be removed and replaced. 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 along the front. 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 described by a uniform depth profile.

Figure 4-8 plots the cumulative probability distribution of circumferential ODSCC arc lengths from the lead plant, Plant G. Of the 65 A600TT industry indications, 62 have come from Plant G. 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 also utilized the adjusted arc length distribution intended for four-cycle analyses.

a,
b

a,
b,
c

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

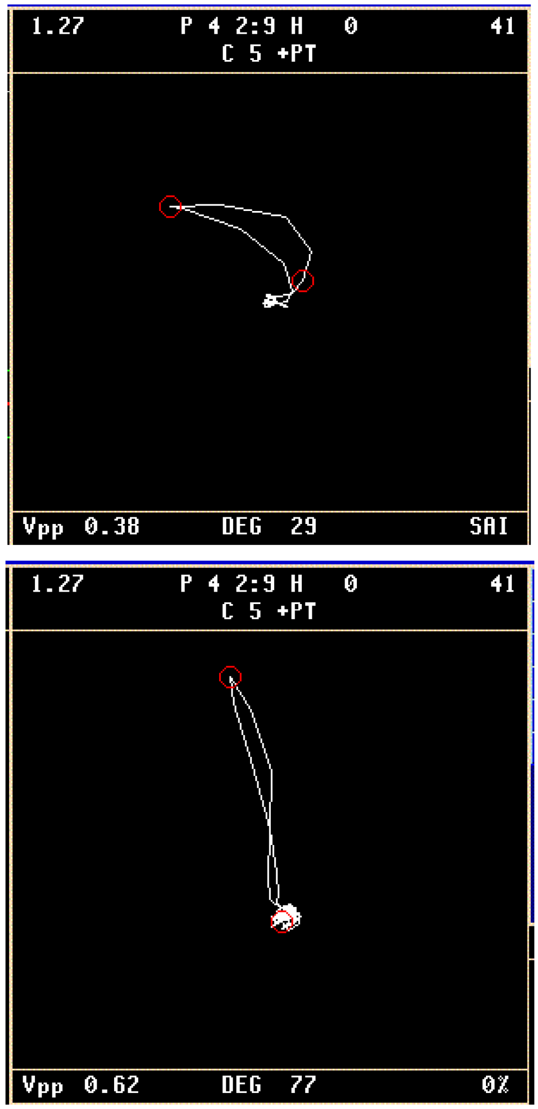


Figure 4 2 — Comparison of Ding ODSCC (top) and TSP ODSCC (bottom) +Point Lissajous Responses.

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.

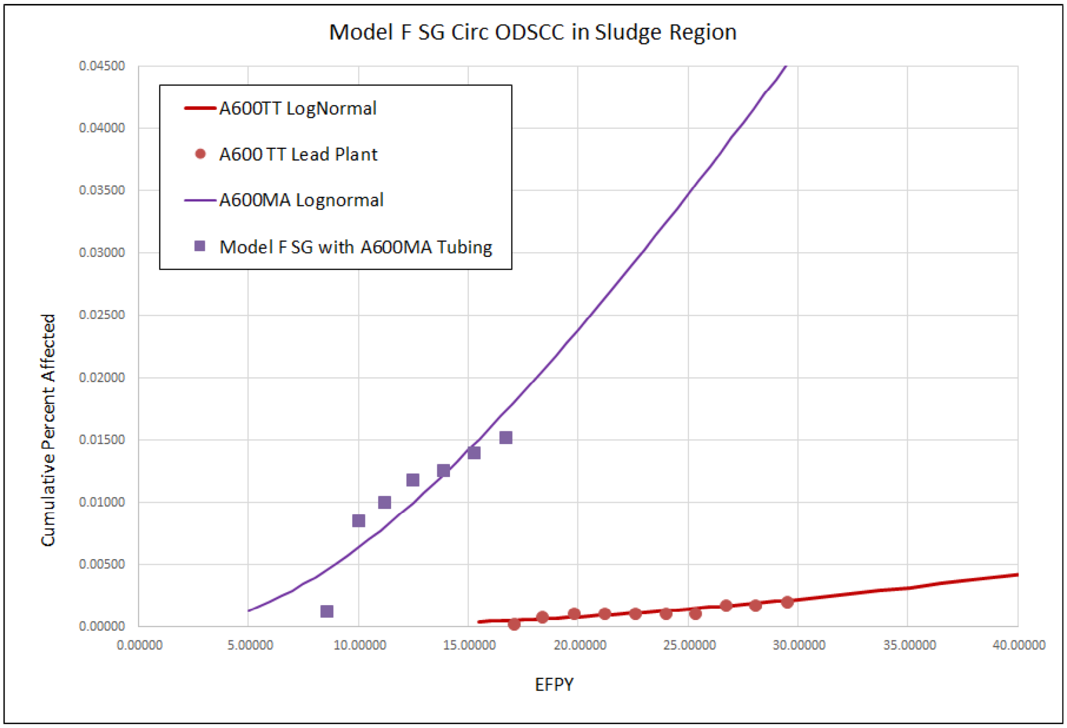


Figure 4-5 — Prediction of Circumferential ODSCC in A600TT Lead Plant and A600MA Plant with Model F SGs.

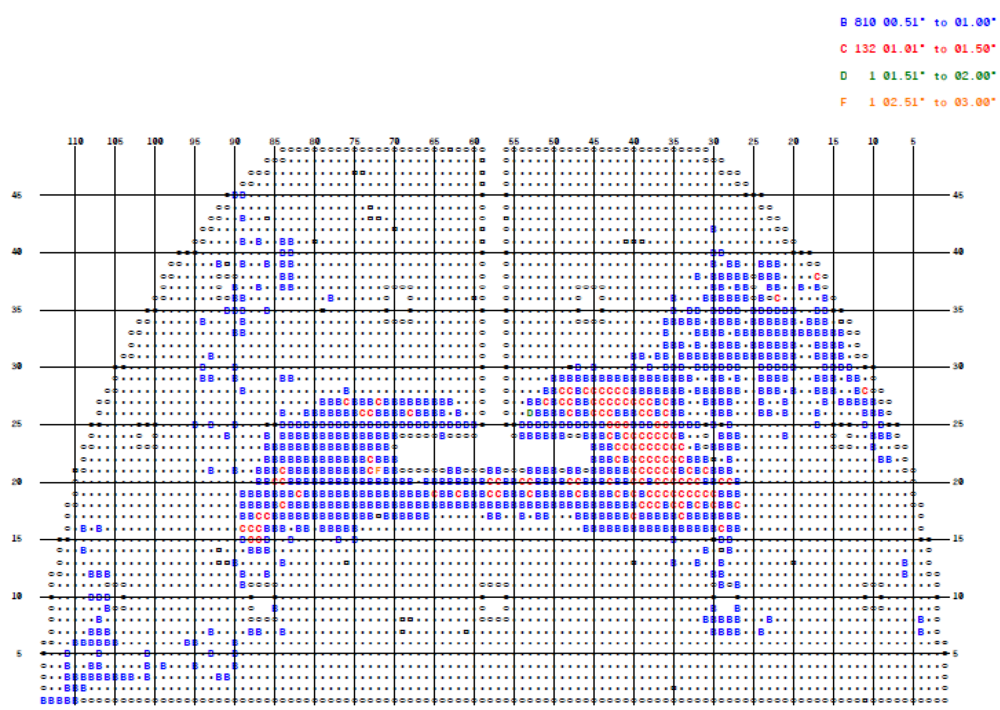


Figure 4-6 — Braidwood Unit 2 SGD Sludge Deposition and Definition of ODSCC Susceptible Region.

a,

b

Figure 4-7 — Axial SCC Length Distribution for A600TT Tubing.

a,

b

Figure 4-8 – Circumferential ODSCC Arc Length Distribution 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 structure mechanisms observed at A2R19 extended to A2R22. 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 another vendor. The deterministic calculations for AVB wear, wear at TSPs, and wear at DSP is based on the guidance contained in [2].

Plug (or repair) on NDE sizing strategy is used in the OA of 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:

$$d_{EOC} < d_{CM} \tag{5-1}$$

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 A2R19 (%TW, NDE)	39%TW	28%TW	5%TW
Applicable ETSS	96004.3 r13	21998.1 r4	96004.3 r13
Bounding degradation growth rate (%TW/EFPY)	2.9	2.1	2.1
Basis for growth rate selection	(Note 1)	(Note 2)	(Note 2)
Projected size at A2R22, 52 EFPM (%TW, NDE)	52%TW	37%TW	14%TW
Bounding degradation geometry	(Note 3)	(Note 3)	(Note 4)
Burst pressure at projected actual A2R22 size (psi)	5330	5110	7530
Condition Monitoring limit at 3xNOPD, 4110 psi (%TW, NDE)	69%TW	49%TW	55%TW
Approximate margin (%TW)	~17%TW	~12%TW	~41%TW

Notes:

(1) Basis for selection: 95th percentile of paired AVB wear indications at A2R17; A2R17 observed growth rates bound observed A2R19 growth rates

(2) Basis for selection: largest observed growth rate for paired wear indications at both TSP and DSP, for both outages (A2R17 and A2R19) [drawn from a total population of nine growth rates]

(3) Volumetric with limited circumferential and axial extent

(4) Volumetric uniform thinning with limited axial extent

5.2 Anti-Vibration Bar Wear

A full-length bobbin probe examination covered 100% of all active tubes at the A2R19 examination. The 1,105 detected indications at A2R19 for wear associated with AVBs ranged in depth from 8 to 46%TW, sized by an EPRI-qualified examination technique (ETSS 96004.3 rev 13). Eight of these indications were at or exceeded the technical specification tube plugging limit of 40%TW and were repaired by plugging; all eight of these indications were in SG 2A. Two of the indications were in the same tube, so a total of seven tubes were plugged in SG 2A at A2R19 for AVB wear. This means the deepest indications associated with AVB wear that were returned to service is 39%TW (NDE depth). There was a total of four such 39%TW AVB wear indications: two in SG 2A, and one each in SG 2C and 2D.

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 (4,110 psi) is the limiting condition for structural integrity performance, and the condition monitoring limit for AVB wear at this pressure is 69%TW (NDE depth).

Observed AVB wear rates at Braidwood Unit 2 were calculated by comparing the change in depth of AVB wear indications from the three most recent examinations at A2R19, A2R17, and A2R16. There were almost 1,000 paired indication data in both A2R19 and A2R17, and approximately half of the paired indications in both outages showed no growth. In general, the observed wear rates at A2R19 are bounded by the observed wear rates at A2R17, indicating that wear rates have attenuated. The applied bounding wear rate was selected from the upper 95th percentile wear rate observed at A2R17; 2.9%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 is 51.5%TW (NDE depth). This is less than the 3×NOPD condition monitoring limit of 69%TW (NDE depth) at A2R22. Therefore, the structural performance criteria of NEI 97 06 will be satisfied, with a margin of approximately 17%TW. The cumulative projected accident leakage contribution from wear mechanisms over the operational period from A2R19 to A2R22 is zero.

5.3 Wear at Tube Support Plates

For Braidwood 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 A2R19 examination. There were two detected indications for wear associated with broached TSPs, at depths of 15%TW (at R49 C53, TSP 07C, in S/G 2D; sized with ETSS 96910.1 rev 10) and 28%TW (at R22 C98, TSP 10C, in S/G 2A; sized with ETSS 21998.1 rev 4). Because neither of these was repaired by plugging, the largest indication associated with TSP wear that was returned to service is 28%TW (NDE depth).

The broached TSPs in the Braidwood 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. However, Braidwood has determined the shape of the deeper of these indications (28%TW) is point wear with very limited axial length (estimated at 0.15 inch long), postulated to have been caused by a small burr left on a TSP land after the broaching process. The length of the deeper indication is assumed to be equal to the width of the full TSP, as a conservative measure, and the condition monitoring limit for broached TSP wear at 3×NOPD is 49%TW (NDE depth).

Observed TSP wear rates at Braidwood Unit 2 were calculated again by comparing the change in depth of TSP wear indications from the three most recent examinations (A2R19, A2R17, and A2R16). There were few paired TSP wear data, so the data from both outages (A2R19 and A2R17) were combined for both broached TSP and drilled support plate wear. The resulting largest observed wear rate was applied, 2.1%TW/EFPY (Section 4.4.1).

The projected size of the deepest TSP wear indication that was returned to service over the three-cycle operating period is 37.1%TW (NDE depth). This is less than the 3×NOPD condition monitoring limit of 49%TW (NDE depth) at A2R22. Therefore, the structural performance criteria of NEI 97 06 will be satisfied, with a margin of approximately 10%TW. The cumulative projected accident leakage will be negligible over the next operational period based on the projected limiting depth sizes for this mechanism.

5.4 Wear at Drilled Tube Hole Support Plates

For Braidwood Unit 2, the DSPs refer to the lowermost flow baffle plate (01H and 01C) and the support plates in the preheater section (ranging between 06C – 02C, inclusive). The full-length bobbin probe examination also detected wear at DSPs during the A2R19 examination. There were three detected indications for wear associated with DSPs, with depths ranging from 2%TW to 5%TW, sized with ETSS 96910.1 rev 10. Because none of these indications were repaired by plugging, the largest indication associated with DSP wear that was returned to service is 5%TW (NDE depth).

The DSPs in the Braidwood 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 55%TW (NDE depth).

Observed TSP wear rates at Braidwood Unit 2 were calculated again by comparing the change in depth of TSP wear indications from the three most recent examinations (A2R19, A2R17, and A2R16). There were few paired DSP wear data, so the data from both outages (A2R19 and A2R17) were combined for both broached TSP and DSP wear. The resulting largest observed wear rate was applied; 2.1%TW/EFPY.

The projected size of the deepest DSP wear indication that was returned to service over the three-cycle operating period is 14.1%TW (NDE depth). This is less than the 3×NOPD condition monitoring limit of 55%TW (NDE depth) at A2R22. Therefore, the structural performance criteria of NEI 97-06 will be satisfied, with a margin of approximately 41%TW. The cumulative projected accident leakage will be negligible over the next operational period based on the projected limiting depth sizes for this mechanism.

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.

5.6 Axial ODSCC at TSP Intersections 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 A2R17 and A2R19, 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 number of high residual stress tubes in each SG is 11 in SG A, 15 in SG B, 14 in SG C, and 28 in SG D. Axial ODSCC at TSP intersections on high stress tubes was first reported 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 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.

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 cluster (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 represent specific points in time in the Braidwood operating history.

As indications were not detected in A2R17 or A2R19, this strongly implies that had initiations been postulated prior to A2R17 that indications would have been detected at A2R19. 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 17. At 6.25 relative EFPY, which represents A2R19, all four susceptible indications have initiated. In the low Weibull slope model, two indications have initiated at the point equivalent to A2R19.

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 A2R19, 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 growth by the model up to A2R22. 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.

5.6.1 Acute Initiation Model Results

The model predictions for number of initiated indications and bobbin detections for the plant outages are shown in Table 5-1. In the model, EFPY equivalent to A2R22 the calculated probability of burst (POB)

is 3.57%, which is less than the limit of 5%, and the probability of leakage (POL) exceeding the AILPC of 0.5 gpm is 1.12%, which is less that the limit of 5% for this mechanism. Thus, the analysis results for the acute model satisfy the performance criteria at A2R22. Table 5-2 provides results of the analysis and key inputs to the OA model.

Table 5-2 — Acute Model Results for 100% Bobbin/X-Probe Examination at A2R19 — Axial ODSCC at TSP Intersections on High Residual Stress Tubes

a,

b,

c

5.6.2 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 A2R19. The model predictions for number of initiated indications and Bobbin detections for the plant outages are shown in Table 5-2. In the model EFPY equivalent to A2R22, the calculated POB is 2.36%, which is less than the limit of 5% for this mechanism, and the POL exceeding the AILPC of 0.5 gpm is 1.58%, 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 A2R22.

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. 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 5-3 provides results of the analysis and key inputs to the OA model.

Table 5-3 — Low Weibull Slope Model Results for 100% Bobbin/X-Probe Examination at A2R19 — Axial ODSCC at TSP Intersections on High Residual Stress Tubes

a,

b,

c

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, Braidwood Unit 2 has not experienced any corrosion degradation at the TTS expansion transition, within the tubesheet at bulges or over-expansions, at small radius U-bends, or at dings or dents on non-high residual stress tubes. Each of these mechanisms has been reported within the A600TT fleet. 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 mechanisms, the same methodology used for existing SCC mechanisms 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 mechanisms 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.

In support of the probabilistic OA for the potential mechanism, a lead-plant evaluation was performed where the operating history of Braidwood 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 Braidwood Unit 2 would have occurred, or will 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 Braidwood 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)
- Tube wear mechanisms

Of this list of SCC degradation mechanisms, only axial ODSCC at TSP intersections and at a freespan ding on a high residual stress tube have been reported at Braidwood Unit 2.

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 Braidwood Unit 2.

6.3 Circumferential ODSCC at TTS Expansion Transitions

Sample inspections have been performed at Braidwood 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 since 2005 (A2R11):

- At A2R11, A2R12, and A2R13, 20% Point sampling in each SG was performed.
- At A2R14, 30% +Point sampling in each SG was performed.
- At A2R15 and A2R16, 25% +Point sampling in each SG was performed.
- At A2R17 and A2R19, 50% X-Probe sampling in each SG was performed.

Eddy current inspections were not performed at A2R18.

Since 50% sampling was applied at A2R17 and A2R19, each inspection subset was evaluated independently. The circumferential ODSCC models were developed consistently 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 A2R17 and 50% of the susceptible population is assumed to exist within the tubes last inspected in A2R19. The configuration of the model conservatively neglects the additional 13% inspected via the peripheral, tube lane, and T-slot inspection.

[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 suggests the presence of significant deposits both within the TSP flow lobes and above/below the TSP. At A2R19 a "soft" chemical cleaning process was applied at Braidwood Unit 2; a total of 3,480 lbs of material were removed from all four SGs. This maintenance activity should proactively address this mechanism. Based on information provided by the licensee [18] the maximum depth growth of the indication from 2016 to 2019 is bounded by the IAGL typical default growth rate.

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 A2R17, the POB is 2.18% and POL is 0.31%, with five predicted detections at A2R22. Table 6-1 provides results of the analysis and key inputs to the OA model. The initial evaluation provided in the Phase 1 report calculated a POL of 0.9%. The leakage estimation was recalculated after a review of the input data, specifically the arc length distribution applied. Section 4 describes the arc length distribution data review.

Table 6-1 — Model Results for 50% X-Probe TTS Examination at A2R17 — Circ ODSCC

a,
b
c

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 A2R22 is reduced to 0.27%. Note that the recommended PDA growth rate bounds the A600TT lead plant PDA growth data and the A600MA plant PDA growth data.

For the 50% tube examination at A2R19, the same approach is followed except that the assumption that one indication initiates in the operating period prior to A2R19 and two initiates are assumed present at the A2R19 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 A2R19, the POB is 0.60% and POL is 0.0%, with three predicted detections at A2R22. Table 6-2 provides results of the analysis and key inputs to the OA model. Note that the calculated POL of 0.0% is based on the originally applied arc length distribution, not the recommended arc length distribution.

Table 6-2 — Model Results for 50% X-Probe TTS Examination at A2R19 — Circ ODSCC

a,
b

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:

$$POB = 1-(1-0.0218)(1-0.006) = 2.77\%$$

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

6.4 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.

The same approach is taken with regard to distribution of the susceptible population between the two inspections (i.e., A2R17 and A2R19).

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

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 A2R17, the POB is 0.26% and POL is 0.16%, with two predicted detections at A2R22. For such low probabilities of burst and leakage for the population that was last inspected at A2R17, there is no reason to perform the same analysis for the population last inspected at A2R19 since these flaws will be in-service for two fewer cycles. The POB and POL for the population last inspected at A2R19 are conservatively assumed to be half the corresponding value computed for A2R17 when the combined probabilities are evaluated below. Table 6-3 provides results of the analysis and key inputs to the A2R17 OA model.

Table 6-3 — Model Results for 50% X-Probe TTS Examination at A2R17 — Axial ODSCC

a,
b

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:

$$POB = 1-(1-0.0026)(1-0.0013) = 0.39\%$$

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

6.5 Axial ODSCC at Dings and Dents

Tube dings and dents in freespans, at U-bends, and at structures, have been tested in past outages with ECT in a sampling program involving bobbin coil for dings/dent signals < 5 volts, and with the +Point for signal voltages as low as >2 volts.

At A2R17, the dent +Point inspection program included dents >2V (Section 2). Even though the hot leg would be expected to lead the cold leg with regard to ding/dent ODSCC initiation, the A2R17 program included 100% +Point inspection of all (hot leg, cold leg, and U-bend) >5V dings and essentially 100% of all hot leg and U-bend dents >2V as well as all >2V dents at 11C (top cold leg TSP). The overall impact of this aggressive ding/dent inspection at A2R17 was to functionally improve the <5V dent POD since as the ding/dent voltage is reduced, the effective bobbin coil POD is increased.

At A2R19 the +Point scope included 50% of all (hot leg, cold leg, and U-bend) >5V dings and >5V dents.

6.5.1 Axial ODSCC at >5V Dings and >5V Dents

The original >5V ding/dent analysis discussed in the Phase 1 report [20] inadvertently neglected the aggressive ding/dent +Point inspection program applied at A2R17 and the original analysis is then considered overly conservative. The Phase 1 report analysis applied the IAGL typical default growth rate combined with the bounding SEL distribution developed from the limiting A600MA plant ding cracking experience. Note that [13] recommends the use of the axial SCC SEL length distribution since the axial SEL length distribution includes all A600TT plant axial ODSCC and axial PWSCC at the TTS as well as all freespan ding and dent cracks. At A2R22, the POB is 1.24% and the POL exceeding the AILPC is 0.6% for this sub-population.

Using the established protocol (as described in the circumferential ODSCC analysis), 100% +Point inspection of all >5V dings and >2V dents was performed at A2R17; thereby, establishing a “clean” condition since presumably any ODSCC present at that outage would have been detected and removed from the susceptible population. At A2R19, >5V ding and >5V dent inspection was 50% by +Point. Therefore, the final A2R19 model allots 50% of the susceptible population to the tubes inspected at A2R19, with the expectation that the remaining 50% of the population would be inspected at A2R21. The number of >5V dings and >5V dents for the SG with the largest number of each category is similar. Thus, the final OA model combines these two populations as one since the applied NDE technique is the same with equal detection performance whether inspecting a ding or a dent. The applied growth rate is

the IAGL typical default growth rate, which has been established to be conservative. In addition, Section 4 presents a growth rate assessment of the axial ODSCC at a freespan ding on a high residual stress tube which establishes that the growth rate of this indication, which is the only axial ODSCC at freespan ding indication in the A600TT fleet, is also bounded by the IAGL typical default growth rate.

As an added measure of conservatism, the final >5V ding and >5V dent model was setup to assign the first flaw initiation at A2R17 instead of A2R18, as the established protocol would have permitted. This case is considered a more appropriate representation than the original model but still more conservative than the defined protocol since it modeled the first initiation two cycles prior to the most recent inspection. The established protocol allots half of the susceptible to the most recent inspection when sampling was performed (A2R19). The entire susceptible population as defined in Section 4 is applied to allow this case to address both >5V dings and >5V dents.

Thus, this case is recommended to replace the original case. For this case, the POB at A2R22 is 0.50% and the POL exceeding the AILPC is 0.09%. For the inspection at A2R19, the evolution of the number of initiations predicted by the model is shown on Table 6-4.

Table 6-4 — Model Results for 50% +Point Examination at A2R19 — >5V Ding and >5V Dents

a,
b,
c

6.5.2 Axial ODSCC at Hot Leg Dings and Dents ≤ 5 Volts

Braidwood Unit 2 has performed 100% full length bobbin inspection in each SG for at least 10 successive inspections. As stated in Section 6.5.1, the aggressive +Point inspection program applied at A2R17 effectively improved the overall bobbin detection program at hot leg dents. However, the program only addressed <5V dents, not <5V dings. The established protocol would suggest that since 100% inspection was performed at A2R19, the first initiation point can be established one cycle prior. As with the final >5V ding/dent case, first initiation was conservatively assumed two cycles prior to A2R19. The susceptible population for the limiting SG was doubled to create one case which addressed both dings and dents as the number of <5V dings is approximately equal to the number of <5V dents in the limiting SG. The larger of these two populations was doubled to provide for a conservative assessment of susceptible population size. At A2R22, the POB is 0.9% and the POL exceeding the AILPC is 0.11% for this sub-population. For the inspection at A2R19, the evolution of the number of initiations predicted by the model is shown in Table 6-5.

Table 6-5 — Model Results for 100% Bobbin Inspection at A2R19 — <5V Ding and <5V Dents

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 (i.e., >5V dings/dents (from Section 6.5.1 above) and <5V dings/dents):

$$POB = 1-(1-0.009)(1-0.005) = 1.4\%$$

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

6.6 PWSCC at TTS Expansion Transitions

6.6.1 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 4-7. 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 A2R22, the judgment that the POB and POL for axial PWSCC are zero is not unrealistic.

6.6.2 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 curve [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 A2R22, the judgment that the POB and POL for circumferential PWSCC are zero is not unrealistic.

6.7 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 68 2-sigma tubes received a 100% sample inspection by X-Probe at all hot leg and cold leg TSP intersections at A2R17 and A2R19. At both A2R17 and A2R19, 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 one such indication on one tube 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. The model results (Table 5-2) predict a conservative number of indications at A2R22 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.

6.8 Other Mechanisms

Axial ODSCC in the freespan without the presence of a ding has been reported on one tube (two indications) across the entire A600TT tubing fleet. This mechanism has been reported on 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 Braidwood Unit 2 at A2R19 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 A2R22, 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. The 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 Braidwood 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.

7 | Summary and Conclusions

Exelon has submitted a one-time license amendment request (LAR) to allow deferring the Braidwood Unit 2 A2R21 SG tube examinations to the next scheduled outage, A2R22, in October 2021. In support of the LAR, this OA was prepared and provides the technical basis for deferring the A2R21 SG inspections to A2R22. The OA conservatively evaluated the existing degradation mechanisms as well as several potential SCC degradation mechanisms. 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 A2R22.

2. Structural integrity performance criterion margin requirement of three times normal operating pressure (3xNOPD) on tube burst will be satisfied at EOC 22 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 22.

Therefore, given the examination scope implemented at the Braidwood Unit 2 A2R17 and A2R19 outages, all structural and accident leakage performance criteria in NEI 97-06 are predicted to be met through the EOC 22 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 A2R22 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 Limiting Existing and Potential Mechanisms

Mechanism	Probe Type	A2R19 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: High Residual Stress Tubes – Acute Model	Bobbin and X-Probe	100%	3.57%	1.43%	1.12%	3.88%	0.01
Axial ODSCC at TSP Intersections: High Residual Stress Tubes – Low Weibull Slope Model (Includes Non-High Residual Stress Tubes	Bobbin and X-Probe	100%	2.36%	2.64%	1.58%	3.42%	0.026
Circ ODSCC at TTS Expansion Transitions	X-Probe	63%	2.77%	2.23%	0.31%	4.69%	0.046
Axial ODSCC at Tube Dings/Dents	Bobbin (<5V) +Point (>5V)	100% <5V 50% >5V	1.4%	3.6%	0.14%	4.86%	0.0
Axial ODSCC at TTS Expansion Transitions	X-Probe	50%	0.39%	4.61%	0.24%	4.76%	0.0
Circ PWSCC at TTS Expansion Transitions (1)	X-Probe	50%	<<2.77%	>>2.23%	~0%	~5%	~0
Axial PWSCC at TTS Expansion Transitions (1)	X-Probe	50%	<<0.39%	>>4.61%	~0%	~5%	~0
PWSCC in Small Radius U-Bends	+Point	50%	<<0.39%	>>4.61%	~0%	~5%	~0
Total Summed Leak Rate for All Mechanisms: AILPC Limit = 0.5 gpm							0.072 (2, 3)

Notes:
1. PWSCC at TTS 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*.

8 | References

[1] "Steam Generator Program Guidelines", Nuclear Energy Institute, NEI 97-06, Revision 3 (January 2011).

[2] "Steam Generator Management Program: Steam Generator Integrity Assessment Guidelines," Revision 4, EPRI 3002007571 Electric Power Research Institute, (June 2016).

[3] A2R17 180 day report, "Braidwood Station, Unit 2 Steam Generator Tube Inspection Report for Refueling Outage 17," 11/14/2014

[4] A2R19 180 day report, "Braidwood Station, Unit 2 Steam Generator Tube Inspection Report for Refueling Outage 19," 08/24/2017

[5] "Steam Generator Management Program: Steam Generator Degradation Specific Management Flaw Handbook, Revision 2," EPRI 3002005426, Electric Power Research Institute, Final Report (August 2015)

[6] "Steam Generator Management Program: Steam Generator In Situ Pressure Testing Guidelines," Revision 5, EPRI 3002007856 (November 2016)

[7] "Depth Based Structural Analysis Methods for Steam Generator Circumferential Indications," Report TR 107197 P1, Electric Power Research Institute, (November 1997)

[8] "User's Manual for OPCON 3.03 - Operational Assessment and Condition Monitoring of Steam Generator Tubes," Aptech Engineering Services, Inc., (2007)

[9] EPRI Examination Technique Specification Sheets, EPRIq database.

[10] WCAP-12522, "Inconel Alloy 600 Tubing-Material Burst and Strength Properties," Westinghouse Electric Corporation, January 1990

[11] Email from Patrick Creegan (Exelon) to William Cullen (Intertek), "Braidwood A2R21 Input for SG Inspection Deferral," dated 3/27/2020

[12] Email from Patrick Creegan (Exelon) to William Cullen (Intertek), "Braidwood A2R21 Input for SG Inspection Deferral SGA Data Dump," dated 3/27/2020

[13] "Feasibility Study for the Potential to Extend Inspection Intervals for A600TT Fleet," Intertek Report AIM-190610636-2-1, Rev. 0, Electric Power Research Institute 10011093, (December 2019).

[14] Email from Patrick Creegan (Exelon) to William Cullen (Intertek), "Braidwood A2R21 Input for SG Inspection Deferral SG B Data Dump," dated 3/27/2020

[15] Email from Patrick Creegan (Exelon) to William Cullen (Intertek), "Braidwood A2R21 Input for SG Inspection Deferral SG C Data Dump," dated 3/27/2020

[16] Email from Patrick Creegan (Exelon) to William Cullen (Intertek), "Braidwood A2R21 Input for SG Inspection Deferral SG D Data Dump," dated 3/27/2020

[17] Pressurized Water Reactor Generic Tube Degradation Predictions: U.S. Recirculating SGs with Alloy 600TT and Alloy 690TT Tubing, EPRI< Palo Alto, CA: 2003. 1003589

[18] Email from Patrick Creegan (Exelon) to William Cullen (Intertek), "Braidwood A2R21 Input for SG Inspection Deferral - high stress tubes," 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 Braidwood 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 A2R22 in the Phase 1 report. This information was primarily used to establish when, or if, initiation at Braidwood 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 Braidwood 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 Braidwood Unit 2 is then 13.65 EFPY.

An "initiation analysis" model was developed which generated the first initiation at 14.16 EFPY, which is consistent with the A2R11 inspection. 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 A2R11. At A2R14, detection is plausible, limited only by the scope of the top-of-tubesheet region +Point inspection (30%). If the inspection scope at 1R14 were 100%, detection would essentially be ensured. By A2R16, there is a very high likelihood that an indication would be detected. If indications were initiated at A2R11 and no indications were reported to date, detection at A2R17 is essentially ensured. Thus, it can be concluded that initiation did not occur at A2R11.

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 Braidwood Unit 2 is 5 EFPY, and if 5.6 EFPY is used for the first initiation at Plant S, the equivalent initiation at Braidwood Unit 2 is 6.61 EFPY. Braidwood Unit 2 reported axial ODSCC on a Seabrook Signature tube at A2R15 (19.85 EFPY). A precursor was observed on this tube. Using the established protocol for estimating first initiation point, the Braidwood Unit 2 initiation point is 9.97 EFPY. This is the only mechanism found in common between Plant S and

Braidwood Unit 2. The ratio of equivalent Braidwood first observation and actual first observation ranges from 0.5 (5 EFPY/9.97 EFPY) to 0.66 (6.61 EFPY/9.97 EFPY).

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.

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 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 Braidwood 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 11. 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. For the >5V dings/dents, the likelihood that an indication would be reported by A2R17 is judged modest; the likelihood that an indication would be reported by A2R19 is judged high. For the <5V ding population the likelihood that an indication would be reported by A2R16 is judged modest; the likelihood that an indication would be reported by A2R17 is judged high. Even though the same initiation point and growth rate is used, the likelihood of detecting axial ODSCC in a <5V ding is higher due to the larger <5V ding population compared to >5V dents. Note the only A600TT fleet events for ding and dents involves <5V dings and >5V dents.

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 A2R22. These analyses also support the selection of the first initiation point as 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 4

Affidavit of Withholding – Westinghouse Electric Company, LLC

Enclosed is:

CAW-20-5038

The enclosure contains information proprietary to Westinghouse Electric Company LLC ("Westinghouse"), it is supported by an Affidavit signed by Westinghouse, the owner of the information. The Affidavit sets forth the basis on which the information may be withheld from public disclosure by the Nuclear Regulatory Commission ("Commission") and addresses with specificity the considerations listed in paragraph (b)(4) of Section 2.390 of the Commission's regulations.

Accordingly, it is respectfully requested that the information which is proprietary to Westinghouse be withheld from public disclosure in accordance with 10 CFR Section 2.390 of the Commission's regulations.

Correspondence with respect to the copyright or proprietary aspects of the items listed above or the supporting Westinghouse Affidavit should reference CAW-20-5038 and should be addressed to Camille T. Zozula, Manager, Regulatory Compliance & Corporate Licensing, Westinghouse Electric Company, 1000 Westinghouse Drive, Suite 165, Cranberry Township, Pennsylvania 16066.

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:
COUNTY OF BUTLER:

(1) I, Zachary S. Harper, have been specifically delegated and authorized to apply for withholding and execute this Affidavit on behalf of Westinghouse Electric Company LLC (Westinghouse).

(2) I am requesting the proprietary portions of LTR-CECO-20-027-P, Revision 1, "Evaluation of Braidwood Unit 2 Steam Generators for Deferral of Secondary Side Foreign Object Inspection in the Spring 2020 Outage (A2R21)," be withheld from public disclosure under 10 CFR 2.390.

(3) I have personal knowledge of the criteria and procedures utilized by Westinghouse in designating information as a trade secret, privileged, or as confidential commercial or financial information.

(4) Pursuant to 10 CFR 2.390, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld.

(i) The information sought to be withheld from public disclosure is owned and has been held in confidence by Westinghouse and is not customarily disclosed to the public.

(ii) Public disclosure of this proprietary information is likely to cause substantial harm to the competitive position of Westinghouse because it would enhance the ability of competitors to provide similar technical evaluation justifications and licensing defense services for commercial power reactors without commensurate expenses. Also, public disclosure of the information would enable others to use the information to meet NRC requirements for licensing documentation without purchasing the right to use the information.

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(5) Westinghouse has policies in place to identify proprietary information. Under that system, information is held in confidence if it falls in one or more of several types, the release of which might result in the loss of an existing or potential competitive advantage, as follows:

(a) The information reveals the distinguishing aspects of a process (or component, structure, tool, method, etc.) where prevention of its use by any of Westinghouse's competitors without license from Westinghouse constitutes a competitive economic advantage over other companies.

(b) It consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), the application of which data secures a competitive economic advantage (e.g., by optimization or improved marketability).

(c) Its use by a competitor would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing a similar product.

(d) It reveals cost or price information, production capacities, budget levels, or commercial strategies of Westinghouse, its customers or suppliers.

(e) It reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

(f) It contains patentable ideas, for which patent protection may be desirable.

(6) The attached documents are bracketed and marked to indicate the bases for withholding. The justification for withholding is indicated in both versions by means of lower case letters (a) through (f) located as a superscript immediately following the brackets enclosing each item of information being identified as proprietary or in the margin opposite such information. These lower case letters

AFFIDAVIT

refer to the types of information Westinghouse customarily holds in confidence identified in Sections (5)(a) through (f) of this Affidavit.

I declare that the averments of fact set forth in this Affidavit are true and correct to the best of my knowledge, information, and belief.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on: 4/15/2020

Zachary S. Harper, Manager
Licensing Engineering

ATTACHMENT 6

Non-Proprietary Evaluation of Braidwood Unit 2 Steam Generators for Deferral of Secondary Side Foreign Object Inspection in the Spring 2020 Outage (A2R21), LTR-CECO-20-027, Rev. 1

Westinghouse

To: Samuel S. Snyder
cc:

Date: April 15, 2020

From: John S. Rees
Ext: 724-722-5435
Fax: 724-722-5889

Your ref:
Our ref: LTR-CECO-20-027-NP, Rev. 1

Subject: **Evaluation of Braidwood Unit 2 Steam Generators for Deferral of Secondary Side Foreign Object Inspection in the Spring 2020 Outage (A2R21)**

(There are no technical changes to Revision 1 of this document. Revision 1 has been created to provide a Proprietary and Non-Proprietary (redacted) version of the document.)

During the spring 2017 refueling outage at Braidwood Unit 2 (A2R19), Foreign Object Search and Retrieval (FOSAR) was performed at the top of the secondary tubesheet in all four steam generators (SGs) and within the preheater region of SG 2A and SG 2C. These inspections identified a small variety of foreign objects and material in the preheater region and at the top of tubesheet and in the preheater region. In addition to the foreign objects identified by visual inspections, eddy current inspection identified volumetric wear and possible loose part signal indications indicative of foreign object wear and presence of foreign objects. These indications were located near the tube support plates (TSPs) in the upper tube bundle.

It is desired to defer the Braidwood Unit 2 steam generator secondary side foreign object inspection and FOSAR that is scheduled for the spring 2020 outage (A2R21). The last secondary side foreign object inspection was in the spring 2017 outage (A2R19). Reference 14 qualified all the remaining foreign objects for 3 effective full power years or 2 fuel cycles. Deferring the foreign object inspection scheduled during the A2R21 outage would mean 3 cycles or 4.5 effective full power years (EFPY) between inspections. The purpose of this letter is to qualify the secondary side foreign objects identified during the A2R19 outage for three cycles or 4.5 effective full power years, until the A2R22 outage.

This letter revises the results of Reference 14, which provided an assessment of the foreign objects identified during the A2R19 FOSAR as well as the results and conclusions of inspections performed for volumetric wear indications in the upper tube bundle. In addition, see below for a high-level executive summary of the evaluations performed in this letter to support steam generator FOSAR and foreign object inspection deferral for the Braidwood Unit 2 Model D5 steam generators.

Executive Summary

Foreign object search and retrieval is typically performed on the steam generator secondary side during a refueling outage where the steam generators (SGs) are inspected. These inspections could result in the identification of a number of foreign objects. For foreign objects that cannot be removed from the SGs, an evaluation must be performed to determine the acceptable duration of continued operation with the objects remaining in the SG. In many cases, the foreign objects are small or are in a region of the tube bundle where little or no tube degradation would be expected to occur over multiple cycles of operation. Evaluation and acceptability of a foreign object remaining in the SG is dependent on various factors, such as size and type of foreign object, material properties of the object, fluid flow characteristics at the location of the object, fixity of the object, the operating duration between inspections, and the object's propensity for causing tube wear (i.e., flaw detected by eddy current examination). The amount of tube wear a particular foreign object can cause is dependent on many factors as described.

Westinghouse uses a proprietary computer code (WEART) to determine wear times for a given foreign object. It uses the Archard equation to determine the volume of metal removed for a given force and sliding distance. Tube vibration parameters (such as natural frequency and associated displacements) are used to obtain the distance and the force is supplied by the local fluid flow conditions. In general, it is assumed the foreign object is in the worst location at or near the periphery of the tube bundle. The evaluation of the potential for fretting and impact/sliding wear caused by the presence of loose objects remaining in the secondary side of steam generators involves postulating scenarios in which the loose objects contact vibrating tubes and wear into the tubes over significant periods of time. The objective is to estimate the time each loose object would require to wear into a tube until the tube wall no longer meets the minimum wall thickness requirements pertaining to the maintenance of tube integrity.

For the foreign objects inventory at Braidwood Unit 2, results were considered from the last outage in which FOSAR and inspections were performed. FOSAR and tube inspections would have been performed during the upcoming spring 2020 (A2R21) outage, therefore, the existing loose parts evaluations (in Reference 14) only show acceptability up to this point. In order to allow a deferral of FOSAR and foreign object inspections, the list of parts identified in Reference 14 must be shown to have acceptability with respect to wear time for an additional 1.5 years, or until fall 2021 (A2R22).

Many of the smaller parts were acceptable for an operating period of 3 years by comparison to bounding dimensions of similar parts in Table 1. In order to show acceptability for a longer period of time (i.e., 4.5 years), the WEART calculations were re-run, and smaller acceptable dimensions are shown in Table 2. The parts that were previously evaluated and shown to be acceptable via comparison to the Table 1 dimensions are also smaller than the Table 2 dimensions, therefore, these parts are acceptable for a period of 4.5 years. Several parts were identified as scale or sludge rock and are not metallic. Non-metallic objects do not pose a potential for tube wear. Finally, several legacy objects were identified that were contained and surrounding tubes were plugged during a previous outage, therefore, they do not require additional evaluation.

In addition to the foreign object inventory, volumetric wear indications in the upper tube bundle were detected during the A2R19 outage. Although there is no evidence that the identified foreign objects will migrate and cause wear on neighboring active tubes, there is evidence that new foreign objects could be generated from an unknown source. Thus, it must be shown that any new foreign objects that are generated during Cycles 20, 21, and 22 will not cause wear that would approach the tube structural limit. A [
]^{a,c,e} model was developed based on the limiting tube wear flaw left in service during

A2R19. The volume growth was applied to the A2R19 flaw over three cycles after A2R19 to determine the projected flaw depth at A2R22 using the [ ]^{a,c,e} model. Using this approach, the largest flaws left in service during A2R19 are projected to be smaller than the condition monitoring structural limit, thus satisfying the SG structural and leakage performance criteria.

To conclude, all parts identified in the steam generators of Braidwood Unit 2 are shown to have wear time results that can be extended by 1.5 years. Therefore, these objects will not reach minimum tube wall thickness requirements pertaining to the maintenance of tube integrity before 3 cycles or 4.5 effective full power years. Westinghouse concludes that no retrieval, inspection, or plugging actions are necessary, and FOSAR and foreign object inspections can be deferred until fall 2021 (A2R22).

Please transmit this document to Exelon via a project letter. If you have any questions or desire further information, please contact the undersigned.

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//Attachments: Attachment A: Foreign Objects Found during A2R19
Attachment B: Foreign Objects Evaluated during Previous Outages
Attachment C: Data for Volumetric Indications in the Upper Tube Bundle
Attachment D: Figures

Electronically Approved Records are authenticated in the Electronic Document Management System

Background / Purpose

During the A2R19 refueling outage at Braidwood Unit 2, foreign object search and retrieval (FOSAR) was performed following sludge lancing activities in each of the four steam generators (SGs). Advanced Scale Conditioning Agent (ASCA) application chemical cleaning was performed in all four SGs prior to sludge lancing. The top of the tubesheet (TTS) secondary tubesheet region, including the tube lane, annulus and T-slot regions were visually inspected as a programmatic inspection and targeted inspections were performed based on the results of the primary side eddy current examinations. FOSAR activities were performed in the preheater regions of SG 2A and SG 2C. The foreign objects identified during these A2R19 inspections are documented in Table A-1 of Attachment A. In addition to the foreign objects identified in Attachment A, eddy current results showed seven newly reported volumetric wear indications near a tube support plate (TSP) and three potential loose parts (PLPs) located on the TSP 08C in SG 2D and are documented in Table A-2 of Attachment A.

This assessment addresses the foreign objects identified during the A2R19 FOSAR inspections as well as the newly reported volumetric wear indications in the upper tube bundle. This assessment also addresses foreign objects and upper bundle wear indications known to be remaining in the Braidwood Unit 2 SGs from previous cycles (Table B-1, Table B-2, and Table B-4 of Attachment B).

Foreign Objects Found during FOSAR and Remaining within SGs

Previous to the FOSAR an investigation of the maximum sizes of a few typical objects were investigated. These objects were evaluated at the worst-case flow conditions with the preheater region (TSP 02C) and bound the conditions at the top of the tubesheet. The sizes below were found to be acceptable for at least 3 years of full power operation.

Table 1. Acceptable Object Sizes for 3 Effective Full Power Years

Small rectangular object such as a gasket	[ ]^{a,c,e} inches long
Wire 0.06-inch diameter or smaller	[ ]^{a,c,e} inches long
Wire 0.12-inch diameter	[ ]^{a,c,e} inches long

It is desired to qualify objects for 3 cycles or 4.5 effective full power years. The WEART spreadsheet was re-run for similar size objects but reducing the length such that the objects were acceptable for 4.5 years of full power operation. The acceptable sizes are shown in Table 2 below.

Table 2. Acceptable Object Sizes for 4.5 Effective Full Power Years

Small rectangular object such as a gasket	[ ]^{a,c,e} inches long
Wire 0.06-inch diameter or smaller	[ ]^{a,c,e} inches long
Wire 0.12-inch diameter	[ ]^{a,c,e} inches long

The WEART spreadsheet documenting the evaluation of these objects is attached to this letter in the Westinghouse Electronic Document Management System (EDMS).

The objects found and not retrieved during the A2R19 outage are listed in Table A-1.

In SG 2A there were 5 objects. Object 2A002 is a bushing. This object is a legacy object and is Object 2A002 in Table A-1 and is listed in Table B-1. The tubes surrounding this object were plugged in a previous outage. The object is larger than the tube gap and therefore cannot enter the tube bundle. The object is located in the annulus region on top of TSP 02C within the preheater. The object is surrounded on three sides by the plugged tubes, the wrapper and the flow block in the annulus. The plugged tubes, wrapper and flow block prevent this object from moving with the direction of the fluid flow. The bushing has not migrated since it was first detected in A2R10. This object has been evaluated in previous evaluations since discovery (i.e., References 6 through 9). The other 4 objects are small bristles (2A003, 2A004, 2A005, 2A006) with the largest (2A006) [ ][a,c,e] inch long and [ ][a,c,e] inch diameter. This is smaller than the 0.06 diameter by [ ][a,c,e] -inch long wire in Table 2 and, therefore, the bristles are acceptable for at least 4.5 effective full power years.

In SG 2B there was one object identified during A2R19 FOSAR – Object 2B001 is weld slag. This is a legacy object and is also listed in Table B-1. The object was first detected during A2R09. The weld slag is firmly wedged between two tubes and was unable to be retrieved. The tubes surrounding this object were plugged in a previous outage. The object has not migrated from its original location since it was discovered. This object has been evaluated in previous evaluations (i.e., References 6 through 9).

In SG 2C there were 15 objects discovered during A2R19 FOSAR that were not removed from the SG. Four of the objects are listed as scale or sludge rock (2C001, 2C002, 2C003 and 2C005 in Table A-1) and are not metallic. Non-metallic objects do not pose a potential for tube wear. Two of the objects are listed as red scale (2C007 and 2C019) and are not metallic. These do not pose a potential for mechanical wear on the tubes. The red scale is further analyzed in other parts of this letter. One object is listed as curved object (2C013) and is listed as not metallic. This does not pose a potential for tube wear. In addition, the object is smaller than the gap between the tubes so it cannot become lodged in between two tubes. The other eight objects are listed as wire or bristles (2C004, 2C008, 2C009, 2C010, 2C011, 2C015, 2C016, 2C020) with the largest (2C015) being [ ][a,c,e] inch long and [ ][a,c,e] inch diameter. This is smaller than the [ ][a,c,e] diameter by [ ][a,c,e] -inch long wire in Table 2 and, therefore, the wires are acceptable for at least 4.5 effective full power years.

In SG 2D there are two objects identified during the A2R19 FOSAR that were not removed from the SG. One object is listed as bristle (2D001) with a length of [ ][a,c,e] inch and a diameter of [ ][a,c,e] inch. This is smaller than the 0.06 inch diameter by [ ][a,c,e] -inch long wire in Table 2 so the bristle is acceptable for at least 4.5 effective full power years. The second object is listed as wedge with a length of [ ][a,c,e] inch, a width of [ ][a,c,e] inch and a height of [ ][a,c,e] inch. This is a legacy object that was first detected during A2R06. It is firmly wedged between Tubes R2C6 and R2C7 and/or corroded to the tubesheet. The object has not migrated since it was first discovered. This is smaller than the small rectangular object in Table 2 so the object is acceptable for at least 4.5 effective full power years.

Table A-4 lists the foreign objects that were identified during A2R19 that were successfully removed from the SGs. No tube wear was identified from eddy current inspections that were associated with these objects. In all SGs a number of sludge rocks and scale were observed during the visual inspections of the tubesheet, flow distribution baffle, and preheater baffle plates. In most cases these objects are not identified in the tables in Appendix A or Appendix B. In general, both sludge rocks and scale are indigenous to the steam

generator and, therefore, not considered to be foreign objects. Scale typically is very fragile and breaks up quite easily and will not adversely affect the SG tubing. However, sludge rocks can sometimes become extremely hard. Usually the edges are rounded from the flow eroding their edges. As a result, they do not historically cause wear on adjacent tubes. There have been no reports of scale or sludge rocks having caused tube wear. The sludge rock and scale objects identified in the Braidwood Unit 2 SGs during A2R19 are all Priority 3 parts as defined by Reference 1 and are not expected to cause any wear on adjacent tubes for at least three operating cycles.

Based on the above evaluations, the foreign objects identified during A2R19 and shown in Table A-1 of this letter are acceptable to remain in the SG for at least three cycles or 4.5 effective full power years at measurement uncertainty recapture (MUR) uprate operating conditions (Reference 5). It is noted that the MUR uprate operating conditions include the effects of the prior 5% power uprate that occurred in 2002. There are two legacy objects in Table A-1 for which the surrounding tubes have previously been plugged. No further action is required for these objects. With the exception of the tubes surrounding the two legacy objects that have previously been plugged, all tubes adjacent to and surrounding the objects in Table A-1 may be left in service.

Objects Previously Identified

Westinghouse reviewed previous foreign object evaluations performed for the Braidwood Unit 2 steam generators to determine if there were any indications that previously evaluated objects had moved. Those objects previously evaluated are identified in Tables B-1 through B-4 of Attachment B and address outages A2R10 through A2R17. Since a 100% full-length bobbin inspection program and targeted **+POINT™**[1] probe program did not identify any wear in tubes surrounding these objects, it can be concluded that the Table 2 analysis of bounding objects for MUR uprate conditions may be applied. Table B-1 shows objects that remained in the steam generators prior to A2R19. Most of these are listed as either wire or wire bristle and are very small wires with the largest wires being [ ]^{a,c,e} inch long by [ ]^{a,c,e} inch diameter and [ ]^{a,c,e} inch long by [ ]^{a,c,e} inch diameter. Most of these objects were probably removed during sludge lancing, but even if they remain they all are smaller than the wires listed in Table 2 and are acceptable to remain for 4.5 effective full power years. One item is listed as machine curl with dimensions of [ ]^{a,c,e} inch by [ ]^{a,c,e} inch by [ ]^{a,c,e} inch. Since the gap between tubes is [ ]^{a,c,e} inches, this object is smaller than the gap and cannot become caught between tubes. One object is the wedge listed in the evaluation of Steam Generator 2D above.

There are a few larger objects listed in Table B-1 (bushing, fit-up bars, weld slag) but these have all been contained by plugging adjacent tubes in previous outages.

Table B-2 lists historical foreign objects that were not located in subsequent inspections. It is most likely that these objects were removed during sludge lancing. Most of the objects are listed as wire or wire bristle with the longest listed as [ ]^{a,c,e} inch long by [ ]^{a,c,e} inch. One is listed as a metal strip [ ]^{a,c,e} inch by [ ]^{a,c,e} inch by [ ]^{a,c,e} inch. One is listed as a metal turning with dimensions of [ ]^{a,c,e} inch by [ ]^{a,c,e} inch by [ ]^{a,c,e} inch. All of these are less than the sizes in Table 2 and are acceptable for 4.5 effective full power years.

[1] *+POINT is a trademark of Zetec, Inc., in the United States and/or other countries. Other names may be trademarks of their respective owners.*

Three possible loose part (PLP) signals at an upper tube support plate were identified by eddy current that were one tube removed from three tubes that were plugged during A2R17 due to foreign object wear and PLP signals. It is believed that the object responsible for the A2R17 wear indications migrated to a new location. These indications were in SG 2D and located on the topside of TSP 08C in Tubes R16C91, R16C92 and R17C92. These three tubes containing the PLP signals were preventatively plugged and stabilized during A2R19. Thus, those objects identified in Attachment B are acceptable to remain in the SGs for at least three cycles or 4.5 effective full power years.

Volumetric Wear in the Upper Tube Bundle

Identification of New Indications

Volumetric wear indications in the upper tube bundle, both with and without accompanying PLP signals, have been identified in the Braidwood Unit 2 SGs since A2R11. The table below summarizes the number of tube wear indications for each outage since A2R11.

Braidwood Unit 2 Outage	Number of SG Upper Bundle Tube Wear Indications Attributed to Foreign Objects
A2R11	1
A2R12	2
A2R13	1
A2R14	5
A2R15	18
A2R16	6
A2R17	3
A2R19	7(1)(2)
(1) One indication was a legacy flaw left in service from A2R17. (2) Three additional tubes contained PLP signals associated with an object that caused tube wear in A2R17.	

All upper bundle volumetric wear indications identified in the Braidwood Unit 2 SGs since A2R11 are listed in Tables C-1 and C-2 of Attachment C. Table C-2 provides additional eddy current information for these indications.

Seven (7) volumetric wear indications were newly reported during the A2R19 eddy current inspections as listed in Table A-2. There was one upper bundle legacy wear indication that was left in service in A2R17 that was also detected in A2R19 and showed no growth (SG 2A R15C47 at TSP 07H-0.62). The +POINT probe did not detect any foreign object in these tubes with identified wear. The flaws were all located at or below the associated TSP and were either aligned with the quatrefoil flow hole or on the edge of the quatrefoil land edge extending into the land and flow hole. Re-analysis of historical eddy current data indicated that a flaw could be traceable to being present in past outages in three of the tubes. The remaining four tubes had no precursor signal during A2R17. The largest flaw depth was measured at [ ]a,c,e through-wall (TW) in Tube SG 2D R22C107 and had no precursor wear or PLP signal during A2R17. This tube was preventatively plugged during A2R19.

As noted, three newly identified PLP signals in adjacent tubes were detected within two tube rows of tubes that were plugged during A2R17 due to volumetric wear and PLP signals. The PLP signals detected in the A2R19 inspection were in SG 2D Tubes R16C91, R16C92, and R17C92. The wear and PLP signals were

located on top of TSP 08C. During the previous A2R17 inspection, nearby Tube R13C92 contained a [ ]a,c,e TW volumetric flaw with a PLP signal and the tube was removed from service. Tube R14C92 contained a [ ]a,c,e TW volumetric flaw with no evidence of a PLP signal and the tube was removed from service in A2R17. Tube R13C91 only contained a PLP signal and was preventatively plugged during A2R17. The A2R17 volumetric wear signals in Tubes R13C92 and R14C92 were traceable to previous outages dating back to 2008 and 2006, respectively. The object that caused the tube wear on these tubes during A2R17 is believed to have migrated between Tube Columns 91/92 to Tube Rows 16/17. Since this object had a history of causing tube wear, Tubes R16C91, R16C92, and R17C92 were preventatively plugged and stabilized in the A2R19 outage.

Potential Impact on Tubes with Wear Within the Upper Bundle

Seven tubes with volumetric wear flaws at upper TSPs were left in service during A2R19 (Table A-2). No foreign material was identified that was associated with any of the flaws. Therefore, no additional flaw progression is expected. Review of historical eddy current data on these tubes and tubes with a similar type of wear from prior inspections shows that the [ ]a,c,e.

An assessment was performed as defense in depth that assumed that the foreign object is still present and could cause wear progression on these seven tubes. In accordance with Reference 1, the basis for the evaluation of foreign objects and their ability to cause impact/sliding wear on a tube is the Archard wear equation. This equation calculates the volume of material lost from the tube as a function of the wear coefficient, contact force, and the distance over which the force acts. The latter two parameters are also known as the "work rate" and are a function of thermal-hydraulic and tube vibrational characteristics. The wear coefficient is based on the materials of the tube and the foreign object. Therefore, as long as the plant conditions remain essentially constant, the volume rate of material removed from the tube also remains essentially constant over time.

A [ ]a,c,e model (Figure D-1) was developed based on [ ]a,c,e, thus satisfying the SG structural and leakage performance criteria. The [ ]a,c,e TW structural limit contains all flaw measurement, material property and burst relation uncertainties at 0.95 probability and 50% confidence level. This result bounds the other volumetric wear flaws in the upper tube bundle that were left in service.

Potential Interaction with Adjacent Tubes Within the Upper Bundle

Three tubes were removed from service during A2R19 due to PLP signals from a migrating foreign object in SG 2D located on top of TSP 08C. These PLP signals were caused by an object that presumably migrated from three tubes plugged for foreign object interaction during A2R17. During A2R17, it was found that this

object caused a [ ]a,c,e TW flaw in Tube R13C92 and a [ ]a,c,e TW flaw in Tube R14C92. Both flaw indications were traced to being present since at least 2009. This means that the flaws were growing for at least three cycles. Since the object has shown the potential to create tube wear, an assessment is made should the object migrate again from its current position adjacent to plugged tubes to active tubes. A [ ]a,c,e model, as described above, was applied to assess the condition after three cycles of operation on adjacent tubes. In this case, the object had caused wear on two tubes, therefore, [

]a,c,e.

Upper bundle volumetric wear indications have been identified at the lower edge or just below the TSPs since A2R11. Although there have been instances within the industry of small objects migrating upward into the SG tube bundle, these occurrences have been infrequent and generally have been limited to the lower support locations such as the flow distribution baffle or first TSP. In addition, these instances are typically associated with SGs manufactured using grid supports where a more open flow area exists that would permit objects to migrate upward. Byron Unit 2 has had similar experience as Braidwood with this type of wear.

The foreign objects in the upper TSPs at Braidwood Unit 2 are located at relatively high elevations and are inside a SG manufactured with quatrefoil broach plate supports, not grids. In addition, the Braidwood Unit 2 SGs are a preheater design so most feedwater, and therefore most foreign objects, would enter through the main feedwater nozzle at a lower elevation and on the cold leg side. Any new foreign objects that entered through the main feedwater nozzle would have to travel through the preheater section and, in this instance, migrate to the hot leg side of the SG at the TSP 08 elevation. Any objects introduced through the auxiliary feedwater nozzle would [

]a,c,e. It is noteworthy that most of the upper bundle wear indications at the lower edge of TSPs in the Braidwood Unit 2 SGs do not have accompanying PLP calls.

A review was performed of the flow fields in the region where the volumetric wear indications were located to determine if the unknown foreign objects could have a significant effect on surrounding active tubes. Table C-1 show that the cross-flow fluid velocities for post-MUR uprate conditions [

]a,c,e. Volumetric wear from unknown foreign objects in the upper TSPs has been identified in the Braidwood Unit 2 SGs since A2R11 (2005). Subsequent inspections during the following seven inspections (A2R12 through A2R19) with no wear identified on adjacent active tubes confirmed this conclusion.

The cross-flow fluid velocities for the tubes with those near the volumetric wear indications identified during A2R19 were compared to the velocities of tubes with wear from previous outages. The intent was to show that the fluid conditions associated with the upper bundle indications identified during A2R19 were similar to the fluid conditions associated with previous upper bundle indications.

Since the MUR uprate was implemented during Cycle 17, [

]^{a,c,e}.

Tables C-1 and C-2 also show that none of the tubes that were identified with volumetric wear in the upper tube bundle during A2R19 are adjacent to tubes with volumetric indications identified during previous outages. Therefore, it can be concluded that [

]^{a,c,e}.

Potential Interaction from New Foreign Objects Within the Upper Bundle

Although there is no evidence that the identified foreign objects will [
]^{a,c,e}, there is evidence that new foreign objects could be generated from an unknown source. Thus, it must be shown that any new foreign objects that are generated during Cycles 20, 21 and 22 will not cause wear that would approach the tube structural limit. Since the unknown foreign objects being generated cannot be visually inspected, [

]^{a,c,e}.

New foreign object tube wear and PLPs have been identified in the upper tube bundle of the Braidwood Unit 2 steam generators since A2R11. Tables A-2 and B-4 list those tubes with wear and/or PLP indications from the unknown foreign objects distributed throughout all four steam generators at five different support locations in the upper tube bundle. The maximum wear depth for all the wear indications was [
]^{a,c,e}. Based on Reference 10, the condition monitoring structural limit for this size wear scar is [ ]^{a,c,e} TW which includes all uncertainties at 0.95 probability and 50% confidence level; hence, there is considerable margin to the structural limit.

The above example is not intended to be a prediction of when the wear scar in Tube R7/C61 will reach the tube structural limit. Rather, it is meant to show that the largest depth of the wear flaws identified in the upper tube bundle of the Braidwood Unit 2 SGs had a significant margin to the tube structural limit. Thus,

there is a low probability that a new foreign object that begins to wear on a different tube during subsequent operating cycles could cause a wear scar that would approach the tube structural limit.

Summary of Results for Volumetric Wear and PLPs in Upper Tube Bundle

Based on historical trends and the cross-flow fluid velocities shown in Table C-1, it is concluded there is a good technical basis to assume that the unknown foreign objects and PLPs will not have a significant effect on adjacent active tubes. The potential for a wear scar in any neighboring active tubes to reach the tube structural limit over three cycles of operation is judged to be unlikely considering all available data, plant-specific operating history, and the analysis results discussed above. Further, the number of volumetric wear indications found to date, as well as the depth of these wear scars, indicate there is a low probability that any new foreign objects generated during Cycles 20, 21 and 22 will cause a wear scar that would approach the tube structural limit. As a result, no additional evaluations are required for these tubes other than routine eddy current examinations of surrounding active tubes during the next scheduled inspection.

Tube Plugging and Stabilizer Recommendations

During the A2R19 outage, Westinghouse recommended that tube SG 2D R22C107 be removed from service by plugging. No tube stabilization was recommended. This tube contained a [ ]^{a,c,e} TW volumetric wear indication at TSP 07H-0.54 inch which is an indication of foreign object wear. Review of historical eddy current data did not detect a precursor wear signal in a prior inspection and, therefore, this tube exhibited a relatively high wear growth rate since the A2R17 inspection. The presence of a foreign object was not detected by A2R19 eddy current inspection.

In addition, Westinghouse recommended that Tubes R16C91, R16C92, and R17C92 in SG 2D be plugged and the cold leg tube stabilized through TSP 09C. These tubes contained PLP indications on the top of TSP 08C. The PLP indications are associated with a known nearby foreign object that resulted in plugging three tubes in A2R17 and has subsequently migrated to these three tubes.

Potential Impact Degradation from Objects Remaining in SGs

Regarding potential impacting effects from foreign objects remaining inside the Braidwood Unit 2 SGs, the foreign objects identified during A2R19 (shown in Table A-1) are much smaller and have less mass than the bounding object evaluated in Reference 2. That object was conservatively assumed to weigh [ ]^{a,c,e} lbs. Even if it was conservatively assumed that this object was in the high flow area, it would not have enough energy to cause eddy current detectable dents or dings in SG tubes. Thus, the foreign objects identified during the Braidwood Unit 2 A2R19 outage are not capable of causing impact degradation to the tubes.

Potential Material Interactions

The foreign objects identified during A2R19 are typical of what has been identified in the Braidwood Unit 2 SGs during previous inspections. In addition to the legacy objects, which included weld slag, back-up bars, and wedge and wires, the predominant new foreign objects were wires and scale/sludge rocks. The principal metals of potential consequence to Alloy 600TT tubing are copper and lead. It is unlikely that any of the foreign objects identified during A2R19 were fabricated from these metals. However, even if some of the objects were made of copper or lead, it would need to dissolve and be incorporated into the tube surface in an elevated oxidation state to participate in thermally treated Alloy 600 (A600TT) corrosion reactions. This action will have very low probability of occurrence as foreign objects typically found in the Braidwood

Unit 2 SGs have been very stable in the operating environment. Therefore, based on engineering judgment, the foreign object material is compatible with the materials of construction.

During A2R16 (Fall 2012), a red substance was identified in various local areas within the 2C SG preheater region (Reference 11). The source and material type of the red substance was unknown. A sample of the material was not possible and, therefore, the material could not be positively identified, but was clearly non-metallic and not capable of causing wear on active tubes. Figure D-2 shows examples of the red substance detected during A2R16. Each tube that was identified as being in contact with the red substance, as identified in Reference 11, was inspected with +POINT probe at both A2R16 and A2R17 and no tube degradation was found. The material was also not detected by eddy current. Follow-up visual inspections of the SG 2C preheater were performed during the next refueling outage, A2R17, and no evidence of the red substance was identified and no deleterious effects of the material was detected on the tubes through eddy current testing (Reference 3).

The A2R19 visual inspection of the 2C SG preheater region detected a red substance very similar, if not identical, to the material found during A2R16 (Figures D-2 and D-3). From these images, it is also apparent that residue of the substance coated the tube scale making the normally gray tube scale have a reddish hue. The pieces of reddish tube scale broke upon contact with the inspection probe. The substance is clearly non-metallic and not capable of causing wear on active tubes and is similar to the substance found and evaluated during A2R16 (2012) which was also contained in SG 2C. The A2R19 eddy current inspection did not detect any tube degradation associated with this material and also did not detect the material itself.
Table A-3 identifies the tubes that are in contact with the red substance and/or red scale. In the absence of any chemical analysis of the foreign material, it is difficult to make a quantitative judgment regarding the localized chemical interaction at the tubing surface. The impact to global steam generator chemistry would likely be observed in either Mode 2 or Mode 1, in which case compliance with the Electric Power Research Institute (EPRI) chemistry guidelines would provide assurance as to the integrity of the SG tubes.

With respect to localized attack on the tubing surfaces, it is unlikely that the presence of this foreign material would challenge the structural integrity of the tubing over the time period of one cycle. This is supported by the melting point of the material relative to the flows and saturation temperature during normal operation, which would reduce the probability of localized concentrations of contaminants as the melted plastic is more mobile. In addition, during normal operating conditions, the feedwater dissolved oxygen action level is [ ]^{a,c,e} parts per billion (ppb). The dissolved oxygen content in the feedwater is higher than the dissolved oxygen in the SG. In the event that this material is polyvinylchloride, at the feedwater concentration of [ ]^{a,c,e} ppb, the chloride concentrations required to initiate stress corrosion cracking in annealed austenitic material is approximately [ ]^{a,c,e} based on Figure 2-6 of Reference 4. Under these conditions, it is unlikely that the structural integrity of the tubing would be challenged over three cycles of operation.

Westinghouse recommends that Exelon consider a visual inspection of the SG 2C preheater during the next planned inspection to determine if the material has degraded or continues to reside within the preheater region. If the material is observed in the preheater following three cycles of operation, Westinghouse recommends that Exelon attempt to obtain a sample, when possible, for chemical analysis which may be used for a longer term disposition. In addition, a sample of those tubes that were in contact with the red substance and red scale identified in Table A-3 should be inspected with +POINT probe or **X-PROBE**™[2]

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[2] *X-PROBE is a trademark of Zetec, Inc., in the United States and/or other countries. Other names may be trademarks of their respective owners.*

during the next planned inspection to determine if there has been any degradation of the affected tubes that may not be detectable by the bobbin coil probe.

Other Considerations

The Exelon procedure (Reference 13) for evaluating loose parts requires that the following aspects be considered:

- Flow blockage (piping, valves, etc.)
- Mechanical interference (active components, valves, pumps, etc.)
- Corrosion or adverse chemical reaction
- Mechanical damage (wear, fretting, deformation, breaking, etc.)
- Other potential impact scenarios, such as pump impeller interaction, valve seating interaction, instrument line blockage, etc.
- The potential for similar debris being elsewhere in the system, the possibility that similar material may still be continuing to be generated, and the impact that this debris may have if transported to other components (e.g., feedwater heaters).
- Cumulative effects considering previously lost parts.

The small foreign objects identified during A2R19 have insufficient mass to affect other systems, structures or components that are connected to the steam generators. They cannot cause flow blockage in the tube bundle and are not likely to migrate to other structures. Even if they do migrate, they are too small to fully block instrumentation taps or to affect any downstream components such as the main steam isolation valves. The only other system these objects could affect would be the blowdown system and they are too small to affect valves or components in that system. Thus, these foreign objects will not result in mechanical interferences with any active components and will not adversely affect systems either upstream or downstream of the SGs.

Westinghouse has also considered the potential cumulative effects of having multiple objects inside the SGs. Although multiple objects were observed in the Braidwood Unit 2 SGs, the objects were not only distributed throughout the four SGs but were also distributed at different locations throughout the individual SGs. From this observation, it can be concluded that the foreign objects are widely distributed and it would be unlikely that more than one foreign object would interact with a single tube. Even if the objects were close to each other, there is no credible mechanism for the objects to interact and produce accelerated tube wear or other SG component degradation. The foreign objects identified during A2R19 are relatively small and consistent with previously identified foreign objects (Tables B-1 through B-4). Thus, Westinghouse concludes that the combined effect of the foreign objects remaining in the Braidwood Unit 2 SGs will not adversely affect plant systems over three operational cycles.

Conclusions

Based on the evaluation of foreign objects identified in Attachments A and B, Westinghouse concludes that they will not cause significant tube wear for at least three cycles at current operating conditions.

One tube with a [ ]^{a,c,e} TW volumetric wear indication in the upper tube bundle in SG 2D was preventatively plugged. Additionally, three tubes containing PLP signals on top of TSP 08C in SG 2D were plugged and stabilized due to the presence of a foreign object that caused wear in nearby tubes during A2R17. Based on historical foreign object trends and fluid conditions in the upper tube bundle, any foreign

objects that appear during Cycles 20, 21 and 22 are not likely to cause tube wear that would challenge the structural or leakage integrity of active tubes over three cycles of operation.

Follow-up visual and eddy current examinations to evaluate the effects of the red substance contained within the preheater section of SG 2C is recommended for A2R22. A sample of the tubes in contact with the red substance is recommended to be inspected with the +POINT probe or the X-PROBE at TSP 02C in SG 2C during A2R22 to determine if any deleterious effects on tube integrity had developed over the operating interval. Additionally, visual inspection of the locations of the red substance in SG 2C should also be performed during A2R22 to assess whether the substance is still present or has dissipated.

References

1. EPRI Report 1019039, "Steam Generator Management Program: Foreign Object Prioritization Strategy for Square Pitch Steam Generators," May 2009.
2. Westinghouse Calculation Note CN-SGDA-10-8, Revision 0, "Loose Parts Analysis of the Byron Unit 2 and Braidwood Unit 2 Steam Generators to Support the 3672 MWt NSSS Power MUR Uprate," July 2010. (Westinghouse Proprietary Class 2)
3. Westinghouse Letter LTR-SGMP-14-42, Revision 0, "Evaluation of Foreign Objects in the Secondary Side of the Braidwood Unit 2 Steam Generators – Spring 2014 Outage (A2R17)," May 2014. (Westinghouse Proprietary Class 2)
4. EPRI Report 3002000505, "Pressurized Water Reactor Primary Water Chemistry Guidelines: Volume 1, Revision 7," April 2014.
5. Westinghouse Calculation Note CN-NCE-10-3, Revision 0, "Thermal-Hydraulic Evaluations of the Byron and Braidwood Unit 2 Steam Generators to Support the 3672 MWt NSSS MUR Uprate Program," July 2010. (Westinghouse Proprietary Class 2)
6. Westinghouse Letter LTR-SGDA-05-90, Revision 0, "Evaluation of Foreign Objects in the Braidwood Unit 2 Steam Generators - Spring 2005 Outage," April 2005. (Westinghouse Proprietary Class 2)
7. Westinghouse Letter LTR-SGDA-06-197, Revision 0, "Evaluation of Foreign Objects in the Braidwood Unit 2 Steam Generators – Fall 2006 Outage," October 2006. (Westinghouse Proprietary Class 2)
8. Westinghouse Letter LTR-SGMP-09-167, Revision 0, "Evaluation of Foreign Objects in the Secondary Side of the Braidwood Unit 2 Steam Generators – Fall 2009 Outage," October 2009. (Westinghouse Proprietary Class 2)
9. Westinghouse Letter LTR-SGDA-11-121, Revision 0, "Evaluation of Foreign Objects in the Secondary Side of the Braidwood Unit 2 Steam Generators – Spring 2011 Outage (A2R15)," May 2011. (Westinghouse Proprietary Class 2)
10. Westinghouse Letter LTR-SGMP-17-8, Revision 1, "Braidwood Unit 2 and Byron Unit 2 Steam Generator Generic Tube Structural Limits Evaluation," September 2017. (Westinghouse Proprietary Class 2)
11. Westinghouse Letter LTR-SGMP-12-94, Revision 0, "Evaluation of Foreign Objects in the Secondary Side of the Braidwood Unit 2 Steam Generators – Fall 2012 Outage (A2R16)," October 2012. (Westinghouse Proprietary Class 2)
12. Westinghouse **ST Max™**[3] Steam Generator Eddy Current Results Database for Braidwood Unit 2. (Westinghouse Proprietary Class 2)
13. Exelon Procedure ER-AA-2006, Revision 10, "Lost Parts Evaluations." (Attached in EDMS) [Revision 10 was current for outage A2R19 when these evaluations were first performed. This document has since been updated to Revision 14.]
14. Westinghouse Letter LTR-CDA-17-27, Revision 0, "Evaluation of Foreign Objects in the Secondary Side of the Braidwood Unit 2 Steam Generators – Spring 2017 Outage (A2R19)," May 2017. (Westinghouse Proprietary Class 2)

[3] *ST MAX is a trademark or registered trademark of Westinghouse Electric Company LLC, its affiliates and/or its subsidiaries in the United States of America and may be registered in other countries throughout the world. All rights reserved. Unauthorized use is strictly prohibited. Other names may be trademarks of their respective owners.*

Attachment A
Foreign Objects Found during A2R19

Table A-1. Braidwood Unit 2 A2R19 Identified Foreign Objects at Top of Tubesheet and Preheater Baffle Plate Remaining in SGs

a,c,e

SG	ID	Priority	Description	Elev	Col	Row	Leg	Length	Width	Height	Metallic	Retrieved	Legacy	Comments
A	2A002	3	Bushing	02C	22	43	CL				yes	no	yes	Legacy, Fixed in place
A	2A003	3	Bristle	02C	43	22	CL				yes	no	no	Row 21-22
A	2A004	3	Bristle	02C	100	23	CL				yes	no	no	Row 22-23
A	2A005	3	Bristle	02C	65	29	CL				yes	no	no	Row 64-65, angled up
A	2A006	2	Bristle	02C	59	46	CL				yes	no	no	Row 46-47, on sheet
B	2B001	3	Weld Slag	TTS	79	21	CL				yes	no	yes	Legacy since A2R09
C	2C001	3	Scale	TOP 8	87	1	HL				no	no	no	Scale, no action required
C	2C002	3	Scale	TOP 8	90	1	CL				no	no	no	Scale, no action required
C	2C003	3	Scale	TOP 8	92	1	CL				no	no	no	Scale, no action required
C	2C004	3	Wire	02C	44	45	CL				yes	no	no	Wire in Crevice
C	2C005	3	Sludge Rock	TTS	65	45	HL				no	no	no	Possible Sludge Rock
C	2C007	3	Red Scale	02C	64	49	CL				no	no	no	Scale very thin. Broke up on contact.
C	2C008	2	Wire	02C	94	42	CL				yes	no	no	Loose. Lost in Annulus.
C	2C009	3	Bristle	02C	99	34	CL				yes	no	yes	Wire in Crevice. Legacy
C	2C010	3	Bristle	02C	70	31	CL				yes	no	yes	Wire in Crevice. Legacy
C	2C011	3	Bristle	02C	64	31	CL				yes	no	yes	Wire in Crevice. Legacy
C	2C013	2	Curved Object	02C	59	11	CL				no	no	no	Part is now loose and moved behind tube 59
C	2C015	3	Wire	02C	60	1	CL				yes	no	no	Not Wires. Scale
C	2C016	3	Wire	02C	59	9	CL				yes	no	no	Wire in Crevice
C	2C019	3	Red Scale	02C	52	49	CL				no	no	no	Broken Up
C	2C020	3	Wire	02C	60	21	CL				yes	no	no	Wire in Crevice
D	2D001	3	Bristle	TTS	30	AN	CL				yes	no	no	In Annulus
D	2D002	3	Wedge	TTS	2	6	HL				yes	no	yes	Fixed in place

Table A-2. Braidwood Unit 2 A2R19 Identified Foreign Object Wear/PLP Signals in Upper Tube Bundle

Outage Detected	SG	Row	Col	Location (inch)	Description	PLP Present?	Wear Depth	Tube Status	Precursor in Prior Outage?
A2R19	2A	2	2	08H – 0.86	Unknown	No	[ ]a,c,e	I/S	Yes
A2R19	2A	8	9	05H – 0.68	Unknown	No		I/S	Yes
A2R19	2A	15	47	07H – 0.62	Unknown	No		I/S(1)	Yes(1)
A2R19	2B	40	50	03H – 0.76	Unknown	No		I/S	Yes
A2R19	2B	2	80	07H – 0.85	Unknown	No		I/S	No
A2R19	2B	21	108	07H – 0.72	Unknown	No		I/S	No
A2R19	2D	24	86	05H – 0.74	Unknown	No		I/S	No
A2R19	2D	22	107	07H – 0.54	Unknown	No		Plugged	No
A2R19	2D	16	91	08C + 0.62	Unknown(2)	Yes	PLP	Plugged Stabilized	No
A2R19	2D	16	92	08C + 0.90	Unknown(2)	Yes	PLP	Plugged Stabilized	No
A2R19	2D	17	92	08C + 1.03	Unknown(2)	Yes	PLP	Plugged Stabilized	No

(1) Legacy Indication. First detected during A2R17. No depth change in A2R19.
(2) Adjacent to tubes with PLP and FO wear that were identified and plugged during A2R17.

Table A-3. Braidwood Unit 2 A2R19 Tube in Contact with Red Substance or Red Scale in SG 2C at TSP 02C(1)

Row	Column	Row	Column	Row	Column	Row	Column
1	56	22	45	33	48	46	39
4	55	22	99	33	77	46	41
4	56	23	40	33	78	46	42
5	55	23	41	33	81	46	43
6	62	23	45	33	83	46	51
7	62	24	37	33	85	46	52
8	54	24	44	34	27	46	54
8	59	24	64	35	21	46	55
11	57	24	71	35	64	46	56
11	60	24	72	39	59	46	60
12	57	24	74	41	60	46	61
12	58	25	19	42	59	46	62
12	62	25	20	42	60	46	63
13	57	25	48	43	50	46	71
13	58	25	79	43	51	46	72
13	61	26	36	43	53	46	73
14	52	26	41	43	60	47	39
14	53	26	43	44	48	47	41
14	55	26	45	44	50	47	42
14	58	26	46	44	51	47	43
14	62	27	41	44	52	47	49
15	55	27	42	44	54	47	65
15	56	27	47	44	61	47	63
15	57	28	18	45	41	47	72
15	62	28	42	45	48	48	34
16	55	29	42	45	49	48	38
16	62	29	44	45	51	48	39
17	52	29	67	45	52	48	41
17	59	30	39	45	53	48	42
18	58	30	44	45	56	48	62
18	62	30	45	45	61	49	62
20	61	30	69	45	62		
21	42	31	95	45	64		
22	40	32	86	46	36		
22	44	33	31	46	38		

(1) All instances of red substance and Red Scale are located in SG 2C on top of TSP 02C.

Table A-4. Braidwood Unit 2 A2R19 Identified Foreign Objects at Top of Tubesheet and Preheater Baffle Plate Removed from the SGs

SG	ID	Priority	Description	Elev	Col	Row	Leg	Length	Width	Height	Metallic	Retrieved	Attempted	Legacy	Comments
A	2A001	-	WIRE	TTS	20	AN	CL				a,c,e yes	yes	yes	no	Found in Annulus during Cleanliness
B	None Retrieved														
C	2C006	3	Scale	TTS	-	AN	HL				no	yes	yes	no	Located in sludge/scale pile
C	2C012	3	Bristle	02C	99	29	CL				yes	yes	yes	no	
C	2C014	2	Wire	02C	55	4	CL				yes	yes	yes	no	Object is touching Tubes in Rows 54 and 55
C	2C017	2	Wire	02C	61	1	CL				yes	yes	yes	no	
C	2C018	2	Wire	02C	62	3	CL				yes	yes	yes	no	
D	None Retrieved														

1. This is the size listed in Reference 14 for object 2C012. The listing of the height as [ ][a,c,e] inches is not clear as to whether this is intended as the length of the bristle or whether this is a typographical error. However, this object was removed from the steam generator during A2R19 so the exact size is no longer important.

Attachment B
Foreign Objects Evaluated during Previous Outages

Table B-1. Braidwood Unit 2 Foreign Objects Remaining in SGs Prior to A2R19

Outage Detected	SG	Elevation	Row	Col	Affected Tube Status	Object Description	Dimensions (inch)	Foreign Object Status	Tube Wear?	No. Adj. Tubes Plugged?	Comments
A2R10	2A	TSP 02C	43 44 43 44	22 22 23 23	PLG No Tube PLG PLG	Bushing	a,c,e	Active; Contained	Yes	None	Located in Annulus.
A2R16	2B	TSP 02C	40	24	I/S	Wire		Active	None	None	Located in TSP crevice
A2R16	2B	TSP 02C	26	26	I/S	Wire		Active	None	None	Located in TSP crevice
A2R16	2B	TSP 02C	40	27	I/S	Wire		Active	None	None	Located in sludge.
A2R16	2B	TSP 02C	21	29	I/S	Wire		Active	None	None	Located in TSP crevice
A2R16	2B	TSP 02C	31	29	I/S	Machine Curl		Active	None	None	Located between tubes.
A2R16	2B	TSP 02C	33	37	I/S	Wire		Active	None	None	Located in TSP crevice
A2R11	2B	TSP 02C	24	46	I/S	Wire Bristle		Active	None	None	Located in TSP crevice
A2R16	2B	TSP 02C	24	48	I/S	Wire		Active	None	None	Located in TSP crevice
A2R16	2B	TSP 02C	13	53	I/S	Wire		Active	None	None	Located in TSP crevice
A2R11	2B	TSP 02C	20	54	I/S	Wire Bristle		Active	None	None	Located in TSP crevice
A2R16	2B	TSP 02C	3	56	I/S	Wire		Active	None	None	Located in TSP crevice
A2R16	2B	TSP 02C	4	56	I/S	Wire		Active	None	None	Located in TSP crevice
A2R16	2B	TSP 02C	12	57	I/S	Wire		Active	None	None	Located in TSP crevice
A2R11	2B	TSP 02C	10	60	I/S	Wire Bristle		Active	None	None	Located in TSP crevice
A2R16	2B	TSP 02C	9	61	I/S	Wire		Active	None	None	Located in TSP crevice
A2R11	2B	TSP 02C	15	61	I/S	Wire Bristle		Active	None	None	Located in TSP crevice
A2R16	2B	TSP 02C	8	62	I/S	Wire		Active	None	None	Located in TSP crevice
A2R16	2B	TSP 02C	13	62	I/S	Wire		Active	None	None	Located in TSP crevice
A2R11	2B	TSP 02C	33	65	I/S	Wire Bristle		Active	None	None	Located in TSP crevice
A2R10	2B	TSP 02C	47 47 47	27 28 29	PLG PLG PLG	Fit-up Bar		Active; Contained	Yes	17	Located in Annulus.

Table B-1. Braidwood Unit 2 Foreign Objects Remaining in SGs Prior to A2R19

Outage Detected	SG	Elevation	Row	Col	Affected Tube Status	Object Description	Dimensions (inch)	Foreign Object Status	Tube Wear?	No. Adj. Tubes Plugged?	Comments
A2R10 A2R11	2B	TSP 02C	8 8	53 54	I/S	Wire Bristle	a,c,e	Active	None	None	Located in TSP crevice
A2R09	2B	TSC	21 22 21 22	79 79 80 80	PLG PLG PLG PLG	Weld Slag		Active; Contained	None	None	Object wedged between 4 tubes
A2R10	2B	TSP 02C	46 45 45 45 45 45 45 45 45	89 90 91 92 93 94 95 96 97	PLG PLG PLG PLG PLG PLG PLG PLG PLG	Fit-up Bar		Active; Contained	Yes	20	Located in Annulus
A2R11	2B	TSP02C	28	98	I/S	Wire		Active	No	None	Located in TSP crevice
A2R16	2C	TSP 02C	31	64	I/S	Wire		Active	None	None	Located in TSP crevice
A2R10	2C	TSP 02C	31	70	I/S	Wire Bristle		Active	None	None	Located in TSP crevice
A2R16	2C	TSP 02C	34	99	I/S	Wire		Active	None	None	Located in TSP crevice
A2R06	2D	TSH	6 7	2 2	I/S	Metal Wedge		Active	None	None	Fixed to Tubesheet
A2R14	2D	TSP 02C	30	17	I/S	Wire		Active	None	None	Located in TSP crevice
A2R14	2D	TSP 02C	34	69	I/S	Wire		Active	None	None	Located in TSP crevice

Table B-2. Braidwood Unit 2 Historical Foreign Objects Not Located in a Subsequent Inspection

Outage Detected	SG	Elevation	Row	Col	Affected Tube Status	Object	Dimensions (inch) a,c,e	Loose Part Status	Outage Not Located	Comments
A2R11	2B	TSP 02C	43	53	I/S	Wire Bristle		Missing	A2R16	Not located during A2R16
A2R11	2B	TSP 02C	4	59	I/S	Wire Bristle		Missing	A2R16	Not located during A2R16
A2R16	2B	TSP 02C	3	62	I/S	Wire		Missing	A2R16	Location unknown
A2R11	2B	TSP 02C	37	78	I/S	Wire Bristle		Missing	A2R16	Not located during A2R16
A2R11	2B	TSP 02C	29-30	87-88	I/S	Wire Bristle		Missing	A2R11	Not re- located during A2R11
A2R11	2B	TSP 02C	26	94	I/S	Wire Bristle		Missing	A2R16	Fell into crevice. Not relocated during A2R16.
A2R11	2B	TSP 02C	28	102	I/S	Wire Bristle		Missing	A2R16	Not located during A2R16
A2R11	2B	TSP 02C	4 5 4 5	53 53 54 54	I/S	Metal Turning		Missing	A2R16	Not located during A2R16
A2R10 A2R11	2B	TSP 02C	13 13	58 59	I/S	Wire Bristle		Missing	A2R16	Fell Into Crevice Not located during A2R16.
A2R12	2C	TSP 02C	22	20	I/S	Wire		Missing	A2R16	Not located during A2R16
A2R16	2C	TSP 02C	26	37	I/S	Wire		Missing	A2R17	Not located during A2R17
A2R12	2C	TSP 02C	44	44	I/S	Wire		Missing	A2R16	Not located during A2R16
A2R12	2C	TSP 02C	26	46	I/S	Wire		Missing	A2R16	Fell into crevice. Not located during A2R16.
A2R16	2C	TSP 02C	25	47	I/S	Wire		Missing	A2R17	Not located during A2R17
A2R10	2C	TSP 02C	22	70	I/S	Wire Bristle		Retrieved	A2R16	Object retrieved during A2R16.
A2R16	2C	TSP 02C	22	103	I/S	Wire		Missing	A2R17	Not located during A2R17
A2R12	2D	TSH	3	3	I/S	Metal Strip		Missing	A2R13	Object is not fixed. Unable to retrieve. Not found in subsequent outages.
A2R15	2D	TSH	21	70	I/S	Wire		Missing	A2R19	Not Located during A2R19

Table B-3. Braidwood Unit 2 A2R16 Tubes with Unknown Red Substance						
Outage	**SG**	**HL/CL**	**Elevation**	**Row**	**Col**	**Object[1]**
A2R16	2C	CL	TSP 02C	29	17	Red Substance
A2R16	2C	CL	TSP 02C	34	18	Red Substance
A2R16	2C	CL	TSP 02C	29	19	Red Substance
A2R16	2C	CL	TSP 02C	32	20	Red Substance
A2R16	2C	CL	TSP 02C	33	21	Red Substance
A2R16	2C	CL	TSP 02C	27	22	Red Substance
A2R16	2C	CL	TSP 02C	29	24	Red Substance
A2R16	2C	CL	TSP 02C	27	25	Red Substance
A2R16	2C	CL	TSP 02C	37	25	Red Substance
A2R16	2C	CL	TSP 02C	38	27	Red Substance
A2R16	2C	CL	TSP 02C	29	30	Red Substance
A2R16	2C	CL	TSP 02C	25	35	Red Substance
A2R16	2C	CL	TSP 02C	32	35	Red Substance
A2R16	2C	CL	TSP 02C	32	37	Red Substance
A2R16	2C	CL	TSP 02C	32	38	Red Substance
A2R16	2C	CL	TSP 02C	32	46	Red Substance
A2R16	2C	CL	TSP 02C	34	50	Red Substance
A2R16	2C	CL	TSP 02C	31	52	Red Substance
A2R16	2C	CL	TSP 02C	33	53	Red Substance
(1) No evidence of unknown red substance found during A2R17 visual inspections.						

Table B-4. Braidwood Unit 2 Foreign Object Wear/PLP Signals in Upper Tube Bundle Prior to A2R19

Outage Detected	SG	Row	Col	Location (inch)	Description Dimension (inch)	PLP Present?	Wear Depth	Tube Status
A2R17	2A	15	47	07H – 0.60	Unknown		[ ]a,c,e	I/S
A2R15	2A	11	50	07H – 0.67	Unknown	PLP		PLG
A2R15	2A	10	51	07H – 0.96	Unknown	PLP		PLG
A2R15	2A	11	51	07H – 1.01	Unknown	PLP		PLG
A2R16	2A	5	67	07H – 0.03	Unknown			PLG
A2R12	2A	12	70	05H – 0.77	Unknown			PLG
A2R15	2A	30	84	09H + 0.82	Unknown	PLP		PLG
A2R15	2A	31	85	09H + 0.70	Unknown	PLP	NDD	PLG
A2R15	2A	8	86	07H – 0.74	Unknown		[ ]a,c,e	PLG
A2R16	2A	13	108	05H – 0.72	Unknown			PLG
A2R15	2B	15	7	07H – 0.70	Unknown			PLG
A2R15	2B	6	8	05H – 0.80	Unknown			PLG
A2R15	2B	7	22	07H – 0.64	Unknown			PLG
A2R16	2B	3	30	07H – 0.75	Unknown			PLG
A2R14	2B	13	38	07H – 0.70	Unknown			PLG
A2R16	2B	8	39	07H – 0.72	Unknown			PLG
A2R14	2B	30	56	07H – 0.74	Unknown			PLG
A2R15	2B	32	56	05H – 0.70	Unknown			PLG
A2R14	2B	21	65	05H – 0.63	Unknown			PLG
A2R14	2B	19	67	05H – 0.78	Unknown			PLG
A2R15	2B	24	68	05H – 0.79	Unknown			PLG
A2R15	2B	29	95	05H – 0.74	Unknown	PLP		PLG
A2R14	2C	10	3	08H – 0.82	Unknown			PLG
A2R12	2C	8	18	07H – 0.81	Unknown			PLG
A2R11	2C	35	44	08H – 0.76	Unknown	PLP		PLG
A2R13	2C	3	85	05C + 2.98	Unknown			PLG
A2R16	2D	13	20	07H – 0.65	Unknown			PLG
A2R15	2D	7	61	08H – 0.83	Unknown			PLG
A2R15	2D	17	72	09H – 0.02	Unknown			PLG
A2R05 A2R05 A2R15	2D	43 43 44	72 73 73	08H + 0.57	Rectangular Object [ ]a,c,e			PLG PLG PLG
A2R15	2D	47	74	07H – 0.61	Unknown			PLG

Table B-4. Braidwood Unit 2 Foreign Object Wear/PLP Signals in Upper Tube Bundle Prior to A2R19

a,c,e

A2R15	2D	47	75	07H – 0.51	Unknown			PLG
A2R15	2D	13	76	05H – 0.64	Unknown			PLG
A2R15	2D	43	86	07H – 0.70	Unknown			PLG
A2R17	2D	13	91	08C + 1.06	Unknown	PLP	NDD	PLG
A2R17	2D	13	92	08C + 0.61	Unknown	PLP		PLG
A2R17	2D	14	92	08C + 0.65	Unknown			PLG
A2R16	2D	21	110	04C + 6.57	Unknown	PLP		PLG

a,c,e

Attachment C
Data for Volumetric Wear Indications in the Upper Tube Bundle

Table C-1. Braidwood Unit 2 Volumetric Wear Indications and PLPs in the Upper Tube Bundle (A2R11-A2R19)(1)

Outage	SG	Affected Tube	Location (inch)	PLP Present?	Wear Depth a,c,e	Post-MUR Velocity(2) a,c,e	Plugged?
A2R19	2A	R2/C2	08H – 0.86	No			No
A2R16	2A	R5/C67	07H – 0.03	No			Yes
A2R19	2A	R8/C9	05H – 0.68	No			No
A2R15	2A	R8/C86	07H – 0.74	No			Yes
A2R15	2A	R10/C51	07H – 0.96	Yes			Yes
A2R15	2A	R11/C50	07H – 0.67	Yes			Yes
A2R15	2A	R11/C51	07H – 1.01	Yes			Yes
A2R12	2A	R12/C70	05H – 0.77	No			Yes
A2R16	2A	R13/C108	05H – 0.72	No			Yes
A2R17	2A	R15/C47	07H – 0.60	No			No
A2R15	2A	R30/C84	09H + 0.82	Yes			Yes
A2R15	2A	R31/C85	09H + 0.70	Yes	PLP		Yes
					a,c,e		
A2R19	2B	R2/C80	07H – 0.85	No			No
A2R16	2B	R3/C30	07H – 0.75	No			Yes
A2R15	2B	R6/C8	05H – 0.80	No			Yes
A2R15	2B	R7/C22	07H – 0.64	No			Yes
A2R16	2B	R8/C39	07H – 0.72	No			Yes
A2R14	2B	R13/C38	07H – 0.70	No			Yes
A2R15	2B	R15/C7	07H – 0.70	No			Yes
A2R14	2B	R19/C67	05H – 0.78	No			Yes
A2R14	2B	R21/C65	05H – 0.63	No			Yes
A2R19	2B	R21/C108	07H – 0.72	No			No
A2R15	2B	R24/C68	05H – 0.79	No			Yes
A2R15	2B	R29/C95	05H – 0.74	Yes			Yes
A2R14	2B	R30/C56	07H – 0.74	No			Yes
A2R15	2B	R32/C56	05H – 0.70	No			Yes
A2R19	2B	R40/C50	03H – 0.76	No			No
A2R13	2C	R3/C85	05C + 2.98	No			Yes
A2R12	2C	R8/C18	07H – 0.81	No			Yes
A2R14	2C	R10/C3	08H – 0.82	No			Yes

Table C-1. Braidwood Unit 2 Volumetric Wear Indications and PLPs in the Upper Tube Bundle (A2R11-A2R19)(1)

Outage	SG	Affected Tube	Location (inch)	PLP Present?	Wear Depth a,c,e	Post-MUR Velocity(2) a,c,e	Plugged?
A2R11	2C	R35/C44	08H – 0.76	Yes	[ ]		Yes
A2R15	2D	R7/C61	08H – 0.83	No	[ ]a,c,e		Yes
A2R16	2D	R13/C20	07H – 0.65	No	[ ]a,c,e		Yes
A2R15	2D	R13/C76	05H – 0.64	No	[ ]a,c,e		Yes
A2R17	2D	R13/C91	08C + 1.06	Yes	PLP		Yes
A2R17	2D	R13/C92	08C + 0.61	Yes	[ ]a,c,e		Yes
A2R17	2D	R14/C92	08C + 0.65	No	[ ]a,c,e		Yes
A2R19	2D	R16/C91	08C + 0.62	Yes	PLP		Yes
A2R19	2D	R16/C92	08C + 0.90	Yes	PLP		Yes
A2R15	2D	R17/C72	09H – 0.02	No	[ ]a,c,e		Yes
A2R19	2D	R17/C92	08C + 1.03	Yes	PLP		Yes
A2R16	2D	R21/C110	04C + 6.57	Yes	a,c,e		Yes
A2R19	2D	R22/C107	07H – 0.54	No			Yes
A2R19	2D	R24/C86	05H – 0.74	No			No
A2R15	2D	R43/C86	07H – 0.70	No			Yes
A2R15	2D	R44/C73	08H + 0.57	No			Yes
A2R15	2D	R47/C74	07H – 0.61	No			Yes
A2R15	2D	R47/C75	07H – 0.51	No			Yes

(1) Data in this table are from the Westinghouse ST Max eddy current results database for the corresponding outage (Reference 12).
(2) Maximum cross-flow fluid velocity in ft/sec at post-MUR uprate conditions per Reference 5.

Table C-2. Braidwood Unit 2 Eddy Current Data from Upper Tube Bundle Wear Indications

Outage First Detected	SG	Row	Col	Locn	Inch1	Wear Depth %TW	Axial Length (in)	Circ Length (in)	Circ Extent (Deg)	+POINT Probe Volts	PLP Present
A2R19	2A	2	2	08H	-0.86	a,c,e	0.21	0.3	46	0.10	
A2R19	2A	8	9	05H	-0.68		0.21	0.32	49	0.15	
A2R17	2A	15	47	07H	-0.60		0.13	0.21	32	0.16	
A2R15	2A	11	50	07H	-0.67		0.24	0.41	63	0.12	Yes
A2R15	2A	10	51	07H	-0.96		0.21	37	56	0.08	Yes
A2R15	2A	11	51	07H	-1.01		0.31	0.47	72	0.32	Yes
A2R16	2A	5	67	07H	-0.03		0.25	0.32	48	0.16	
A2R15	2A	30	84	09H	0.82		0.32	0.41	63	0.44	Yes
A2R15	2A	31	85	09H	0.93	PLP					
A2R15	2A	8	86	07H	-0.74	a,c,e	0.18	0.5	77	0.10	
A2R16	2A	13	108	05H	-0.72		0.26	0.43	66	0.14	
A2R15	2B	15	7	07H	0.70		0.14	0.45	69	0.12	
A2R15	2B	6	8	05H	-0.80		0.24	0.41	63	0.21	
A2R15	2B	7	22	07H	0.64		0.22	0.39	59	0.19	
A2R16	2B	3	30	07H	-0.75		0.24	0.44	67	0.14	
A2R16	2B	8	39	07H	-0.72		0.33	0.58	88	0.46	
A2R19	2B	40	50	03H	-0.76		0.14	0.32	49	0.14	
A2R15	2B	32	56	05H	0.70		0.22	0.38	58	0.10	
A2R15	2B	24	68	05H	-0.79		0.24	0.46	71	0.27	
A2R19	2B	2	80	07H	-0.85		0.2	0.3	46	0.16	
A2R15	2B	29	95	05H	0.74		0.27	0.45	69	0.24	Yes
A2R19	2B	21	108	07H	-0.72		0.21	0.32	49	0.23	
A2R16	2D	13	20	07H	-0.65		0.29	0.39	59	0.20	
A2R15	2D	7	61	08H	-0.83		0.25	0.41	63	0.48	
A2R15	2D	17	72	09H	-0.02		0.14	0.21	32	0.16	
A2R15	2D	44	73	08H	0.57		0.19	0.36	55	0.20	
A2R15	2D	47	74	07H	-0.61		0.19	0.36	55	0.15	
A2R15	2D	47	75	07H	-0.51		0.24	0.49	76	0.31	
A2R15	2D	13	76	05H	-0.64		0.25	0.49	76	0.42	
A2R19	2D	24	86	05H	-0.74		0.16	0.17	26	0.22	
A2R15	2D	43	86	07H	-0.70		0.25	0.43	66	0.17	
A2R17	2D	13	91	08C	1.06	PLP					Yes
A2R19	2D	16	91	08C	0.62	PLP					Yes

Table C-2. Braidwood Unit 2 Eddy Current Data from Upper Tube Bundle Wear Indications											
A2R17	2D	13	92	08C	0.59	[ ]a,c,e	0.19	0.26	40	0.35	Yes
A2R17	2D	14	92	08C	0.65		0.1	0.15	23	0.16	
A2R19	2D	16	92	08C	0.90	PLP					Yes
A2R19	2D	17	92	08C	1.03	PLP					Yes
A2R19	2D	22	107	07H	-0.54	[ ]a,c,e	0.21	0.15	23	0.55	
A2R16	2D	21	110	04C	6.57		0.41	0.55	84	0.64	Yes

*Data taken from Westinghouse ST Max eddy current database for the Braidwood 2 for the applicable outage (Reference 12).

Attachment D
Figures

a,c,e

Figure D-1. Sample [ ]^{a,c,e} Model

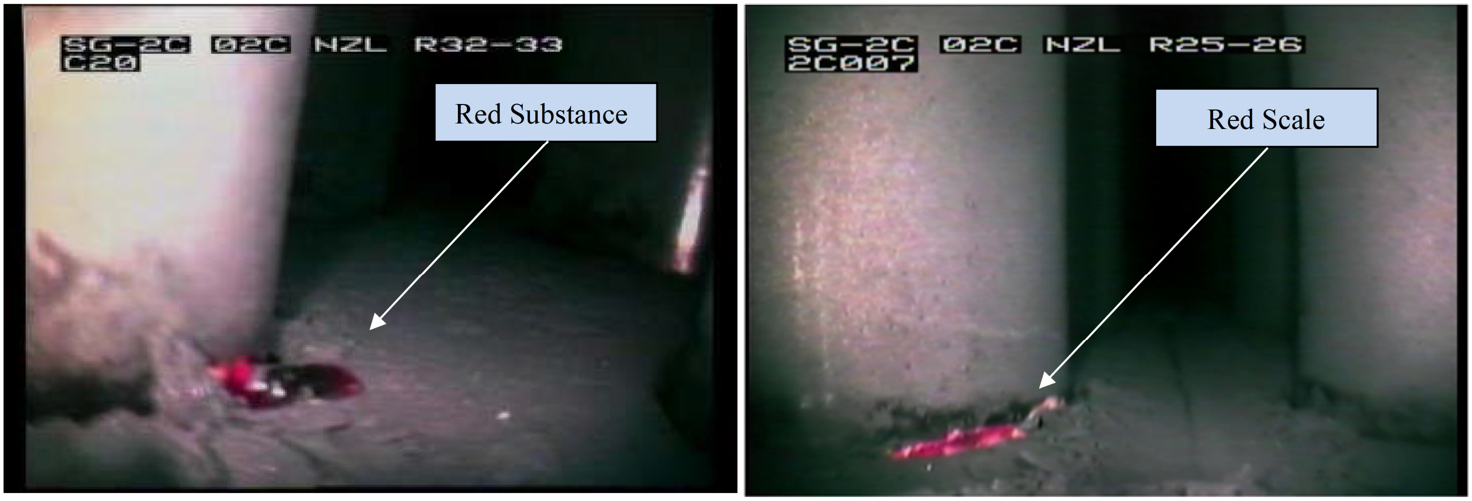

Figure D-2. A2R16 Examples of Red Substance and Red Scale in SG 2C TSP02C

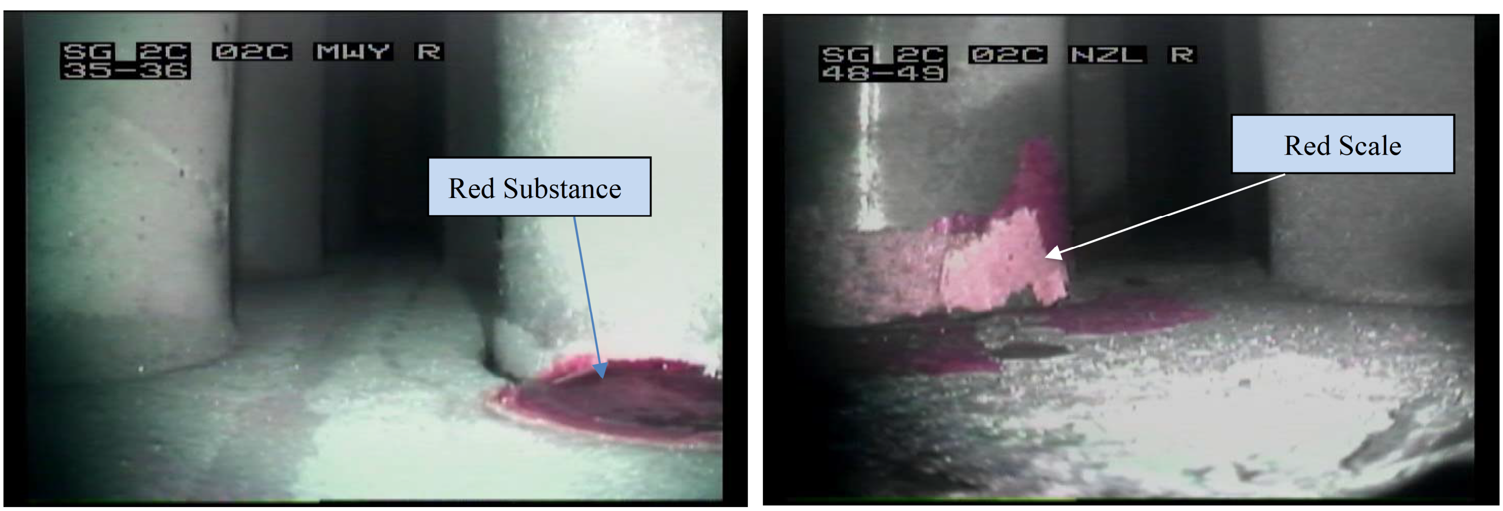

Figure D-3. A2R19 Examples of Red Substance and Red Scale in SG 2C TSP02C