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10 CFR 50.90

RS-05-044

April 11, 2005

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

Braidwood Station, Units 1 and 2
Facility Operating License Nos. NPF-72 and NPF-77
NRC Docket Nos. STN 50-456 and STN 50-457

Subject: Request for Exigent License Amendment Related to Technical Specification 5.5.9, "Steam Generator (SG) Tube Surveillance Program"

In accordance with 10 CFR 50.90, "Application for amendment of license or construction permit," Exelon Generation Company, LLC (EGC) is requesting an amendment to Appendix A, Technical Specifications (TS), of Facility Operating License Nos. NPF-72 and NPF-77 for Braidwood Station, Units 1 and 2, respectively.

The proposed one time change would revise TS 5.5.9, "Steam Generator (SG) Tube Surveillance Program," to incorporate changes in the SG inspection scope for Braidwood Station, Unit 2, during Refueling Outage 11 and the subsequent operating cycle. The proposed changes are applicable to only Unit 2 for inspections during Refueling Outage 11 and for the subsequent operating cycle. The proposed changes modify the inspection requirements for portions of SG tubes within the hot leg tubesheet region of the SGs. The license for Braidwood Station, Unit 1, is affected only due to the fact that Unit 1 and Unit 2 use common Technical Specifications.

The attached amendment request is subdivided as shown below.

Attachment 1 provides an evaluation of the proposed changes.

Attachment 2 includes the marked-up TS pages with the proposed changes indicated for Braidwood Station.

Attachment 3 includes the associated typed TS pages with the proposed changes incorporated for Braidwood Station.

Attachment 4 provides a List of Commitments resulting from this submittal.

Attachment 5 provides an application for withholding, affidavit, proprietary information notice, and copyright notice for information proprietary to Westinghouse Electric Company, LLC.

> Attachment 6 provides a non-proprietary version of Westinghouse Electric Company LTR-CDME-05-32-NP, "Limited Inspection of the Steam Generator Tube Portion Within the Tubesheet at Byron 2 & Braidwood 2," dated April 2005.
>
> Attachment 7 provides a proprietary version of Westinghouse Electric Company LTR-CDME-05-32-P, "Limited Inspection of the Steam Generator Tube Portion Within the Tubesheet at Byron 2 & Braidwood 2," dated April 2005.

Attachment 7 contains information proprietary to Westinghouse Electric Company LLC; 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 NRC and addresses with specificity the considerations listed in paragraph (b)(4) of 10 CFR 2.390, "Public inspections, exemptions, requests for withholding." Accordingly, it is respectfully requested that the information which is proprietary to Westinghouse be withheld from public disclosure in accordance with 10 CFR 2.390.

EGC requests that this proposed change be approved prior to initial entry into Mode 4 following Refueling Outage 11. We request that this proposed change be considered under exigent circumstances as described in 10 CFR 50.91, "Notice for public comment; State consultation," paragraph (a)(6), in that failure to act quickly could result in an extended outage for Braidwood Station, Unit 2. A statement of the exigent circumstances surrounding this request, as required by 10 CFR 50.91(a)(6), is included in Attachment 1.

The proposed amendment has been reviewed by the Braidwood Station Plant Operations Review Committee and approved by the Nuclear Safety Review Board in accordance with the requirements of the EGC Quality Assurance Program.

EGC is notifying the State of Illinois of this application for a change to the TS by sending a copy of this letter and its attachments to the designated State Official.

If you have any questions about this letter, please contact C. W. Szabo at (630) 657-2821.

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

Executed on April 11, 2005

Joseph A. Bauer
Joseph A. Bauer
Manager – Licensing

Attachment 1: Evaluation of Proposed Changes
Attachment 2: Markup of Proposed Technical Specifications Page Changes for Braidwood Station
Attachment 3: Typed Pages for Technical Specification Changes for Braidwood Station
Attachment 4: List of Commitments
Attachment 5: Westinghouse Application for Withholding and Affidavit

Attachment 6: Westinghouse Electric Company LTR-CDME-05-32-NP, "Limited Inspection of the Steam Generator Tube Portion Within the Tubesheet at Byron 2 & Braidwood 2," dated April 2005 - Non-Proprietary Version

Attachment 7: Westinghouse Electric Company LTR-CDME-05-32-P, "Limited Inspection of the Steam Generator Tube Portion Within the Tubesheet at Byron 2 & Braidwood 2," dated April 2005 – Proprietary Version

ATTACHMENT 1
Evaluation of Proposed Changes

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ATTACHMENT 1
Evaluation of Proposed Changes

1.0 DESCRIPTION

The proposed one time change would revise Technical Specification (TS) 5.5.9, "Steam Generator (SG) Tube Surveillance Program," to incorporate changes in the SG inspection scope for Braidwood Station, Unit 2, during Refueling Outage 11 and the subsequent operating cycle. The proposed changes are applicable to only Unit 2 for inspections during Refueling Outage 11 and for the subsequent operating cycle. The proposed changes modify the inspection requirements for portions of SG tubes within the hot leg tubesheet region of the SGs. The license for Braidwood Station, Unit 1, is affected only due to the fact that Unit 1 and Unit 2 use common Technical Specifications.

2.0 PROPOSED CHANGE

Proposed changes to TS 5.5.9 are summarized below.

TS 5.5.9.b, "SG Tube Sample Selection and Inspection"

A new requirement has been added (i.e., TS 5.5.9.b.5) to state:

> "For Unit 2 during Refueling Outage 11, a 20% minimum sample of all inservice tubes from the top of the hot leg tubesheet to 17 inches below the top of the tubesheet shall be inspected by rotating probe. This sample shall include a 20% minimum sample of the total population of bulges and overexpansions within the SG from the top of the hot leg tubesheet to 17 inches below the top of the tubesheet."

TS 5.5.9.e.6, "Plugging or Repair Limit"

Two new paragraphs have been added to state:

> "For Unit 2 during Refueling Outage 11 and the subsequent operating cycle, this definition does not apply to degradation identified in the portion of the tube below 17 inches from the top of the hot leg tubesheet. Degradation found in the portion of the tube below 17 inches from the top of the hot leg tubesheet does not require repair.
>
> For Unit 2 during Refueling Outage 11 and the subsequent operating cycle, degradation identified in the portion of the tube from the top of the hot leg tubesheet to 17 inches below the top of the tubesheet shall be repaired upon detection."

TS 5.5.9.e.8, "Tube Inspection"

A new paragraph has been added to state:

> "For Unit 2 during Refueling Outage 11 and the subsequent operating cycle, the portion of the tube below 17 inches from the top of the hot leg tubesheet is excluded."

TS 5.5.9.e, "Acceptance Criteria"

TS 5.5.9.e.12 has been added to define "Bulge" and "Overexpansion:"

> "For Unit 2 during Refueling Outage 11 and the subsequent operating cycle:
>
> Bulge refers to a tube diameter deviation within the tubesheet of 18 volts or greater as measured by bobbin coil probe; and
>
> Overexpansion refers to a tube diameter deviation within the tubesheet of 1.5 mils or greater as measured by bobbin coil probe."

The above proposed changes are applicable only to Braidwood Station, Unit 2, and are only applicable for SG tube inspections conducted during Refueling Outage 11 and the subsequent operating cycle. The license for Braidwood Station, Unit 1, is affected only due to the fact that Braidwood Station, Units 1 and 2, use common TS.

3.0 BACKGROUND

Braidwood Station, Unit 2, contains four Westinghouse Model D5 recirculating, pre-heater type SGs. Each SG contains 4,570 thermally treated Alloy-600 U-tubes that have an outer diameter of 0.750 inch with a 0.043 inch nominal wall thickness. The support plates are 1.125 inch thick stainless steel and have quatrefoil broached holes. The tubing within the tubesheet is hydraulically expanded throughout the full thickness of the tubesheet. The tubesheet is approximately 21 inches thick. The low row U-bend region, up through row nine, received additional thermal stress relief following tube bending. The unit operates on approximately 18-month fuel cycles.

The most recent Braidwood Station, Unit 2, SG tube inspection was performed in the November 2003 refueling outage. The SG inspection scope was governed by: Braidwood Station TS 5.5.9, the Electric Power Research Institute (EPRI) Pressurized Water Reactor (PWR) SG Examination Guidelines; regulatory documents and commitments; Exelon ER-AP-420 procedure series (Steam Generator Management Program Activities); and the results of a Braidwood Station, Unit 2, degradation assessment. The inspection techniques and equipment were capable of reliably detecting the known and potential specific degradation mechanisms applicable to the Braidwood Station, Unit 2, SGs. The inspection techniques, essential variables and equipment were qualified to Appendix H, "Performance Demonstration for Eddy Current Examination," of the EPRI PWR SG Examination Guidelines.

Subsequent to the most recent Braidwood Station, Unit 2, SG tube inspection, indications of cracking were reported based on the results from the nondestructive, eddy current examination of the SG tubes during the fall 2004 outage at Catawba Nuclear Station, Unit 2, as described in NRC Information Notice 2005-09, "Indications in Thermally Treated Alloy 600 Steam Generator Tubes and Tube-to-Tubesheet Welds," dated April 7, 2005. Tube indications were reported approximately seven inches from the top of the hot leg tubesheet in one tube, and just above the tube-to-tubesheet welds in a region of the tube known as the tack expansion in several other tubes. Finally, indications were also reported in the tube-end welds (TEWs), also known as tube-to-tubesheet welds, joining the tube to the tubesheet.

Catawba Nuclear Station, Unit 2, has Westinghouse designed Model D5 SGs similar to those in service at Braidwood Station, Unit 2. Model D5 SGs were fabricated with Alloy 600TT (i.e., thermally treated) tubes. Thus, there is a potential for tube indications similar to those reported at Catawba Nuclear Station, Unit 2, within the hot leg tubesheet region to be identified in the Braidwood Station, Unit 2, SGs if similar inspections were to be performed during the Refueling Outage 11 SG inspection. It is noted that the fabrication technique used for the installation of the SG tubes at Braidwood Station, Unit 2, would be expected to lead to a much lower likelihood for crack-like indications to be present in the region known as the tack expansion relative to Catawba Nuclear Station, Unit 2. The Braidwood Station, Unit 2, fabrication technique results in lower residual stress.

Potential inspection plans for the tubes and the welds underwent intensive industry discussions in March 2005. The findings in the Catawba Nuclear Station, Unit 2, SG tubes present three distinct issues with regard to the SG tubes at Braidwood Station, Unit 2:

1) indications in internal bulges and overexpansions within the hot leg tubesheet;
2) indications at the elevation of the tack expansion transition; and
3) indications in the tube-to-tubesheet welds and propagation of these indications into the adjacent tube material.

In order to preclude unnecessarily plugging tubes in the Braidwood Station, Unit 2, SGs, an analysis was performed to identify the portion of the tube within the hot leg tubesheet necessary to maintain structural and leakage integrity for both normal operating and accident conditions. Tube inspections will be limited to identifying and repairing degradation in this portion of the tubes. The technical justification for the inspection and repair methodology is provided in Westinghouse Electric Company LTR-CDME-05-32-P, "Limited Inspection of the Steam Generator Tube Portion Within the Tubesheet at Byron 2 & Braidwood 2," dated April 2005. The limited hot leg tubesheet inspection criteria were developed for the hot leg tubesheet region of Model D5 SGs considering the most stringent loads associated with plant operation, including transients and postulated accident conditions. The limited hot leg tubesheet inspection criteria were selected to prevent tube burst and axial separation due to axial pullout forces acting on the tube and to ensure that the steam line break (SLB) leakage limits are not exceeded. LTR-CDME-05-32-P provides technical justification for allowing tubes with indications that are below 17 inches from the top of the hot leg tubesheet (i.e., within approximately four inches of the tube end) to remain in-service.

Constraint provided by the hot leg tubesheet precludes tube burst for cracks within the tubesheet. The criteria for tube burst described in Nuclear Energy Institute (NEI) 97-06, "Steam Generator Program Guidelines," Revision 1 dated January 2001, and NRC Regulatory Guide (RG) 1.121, "Bases for Plugging Degraded PWR Steam Generator Tubes," dated August 1976, are satisfied due to the constraint provided by the tubesheet. Through application of the limited hot leg tubesheet inspection scope described herein, the existing operating leakage limit provides assurance that excessive leakage (i.e., greater than accident analysis assumptions) will not occur during a postulated SLB event.

Implementation of this proposed methodology involves limited inspection of the tubes within the hot leg tubesheet to depths of 17 inches from the top of the tubesheet using specialized rotating eddy current probes. The limited tubesheet inspection length of tubing must be demonstrated to be non-degraded below the top of the tubesheet interface. If cracks are found within the top of hot leg tubesheet to 17 inches below the top of tubesheet, the tube must be repaired or removed from service.

During a conference call on April 5, 2005, EGC and NRC personnel discussed the proposed limited hot leg tubesheet inspection for the Braidwood Station, Unit 2, SGs. It was concluded that application of a limited hot leg tubesheet inspection in areas where degradation potential could occur required a change to the Braidwood Station TS.

4.0 TECHNICAL ANALYSIS

A technical justification has been developed to identify the safety significant portion of the tube within the tubesheet. This justification is provided as Attachment 7 (i.e., LTR-CDME-05-32-P). The safety significant portion of the tube is the length of tube that is engaged in the tubesheet from the secondary face that is required to maintain structural and leakage integrity over the full range of steam generator operating conditions, including the most limiting accident conditions. The evaluation determined that degradation in tubing below the safety significant portion of the tube does not require repair and serves as the bases for the tubesheet inspection program.

The bases for determining the safety significant portion of the tube within the tubesheet is based upon analyses and testing programs that quantified the tube-to-tubesheet radial contact pressure for bounding plant conditions as described in LTR-CDME-05-32-P. The tube-to-tubesheet radial contact pressure provides resistance to tube pull-out and resistance to leakage during plant operation and transients. Temperature effects and upward bending of the tubesheet due to primary and secondary differential pressure during normal and transient conditions, result in the tube-to-tubesheet contact pressure increasing with distance from the top of the tubesheet. Due to these effects, the tubesheet bore tends to dilate near the top of the tubesheet and constricts the tube near the bottom of the tubesheet. Testing and analyses have shown that tube-to-tubesheet engagement lengths of approximately three inches to 8.6 inches were sufficient to maintain structural integrity (i.e., resist tube pull-out resulting from loading considering differential pressures of three times the normal operating pressure difference and 1.4 times the limiting accident pressure difference). The variation of the required engagement length is a function of the radial tube location within the tube bundle. EGC has decided to add additional conservatism to the minimum structural distances of three inches to 8.6 inches by performing inspections to depths of 17 inches below the top of the hot leg tubesheet. The increase in contact pressure at this depth significantly increases the tube structural strength and resistance to leakage.

Since the proposed 17-inch tube inspection depth traverses below the mid-plane of the hot leg tubesheet, the tube-to-tubesheet contact pressure significantly aids in restricting primary-to-secondary leakage as differential pressure increases. Based on engineering judgment, given that there is no significant primary-to-secondary leakage during normal operation, there will be no significant leakage during postulated accident conditions from indications located below the mid-plane of the tubesheet (i.e., greater than approximately

10.5 inches below the top of the tubesheet). The rationale for this conclusion is based upon the interaction of temperature and tubesheet bending effects that increases the contact pressure between the tube and the tubesheet.

Primary-to-secondary leakage from tube degradation in the tubesheet area during the limiting accident (i.e., a steam line break (SLB)) is limited by flow restrictions resulting from the crack and tube-to-tubesheet contact pressures that provide a restricted leakage path above the indications and also limit the degree of potential crack face opening as compared to free span indications. The primary-to-secondary leak rate during postulated SLB accident conditions would be expected to be less than that during normal operation for indications near the bottom of the tubesheet (i.e., including indications in the tube end welds). This conclusion is based on the observation that while the driving pressure causing leakage increases by approximately a factor of two, the flow resistance associated with an increase in the tube-to-tubesheet contact pressure, during a SLB, increases by approximately a factor of 2.5. While such a leakage decrease is logically expected, the postulated accident leak rate could be conservatively bounded by twice the normal operating leak rate if the increase in contact pressure is ignored. Since normal operating leakage is limited to less than 0.104 gpm (150 gpd) per TS 3.4.13, "RCS Operational Leakage," the associated accident condition leak rate, assuming all leakage to be from lower tubesheet indications, would be bounded by approximately 0.2 gpm. This value is well within the assumed accident leakage rate of 0.5 gpm discussed in Byron/Braidwood Updated Final Safety Analysis Report, Table 15.1-3, "Parameters Used in Steam Line Break Analyses." Hence it is reasonable to omit any consideration of inspection of the tube, tube end weld, bulges/overexpansions or other anomalies below 17 inches from the top of the hot leg tubesheet.

The proposed inspection sampling length of 17 inches from the top of the hot leg tubesheet provides a high level of confidence that the structural and leakage criteria are maintained during normal operating and accident conditions.

Degradation found in the portion of the tube below 17 inches from the top of the hot leg does not require repair or plugging as shown in LTR-CDME-05-32-P.

Exelon will implement the following inspection requirements in each SG in order to use the limited hot leg tubesheet inspection methodology:

1. Perform a 20% minimum inspection of the hot leg side tubes using rotating pancake probe (RPC) technology from three inches above the top of the hot leg tubesheet to three inches below the top of the tubesheet. Expand to 100% of the affected SG in this region only if cracking is found that is not associated with a bulge or overexpansion as described below.
2. Perform a 20% minimum inspection of the hot leg side tubes using RPC technology from the top of the hot leg tubesheet to 17 inches below the top of the tubesheet.

3. Perform a 20% minimum sample of the total population of bulges and overexpansions within the SG from the top of the hot leg tubesheet to 17 inches below the top of the tubesheet.
    a. Bulge refers to a tube diameter deviation within the tubesheet of 18 volts or greater as measured by bobbin coil probe based on review of the previous cycle bobbin data; and
    b. Overexpansion refers to a tube diameter deviation within the tubesheet of 1.5 mils or greater as measured by bobbin coil probe based on review of the previous cycle bobbin data.
4. If cracking is found in the sample population of bulges or overexpansions, the inspection scope will be increased to 100% of the bulges and overexpansions population for the region from the top of the hot leg tubesheet to 17 inches below the top of the tubesheet in the affected SG.
5. If cracking is reported at one or more tube locations not designated as either a top of the tubesheet expansion transition, a bulge or an overexpansion, an engineering evaluation will be performed. This evaluation will determine the cause for the signal, e.g., some other tube anomaly, in order to identify a critical area for the expansion of the inspection. This expanded inspection will be limited to the identified critical area within 17 inches from the top of the hot leg tubesheet.

Exelon will implement the following repair/plugging criteria and acceptance criteria.

- Degradation below 17 inches from the top of hot leg tubesheet is acceptable.
- Degradation within 17 inches from the top of hot leg tubesheet must be repaired.

In addition, the following regulatory commitment has been made: during Refueling Outage 11 and the subsequent operating cycle, no SG tube sleeves that have a connecting joint below 17 inches from the top of the hot leg tubesheet will be installed.

In summary:

- LTR-CDME-05-32-P notes that the structural integrity requirements of NEI 97-06, and RG 1.121, are met by sound tube engagement lengths ranging from approximately three to 8.6 inches from the top of the hot leg tubesheet. The region of the tube below those elevations, including the tube-to-tubesheet weld, is not needed for structural integrity during normal operation or accident conditions. EGC will, however, perform inspections to a depth of 17 inches from the top of the hot leg tubesheet.
- NEI 97-06 defines the tube as extending from the tube-to-tubesheet weld at the tube inlet to the tube-to-tubesheet weld at the tube outlet, but specifically excludes the tube-to-tubesheet weld from the definition of the tube.
- The welds were originally designed and analyzed as the primary pressure boundary in accordance with the requirements of Section III of the 1971 edition of the ASME Code,

Summer 1972 Addenda and selected paragraphs of the Winter 1974 Addenda for the Braidwood Station, Unit 2, SGs. This proposed license amendment request redefines the primary pressure boundary from the tube end weld to 17 inches below the top of the hot leg tube sheet.

- Section XI of the ASME Code deals with the in-service inspection of nuclear power plant components. The ASME Code (i.e., Editions 1971 through 2004) specifically recognizes that the SG tubes are under the purview of the NRC through the implementation of the requirements of the TS as part of the plant operating license.

5.0 REGULATORY ANALYSIS

5.1 No Significant Hazards Consideration

According to 10 CFR 50.92, "Issuance of amendment," paragraph (c), a proposed amendment to an operating license involves no significant hazards consideration if operation of the facility in accordance with the proposed amendment would not:

(1) Involve a significant increase in the probability or consequences of an accident previously evaluated; or

(2) Create the possibility of a new or different kind of accident from any accident previously evaluated; or

(3) Involve a significant reduction in a margin of safety.

In support of this determination, an evaluation of each of the three criteria set forth in 10 CFR 50.92 is provided below regarding the proposed license amendment.

Overview

In accordance with 10 CFR 50.90, "Application for amendment of license or construction permit," Exelon Generation Company, LLC (EGC) is requesting an amendment to Appendix A, Technical Specifications (TS), of Facility Operating License Nos. NPF-72 and NPF-77 for Braidwood Station, Units 1 and 2, respectively.

The proposed one time change would revise TS 5.5.9, "Steam Generator (SG) Tube Surveillance Program," to incorporate changes in the SG inspection scope for Braidwood Station, Unit 2, during Refueling Outage 11 and the subsequent operating cycle. The proposed changes are applicable to only Unit 2 for inspections during Refueling Outage 11 and for the subsequent operating cycle. The proposed changes modify the inspection requirements for portions of SG tubes within the hot leg tubesheet region of the SGs. The license for Braidwood Station, Unit 1, is affected only due to the fact that Unit 1 and Unit 2 use common Technical Specifications.

EGC has evaluated whether or not a significant hazards consideration is involved with the proposed TS changes by focusing on the three criteria set forth in 10 CFR 50.92 as discussed below:

Criteria

1. **Does the proposed change involve a significant increase in the probability or consequences of an accident previously evaluated?**

   Response: No.

   The previously analyzed accidents are initiated by the failure of plant structures, systems, or components. The proposed changes that alter the SG inspection criteria do not have a detrimental impact on the integrity of any plant structure, system, or component that initiates an analyzed event. The proposed changes will not alter the operation of, or otherwise increase the failure probability of any plant equipment that initiates an analyzed accident. Therefore, the proposed change does not involve a significant increase in the probability of an accident previously evaluated.

   Of the applicable accidents previously evaluated, the limiting transients with consideration to the proposed changes to the SG tube inspection criteria, are the SG tube rupture (SGTR) event and the steam line break (SLB) accident.

   During the SGTR event, the required structural integrity margins of the SG tubes will be maintained by the presence of the SG tubesheet. SG tubes are hydraulically expanded in the tubesheet area. Tube rupture in tubes with cracks in the tubesheet is precluded by the constraint provided by the tubesheet. This constraint results from the hydraulic expansion process, thermal expansion mismatch between the tube and tubesheet and from the differential pressure between the primary and secondary side. Based on this design, the structural margins against burst, discussed in Regulatory Guide (RG) 1.121, "Bases for Plugging Degraded PWR SG Tubes," are maintained for both normal and postulated accident conditions.

   The proposed changes do not affect other systems, structures, components or operational features. Therefore, the proposed changes result in no significant increase in the probability of the occurrence of a SGTR accident.

   At normal operating pressures, leakage from primary water stress corrosion cracking (PWSCC) below the proposed limited inspection depth is limited by both the tube-to-tubesheet crevice and the limited crack opening permitted by the tubesheet constraint. Consequently, negligible normal operating leakage is expected from cracks within the tubesheet region. The consequences of an SGTR event are affected by the primary-to-secondary leakage flow during the event. Primary-to-secondary leakage flow through a postulated broken tube is not affected by the proposed change since the tubesheet enhances the tube integrity in the region of the hydraulic expansion by precluding tube deformation beyond its initial hydraulically expanded outside diameter.

   The probability of a SLB is unaffected by the potential failure of a SG tube as this failure is not an initiator for a SLB.

   The consequences of a SLB are also not significantly affected by the proposed changes. During a SLB accident, the reduction in pressure above the tubesheet on the shell side of the SG creates an axially uniformly distributed load on the tubesheet due to the reactor coolant system pressure on the underside of the tubesheet. The resulting bending action constrains the tubes in the tubesheet thereby restricting primary-to-secondary leakage below the midplane.

Primary-to-secondary leakage from tube degradation in the tubesheet area during the limiting accident (i.e., a steam line break (SLB)) is limited by flow restrictions resulting from the crack and tube-to-tubesheet contact pressures that provide a restricted leakage path above the indications and also limit the degree of potential crack face opening as compared to free span indications. The primary-to-secondary leak rate during postulated SLB accident conditions would be expected to be less than that during normal operation for indications near the bottom of the tubesheet (i.e., including indications in the tube end welds). This conclusion is based on the observation that while the driving pressure causing leakage increases by approximately a factor of two, the flow resistance associated with an increase in the tube-to-tubesheet contact pressure, during a SLB, increases by approximately a factor of 2.5. While such a leakage decrease is logically expected, the postulated accident leak rate could be conservatively bounded by twice the normal operating leak rate if the increase in contact pressure is ignored. Since normal operating leakage is limited to less than 0.104 gpm (150 gpd) per TS 3.4.13, "RCS Operational Leakage," the associated accident condition leak rate, assuming all leakage to be from lower tubesheet indications, would be bounded by approximately 0.2 gpm. This value is well within the assumed accident leakage rate of 0.5 gpm discussed in Updated Final Safety Analysis Table 15.1-3, "Parameters Used in Steam Line Break Analyses." Hence it is reasonable to omit any consideration of inspection of the tube, tube end weld, bulges/overexpansions or other anomalies below 17 inches from the top of the hot leg tubesheet. Therefore, the consequences of a SLB accident remain unaffected.

Based on the above discussion, the proposed changes do not involve an increase in the consequences of an accident previously evaluated.

2. **Does the proposed change create the possibility of a new or different kind of accident from any accident previously evaluated?**

Response: No.

The proposed changes do not involve the use or installation of new equipment and the currently installed equipment will not be operated in a new or different manner. No new or different system interactions are created and no new processes are introduced. The proposed changes will not introduce any new failure mechanisms, malfunctions, or accident initiators not already considered in the design and licensing bases.

Based on this evaluation, the proposed change does not create the possibility of a new or different kind of accident from any accident previously evaluated.

3. **Does the proposed change involve a significant reduction in a margin of safety?**

Response: No.

The proposed changes maintain the required structural margins of the SG tubes for both normal and accident conditions. Nuclear Energy Institute (NEI) 97-06, "Steam Generator Program Guidelines," Revision 1 and Regulatory Guide (RG) 1.121, "Bases for Plugging Degraded PWR Steam Generator Tubes," are used as the bases in the development of the limited hot leg tubesheet inspection depth methodology for determining that SG tube integrity considerations are maintained within acceptable limits. RG 1.121 describes a method acceptable to the NRC for meeting General Design Criteria (GDC) 14, "Reactor coolant pressure boundary," GDC 15, "Reactor coolant system design," GDC 31, "Fracture prevention of reactor coolant pressure boundary," and GDC 32, "Inspection of reactor coolant pressure boundary," by reducing the probability and consequences of a SGTR. RG 1.121 concludes that by determining the limiting safe conditions for tube wall degradation the probability and consequences of a SGTR are reduced. This RG uses safety factors on loads for tube burst that are consistent with the requirements of Section III of the American Society of Mechanical Engineers (ASME) Code.

For axially oriented cracking located within the tubesheet, tube burst is precluded due to the presence of the tubesheet. For circumferentially oriented cracking, Westinghouse letter LTR-CDME-05-32-P, "Limited Inspection of the Steam Generator Tube Portion Within the Tubesheet at Braidwood Unit 2 and Byron Unit 2," dated April 2005, defines a length of degradation free expanded tubing that provides the necessary resistance to tube pullout due to the pressure induced forces, with applicable safety factors applied. Application of the limited hot leg tubesheet inspection depth criteria will preclude unacceptable primary-to-secondary leakage during all plant conditions. The methodology for determining leakage provides for large margins between calculated and actual leakage values in the proposed limited hot leg tubesheet inspection depth criteria.

Therefore, the proposed changes do not involve a significant hazards consideration under the criteria set forth in 10 CFR 50.92(c).

5.2 Applicable Regulatory Requirements Criteria

Section 182a of the Atomic Energy Act requires applicants for nuclear power plant operating licenses to include technical specifications (TS) as part of the license. The Commission's regulatory requirements related to the content of the TS are contained in Title 10, Code of Federal Regulations (10 CFR), Section 50.36, "Technical specifications." The TS requirements in 10 CFR 50.36 include the following categories: (1) safety limits, limiting safety systems settings and control settings, (2) limiting conditions for operation (LCO), (3) surveillance requirements, (4) design features, and (5) administrative controls. The SG tube inspection requirements are included in the TS in accordance with 10 CFR 50.36(c)(5), "Limiting Conditions for Operation."

As stated in 10 CFR 50.59, "Changes, tests, and experiments," paragraph (c)(1)(i), a licensee is required to submit a license amendment pursuant to 10 CFR 50.90, "Application for amendment of license or construction permit," if a change to the TS is required. Furthermore, the requirements of 10 CFR 50.59 necessitate that the NRC approve the TS changes before the TS changes are implemented. EGC's submittal meets the requirements of 10 CFR 50.59(c)(1)(i) and 10 CFR 50.90.

Regulatory Guide (RG) 1.121, "Bases for Plugging Degraded PWR Steam Generator Tubes," margins against burst are maintained for both normal and postulated accident conditions due to the constraint provided by the tubesheet.

NRC Information Notice 2005-09, “Indications in Thermally Treated Alloy 600 Steam Generator Tubes and Tube-to-Tubesheet Welds,” dated April 7, 2005, provides additional regulatory insight regarding SG tube degradation.

6.0 ENVIRONMENTAL CONSIDERATION

A review has determined that the proposed amendment would change a requirement with respect to installation or use of a facility component located within the restricted area, as defined in 10 CFR 20, “Standards for protection against radiation,” or would change an inspection or surveillance requirement. However, the proposed amendment does not involve (i) a significant hazards consideration, (ii) a significant change in the types or significant increase in the amounts of any effluent that may be released offsite, or (iii) a significant increase in individual or cumulative occupational radiation exposure. Accordingly, the proposed amendment meets the eligibility criterion for categorical exclusion set forth in paragraph (c)(9) of 10 CFR 51.22, “Criterion for categorical exclusion; identification of licensing and regulatory actions eligible for categorical exclusion or otherwise not requiring environmental review.” Therefore, pursuant to 10 CFR 51.22(b), no environmental impact statement or environmental assessment need be prepared in connection with the proposed amendment.

7.0 STATEMENT OF EXIGENT CIRCUMSTANCES

10 CFR 50.91, “Notice for public comment; State consultation,” paragraph (a)(6), states that whenever an exigent condition exists, a licensee requesting an amendment must explain why this exigent situation occurred and why it could not be avoided.

On December 17, 2004, the industry was notified that tube degradation had been detected in the tubesheet region in Catawba Nuclear Station, Unit 2, Westinghouse Model D5 steam generators (SGs), which are similar in design to the Braidwood Station, Unit 2, SGs. This information was considered in the Braidwood Station, Unit 2, Refueling Outage 11 degradation assessment that was completed on January 26, 2005. The degradation assessment concluded that tube degradation could potentially occur in the Braidwood Station, Unit 2, SG tubesheet region. Specific potential degradation locations are the top of tubesheet expansion transition region, tube bulge or overexpansion locations, tack expansion region and degradation propagating from the tube end weld into the tube. Consequently, a sampling program was developed to inspect these areas. In preparation for the inspection of these regions, a method for dispositioning potential indications within the tube end weld was initiated. By mid-March 2005, EGC concluded that degradation contained within the tube end weld could not be properly addressed by American Society of Mechanical Engineers (ASME) code analysis methods. EGC also determined that the bottom portion of the tube is not a critical portion of the tube necessary to maintain structural and leakage integrity. An analysis was performed to justify a limited tubesheet inspection in the region from the top of the hot leg tubesheet to 17 inches below the top of the tubesheet.

During a conference call on April 5, 2005, EGC and NRC personnel discussed the proposed limited tubesheet inspection for the Braidwood Station, Unit 2, SGs. It was concluded that application of a limited tubesheet inspection in areas where degradation potential could occur required a change to the Technical Specification (TS) 5.5.9, “Steam Generator (SG)

Tube Surveillance Program." Additional regulatory guidance is contained in NRC Information Notice 2005-09, "Indications in Thermally Treated Alloy 600 Steam Generator Tubes and Tube-to-Tubesheet Welds," issued on April 7, 2005. Information Notice 2005-09 provided further details of the findings at Catawba Nuclear Station, Unit 2.

Due to the short time interval between identification of the need for a TS change to allow a limited SG inspection scope based on the guidance provided in Information Notice 2005-09, and the actual performance of the Braidwood, Unit 2, SG inspection in the upcoming refueling outage, insufficient time remains for normal NRC processing and notification. Therefore, EGC requests that this proposed TS change be considered under exigent circumstances as described in 10 CFR 50.91(a)(6).

8.0 REFERENCES

1. LTR-CDME-05-32-P, "Limited Inspection of the Steam Generator Tube Portion Within the Tubesheet at Braidwood Unit 2 and Byron Unit 2," April 2005

2. NRC Information Notice 2005-09, "Indications in Thermally Treated Alloy 600 Steam Generator Tubes and Tube-to-Tubesheet Welds," dated April 7, 2005

3. NEI 97-06, "Steam Generator Program Guidelines," Revision 1 dated January 2001

4. Regulatory Guide 1.121, "Bases for Plugging Degraded PWR Steam Generator Tubes," dated August 1976

Attachment 2

BRAIDWOOD STATION
UNITS 1 AND 2

Docket Nos. 50-456 and 50-457

License Nos. NPF-72 and NPF-77

Request for Exigent License Amendment Related to Technical Specification 5.5.9, "Steam Generator (SG) Tube Surveillance Program"

Markup of Technical Specifications Pages

5.5-9
5.5-12
5.5-13
5.5-14

5.5 Programs and Manuals

5.5.9 Steam Generator (SG) Tube Surveillance Program (continued)

4. A random sample of ≥ 20% of the total number of laser welded sleeves and ≥ 20% of the total number of Tungsten Inert Gas (TIG) welded sleeves installed shall be inspected for axial and circumferential indications at the end of each cycle. In the event that an imperfection exceeding the repair limit is detected, an additional 20% of the unsampled sleeves shall be inspected and if an imperfection exceeding the repair limit is detected in the second sample, all remaining sleeves shall be inspected. These inservice inspections will include the entire sleeve, the tube at the heat treated area, and the tube-to-sleeve joints. The inservice inspection for the sleeves is required on all types of sleeves installed in the SGs to demonstrate acceptable structural integrity☒ ;

c. Inspection Results Classification

The results of each sample inspection shall be classified into one of the following three categories:

----------------------------NOTE----------------------------
Previously degraded tubes or sleeves must exhibit significant (> 10% of wall thickness) further wall penetrations to be included in the percentage calculations.

Category	Inspection Results
C-1	< 5% of the total tubes inspected are degraded tubes and none of the inspected tubes are defective.
C-2	One or more tubes, but ≤ 1% of the total tubes inspected are defective, or ≥ 5% and ≤ 10% of the total tubes inspected are degraded tubes.
C-3	> 10% of the total tubes inspected are degraded tubes or > 1% of the inspected tubes are defective.

5. For Unit 2 during Refueling Outage 11, a 20% minimum sample of all inservice tubes from the top of the hot leg tubesheet to 17 inches below the top of the tubesheet shall be inspected by rotating probe. This sample shall include a 20% minimum sample of the total population of bulges and overexpansions within the SG from the top of the hot leg tubesheet to 17 inches below the top of the tubesheet.

5.5 Programs and Manuals

5.5.9 Steam Generator (SG) Tube Surveillance Program (continued)

e. Acceptance Criteria

1. Imperfection means an exception to the dimensions, finish or contour of a tube or sleeve from that required by fabrication drawings or specifications. Eddy current testing indications < 20% of the nominal tube or sleeve wall thickness, if detectable, may be considered as imperfections;

2. Degradation means a service induced cracking, wastage, wear or general corrosion occurring on either inside or outside of a tube or sleeve;

3. Degraded Tube means a tube or sleeve containing unrepaired imperfections ≥ 20% of the nominal tube or sleeve wall thickness caused by degradation;

4. % Degradation means the percentage of the tube or sleeve wall thickness affected or removed by degradation;

5. Defect means an imperfection of such severity that it exceeds the plugging or repair limit. A tube or sleeve containing an unrepaired defect is defective;

6. Plugging or Repair Limit means the imperfection depth at or beyond which the tube shall be removed from service by plugging or repaired by sleeving in the affected area. The plugging or repair limit imperfection depth for the tubing is equal to 40% of the nominal wall thickness. The plugging limit imperfection depth for laser welded sleeves is equal to 38.7% of the nominal wall thickness. The plugging limit imperfection depth for TIG welded sleeves is equal to 32% of the nominal wall thickness~~;~~ ← .

For Unit 2 during Refueling Outage 11 and the subsequent operating cycle, this definition does not apply to degradation identified in the portion of the tube below 17 inches from the top of the hot leg tubesheet. Degradation found in the portion of the tube below 17 inches from the top of the hot leg tubesheet does not require repair.

For Unit 2 during Refueling Outage 11 and the subsequent operating cycle, degradation identified in the portion of the tube from the top of the hot leg tubesheet to 17 inches below the top of the tubesheet shall be repaired upon detection;

7. Unserviceable describes the condition of a tube if it leaks or contains a defect large enough to affect its structural integrity in the event of an OBE, LOCA, or a steam line or feedwater line break as specified in Specification 5.5.9.d.4;

5.5 Programs and Manuals

5.5.9 Steam Generator (SG) Tube Surveillance Program (continued)

8. Tube Inspection means an inspection of the SG tube from the point of entry (hot leg side) completely around the U-bend to the top support of the cold leg. For a tube that has been repaired by sleeving, the tube inspection shall include the sleeved portion of the tube~~;~~ .

9. Preservice Inspection means an inspection of the full length of each tube in each SG performed by eddy current techniques prior to service to establish a baseline condition of the tubing. This inspection shall be performed prior to initial MODE 1 operation using the equipment and techniques expected to be used during subsequent inservice inspections;

10. Tube Repair refers to a process that reestablishes tube serviceability. Acceptable tube repairs will be performed by the following processes:

    i. Laser welded sleeving as described in a Westinghouse Technical Report and subject to the limitations and restrictions as approved by the NRC, or

    ii. TIG welded sleeving as described in ABB Combustion Engineering Inc., Technical Reports: Licensing Report CEN-621-P, Revision 00, "Commonwealth Edison Byron and Braidwood Unit 1 and 2 Steam Generators Tube Repair Using Leak Tight Sleeves, FINAL REPORT," April 1995; and Licensing Report CEN-627-P, Operating Performance of the ABB CENO Steam Generator Tube Sleeve for Use at Commonwealth Edison Byron and Braidwood Units 1 and 2," January 1996; subject to the limitations and restrictions as noted by the NRC Staff.

    Tube repair includes the removal of plugs that were previously installed as a corrective or preventative measure. A tube inspection per Specification 5.5.9.e.8 is required prior to returning previously plugged tubes to service; ~~and~~

For Unit 2 during Refueling Outage 11 and the subsequent operating cycle, the portion of the tube below 17 inches from the top of the hot leg tubesheet is excluded;

5.5 Programs and Manuals

5.5.9 Steam Generator (SG) Tube Surveillance Program (continued)

11. The SG shall be determined OPERABLE after completing the corresponding actions (plug or repair in the affected area all tubes exceeding the plugging or repair limit) required by Table 5.5.9-2~~.~~ ; and

---

5.5.10 Secondary Water Chemistry Program

This program provides controls for monitoring secondary water chemistry to inhibit SG tube degradation. The program shall include:

a. Identification of a sampling schedule for the critical variables and control points for these variables;

b. Identification of the procedures used to measure the values of the critical variables;

c. Identification of process sampling points, which shall include monitoring the discharge of the condensate pumps for evidence of condenser inleakage;

d. Procedures for the recording and management of data;

e. Procedures defining corrective actions for all off control point chemistry conditions; and

f. A procedure identifying the authority responsible for the interpretation of the data and the sequence and timing of administrative events, which is required to initiate corrective action.

12. For Unit 2 during Refueling Outage 11 and the subsequent operating cycle:

<u>Bulge</u> refers to a tube diameter deviation within the tubesheet of 18 volts or greater as measured by bobbin coil probe; and

<u>Overexpansion</u> refers to a tube diameter deviation within the tubesheet of 1.5 mils or greater as measured by bobbin coil probe.

Attachment 3

BRAIDWOOD STATION
UNITS 1 AND 2

Docket Nos. 50-456 and 50-457

License Nos. NPF-72 and NPF-77

Request for Exigent License Amendment Related to Technical Specification 5.5.9, “Steam Generator (SG) Tube Surveillance Program”

Typed Technical Specifications Pages

5.5-9
5.5-12
5.5-13
5.5-14

5.5 Programs and Manuals

5.5.9 Steam Generator (SG) Tube Surveillance Program (continued)

4. A random sample of ≥ 20% of the total number of laser welded sleeves and ≥ 20% of the total number of Tungsten Inert Gas (TIG) welded sleeves installed shall be inspected for axial and circumferential indications at the end of each cycle. In the event that an imperfection exceeding the repair limit is detected, an additional 20% of the unsampled sleeves shall be inspected and if an imperfection exceeding the repair limit is detected in the second sample, all remaining sleeves shall be inspected. These inservice inspections will include the entire sleeve, the tube at the heat treated area, and the tube-to-sleeve joints. The inservice inspection for the sleeves is required on all types of sleeves installed in the SGs to demonstrate acceptable structural integrity;

5. For Unit 2 during Refueling Outage 11, a 20% minimum sample of all inservice tubes from the top of the hot leg tubesheet to 17 inches below the top of the tubesheet shall be inspected by rotating probe. This sample shall include a 20% minimum sample of the total population of bulges and overexpansions within the SG from the top of the hot leg tubesheet to 17 inches below the top of the tubesheet.

c. Inspection Results Classification

The results of each sample inspection shall be classified into one of the following three categories:

----------------------------NOTE----------------------------

Previously degraded tubes or sleeves must exhibit significant (> 10% of wall thickness) further wall penetrations to be included in the percentage calculations.

Category	Inspection Results
C-1	< 5% of the total tubes inspected are degraded tubes and none of the inspected tubes are defective.
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C-3	> 10% of the total tubes inspected are degraded tubes or > 1% of the inspected tubes are defective.

5.5.9 Steam Generator (SG) Tube Surveillance Program (continued)

e. Acceptance Criteria

1. Imperfection means an exception to the dimensions, finish or contour of a tube or sleeve from that required by fabrication drawings or specifications. Eddy current testing indications < 20% of the nominal tube or sleeve wall thickness, if detectable, may be considered as imperfections;

2. Degradation means a service induced cracking, wastage, wear or general corrosion occurring on either inside or outside of a tube or sleeve;

3. Degraded Tube means a tube or sleeve containing unrepaired imperfections ≥ 20% of the nominal tube or sleeve wall thickness caused by degradation;

4. % Degradation means the percentage of the tube or sleeve wall thickness affected or removed by degradation;

5. Defect means an imperfection of such severity that it exceeds the plugging or repair limit. A tube or sleeve containing an unrepaired defect is defective;

6. Plugging or Repair Limit means the imperfection depth at or beyond which the tube shall be removed from service by plugging or repaired by sleeving in the affected area. The plugging or repair limit imperfection depth for the tubing is equal to 40% of the nominal wall thickness. The plugging limit imperfection depth for laser welded sleeves is equal to 38.7% of the nominal wall thickness. The plugging limit imperfection depth for TIG welded sleeves is equal to 32% of the nominal wall thickness.

   For Unit 2 during Refueling Outage 11 and the subsequent operating cycle, this definition does not apply to degradation identified in the portion of the tube below 17 inches from the top of the hot leg tubesheet. Degradation found in the portion of the tube below 17 inches from the top of the hot leg tubesheet does not require repair.

   For Unit 2 during Refueling Outage 11 and the subsequent operating cycle, degradation identified in the portion of the tube from the top of the hot leg tubesheet to 17 inches below the top of the tubesheet shall be repaired upon detection;

5.5 Programs and Manuals

5.5.9 <u>Steam Generator (SG) Tube Surveillance Program</u> (continued)

7. <u>Unserviceable</u> describes the condition of a tube if it leaks or contains a defect large enough to affect its structural integrity in the event of an OBE, LOCA, or a steam line or feedwater line break as specified in Specification 5.5.9.d.4;

8. <u>Tube Inspection</u> means an inspection of the SG tube from the point of entry (hot leg side) completely around the U-bend to the top support of the cold leg. For a tube that has been repaired by sleeving, the tube inspection shall include the sleeved portion of the tube.

   For Unit 2 during Refueling Outage 11 and the subsequent operating cycle, the portion of the tube below 17 inches from the top of the hot leg tubesheet is excluded;

9. <u>Preservice Inspection</u> means an inspection of the full length of each tube in each SG performed by eddy current techniques prior to service to establish a baseline condition of the tubing. This inspection shall be performed prior to initial MODE 1 operation using the equipment and techniques expected to be used during subsequent inservice inspections;

10. <u>Tube Repair</u> refers to a process that reestablishes tube serviceability. Acceptable tube repairs will be performed by the following processes:

    i. Laser welded sleeving as described in a Westinghouse Technical Report and subject to the limitations and restrictions as approved by the NRC, or

    ii. TIG welded sleeving as described in ABB Combustion Engineering Inc., Technical Reports: Licensing Report CEN-621-P, Revision 00, "Commonwealth Edison Byron and Braidwood Unit 1 and 2 Steam Generators Tube Repair Using Leak Tight Sleeves, FINAL REPORT," April 1995; and Licensing Report CEN-627-P, Operating Performance of the ABB CENO Steam Generator Tube Sleeve for Use at Commonwealth Edison Byron and Braidwood Units 1 and 2," January 1996; subject to the limitations and restrictions as noted by the NRC Staff.

5.5 Programs and Manuals

5.5.9 Steam Generator (SG) Tube Surveillance Program (continued)

Tube repair includes the removal of plugs that were previously installed as a corrective or preventative measure. A tube inspection per Specification 5.5.9.e.8 is required prior to returning previously plugged tubes to service;

11. The SG shall be determined OPERABLE after completing the corresponding actions (plug or repair in the affected area all tubes exceeding the plugging or repair limit) required by Table 5.5.9-2; and

12. For Unit 2 during Refueling Outage 11 and the subsequent operating cycle:

    Bulge refers to a tube diameter deviation within the tubesheet of 18 volts or greater as measured by bobbin coil probe; and

    Overexpansion refers to a tube diameter deviation within the tubesheet of 1.5 mils or greater as measured by bobbin coil probe.

5.5.10 Secondary Water Chemistry Program

This program provides controls for monitoring secondary water chemistry to inhibit SG tube degradation. The program shall include:

a. Identification of a sampling schedule for the critical variables and control points for these variables;

b. Identification of the procedures used to measure the values of the critical variables;

c. Identification of process sampling points, which shall include monitoring the discharge of the condensate pumps for evidence of condenser inleakage;

d. Procedures for the recording and management of data;

e. Procedures defining corrective actions for all off control point chemistry conditions; and

f. A procedure identifying the authority responsible for the interpretation of the data and the sequence and timing of administrative events, which is required to initiate corrective action.

Attachment 4

BRAIDWOOD STATION
UNITS 1 AND 2

Docket Nos. 50-456 and 50-457

License Nos. NPF-72 and NPF-77

Request for Exigent License Amendment Related to Technical Specification 5.5.9, “Steam Generator (SG) Tube Surveillance Program”

List of Commitments

List of Commitments

The following table identifies those actions committed to by Exelon in this document. Any other statements in this submittal are provided for information purposes and are not considered to be regulatory commitments.

Commitment	Scheduled Completion Date
During Braidwood Station, Unit 2, Refueling Outage 11 and the subsequent operating cycle, no SG tube sleeves that have a connecting joint below 17 inches from the top of the hot leg tubesheet will be installed.	Upon Implementation

Attachment 5

BRAIDWOOD STATION
UNITS 1 AND 2

Docket Nos. 50-456 and 50-457

License Nos. NPF-72 and NPF-77

Request for Exigent License Amendment Related to Technical Specification 5.5.9, "Steam Generator (SG) Tube Surveillance Program"

Westinghouse Application for Withholding and Affidavit

Westinghouse

Westinghouse Electric Company
Nuclear Services
P.O. Box 355
Pittsburgh, Pennsylvania 15230-0355
USA

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

Direct tel: (412) 374-4643
Direct fax: (412) 374-4011
e-mail: greshaja@westinghouse.com

Our ref: CAW-05-1979

April 8, 2005

APPLICATION FOR WITHHOLDING PROPRIETARY INFORMATION FROM PUBLIC DISCLOSURE

Subject: LTR-CDME-05-32-P, "Limited Inspection of the Steam Generator Tube Portion Within the Tubesheet at Byron 2 and Braidwood 2" (Proprietary)

The proprietary information for which withholding is being requested in the above-referenced report is further identified in Affidavit CAW-05-1979 signed by the owner of the proprietary information, Westinghouse Electric Company LLC. The affidavit, which accompanies this letter, sets forth the basis on which the information may be withheld from public disclosure by the Commission and addresses with specificity the considerations listed in paragraph (b)(4) of 10 CFR Section 2.390 of the Commission's regulations.

Accordingly, this letter authorizes the utilization of the accompanying affidavit by Exelon Generation Company, LLC.

Correspondence with respect to the proprietary aspects of the application for withholding or the Westinghouse affidavit should reference this letter, CAW-05-1979, and should be addressed to J. A. Gresham, Manager, Regulatory Compliance and Plant Licensing, Westinghouse Electric Company LLC, P.O. Box 355, Pittsburgh, Pennsylvania 15230-0355.

Very truly yours,

JAGresham

J. A. Gresham, Manager
Regulatory Compliance and Plant Licensing

Enclosures

cc: B. Benney, NRC
L. Feizollahi, NRC

bcc: J. A. Gresham (ECE 4-7A) 1L
R. Bastien, 1L (Nivelles, Belgium)
C. Brinkman, 1L (Westinghouse Electric Co., 12300 Twinbrook Parkway, Suite 330, Rockville, MD 20852)
RCPL Administrative Aide (ECE 4-7A) 1L, 1A (letter and affidavit only)
E. P. Morgan, Waltz Mill
J. Bunecicky, ECE 5 10C
D. W. Alexander, ECE 510
G. W. Whiteman, Waltz Mill
R. F. Keating, Waltz Mill
H. O. Lagally Waltz Mill

CAW-05-1979

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF ALLEGHENY:

Before me, the undersigned authority, personally appeared J. **A.** Gresham, who, being by me duly sworn according to law, deposes and says that he is authorized to execute this Affidavit on behalf of Westinghouse Electric Company LLC (Westinghouse), and that the averments of fact set forth in this Affidavit are true and correct to the best of his knowledge, information, and belief:

JA Gresham

J. A. Gresham, Manager
Regulatory Compliance and Plant Licensing

Sworn to and subscribed
before me this 8th day
of April, 2005

Sharon L. Fiori
Notary Public

Sharon L. Fiori, Notary Public
My Commission Expires January 29, 2007

(1) I am Manager, Regulatory Compliance and Plant Licensing, in Nuclear Services, Westinghouse Electric Company LLC (Westinghouse), and as such, I have been specifically delegated the function of reviewing the proprietary information sought to be withheld from public disclosure in connection with nuclear power plant licensing and rule making proceedings, and am authorized to apply for its withholding on behalf of Westinghouse.

(2) I am making this Affidavit in conformance with the provisions of 10 CFR Section 2.390 of the Commission's regulations and in conjunction with the Westinghouse "Application for Withholding" accompanying this Affidavit.

(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 the provisions of paragraph (b)(4) of Section 2.390 of the Commission's regulations, 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.

(ii) The information is of a type customarily held in confidence by Westinghouse and not customarily disclosed to the public. Westinghouse has a rational basis for determining the types of information customarily held in confidence by it and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The application of that system and the substance of that system constitutes Westinghouse policy and provides the rational basis required.

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.

There are sound policy reasons behind the Westinghouse system which include the following:

(a) The use of such information by Westinghouse gives Westinghouse a competitive advantage over its competitors. It is, therefore, withheld from disclosure to protect the Westinghouse competitive position.

(b) It is information that is marketable in many ways. The extent to which such information is available to competitors diminishes the Westinghouse ability to sell products and services involving the use of the information.

(c) Use by our competitor would put Westinghouse at a competitive disadvantage by reducing his expenditure of resources at our expense.

(d) Each component of proprietary information pertinent to a particular competitive advantage is potentially as valuable as the total competitive advantage. If competitors acquire components of proprietary information, any one component may be the key to the entire puzzle, thereby depriving Westinghouse of a competitive advantage.

(e) Unrestricted disclosure would jeopardize the position of prominence of Westinghouse in the world market, and thereby give a market advantage to the competition of those countries.

(f) The Westinghouse capacity to invest corporate assets in research and development depends upon the success in obtaining and maintaining a competitive advantage.

(iii) The information is being transmitted to the Commission in confidence and, under the provisions of 10 CFR Section **2.390,** it is to be received in confidence by the Commission.

(iv) The information sought to be protected is not available in public sources or available information has not been previously employed in the same original manner or method to the best of our knowledge and belief.

(v) The proprietary information sought to be withheld in this submittal is that which is appropriately marked in LTR-CDME-05-32-P, "Limited Inspection of the Steam Generator Tube Portion Within the Tubesheet at Byron 2 and Braidwood Unit **2"** (Proprietary) dated April 2005. The information is provided in support of a submittal to the Commission, being transmitted by Exelon Generation Co., LLC and Application for Withholding Proprietary Information from Public Disclosure, to the Document Control Desk. The proprietary information as submitted for use by Westinghouse for Braidwood Unit 2 is expected to be applicable to other licensee submittals in support of implementing a limited inspection of the tubejoint with a rotating probe within the tubesheet region of the steam generators.

This information is part of that which will enable Westinghouse to:

(a) Provide documentation of the analyses, methods, and testing for the implementation of the limited inspection length of the steam generator tubejoint.

(b) Provide a primary-to-secondary leakage evaluation for Braidwood Unit 2 during all plant conditions.

(c) Assist the customer to respond to NRC requests for additional information.

Further this information has substantial commercial value as follows:

(a) Westinghouse plans to sell the use of similar information to its customers for purposes of meeting NRC requirements for licensing documentation.

(b) Westinghouse can sell support and defense of this information to its customers in the licensing process.

(c) The information requested to be withheld reveals the distinguishing aspects of a methodology which was developed by Westinghouse.

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 licensing support documentation 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.

The development of the technology described in part by the information is the result of applying the results of many years of experience in an intensive Westinghouse effort and the expenditure of a considerable sum of money.

In order for competitors of Westinghouse to duplicate this information, similar technical programs would have to be performed and a significant manpower effort, having the requisite talent and experience, would have to be expended.

Further the deponent sayeth not.

PROPRIETARY INFORMATION NOTICE

Transmitted herewith are proprietary and/or non-proprietary versions of documents furnished to the NRC in connection with requests for generic and/or plant-specific review and approval.

In order to conform to the requirements of 10 CFR 2.390 of the Commission's regulations concerning the protection of proprietary information so submitted to the NRC, the information which is proprietary in the proprietary versions is contained within brackets, and where the proprietary information has been deleted in the non-proprietary versions, only the brackets remain (the information that was contained within the brackets in the proprietary versions having been deleted). The justification for claiming the information so designated as proprietary is indicated in both versions by means of lower case letters (a) through **(9** 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 refer to the types of information Westinghouse customarily holds in confidence identified in Sections (4)(ii)(a) through (4)(ii)(f) of the affidavit accompanying this transmittal pursuant to 10 CFR 2.390(b)(1).

COPYRIGHT NOTICE

The reports transmitted herewith each bear a Westinghouse copyright notice. The NRC is permitted to make the number of copies of the information contained in these reports which are necessary for its internal use in connection with generic and plant-specific reviews and approvals as well as the issuance, denial, amendment, transfer, renewal, modification, suspension, revocation, or violation of a license, permit, order, or regulation subject to the requirements of 10 CFR 2.390 regarding restrictions on public disclosure to the extent such information has been identified as proprietary by Westinghouse, copyright protection notwithstanding. With respect to the non-proprietary versions of these reports, the NRC is permitted to make the number of copies beyond those necessary for its internal use which are necessary in order to have one copy available for public viewing in the appropriate docket files in the public document room in Washington, DC and in local public document rooms as may be required by NRC regulations if the number of copies submitted is insufficient for this purpose. Copies made by the NRC must include the copyright notice in all instances and the proprietary notice if the original was identified as proprietary.

Attachment 6

BRAIDWOOD STATION
UNITS 1 AND 2

Docket Nos. 50-456 and 50-457

License Nos. NPF-72 and NPF-77

Request for Exigent License Amendment Related to Technical Specification 5.5.9, “Steam Generator (SG) Tube Surveillance Program”

Westinghouse Electric Company LTR-CDME-05-32-NP, “Limited Inspection of the Steam Generator Tube Portion Within the Tubesheet at Byron 2 & Braidwood 2,” dated April 2005

Non-Proprietary Version

LTR-CDME-05-32-NP

Limited Inspection of the Steam Generator Tube Portion Within the Tubesheet at Byron 2 & Braidwood 2

April 2005

Author: /s/ Robert F. Keating
Robert F. Keating
Major Component Replacements & Engineering

Verified: /s/ Hermann O. Lagally
Hermann O. Lagally
Chemistry Diagnostics & Materials Engineering

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Abstract

Nondestructive examination indications of primary water stress corrosion cracking were found in the Alloy 600 thermally treated Westinghouse Model D5 steam generator tubes at the Catawba 2 nuclear power plant in the fall of 2004. Most of the indications were located in the tube-to-tubesheet welds with a few of the indications being reported as extending into the parent tube. In addition, a small number of tubes were reported with indications about 3/4 inch above the bottom of the tube, and multiple indications were reported in one tube at internal bulge locations in the upper third of the tubesheet. The tube end weld indications were dominantly axial in orientation and almost all of the indications were concentrated in one steam generator. Circumferential cracks were also reported at internal bulge locations in two of the Alloy 600 thermally treated steam generator tubes at the Vogtle 1 plant site in the spring of 2005. Based on recent requirements interpretations published by the NRC staff in GL 2004-01, Exelon requested that a recommendation be developed for examination of the Westinghouse Model D5 steam generator tubesheet regions at the Byron 2 and Braidwood 2 power plants. An evaluation was performed that considered the requirements of the ASME Code, Regulatory Guides, NRC Generic Letters, NRC Information Notices, the Code of Federal Regulations, NEI 97-06, and additional industry requirements. The conclusion of the technical evaluation is that the structural integrity of the primary-to-secondary pressure boundary is unaffected by degradation of any level below a depth of 17 inches from the top of the 21 inch thick tubesheet or the tube end welds because the tube-to-tubesheet hydraulic joints make it extremely unlikely that any operating or faulted condition loads are applied to the tube tack expanded region or the tube welds. Internal tube bulges, i.e., within the tubesheet, were created in a number of tubes as an artifact of the manufacturing process. The possibility of degradation at these locations exists based on the reported degradation at Catawba 2 and Vogtle 1. A recommendation is made for examination of a sample of the tubes to a depth of 17 inches below the top of the tubesheet based on the use of a bounding leak rate evaluation and the application of a structural analysis of the tube-to-tubesheet joint first documented in WCAP-16152 and repeated in Appendix A of this report. Application of the bounding leak rate and structural analysis approaches supporting this conclusion requires the approval of the NRC staff through a license amendment because it is based on a redefinition of the primary-to-secondary pressure boundary relative to the original design of the plant.

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1.0 Introduction

Indications of cracking were reported based on the results from the nondestructive, eddy current examination of the steam generator (SG) tubes during the fall 2004 outage at the Catawba 2 nuclear power plant operated by the Duke Power Company, References 1, 2 and 3. The tube indications at Catawba were reported about 7.6 inches from the top of the tubesheet in one tube, and just above the tube-to-tubesheet welds in a region of the tube known as the tack expansion (TE) in several other tubes. Finally, indications were also reported in the tube-end welds (TEWs), also known as tube-to-tubesheet welds, joining the tube to the tubesheet. The spatial distribution by row and column number is shown on Figure 1 for SG A, Figure 2 for SG B, and Figure 3 for SG D at Catawba. There were no indications in SG C. The Catawba 2 plant has Westinghouse designed, Model D5 SGs similar to those in service at the Exelon Corporation's Byron Unit 2 and Braidwood Unit 2 plant sites. Model D5 SGs were fabricated with Alloy 600TT (thermally treated) tubes. Although the remaining other plant site with Westinghouse Model D5 SGs, which belongs to another utility, has not reported similar indications, it is believed that no RPC (rotating probe coil) inspection of the tube region in the vicinity of the tack expansions or the tube-to-tubesheet welds with inspection techniques other than visual examination using SG bowl cameras has been performed. In other words, eddy current test (ECT) inspections using techniques capable of detecting circumferential cracking within the tubesheet have not been used in areas significantly below the top-of-tubesheet expansion transition region, typically limited to a depth of 3 inches from the top of tubesheet or the tube transition region. This experience is similar to that at the Braidwood 2 and Byron 2 plant sites. Thus, there is a potential for tube indications similar to those reported at Catawba within the tubesheet region to be reported in the Braidwood 2 and Byron 2 SGs if similar inspections were to be performed during the spring and fall 2005 inspections of their respective SGs.

It was subsequently noted that an indication was reported in each of two SG tubes at the Vogtle Unit 1 plant operated by the Southern Nuclear Operating Company. The Vogtle SGs are of the Westinghouse Model F design with slightly smaller A600TT tubes.

The SGs for all four Model D5 plant sites were fabricated in the 1978 to 1980 timeframe using similar manufacturing processes with a few exceptions. For example, the fabrication technique used for the installation of the SG tubes at Braidwood 2 would be expected to lead to a much lower likelihood for crack-like indications to be present in the region known as the tack expansion relative to Catawba 2 because a different process for effecting the tack expansions was adopted prior to the time of the fabrication of the Braidwood 2 SGs. The same statement cannot be made with regard to the tack expansion region in the Byron 2 SGs since they were fabricated at about the same time as the Catawba 2 SGs using the same tack expansion process.

A recommended examination plan for the tubes and welds is delineated in Section 9.0 of this report. With regard to the tack expansion region of the tube and the tube end welds, the recommendation is to not perform any specific inspection of the SG tubes at either the Byron 2 or Braidwood 2 plant sites. Exelon is not attempting to license the H* methodology as described in Reference 5 for application to the tubes in the Byron 2 and Braidwood 2 SGs, but the structural analysis of the tube and the tubesheet documented in that reference is valid for use in supporting the application of a recently developed independent leakage evaluation methodology based on the change in contact pressure between the tube and the tubesheet between normal operation and postulated accident conditions. Moreover, in order to address potential uncertainties associated with the determination of specific leak rates, Exelon decided to increase the depth of RPC inspection of the tubes to 17 inches from the top of tubesheet (TTS). This allows the use of the newly developed leak rate methodologies since excluded potential degradation regions would be limited to the bottom 4.23 inches of the tube in the nominally 21.23 inch thick tubesheet, which is well below the mid-plane of the tubesheet. As described in Section 6.1 of this report, the potential leakage due to degradation below 17 inches from the TTS would clearly be below allowable accident limits.

The findings in the Catawba 2 and Vogtle 1 SG tubes present three distinct issues with regard to the SG tubes at the Byron 2 and Braidwood 2 plants:

1) indications in internal bulges within the tubesheet,
2) indications at the elevation of the tack expansion transition, and
3) indications in the tube-to-tubesheet welds.

The scope of this document is to: a) address the applicable requirements, including the original design basis, Reference 7, and regulatory issues, Reference 8, and b) provide analysis support for technical arguments to limit inspection of the tubesheet region to an area above which degradation could result in potentially not meeting the SG performance criteria, i.e., the depths specified in Reference 5 or 17 inches as recommended herein. The application of an H* type of justification to limit the inspection and repair extent of the tubes requires a redefinition of the primary-to-secondary pressure boundary for plants with hydraulically expanded tube-to-tubesheet joints for which a license amendment must be granted by the NRC for implementation. In order to limit the extent of the inspection in the spring 2005 inspection of the Braidwood 2 SGs an exigent technical specification, a.k.a. the TS, amendment is being sought. This report was prepared to facilitate the approval of a modification of the H* criteria to limit the RPC exclusion zone to the upper 17 inches of the tube within the tubesheet and provide the necessary information for a NRC staff review of the technical basis for that request.

It should be specifically noted that although the terminology of "H*" is used extensively throughout this document, Exelon is not attempting to license H*, but to use data extracted from the existing H* report, Reference 5, in order to support justification of a limited tube inspection extent from the top of the hot leg side of the tubesheet to a depth of 17 inches. Therefore, degradation remaining in the top 17 inches of tube within the tubesheet can remain in service since it is demonstrated herein to be not safety significant.

The development of the H* criteria involved consideration of the performance criteria for the operation of the SG tubes as delineated in NEI 97-06, Revision 1, Reference 9, and draft RG

1.121, Reference 10. The bases for the performance criteria are the demonstration of both structural and leakage integrity during normal operation and postulated accident conditions. The Reference 5 report included documentation of structural analyses regarding the efficacy of the tube-to-tubesheet joint, and leak rate analyses based on empirical data and computer code modeling of the leakage from tubes postulated to be cracked 100% throughwall within the tubesheet. The structural model was based on standard analysis techniques and finite element models as used for the original design of the SGs and documented in numerous submittals for the application of criteria to deal with tube indications within the tubesheet of other models of Westinghouse designed SGs with tube-to-tubesheet joints fabricated by other techniques, e.g., explosive expansion. The structural analysis of the Byron 2 and Braidwood 2 SG tube-to-tubesheet joints is provided in Appendix A to this report. The content is the same as that in Reference 5 and permits for the review of the structural analysis to be performed independent of the Reference 5 information.

All full depth expanded tube-to-tubesheet joints in Westinghouse designed SGs have a residual radial preload between the tube and the tubesheet. Early vintage SGs involved hard rolling which resulted in the larges magnitude of the residual interface pressure. Hard rolling was replaced by explosive expansion which resulted in a reduced magnitude of the residual interface pressure. Finally, hydraulic expansion replaced explosive expansion for the installation of SG tubes, resulting in a further reduction in the residual interface pressure. In general, it was found that the leak rate through the joints in hard rolled tubes, if any, is insignificant. Testing demonstrated that the leak rate resistance of explosively expanded tubes was not as great and prediction methods based on empirical data to support theoretical models were developed to deal with the potential for leakage. The same approach was followed to develop a prediction methodology for hydraulically expanded tubes. However, the model has been under review since its inception, with the intent of verifying its accuracy because it involved analytically combining the results from independent tests of leak rate through cracks with the leak rate through the tube-to-tubesheet crevice. The H* model for leak rate is such a model and its review could be time consuming since it has not been previously reviewed by the NRC staff. An alternative approach was developed for application at Braidwood 2 for the spring 2005 outage and Byron 2 for the fall 2005 outage based on engineering expectations of potential differences in the leak rate between normal operation and postulated accident conditions based on a first principles approach to the engineering. However, there are no technical reasons why the use of the alternate methodology should be limited to a single application at either plant site.

A summary of the evaluation is provided in Section 2.0 of this report. The historical background and design requirements for the tube-to-tubesheet joint are discussed in Sections 3.0 and 4.0 respectively, a summary of the conclusions from the structural analysis of the joint is provided in Section 5.0, the leak rate analysis in Section 6.0, dispositioning of cracked tubes inadvertently found below the inspection distance is discussed in Section 7.0, conclusions from the structural and leak rate evaluations are provided in Section 8.0, and recommended tube inspection plans are contained in Section 9.0.

2.0 Summary Discussion

Evaluations were performed to assess the need for special purpose NDE probe examinations, e.g., RPC, of the SG tubes region within the tubesheet at the Byron 2 and Braidwood 2 power plants. The conclusions from the evaluation are that a 20% sample of the tube in each SG could be performed to at least the minimum depths specified in Reference 5, identified as H* in that reference, to ensure structural integrity. Exelon has decided to perform sampling RPC inspections to a depth of 17 inches below the top of the tubesheet for the spring 2005 inspection of the Braidwood 2 SGs and the fall 2005 inspection at Byron 2 in order to assure that leakage requirements in addition to the structural requirements are met.

It is noted that the above inspection recommendation excludes the region of the tube referred to as the tack expansion or the tack expansion transition. In addition, consideration was given to the need to perform inspections of the tube-to-tubesheet weld in spite of the fact that the weld is specifically not part of the tube in the sense of the plant technical specification, see Reference 2. With regard to the latter two regions of the primary-to-secondary pressure boundary in accord with the original design of the SGs, it is concluded that there is no need to inspect either the tack expansion, its transition, or the tube-to tubesheet welds for degradation because the tube in these regions has been shown to meet structural and leak rate criteria regardless of the level of degradation. Furthermore, it could also be concluded that for some of the tubes, depending on radial location in the tubesheet, there is not a need to inspect the region of the tube below the neutral plane of the tubesheet, roughly 11 inches below the top. The results from the evaluations performed as described herein demonstrate that the inspection of the tube within a nominal 4.23 inches of the tube-to-tubesheet weld and of the weld is not necessary for structural adequacy of the SG during normal operation or during postulated faulted conditions, nor for the demonstration of compliance with leak rate limits during postulated faulted events.

In summary:

- WCAP-16152, Reference 5, notes that the structural integrity requirements of NEI 97-06, Reference 9, and draft RG 1.121, Reference 10, are met by sound tube engagement lengths ranging from 2.95 to 8.61 inches from the top of the tubesheet, thus the region of the tube below those elevations, including the tube-to-tubesheet weld is not needed for structural integrity during normal operation or accident conditions.
- NEI 97-06, Reference 9, defines the tube as extending from the tube-to-tubesheet weld at the tube inlet to the tube-to-tubesheet weld at the tube outlet, but specifically excludes the tube-to-tubesheet weld from the definition of the tube. The acceptance of the definition by the NRC staff was recorded in the Federal Register on March 2, 2005, Reference 11.
- The welds were originally designed and analyzed as primary pressure boundary in accordance with the requirements of Section III of the 1971 edition of the ASME Code, Summer 1972 Addenda and selected paragraphs of the Winter 1974 Addenda, Reference 7. The analyses are documented in References 12 and 13 for the Byron 2 and Braidwood 2 SGs respectively. The typical as-fabricated and the as-analyzed weld configurations are illustrated on Figure 4.

- Section XI of the ASME Code, Reference 14 (1971) through 15 (2004), deals with the inservice inspection of nuclear power plant components. The ASME Code specifically recognizes that the SG tubes are under the purview of the NRC through the implementation of the requirements of the Technical Specifications as part of the plant operating license.

The hydraulically expanded tube-to-tubesheet joints in Model D5 SGs are not leak-tight and considerations were also made with regard to the potential for primary-to-secondary leakage during postulated faulted conditions. Two evaluation approaches were considered, one based on the leak rate during normal operation relative to that during postulated accident conditions and the second based on leak rate prediction analyses documented in WCAP-16152, Reference 5, prepared for the purpose of identifying a structurally based depth for RPC inspection in the event that circumferential cracking below the top of the tubesheet was postulated to be present and estimating the leak rate that could be expected from a conservatively based prediction of the number of non-detected indications potentially present. Owing to the potential for a lengthy review process for the second approach, the method was not pursued for evaluation and implementation.

The leak rate during postulated accident conditions would be expected to be less than that during normal operation for indications near the bottom of the tubesheet (including indications in the tube end welds) based on the observation that while the driving pressure increases by about a factor of two, the flow resistance increase associated with an increase in the tube-to-tubesheet contact pressure can be up to a factor of 3, Reference 5. While such a decrease is rationally expected, the postulated accident leak rate could conservatively be taken to be bounded by twice the normal operating leak rate if the increase in contact pressure is ignored. Since normal operating leakage is limited to less than 0.1 gpm, the attendant accident condition leak rate, assuming all leakage to be from lower tubesheet indications, would be bounded by 0.2 gpm. Therefore, the leak rate under normal operating conditions could exceed its allowed value before the accident condition leak rate would be expected to exceed its allowed value. This approach is termed an application of the "bellwether principle." This assessment also envelopes postulated circumferential cracking of the tube or the tube-to-tubesheet weld that is 100% deep by 360° in extent because it is based on the premise that no weld is present.

Based on the information summarized above, no inspection of the tube-to-tubesheet welds, tack roll region or bulges below the distance determined to have the potential for safety significance as specified in Reference 5, i.e., the H* depths, would be considered to be necessary to assure compliance with the structural and primary-to-secondary leak rate requirements for the SGs. In addition, based on the results from consideration of application of the bellwether principle regarding potential leakage during postulated accident conditions, the planned inspection to a depth of 17 inches below the top of the tubesheet is conservative and justified.

The selection of a depth of 17 inches obviates the need to consider the location of the tube expansion transition below the TTS, usually bounded by a length of about 0.3 inches. For structural purposes, the value of 17 inches greatly exceeds the engagement lengths determined from the analysis documented in Appendix A. The application of the bellwether approach to the leak rate analysis as described in Section 6.1 negates the need to consider specific distances from the TTS and relies only on the magnitude of the contact pressure in the vicinity of the tube above 17 inches below the TTS.

3.0 Historical Background Regarding Tube Indications in the Tubesheet

There has been extensive experience associated with the operation of SGs wherein it was believed, based on NDE, that throughwall tube indications were present within the tubesheet. The installation of the SG tubes usually involves the development of a short interference fit, referred to as the tack expansion, at the bottom of the tubesheet. The tack expansion was usually effected by hard rolling through October of 1979 and thereafter, in most instances, by the Poisson expansion of a urethane plug inserted into the tube end and compressed in the axial direction. The rolling process by its very nature is considered to be more aggressive with regard to metalworking at the inside surface of the tube and would be expected to lead to higher residual surface stresses. It is believed that the rolling process was used during fabrication of the Byron Unit 2 SGs, while the urethane plug (Poisson) expansion process was used for those at Braidwood Unit 2. The tube-to-tubesheet weld was then performed to create the ASME Code pressure boundary between the tube and the tubesheet.[1]

The development of the F* alternate repair criterion (ARC) in 1985-1986 for tubes hard rolled into the tubesheet was prompted by the desire to account for the inherent strength of the tube-to-tubesheet joint away from the weld and to allow tubes with degradation within the tubesheet to remain in service, Reference 14. The result of the development activity was the demonstration that the tube-to-tubesheet weld was superfluous with regard to the structural and leakage integrity of the rolled joint between the tube and the tubesheet. Once the plants were in operation, the structural and leakage resistance requirements for the joints were based on the plant Technical Specifications, and a means of demonstrating joint integrity that was acceptable to the NRC staff was delineated in Reference 10. License amendments were sought and granted for several plants with hard rolled tube-to-tubesheet joints to omit the inspection of the tube below a depth of about 1.5 inches from the top of the tubesheet. Similar criteria, designated as W*, were developed for explosively expanded tube-to-tubesheet joints in Westinghouse designed SGs in the 1991-1992 timeframe, Reference 17. The W* criteria were first applied to operating SGs in 1999 based on a generic evaluation for Model 51 SGs, Reference 18, and the subsequent safety evaluation by the NRC staff, Reference 19. However, the required engagement length to meet structural and leakage requirements was on the order of 4 to 6 inches because the explosively expanded joint does not have the same level of residual interference fit as that of a rolled joint. It is noted that the length of joint necessary to meet the structural requirements is not the same as, and is usually shorter than, that needed to meet the leakage integrity requirements.

The post-weld expansion of the tube into the tubesheet in the Byron 2 and Braidwood 2 SGs was effected by a hydraulic expansion of the tube instead of rolling or explosive expansion. The hydraulically formed joints do not exhibit the level of interference fit that is present in rolled or

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[1] The actual weld is between the Alloy 600 tube and weld buttering on the bottom of the carbon steel tubesheet.

explosively expanded joints, however, when the thermal and internal pressure expansion of the tube is considered during normal operation and postulated accident conditions, appropriate conclusions regarding the need for the weld similar to those for the other two types of joint can be made. Evaluations were performed in 1996 of the effect of tube-to-tubesheet weld damage that occurred from an object in the bowl of a SG with tube-to-tubesheet joints similar to those in the Byron 2 and Braidwood 2 SGs, on the structural and leakage integrity of the joint, Reference 20. It was concluded in that evaluation that the strength of the tube-to-tubesheet joint is sufficient to prevent pullout in accordance with the requirements of the performance criteria of Reference 9 and that a significant number of tubes could be damaged without violating the performance criterion related to the primary-to-secondary leak rate during postulated accident conditions.

4.0 Design Requirements for the Tube-to-Tubesheet Joint Region

This section provides a review of the applicable design and analysis requirements, including the ASME Code pre-service design requirements of Section III and the operational/maintenance requirements of Section XI. The following is the Westinghouse interpretation of the applicable analysis requirements and criteria for the condition of TEW cracking. Recommendations that include code requirements and the USNRC position as expressed in References 8 and 9. Reference 8 notes that:

> *"In accordance with Section III of the Code, the original design basis pressure boundary for the tube-to-tubesheet joint included the tube and tubesheet extending down to and including the tube-to-tubesheet weld. The criteria of Section III of the ASME Code constitute the "method of evaluation" for the design basis. These criteria provide a sufficient basis for evaluating the structural and leakage integrity of the original design basis joint. However, the criteria of Section III do not provide a sufficient basis by themselves for evaluating the structural and leakage integrity of a mechanical expansion joint consisting of a tube expanded against the tubesheet over some minimum embedment distance. If a licensee is redefining the design basis pressure boundary and is using a different method of evaluation to demonstrate the structural and leakage integrity of the revised pressure boundary, an analysis under 10 CFR 50.59 would determine whether a license amendment is required."*

The industry definition of Steam Generator Tubing excludes the tube-end weld from the pressure boundary as noted in NEI 97-06 (Reference 9):

> *"Steam generator tubing refers to the entire lengtho f the tube, including the tube wall and any repairs to it, between the tube-to-tube sheet weld at the tube inlet and the tube-to-tube sheet weld at the tube outlet. The tube-to-tube sheet weld is not considered part of the tube."*

The NRC has indicated its concurrence with this definition, see, for example, Reference 11. In summary, from a non-technical viewpoint, no specific inspection of the tube-end welds would be required because:

1. The industry definition of the tube excludes the tube-end weld,
2. The ASME Code defers the judgment regarding the redefined pressure boundary to the licensing authority under 10CFR50.59,
3. The NRC has accepted this definition; therefore, by inference, may not consider cracked welds to be a safety issue on a level with that of cracked tubes, and
4. There is no qualified technique that can realistically be applied to determine if the tube-end welds are cracked.

However, based on the discussion of Information Notice 2005-09, Reference 2, it is clear that the NRC staff has concluded that "the findings at Catawba illustrate the importance of inspecting the parent tube adjacent to the weld and the weld itself for degradation." The technical considerations documented herein obviate the need for consideration of any and all non-technical arguments.

5.0 Structural Analysis of Tube-to-Tubesheet Joint

This section summarizes the structural aspects and analysis of the entire tube-to-tubesheet joint region, the details of which are provided in Appendix A. The tube end weld was originally designed as a pressure boundary structural element in accordance with the requirements of Section III of the ASME (American Society of Mechanical Engineers) Boiler and Pressure Vessel Code, Reference 7. The construction code for the Byron and Braidwood Unit 2 SGs was the 1971 edition with the Summer 1972 and some paragraphs of the Winter 1974 addenda. This means that there were no strength considerations made with regard to the expansion joint between the tube and the tubesheet, including the tack expansion regardless of whether it was achieved by rolling or Poisson expansion of a urethane plug.

An extensive empirical and analytical evaluation of the structural capability of the as-installed tube-to-tubesheet joints based on considering the weld to be absent was performed specifically for the Byron 2 and Braidwood 2 Model D5 SGs and the results were reported in Westinghouse report WCAP-16152, Reference 5; again, the structural analysis section of that reference is included herein as Appendix A. Typical Model D5 hydraulic expansion joints with lengths comparable to those being proposed in Reference 5 for limiting RPC examination were tested for pullout resistance strength at temperatures ranging from 70 to 600°F. The results of the tests coupled with those from finite element evaluations of the effects of temperature and primary-to-secondary pressure on the tube-to-tubesheet interface loads were used to demonstrate that engagement lengths of approximately 3 to 8.6 inches were sufficient to equilibrate the axial loads resulting from consideration of 3 times the normal operating and 1.4 times the limiting accident condition pressure differences. The variation in required engagement length is a function of tube location, i.e., row and column, and decreases away from the center of the SG where the maximum value applies. The tubesheet bows, i.e., deforms, upward from the primary-to-secondary pressure difference and results in the tube holes becoming dilated above the neutral plane of the tubesheet, which is little below the mid-plane because of the effect of the tensile membrane stress from the pressure loading. The amount of dilation is a maximum very near the radial center of the tubesheet (restricted by the divider plate) and diminishes with increasing radius outward. Moreover, the tube-to-tubesheet joint becomes tighter below the neutral axis and is a maximum at the bottom of the tubesheet[2]. In conclusion, the need for the weld is obviated by the interference fit between the tube and the tubesheet. Axial loads are not transmitted to the portion of the tube below the H* distance during operation or faulted conditions, by factors of safety of at least 3 and 1.4 respectively, including postulated loss of coolant accidents (LOCA), and inspection of the tube below the H* distance including the tube-to-tubesheet weld is not technically necessary. Also, if the expansion joint were not present, there would be no effect on the strength of the weld from axial cracks, and tubes with circumferential cracks up to about 180° by 100% deep would have sufficient strength to meet the nominal ASME Code structural requirements, based on the margins of safety reported in Reference 12, and the requirements of RG 1.121, Reference 10.

An examination of Tables A.7 through A.11 illustrates that the holding power of the tube-to-tubesheet joint in the vicinity of the maximum inspection depth of 17 inches is much greater than at the top of the tubesheet in the range of the originally developed H* of Reference 5. Note that the radii reported in these tables were picked to conservatively represent the entire radial zones of consideration as defined on Figure 5 (taken from Reference 5). For example, Zone C has a maximum radius of 34.4 inches. However, in order to establish H* values that were conservative throughout the zone, the tube location for which the analysis results were most severe above the neutral axis were reported, i.e., those values calculated for a tube at a radius of 4.08 inches. The values are everywhere conservative above the neutral surface of the tubesheet for tubes in Zone C. Likewise for tubes in Zone B under the heading 49.035 inches where the basis for the calculation was a tube at a radius of 34.4 inches. The purpose of this discussion is to illustrate the extreme conservatism associated with the holding power of the joint below the neutral surface of the tubesheet, and to identify the proper tube radii for consideration. In the center of the tubesheet the incremental holding strength in the 4.9 inch range from 12 to 16.9 inches below the top of the tubesheet is about 1191 lbf per inch during normal operation. The performance criterion for $3 \cdot \Delta P$ is met by the first 1.7 inch of engagement above 17 inches. At a radius of 59 inches the corresponding length of engagement needed is about 2.1 inches. The corresponding values for steam line break conditions are 1.07 and 1.69 inches at radii of 4.08 and 58.8 inches respectively. In other words, while a value of 8.6 inches was determined for H* from the top of the tubesheet, a length of 1.7 to 1.85 inches would be sufficient at the bottom of the inspection length, where the latter value corresponds to a radius of 34.4 inches from the center of the tubesheet, the maximum extent of Zone C.

6.0 Leak Rate Analysis of Cracked Tube-to-Tubesheet Joints

This section of the report presents a discussion of the leak rate expectations from axial and circumferential cracking confined to the tube-to-tubesheet joint region, including the tack expansion region, the tube-to-tubesheet welds and areas where degradation could potentially occur due to bulges and overexpansions within the tube. Although the welds are not part of the tube per the technical specifications, consideration is given in deference to the discussions of the NRC staff in References 2 and 8. Consideration of the leak rate through 100% throughwall cracks in the SG

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[2] There is a small reversal of the bending stress beyond a radius of about 55 inches because the support ring prevents rotation and the hole dilation is at the bottom of the tubesheet.

tubes at locations below the top of the tubesheet was given extensively in Reference 5. Although the hydraulically expanded joint is not leak tight, the leak rate is a function of the distance to the tip of the crack from the top of the tubesheet and the contact pressure between the tube and the tubesheet. The approach to dealing with leakage in Reference 5 is based on counting the number of cracks present in the inspected region above a critical depth designated therein as H* in order to predict the distribution of cracks below H* and then estimating the leak rate from those cracks. A bounding distribution of cracks was proposed for initial application based on the number of cracks that were detected in the SGs at a plant where the tubes were made from Alloy 600 mill annealed (A600MA) material. The thermally treated tube material in the Byron 2 and Braidwood 2 SG tubes has been demonstrated experimentally to be much more resistant to PWSCC so the number of indications observed at that plant is expected to be bounding by a very significant margin at similar times of operation when adjusted for temperature. Moreover, the distribution used as bounding was based on the number of indications present several years after the first indications had been observed, thus the distribution was more mature. It is noted that the degradation reported in the Catawba 2 and Vogtle 1 SG tubes was bounded (significantly) by the degradation extent specified for application by Reference 5. Moreover, the methodology for estimating the leak rate from such indications as delineated in Reference 5 is grossly conservative in that it omits consideration of the operating characteristics of the plant with regard to primary-to-secondary leakage. Although the methodology applies throughout the tubesheet, other considerations can be made with regard to assessing the reduction in the potential for leakage when the indications are below the neutral surface of the tubesheet, which is located slightly below the mid-plane because the primary-to-secondary pressure difference induces a membrane stress in addition to the bending stress. Both approaches are explained in the following sections, however, because of the major importance of the additional consideration, referred to as the bellwether approach, it is discussed first. It is noted that the application of the discussed methods requires approval from the NRC staff to change the Technical Specification prior to returning to service after the spring 2005 outage for Braidwood 2. With regard to the inherent conservatism embodied in the application of any predictive methods it is noted that the presence of cracking was not confirmed through removal of a tube section followed by destructive metallurgical examination at Catawba 2 or Vogtle 1.

6.1 The Bellwether Principle for Normal Operation to Steam Line Break Leak Rates

From an engineering expectation standpoint, if there is no meaningful primary-to-secondary leakage during normal operation, there should likewise be no meaningful leakage during postulated accident conditions from indications located below the mid-plane of the tubesheet. The rationale for this is based on considerations regarding the deflection of the tubesheet with accompanying dilation and diminution of the tubesheet holes. In effect, the area presented as a leak path between the tube and tubesheet would not be expected to increase under postulated accident conditions and would really be expected to decrease for most of the SG tubes. During the development of the RPC inspection criteria of Reference 5, consideration was given of the potential for leak rate during normal operation to act as a bellwether or leading indicator with regard to the leak rate that could be expected during postulated accident conditions. The results from these considerations were not included in the final versions of the document because of concerns associated with the accuracy of the approach for indications above the neutral plane of the tubesheet where the tube-to-tubesheet contact pressure would usually be expected to diminish during faulted conditions. For example, if it was intended to stop the RPC examination at a depth of 3 to 9 inches from the top of the tubesheet, then severe circumferential cracking would have been postulated to occur immediately below that depth and the potential leak rate as compared to that during normal operation estimated. The primary-to-secondary pressure difference during normal operation is on the order of 1200 to 1400 psi, while that during a postulated accident, e.g., steam line and feed line break, is on the order of 2560 to 2650 psi.[3] Above the neutral plane of the tubesheet the tube holes experience a dilation due to pressure induced bow of the tubesheet. This means that the contact pressure between the tubes and the tubesheet would diminish above the neutral plane in the central region of the tubesheet at the same time as the driving potential would increase, leading to an expectation of an increase in the potential leak rate through the crevice. Estimating the change in leak rate as a function of the change in contact pressure under faulted conditions on a generic basis was expected to be problematic. However, below the neutral plane of the tubesheet the tube holes diminish in size because of the upward bending and the contact pressure between the tube and the tubesheet increases. When the differential pressure increases during a postulated faulted event the increased bow of the tubesheet leads to an increase in the tube-to-tubesheet contact pressure, increasing the resistance to flow. Thus, while the dilation of the tube holes above the neutral plane of the tubesheet presents additional analytic problems in estimating the leak rate for indications above the neutral plane, the diminution of the holes below the neutral plane presents definitive statements to be made with regard to the trend of the leak rate, hence, the bellwether principle. Independent consideration of the effect of the tube-to-tubesheet contact pressure leads to similar conclusions with regard to the opening area of the cracks in the tubes, thus further restricting the leak rate beyond that through the interface between the tube and the tubesheet.

In order to accept the concept of normal operation being a bellwether for the postulated accident leak rate for indications above the neutral plane of the tubesheet, the change in leak rate had to be quantified using a somewhat complex, physically sound model of the thermal-hydraulics of the leak rate phenomenon. This is not necessarily the case for cracks considered to be present below the neutral plane of the tubesheet. This is because a diminution of the holes takes place during postulated accident conditions below the neutral plane relative to normal operation. For example, at a radius of approximately 34 inches from the center of the SG, the contact pressure during normal operation is calculated to be about 2010 to 2200 psi[4], see the last contact pressure entry in the center columns of Table A.8 and Table A.7 respectively, while the contact pressure during a postulated steam line break would be on the order of 3320 psi at the bottom of the tubesheet, Table A.9, and during a postulated feed line break would be on the order of 4250 to 4290 psi at the bottom of the tubesheet, Table A.10 and Table A.11 respectively. (Note: The radii specified in the heading of the tables are the maximum values for the respective zones analyzed, hence the contact pressures in the center column correspond to the radius specified for the left column, etc. The leftmost column lists the contact pressure values for a radius of 4.08 inches.) The analytical model for the flow through the crevice, the Darcy equation for flow through porous media, indicates that

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[3] The differential pressure may be on the order of 2405 psi if it is demonstrated that the power operated relief valves will be functional.

[4] The change occurs as a result of considering various hot and cold leg operating temperatures.

flow would be expected to be proportional to the differential pressure. Thus, a doubling of the leak rate could be predicted if the change in contact pressure between the tube and the tubesheet were ignored. Examination of the nominal correlation on Figure 6 (Figure 6.1 of Reference 5) indicates that the resistance to flow (the loss coefficient) would increase by a factor of about 3. If the leak rate during normal operation was 0.104 gpm (150 gpd), the postulated accident condition leak rate would be on the order of 0.2 gpm considering only the change in differential pressure, but the estimate would be reduced to 0.07 gpm when the increase in contact pressure is included, i.e., about 70% of that during normal operation based on the factor of 3. This latter value is significantly less than the allowable limit during faulted conditions of 0.5 gpm at room temperature density. Even without inclusion of the effect of the change in contact pressure, the predicted leak rate would be significantly less than the allowable rate of 0.5 gpm.

The above argument considered indications located where the expectations associated with the bellwether principle would be a maximum, i.e., where the relative increase in contact pressure from normal to faulted conditions is a maximum. Thus, the conclusions of this section apply directly to indications in the tube somewhat near the bottom of the tubesheet, i.e., as a minimum to tube indications within a little more than 4 inches from the bottom of the tubesheet and to postulated indications in the tube-to-tubesheet welds. An examination of the contact pressures as a function of depth in the tubesheet from the finite element analyses of the tubesheet as reported in Table A.7 through Table A.11 shows that the bellwether principle applies to a significant extent to all indications below the neutral plane of the tubesheet. At the central plane of the tubesheet the increase in contact pressure is more on the order of 15% relative to that during normal operation for all tubes regardless of radius. Still, the fact that the contact pressure increases means that the leak rate would be expected to be bounded by a factor of two relative to normal operation. At a depth of 17 inches from the top of the tubesheet the contact pressure increases by about 50% relative to that during normal operation. The flow resistance would be expected to increase by about 60%, thus the increase in driving pressure would be mostly offset by the increase in the resistance of the joint.

The numerical results from the finite element analyses are presented on Figure 7 at the elevation of the mid-plane of the tubesheet through Figure 10 at the bottom of the tubesheet. A comparison of the contact pressure during postulated SLB conditions relative to that during normal operation is provided for depths of 10.5, 12.6, 16.9, and 21 inches below the top of the tubesheet, the last being at the bottom of the tubesheet.

- At roughly the neutral surface, about 10.5 inches, the contact pressure during SLB is uniformly greater than that during normal operation by about 270 psi (ranging from 255 to 291 psi).
- At a depth of 12.6 inches the contact pressure increase ranges from a maximum of 537 psi near the center of the tubesheet to 275 psi at a radius of 55 inches, see Figure 8.
- At 16.9 inches below the top of the tubesheet and 4.13 inches above the bottom of the tubesheet the contact pressure increases by a maximum of 821 psi to a minimum of 236 psi at a radius of 56 inches, Figure 9.

- At the bottom of the tubesheet, Figure 10, the contact pressure increases by over 1700 psi near the center of the tubesheet, exhibits no change at a radius of about 55 inches, and diminishes by 369 psi at the extreme periphery, a little less than 61 inches from the center.

At a depth of about 6 inches from the top of the tubesheet the contact pressure decreases by about 370 psi near the center of the tubesheet, is unchanged at a radius of about 42 inches and increases by a maximum of 251 psi at a radius of 58 inches. A similar comparison is illustrated on Figure 11 at a depth of 8.25 inches from the top of the tubesheet, roughly equal to the originally derived H* depth for the worst location in the tubesheet as determined using SLB conditions. Here the contact pressure decreases at most by 53 psi at a radius of 3.1 inches, is unchanged at a radius of 21 inches, and increases by a maximum of 268 psi at a radius of 56.9 inches. The density of the number of tubes populating the tubesheet increases with the square of the radius, thus, even at the H* depth there are far more tubes for which the contact pressure is unchanged or increases at that elevation than there are tubes for which the contact pressure decreases, i.e., 88% of he tubes are at a radius greater than 21 inches from the center of the tubesheet.

The leak rate from any indication is determined by the total resistance of the crevice from the elevation of the indication to the top of the tubesheet, ignoring the resistance from the crack itself. Thus, it would not be sufficient to simply use the depth of 8.25 inches and suppose that the leak rate would be relatively unchanged even if the pressure potential difference were the same. However, the fact that the contact pressure generally increases below that elevation indicates that the leak rate would be relatively unaffected for indications a little deeper into the tubesheet. For example, it would be expected that the leak rate would not increase meaningfully from any indications below the mid-plane of the tubesheet. A comparison of the curves on Figure 11 relative to those on Figure 7 indicates that the contact pressure generally increases for a length of at least 2 inches upward from the mid-plane for tubes with a radius of 21 inches from the center of the tubesheet. For radial locations greater than 21 inches from the center of the tubesheet the length for which the contact pressure increases would be greater than 2 inches.

The trend is consistent, at radii where the contact pressure decreases or the increase is not as great near the bottom of the tubesheet, the increase at higher elevations would be expected to compensate. For example, the contact pressures on Figure 10 at the bottom of the tubesheet show a decrease beyond a radius of 55 inches, however, the increase at 8.4 inches above the bottom, Figure 8, is significant. For the outboard tubes the increase in contact pressure extends all the way to the top of the tubesheet.

A comparison of the curves at the various elevations leads to the conclusion that for a length of 8 inches upward from an elevation of 4.23 inches above the bottom of the tubesheet there is always an increase in the contact pressure in going from normal operation conditions to postulated SLB conditions. Hence, it is reasonable to omit any consideration of inspection of bulges or other artifacts below a depth of 17 inches from the top of the tubesheet. Therefore, applying a very conservative inspection sampling length of 17 inches downward from the top of the tubesheet during the Braidwood 2 spring 2005 and the Byron 2 fall 2005 outages provides a high level of confidence that the potential leak rate from indications below the lower bound inspection elevation during a postulated SLB event will be bounded by twice the normal operation primary-to-secondary leak rate.

6.2 Leakage Analysis from H* Calculations for Comparison

The evaluation of the accident (SLB) leakage for both axial and circumferential cracking in the tube end welds is naturally based on the information presented in WCAP-16152, Reference 5. The leakage analysis uses methods that were developed by Westinghouse to prepare the technical bases for justifying limited RPC inspection depths into the tubesheet expansion region, e.g., Reference 5. The discussion of these methods is included in this report for use at the discretion of Exelon since examination of the welds is not a recommended action resulting from this report. It is included herein to provide the potential for dealing with some unexpected eventuality that would lead to a specific examination of the welds.

For axial cracks, a crack confined to the TEW will intersect the TS crevice at only a single point unless the crack extends into the tack expansion zone of the tube above the weld. The intersection of a circumferential crack with the expansion zone crevice would be expected to result in a configuration similar to that of a circumferential crack in the parent tube, bounding both conditions. This is precisely the configuration that was evaluated for both tube retention and potential leak rate in the Reference 5 analyses. The evaluations in that case utilized empirical data developed to quantify the potential leak rate from circumferential cracks located at higher elevations within the tubesheet of Model D5 SGs. The loading conditions that apply under accident conditions were considered in the leak rate analyses of Reference 5. For example, differential pressure loading on the tubesheet during a SLB event causes tubesheet bowing and affects the tightness of the joint at the TEW. The analyses also considered the potential leak rate from tubes for which the weld was absent. The conclusion from the analyses was that 600 tubes without a tube-to-tubesheet weld and located in the most severe region of the tubesheet would be expected to leak at a total rate of less than 0.195 gpm or about 40% of the site allowable during postulated faulted conditions.

The application of the Reference 5 approach to predicting leak rate has been demonstrated to be conservative to and obviated by the application of the bellwether principle and the selection of an inspection depth of 17 inches below the top of the tubesheet. The discussion was included in this report for comparison purposes only and is not planned for application with regard to leak rate prediction calculations described in Reference 5 for the Braidwood 2 spring 2005 and the Byron 2 fall 2005 SG inspection outages.

7.0 Recommendations for Dispositioning Tube Cracks in the Tube-to-Tubesheet Joint

Although the information contained in this report supports using the methodology provided in Reference 5 for indications found within H* for condition monitoring and for assessing the bounding leak rate from non-detected indications in the uninspected range below the H*, its use is not recommended for the spring and fall 2005 outages at Braidwood 2 and Byron 2 respectively for indications above the 17 inch inspection depth. The evaluations also provide a technical basis for bounding the potential leak rate from non-detected indications in the tube region below 17 inches from the top of the tubesheet as no more than twice the leak rate during normal operation. This applies equally to any postulated indications in the tack expansion region and in the tube-to-tubesheet welds. If cracks are found within the specified inspection depth, it is recommended that the inspection be expanded to include 100% of the tubes in the affected SG using that same specified inspection depth, e.g., 17 inches, as discussed in item 4 of Section 9.0. If the cracking is identified at an existing bulge or over expansion location, the scope expansion can be limited to the population of identified bulges and over expansions within the inspection region. As noted in the introduction to this report, the reporting of crack-like indications in the tube-to-tubesheet welds would be expected to occur inadvertently since no structural or leak rate technical reason exists for a specific examination to take place.

8.0 Conclusions

The evaluations performed as reported herein have demonstrated that:

1) There is no structural integrity concern associated with tube or tube weld cracking of any extent provided it occurs below the H* distance as reported in Appendix A, i.e., Reference 5. The pullout resistance of the tubes has been demonstrated for axial forces associated with 3 times the normal operating differential pressure and 1.4 times differential pressure associated with the most severe postulated accident.
2) Contact forces during postulated LOCA events are sufficient to resist axial motion of the tube. Also, if the tube end welds are not circumferentially cracked, the resistance of the tube-to-tubesheet hydraulic joint is not necessary to resist push-out. Moreover, the geometry of any postulated circumferential cracking of the weld would result in a configuration that would resist pushout in the event of a loss of coolant accident. In other words, the crack flanks would not form the cylindrical surface necessary such that there would be no resistance to expulsion of the tube in the downward direction.
3) The leak rate for indications below the neutral plane of the tubesheet is expected to be bounded on average by twice the leak rate that is present during normal operation of the plant.
4) The leak rate for indications below a depth of about 17 inches from the top of the tubesheet would be bounded by twice the leak rate that is present during normal operation of the plant regardless of tube location in the bundle. This is apparent from comparison of the contact pressures from the finite element analyses over the full range of radii from the center of the tubesheet, and ignores any increase in the leak rate resistance due to the contact pressure changes and associated tightening of the crack flanks.

9.0 Recommended Inspection Plans

The recommendations with regard to the inspection of the welds at Braidwood 2 and Byron 2 are based on the following:

1) Examination of the tubes below the H* elevations as described in Reference 5 could be omitted based on structural considerations alone if a license amendment were obtained to that effect.

2) Similar considerations lead to the conclusion that the leak rate during postulated faulted events would be bounded by twice the leak rate during normal operation and the examination of the tube below the specified inspection depth of 17 inches (which includes the tack expansions and the welds) can be omitted from consideration.

3) The prior conclusions rely on the inherent strength and leak rate resistance of the hydraulically expanded tube-to-tubesheet joint, a feature which was not considered or permitted to be considered for the original design of the SG. Thus, omission of the inspection of the weld constitutes a reassignment of the pressure boundary to the tube-to-tubesheet interface. Similar considerations for tube indications require NRC staff approval of a license amendment.

Based on the summary discussion, Westinghouse has reviewed and endorses the following SG tubes inspection plan with regard to the tubesheet region in each SG as discussed with Exelon (Messrs. M. Sears and S. Leshnoff) on March 21 through April 9, 2005, for the Braidwood 2 and Byron 2 spring and fall 2005 outages respectively:

1. Perform a 20% inspection of the hot leg side tubes using RPC technology from 3 inches above the top of the tubesheet to 3 inches below the top of the tubesheet. Expand to 100% of the affected SG in this region only if cracking is found that is not associated with a bulge or overexpansion as described below.
2. Perform a 20% inspection of the hot leg side tubes using RPC technology for depths indicated down to the top of the tubesheet minus 17 inches for indications of bulges ≥ 18 Volts and over expansions ≥ 1.5 mils on the diameter, as obtained from a review of the cycle 10 data for Braidwood 2 and cycle 11 data for Byron 2. Note, the 20% sample could be developed by examining 20% of the parent tube population and biasing the selection process to assure that at least 20% of the bulge and over expansion indications within the 17 inch length were also sampled. It is also noted that the inspection of a single tube can simultaneously contribute to meeting the scope of both inspection items 1 and 2.
3. If cracking is found in the sample population of bulges or over expansions, the inspection scope should be increased to 100% of the population of bulge and overexpansion locations for the region of the top of the tubesheet minus 17 inches in the affected SG.
4. If cracking is reported at one or more tube locations not designated as either a top of the tubesheet expansion transition, a bulge or an over expansion, an engineering evaluation can be performed aimed at determining the cause for the signal, e.g., some other tubesheet anomaly, in order to identify a critical area for the expansion of the inspection. This inspection will be limited to the original specified depth of 17 inches.

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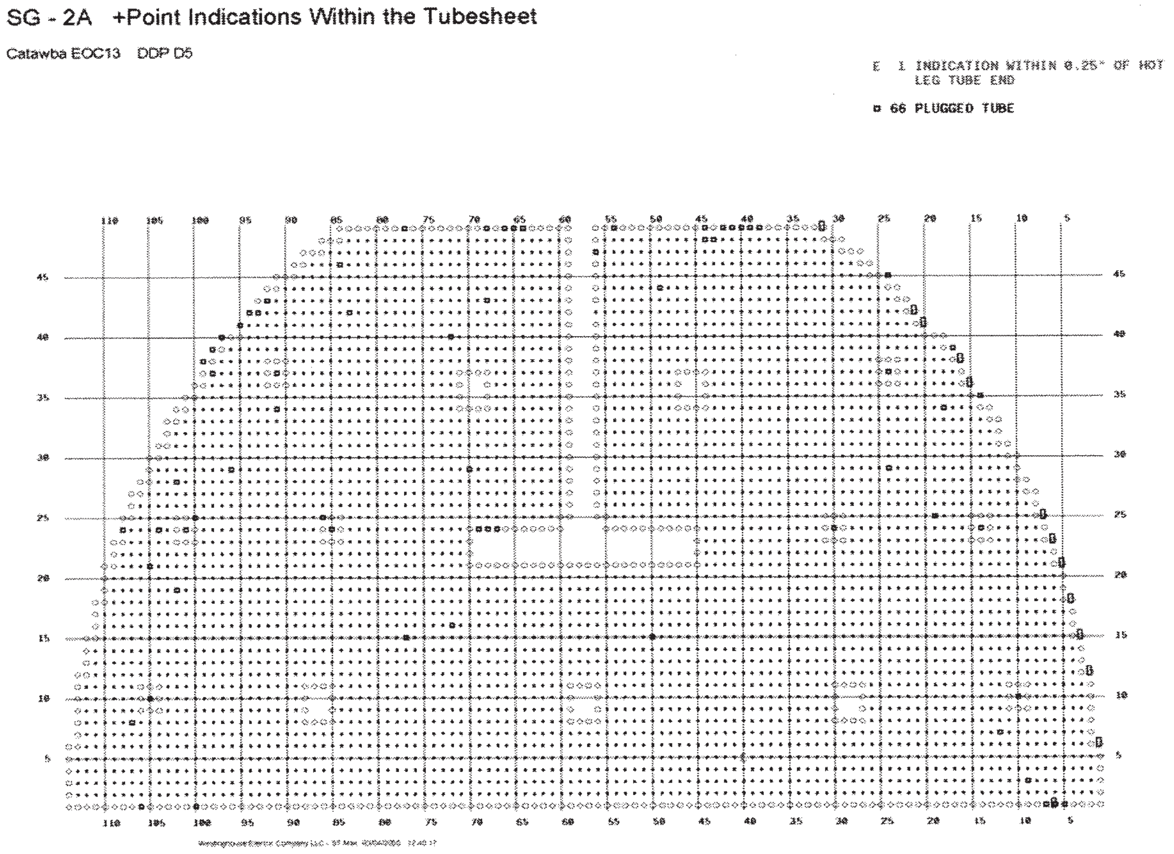

Figure 1: Distribution of Indications in SG A at Catawba 2

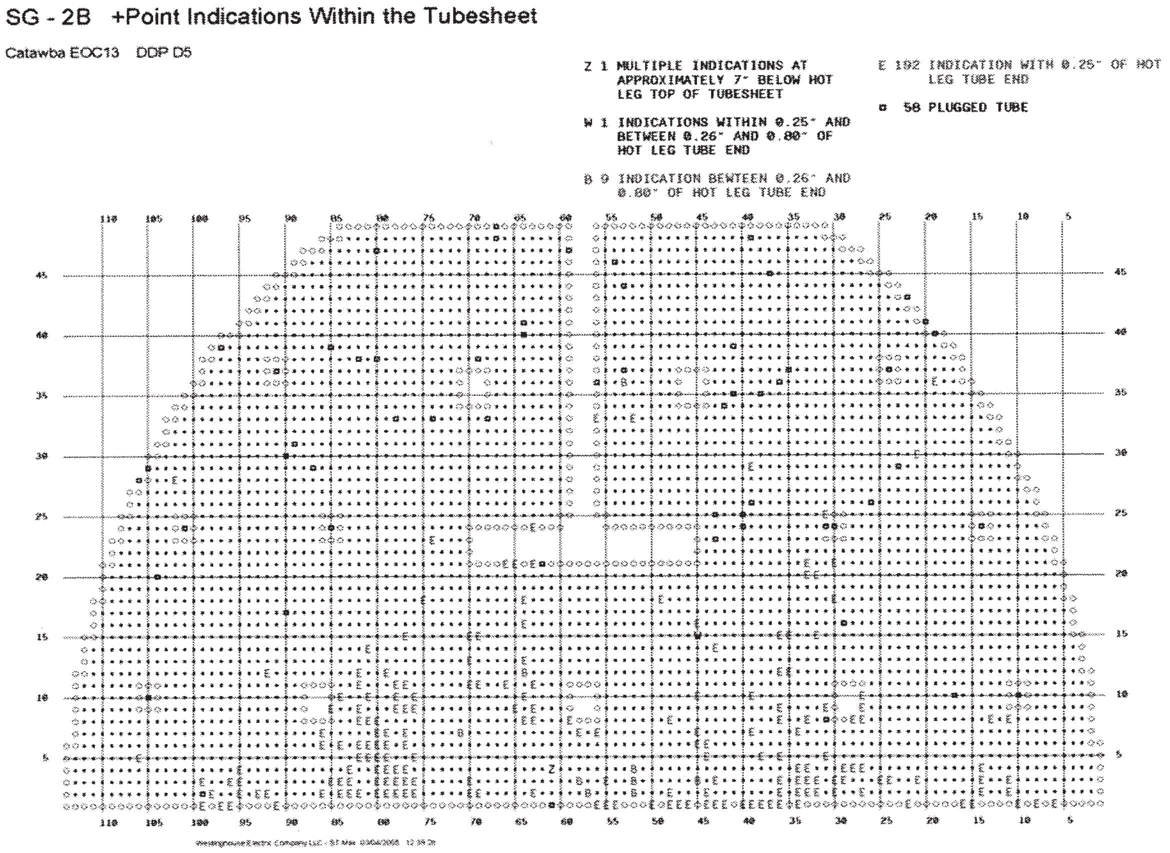

Figure 2: Distribution of Indications in SG B at Catawba 2

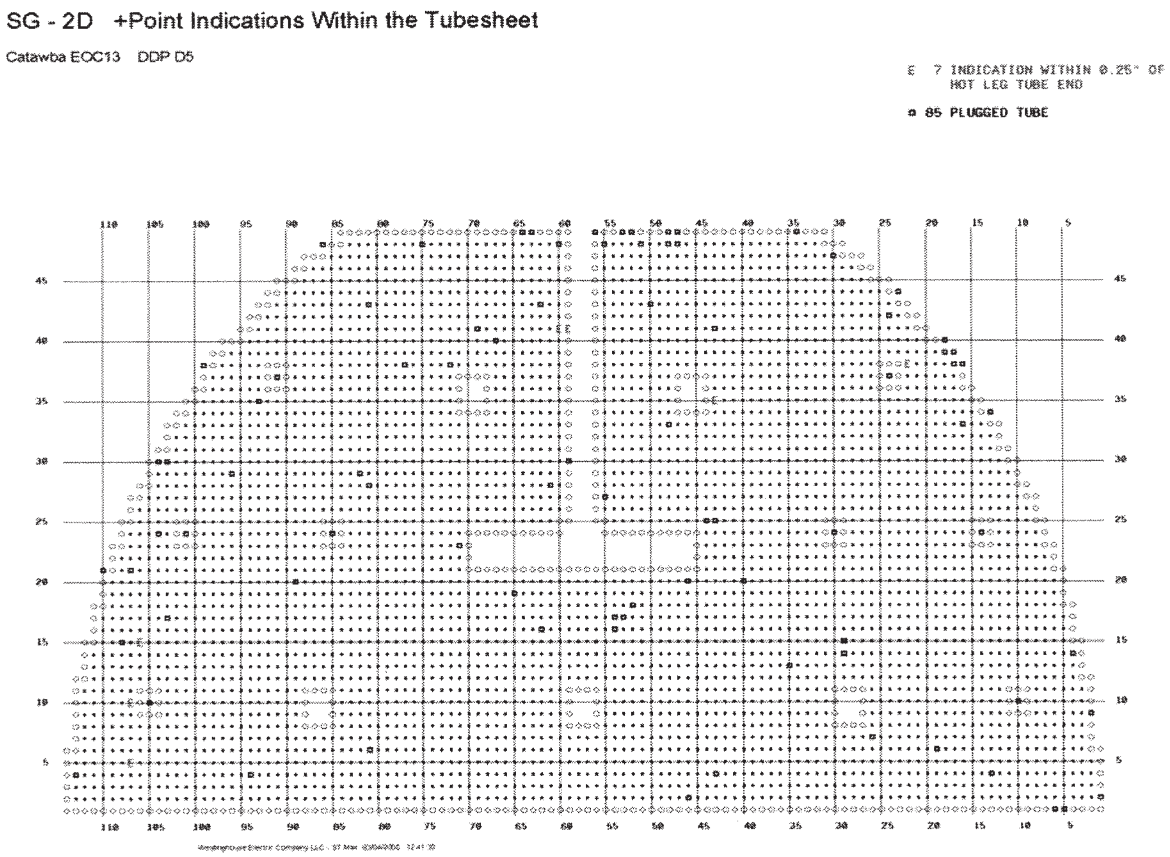

Figure 3: Distribution of Indications in SG D at Catawba 2

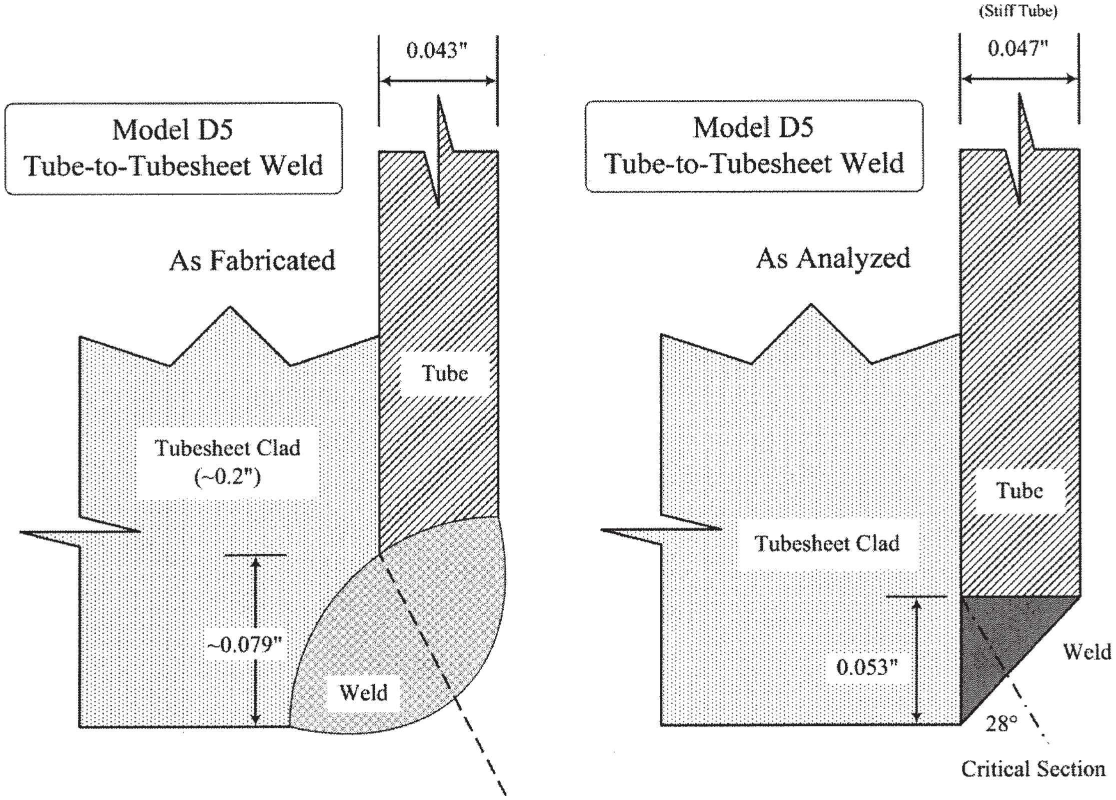

Figure 4: As-Fabricated & Analyzed Tube-to-Tubesheet Welds

a,c,e

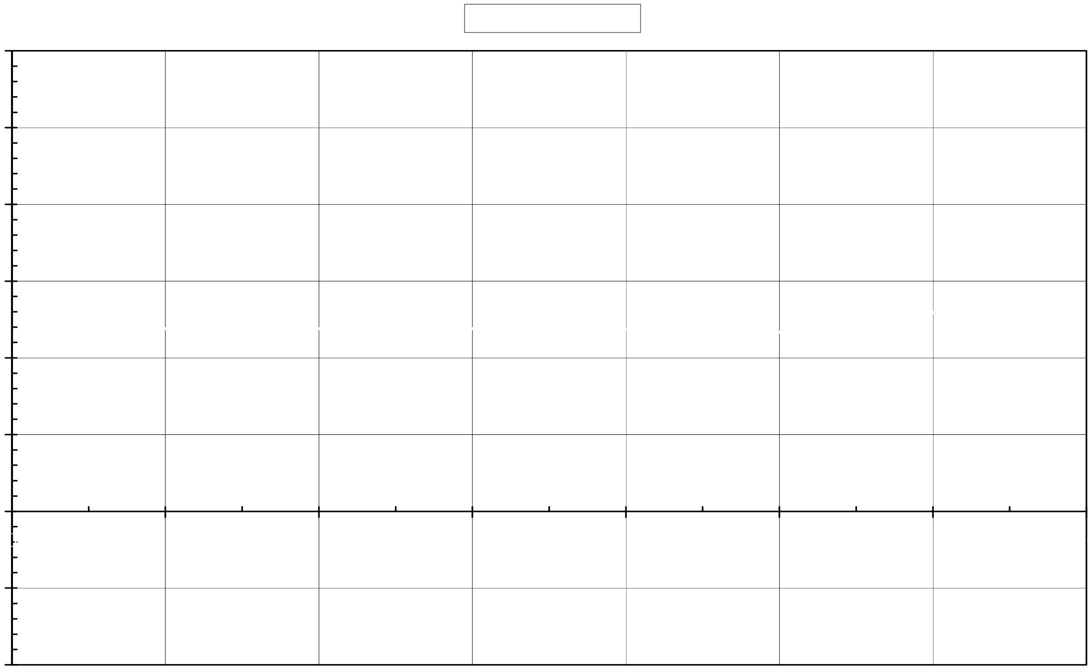

Figure 5: Definition of H* Zones from Reference 5

a,c,e

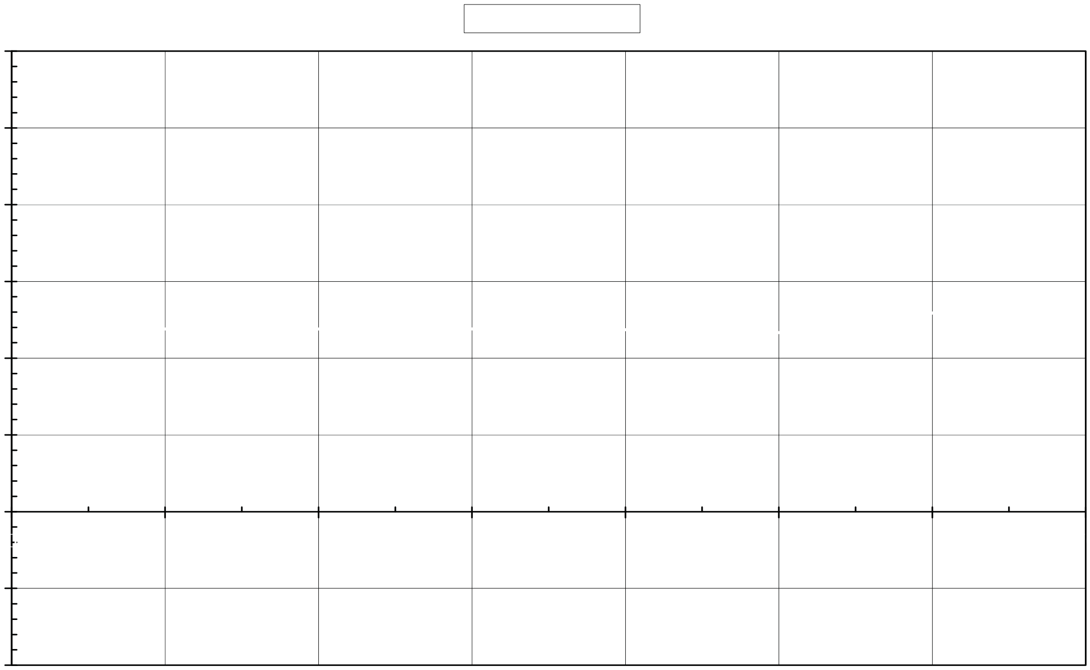

Figure 6: Flow Resistance Curve from Reference 5

a,c,e

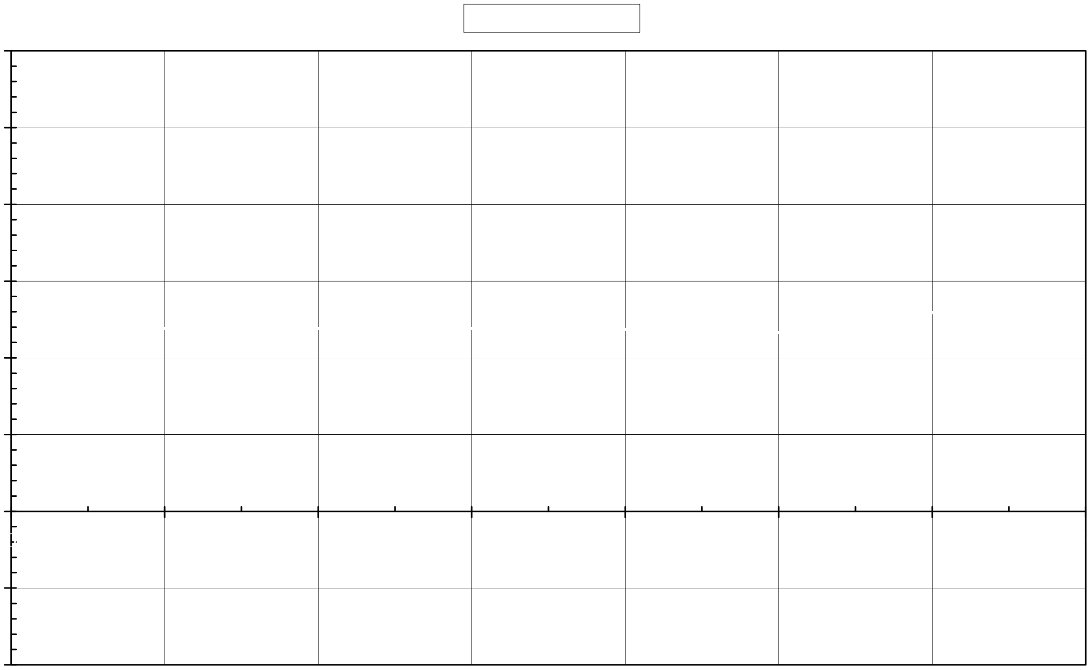

Figure 7: Change in contact pressure at 10.5 inches below the TTS

a,c,e

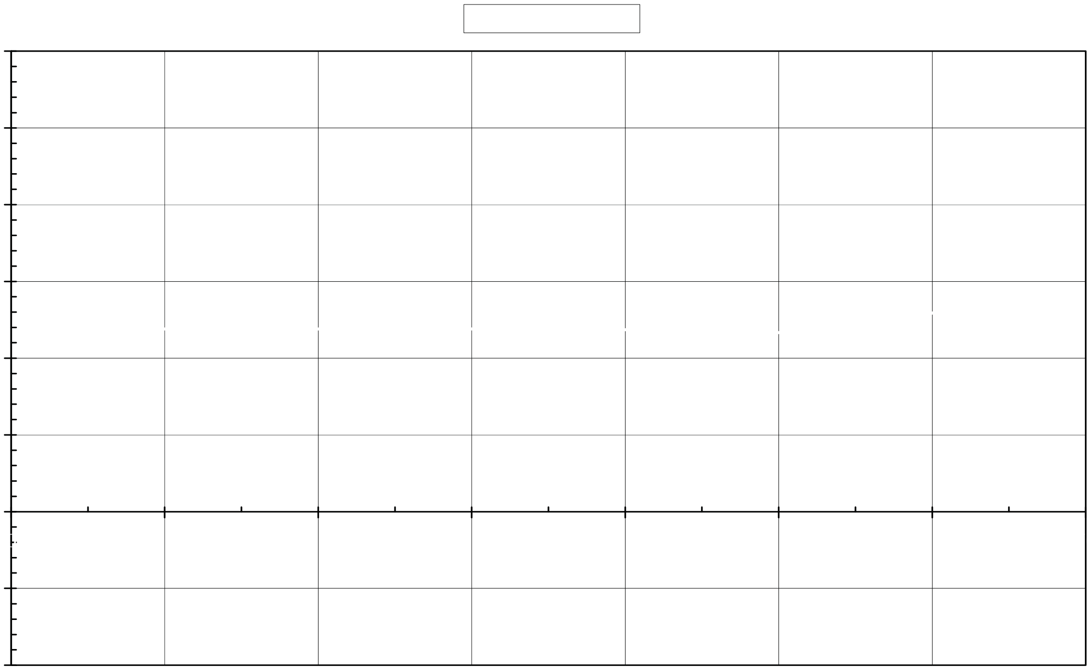

Figure 8: Change in contact pressure at 12.6 inches below the TTS

a,c,e

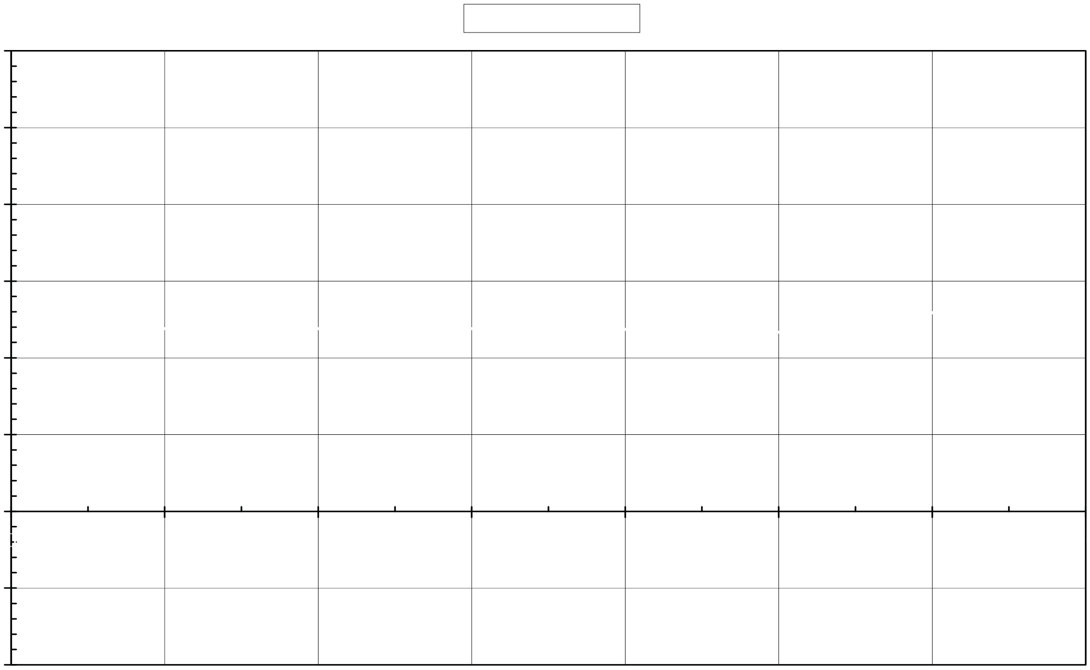

Figure 9: Change in contact pressure at 16.9 inches below the TTS

a,c,e

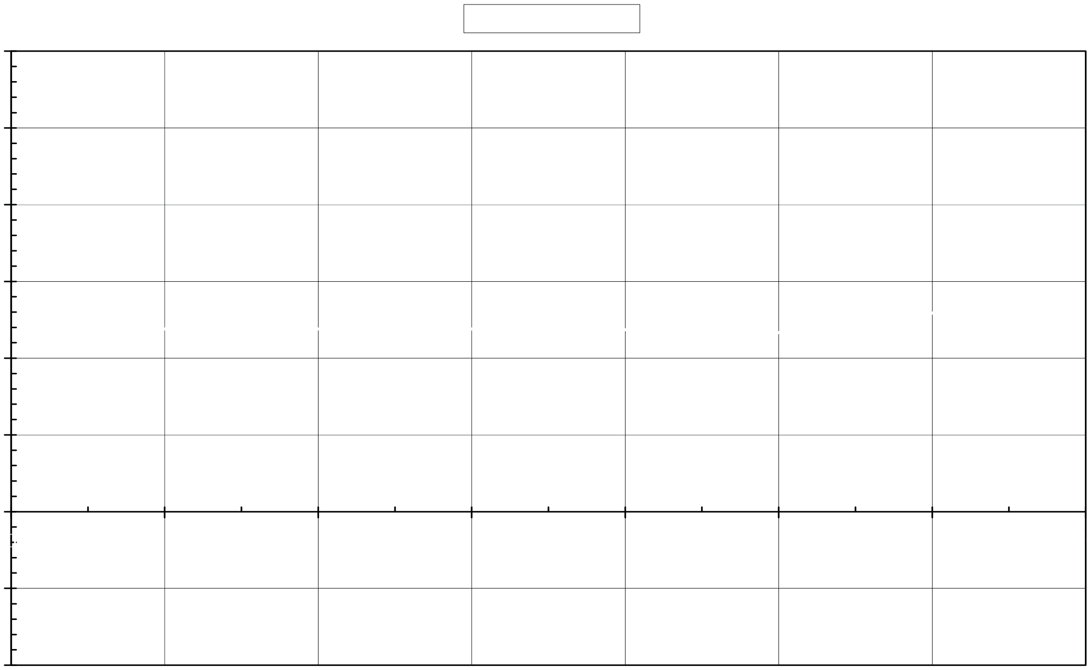

Figure 10: Change in contact pressure at the bottom of the tubesheet

a,c,e

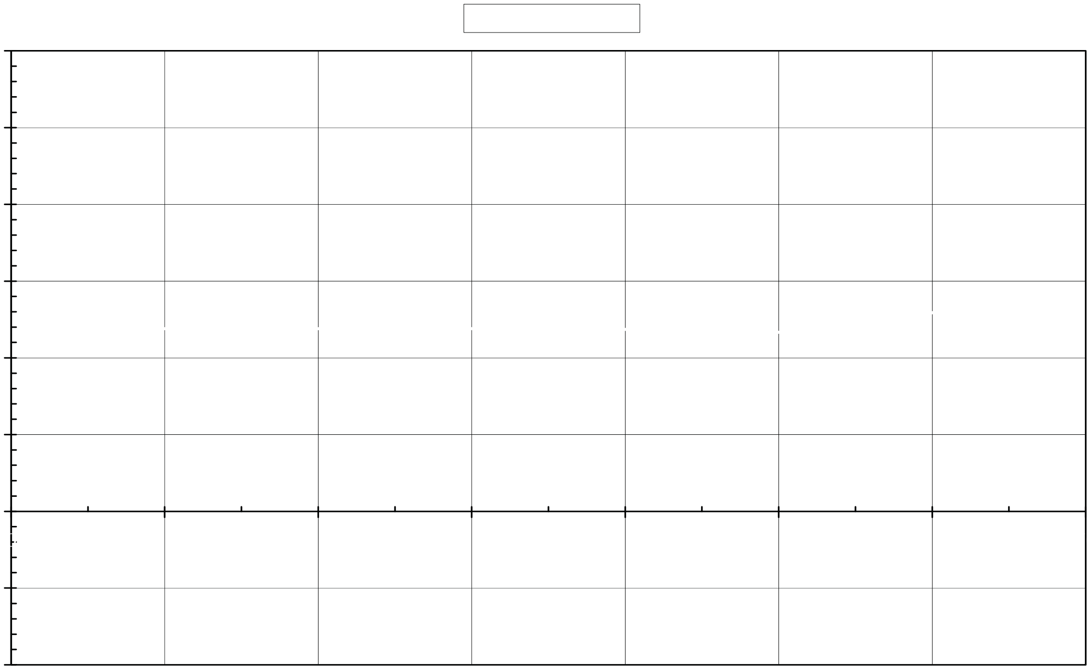

Figure 11: Change in contact pressure at 8.25 inches below the TTS

Appendix A ─ Structural Analysis of the Tube-to-Tubesheet Contact Pressure

A. Structural Analysis of the Tube-to-Tubesheet Interface Joint

An evaluation was performed to determine the contact pressures between the tubes and the tubesheet in the Byron 2 & Braidwood 2 SGs to support the determination of the engagement length needed to resist the performance criteria end cap loads and estimation of potential leak rates through the tube-to-tubesheet joints. The evaluation utilized [

]^{a,c,e}, were determined.

The same contact pressure results were used in the bellwether analysis to establish bounding values for the potential leak rate during postulated accident conditions relative to that during normal operation.

A.1 Evaluation of Tubesheet Deflection Effects for Tube-to-Tubesheet Contact Pressure

A finite element model was developed for the Model D5 tubesheet, channel head, and shell region to determine the tubesheet hole dilations in the Byron/Braidwood steam generators. [

]^{a,c,e}

loads in the tube.

A.1.1 Material Properties and Tubesheet Equivalent Properties

The tubes in the Byron 2 and Braidwood 2 SGs were fabricated of A600TT material. Summaries of the applicable mechanical and thermal properties for the tube material are provided in Table A.1. The tubesheets were fabricated from SA-508, Class 2a, material for which the properties are listed in Table A.2. The shell material is SA-533 Grade A Class 2, and its properties are in Table A.3. Finally, the channel head material is SA-216 Grade WCC, and its properties are in Table A.4. The material properties are from Reference A-4, and match the properties listed in the ASME Code.

The perforated tubesheet in the Model D5 channel head assembly is treated as an equivalent solid plate in the global finite element analysis. An accurate model of the overall plate behavior was achieved by using the concept of an equivalent elastic material with anisotropic properties. For square tubesheet hole patterns, the equivalent material properties depend on the orientation of loading with respect to the symmetry axes of the pattern. An accurate approximation was developed, Reference A-12, where energy principles were used to derive effective average isotropic elasticity matrix coefficients for the in-plane loading. The average isotropic stiffness formulation gives results that are consistent with those using the Minimum Potential Energy Theorem, and the elasticity problem thus becomes axisymmetric. The solution for strains is sufficiently accurate for design purposes, except in the case of very small ligament efficiencies, which are not of issue for the evaluation of the SG tubesheet.

The stress-strain relations for the axisymmetric perforated part of the tubesheet are given by:

$$\begin{bmatrix} \sigma_R^* \\ \sigma_\theta^* \\ \sigma_Z^* \\ \tau_{RZ}^* \end{bmatrix} = \begin{bmatrix} D_{11} & D_{12} & D_{13} & 0 \\ D_{21} & D_{22} & D_{23} & 0 \\ D_{31} & D_{32} & D_{33} & 0 \\ 0 & 0 & 0 & D_{44} \end{bmatrix} \begin{bmatrix} \varepsilon_R^* \\ \varepsilon_\theta^* \\ \varepsilon_Z^* \\ \gamma_{RZ}^* \end{bmatrix}$$

with the elasticity coefficients are calculated as:

$$\mathrm{D}_{11} = \mathrm{D}_{22} = \frac{\overline{\mathrm{E}}_{\mathrm{p}}^*}{\mathrm{f}(1+\overline{\nu}_{\mathrm{p}}^*)}\left[1-\frac{\overline{\mathrm{E}}_{\mathrm{p}}^*}{\mathrm{E}_{\mathrm{Z}}^*}\nu^2\right]+\frac{1}{2}\left[\overline{\mathrm{G}}_{\mathrm{p}}^*-\frac{\overline{\mathrm{E}}_{\mathrm{p}}^*}{2(1+\overline{\nu}_{\mathrm{p}}^*)}\right]$$

$$\mathrm{D}_{21} = \mathrm{D}_{12} = \frac{\overline{\mathrm{E}}_{\mathrm{p}}^*}{\mathrm{f}(1+\overline{\nu}_{\mathrm{p}}^*)}\left[\overline{\nu}_{\mathrm{p}}^*+\frac{\overline{\mathrm{E}}_{\mathrm{p}}^*}{\mathrm{E}_{\mathrm{Z}}^*}\nu^2\right]-\frac{1}{2}\left[\overline{\mathrm{G}}_{\mathrm{p}}^*-\frac{\overline{\mathrm{E}}_{\mathrm{p}}^*}{2(1+\overline{\nu}_{\mathrm{p}}^*)}\right]$$

$$\mathrm{D}_{13} = \mathrm{D}_{23} = \mathrm{D}_{31} = \mathrm{D}_{32} = \frac{\overline{\mathrm{E}}_{\mathrm{p}}^*\nu}{\mathrm{f}}$$

$$\mathrm{D}_{33} = \frac{\mathrm{E}_{\mathrm{Z}}^*(1-\overline{\nu}_{\mathrm{p}}^*)}{\mathrm{f}} \text{ and } \mathrm{D}_{44} = \overline{\mathrm{G}}_{\mathrm{Z}}^*$$

$$\text{where } \mathrm{f} = 1-\overline{\nu}_{\mathrm{p}}^* - 2\frac{\overline{\mathrm{E}}_{\mathrm{p}}^*}{\mathrm{E}_{\mathrm{Z}}^*}\nu^2 \text{ and } \overline{\mathrm{G}}_{\mathrm{p}}^* = \frac{\overline{\mathrm{E}}_{\mathrm{d}}^*}{2(1+\overline{\nu}_{\mathrm{d}}^*)}.$$

Here,

$\overline{E}_p^*$ = Effective elastic modulus for in-plane loading in the pitch direction,
E_z^* = Effective elastic modulus for loading in the thickness direction,
$\overline{\nu}_p^*$ = Effective Poisson's ratio for in-plane loading in the pitch direction,
$\overline{\mathrm{G}}_{\mathrm{p}}^*$ = Effective shear modulus for in-plane loading in the pitch direction,
$\overline{\mathrm{G}}_{\mathrm{z}}^*$ = Effective modulus for transverse shear loading,
$\overline{E}_d^*$ = Effective elastic modulus for in-plane loading in the diagonal direction,
$\overline{\nu}_d^*$ = Effective Poisson's ratio for in-plane loading in the diagonal direction, and,
ν = Poisson's ratio for the solid material.

The tubesheet is a thick plate and the application of the pressure load results in a generalized plane strain condition. The pitch of the square, perforated hole pattern is 1.0625 inches and nominal hole diameters are 0.764 inch. The ID of the tube after expansion into the tubesheet is taken to be

0.67886 inch based on an assumption of 1% thinning during installation. Equivalent properties of the tubesheet are calculated without taking credit for the stiffening effect of the tubes.

$$\text{Ligament Efficiency, } \eta = \frac{h_{\text{nominal}}}{P_{\text{nominal}}}$$

where:
h_{nominal} = P_{nominal} - d_{maximum}
P_{nominal} = 1.0625 inches, the pitch of the square hole pattern
d_{maximum} = .764 inches, the tube hole diameter

Therefore, h_{nominal} = 0.2985 inches (1.0625-0.764), and η = 0.2809 when the tubes are not included. From Slot, Reference A-13, the in-plane mechanical properties for Poisson's ratio of 0.3 are:

Property	Value
$\overline{E}_p^* / E$	= 0.3992
$\overline{\nu}_p^*$	= 0.1636
$\overline{G}_p^* / G$	= 0.1674
E_z^* / E	= 0.5935
G_z^* / G	= 0.4189

where the subscripts p and d refer to the pitch and diagonal directions, respectively. These values are substituted into the expressions for the anisotropic elasticity coefficients given previously. In the global model, the X-axis corresponds to the radial direction, the Y-axis to the vertical or tubesheet thickness direction, and the Z-axis to the hoop direction. The directions assumed in the derivation of the elasticity coefficients were X- and Y-axes in the plane of the tubesheet and the Z-axis through the thickness. In addition, the order of the stress components in the WECAN/Plus (Reference A-14) elements used for the global model is σ_{xx}, σ_{yy}, τ_{xy}, and σ_{zz}. The mapping between the Reference A-12 equations and WECAN/+ is therefore:

Coordinate Mapping	
Reference A-12	WECAN/+
1	1
2	4
3	2
4	3

Table A.2 gives the modulus of elasticity, E, of the tubesheet material at various temperatures. Using the equivalent property ratios calculated above in the equations presented at the beginning of this section gives the elasticity coefficients for the equivalent solid plate in the perforated region of the tubesheet. These are listed in Table A.5 for the tubesheet, without accounting for the effect of the tubes. The values for 600°F were used for the finite element unit load runs. The material properties of the tubes are not utilized in the finite element model, but are listed in Table A.1 for use in the calculations of the tube/tubesheet contact pressures.

A.1.2 Finite Element Model

The analysis of the contact pressures utilizes conventional (thick shell equations) and finite element analysis techniques. A finite element model was developed for the Model D5-2 SG channel head/tubesheet/shell region (which includes the Byron/Braidwood steam generator) in order to determine the tubesheet rotations. The elements used for the models of the channel head/tubesheet/shell region were the quadratic version of the 2-D axisymmetric isoparametric elements STIF53 and STIF56 of WECAN/Plus (Reference A-14). The model for the D5-2 steam generator is shown in Figure A.1.

The unit loads applied to this model is listed below:

Unit Load	Magnitude
Primary Side Pressure	1000 psi
Secondary Side Pressure	1000 psi
Tubesheet Thermal Expansion	500°F
Shell Thermal Expansion	500°F
Channel Head Thermal Expansion	500°F

The three temperature loadings consist of applying a uniform thermal expansion to each of the three component members, one at a time, while the other two remain at ambient conditions. The boundary conditions imposed for all five cases are: UX=0 at all nodes on the centerline, and UY=0 at one node on the lower surface of the tubesheet support ring. In addition, an end cap load is applied to the top of the secondary side shell for the secondary side pressure unit load equal to:

$$P_{endcap} = -\left[\frac{(R_i)^2}{(R_o)^2 - (R_i)^2}\right]P = -9708.43 \text{ psi}$$

where, R_i = Inside radius of secondary shell in finite element model = 64.69 in.
R_o = Outside radius of secondary shell in finite element model = 67.94 in.
P = Secondary pressure unit load = 1000 psi.

This yielded displacements throughout the tubesheet for the unit loads.

A.1.3 Tubesheet Rotation Effects

Loads are imposed on the tube as a result of tubesheet rotations under pressure and temperature conditions. Previous calculations performed [

]^{a,c,e}.

The radial deflection at any point within the tubesheet is found by scaling and combining the unit load radial deflections at that location according to:

$$\left[\qquad \right]^{a,c,e}$$

This expression is used to determine the radial deflections along a line of nodes at a constant axial elevation (e.g. top of the tubesheet) within the perforated area of the tubesheet. The expansion of a hole of diameter D in the tubesheet at a radius R is given by:

$$\left[\qquad \right]^{a,c,e}$$

UR is available directly from the finite element results. dUR/dR may be obtained by numerical differentiation.

The maximum expansion of a hole in the tubesheet is in either the radial or circumferential direction. [

]^{a,c,e}

Where SF is a scale factor between zero and one. For the eccentricities typically encountered during tubesheet rotations, [ ]^{a,c,e}. These values are listed in the following table:

a,c,e

The data were fit to the following polynomial equation:

[$]^{a,c,e}$

The hole expansion calculation as determined from the finite element results includes the effects of tubesheet rotations and deformations caused by the system pressures and temperatures. It does not include the local effects produced by the interactions between the tube and tubesheet hole. Standard thick shell equations, including accountability for the end cap axial loads in the tube (Reference A-15), in combination with the hole expansions from above are used to calculate the contact pressures between the tube and the tubesheet.

The unrestrained radial expansion of the tube OD due to thermal expansion is calculated as:

$$\Delta R_t^{th} = c\,\alpha_t\,(T_t - 70)$$

and from pressure acting on the inside and outside of the tube as,

$$\Delta R_{to}^{pr} = \frac{P_i c}{E_t}\left[\frac{(2-\nu)b^2}{c^2 - b^2}\right] - \frac{P_o c}{E_t}\left[\frac{(1-2\nu)c^2 + (1+\nu)b^2}{c^2 - b^2}\right],$$

where: P_i = Internal primary side pressure, P_{pri} psi
P_o = External secondary side pressure, P_{sec} psi
b = Inside radius of tube = 0.33943 in.
c = Outside radius of tube = 0.382 in.
α_t = Coefficient of thermal expansion of tube, in/in/°F
E_t = Modulus of Elasticity of tube, psi
T_t = Temperature of tube, °F ,and,
ν = Poisson's Ratio of the material.

The thermal expansion of the hole ID is included in the finite element results and does not have to be expressly considered in the algebra, however, the expansion of the hole ID produced by pressure is given by:

$$\Delta R_{TS}^{pr} = \frac{P_i c}{E_{TS}}\left[\frac{d^2 + c^2}{d^2 - c^2} + \nu\right],$$

where: E_{TS} = Modulus of Elasticity of tubesheet, psi
d = Outside radius of cylinder which provides the same radial stiffness as the tubesheet, that is, [$]^{a,c,e}$.

If the unrestrained expansion of the tube OD is greater than the expansion of the tubesheet hole, then the tube and the tubesheet are in contact. The inward radial displacement of the outside surface of the tube produced by the contact pressure is given by: (Note: The use of the term δ in this section is unrelated its potential use elsewhere in this report.)

$$\delta_t = \frac{P_2 c}{E_t}\left[\frac{c^2 + b^2}{c^2 - b^2} - \nu\right]$$

The radial displacement of the inside surface of the tubesheet hole produced by the contact pressure between the tube and hole is given by:

$$\delta_{TS} = \frac{P_2 c}{E_{TS}}\left[\frac{d^2 + c^2}{d^2 - c^2} + \nu\right]$$

The equation for the contact pressure P_2 is obtained from:

$$\delta_{to} + \delta_{TS} = \Delta R_{to} - \Delta R_{TS} - \Delta R_{ROT}$$

where ΔR_{ROT} is the hole expansion produced by tubesheet rotations obtained from finite element results. The ΔR's are:

$$\Delta R_{to} = c\alpha_t (T_t - 70) + \frac{P_{pri} c}{E_t}\left[\frac{(2-\nu)b^2}{c^2 - b^2}\right] - \frac{P_{sec} c}{E_t}\left[\frac{(1-2\nu)c^2 + (1+\nu)b^2}{c^2 - b^2}\right]$$

$$\Delta R_{TS} = \frac{P_{sec} c}{E_{TS}}\left[\frac{d^2 + c^2}{d^2 - c^2} + \nu\right]$$

The resulting equation is:

a,c,e

For a given set of primary and secondary side pressures and temperatures, the above equation is solved for selected elevations in the tubesheet to obtain the contact pressures between the tube and tubesheet as a function of radius. The elevations selected ranged from the top to the bottom of the tubesheet. Negative "contact pressure" indicates a gap condition.

The OD of the tubesheet cylinder is equal to that of the cylindrical (simulate) collars (1.80 inches) designed to provide the same radial stiffness as the tubesheet, which was determined from a finite element analysis of a section of the tubesheet (Reference A-16).

The tube inside and outside radii within the tubesheet are obtained by assuming a nominal diameter for the hole in the tubesheet (0.764 inch) and wall thinning in the tube equal to the average of that measured during hydraulic expansion tests. That thickness is 0.04257 inch for the tube. The following table lists the values used in the equations above, with the material properties evaluated at 600°F. (Note that the properties in the following sections are evaluated at the primary fluid temperature).

Thick Cylinder Equations Parameter	Value
b, inside tube radius, in.	0.33943
c, outside tube radius, in.	0.382
d, outside radius of cylinder w/ same radial stiffness as TS, in.	[ ]^{a,c,e}
α_t, coefficient of thermal expansion of tube, in/in °F	$7.83\cdot10^{-6}$
E_t, modulus of elasticity of tube, psi	$28.7\cdot10^{6}$
α_{TS}, coefficient of thermal expansion of tubesheet, in/in °F	$7.42\cdot10^{-6}$
E_{TS}, modulus of elasticity of tubesheet, psi	$26.4\cdot10^{6}$

A.1.4 Byron/Braidwood 2 Contact Pressures

A.1.4.1 Normal Operating Conditions

The loadings considered in the analysis are based on an umbrella set of conditions as defined in References A-11 through A-13. The current operating parameters from Reference A-2 are used. The temperatures and pressures for normal operating conditions at Byron/Braidwood Unit 2 are bracketed by the following two cases:

Loading	T_{min}(1)	T_{max}(2)
Primary Pressure	2235 psig	2235 psig
Secondary Pressure	796 psig	938 psig
Primary Fluid Temperature (T_{hot})	608.0°F	620.3°F
Secondary Fluid Temperature	519.8°F	538.8°F

(1) Low T_{ave} with 10% Tube Plugging case in Reference A-2.
(2) High T_{ave} with 0% Tube Plugging case in Reference A-2.

The primary pressure [

]^{a,c,e}.

A.1.4.2 Faulted Conditions

Of the faulted conditions, Feedline Break (FLB) and Steamline Break (SLB) are the most limiting. FLB has a higher ΔP across the tubesheet, while the lower temperature of SLB results in less thermal tightening. Both cases are considered in this section.

Previous analyses have shown that FLB and SLB are the limiting faulted conditions, with tube lengths required to resist push out during a postulated loss of coolant accident (LOCA) typically less than one-fourth of the tube lengths required to resist pull out during FLB and SLB (References A-15 and A-17). Therefore LOCA was not considered in this analysis.

A.1.4.2.1 Feedline Break

The temperatures and pressures for Feedline Break at Byron/Braidwood Unit 2 are bracketed by the following two cases:

Loading	T_{min}(1)	T_{max}(2)
Primary Pressure	2835 psig	2835 psig
Secondary Pressure	0 psig	0 psig
Primary Fluid Temperature (T_{hot})	608.0°F	620.3°F
Secondary Fluid Temperature	519.8°F	538.8°F
(1) Low T_{ave} with 10% Tube Plugging case in Reference A-2. (2) High T_{ave} with 0% Tube Plugging case in Reference A-2.		

The Feedline Break condition [

]^{a,c,e}.

A.1.4.2.2 Steam Line Break

As a result of SLB, the faulted SG will rapidly blow down to atmospheric pressure, resulting in a large ΔP across the tubes and tubesheet. The entire flow capacity of the auxiliary feedwater system would be delivered to the dry, hot shell side of the faulted SG. The primary side re-pressurizes to the pressurizer safety valve set pressure. The hot leg temperature decreases throughout the transient, reaching a minimum temperature of 297°F at 2000 seconds for four loop plants. The pertinent parameters are listed below. The combination of parameters yielding the most limiting results is used.

Primary Pressure = 2560 psig
Secondary Pressure = 0 psig
Primary Fluid Temperature (T_{hot}) = 297°F
Secondary Fluid Temperature = 212°F

For this set of primary and secondary side pressures and temperatures, the equations derived in Section A.1.3 are solved for the selected elevations in the tubesheet to obtain the contact pressures between the tube and tubesheet as a function of tubesheet radius for the hot leg.

A.1.5 Summary of FEA Results for Tube-to-Tubesheet Contact Pressures

For Byron/Braidwood 2, the contact pressures between the tube and tubesheet for various plant conditions are listed in Table A.6 and plotted versus radius in Figure A.2 through Figure A.6. The application of these values to the determination of the required engagement length is discussed in Section A.2 following.

A.2 Determination of Required Engagement Length of the Tube in the Tubesheet

The elimination of a portion of the tube within the tubesheet from the in-service inspection requirement constitutes a change in the pressure boundary. This is the case regardless of whether or not the inspection is being eliminated in its entirety or if RPC examination is being eliminated when the potential for the existence of circumferential cracks is determined to be necessary for consideration. The elimination of the lower portion of the tube from examination is an H* partial-length RPC justification in the sense of WCAP-16152 and relies on knowledge of the tube-to-tubesheet interfacial, mechanical interference fit contact pressure at all elevations in the tube joint. In order to maintain consistency with other reports on this subject, the required length of engagement of the tube in the tubesheet to resist performance criteria tube end cap loads is designated by the variable H*. This length is based on structural requirements only and does not include any connotation associated with leak rate, except perhaps in a supporting role with regard to the leak rate expectations relative to normal operating conditions. Since the H* length is usually some distance from the top of the tubesheet, this is especially in the upper half of the tube joint. The contact pressure is used for estimating the magnitude of the anchorage of the tube in the tubesheet over the H* length. It is also used in estimating the impact of changes in the contact pressure on potential primary-to-secondary leak rate during postulated accident conditions.

To take advantage of the tube-to-tubesheet joint anchorage, it is necessary to demonstrate that the [

$]^{a,c,e}$

The end cap loads for Normal and Faulted conditions are:

Normal (maximum): $\pi * (2235\text{-}792) * (0.764)^2 /4 = 659.69$ lbs.
Faulted (FLB): $\pi * 2835 * (0.764)^2 /4 = 1299.66$ lbs.
Faulted (SLB): $\pi * 2560 * (0.764)^2 /4 = 1173.59$ lbs.

Seismic loads have also been considered, but they are not significant in the tube joint region of the tubes.

A key element in estimating the strength of the tube-to-tubesheet joint during operation or postulated accident conditions is the residual strength of the joint stemming from the expansion preload due to the manufacturing process, i.e., hydraulic expansion. During operation the preload increases because the thermal expansion of the tube is greater than that of the tubesheet and because a portion of the internal pressure in the tube is transmitted to the interface between the tube and the tubesheet. However, the tubesheet bows upward leading to a dilation of the tubesheet holes at the top of the tubesheet and a contraction at the bottom of the tubesheet when the primary-to-secondary pressure difference is positive. The dilation of the holes acts to reduce the contact pressure between the tubes and the tubesheet. The H* lengths are based on the pullout resistance associated with the net contact pressure during normal or accident conditions. The calculation of the residual strength involves a conservative approximation that the strength is uniformly distributed along the entire length of the tube. This leads to a lower bound estimate of the strength and relegates the contribution of the preload to having a second order effect on the determination of H*.

A series of tests were performed to determine of the residual strength of the joint. The data from this series of pullout tests are listed in Table A.12. Three (3) each of the tests were performed at room temperature, 400°F, and 600°F. (Note: Three other tests were performed with internal pressure in the tube. However, in these tests, the resistance to pullout was so great that the tube yielded, furnishing only input information of joint lower bound strength. These data were not used.) A comparison of the implied net contact pressure, “Net P,” from the tests can be effected by looking at the values in the next to last column. These include a correction factor to account for the increase in interface pressure, “Thermal P,” due to the increased thermal expansion of the tube relative to the TS simulant. The last column converts the “Net P” into a “Net Force/inch” of engagement for use in the H* calculations. The results exhibit a degree of scatter, with an average net force of 541.2 lbf/inch, and a standard deviation of 214.4 lbf/inch. For these calculations a realistic value of the coefficient of friction between the tube and the tubesheet of 0.3 was used, which is conservative relative to the value of 0.2 that is used to conservatively calculate the criteria to be applied. A conservative value used for the pullout force in the H* calculations was the average minus the standard deviation, or 326.8 lb./inch. The pullout test results as a function of engagement length are plotted on Figure A.7.

For the partial-length RPC evaluation, tube-to-tubesheet contact pressure was calculated for the entire tube length in the TS, at six radii from the bundle vertical centerline. The first radius, R, was the location of greatest tubesheet hole dilation, caused by the greatest bending from out-of-plane deflection of the tubesheet at a radius of 4.076 inches. Three radii were evaluated toward the middle of the tubesheet, 11.898. 20.698, and 34.386 inches respectively. Finally, two radii, 49.053 and 58.830 inches, were evaluated near the bundle periphery. Only the following outboard radii were used in establishing the H* distances: 34.386, 49.053 and 58.83 inches. This is conservative because the value determined for 4.076 inches was used for all tubes within 34.386 inches, et cetera. The top part of Table A.7 and Table A.8 for the hot leg lists the contact pressures through the thickness at each of the three analyzed sections for normal operation conditions.]^{a,c,e}

The force resisting pullout acting on a length of a tube between elevations h_1 and h_2 is given by:

$$F_i = (h_2 - h_1)F_{HE} + \mu\pi d \int_{h_1}^{h_2} P\,dh$$

where: F_{HE} = Resistance to pull out due to the initial hydraulic expansion = 326.8 lb/inch,
P = Contact pressure acting over the incremental length segment dh, and,
μ = Coefficient of friction between the tube and tubesheet, conservatively assumed to be 0.2 for the pullout analysis to determine H*.

The contact pressure is assumed to vary linearly between adjacent elevations in the top part of Table A.7 through Table A.11, so that between elevations L_1 and L_2,

$$P = P_1 + \frac{(P_2 - P_1)}{(L_2 - L_1)}(h - L_1)$$

or,

[ ]^{a,c,e}

so that,

[ ]^{a,c,e}

This equation was used to accumulate the force resisting pullout from the top of the tubesheet to each of the elevations listed in the lower parts of Table A.7 through Table A.11. The above equation is also used to find the minimum contact lengths needed to meet the pullout force requirements. The length calculated was 7.03 inches for the 3 times the normal operating pressure performance criterion which corresponds to a pullout force of 1979 lbf in the Hot Leg.

The top part of Table A.9 lists the contact pressures through the thickness at each of the radial sections for Faulted (SLB) condition. The last row, "h(0)," of this part of the table lists the maximum tubesheet elevation at which the contact pressure is greater than or equal to zero. The above equation is used to accumulate the force resisting pull out from the top of the tubesheet to each of the elevations listed in the lower part of Table A.9. The above equation is also used to find the minimum contact lengths needed to meet the pull out force requirements. This length is 8.61 inches for the 1.43 times the accident pressure performance criterion which corresponds to a pullout force of 1859 lbs in the Hot Leg for the Faulted (SLB) condition. The minimum contact length needed to meet the pullout force requirement of 1859 lb. for the Faulted (FLB) condition is less as is shown in Table A.10 and Table A.11. The H* calculations for each loading condition at each of the radii considered are summarized in Table A.13. The H* results for each zone are summarized in Table A.14.

Therefore, the bounding condition for the determination of the H* length is the SLB performance criterion. The minimum contact length for the SLB faulted condition is 8.61 inches in Zone C, Reference A-18.

A.3 References

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Table A.1: Summary of Material Properties Alloy 600 Tube Material							
Property	Temperature (°F)						
	70	200	300	400	500	600	700
Young's Modulus ($psi \cdot 10^6$)	31.00	30.20	29.90	29.50	29.00	28.70	28.20
Thermal Expansion ($in/in/°F \cdot 10^{-6}$)	6.90	7.20	7.40	7.57	7.70	7.82	7.94
Density ($lb\text{-}sec^2/in^4 \cdot 10^{-4}$)	7.94	7.92	7.90	7.89	7.87	7.85	7.83
Thermal Conductivity ($Btu/sec\text{-}in\text{-}°F \cdot 10^{-4}$)	2.01	2.11	2.22	2.34	2.45	2.57	2.68
Specific Heat ($Btu\text{-}in/lb\text{-}sec^2\text{-}°F$)	41.2	42.6	43.9	44.9	45.6	47.0	47.9

Table A.2: Summary of Material Properties for SA-508 Class 2a Tubesheet Material							
Property	Temperature (°F)						
	70	200	300	400	500	600	700
Young's Modulus ($psi \cdot 10^6$)	29.20	28.50	28.00	27.40	27.00	26.40	25.30
Thermal Expansion ($in/in/°F \cdot 10^{-6}$)	6.50	6.67	6.87	7.07	7.25	7.42	7.59
Density ($lb\text{-}sec^2/in^4 \cdot 10^{-4}$)	7.32	7.30	7.29	7.27	7.26	7.24	7.22
Thermal Conductivity ($Btu/sec\text{-}in\text{-}°F \cdot 10^{-4}$)	5.49	5.56	5.53	5.46	5.35	5.19	5.02
Specific Heat ($Btu\text{-}in/lb\text{-}sec^2\text{-}°F$)	41.9	44.5	46.8	48.8	50.8	52.8	55.1

Table A.3: Summary of Material Properties SA-533 Grade A Class 2 Shell Material							
Property	Temperature (°F)						
	70	200	300	400	500	600	700
Young's Modulus ($psi \cdot 10^6$)	29.20	28.50	28.00	27.40	27.00	26.40	25.30
Thermal Expansion ($in/in/°F \cdot 10^{-6}$)	7.06	7.25	7.43	7.58	7.70	7.83	7.94
Density ($lb\text{-}sec^2/in^4 \cdot 10^{-4}$)	7.32	7.30	7.283	7.265	7.248	7.23	7.211

Table A.4: Summary of Material Properties SA-216 Grade WCC Channelhead Material							
Property	Temperature (°F)						
	70	200	300	400	500	600	700
Young's Modulus (psi·10^6)	29.50	28.80	28.30	27.70	27.30	26.70	25.50
Thermal Expansion (in/in/°F·10^{-6})	5.53	5.89	6.26	6.61	6.91	7.17	7.41
Density (lb-sec^2/in^4·10^{-4})	7.32	7.30	7.29	7.27	7.26	7.24	7.22

a,c,e

Table A.5: Equivalent Solid Plate Elasticity Coefficients for D5 Perforated TS SA-508 Class 2a Tubesheet Material

a,c,e

Table A.6:

a,c,e

Table A.7:			

a,c,e

Table A.8:

a,c,e

Table A.9:

a,c,e

Table A.10:

a,c,e

Table A.11:

a,c,e

Table A.12:

a,c,e

Table A.13:

Table A.14: H* Summary Table

Zone	Limiting Loading Condition	Engagement from TTS (inches)
A	3.0 NO ΔP $^{(1,2)}$	2.95 $^{(3)}$
B	1.43 SLB ΔP $^{(1,2)}$	6.00
C	1.43 SLB ΔP $^{(1,2)}$	8.61

Notes:

1. Seismic loads have been considered and are not significant in the tube joint region (Reference A-19 8.17).
2. The scenario of tubes locked at support plates is not considered to be a credible event in Model D5 SGs as they are manufactured with stainless steel support plates. However, conservatively assuming that the tubes become locked at 100% power conditions, the maximum force induced in an active tube as the SG cools to room temperature is
[ ]^{a,c,e}
3. 0.3 inches added to the maximum calculated H* for Zone A from Table 7.2-5 to account for the hydraulic expansion transition region at the top of the tubesheet.

a,c,e

Figure A.1: Finite Element Model of Model D5-3 Tubesheet Region

a,c,e

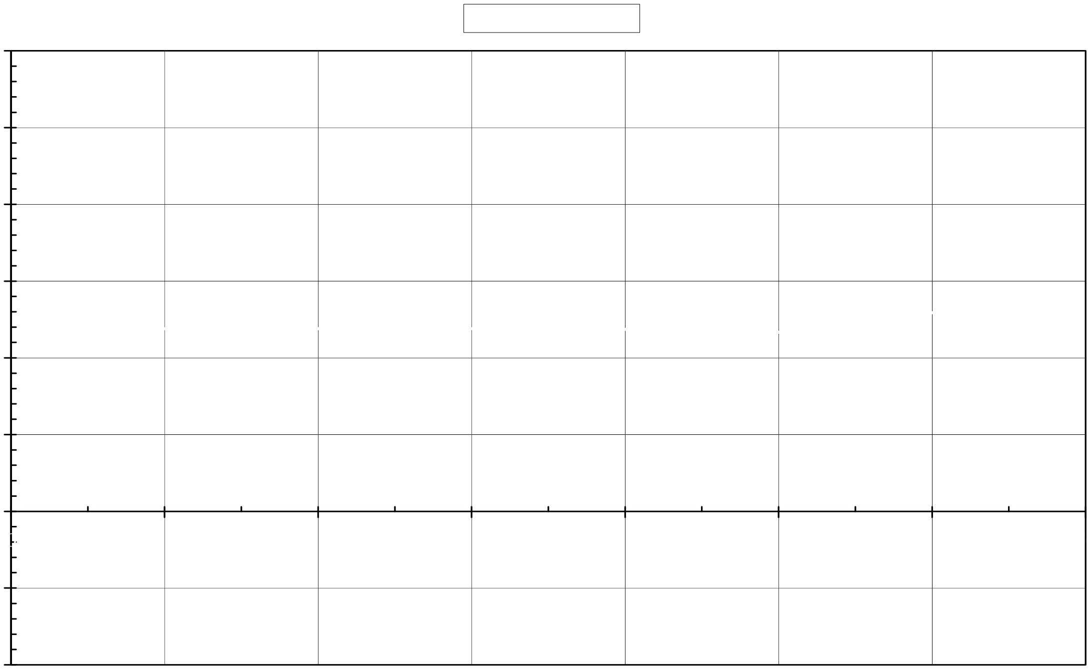

Figure A.2: Contact Pressures for Normal Condition (T_{min}) at Byron/Braidwood 2

a,c,e

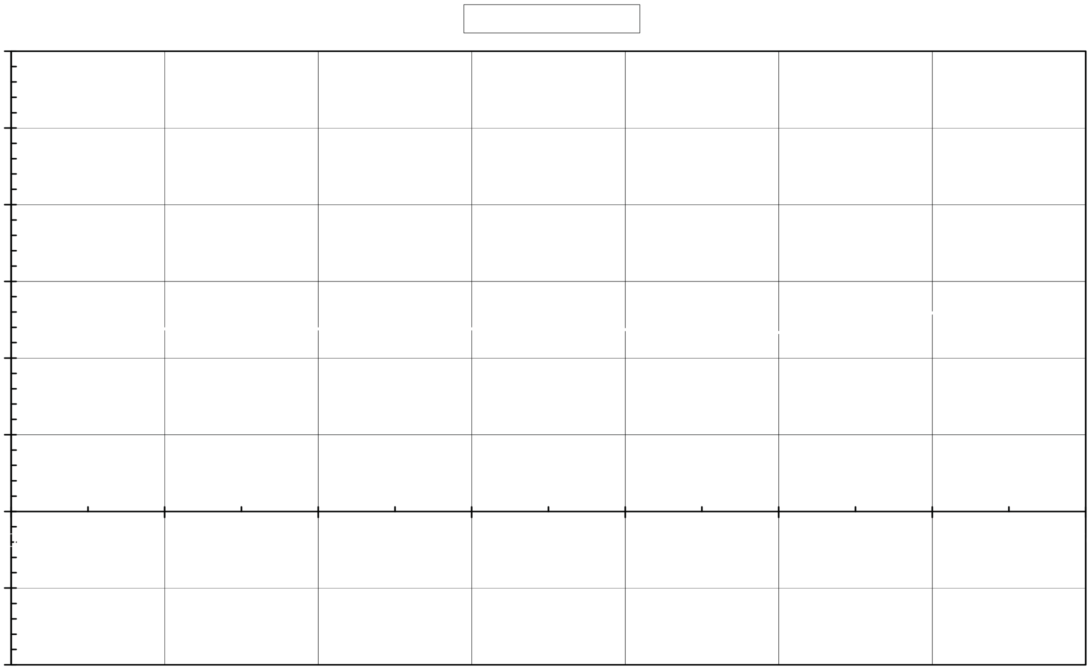

Figure A.3: Contact Pressures for Normal Condition (T_{max}) at Byron and Braidwood Unit 2

a,c,e

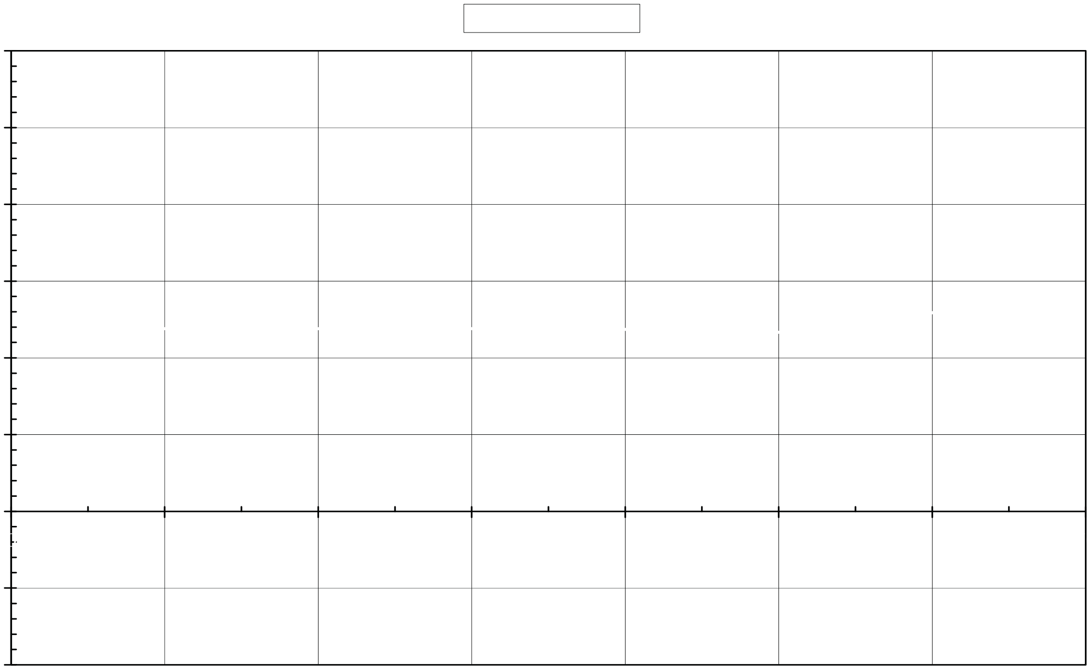

Figure A.4: Contact Pressures for SLB Faulted Condition at Byron and Braidwood 2

a,c,e

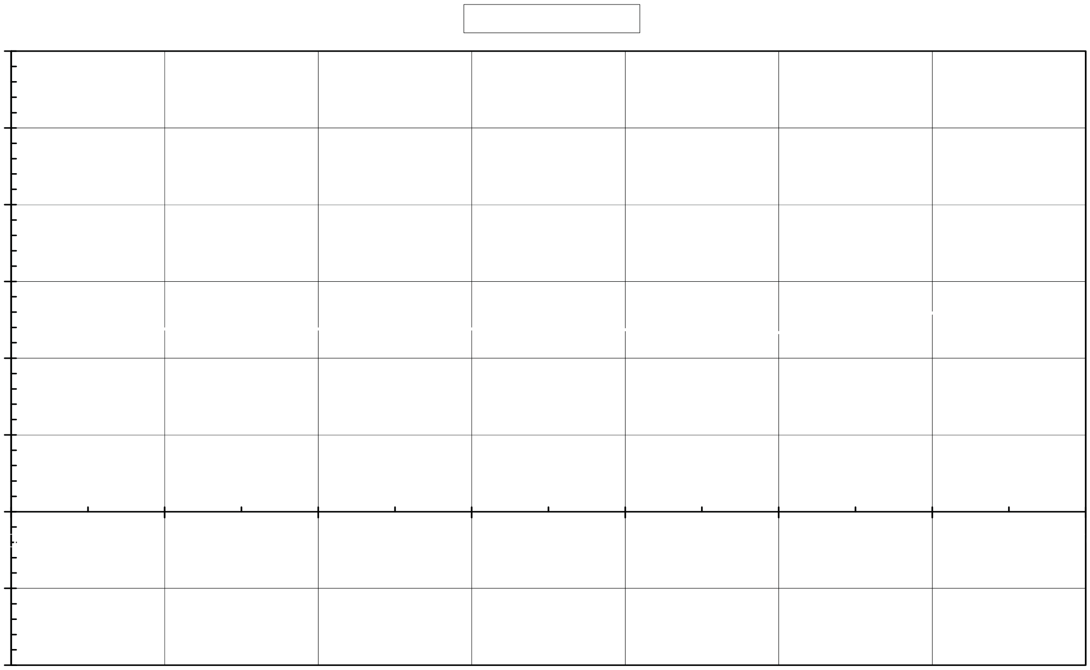

Figure A.5: Contact Pressures for FLB Faulted Condition at Byron and Braidwood 2 (T_{min})

a,c,e

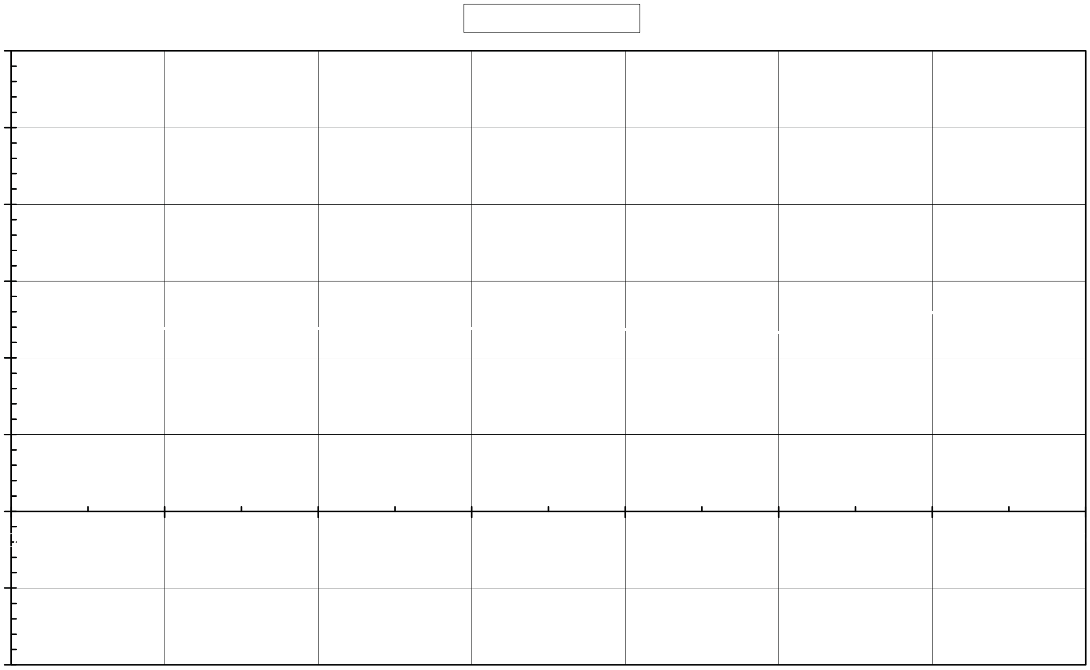

Figure A.6: Contact Pressures for FLB Faulted Condition at Byron and Braidwood 2 (T_{max})

a,c,e

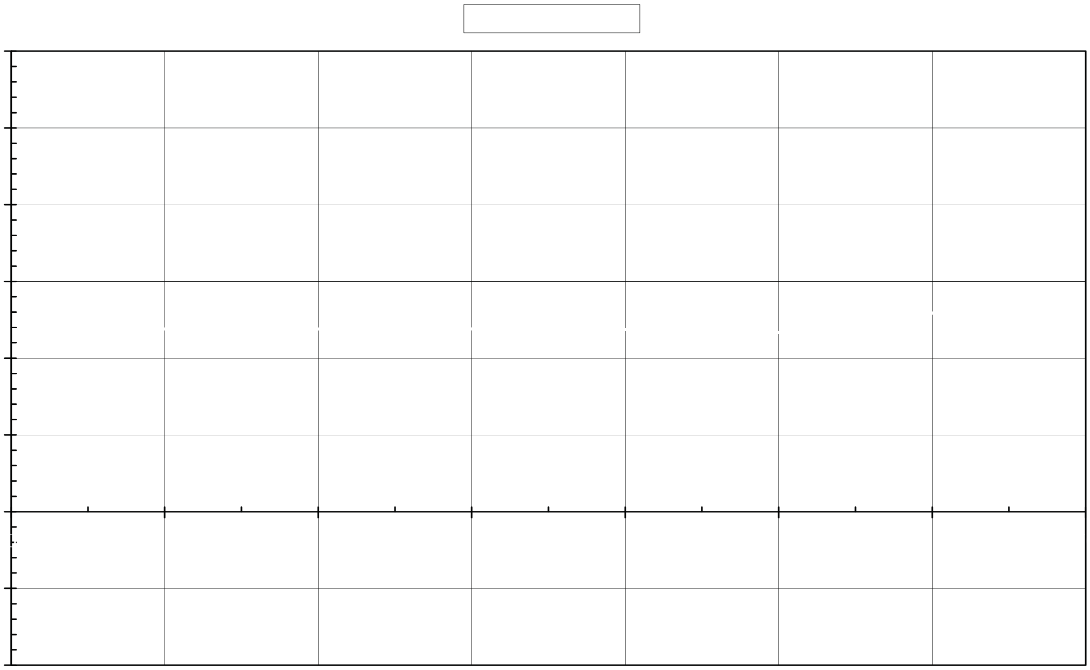

Figure A.7: D5 Pullout Test Results for Force/inch at 0.25 inch Displacement

Attachment 7

BRAIDWOOD STATION
UNITS 1 AND 2

Docket Nos. 50-456 and 50-457

License Nos. NPF-72 and NPF-77

Request for Exigent License Amendment Related to Technical Specification 5.5.9, “Steam Generator (SG) Tube Surveillance Program”

Westinghouse Electric Company LTR-CDME-05-32-P, “Limited Inspection of the Steam Generator Tube Portion Within the Tubesheet at Byron 2 & Braidwood 2,” dated April 2005

Proprietary Version