July 29, 2016

NRC 2016-0030
10 CFR 50.90

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

Point Beach Nuclear Plant
Unit 1
Docket No. 50-266
Renewed Facility Operating License No. DPR-24

License Amendment Request 285

License Amendment Request for H*: Alternate Repair Criteria for Steam Generator Tube Sheet Expansion Region

In accordance with 10 CFR 50.90, NextEra Energy Point Beach, LLC (NextEra) hereby requests a license amendment to revise the technical specifications (TS) for Point Beach Unit 1. The proposed change revises TS 3.4.13, RCS Operational Leakage; TS 5.5.8, Steam Generator (SG) Program; and TS 5.6.8, Steam Generator Tube Inspection Report, to exclude a portion of the tubes below the top of the SG tube sheet from periodic inspections and plugging.

The Enclosure to this letter provides NextEra's evaluation of the proposed change. Attachment 1 to the enclosure provides a markup of the TS showing the proposed changes, and Attachment 2 provides the proposed TS Bases changes. The changes to the TS Bases are provided for information only and will be incorporated in accordance with the TS Bases Control Program upon implementation of the approved amendment.

Attachments 5 and 7 contain non-proprietary and proprietary versions, respectively, of WCAP-18089, "Point Beach Unit 1 Steam Generator Tube Alternate Repair Criterion, H*." Attachments 6 and 8 contain non-proprietary and proprietary versions, respectively, of "Responses to Information Requests from the Nuclear Regulatory Commission Staff (NRC) Concerning the Point Beach Unit 1 H* License Amendment Request Submittal."

Attachments 7 and 8 contain information proprietary to Westinghouse Electric Company LLC, and are supported by affidavits in Attachments 3 and 4, signed by Westinghouse, the owner of the information. The affidavits set 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 2.390. Accordingly, it is requested that the information that is proprietary to Westinghouse be withheld from public disclosure in accordance with

10 CFR 2.390. Correspondence with respect to the copyright or proprietary aspects of the items listed above or the supporting Westinghouse Affidavits should reference CAW-16-4387 or CAW-16-4388 and should be addressed to James A. Gresham, Manager, Regulatory Compliance, Westinghouse Electric Company, 1000 Westinghouse Drive, Building 3 Suite 310, Cranberry Township, Pennsylvania 16066.

As discussed in the evaluation, the proposed change does not involve a significant hazards consideration pursuant to 10 CFR 50.92, and there are no significant environmental impacts associated with the change. This change has been reviewed by the Point Beach Onsite Review Group.

In accordance with 10 CFR 50.91, a copy of this letter is being forwarded to the State of Wisconsin designee.

This letter contains no new or revised regulatory commitments.

NextEra requests approval of the amendment by July 31, 2017, and implementation within 90 days.

Should you have any questions regarding this submittal, please contact Mr. Bryan Woyak, Licensing Manager, at 920-755-7599.

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

Executed on July 29, 2016

Sincerely,

NextEra Energy Point Beach, LLC

Robert Coffey
Site Vice President

Enclosure

cc: Administrator, Region III, USNRC
Project Manager, Point Beach Nuclear Plant, USNRC
Resident Inspector, Point Beach Nuclear Plant, USNRC
PSCW
Kim Schmitt Boiler Section Chief - Wisconsin Department of Safety & Professional Services - Boilers

<u>ENCLOSURE</u>

LICENSE AMENDMENT REQUEST 285

Evaluation of the Proposed Change

SUBJECT: License Amendment Request for H*: Alternate Repair Criteria for Steam Generator Tube Sheet Expansion Region

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Attachment 1 - Markup of Technical Specifications

Attachment 2 - Markup of Technical Specification Bases

Attachment 3 - Application for Withholding Proprietary Information from Public Disclosure CAW-16-4388

Attachment 4 - Application for Withholding Proprietary Information from Public Disclosure CAW-16-4387

Attachment 5 - WCAP-18089-NP,“Point Beach Unit 1 Steam Generator Tube Alternate Repair Criterion, H*” (Non-Proprietary)

Attachment 6 - Responses to Information Requests from the Nuclear Regulatory Commission Staff (NRC) Concerning the Point Beach Unit 1 H* License Amendment Request Submittal (Non-Proprietary)

Attachment 7 - WCAP-18089-P, “Point Beach Unit 1 Steam Generator Tube Alternate Repair Criterion, H*” (Proprietary)

Attachment 8 - Responses to Information Requests from the Nuclear Regulatory Commission Staff (NRC) Concerning the Point Beach Unit 1 H* License Amendment Request Submittal” (Proprietary)

1.0 SUMMARY DESCRIPTION

NextEra Energy Point Beach, LLC (NextEra) proposes to revise Technical Specification (TS) 3.4.13, "RCS Operational LEAKAGE;" TS 5.5.8, "Steam Generator (SG) Program;" and TS 5.6.8, "Steam Generator Tube Inspection Report," to exclude portions of the tubes from inspection and repair of tube indications in the Point Beach Unit 1 SGs. Regulatory requirements are to inspect the SG tubes from tube end to tube end unless a technical justification is made to limit the extent of the inspection to a shorter length. Application of the supporting structural analysis and leakage evaluation results to exclude portions of the tubes from inspection and repair of tube indications is interpreted to constitute a redefinition of the primary to secondary pressure boundary.

This permanent change is supported by WCAP-18089-P, "Point Beach Unit 1 Steam Generator Tube Alternate Repair Criterion, H*," March 2016 [Reference 1], which recommends a 95/95 H* value of 20.6 inches from the top of the tubesheet.

2.0 DETAILED DESCRIPTION

Proposed changes to current TS

TS 5.5.8.c is revised as follows: Added text is italicized and bolded.

> Provisions for SG tube plugging criteria. Tubes found by inservice inspection to contain flaws with a depth equal to or exceeding 40% of the nominal tube wall thickness shall be plugged.
>
> ***The following alternate tube plugging criteria shall be applied as an alternative to the 40% depth based criteria:***
>
>> ***For Unit 1 only, tubes with service-induced flaws located greater than 20.6 inches below the top of the tubesheet do not require plugging. Tubes with service-induced flaws located in the portion of the tube from the top of the tubesheet to 20.6 inches below the top of the tubesheet shall be plugged upon detection.***
>>
>> ***This alternate tube plugging criteria is not applicable to the tube at row 38 column 69 in the A steam generator, which is not expanded in the hot leg the full length of the tubesheet. This tube has been removed from service by plugging (during U1R31).***

TS 5.5.8.d is revised as follows:

> Provisions for SG tube inspections. Periodic SG tube inspections shall be performed. ***For Unit 1,*** the number and portions of the tubes inspected and methods of inspection shall be performed with the objective of detecting flaws of any type (e.g., volumetric flaws, axial and circumferential cracks) that may be present along the length of the tube ***from 20.6 inches below the top of the tubesheet on the hot leg side to 20.6 inches below the top of the tubesheet on the cold leg side and that may satisfy the applicable tube plugging criteria. For Unit*** 2, the number and portions of the tubes inspected and methods of inspection shall be performed with the objective of detecting

flaws of any type (e.g., volumetric flaws, axial and circumferential cracks) that may be present along the length of the tube.

For Unit 1 and 2: The tube-to-tubesheet weld is not part of the tube. In addition to meeting the requirements of d.1, d.2, and d.3 below, the inspection scope, inspection methods, and inspection intervals shall be such to ensure that SG tube integrity is maintained until the next SG inspection. A degradation assessment shall be performed to determine the type and location of flaws to which the tubes may be susceptible and, based on this assessment, to determine which inspection methods need to be employed and at what location.

TS 5.5.8.d.3 is revised as follows:

For Unit 1, if crack indications are found in any SG tube ***from 20.6 inches below the top of the tubesheet on the hot leg side to 20.6 inches below the top of the tube sheet on the cold leg side,*** then the next inspection for each affected and potentially affected SG for the degradation mechanism that caused the crack indication shall not exceed 24 effective full power months or one refueling outage (whichever results in more frequent inspections). If definitive information, such as from examination of a pulled tube, diagnostic non-destructive testing, or engineering evaluation indicates that a crack-like indication is not associated with a crack(s), then the indication need not be treated as a crack.

***For Unit* 2,** if crack indications are found in any SG tube, then the next inspection for each affected and potentially affected SG for the degradation mechanism that caused the crack indication shall not exceed 24 effective full power months or one refueling outage (whichever results in more frequent inspections). If definitive information, such as from examination of a pulled tube, diagnostic non-destructive testing, or engineering evaluation indicates that a crack-like indication is not associated with a crack(s), then the indication need not be treated as a crack.

TS 5.6.8 is revised to include three additional reporting requirements for Unit 1:

A report shall be submitted within 180 days after the initial entry into MODE 4 following completion of an inspection performed in accordance with Specification 5.5.8, Steam Generator (SG) Program. The report shall include:

a. The scope of inspections performed on each SG,
b. Degradation mechanisms found,
c. Nondestructive examination techniques utilized for each degradation mechanism,
d. Location, orientation (if linear), and measured sizes (if available) of service induced indications,
e. Number of tubes plugged during the inspection outage for each degradation mechanism,
f. The number and percentage of tubes plugged to date, and the effective plugging percentage in each steam generator,

g. The results of condition monitoring, including the results of tube pulls and in-situ testing,

h. For Unit 1 only, the primary to secondary leakage rate observed in each SG (if it is not practical to assign the leakage to an individual SG, the entire primary to secondary leakage should be conservatively assumed to be from one SG) during the cycle preceding the inspection which is the subject of the report,

i. For Unit 1 only, the calculated accident induced leakage rate from the portion of the tubes below 20.6 inches from the top of the tubesheet for the most limiting accident in the most limiting SG. In addition, if the calculated accident induced leakage rate from the most limiting accident is less than 5.22 times the maximum operational primary to secondary leakage rate, the report should describe how it was determined, and

j. For Unit 1 only, the results of monitoring for tube axial displacement (slippage). If slippage is discovered, the implications of the discovery and corrective action shall be provided.

TS LCO 3.4.13.d is revised as follows:

72 gallons per day (Unit 1) and 150 gallons per day ***(Unit 2)*** primary to secondary LEAKAGE through any one steam generator (SG).

TS SR 3.4.13.2 is revised as follows:

Verify primary to secondary LEAKAGE is ***≤72 gallons per day (Unit 1) and*** ≤ 150 gallons per day ***(Unit 2)*** through any one SG.

3.0 TECHNICAL EVALUATION

3.1 Background

Point Beach Unit 1 is a two loop Westinghouse designed plant with Model 44F SGs having 3214 tubes in each SG. The design of the SG includes Alloy 600 thermally treated tubing, full depth hydraulically expanded tubesheet joints, and stainless steel tube support plates with broached hole quatrefoils.

The SG inspection scope is governed by TS 5.5.8, Steam Generator (SG) Program; Nuclear Energy Institute (NEI) 97-06, Steam Generator Program Guidelines [Reference 2]; EPRI 1013706, Pressurized Water Reactor Steam Generator Examination Guidelines [Reference 3]; EPRI 1019038, Steam Generator Integrity Assessment Guidelines [Reference 4]; and the results of the degradation assessments required by the Point Beach Unit 1 SG Program. Criterion IX, "Control of Special Processes" of 10 CFR Part 50, Appendix B, requires in part that nondestructive testing be accomplished by qualified personnel using qualified procedures in accordance with the applicable criteria. The inspection techniques and equipment are capable of reliably detecting the known and potential specific degradation mechanisms applicable to Point Beach Unit 1. The inspection techniques, essential variables and equipment are qualified to Appendix H, "Performance Demonstration for Eddy Current Examination" of the EPRI Steam Generator Examination Guidelines.

Catawba Nuclear Station, Unit 2, (Catawba) reported indications of cracking following nondestructive eddy current examination of the SG tubes during their fall 2004 outage. NRC Information Notice (IN) 2005-09, "Indications in Thermally Treated Alloy 600 Steam Generator Tubes and Tube-to-Tubesheet Welds" [Reference 5], provided industry notification of the Catawba issue. IN 2005-09 noted that Catawba reported crack-like indications in the tubes approximately seven inches below 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. Indications were also reported in the tube-end welds, also known as tube-to-tubesheet welds, which join the tube to the tubesheet.

NextEra policies and programs require the use of applicable industry operating experience in the operation and maintenance of Point Beach Unit 1. The experience at Catawba, as noted in IN 2005-09, shows the importance of monitoring all tube locations (such as bulges, dents, dings, and other anomalies from the manufacture of the SGs) with techniques capable of finding potential forms of degradation that may be occurring at these locations (as discussed in Generic Letter 2004-01, "Requirements for Steam Generator Tube Inspections" [Reference 8]). Since the Point Beach Unit 1 Westinghouse Model 44F SGs were fabricated with Alloy 600 thermally treated tubes similar to the Catawba Unit 2 Westinghouse Model DS SGs, a potential exists for Point Beach Unit 1 to identify tube indications similar to those reported at Catawba within the hot leg tubesheet region when inspections are performed during future refueling outages.

Potential inspection plans for the tubes and tube welds underwent intensive industry discussions in March 2005. The findings in the Catawba SG tubes present two distinct issues with regard to the SG tubes at Point Beach Unit 1:

1) Indications in internal bulges and overexpansions within the hot leg tubesheet, and
2) Indications at the elevation of the tack expansion transition

Prior to each SG tube inspection, a degradation assessment, which includes a review of operating experience, is performed to identify degradation mechanisms that have a potential to be present in the Point Beach Unit 1 SGs. A validation assessment is also performed to verify that the eddy current techniques utilized are capable of detecting those flaw types that are identified in the degradation assessment. Based on the Catawba operating experience, Point Beach Unit 1 has revised the SG inspection plan to include sampling of bulges and over expansions within the tubesheet region on the hot leg side. The sample was based on the guidance contained in Reference 3 and TS 5.5.8, Steam Generator (SG) Program. According to the EPRI SG examination guidelines, the inspection plan is expanded if necessary due to confirmed degradation in the region required to be examined (i.e., a tube crack).

As a result of these potential issues and the possibility of unnecessarily plugging tubes in the Point Beach Unit 1 SGs, NextEra is proposing changes to TS 3.4.13, TS 5.5.8.c, TS 5.5.8.d and TS 5.6.8 to limit the SG tube inspection and repair (plugging) to the portion of tubing from 20.6 inches below the top of the tubesheet.

3.2 Evaluation

H* (H-star) is an alternate SG tube repair criterion (ARC) that replaces the tube end weld with the hydraulic expansion joint within the tubesheet (TS) as the primary pressure boundary in order to limit the inspection depth in the tubesheet (TS) expansion region to less than the full depth of the tubesheet. Regulatory requirements are to inspect the SG tubes from tube end to tube end unless a technical argument is made to limit the extent of the inspection to a shorter length. Industry operating experience for SGs with Alloy 600TT tubing has shown that some stress corrosion cracks (SCC) have been detected in a region from the tube-end weld to about one inch above the tube-end weld. H* eliminates the need to inspect below the H* distance, thus enabling most tubes with such SCC indications to remain in service.

The two principal requirements for H* are:

1. Assure that the tube(s) do not pull out of the tubesheet under the most limiting loads during normal operating or accident conditions.

2. Assure that the primary coolant leakage through the tube-to-tubesheet crevice is no greater than the leakage assumed in the final safety analysis report (FSAR) for the most limiting accident.

The United States Nuclear Regulatory Commission (USNRC) has licensed H* for permanent application in 15 plants with Model F, Model D, Model 44F, and Model 51F SGs (Reference 1). A satisfactory H* solution could not be achieved for Point Beach Unit 1, a two-loop plant with Model 44F SGs, during the development of the technology on which the USNRC licenses are based. Application of the methods on which the USNRC based its licensing approval resulted in a sector of tubes in Point Beach Unit 1 that did not meet the principal requirements noted above. The current licensing basis for Model 44F plants is principally contained in WCAP-17378-P, Rev. 1 (Reference 7), but also includes other documents contained in the respective license amendment requests (LARs) from the respective Model 44F plants.

What makes Point Beach Unit 1 unique among H*-candidate Model 44F plants is the input conditions of differential pressure and temperature. These conditions are based on the bounding assumptions made in the SG design specification, and are not derived from any accident analyses. They are intended to bound the worst case Steam Line Break (SLB) accident. Use of the SG design specification assumptions is consistent with other previously performed H* analyses.

The H* distance depends primarily on differential thermal expansion between the tubes and the tubesheet and a contribution from tubesheet deflection under accident conditions, and on the differential pressure tending to pull the tubes from the tubesheet. Due to the low temperature and high pressure differential of the assumed Point Beach Unit 1 SLB condition, and because the deflection of the tubesheet is small due to the relatively stiff structure, it was not possible to show that sufficient resistance against tube pullout existed for 928 tubes in each SG with the use of the prior C^2 model. Reference 7 shows an "Exclusion Region" of tubes between a tubesheet radial distance of 40.987 inches to 51.026 inches.

Reference 1 documents a modified calculation approach for Point Beach Unit 1 that provides an acceptable H* distance for all tubes in Point Beach Unit 1. The bulk of the prior technical justification still applies; only the structural model to calculate the tube-to-tubesheet contact pressures has been changed. Previously, the contact pressures were calculated using a model known as the square-cell (C^2) model which represented a unit tube cell in the tubesheet thickness as a stack of individual models at discreet elevations which are not coupled in the horizontal plane. The C^2 model has been replaced by a three dimensional tube unit cell submodel (3DSM) that represents the tubesheet thickness in a single, continuous model. The advantage of the 3DSM is that it takes into account the bending of the tubesheet and tube in computing the tube-to-tubesheet contact pressures at operating conditions and produces H* distances within the thickness of the tubesheet.

Structural Assessment

To preclude unnecessarily plugging tubes in the Point Beach Unit 1 SGs, tube inspections will be limited to identifying and plugging degradation in the portion of the tube within the tubesheet necessary to maintain structural and leakage integrity in both normal and accident conditions. The technical evaluation for the inspection and repair methodology is provided in Westinghouse Electric Company, LLC, WCAP-18089-P, "Point Beach Unit 1 Steam Generator Tube Alternate Repair Criterion, H*" (Reference 1). The evaluation is based on the use of finite element model structural analysis and a bounding leak rate evaluation based on contact pressure between the tube and the tubesheet during normal and postulated accident conditions. The limited tubesheet inspection criteria were developed for the tubesheet region of the Point Beach Unit 1 Model 44F SGs considering the most stringent loads associated with plant operation, including transients and postulated accident conditions. The limited tubesheet inspection criteria were selected to prevent tube pull out from the tubesheet due to axial end cap loads acting on the tube and to ensure that the accident induced leakage limits are not exceeded. WCAP-18089-P provides technical justification for limiting the inspection in the tubesheet expansion region to less than the full depth of the tubesheet.

The basis for determining the portion of the tube which requires eddy current inspection within the tubesheet is based upon evaluation and testing programs that quantified the tube-to-tubesheet radial contact pressure for bounding plant conditions as described in WCAP-18089-P. The tube-to-tubesheet radial contact pressure provides resistance to tube pull out.

In order to more realistically calculate tube-to-tubesheet contact pressures that occur during the most limiting postulated plant conditions in the Point Beach Unit 1 SGs, a 3D unit cell structural submodel (3DSM) was developed to replace the C^2 model. As discussed above, the 3DSM is effectively a 3D version of the C^2 model that is a single structural unit cell model of the entire depth of the tubesheet, centered on the tube pitch, in which the previously uncoupled C^2 tubesheet segments are now coupled.

The 3DSM and the C^2 Model share the same boundary dimensions as described in Reference 1. However, the 3DSM replaces the quarter symmetry modeling of the C^2 model with a full tube and square tubesheet sub model that enables the direct import of the tubesheet displacement from the Lower SG Assembly Model. Displacement inputs to the C^2 model required post-processing and manual input.

The contact pressure analysis previously performed for Point Beach Unit 1, using the C^2 model, was used as the basis for benchmarking the 3DSM. Comparison of the results from the models was limited to application of the same thermal and internal pressure loadings on the tube/tubesheet only because it is the most direct manner to compare the results from both models. Application of a displacement profile to the tubesheet would not provide a good comparison because the C^2 model is a stacked model, uncoupled in the horizontal plane, which would be expected to result in different results than the continuous structure of the 3DSM. It has been shown in Section 3.4 of Reference 1 that the 3DSM is an acceptable structural model that provides characteristically the same results as the C^2 model that was applied in the currently licensed H* analyses.

The tube in the 3DSM extends beyond the top of the tubesheet to enable direct application of the pull out force (end cap load) and direct calculation of the Poisson contraction effect while avoiding end effects at the top of the tubesheet that could affect the contact pressure calculation. (The Poisson contraction effect was, of necessity, a separate calculation in prior analyses because the C^2 segments that represented the tubesheet thickness were not connected in the horizontal plane.) The final length of the tube extension was determined as half the distance from the top of the tubesheet to the first tube support plate as discussed in Section 3.3.1.2 of Reference 1.

The constraint that is provided by the tubesheet precludes tube burst for cracks within the tubesheet. The criteria for tube burst described in NEI 97-06 and NRC Regulatory Guide (RG) 1.121, "Bases for Plugging Degraded PWR Steam Generator Tubes," [Reference 6) are satisfied due to the constraint provided by the tubesheet. The H* distance is defined as the length of contact, measured from the top of the tubesheet, required to resist the pull out forces acting on the tube. The pull out forces are defined as the end cap load on the tube which are the primary-to-secondary pressure difference with appropriate factors of safety acting on the area of the tube for the NOP and SLB conditions. The end cap loads include a factor of safety of 3 for NOP and 1.4 for SLB.

The primary limiting accident condition for Point Beach Unit 1 is the postulated steam line break (SLB). The specified conditions for the SLB event for Point Beach Unit 1 differentiate the plant from others in that it exhibits the lowest temperature among the candidate plants for H* (Reference 1). Because H* is driven primarily by differential thermal growth between the tube and the tubesheet, this established a unique challenge for Point Beach Unit 1.

The required probabilistic value of H* is the 0.95 probability at 95% confidence. Another important probabilistic value of H* is that at 0.95 probability at 50% confidence. The required probability level was established during the prior licensing effort for H* (Reference 1).

The probabilistic estimate of H* was developed using a Monte Carlo simulation for the effect of varying the critical parameters affecting contact pressure between the tube and TS. It was previously established in Reference 1 that these parameters are the tubesheet coefficient of thermal expansion (CTE) and the tube CTE. The final result of the simulation is the combination of tubesheet and tube CTEs that define the 0.95 probability at a 95% confidence estimate for H* during the limiting operating condition at the limiting tubesheet TS radius. The predicted combination of CTEs from the simulation is input to the lower SG assembly model and the 3DSM to calculate the value of H* for the required probabilistic estimate.

The final H* distance to prelude tube pullout during SLB conditions at 0.95 probability at 95% confidence is 20.60 inches.

Accident Induced Leakage Assessment

Primary-to-secondary leakage from tube degradation in the tubesheet area is assumed to occur in several design basis accidents: steam line break (SLB), locked rotor, and control rod ejection. The radiological dose consequences associated with this assumed leakage are evaluated to ensure that they remain within regulatory limits (10 CFR Part 50.67). The accident induced leakage performance criteria are intended to ensure the primary-to-secondary leak rate during any accident does not exceed the primary-to-secondary leak rate assumed in the accident analysis.

The Darcy formulation is used in Reference 1 to develop the ratio of leak rates (Q) between postulated accident-induced conditions (SLB) and normal operating conditions (NOP). The driving heads (Δp) at both of these conditions are known, as are the temperatures and pressures to define the fluid viscosity (μ). The contact length, l, is determined from the contact pressure calculations. The resulting Darcy flow equation ratio can be separated into four "subfactors" as follows:

$$\frac{Q_{DBA}}{Q_{NOP}} = \frac{\Delta p_{DBA}}{\Delta p_{NOP}} \quad \frac{\mu_{NOP}}{\mu_{DBA}} \quad \frac{K_{NOP}}{K_{DBA}} \quad \frac{l_{NOP}}{l_{DBA}}$$

The available data for hydraulically expanded tubes in tubesheet simulants, both at room temperature and at elevated temperature, are utilized in Reference 1 to show that no correlation between loss coefficient (K) and contact pressure exists for conditions that simulate the Model DS and Model F SG conditions. However, because the test data exhibit considerable scatter, confidence in this data analysis is low among the regulatory authorities. Engineering intuition could suggest that loss coefficient might be related to the absolute contact pressure between the tubes and the tubesheet. Hence, a requirement was applied to the H* leakage analysis by the regulatory authorities that it is necessary to show that the contact pressure at accident-induced conditions exceeds the contact pressure at normal operating conditions (P_{cSLB}:P c_{NOP}>1).

The calculated contact pressure results for all models of SGs are, to a large degree, dependent on the temperatures at a particular operating condition. The limiting accident leakage condition for H* for the Point Beach Unit 1 Model 44F SGs is the SLB condition, as documented in Reference 1. The Point Beach Unit 1 SLB transient includes a significantly lower temperature than even the Model 44F 3-loop SGs. As a result, it cannot be shown that the contact pressures at accident conditions exceed those at normal operating conditions, and the criterion for contact pressure (P_{cSLB}:P_{cNOP}>1) is not met.

Therefore, as noted by the USNRC in the prior licensing efforts for H*, the loss coefficient subfactor (K) cannot be conservatively considered to be 1.0 during a postulated SLB and the standard approach for calculating leak rate factor cannot be used for Point Beach Unit 1. It is necessary to utilize a different approach for leakage analysis to show that the accident-induced leakage value assumed in the Updated Final Safety Analysis Report (UFSAR) is not exceeded (Reference 11).

Two alternate approaches are considered:

1. Parametric assumptions of loss coefficient dependency on contact pressure.
2. Application of parallel plate theory.

Both approaches rely on the existing Model DS leak rate data to varying degrees. No leak rate data are available for the Model 44F geometry. The use of the leak rate data developed for the Model DS geometry for application to the Model 44F geometry is acceptable for this study because absolute leak rates are not in question; rather, the significance of a functional relationship between loss coefficient and contact pressure and the ratio of leak rates for NOP and SLB conditions are considered here. The approach of assuming various proportionality formulations between the loss coefficient and contact pressure and benchmarking them against the existing data is the most direct application. The parallel plate theory utilizes accepted theory to calculate a flow area based on the leakage test results and relates that flow area (and consequential leak rate) to the contact pressure conditions for the test specimens to develop leak rates for both SLB and NOP conditions.

As discussed in Reference 1, the design specification curves for the locked rotor and control rod ejection events apply for the leakage factors for these transients. These transients are of very short duration. Because of the short duration, as is also the case for the remainder of the H* fleet, no leakage factors are required for a postulated locked rotor and control rod ejection event for the Model 44F 2-loop SG.

<u>Resistance Leakage Model Assessment</u>

The parametric proportionality approach utilizes the Darcy formulation for leakage through a porous medium and assumes various functional relationships between loss coefficient and contact pressure within the available test data. The mathematical relationships evaluated are not based on the actual leak test data but are simply assumed to test the hypothesis that loss coefficient is functionally related to contact pressure.

Consider an electrical analogy to the leakage through the crevice based on Ohm's law:

> V(potential) = I(current) times R(Resistance), or in terms of flow:
>
> I =V/R
>
> where:
>
> I, the current, is equivalent to leak rate, Q
>
> V, voltage, is the driving potential, equivalent to ~P
>
> R, resistance is equivalent to the flow resistance, (121J.KI), which must be calculated.

For an electrical system, with resistances in series, the total resistance is the sum of the individual resistances. Likewise, for a potential leak path that is divided into a number of sections, the total leakage through the entire path depends on the total resistance of the path, i.e., the sum of the resistances of the segments.

The leak rate through the crevice above H* can be considered a series related network of flow resistances in which the total resistance is the sum of the segment resistances, as for the electrical analogy. The calculations for H* for Point Beach Unit 1 divide the thickness of the tubesheet into eleven axial segments, although not of equal length. No attempt was made to evenly distribute the segments over the tubesheet thickness; the segment lengths are those defined by the structural model used in the original H* analysis in Reference 7. At the end-point of each segment, contact pressures are calculated as part of the normal H* calculations. The assumptions necessary for this approach are:

1. The local crevice length is the distance between the axial locations where contact pressures are calculated.
2. The contact pressure that applies over the local crevice length is the average of the contact pressures at the end-points of the local length.

The total resistance to leakage above the H* distance is the sum of the local resistances in the segments above H*.

As described in WCAP-18089-P, relationships with a positive slope were considered which bound the data both as an upper bound of the K (loss coefficient) values and as a lower bound of the K values. If it is postulated that the loss coefficient increases with increasing contact pressure, intuitively, a bounding case would be a function that has the steepest slope of loss coefficient from low to high contact pressure based on the available data. Such a function was also considered even though it is considered unlikely that any data set would support such a function.

Five arbitrary mathematical relationships were assumed to model the available test data, some with extreme slopes, and others that essentially envelope the upper and lower bounds of the available data. It should be noted that the K versus contact pressure data from the tests were used only as a benchmark for the assumed relationships. The assumed relationships are, as stated, assumed relationships that meet the postulated criterion of increasing loss coefficient with increasing contact pressure. Different slopes of the relationships were investigated as well as various absolute positions relative to the available database. The purpose was to investigate to what degree a presumed function between loss coefficient and contact pressure would affect the leak rate ratio between SLB and NOP conditions.

Conservatively, for the Point Beach Unit 1 SGs, a maximum leakage rate factor of 5.22 was determined to establish an allowable primary-to-secondary leak rate limit following the implementation of H*. A leakage rate factor of 5.22 represents a factor of 3.2 increase in leak rate factor for the SLB condition (5.22/1.63), where 1.63 is the ratio of the SLB to NOP pressure differential, (i.e., 2485psid/1523psid) when the "four subfactor" Darcy flow equation (Equation 8.2) is used to calculate the leak rate factor assuming a loss coefficient subfactor of 1.0. Similarly, for the inner 3 radii, this same relationship results in a factor of 1.6 (5.22/3.26) increase in leak rate factor assuming a loss coefficient subfactor of 1 and an effective crevice length subfactor of 2. An effective crevice length subfactor of 2 is used because positive contact pressure only occurs for one-half of the distance of the thickness of the tubesheet during a postulated SLB for the inner radii of the tube bundle in the Point Beach Unit 1 SGs.

Further basis for the use of a maximum leak rate factor of 5.22 is discussed in Appendix A of Reference 1.

Parallel Plate Theory Assessment

A second approach to calculating leak rate ratio is an application of parallel plate flow theory, which provides a formulation for calculating steady, laminar flow between fixed, parallel plates. It is assumed that flow continuity applies and that the flow is unidirectional, constant and laminar. The use of this formulation for the tube in the tubesheet is appropriate because the direction of fluid particles can be assumed to be in a single direction along the tube-to-tubesheet bore crevice. Adapted to the geometry of concentric cylinders such as the tube in the tubesheet bore, the governing equation is:

$$Q = \frac{\pi D \Delta p a^3}{12 \mu l}$$

where,

Q	is the flow rate of the fluid through the gap between the tube-to-tubesheet bore, in^3/sec
Δp	is difference in pressure (or driving head) acting to force the fluid through the gap, lbf/in^2
μ	is the viscosity of the fluid, lbf-sec/in^2
D	is the tubesheet bore inner diameter in inches
l	is the axial length of hydraulic expansion, in inches
a	is the gap between the tube and the tubesheet, in inches

The use of this relationship is acceptable for the tube-in-tubesheet case because the flow is continuous and laminar, and can conservatively be assumed to be in a single direction (axial) within the tubesheet crevice.

Analyses using the parallel plate theory approach shows that the resistance to leakage under both normal operating and SLB leakage conditions is developed in the lower portion of the H* distance. It is expected that the leak rate ratio existing in this region would dominate the overall leakage ratio existing over the entire H* distance. For leakage emanating below an H* distance of 20.6 inches from the top of the tubesheet, the expected leak rate factor is of the same order of magnitude as the resistance leakage model leakage rate factor for all tube bundle radii evaluated.

Next Era will apply a factor of 5.22 to the normal operating leakage associated with the tubesheet expansion region in the condition monitoring (CM) and operational assessment (OA). The leakage factor of 5.22 is a bounding value for all steam generators, both hot and cold legs. Specifically, for the CM assessment, the component of leakage from the prior cycle from below the H* distance will be multiplied by a factor of 5.22 and added to the total leakage from any other source and compared to the allowable accident induced leakage limit. For the OA, the difference between the allowable accident-induced leakage and the accident-induced leakage from sources other than the tubesheet expansion region will be divided by 5.22 and compared to the observed operational leakage.

Through application of the limited tubesheet inspection scope as described below, the existing operational leakage limit in TS 3.4.13 provides assurance that excessive leakage (i.e., greater than accident analysis assumptions) will not occur. The accident-induced leak rate limit for Point Beach Unit 1 is 500 gpd (at operating conditions) as described in Reference 1. As noted above, the ratio of the potential SLB leakage to normal operating leakage from the tubesheet region was determined to be 5.22. This leakage ratio requires a reduction in the allowable SG tube primary to secondary leakage during normal operation (TS 3.4.13. LCO) from 150 gpd to 72 gpd.

Reference 1 redefines the primary pressure boundary. The tube to tubesheet weld no longer functions as a portion of this boundary. The hydraulic expansion of the tube into the tubesheet over the H* distance now functions as the primary pressure boundary in the area of the tube and tubesheet, maintaining the structural and leakage integrity over the full range of steam generator operating conditions, including the most limiting accident conditions. The evaluation in Reference 1 determined that degradation in tubing below 20.6 inches from the top of the tubesheet does not require inspection or repair (plugging). The inspection of the portion of the tubes above 20.6 inches from the top of the tubesheet for tubes that have been hydraulically expanded in the tubesheet provides a high level of confidence that the structural and leakage performance criteria of NEI 97-06, Rev. 3 are maintained during normal operating and accident conditions.

Reference 10, Section 9.8, provides a review of leak rate susceptibility to tube slippage and concludes that the tubes are fully restrained against motion under very conservative design and analysis assumptions such that tube slippage is not a credible event for any tube in the bundle. However, in response to a NRC staff request, NextEra commits to monitor for tube slippage as part of the steam generator tube inspection program.

In addition the NRC staff has requested that licensees determine if there are any significant deviations in the location of the bottom of the expansion transition (BET) relative to the top of tubesheet that would invalidate assumptions in WCAP-18089-P. Therefore, NextEra performed a verification of tube expansion locations to determine if any significant deviations exist from the top of tubesheet to the BET. As a result, this alternate tube repair criteria is not applicable to the tube at row 38 column 69 in the A SG, which is not expanded in the hot leg the full length of the tubesheet. This tube has been removed from service by plugging (during U1R31) (Reference 9).

4.0 REGULATORY EVALUATION

4.1 Applicable Regulatory Requirements/Criteria

Point Beach Unit 1 was licensed prior to the 1971 publication of Appendix A, "General Design Criteria (GDC) for Nuclear Power Plants," to 10 CFR 50. As such, Point Beach Unit 1 is not licensed to the Appendix A GDC. The Point Beach Unit 1 Final Safety Analysis Report (FSAR) lists the plant specific GDC to which the plant was licensed. The Point Beach Unit 1 GDC are similar in content to the draft GDC proposed for public comment in 1967. The Point Beach Unit 1 GDC addressing the reactor coolant pressure boundary are GDC 9 (Reactor Coolant Pressure Boundary), GDC 33 (Reactor Coolant Pressure Boundary Capability), GDC 34 (Reactor Coolant Pressure Boundary Rapid Propagation Failure Prevention), and GDC 36

(Reactor Coolant Pressure Boundary Surveillance. The applicable criteria for this system are discussed in FSAR Section 4.1, "Reactor Coolant System -Design Basis."

Point Beach Unit 1 GDC 9, 33, 34, and 36 require, in part, that the reactor coolant pressure boundary shall be designed, fabricated, and constructed so as to have an exceedingly low probability of gross rupture or significant uncontrolled leakage during its design lifetime; be capable of accommodating without rupture the static and dynamic loads imposed on any pressure boundary component; be designed and operated to reduce to an acceptable level the probability of rapidly propagating failure. The Point Beach Unit 1 GDC are similar to Appendix A GDC 14, 15, 31 and 32 (Reference 9).

The proposed change excludes from inspection those portions of the steam generator tubes that are not safety significant with respect to maintaining the reactor coolant pressure boundary. Structural analyses demonstrate that the safety significant portion of the steam generator tube within the tubesheet maintains the capability to accommodate, without rupture, the sudden release of energy into the coolant.

10 CFR 50, Appendix B, establishes quality assurance requirements for the design, construction, and operation of safety related components. The pertinent requirements of this appendix apply to all activities affecting the safety related functions of these components. These requirements are described in Criteria IX, XI, and XVI of Appendix B and include control of special processes, inspection, testing, and corrective action.

10 CFR 50.36 (c) (5) states that, "Administrative controls are the provisions relating to organization and management, procedures, record keeping, review and audit, and reporting necessary to assure safe operation of the facility." The technical evaluation performed in Section 3.2 above supports the conclusion that the proposed changes to TS 5.5.8 and TS 3.4.13 will continue to provide the appropriate procedural and program controls for inservice testing and steam generator tube surveillance.

GDC 19 of 10 CFR 50, Appendix *A,* defines requirements for the control room and for the radiation protection of the operators working within it. Accidents involving the leakage or burst of SG tubing comprise a challenge to the habitability of the control room.

10 CFR 50.67*,* Reactor Site Criteria, establishes reactor site criteria, with respect to the risk of public exposure to the release of radioactive fission products. Accidents involving leakage or tube burst of SG tubing may comprise a challenge to containment and therefore involve an increased risk of radioactive release.

Under 10 CFR *50.65,* the Maintenance Rule, licensees classify SGs as risk significant components because they are relied upon to remain functional during and after design basis events. SGs are to be monitored under 10 CFR 50.65(a) (2) against industry established performance criteria. Meeting the performance criteria of NEI 97-06, Revision 3, provides reasonable assurance that the SG tubing remains capable of fulfilling its specific safety function of maintaining the reactor coolant pressure boundary. The NEI 97-06*,* Revision 3*,* SG performance criteria are:

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

- The primary-to-secondary accident induced leakage rate for any design basis accident, other than a SG tube rupture, shall not exceed the leakage rate assumed in the accident analysis in terms of total leakage rate for all SGs and leakage rate for an individual SG. Leakage is not to exceed 1 gpm per SG, except for specific types of degradation at specific locations when implementing alternate repair criteria as documented in the Steam Generator Program technical specifications.

- The RCS operational primary-to-secondary leakage through any one SG shall be limited to 150 gallons per day.

The structural performance criterion used to develop the H* distance documented in Section 4.2 and Section 5.0 of Reference 1 meets the requirements of NEI 97-06, Revision 3. The applicable structural criterion is to show that tube pullout is prevented under the limiting loading with the appropriate factor of safety specified in NEI 97-06, Revision 3. The reduced primary-to-secondary leakage criterion of 72 gpd precludes unacceptable leakage during postulated accident conditions. As noted in Section 2.3 of Reference 2, the operational leakage performance criterion provides a defense-in-depth added margin against tube rupture under accident conditions. However, the reduced leakage limit of 72 gpd is not required to preclude tube pullout for the Point Beach Unit 1 SGs.

The Technical Evaluation in Section 3.2 above concludes that the proposed changes to TS 5.5.8, TS 5.6.8, and TS 3.4.13 will continue to assure that the design requirements of the reactor coolant pressure boundary are met. The proposed change defines the length of tube that is engaged in the tubesheet from the secondary face that is required to maintain structural and leakage integrity in compliance with NEI 97-06, Rev. 3 requirements over the full range of SG operating conditions, including the most limiting accident conditions. The evaluation in Reference 1 determined that degradation in tubing below 20.6 inches from the top of the tubesheet portion of the tube does not require plugging and serves as the bases for the SG tube inspection program. As such, the Point Beach Unit 1 inspection program, coupled with a reduced SG primary-to-secondary leakage requirement from 150 gpd to 72 gpd, provides a high level of confidence that the structural and leakage criteria are maintained during normal operating and accident conditions.

4.2 No Significant Hazards Consideration

This amendment application proposes to revise Technical Specification (TS) 3.4.13, "RCS Operational LEAKAGE," TS 5.5.8, "Steam Generator (SG) Program," and TS 5.6.8, "Tube Inspection Report Requirements," to provide reporting requirements specific to the permanent alternate repair criteria. Application of the structural analysis and leak rate evaluation results to exclude portions of the tubes from inspection and repair is interpreted to constitute a redefinition of the primary-to-secondary pressure boundary.

The proposed change defines the portion of the tube that must be inspected and repaired. A justification has been developed by Westinghouse Electric Company, LLC to identify the specific inspection depth below the top of the tubesheet which any type of axial or circumferential primary water stress corrosion cracking can be shown to have no impact on Nuclear Energy Institute (NEI) 97-06 (Reference 2), "Steam Generator Program Guidelines," performance criteria.

1. *The proposed changes do not involve a significant increase in the probability or consequences of an accident previously evaluated.*

   The proposed changes to TS 3.4.13, TS 5.5.8, and TS 5.6.8 have no effect on accident probabilities or consequences. The previously analyzed accidents are initiated by the failure of plant structures, systems, or components. The proposed change that alters the steam generator (SG) inspection and reporting criteria does not have a detrimental impact on the integrity of any plant structure, system, or component that initiates an analyzed event. The proposed change will not alter the operation of, or otherwise increase the failure probability of any plant equipment that initiates an analyzed accident.

   Of the applicable accidents previously evaluated, the limiting transients with consideration to the proposed change to the SG tube inspection and repair criteria are: the steam generator tube rupture (SGTR) event, the steam line break (SLB), locked rotor and control rod ejection postulated accidents. Loss of Coolant Accident conditions cause a compressive load to act on a tube. This accident attempts to displace the tube into the tubesheet rather than pull it out, and, therefore, is not a factor in this amendment request. Another faulted load consideration is a safe shutdown earthquake; however, seismic analysis has shown that axial loading of the tubes is negligible during this event (Section 5.0 of Reference 10).

   Addressing the SGTR event, the required structural integrity margins of the SG tubes and the tube-to-tubesheet joint over the H* distance will be maintained. Tube rupture in tubes with cracks within the tubesheet is precluded by the constraint provided by the presence of the tubesheet and the tube-to-tubesheet joint. Tube burst cannot occur within the thickness of the tubesheet. The tube-to-tubesheet joint constraint results from the hydraulic expansion process, thermal expansion mismatch between the tube and tubesheet, from the differential pressure between the primary and secondary side, and tubesheet rotation. Based on this design, the structural margins against burst/ tube pullout, as discussed in Regulatory Guide (RG) 1.121, "Bases for Plugging Degraded PWR Steam Generator Tubes," and TS 5.5.8 are maintained for both normal and postulated accident conditions. The final H* distance to preclude tube pullout from the tubesheet at 0.95 probability at 95% confidence is 20.60 inches.

The proposed change has no impact on the structural or leakage integrity of the portion of the tube outside of the tubesheet. The proposed change maintains structural and leakage integrity of the SG tubes consistent with the performance criteria in TS 5.5.8. Therefore, the proposed change results in no significant increase in the probability of the occurrence of a SGTR accident.

At normal operating pressures, leakage from tube degradation below the proposed limited inspection depth is limited by the tube-to-tubesheet crevice. Consequently, negligible normal operating leakage is expected from degradation below the inspected depth within the tubesheet region. The consequences of an SGTR event are not affected by the primary-to-secondary leakage flow during the event as primary-to-secondary leakage flow through a postulated tube that has been pulled out of the tubesheet is essentially equivalent to a severed tube. Therefore, the proposed change does not result in a significant increase in the consequences of a SGTR.

Concerning a postulated SLB event, NextEra will apply a leakage factor of 5.22 to the normal operating leakage associated with the tubesheet expansion region in the condition monitoring (CM) and operational assessment (OA). The leakage factor of 5.22 is a bounding value for all SGs, both hot and cold legs. The accident-induced leak rate limit for Point Beach Unit 1 is 500 gpd at accident conditions. As a result, the TS operational leak rate limit is reduced from 150 gpd to 72 gpd through any one steam generator to help to ensure that accident induced leakage in excess of SLB accident analysis assumptions will not occur.

For the CM assessment, the component of leakage from the prior cycle from below the H* distance will be multiplied by a factor of 5.22 and added to the total leakage from any other source and compared to the allowable accident induced leakage limit. For the OA, the difference in the leakage between the allowable leakage and the accident induced leakage from sources other than the tubesheet expansion region will be divided by 5.22 and compared to the observed operational leakage.

No leakage factor will be applied to the locked rotor or control rod ejection transients due to their short duration.

Based on the above, the proposed changes do not involve a significant increase in the probability or consequences of an accident previously evaluated.

2. *The proposed changes do not create the possibility of a new or different kind of accident from any previously evaluated.*

The proposed changes to TS 3.4.13, TS 5.5.8, and TS 5.6.8 that alter the SG inspection and reporting criteria do not introduce any new equipment, create new failure modes for existing equipment, or create any new limiting single failures. Plant operation will not be altered, and all safety functions will continue to perform as previously assumed in accident analyses. Tube bundle integrity is maintained for all plant conditions upon implementation of the permanent alternate repair criteria.

Therefore, based on the above, the proposed change does not create the possibility of a new or different kind of accident from any previously evaluated.

3. *The proposed changes do not involve a significant reduction in the margin of safety.*

   The proposed changes to TS 3.4.13, TS 5.5.8, and TS 5.6.8 define the safety significant portion of the tube that must be inspected and repaired. WCAP-18089-P identifies the specific inspection depth from the top of the tubesheet below which any type of tube degradation is shown to have no impact on the performance criteria in NEI 97-06 Rev. *3,* "Steam Generator Program Guidelines."

   The proposed change that alters the SG inspection and reporting criteria maintains the required structural margins of the SG tubes for both normal and accident conditions. Nuclear Energy Institute 97-06, "Steam Generator Program Guidelines," and NRC Regulatory Guide (RG) 1.121, "Bases for Plugging Degraded PWR Steam Generator Tubes," are used as the bases in the development of the limited 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 WCAP-18089-P 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 and cold leg tubesheet inspection criteria will preclude unacceptable primary-to-secondary leakage during all plant conditions. Using the methodology for determining leakage as described in WCAP-18089-P, it is shown that significant adequate margin exists between conservatively estimated accident induced leakage and the allowable accident leakage (500 gpd at operating conditions) if either SG is assumed to be leaking at the TS leakage limit of 72 gpd at the beginning of the design basis accident.

   Therefore, the proposed changes do not involve a significant reduction in any margin of safety.

   Based on the above, NextEra concludes that the proposed amendment presents no significant hazards consideration under the standards set forth in 10 CFR 50.92(c) and, accordingly, a finding of "no significant hazards consideration" is justified.

4.3 Conclusion

The hydraulically expanded portion of the tube 20.6 inches below the top of the tubesheet is the length of tube that is engaged within the tubesheet to the top of the tube sheet (secondary face) that is required to maintain structural and leakage integrity over the full range of SG operating conditions, including the most limiting accident conditions. WCAP-18089-P determined that degradation below this distance from the top of the tubesheet does not require plugging and serves as the basis for the limited tubesheet inspection criteria. WCAP-18089-P also shows that, upon implementation of the H* criterion, that the TS leakage limit of 72 gpd precludes unacceptable leakage during any postulated accident that models primary-to-secondary leakage.

In conclusion, (1) there is reasonable assurance that the health and safety of the public will not be endangered by operation in the proposed manner, (2) such activities will be conducted in compliance with the Commission's regulations, and (3) the issuance of the amendment will not be inimical to the common defense and security or to the health and safety of the public.

5.0 ENVIRONMENTAL CONSIDERATION

NextEra has evaluated the proposed amendment for environmental considerations. The 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, 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. The proposed change maintains the required structural margins for the steam generator tubes for both normal and accident conditions. Accordingly, the proposed amendment meets the eligibility criterion for categorical exclusion set for in 10 CFR 51.22(c) (9). Therefore, pursuant to 10 CFR 51.22(b), no environmental impact statement or environmental assessment needs to be prepared in connection with the proposed amendment.

6.0 REFERENCES

1. Westinghouse Electric Company WCAP-18089-P, "Point Beach Unit 1 Steam Generator Tube Alternate Repair Criterion, H*," March 2016.

2. NEI 97-06, "Steam Generator Program Guidelines" Revision 3, June 2011.

3. SGMP: Pressurized Water Reactor Steam Generator Examination Guidelines, Revision 7, EPRI, Palo Alto, CA: 2007. 1013706.

4. EPRI 1019038, "Steam Generator Management Program: Steam Generator Integrity Assessment Guidelines", Revision 3, EPRI, Palo Alto, CA: 2009. 1019038.

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

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

7. WCAP-17378-P, Rev. 1, "H*: Resolution of NRC Technical issue Regarding Tubesheet Bore Eccentricity (Modei44F, 2-Loop)," June 2011.

8. NRC Generic Letter 2004-01, "Requirements for Steam Generator Tube Inspections," August 30, 2004.

9. SG-SGMP-08-7, Revision 0, "Steam Generator Condition Monitoring Assessment of Fall 2008 Inspection Results and Operational Assessment for Operating Cycles 32 and 33 Point Beach Unit 1 U1R31," November 2008.

10. WCAP-17091-P, Revision 0, "H*: Alternate Repair Criteria for the Tubesheet Expansion Region in Steam Generators with Hydraulically Expanded Tubes (Model 44F)," June 2009.

11. Point Beach UFSAR 2012 Section 14.2.5, "Rupture of a Steam Pipe.

ATTACHMENT 1

Markup of the Technical Specifications

6 Pages follow

INSERT 1

The following alternate tube plugging criteria shall be applied as an alternative to the 40% depth based criteria:

> For Unit 1 only, tubes with service-induced flaws located greater than 20.6 inches below the top of the tubesheet do not require plugging. Tubes with service-induced flaws located in the portion of the tube from the top of the tubesheet to 20.6 inches below the top of the tubesheet shall be plugged upon detection.
>
> This alternate tube plugging criteria is not applicable to the tube at row 38 column 69 in the A steam generator, which is not expanded in the hot leg the full length of the tubesheet. This tube has been removed from service by plugging (during U1R31).

INSERT 2

For Unit 1, the number and portions of the tubes inspected and methods of inspection shall be performed with the objective of detecting flaws of any type (e.g., volumetric flaws, axial and circumferential cracks) that may be present along the length of the tube from 20.6 inches below the top of the tubesheet on the hot leg side to 20.6 inches below the top of the tubesheet on the cold leg side and that may satisfy the applicable tube plugging criteria. For Unit 2, the

INSERT 3

For Unit 2, if crack indications are found in any SG tube, then the next inspection for each affected and potentially affected SG for the degradation mechanism that caused the crack indication shall not exceed 24 effective full power months or one refueling outage (whichever results in more frequent inspections). If definitive information, such as from examination of a pulled tube, diagnostic non-destructive testing, or engineering evaluation indicates that a crack-like indication is not associated with a crack(s), then the indication need not be treated as a crack.

3.4 REACTOR COOLANT SYSTEM (RCS)

3.4.13 RCS Operational LEAKAGE

LCO 3.4.13 RCS operational LEAKAGE shall be limited to:

a. No pressure boundary LEAKAGE;

b. 1 gpm unidentified LEAKAGE;

c. 10 gpm identified LEAKAGE; and

d. 72 gallons per day (Unit 1) and 150 gallons per day (Unit 2) primary to secondary LEAKAGE through any one steam generator (SG).

APPLICABILITY: MODES 1, 2, 3, and 4.

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. RCS operational LEAKAGE not within limits for reasons other than pressure boundary LEAKAGE or primary to secondary LEAKAGE.	A.1 Reduce LEAKAGE to within limits.	4 hours
B. Required Action and associated Completion Time of Condition A not met. <u>OR</u> Pressure boundary LEAKAGE exists. OR Primary to secondary LEAKAGE not within limit.	B.1 Be in MODE 3. <u>AND</u> B.2 Be in MODE 5.	6 hours 36 hours

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.4.13.1	---------------------------NOTES------------------------- 1. Not required to be performed until 12 hours after establishment of steady state operation. 2. Not applicable to primary to secondary LEAKAGE. --- Verify RCS Operational LEAKAGE is within limits by performance of RCS water inventory balance.	In accordance with the Surveillance Frequency Control Program
SR 3.4.13.2	---------------------------NOTE--------------------------- Not required to be performed until 12 hours after establishment of steady state operation. --- Verify primary to secondary LEAKAGE is ≤ 150 gallons per day through any one SG. (Unit 2) ≤ 72 gallons per day (Unit 1) and	In accordance with the Surveillance Frequency Control Program

5.5 Programs and Manuals

5.5.8 Steam Generator (SG) Program (continued)

for all SGs and leakage rate for an individual SG. Leakage is not to exceed 500 gallons per day per SG.

3. The operational LEAKAGE performance criterion is specified in LCO 3.4.13, "RCS Operational LEAKAGE."

c. Provisions for SG tube plugging criteria. Tubes found by inservice inspection to contain flaws with a depth equal to or exceeding 40% of the nominal tube wall thickness shall be plugged.

INSERT 1

INSERT 2

¶ For Unit 1 and Unit 2:

d. Provisions for SG tube inspections. Periodic SG tube inspections shall be performed. ~~The~~ number and portions of the tubes inspected and methods of inspection shall be performed with the objective of detecting flaws of any type (e.g., volumetric flaws, axial and circumferential cracks) that may be present along the length of the tube, from the tube-to-tubesheet weld at the tube inlet to the tube-to-tubesheet weld at the tube outlet, and that may satisfy the applicable tube plugging criteria. The tube-to-tubesheet weld is not part of the tube. In addition to meeting the requirements of d.1, d.2, and d.3 below, the inspection scope, inspection methods, and inspection intervals shall be such as to ensure that SG tube integrity is maintained until the next SG inspection. A degradation assessment shall be performed to determine the type and location of flaws to which the tubes may be susceptible and, based on this assessment, to determine which inspection methods need to be employed and at what location.

1. Inspect 100% of the tubes in each SG during the first refueling outage following SG installation.

2. i. Unit 1 (alloy 600 Thermally Treated tubes): After the first refueling outage following SG installation, inspect each SG at least every 48 effective full power months or at least every other refueling outage (whichever results in more frequent inspections). In addition, the minimum number of tubes inspected at each scheduled inspection shall be the number of tubes in all SGs divided by the number of SG inspection outages scheduled in each inspection period as defined in a, b, and c below. If a degradation assessment indicates the potential for a type of degradation to occur at a location not previously inspected with a technique capable of detecting this type of degradation at this location and that may satisfy the applicable

inspected with such a capable inspection technique during the remainder of the inspection period may be prorated. The fraction of locations to be inspected for this potential type of degradation at this location at the end of the inspection period shall be no less than the ratio of the number of times the SG is scheduled to be inspected in the inspection period after the determination that a new form of degradation could potentially be occurring at this location divided by the total number of times the SG is scheduled to be inspected in the inspection period. Each inspection period defined below may be extended up to 3 effective full power months to include a SG inspection outage in an inspection period and the subsequent inspection period begins at the conclusion of the included SG inspection outage.

a) After the first refueling outage following SG installation, inspect 100% of the tubes during the next 144 effective full power months. This constitutes the first inspection period;

b) During the next 120 effective full power months, inspect 100% of the tubes. This constitutes the second inspection period;

c) During the next 96 effective full power months, inspect 100% of the tubes. This constitutes the third inspection period; and

d) During the remaining life of the SGs, inspect 100% of the tubes every 72 effective full power months. This constitutes the fourth and subsequent inspection periods.

For Unit 1, if

3. ~~If~~ crack indications are found in any SG tube, then the next inspection for each affected and potentially affected SG for the degradation mechanism that caused the crack indication shall not exceed 24 effective full power months or one refueling outage (whichever results in more frequent inspections). If definitive information, such as from examination of a pulled tube, diagnostic non-destructive testing, or engineering evaluation indicates that a crack-like indication is not associated with a crack(s), then the indication need not be treated as a crack.

INSERT 3

e. Provisions for monitoring operational primary to secondary LEAKAGE.

from 20.6 inches below the top of the tubesheet on the hot leg side to 20.6 inches below the top of the tubesheet on the cold leg side, 5.6 Reporting Requirements

5.6.8 Steam Generator Tube Inspection Report (continued)

e. Number of tubes plugged during the inspection outage for each degradation mechanism,

f. The number and percentage of tubes plugged to date, and the effective plugging percentage in each steam generator,

g. The results of condition monitoring, including the results of tube pulls and in-situ testing.

h. For Unit 1 only, the primary to secondary leakage rate observed in each SG (if it is not practical to assign the leakage to an individual SG, the entire primary to secondary leakage should be conservatively assumed to be from one SG) during the cycle preceding the inspection which is the subject of the report,

.

i. For Unit 1 only, the calculated accident induced leakage rate from the portion of the tubes below 20.6 inches from the top of the tubesheet for the most limiting accident in the most limiting SG. In addition, if the calculated accident induced leakage rate from the most limiting accident is less than 5.22 times the maximum operational primary to secondary leakage rate, the report should describe how it was determined, and

.

j. For Unit 1 only, the results of monitoring for tube axial displacement (slippage). If slippage is discovered, the implications of the discovery and corrective action shall be provided.

ATTACHMENT 2

Markup of the Technical Specification Bases

5 Pages follow

INSERT BASES 1

In the context of this Specification, for Unit 1, the safety significant portion of a SG tube from 20.6 inches below the top of the tubesheet on the hot leg to 20.6 inches below the top of the tubesheet on the cold leg including the tube wall is subject to inspection. The tube-to-tubesheet weld is not considered part of the tube.

INSERT BASES 2

For Unit 1, the alternate tube plugging criteria, H*, is not applicable to the tube at row 38 column 69 in the A steam generator, which is not expanded the full length of the tubesheet.

INSERT BASES 3

For Unit 1, a single crack located 20.6 inches below the top of the tubesheet, leaking less than or equal to 72 gallons per day, would not exceed accident analysis primary to secondary leakage assumptions during a main steam line break or propagate to a SGTR under stress conditions of a LOCA or a main steam line break.

BASES

LCO (continued)

b. Unidentified LEAKAGE

One gallon per minute (gpm) of unidentified LEAKAGE is allowed as a reasonable minimum detectable amount that the containment air monitoring and containment sump level monitoring equipment can detect within a reasonable time period. Violation of this LCO could result in continued degradation of the RCPB, if the LEAKAGE is from the pressure boundary.

c. Identified LEAKAGE

Up to 10 gpm of identified LEAKAGE is considered allowable because LEAKAGE is from known sources that do not interfere with detection of unidentified LEAKAGE and is well within the capability of the RCS Makeup System. Identified LEAKAGE includes LEAKAGE to the containment from specifically known and located sources, but does not include pressure boundary LEAKAGE or controlled reactor coolant pump (RCP) seal leakoff (a normal function not considered LEAKAGE). Violation of this LCO could result in continued degradation of a component or system.

72 gallons per day (Unit 1) and 150 gallons per day (Unit 2)

d. Primary to Secondary LEAKAGE through Any One SG

The limit of ~~150 gallons per day~~ per SG is based on the operational LEAKAGE performance criterion in NEI 97-06, Steam Generator Program Guidelines (Ref. 3). The Steam Generator Program operational LEAKAGE performance criterion in NEI 97-06 states, "The RCS operational primary to secondary leakage through any one SG shall be limited to 150 gallons per day." ~~The limit is~~ based on operating experience with SG tube degradation mechanisms that result in tube leakage. The operational leakage rate criterion in conjunction with the implementation of the Steam Generator Program is an effective measure for minimizing the frequency of steam generator tube ruptures.

The limit for Unit 1 has been permanently reduced as a result of the SG tube alternate repair criterion that has been implemented for this unit, The limits are

APPLICABILITY

In MODES 1, 2, 3, and 4, the potential for RCPB LEAKAGE is greatest when the RCS is pressurized.

In MODES 5 and 6, LEAKAGE limits are not required because the reactor coolant pressure is far lower, resulting in lower stresses and reduced potentials for LEAKAGE.

BASES

72 gallons per day (Unit 1) and less than or equal to

SURVEILLANCE REQUIREMENTS (continued)

<u>SR 3.4.13.2</u>

(Unit 2)

This SR verifies that primary to secondary LEAKAGE is less or equal to 150 gallons per day through any one SG. Satisfying the primary to secondary LEAKAGE limit ensures that the operational LEAKAGE performance criterion in the Steam Generator Program is met. If this SR is not met, compliance with LCO 3.4.17, "Steam Generator Tube Integrity," should be evaluated. ~~The 150 gallons per day limit is~~ measured at room temperature as described in Reference 4. The operational LEAKAGE rate limit applies to LEAKAGE through any one SG. If it is not practical to assign the LEAKAGE to an individual SG, all the primary to secondary LEAKAGE should be conservatively assumed to be from one SG.

The 72 gallons per day (Unit 1) and 150 gallons per day (Unit 2) limits are

The Surveillance is modified by a Note which states that the Surveillance is not required to be performed until 12 hours after establishment of steady state operation. For RCS primary to secondary LEAKAGE determination, steady state is defined as stable RCS pressure, temperature, power level, pressurizer and makeup tank levels, makeup and letdown, and RCP seal injection and return flows. The Surveillance Frequency is controlled under the Surveillance Frequency Control Program. The primary to secondary LEAKAGE is determined using continuous process radiation monitors or radiochemical grab sampling in accordance with the EPRI guidelines (Ref. 4).

REFERENCES

1. FSAR Section 1.3.3.
2. FSAR, Section 14.
3. NEI 97-06, "Steam Generator Program Guidelines."
4. EPRI, "Pressurized Water Reactor Primary-to-Secondary Leak Guidelines."
5. 10 CFR 50.67, Accident Source Term.

BASES

APPLICABLE SAFETY ANALYSES

The steam generator tube rupture (SGTR) accident is the limiting design basis event for SG tubes and avoiding an SGTR is the basis for this Specification. The analysis of a SGTR event assumes a bounding primary to secondary LEAKAGE rate greater than or equal to equal to the operational LEAKAGE rate limits in LCO 3.4.13, "RCS Operational LEAKAGE," plus the leakage rate associated with a double-ended rupture of a single tube. The accident analysis for a SGTR assumes the contaminated secondary fluid is released to the atmosphere via safety valves.

The analysis for design basis accidents and transients other than a SGTR assume the SG tubes retain their structural integrity (i.e., they are assumed not to rupture.) In these analyses, the steam discharge to the atmosphere is based on the total primary to secondary LEAKAGE from all SGs of 500 gallons per day or is assumed to increase to 500 gallons per day as a result of accident induced conditions. For accidents that do not involve fuel damage, the primary coolant activity level of DOSE EQUIVALENT I-131 is assumed to be equal to the LCO 3.4.16, "RCS Specific Activity," limits. For accidents that assume fuel damage, the primary coolant activity is a function of the amount of activity released from the damaged fuel. The dose consequences of these events are within the limits of GDC 19 (Ref. 2), and 10 CFR 50.67 (Ref. 3) dose guideline limit.

Steam generator tube integrity satisfies Criterion 2 of 10 CFR 50.36(c)(2)(ii).

LCO

The LCO requires that SG tube integrity be maintained. The LCO also requires that all SG tubes that satisfy the plugging criteria be plugged in accordance with the Steam Generator Program.

During an SG inspection, any inspected tube that satisfies the Steam Generator Program plugging criteria is removed from service by plugging. If a tube was determined to satisfy the plugging criteria but was not plugged, the tube may still have tube integrity.

INSERT BASES 1

for Unit 2

In the context of this Specification, an SG tube is defined as the entire length of the tube, including the tube wall, between the tube-to-tubesheet weld at the tube inlet and the tube-to-tubesheet weld at the tube outlet. The tube-to-tubesheet weld is not considered part of the tube.

INSERT BASES 2

A SG tube has tube integrity when it satisfies the SG performance criteria. The SG performance criteria are defined in Specification 5.5.8, "Steam Generator Program," and describe acceptable SG tube performance.

BASES

(Unit 2)

The limit for Unit 2

LCO (continued)

primary to secondary LEAKAGE induced during the accident. The operational LEAKAGE performance criterion provides an observable indication of SG tube conditions during plant operation. The limit on operational LEAKAGE is contained in LCO 3.4.13, "RCS Operational LEAKAGE," and limits primary to secondary LEAKAGE through any one SG to 150 gallons per day. ~~This limit~~ is based on the assumption that a single crack leaking this amount would not propagate to a SGTR under the stress conditions of a LOCA or a main steam line break. If this amount of LEAKAGE is due to more than one crack, the cracks are very small, and the above assumption is conservative.

72 gallons per day (Unit 1) and

INSERT BASES 3

APPLICABILITY

Steam generator tube integrity is challenged when the pressure differential across the tubes is large. Large differential pressures across SG tubes can only be experienced in MODE 1, 2, 3, or 4.

RCS conditions are far less challenging in MODES 5 and 6 than during MODES 1, 2, 3, and 4. In MODES 5 and 6, primary to secondary differential pressure is low, resulting in lower stresses and reduced potential for LEAKAGE.

ACTIONS

The ACTIONS are modified by a Note clarifying that the Conditions may be entered independently for each SG tube. This is acceptable because the Required Actions provide appropriate compensatory actions for each affected SG tube. Complying with the Required Actions may allow for continued operation, and subsequent affected SG tubes are governed by subsequent Condition entry and application of associated Required Actions.

A.1 and A.2

Condition A applies if it is discovered that one or more SG tubes examined in an inservice inspection satisfy the tube plugging criteria but were not plugged in accordance with the Steam Generator Program as required by SR 3.4.17.2. An evaluation of SG tube integrity of the affected tube(s) must be made. Steam generator tube integrity is based on meeting the SG performance criteria described in the Steam Generator Program. The SG plugging criteria define limits on SG tube degradation that allow for flaw growth between inspections while still providing assurance that the SG performance criteria will continue to be met. In order to determine if a SG tube that should have been plugged has tube integrity, an evaluation must be completed that demonstrates that the SG performance criteria will continue to be met until the next refueling outage or SG tube inspection. The tube integrity determination

ATTACHMENT 3

Application for Withholding Proprietary Information from Public Disclosure CAW-16-4388

7 Pages follow

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NEXT-16-39

CAW-16-4388

March 23, 2016

APPLICATION FOR WITHHOLDING PROPRIETARY
INFORMATION FROM PUBLIC DISCLOSURE

Subject: WCAP-18089-P, Revision 0, "Point Beach Unit 1 Steam Generator Tube Alternate Repair Criterion H*" (Proprietary)

The Application for Withholding Proprietary Information from Public Disclosure is submitted by Westinghouse Electric Company LLC (Westinghouse), pursuant to the provisions of paragraph (b)(1) of Section 2.390 of the Commission's regulations. It contains commercial strategic information proprietary to Westinghouse and customarily held in confidence.

The proprietary information for which withholding is being requested in the above-referenced report is further identified in Affidavit CAW-16-4388 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 NextEra Energy Point Beach.

Correspondence with respect to the proprietary aspects of the Application for Withholding or the Westinghouse Affidavit should reference CAW-16-4388 and should be addressed to James A. Gresham, Manager, Regulatory Compliance, Westinghouse Electric Company, 1000 Westinghouse Drive, Building 3 Suite 310, Cranberry Township, Pennsylvania 16066.

James A. Gresham, Manager
Regulatory Compliance

CAW-16-4388

March 23, 2016

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF BUTLER:

I, James A. Gresham, am 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 my knowledge, information, and belief.

James A. Gresham, Manager
Regulatory Compliance

(1) I am Manager, Regulatory Compliance, 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 Proprietary Information from Public Disclosure 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 constitute Westinghouse policy and provide 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.

(iii) 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.

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

(v) 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.

(vi) The proprietary information sought to be withheld in this submittal is that which is appropriately marked in WCAP-18089-P, Revision 0, "Point Beach Unit 1 Steam Generator Alternate Repair Criteria H*" (Proprietary), dated March 2016, for submittal to the Commission, being transmitted by NextEra Energy Point Beach letter and Application for Withholding Proprietary Information from Public Disclosure, to the Document Control Desk. The proprietary information as submitted by Westinghouse is that associated with Westinghouse's request for NRC approval of WCAP-18089-P, and may be used only for that purpose.

(a) This information is part of that which will enable Westinghouse to provide technical support for licensing the alternate steam generator tube repair criteria, H*, for use at Point Beach Unit 1.

(b) Further, this information has substantial commercial value as follows:

(i) Westinghouse plans to sell the use of similar information to its customers for the purpose of providing technical support for licensing the steam generator tube alternate repair criteria, H*..

(ii) Westinghouse can sell support and defense of industry guidelines and acceptance criteria for plant-specific applications.

(iii) 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 technical evaluation justifications and licensing defense services for commercial power reactors without commensurate expenses. Also, public disclosure of the information would enable others to use the information to meet NRC requirements for licensing documentation without purchasing the right to use the information.

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 non-proprietary versions of a document, 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 (f) located as a superscript immediately following the brackets enclosing each item of information being identified as proprietary or in the margin opposite such information. These lower case letters 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).

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ATTACHMENT 4

Application for Withholding Proprietary Information from Public Disclosure CAW-16-4387

7 Pages follow

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NEXT-16-39

CAW-16-4387

March 23, 2016

APPLICATION FOR WITHHOLDING PROPRIETARY INFORMATION FROM PUBLIC DISCLOSURE

Subject: LTR-SGMP-16-14 P-Attachment, "Responses to Information Requests from the Nuclear Regulatory Commission (NRC) Staff Concerning the Point Beach Unit 1 H* License Amendment Request Submittal" (Proprietary)

The Application for Withholding Proprietary Information from Public Disclosure is submitted by Westinghouse Electric Company LLC (Westinghouse), pursuant to the provisions of paragraph (b)(1) of Section 2.390 of the Commission's regulations. It contains commercial strategic information proprietary to Westinghouse and customarily held in confidence.

The proprietary information for which withholding is being requested in the above-referenced report is further identified in Affidavit CAW-16-4387 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 NextEra Energy Point Beach.

Correspondence with respect to the proprietary aspects of the Application for Withholding or the Westinghouse Affidavit should reference CAW-16-4387, and should be addressed to James A. Gresham, Manager, Regulatory Compliance, Westinghouse Electric Company, 1000 Westinghouse Drive, Building 3 Suite 310, Cranberry Township, Pennsylvania 16066.

James A. Gresham, Manager
Regulatory Compliance

CAW-16-4387
March 23, 2016

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF BUTLER:

I, James A. Gresham, am 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 my knowledge, information, and belief.

James A. Gresham, Manager
Regulatory Compliance

(1) I am Manager, Regulatory Compliance, 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.

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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.

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(v) 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.

(vi) The proprietary information sought to be withheld in this submittal is that which is appropriately marked in LTR-SGMP-16-14 P-Attachment, "Responses to Information Requests from the Nuclear Regulatory Commission (NRC) Staff Concerning the Point Beach Unit 1 H* License Amendment Request Submittal" (Proprietary), for submittal to the Commission, being transmitted by NextEra Energy Point Beach letter and Application for Withholding Proprietary Information from Public Disclosure, to the Document Control Desk. The proprietary information as submitted by Westinghouse is that associated with Westinghouse's request for NRC approval of LTR-SGMP-16-14 P-Attachment, and may be used only for that purpose.

(a) This information is part of that which will enable Westinghouse to provide technical support for licensing the alternate steam generator tube repair criteria, H*, for use at Point Beach Unit 1.

(b) Further, this information has substantial commercial value as follows:

(i) Westinghouse plans to sell the use of similar information to its customers for the purpose of providing technical support for licensing the steam generator tube alternate repair criteria, H*.

(ii) Westinghouse can sell support and defense of industry guidelines and acceptance criteria for plant-specific applications.

(iii) 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 technical evaluation justifications and licensing defense services for commercial power reactors without commensurate expenses. Also, public disclosure of the information would enable others to use the information to meet NRC requirements for licensing documentation without purchasing the right to use the information.

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.

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ATTACHMENT 5

WCAP-18089-NP,"Point Beach Unit 1 Steam Generator Tube Alternate Repair Criterion, H*"
(Non-Proprietary)

111 Pages follow

WCAP-18089-NP
Revision 0

March 2016

Point Beach Unit 1
Steam Generator Tube
Alternate Repair Criterion, H*

WCAP-18089-NP
Revision 0

Point Beach Unit 1 Steam Generator Tube Alternate Repair Criterion, H*

March 2016

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (cont.)

LIST OF FIGURES (cont.)

1 INTRODUCTION

1.1 REPORT OBJECTIVES

This report provides the basis for implementing an alternate steam generator tube plugging criterion, known as H*, for the tubesheet (TS) region for all tubes in the Point Beach Unit 1 steam generators (SGs). Section 2.0 of this report provides an executive summary of the results of the H* analysis using a more accurate three-dimensional submodel (3DSM) to determine the final H* mean and probabilistic distance and the applicable leak rate factors. Section 3.0 of this report includes descriptions of the prior two-dimensional square cell (C^2) model and new 3DSM for calculating contact pressures. Key differences between the previous C^2 model and the new 3DSM are discussed. Section 4.0 describes the structural analysis results for H*, identifies the mean H* distances, and defines the critical radius using the 3DSM. Section 5.0 develops the probabilistic H* distance. Section 6.0 determines the crevice pressure adjustment length. Section 7.0 defines the final probabilistic H* length. Section 8.0 identifies the bounding steam line break leak rate factor to be used to determine acceptability of accident-induced leakage. Section 9.0 provides the conclusion for the report.

1.2 PURPOSE OF H*

H* (H-star) is an alternate steam generator tube repair criterion (ARC) that replaces the tube end weld with the hydraulic expansion joint within the TS as the primary pressure boundary in order to limit the inspection depth in the TS expansion region to less than the full depth of the TS. Regulatory requirements are to inspect the SG tubes from tube end to tube end unless a technical argument is made to limit the extent of the inspection to a shorter length. Industry operating experience for SGs with Alloy600TT tubing has shown that some stress corrosion cracks (SCC) have been detected in a region from the tube end weld to about 1 inch above the tube end weld. H* eliminates the need to inspect below the H* distance, thus enabling keeping most tubes with such SCC indications in service.

The two principal requirements for H* are:

1. Assure that the tube(s) do not pull out of the tubesheet under the most limiting loads during normal operating or accident conditions.

2. Assure that the primary coolant leakage through the tube-to-tubesheet crevice is no greater than the leakage assumed in the Final Safety Analysis Report (FSAR) for the most limiting accident.

The United States Nuclear Regulatory Commission (USNRC) has licensed H* for permanent application in 15 plants with Model F, Model D, Model 44F and Model 51F SGs. A satisfactory H* solution could not be achieved for Point Beach Unit 1, a two-loop plant with Model 44F SGs, during the development of the technology on which the USNRC licenses are based. Application of the methods on which the USNRC based its licensing approval resulted in a sector of tubes in Point Beach Unit 1 that did not meet the principal requirements noted above. The current licensing basis for Model 44F plants is principally contained in WCAP-17091-P (Reference 1), but also includes other documents contained in the respective licensing amendment requests (LARs) from the respective Model 44F plants.

The results of the prior analysis for Point Beach Unit 1, documented in Reference 2, are summarized in Section 1.2.

This report documents the improved approach used to determining a viable H* value for Point Beach Unit 1. The bulk of the analysis from the current licensing basis continues to apply for this improved analysis. (In this report, reference to "current licensing basis" means the basis on which permanent H* licenses were provided, including the 3-loop Model 44F SG plants). This report incorporates responses to the relevant questions raised in prior Requests for Additional Information (RAI) and, in particular, those contained in Reference 22.

The principal differences between this analysis and the current licensing basis are:

- A full-depth 3D structural submodel (3DSM) representing a tube unit cell replaces the square-cell (C^2) model applied in the current licensing basis. The 3DSM more accurately represents the physical condition of the tube in the TS in that it is a continuous structural model over the full depth of the tubesheet. The C^2 model represents the depth of the TS as a stack of models that are not coupled in the horizontal plane, thus neglecting the bending continuity of the tube and tubesheet through the depth of the TS.

- A conservative assumption made in the current licensing basis, that is, disconnecting the divider plate from the tubesheet to avoid the potential effects of degradation of the divider plate-to-TS weld, was found not to be conservative for Point Beach Unit 1. A more conservative (longer) value for H* was calculated with the divider plate attached to the tubesheet. Therefore, if any continuing concerns regarding tubesheet weld degradation are realized, they will lead to a shorter (less conservative) value of H* for Point Beach Unit 1.

Figure 1-1 shows the flow chart of the calculation process for H*. This is the same calculation process as discussed in prior H* reports (i.e., Reference 1) except that the contact pressure model is now a three-dimensional model replacing the prior two-dimensional model, C^2, and the treatment of the divider plate as noted above.

As previously stated, the limiting H* estimates for normal operating (NOP) and steam line break (SLB) conditions are determined for the worst-case sector of the tubesheet, which is the region of the tubesheet perpendicular to the tube lane, plus or minus five degrees azimuthally (see Section 6.2.3 of Reference 1). The H* value is determined using displacements calculated for the worst-case sector of the TS using a 3D half-symmetry finite element model of the lower SG assembly described in Section 6.2.1 of Reference 1 and further discussed in Section 3.2 of this report. The TS displacements are input to the 3DSM for calculation of contact pressure between the tube and the tubesheet at each selected tubesheet radius in the limiting sector. The distribution of contact pressure as a function of elevation at a given TS radius (see Section 4.1) defines the pull out resistance of a SG tube to the applied end cap load at that radius. The end cap load results from the primary side to secondary side pressure differential across the tubes with appropriate factors of safety. The required H* length is defined by the integration of the axially distributed contact pressures between the tube and tubesheet, multiplied by a conservative coefficient of friction to determine the cumulative pull out resistance as a function of depth into the tubesheet.

The structural model used to calculate the contact pressures between the TS and the tube is the 3DSM. The 3DSM is a full-depth model of the tube and tubesheet material in a single tube pitch subjected to applied operating pressure and temperature and applied displacements from the tubesheet from the lower SG assembly model. The radial location of the limiting H* estimate is the TS radius with the longest required engagement length to balance an end cap load of $3\Delta P_{NOP}$ or $1.4\Delta P_{DBA}$ (whichever condition results in a greater H* value) assuming mean material properties. The probabilistic estimate of H* was developed using a Monte Carlo simulation for the effect of varying the critical parameters affecting contact pressure between the tube and TS. It was previously established in Reference 1 that these parameters are the TS coefficient of thermal expansion (CTE) and the tube CTE. The final result of the simulation is the combination of TS and tube CTEs that define the 0.95 probability at a 95% confidence estimate for H* during the limiting operating condition at the limiting TS radius. The predicted combination of CTEs from the simulation is input to the lower SG assembly model and the 3DSM to calculate the value of H* for the required probabilistic estimate.

In satisfaction of the second principal requirement noted above, a leak rate factor is also determined to assure that primary-to-secondary leakage remains within UFSAR accident analysis assumptions during all plant conditions as described in detail in Section 8.0 of this report. The leak rate factor is the ratio of the predicted leakage during accident conditions to the predicted leakage during normal operating conditions.

1.3 PRIOR POINT BEACH RESULTS

Point Beach Unit 1 is a 2-loop plant with Model 44F SGs, unique among the other plants who participated in the development of H*. Three other plants with Model 44F SGs participated in the development of H*; however, these were 3-loop plants. What makes Point Beach Unit 1 unique among H*-candidate Model 44F plants is the input conditions of differential pressure and temperature. These conditions are based on the bounding assumptions made in the steam generator design specification, and are not derived from any accident analyses. They are intended to bound the worst-case Steam Line Break (SLB) accident. Use of the steam generator design specification assumptions is consistent with other previously performed H* analyses.

The H* distance depends primarily on differential thermal expansion between the tubes and the tubesheet and a contribution from tubesheet deflection under accident conditions and on the differential pressure tending to pull the tubes from the tubesheet. Due to the low temperature and high differential pressure of the assumed Point Beach Unit 1 SLB condition and because the deflection of the tubesheet is small due to the relatively stiff structure, it was not possible to show that sufficient resistance against tube pull out existed for 928 tubes in each SG with the use of the prior C^2 model. Reference 2 shows an "Exclusion Region" of tubes between a TS radial distance of **[** **]**^{a,c,e} inches to **[** **]**^{a,c,e} inches.

a,c,e

Figure 1-1. Flow Chart of H* Calculation Process

2 EXECUTIVE SUMMARY

The Alternate Repair Criterion (ARC), H*(H-star), replaces the tube end weld with the hydraulic expansion as the primary pressure boundary in the steam generator. When implemented, H* limits the length of tube requiring inspection from that length from the bottom of the H* distance on the hot leg side to the bottom of the H* length on the cold leg side, thus eliminating the need to inspect the tube ends.

H* has been previously licensed by the USNRC for 15 plants; however, an acceptable H* distance could not be demonstrated for all tubes in Point Beach Unit 1 using the same method for calculating tube-to-tubesheet contact pressures as was used for the prior licenses granted.

This report documents a modified calculation approach for Point Beach Unit 1 that provides an acceptable H* distance for all tubes in Point Beach Unit 1. The bulk of the prior technical justification still applies; only the structural model to calculate the tube-to-tubesheet contact pressures has been changed. Previously, the contact pressures were calculated using a model known as the square-cell (C^2) model which represented a unit tube cell in the tubesheet thickness as a stack of individual models at discreet elevations which are not coupled in the horizontal plane. The C^2 model has been replaced by a three-dimensional tube unit cell submodel (3DSM) that represents the tubesheet thickness in a single, continuous model. The advantage of the 3DSM is that it takes into account the bending of the tubesheet and tube in computing the tube-to-tubesheet contact pressures at operating conditions and produces H* distances within the thickness of the tubesheet.

The limiting operating condition for Point Beach Unit 1 is the postulated steam line break (SLB). The definition of the SLB for Point Beach Unit 1 differentiates the plant from others in that it exhibits the lowest temperature among the candidate plants for H*. Because H* is driven primarily by differential thermal growth between the tube and the tubesheet, this established a unique challenge for Point Beach Unit 1.

Because of the limiting operating conditions for Point Beach Unit 1, the connection between the divider plate and the tubesheet was re-established because this produced a more conservative H* distance. In prior analyses, the connection between the divider plate and the tubesheet was severed in the analysis because of concerns regarding degradation of the divider plate-to-tubesheet weld. For Point Beach Unit 1, the H* result is conservative for all divider plate conditions.

The final H* distance at 0.95 probability at 95% confidence is 20.60 inches and is referenced from the top of the tubesheet. The total thickness of the tubesheet is **[ ]**^{a,c,e} inches. The ratio of the potential SLB leakage to normal operating leakage from the tubesheet region was determined to be 5.22. This leakage ratio requires a reduction in the allowable SG tube primary to secondary leakage during normal operation (TS 3.4.13. LCO) from 150 gpd to 72 gpd.

The structural performance criterion used to develop the H* distance documented in Section 4.2 and Section 5.0 of this report meets the requirements of NEI 97-06, Revision 3. The applicable structural criterion is to show that tube pull out is prevented under the limiting loading with the appropriate factor of safety specified in NEI 97-06, Revision 3. The reduced primary-to-secondary leakage criterion of 72 gpd precludes unacceptable leakage during postulated accident conditions. As noted in Section 2.3 of Reference 19, the operational leakage performance criterion provides a defense-in-depth added margin against tube rupture under accident conditions. However, the reduced leakage limit of 72 gpd is not required to preclude tube pull out for the Point Beach Unit 1 steam generators.

3 STRUCTURAL MODELS

3.1 OVERVIEW – COMPARISON OF 2D C^2 VERSUS 3D SUBMODEL USED TO CALCULATE TUBE-TO-TUBESHEET CONTACT PRESSURES

As discussed in Section 1.2 above, the limiting H* estimate for normal operating (NOP) and steam line break (SLB) conditions is determined for the worst-case sector of the tubesheet, which is the region of the tubesheet perpendicular to the tube lane, plus or minus five degrees azimuthally (see Section 6.2.3 of Reference 1). The H* value is, in part, determined using tubesheet (TS) displacements from the worst-case sector of the tubesheet which are calculated using a 3D half-symmetry finite element model of the lower SG assembly described in Section 6.2.1 of Reference 1 and further discussed in Section 3.2 of this report. The tubesheet displacements are input to the unit cell model of the tube to calculate the tube-to-tubesheet contact pressure between the tube and the tubesheet at each tubesheet radius of interest in the limiting sector. In prior analysis, the unit cell tube model was the C^2 model; in the current evolution the unit cell model is the 3DSM.

The distribution of contact pressure as a function of elevation at a given TS radius (see Section 4.1) defines the resistance to pull out of a SG tube against an applied end cap load at that radius. The required H* length is defined by the integration of the axially distributed contact pressures multiplied by a conservative coefficient for friction to determine the cumulative pull out resistance as a function of depth into the tubesheet. The approved value of coefficient of friction is **[ ]**^{a,c,e}, the same as that for prior, licensed applications of H*.

3.1.1 C^2 Model Description (General)

The C^2 model is a quarter symmetry plane-strain model of a tube unit cell which includes the tube in the center of the cell. The boundaries of the unit cell are defined by the centerlines between the tube pitch in both directions of the horizontal plane of the tubesheet. The thickness of the tubesheet is represented by twelve individual C^2 models at discreet elevations which are not coupled in the horizontal plane. This approach neglects the bending continuity of the tubesheet under pressure and thermal loads. The C^2 model and its application to Point Beach Unit 1 are described in detail in Reference 2.

3.1.2 3D Submodel General Description

In order to more realistically calculate tube-to-tubesheet contact pressures that occur during all plant conditions in the Point Beach Unit 1 SGs, a 3D unit cell structural submodel (3DSM) was developed to replace the C^2 model. The 3DSM is effectively a 3D version of the C^2 model that is a single structural unit cell model of the entire depth of the tubesheet, centered on the tube pitch, in which the previously uncoupled C^2 tubesheet segments are now coupled. The critical dimensions for the C^2 and 3DSM are summarized in Table 3-1.

The 3DSM and the C^2 Model share the same boundary dimensions as described in Reference 2. However, the 3DSM replaces the quarter symmetry modeling of the C^2 model with a full tube and square tubesheet (TS) submodel that enables the direct import of the tubesheet displacement from the Lower SG Assembly Model (Figure 3-1). Displacement inputs to the C^2 model required post-processing and manual input.

The 3DSM was benchmarked against prior results as described in Section 3.4. Figure 3-2 and Figure 3-3 illustrate each model used in the benchmarking (Reference 3).

The tube in the 3DSM extends beyond the top of the TS to enable direct application of the pull out force (end cap load) and direct calculation of the Poisson contraction effect while avoiding end effects at the top of the tubesheet that could affect the contact pressure calculation. (The Poisson contraction effect was, of necessity, a separate calculation in prior analyses because the C^2 segments that represented the tubesheet thickness were not connected in the horizontal plane.) The final length of the tube extension was determined as half the distance from the top of the tubesheet to the first tube support plate as documented in Reference 4 and discussed in Section 3.3.1.2.

3.1.2.1 Tube-to-Tubesheet Contact Setup

The setup of the contact region between the tube and the TS is the same as that for the C2 model described in Section 2.5 of Reference 2. The pinball radius utilized in both models is the same. Figure 3-4 summarizes the contact region setup in ANSYS®[1] 14.5.7.

The dimensions used for the finite element model were nominal dimensions for pitch and the minimum dimension for the tubesheet bore.

As is the case with the C^2 Model, the 3DSM excludes any residual contact pressure effects from the tube hydraulic expansion.

3.1.2.2 Model Mesh

The fine mesh utilized in the application of the C^2 model (Figure 3-5) was not necessary in the 3DSM because all tubesheet elevations are encompassed in one model for the full depth of the TS, versus multiple models in the C^2 approach. The reduced mesh of the 3DSM (Figure 3-6 and Figure 3-7) was shown to be acceptable for determining the contact pressure by comparing the contact pressure results using the reduced mesh in the 3DSMl to the results when the number of elements was doubled in the 3DSM. The difference in contact pressure results between these two meshes was less than 2%.

1. ANSYS is a registered trademark of ANSYS, Inc. in the United States or other countries.

3.1.3 Summary of Differences between the C^2 Model and the 3D Submodel

The key assumptions made for the 3DSM of the tube unit cell remain the same as for the C^2 model. For example, in the unloaded state, the tube is considered to be in zero pressure; line-on-line contact with the tubesheet bore; that is, residual contact pressure from the hydraulic expansion was ignored. Also, as noted above, the same assumptions relative to the contact surface, as defined in Figure 3-4 between the tube and the tubesheet bore, were used. The significant differences in application of the new 3DSM and the prior C^2 model are:

1) The added tube-to-tubesheet contact forces due to tube resistance to tubesheet bending, which are neglected in the C^2 Model, are accounted for in the 3DSM. Additional discussion of this is provided in Section 3.3.2.1.

2) The effect of Poisson contraction on H* is calculated directly in the 3DSM, thus avoiding a post-process correction of the H* length as described in Section 3.5 of Reference 2 for the C^2 model. This eliminates any potential uncertainty in the use of a post-process correction. Additional discussion of this is provided in Section 3.3.2.2.

3) The sensitivity of H* to variations of the significant variables (tube and tubesheet CTEs) can be directly calculated using the 3DSM results without relying on prior results based on application of the thick shell equation results. This also eliminates an area of potential uncertainty. Additional discussion of this is provided in Section 5.

4) ANSYS automatically provides the map results, such as temperature and displacement, to the new nodes of the 3DSM from the lower SG assembly model. In the prior application using the C2 model, displacement inputs to the C2 model required interpolation among the displacement results from the lower SG assembly model. A uniform displacement was then applied along the X and Z direction to each of the twelve separate C2 models.

a,c,e

Figure 3-1. Lower SG Assembly Model Used to Calculate the Thermal and Structural Displacements that are Transferred to Both the C^2 Model and 3DSM

a,c,e

Figure 3-2. C² Model Used in Prior Point Beach Unit 1 H* Analysis (Reference 2)

a,c,e

Figure 3-3. Image of 3DSM with Extended Tube End

Table 3-1. Dimensions of the 3DSM and C^2 Model

Component Description	Dimension (in)(4)
Inner Tube Radius	
Outer Tube Radius	
Horizontal Distance from the Tube OD-to-Tubesheet Unit Cell Side; Parallel to the Tube Lane(3)	
Horizontal Distance from the Tube OD-to-Tubesheet Unit Cell Side; Perpendicular to the Tube Lane	
Vertical Distance of Tubesheet Section (Half Tube Pitch)	
Thickness of Tubesheet	
Tube Extension Length (from Top of Tubesheet)	
Notes: (1) Assumes tube expanded to the dimension of the minimum tubesheet bore diameter. (2) The length of tube above the top of the tubesheet. Applies to the 3DSM only. (3) Corresponds to the z-direction in the 3DSM and y-direction in the C2 model. (4) See Table 4-4 of Reference 7	

a,c,e

Scope	
Scoping Method	Geometry Selection
Contact	1 Face
Target	1 Face
Contact Bodies	Tube4_TS8
Target Bodies	T8
Definition	
Type	Frictional
Friction Coefficient	0.2
Scope Mode	Automatic
Behavior	Symmetric
Trim Contact	Program Controlled
Trim Tolerance	0.11134 in
Suppressed	No
Advanced	
Formulation	Augmented Lagrange
Detection Method	Program Controlled
Penetration Tolerance	Program Controlled
Elastic Slip Tolerance	Program Controlled
Interface Treatment	Adjust to Touch
Normal Stiffness	Program Controlled
Update Stiffness	Each Iteration
Stabilization Damping Factor	0.
Pinball Region	Radius
Pinball Radius [	]a,c,e
Time Step Controls	None

(C^2 model would be selected edges instead of faces; all other parameters are the same)

Figure 3-4. ANSYS Screenshot of the Setup for the Contact Regions for the 3DSM and C^2 Models

a,c,e

Figure 3-5. Mesh Generated for 2D C^2 Model (from Reference 1)

a,c,e

Figure 3-6. Front Face View of Mesh Generated for 3DSM

a,c,e

Figure 3-7. Full Side View of Mesh Generated for 3DSM

3.2 LOWER SG ASSEMBLY MODEL

The lower SG assembly model (Figure 3-1) is a 3D symmetric model of the lower components of the SG (i.e., tubesheet, lower shell, channelhead and divider plate) and is, with two exceptions, the same as the lower subassembly model documented in the prior analysis (Reference 2). The two differences are discussed below.

3.2.1 Differences from Prior Analysis

In the previous application described in Reference 2, the lower SG assembly model and the model utilized to calculate tube-to-tubesheet contact pressure, the C^2 model, were independent models. Tubesheet displacements were manually calculated for desired tube positions by interpolating between the results for the nodes nearest to the desired tube position and used as input to the stack of C^2 models that represented the tubesheet. In contrast, the 3DSM is a detailed unit cell model that is integrated into the larger lower SG assembly model. This enables direct transfer of displacement from thermal and mechanical loading of the lower SG assembly model to the 3DSM and avoids manual calculation of inputs to the tube unit cell submodel. A slight change to the original mesh was made to locate the lower SG assembly model nodes at the actual radial locations of the tubes. This change provided the capability to easily position the 3DSM at any desired location and calculate the tube-to-tubesheet contact pressures at that location. Further, this change also permitted relatively rapid calculation of the response to various material parameter variations (see Section 5).

A second modification to the lower SG assembly model involves treatment of the divider plate. In the Model 44F steam generator, the divider plate is initially welded to the channel head and then attached to the tubesheet via a weld strip of metal on the primary side of the tubesheet called the stub runner. In prior analyses, because of regulatory concern regarding potential degradation of the weld between the divider plate and the stub runner or tubesheet, the connection between the divider plate and tubesheet was eliminated. It was also determined that disregarding the weld provided conservative H* results. As a result, the upper five inches of the divider plate were not included in the model (Reference 2). A formal peer review of the 3DSM resulted in a recommendation to review the treatment of the divider plate in the application of the 3DSM in the lower SG assembly model for Point Beach Unit 1. Comparative studies were performed and it was determined that, for Point Beach Unit 1, more conservative H* distances were predicted with the divider plate attached to the tubesheet (i.e., the opposite of the conclusion for prior H* analyses). Figure 3-8 and Figure 3-9 show the lower SG assembly model for Point Beach Unit 1.
The discussion of the divider plate analysis is contained in Section 3.3.2.3.

a,c,e

Figure 3-8. View of Lower SG Assembly Model with the Applied Mesh and Attached Divider Plate

a,c,e

Figure 3-9. Zoomed in View of Lower SG Assembly Model with Mesh

3.2.2 Thermal and Structural Loads

The lower SG assembly model uses the same thermal and structural loads that were applied to the lower SG assembly model in Reference 2, with one exception. The steam line break (SLB) transient is defined in Reference 23 and it represents the current licensing basis for the Point Beach Unit 1 SGs. As a result, the peak pressure in the primary system during a postulated SLB increased from **[ ]**^{a,c,e} psia to **[ ]**^{a,c,e} psia. The long-term primary and secondary side temperature remains the same at **[ ]**^{a,c,e} °F. Table 3-2 summarizes the values of the applied thermal and structural loads for both NOP and SLB.

The applied loading on the tubesheet bends the tubesheet and tubes. This bending is caused by temperature changes and temperature gradients as well as the pressure differential across the tubesheet and increases tube-to-tubesheet contact pressure. Unlike the C^2 Model, which consisted of twelve individual C^2 models which are not coupled in the horizontal plane to represent the tubesheet, the use of the 3DSM includes the bending continuity of the tubesheet under pressure and temperature loads.

For Point Beach Unit 1, Figure 3-10 through Figure 3-19 illustrate the application of the thermal and structural loads. Figure 3-10 shows the location of the primary side hot leg temperature and pressure in the lower SG assembly model. Similarly, Figure 3-11 shows the same for the cold leg of the SG. Figure 3-12 shows the location of the applied secondary side temperature and pressure on the lower SG assembly model. Figure 3-13 shows the location of the applied end cap load on the SG shell on the lower SG assembly. Figure 3-14 shows the location of the applied tube lane temperature for the lower SG assembly model.

Figure 3-15 and Figure 3-16 show the application of temperatures two inches from the top of the tubesheet for the hot leg and cold leg during normal operating conditions, respectively. An analysis documented in section 6.2.2.2.5 of Reference 1 has shown that, in general, the tubesheet is approximately at the primary side temperature through its thickness, except for a sharp gradient that exists in the top two inches. In the thermal analysis, the secondary side of the tubesheet was assumed to be at a temperature equal to the average of the steam temperature and the feedwater temperature. No temperature gradient exists during the limiting condition, a postulated SLB.

Figure 3-17 shows the symmetry plane of the lower SG assembly model. Figure 3-18 and Figure 3-19 show the constraint applied to the lower SG assembly model to prevent motion in the x-direction and y-direction, respectively. The coordinate system is defined on Figure 3-17.

a,c,e

Figure 3-10. Highlighted in Red, the Location of the Applied Primary Side Hot Leg Temperature and Pressure on Lower SG Assembly Model

a,c,e

Figure 3-11. Highlighted in Red, the Location of the Applied Primary Side Cold Leg Temperature and Pressure on Lower SG Assembly Model

a,c,e

Figure 3-12. Highlighted in Red, the Location of the Applied Secondary Side Temperature and Pressure on Lower SG Assembly Model

a,c,e

Figure 3-13. Highlighted in Red, the Location of the Applied End Cap Load on Lower SG Assembly Model

a,c,e

Figure 3-14. Highlighted in Red, the Location of the Applied Tube Lane Temperature on Lower SG Assembly Model

a,c,e

Figure 3-15. Highlighted in Red, the Location of a Forced Temperature on the Hot Leg Side Two Inches below the Top of the Tubesheet on the Lower SG Assembly Model

a,c,e

Figure 3-16. Highlighted in Red, the Location of a Forced Temperature on the Cold Leg Side Two Inches below the Top of the Tubesheet on the Lower SG Assembly Model

a,c,e

Figure 3-17. Highlighted in Yellow, the Location of the Symmetry Plane on the Lower SG Assembly Model

(Prevents Rigid Body Movement in the Z-Direction)

a,c,e

Figure 3-18. Highlighted in Yellow, the Location of the X-Displacement Constraint on the Lower SG Assembly Model

(Prevents Rigid Body Movement in the X-Direction)

a,c,e

Figure 3-19. Highlighted in Yellow, the Location of the Y-Displacement Constraint on the Lower SG Assembly Model

(Prevents Rigid Body Movement in the Y-Direction)

Table 3-2. Loads Applied to the Lower SG Assembly Model for Both Operating Conditions

Applied Loads and Location	NOP[(2)]	SLB[(3)]
Hot Leg Pressure (Primary Side Only)		
Cold Leg Pressure (Primary Side Only)		
Secondary Side Pressure		
End Cap Load(Equivalent Pressure)		
Hot Leg Temperature (Primary Side Only)		
Cold Leg Temperature (Primary Side Only)		
Hot Leg Cut Face Temperature		
Cold Leg Cut Face Temperature		
Secondary Side Temperature		
Tube Lane Temperature		

a,c,e

1. The vessel end cap pressure is calculated using the thin shell relationship $\sigma = P_{sec}*R_m/2t$ and applied to the top surface of the lower shell (Reference 1, p 6-27). The vessel end cap load is calculated in Reference 7. P_{sec} = SG Secondary Side Pressure.
2. Case 2 from Reference 24 is the source of the NOP pressures and temperatures.
3. References 7 and 23 are the source of the SLB design condition pressures and temperatures.

3.3 3D SUBMODEL (3DSM)

3.3.1 Applied Displacements and Loads

3.3.1.1 3DSM: Tubesheet Portion

The primary purpose of the 3DSM as described in Section 3.1.2 is to provide a physically more realistic representation of the interaction between a tube and the tubesheet in the calculation of contact forces. Prior H* calculations for Point Beach Unit 1 utilized the C^2 model which represents the tubesheet as a stack of separate models that are uncoupled in the horizontal plane. It was expected that a unit cell model, continuous through the thickness of the TS, the 3DSM, would more accurately represent the physical reality of the tubes and, thus, provide an improved calculation of contact loads for use in H*.

The use of the 3DSM model permits direct importing of the structural and thermal loads that are determined using the lower SG assembly model. These imported loads are applied only to the tubesheet portion of the 3DSM. Figure 3-20 through Figure 3-22 show how the imported loads are applied to the tubesheet portion of the 3DSM. Because the 3DSM is made an integral part of the larger lower SG assembly structural model, the transfer of loads and displacements is accomplished automatically within *ANSYS*. By incorporating the 3DSM directly in the lower SG assembly model, the global coordinates of the geometry and nodes are maintained. Although a different, finer mesh is applied in the 3DSM compared to the lower SG assembly model, *ANSYS* is able to automatically apply the correct corresponding nodal displacement and temperature by calculating the appropriate values for the new nodes based on the results from the lower SG assembly model to match the 3DSM mesh. The structural displacements are imported only to the outer faces of the 3DSM TS portion while the temperature results are applied to the 3DSM TS region body as a whole. Figure 3-20 illustrates the application of TS displacement to the outer edges of the 3DSM model tubesheet portion and Figure 3-21 shows a graphical representation of the 3DSM after the displacement has been applied. Figure 3-22 shows the 3DSM after application of the TS body temperatures to it.

a,c,e

Figure 3-20. Location of Imported Loads on TS in 3DSM

(For Displacement, it is only outer faces. For Temperature, it is the entire TS body.)

a,c,e

Figure 3-21. Example of the Outer TS Faces after Displacement is Imported from the Lower SG Assembly Model

a,c,e

Figure 3-22. Example of TS Body after Temperature is Imported from the Lower SG Assembly Model

3.3.1.2 3DSM: Tube

The tube in the 3DSM has its own specific thermal and structural inputs that are required for accurate calculation of the contact pressures.

The input to the structural model of the tube includes only the horizontal displacements calculated with the lower SG assembly model, applied at the bottom face of the tube. Figure 3-23 illustrates the location of the displacement inputs (x and z directions) to the tube portion of the 3DSM.The model simulates the movement of the tube in the lower SG assembly model, but suppresses the vertical (Y) displacement. Suppressing vertical displacement models the tube without a weld in the tubesheet but results in a contact pressure end effect at the bottom of the tube (Figure 3-24). To eliminate the localized bottom end effect in the 3DSM (see Figure 3-24), a constant, conservative contact pressure equal to the value at BTS + 1.0 inch is applied up to the first inch of the tube from the bottom of the tubesheet. As H* is determined from the top of the tubesheet, this post-processing step at the bottom of the tubesheet does not affect the outcome of the structural analysis. There is also no impact on the leakage analysis which depends on the resistance to leakage resulting from the length of the tube-to-tubesheet annulus above 20.60 inches (starting 0.21 inch above the BTS = 1.0 inch elevation).

The tube extension in the 3DSM, the length of tube extending beyond the top of the tubesheet (TTS), is necessary to avoid contact pressure end effects due to Poisson contraction at the TTS resulting from applying the end cap load at the end of the tube end. The peer review (Reference 4) questioned the length of the extension and recommended investigating the length of the tube extension and the effect of lateral constraint on the tube (i.e., at the TSP) to determine the necessary length and constraints to avoid undesirable end effects in contact pressure at the TTS. Analysis performed to determine the necessary tube length to achieve this objective concluded that a length of about **[**

]^{a,c,e} was sufficient to eliminate end effects and support efficient model performance. The analysis determined that there is negligible difference in the calculated contact pressures using the actual length of tube to the first tube support plate or half that length. Figure 3-25 shows the results of the tube extension length study; a significant spike in the contact pressure results with shorter tube extensions is effectively eliminated with a tube extension length half the distance to the first TSP. It was also determined that simulating a gap between the tube and TSP versus the presence of a lateral support at the end of the tube extension does not change the contact pressure results between the tube and tubesheet. However, including the simulated gap did increase processing time; therefore, a lateral constraint is included in the model and the tube extension length of **[** **]**^{a,c,e} inches was selected.

Independent of the length of the tube extension, the model produced an increase in contact pressure at the top of the tubesheet as a result of the large temperature difference between the tube and the tubesheet at this location (Figure 3-25). This TTS contact pressure spike has no effect on the H* calculations because the contact pressure from the top of the tubesheet to the BET was set to zero. The bottom of the expansion transition (BET) obviates the presence of any positive contact pressure above it.

The axial end cap load is the force generated by the internal pressure in the tube that attempts to pull the tube vertically from the tubesheet. This load is applied at the end of the tube extension to directly calculate the Poisson contraction of the tube. The end cap load is applied as an equivalent pressure on the top tube face in the 3DSM (Figure 3-26) to apply a uniform force to the tube. The equivalent pressure is determined by dividing the known end cap forces for NOP and SLB conditions by the cross-sectional area of the nominal tube ([ ]^{a,c,e} inch diameter and [ ]^{a,c,e} inch wall thickness). Table 3-3 summarizes the adjusted tube end applied pressures that represent the conservatively calculated end cap loads under NOP and SLB conditions.

Because of the uncertainty in the geometry of the tube expansion transition, the 3DSM utilizes a conservative, simplified model of the expansion transitions. The dimensions for the transition region, shown on Figure 3-27, reflect the limiting 99th percentile BET dimension, [ ]^{a,c,e} inch, for the Point Beach Unit 1 SGs (Reference 5). The tube extension is modeled at the expanded uniform bore diameter ([ ]^{a,c,e} inch) over the entire length of the tube instead of the nominal tube diameter of [ ]^{a,c,e} inch. However, the equivalent pressure applied at the end of the tube extension is calculated based on the nominal dimension of the tube instead of the expanded dimension of the tube (Reference 4). The tube end end cap load equivalent pressure for Point Beach Unit 1 is calculated by dividing the end cap force from Reference 1 ([ ]^{a,c,e} lbs. for NOP, and [ ]^{a,c,e} lbs. for SLB) by the nominal, unexpanded area ([ ]^{a,c,e} in^2) of the tube cross section. Table 3-3 summarizes the equivalent tube extension end face applied pressures that represent the conservatively calculated end cap loads under NOP and SLB conditions.

Consequently, the effective force on the tube extension is conservative because the equivalent pressure is applied over a larger area than that of the nominal tube and leads to a conservative calculation of the Poisson contraction.

Because the BET defines the effective top of the tubesheet for the crevice pressure profile from the bottom of the tubesheet to the top of the tubesheet, it was necessary to calculate an effective internal pressure that acts on the tube at, and above, the BET to properly model the tube structure. The internal pressures applied to the tube are as follows: From the bottom of the tubesheet to the location of the BET, the internal pressure in the tube varies as the difference between the primary side pressure and the crevice pressure. Above the location of the BET, the tube internal applied pressure is constant and equal to the difference between the primary side pressure and the secondary side saturation pressure because the tube is no longer in contact with the tubesheet. The resultant internal pressure is the pressure applied to the inner diameter of the tube within the 3DSM as illustrated on Figure 3-28. Table 3-4 summarizes the resultant internal pressures applied during the NOP and SLB for Point Beach Unit 1.

The 99th percentile value of the BET ([ ]^{a,c,e} inch) from Reference 5 was used for all locations. (The mean values of the BET for the two SGs in Point Beach Unit 1 are [ ]^{a,c,e} inch and [ ]^{a,c,e} inch, respectively.) Use of the 99th percentile location of the BET is conservative because shorter H* values would result if the mean values of the location of the BET were used. The contact pressure above the BET is set to zero in order to determine the H* length.

For normal operating conditions, the temperature distribution in the tube varies along the length of the tube and is applied using a tabular input format in *ANSYS*. Figure 3-29 graphically illustrates the temperature distribution along the tube. The tube temperature remains constant within the TS, but slowly decreases beyond the TTS because the tube is exposed to the secondary side environment. This individual tube temperature distribution is based on the primary side hot leg and cold leg temperature, and the length of the tube at the radius of interest. Since each tubesheet radius has a different tube length from tube end to tube end, the change in temperature per unit length (inch) to reach the cold leg side temperature is different. Equation 3.1 is used to calculate the unit length temperature change above the bottom of the tubesheet plus **[ ]**^{a,c,e} inches.

$$T_{PLD} = -(T_{HL}-T_{CL})/L_T \qquad \text{Eq. 3.1}$$

where,

T_{PLD} is the unit length temperature change above the tubesheet hot leg (BTS + **[ ]**^{a,c,e} inches)

T_{HL} is the hot leg temperature at the top of the tubesheet (BTS +**[ ]**^{a,c,e} inches)

T_{CL} is the cold leg temperature at the top of the tubesheet (BTS+**[ ]**^{a,c,e} inches)

L_T is the tube length (Tube end to tube end minus 2***[ ]**^{a,c,e} inches)

The following is an example of how a linear relationship of the tube temperature as a function of tube length is calculated for radius 7.128:

$$For\ Radius\ 7.128\ at\ NOP:$$

$$T_{Hot\ Leg} = [\quad]^{a,c,e}\ {}^{\circ}F$$

$$T_{Cold\ Leg} = [\quad]^{a,c,e}\ {}^{\circ}F$$

$$L_{Tube} = [\quad]^{a,c,e}\ in$$

$$Temp_{PLD} = \frac{-(T_{HL}-T_{CL})}{L_{Tube}} = \frac{([\quad]^{a,c,e}\ {}^{\circ}F - [\quad]^{a,c,e}\ {}^{\circ}F)}{[\quad]^{a,c,e}} = -0.1006\ {}^{\circ}F/in$$

For radius 7.128 inches, the tube temperature is calculated to drop 0.1006°F for every inch from the top of the tubesheet on the hot leg side to the top of the tubesheet on the cold leg side.

Table 3-8 shows the tube temperature applied on each radius for the Point Beach Unit 1 3DSM for normal operating conditions taken from Reference 7.

For SLB, there is no tube temperature gradient along the tube because the SG maintains a constant temperature of **[ ]**^{a,c,e} °F.

Table 3-3. Equivalent Pressure Applied to Top of the Tube in the 3DSM

	NOP	SLB
End Cap Force (lbs.)		
Equivalent Pressure (psi)		
Nominal Tube Cross-sectional Area = [ ]a,c,e in^2		

a,c,e

Table 3-4. 3DSM Tube Resultant Internal Pressure vs. Elevation

Tube Elevation (in)	Resultant Internal Pressure	
	NOP (psi)	SLB (psi)
0 (BTS)		
2		
3.523		
5.442		
7		
9		
10.905		
13		
16.368		
18.287		
19.81		
[ ]a,c,e (BET Location)(1)		
21.28		
21.51		
21.61		
21.71		
21.81 (TTS)		
[ ]a,c,e		
(1) Based on 99th percentile value of BET location for Point Beach Unit 1		

a,c,e

Table 3-5. Tube Temperature During NOP

Tube Elevation (in)	Tube Temperature for NOP				
	Radius 7.128	Radius 28.110	Radius 40.454	Radius 47.861	Radius 51.564
0.00 (BTS)					
21.81					
21.48					
23.02					
24.55					
26.09					
27.62					
29.16					
30.69					
32.23					
33.76					
35.30					
36.83					
38.36					
39.90					
41.43					
42.97					
44.50 (Top of Tube)					

a,c,e

a,c,e

Figure 3-23. Location Where Horizontal Displacement is Imported onto Bottom of Tube

a,c,e

Figure 3-24. Comparison of each Method to Displace the Bottom of the Tube for Radius 7.126 during SLB

a,c,e

Figure 3-25. 3DSM: Results of Tube Extension Length Study

a,c,e

Figure 3-26. End Cap Pressure and Displacement Boundary Condition Location

a,c,e

Figure 3-27. Simplified View of the Location of BET in TS

a,c,e

Figure 3-28. Location of Resultant Internal Pressure Applied to 3DSM (Inside of Tube Only) (Maximum Pressure begin Above the BET)

a,c,e

Figure 3-29. Thermal Gradient Present on 3DSM Tube

3.3.2 Summary of Key Differences between C^2 Model and 3DSM and their Application

The key differences between the C^2 model and the 3DSM model are summarized in Section 3.1.3. Additional information is provided in this section regarding these key differences as well as additional information regarding the difference in application of the models in the calculations for H* for Point Beach Unit 1.

3.3.2.1 Continuous Contact Pressures Calculated in the Tubesheet

The 3DSM provides a physically accurate model of the tube/tubesheet interface. A significant benefit of utilizing the 3DSM is that data can be extracted at all elevations along the tube versus only finite locations when using the C^2 Model. The C^2 model represented the TS thickness and tubes as axial segments of selected lengths through the thickness of the tubesheet.

3.3.2.2 Post-processing Calculation of Poisson Contraction Effect No Longer Necessary

The 3DSM provides the capability to directly calculate the effect of Poisson contraction due to the end cap load on the tube-to-tubesheet contact pressures although it requires an extension of the tube above the TS to avoid potential end effects on the predicted contact pressures. Direct calculation of the Poisson reduction of contact pressure eliminates a potential uncertainty in the final H* calculations. Previously, with the C^2 model, the post-processing method used to evaluate the effect of Poisson's ratio on the H* length was a simplified approach using approximations to determine the reductions in contact pressure. The classical thick-shell equations were used to calculate the change in tube radius due to Poisson's ratio from an applied end cap load. This change in radius was converted to a contact pressure using the thick shell equations. This contact pressure was then subtracted from the calculated contact pressure distribution and the final H* distance was calculated. This post-processing step is no longer needed using the 3DSM as the Poisson contraction effect is calculated directly.

Consistent with the prior practice, all calculations for Poisson's contraction using the 3DSM are based on the calculated end cap load without a factor of safety.

3.3.2.3 Connected Divider Plate Used in the Lower SG Assembly Model

The current licensing basis assumes that the divider plate is not connected to the TS as documented in Reference 1. In a formal peer review of the 3DSM (see Section 3.4.2 and Reference 4), the reviewers questioned whether omitting the connection between the divider plate and the tubesheet, as is the case in all currently licensed H* applications, still provided conservative H* results. Consequently, to respond to this question, the Divider Plate was re-attached in the Lower Structural Assembly model and the analysis was repeated. This showed results that increased the Mean H* length for Point Beach Unit 1 at the critical Radius of 40.454 inches during SLB (Figure 3-30). The reason for this result was determined to be uniquely related to the cold SLB condition for the Point Beach Unit 1 SGs and is discussed below.

The principal reason for this change to the prior H* analysis result is the low temperature SLB condition. For Point Beach Unit 1, the SG component design basis SLB condition eventually results in a constant primary and secondary side temperature of **[ ]**^{a,c,e} °F for the entire SG (Reference 24). This constant temperature greatly affects the final tube-to-tubesheet contact pressure results because the vertical and horizontal deflections of the TS, which are now directly imported to the 3DSM, are dependent upon the differential temperatures and pressures experienced in the lower SG assembly model. The absence of a temperature differential from the hot leg to the cold leg of the SG in the faulted loop results in a reduction in the horizontal displacement components of the tubesheet deflection, which causes a reduction in contact pressure from tube resistance to bending. This effect is exacerbated when the divider plate is attached to the tubesheet as shown on Figure 3-30. Figure 3-31 and Figure 3-32 compare the displacement vectors from the lower SG assembly model for both conditions of divider plate attached and not attached to the tubesheet for the same loading conditions. Figure 3-33 shows the vertical displacement at the critical radius for both the divider plate attached and not attached to the tubesheet. The vertical displacement with the divider plate attached is seen to be less than that for the case of the divider plate not attached. Further, less horizontal displacement occurs in the periphery of the tube bundle with the divider plate attached resulting in less tube resistance to tubesheet bending. The same effect was not observed in the previous C^2 results because the C^2 model did not include the effect on contact pressures of tube resistance to tubesheet bending. The tube resistance to tubesheet bending component of contact pressure is much more significant during the low steam line break temperature transient than during normal operating conditions. During NOP, the contact pressures for the critical radius are increased with the divider plate attached, as expected in the previous studies of H* (Reference 12).

Multiple test cases were generated to demonstrate the explanation above. First, a hypothetical case for the Point Beach Unit 1 SLB condition was run to test the effect a functional (attached) DP has on the contact pressures. This hypothetical SLB condition had the secondary side cold leg temperature set to 200°F while the hot leg was set to **[ ]**[a,c,e]°F with the DP connected to the TS. This relatively small change in temperature differential improved the mean H* length to **[ ]**[a,c,e] inches. This is a **[ ]**[a,c,e] inch improvement from the mean H* at constant **[ ]**[a,c,e] °F. The temperature differential between SG hot leg and cold leg causes the DP to positively affect the horizontal displacement component of the TS causing an increase in tube-to-tubesheet contact pressures.

The second test was to vary the constant temperature at SLB condition. For both structural models, including and excluding the DP, the SLB condition was changed to constant temperatures of 300°F, 400°F, and 500°F in separate cases. The results show that PB1's unique cold SLB requires the DP to be attached for the more conservative results. At the elevated temperatures considered in these cases, the resulting H* lengths are consistent with the results in the current licensing basis.

The difference in the mean H* length thus determined at the critical radius with and without the connected divider plate is summarized in Table 3-6 and Table 3-7 for the reference Point Beach Unit 1 case and for the test cases. As can be seen from a review of the test case results in Table 3-7, at temperatures 300°F and above, as was the case with the current licensing basis, the functional divider plate substantially restricts tubesheet displacements and results in shorter mean H* lengths when using the 3DSM.

a,c,e

Figure 3-30. Contact Pressure Generated for Critical Radius 40.454 during SLB for Both Divider Plate Included and Removed.

Results show that Divider Plate should be included in PB1 H* analysis for conservatism.

a,c,e

Figure 3-31. Total Deformation Plot of the Lower SG Assembly Model for the SLB Condition with the DP Included.

The arrows represent the resultant vectors of deflection.

a,c,e

Figure 3-32. Total Deformation of the SLB with DP Excluded

a,c,e

a,c,e

Figure 3-33. Top Image is the Vertical Displacement of the Critical Radius with Divider Plate Included. Bottom Image is the Vertical Displacement of the Critical Radius (Divider Plate Excluded).

Note, the displacement is reduced in the top image from the bottom.

Table 3-6. H* Lengths for NOP, SLB, and TEST SLB Cases for Point Beach Unit 1

Operating Condition	H* Length Results Divider Plate Included (inches)	H* Length Results Divider Plate Excluded (inches)
NOP	[ ]^{a,c,e}	[ ]^{a,c,e}
SLB	[ ]^{a,c,e}	[ ]^{a,c,e}
Test SLB Case (1)	[ ]^{a,c,e}	NA
Note 1: Test case where Cold Leg and Secondary Side Temperature set to 200°F. Hot Leg set to [ ]^{a,c,e} °F.		

Table 3-7. H* Length Results for Varying Constant SLB Condition with and without Divider Plate Attached

Divider Plate Attached?	H* Length at Varying SLB Temperatures (inches)			
	SLB at [ ]^{a,c,e} °F (Base Case)	SLB at 300°F	SLB at 400°F	SLB at 500°F
Yes	[ ]^{a,c,e}	[ ]^{a,c,e}	[ ]^{a,c,e}	[ ]^{a,c,e}
No	[ ]^{a,c,e}	[ ]^{a,c,e}	[ ]^{a,c,e}	[ ]^{a,c,e}

3.4 BENCHMARKING OF THE 3DSM

Because the 3DSM is a new model that replaces the C^2 model utilized in prior H* analyses to calculate the contact pressures between the tube and tubesheet, it was necessary to repeat a previous analysis based on the use of the C^2 model but using the 3DSM. This process is called “benchmarking”, the process used to validate the new model. Successful benchmarking requires that the input to both models be the same and that no intermediate steps influence the results. The 3DSM was developed to more closely model the physical interface between the tube and tubesheet than the prior application of the C^2 model (see Section 3.1.2) and it was expected that the new model would lead to a similar contact pressure profile through the thickness of the tubesheet at the same loading conditions. Loadings (from bending of the tubesheet and from end cap loads) are not considered because the basis of comparison – the contact pressures - must depend on the 3DSM and C^2 model. Thus, the criterion for successful benchmarking was that the contact pressure profile through the thickness of the tubesheet should exhibit a similar characteristic profile for both the 3DSM and C^2 model when only temperature and pressure loading were considered. It is noted that the C^2 model was benchmarked previously against the results using the classical thick-shell equations as documented in Reference 2.

It was expected that slightly higher contact forces between the tube and tubesheet would result using the 3DSM, but this was not a criterion for acceptability of the model.

3.4.1 Benchmarking Method and Results Discussion

The contact pressure analysis previously performed for Point Beach Unit 1, using the C^2 model, was used as the basis for benchmarking the 3DSM. Comparison of the results from the models was limited to application of the same thermal and internal pressure loadings on the tube/tubesheet only because it is the most direct manner to compare the results from both models. Application of a displacement profile to the tubesheet would not provide a good comparison because the C^2 model is a stacked model, uncoupled in the horizontal plane, which would be expected to result in different results than the continuous structure of the 3DSM.

Mean material properties were utilized in both the 3DSM and the C^2 model for the benchmarking analysis. The mean material properties are taken from Section 6.2.2 of Reference 1 and are the same as those used in the current licensing basis.

The applied loads include the temperature of the tube, temperature of the tubesheet, and the resultant internal pressure acting on the inside of the tube (Table 3-8). The 3DSM was subjected to the same thermal loads for both Normal 100% Power (NOP) and Steam Line Break (SLB) conditions. Figure 3-34, Figure 3-35, Figure 3-36 and Figure 3-37 illustrate how the component temperatures were applied to the models.

The applicable differential pressure profile (primary side pressure less crevice pressure axial distribution) in the tube through the thickness of the tubesheet was applied. No bending displacements from the lower tubesheet model were used in the benchmarking analysis because, without the increase in tube-to-tubesheet contact pressures that occurs due to bending of the tubesheet, the C^2 model and 3DSM results are expected to be similar.

For both NOP and SLB the tube temperature is constant ([ ][a,c,e] °F for NOP, and [ ][a,c,e] °F for SLB). Table 3-8 shows the axial temperature distribution and the resultant internal pressure throughout the TS for both NOP and SLB for the benchmarking analysis. The resultant tube internal pressure is the difference between the primary side pressure and the calculated crevice pressure for Point Beach Unit 1 from Reference 2. The resultant internal pressure is applied to the inside face in the 3DSM (Figure 3-39) and to the edge of the tube for the C^2 model (Figure 3-38).

Appropriate boundary conditions were applied to both models to prevent rigid body movement errors in *ANSYS*. For both models, two edges (faces for the 3DSM) on the TS were selected that prevent horizontal displacement. Figure 3-40 shows the boundary conditions applied in C^2 model to prevent displacement. The bottom faces of the 3DSM have a zero vertical displacement boundary condition applied. Figure 3-41 and Figure 3-42 show the boundary condition applied in the 3DSM to prevent horizontal motion in the plane of the tubesheet. Figure 3-43 shows the constraint applied to the 3DSM to prevent vertical displacement of the tube unit cell.

Because the purpose of the benchmarking analysis is a comparison of predicted tube-to-tube contact pressures under the same loading conditions for both the 3DSM and C^2 model, the location of where the contact pressures are taken from is important. Figure 3-44 shows the location at which the calculated contact pressures are extracted from the C^2 model. Similarly, Figure 3-45 shows the location at which the contact pressure is extracted from the 3DSM.

The predicted contact pressures from the 3DSM and the C^2 model under the loading conditions described above are shown in Figure 3-46 and Figure 3-47 for NOP and SLB conditions, respectively. These figures show that the 3DSM calculates similar tube-to-tubesheet contact pressures to the previous C^2 model results when tubesheet bending is not considered. In both cases, the characteristic of the contact pressure is the same for both the 3DSM and the C^2 model. The increase in the contact pressures was expected as noted previously and is due to the effects of the continuous 3DSM versus the separated models of the stacked setup of the 2D model. Therefore, it was concluded that the 3DSM is an acceptable structural model that provides characteristically the same results as the C^2 model that was applied in the currently licensed H* analyses.

Table 3-8. Pressure and Temperature Inputs for NOP and SLB for Benchmarking Analysis

a,c,e

TS Elevation	Resultant Internal Pressure		TS Temperature[(1)]	
in				
0.000 (BTS)				
2.000				
3.523				
5.442				
10.905				
16.368				
18.287				
19.810				
21.810(TTS)				

(1) Tube temperature is constant throughout the thickness of the tubesheet;
NOP= [ ][a,c,e] °F, SLB= [ ][a,c,e] °F.

a,c,e

Figure 3-34. Thermal Load Applied to Tube for C^2 Model

(Tube temperature is constant for each segment through the TS.)

a,c,e

Figure 3-35. Thermal Load Applied to Tube in 3DSM

(The temperature is constant throughout the entire length of the tube for each operating condition in the Isothermal Case.)

a,c,e

Figure 3-36. Thermal Load Applied to Tubesheet for 2D C2 Model

(The TS temperature varies for each elevation as shown on Table 3-8)

a,c,e

Figure 3-37. Thermal Load Applied to TS Body in 3DSM

(The TS temperature varies along the thickness of the TS as shown on Table 3-8.)

a,c,e

Figure 3-38. The Edge where the Resultant Internal Pressure is Applied on the 2D C^2 Model

(This varies for each elevation based on the values in Table 3-8).

a,c,e

Figure 3-39. Location of Resultant Internal Pressure on (Cut View) 3DSM

a,c,e

Figure 3-40. Edges Selected to Prevent Displacement (C^2 Model)

a,c,e

Figure 3-41. Face of 3DSM that Prevents Horizontal Displacement in Z-Direction

a,c,e

Figure 3-42. Face of 3DSM that Prevents Horizontal Displacement in X-Direction

a,c,e

Figure 3-43. Bottom Faces Selected in 3DSM to Prevent Vertical Displacement

a,c,e

Figure 3-44. Location of Edge Where Contact Pressures are Calculated in the C^2 Model

a,c,e

Figure 3-45. Outer Face of Tube Where Contact Pressures are Calculated in the 3DSM

a,c,e

Figure 3-46. 2D vs. 3D Comparison Average Contact Pressures Calculated for NOP Condition

(The top of the TS is at [ ]a,c,e inches and the bottom of the TS is at 0.0 inch.)

a,c,e

Figure 3-47. 2D vs. 3D Comparison Average Contact Pressures Calculated for SLB Condition

(The top of the TS is at [ ]a,c,e inches and the bottom of the TS is at 0.0 inch.)

3.4.2 Peer Review Summary

In accordance with Westinghouse procedures, a formal internal Peer Review among structural analysis and *ANSYS* experts was held (Reference 6). The intention of the Peer Review was to review the technical adequacy of the 3DSM for determining contact pressures between the tubes and tubesheet for Point Beach Unit 1. The 3DSM was developed using the finite element computer program, *ANSYS*, Version 14.5.7. The 3DSM more realistically simulates the true 3D behavior of the tubesheet and tube (bending and tubesheet bore geometry changes) than the prior application of the C^2 model and directly includes axial load effects on the tube (Poisson contraction effect).

All action items identified by the Peer Review team are listed in Table 3-9. The final resolution of each action item is summarized in Table 3-10. All of the peer review action items have been resolved (Reference 4).

The C^2 model was used to calculate H* by evaluating the contact pressure between the tube and tubesheet at various elevations through the tubesheet thickness. The C^2 finite element analysis (FEA) solution is primarily a plane strain solution. A stack of models was used to represent the tubesheet and each separate model was not horizontally coupled to its neighbor. Therefore, the Poisson contraction effect due to the axial loading of the end cap load was not directly included but required post-processing of the results as described in Reference 1.

As described previously in Section 3.3.1.2, the results show similar tube-to-tubesheet contact pressure versus tubesheet elevation trends between the C^2 and 3DSM except at the top and bottom of the tubesheet. The bottom “end effect” is a “jump” in contact pressure at the 2-inch elevation caused by directly mapping the bottom tube displacements from the coarse mesh tubesheet model (similar to the general submodel boundary conditions). The bottom end effect has been addressed through post-processing as described in Table 3-10 in response to action item Number 4 of the Peer Review.

The top “end effect” shows increasing contact pressure, contrary to the expected Poisson effect which should radially shrink the tube and, therefore, reduce the contact pressure. The tubesheet hole deforms causing increased contact pressure on part of the tube. Also, as described in Section 3.3.1.2, the top end effect has also been addressed by setting the contact pressure above the elevation of the BET to zero as described in Table 3-10 in response to action item Number 3 of the Peer Review.

Table 3-9. List of Action Items Created by the Peer Review Team

Action Item Number	Description
1	Account for Tube Support Plate (TSP) height above the Tubesheet.
2	Include the TSP hole gap, if any, to properly offset the lateral TSP constraint.
3	Modify the extended Tube to include the transition zone from the full hydraulic expansion to the unexpanded tube below the top of the Tubesheet.
4	Remove the mapped displacements [from Bottom of Tube Face] and replace with coupled degrees of freedom between the Tube and Tubesheet at this elevation in the 3DSM. Couple the Tube/Tubesheet interface node pair in lateral Translation (UX, UZ).
5	Attach the Divider Plate in the Lower Steam Generator Coarse Model(1) and re-analyze the Steamline Break loading. If beneficial, utilize the Electric Power Research Institute (EPRI) study to support the analytical change.
6	Expand the 3DSM to include the nearest tubes to determine possible interaction between tubes.
7	Investigate other Westinghouse nuclear components and/or published results that can be used to support a larger friction factor.

Note:

1. This is the Lower SG Assembly Model referred to in this report.

Table 3-10. Summary of the Resolution of Peer Review Action Items

Action Item Number	Resolution to Action Item
1 and 2	Tube End length will be set to [ ]^{a,c,e} inches (from the TTS). For added conservatism, the contact pressures near the TTS will be set to zero above the BET to remove the top "End Effect."
3	The adjusted pressure method to simulate the hydraulic expansion transition zone will be applied to the 3DSM. For added conservatism and removal of the top "end effect," a post-processing technique is employed to set the contact pressures, at and above the bottom of the expansion transition (BET), to zero.
4	The bottom face of the tube will only receive the imported displacement in the X and Z (lateral) direction as if the tubes in the tubesheet are not welded. Also, the contact pressures at the bottom of the tube will also be post-processed to remove unrealistic, localized, contact pressure spikes.
5	The Divider Plate will be applied to the Lower SG Coarse model because it results in a more conservative H* length for the SLB condition.
6	The results of the critical radius ([ ]^{a,c,e}) show that the Multi-Tube setups are comparable to the Single Tube setup. This causes a negligible change in the final H* lengths between each method. Therefore, for expediency, the H* team will continue to use a Single Tube model design.
7	The H* Team will continue to use the [ ]^{a,c,e} coefficient of friction for the H* analysis because it has been approved in prior H* licensing actions and no significant data exist to support use of a higher value.

4 STRUCTURAL CALCULATIONS FOR H*

4.1 OVERVIEW

Figure 4-1 shows the complete flow chart of the current calculation process for H*. The only significant difference between prior calculations of H* and the calculations summarized in this report is the replacement of the local model , the C^2 model, that calculates the final contact pressures between the tube and tubesheet, with a new model, the 3DSM. Section 3.0 summarized the structural models utilized in the process of calculating the H* distance. The 3DSM was benchmarked against the C^2 model (Section 3.4) and was determined to be an acceptable model for calculating the contact pressures. These calculated contact pressures are used to determine the H* length for the plant.

> The lower SG assembly model generates overall thermal and structural displacements under different operating conditions that are then transferred to the 3DSM for calculating the axial distribution of contact pressures within the thickness of the tubesheet.

Figure 4-2 shows a flow chart of the *ANSYS* calculation process and the flow of data through the lower SG assembly model to the 3DSM and the final results.

To solve for the tube-to-tubesheet contact pressures, the lower SG assembly model analysis must be run first. This is accomplished by solving the model with both the thermal and structural inputs discussed in Section 3.2.2. These results for the lower SG assembly model are then transferred to the 3DSM and solved with the tube inputs discussed in Section 3.3.

a,c,e

Figure 4-1. Flow Chart of H* Calculation Process

a,c,e

Figure 4-2. Workflow Schematic Illustrating Relationship Between Lower SG Model and 3DSM

4.2 CONTACT PRESSURE RESULTS

The axial distribution of contact pressures for Point Beach Unit 1 calculated using the 3DSM for NOP and SLB are summarized in Table 4-2 and Table 4-3, respectively. These results are based on the use of mean material properties taken from Section 6.2.2 of Reference 1. Plots of the contact pressure versus TS elevation are provided in Figure 4-3, Figure 4-4, Figure 4-5, Figure 4-6 and Figure 4-7 for the tubesheet radii selected. These pressures are the basis for calculating the mean H* length for Point Beach Unit 1.

The H* distance is defined as the length of contact, measured from the top of the tubesheet, required to resist the pull out forces acting on the tube. The pull out forces are defined as the end cap load on the tube which are the primary-to-secondary pressure difference with appropriate factors of safety acting on the area of the tube for the NOP and SLB conditions. Table 4-1 summarizes the end cap loads. Note that the end cap loads shown on Table 4-1 include a factor of safety of 3 for NOP and 1.4 for SLB.

The mean H* for each radius of each model is calculated using the contact pressure results shown on Table 4-2 and Table 4-3 and applying Equation 4.1. Equation 4.1 is an integration of the contact pressures between the tube and tubesheet multiplied by the coefficient of friction, μ, and the contact area. The value of 0.2 for μ has been accepted in prior licensed H* as a sufficiently conservative value.

$$End\ Cap\ Load := \int_0^y (mu)(\pi)(do)(PconTheta)dy \qquad \text{Eq 4.1}$$

This equation is used to generate the accumulated resistance to pull out load throughout the thickness of the tubesheet at each radius (Reference 1). Contact pressures are piece-wise integrated using the trapezoidal rule. The distance to balance the end cap load is then found by linear interpolation.

The mean H* lengths for both NOP and SLB are listed in Table 4-2 and Table 4-3. The mean values of H* are calculated at the worst-case sector of the tubesheet as defined in Section 6.2.3 of Reference 1. Figure 6-21 of Reference 1 shows that the pull out resistance of a tube increases the closer the tube is to the tube lane area. Therefore, the 0° sector face, normal to the tube lane, is the limiting sector in the tube bundle. The probabilistic H* length is based on the mean H* value for the limiting tubesheet radius at the limiting plant condition (Section 1.2.4 of Reference 2). The critical radius is defined as the tubesheet radius at which the maximum mean H* length is calculated for the limiting operating conditions.

The results on Table 4-4 show that the critical radius for Point Beach Unit 1 is radius **[ ]**[a,c,e] inches with an H* length of **[ ]**[a,c,e] inches during a postulated SLB condition.

Table 4-1. H* End Cap Loads Inputs

	NOP	SLB	
SG Model	**End Cap Load (lb)**	**End Cap Load (lb)**	**Tube Outside Diameter/TS Bore Diameter (in)**
Model 44F	[ ]a,c,e	[ ]a,c,e	[ ]a,c,e
Note: 1. The end cap load values shown include a factor of safety of 3 for NOP and 1.4 for SLB.			

Table 4-2. Contact Pressures Calculated for Selected Elevations during NOP

Tubesheet Radius (in)	7.126	28.11	40.454	47.861	51.564
Elevation (in)					
0 (BTS)					
2					
3.523					
5.442					
7					
9					
10.905					
13					
16.368					
18.287					
19.81					
21.81 (TTS)	0	0	0	0	0

a,c,e

Table 4-3. Contact Pressures Calculated for Selected Elevations during SLB

Radius (in) / Elevation (in)	7.126	28.11	40.454	47.861	51.564
0 (BTS)					
2					
3.523					
5.442					
7					
9					
10.905					
13					
16.368					
18.287					
19.81					
21.81 (TTS)	0	0	0	0	0

a,c,e

Table 4-4. Mean H* Lengths Calculated from the 3DSM for Point Beach Unit 1

Tubesheet Radius (in)	H* Length for NOP (in)	H* length for SLB (in)
7.126		
28.110		
40.454		
47.861		
51.564		

a,c,e

Note:
1. This is the critical radius because it is the largest H* length for all radii and all operating conditions. Probabilistic evaluations are based on this radius.

a,c,e

Figure 4-3. Contact Pressure Chart for Radius 7.126

a,c,e

Figure 4-4. Contact Pressure Chart for Radius 28.110

a,c,e

Figure 4-5. Contact Pressure Chart for Radius 40.454

a,c,e

Figure 4-6. Contact Pressure Chart for Radius 47.861

a,c,e

Figure 4-7. Contact Pressure Chart for Radius 51.564

4.3 CIRCUMFERENTIAL CONTACT PRESSURES

In previous H* licensing actions, a question was raised regarding the potential of flow channeling through the thickness of the tubesheet. This question was originally addressed in Section 6.2.5.3 of Reference 1 and Section 3.3.12 of Reference 2. Because a new model, the 3DSM, was applied in this analysis, it is necessary to re-address this issue.

For the tube-to-tubesheet joint, the porous medium is defined as the interaction of asperities of the surface finishes of the tubesheet bore and the tube outside surface. During the tubesheet expansion process, the peaks of the surface asperities of the respective components are deformed creating a randomly distributed porous interface over the length of the tube expansion. For the H* analysis, the resistance of the porous medium to leakage is assumed to be uniform around the circumference of the tube. An assessment follows showing that the assumption of circumferentially uniformly distributed porous medium is appropriate and conservative for application to the leakage evaluation and that channeling of the flow due to tube ovalization does not occur.

The mean contact pressure reported for each tubesheet elevation is the circumferential average of the contact pressure along the tube and tubesheet contact surface (i.e., the outer surface of the tube and the inner surface of the tubesheet tube bore). The average contact pressure along the contact surface is defined as taking the sum of the nodal normal stress in the radial direction and dividing by the number of nodes along contact surface. Figure 4-8, Figure 4-9 and Figure 4-10 show examples of the circumferential contact pressure at the contact surface used in defining the average contact pressure in the H* analysis for the critical radius, the minimum radius and for the maximum radius. The figures show the contact pressures at each node on the interface between the tube and the tubesheet based on the 3DSM results. The oscillations about the mean contact pressures are computational artifacts of the model and its convergence criteria. Because the contact pressures at all non-zero contact pressure elevations are positive, it is concluded that positive pressure exists circumferentially around the tube at the non-zero contact pressure elevations. Therefore, it is concluded that the potential for flow channeling does not exist during the limiting condition for Point Beach Unit 1, a postulated SLB event.

a,c,e

Figure 4-8. Circumferential Contact Pressure – Point Beach Unit 1, Critical Radius

a,c,e

[redacted]

Figure 4-9. Circumferential Contact Pressure – Point Beach Unit 1, Minimum Radius

a,c,e

Figure 4-10. Circumferential Contact Pressure – Point Beach Unit 1, Maximum Radius

5 CALCULATION OF PROBABILISTIC H*USING THE 3DSM

The limiting operating condition for Point Beach Unit 1 is the SLB conditions as established in Section 4.2. Therefore, it is not necessary to perform a "whole plant" analysis because only one loop is affected by the definition of the SLB accident. A whole plant probability analysis is required only when the limiting operating condition is NOP, under which all tubes in the plant are exposed to the same conditions at the same time.

The required probabilistic value of H* is the 0.95 probability at 95% confidence. Another important probabilistic value of H* is that at 0.95 probability at 50% confidence. The required probability level was established during the prior licensing effort for H*.

The limiting radius for H* for the Point Beach Unit 1 Model 44F SGs is **[** **]**^{a,c,e} inches (see Section 4.2). This value differs from the 3-loop Model 44F SGs because the limiting loading condition is the postulated SLB condition rather than the NOP condition. All other structural models and inputs are the same as discussed in Reference 2 including the range of significant material properties, the CTEs for the tubesheet and tube material. The mean values of CTEs for the tube and the tubesheet and their respective standard deviations (2.33 % for the tube material CTE and 1.62 % for the tubesheet material) are taken from the licensing basis documentation, Reference 1. Other variables, such as the Young's Modulus of the materials, were shown to be insignificant to variations of H* over the temperature range of interest.

In order to calculate a probabilistic value of H*, the variability of H* to changes in the principal variables must be known. A map of this variability is known as a "response surface". The initial calculations for H* (Reference 1) were based on use of the thick-shell equations, a closed-form solution for contact pressures as a function of variation of the significant variables which enabled rapid development of the H* response to these variables. Subsequently, application of the C^2 model in the current licensing basis rendered it unfeasible to develop a variability surface due to the extreme number of calculations required; therefore, a rationale was developed and documented to use the original thick-shell equation based response surface. Development of the 3DSM to replace the C^2 model again enabled the calculation of the variability surface directly and efficiently (Reference 26).

As in the current licensing basis, the H* response surface was randomly sampled using a Monte Carlo approach to develop a 10,000 entry vector of random sample results for the extreme H* values and the corresponding values of the significant variables for each of the random samples. The estimated H* value is determined in each random trial by linear interpolation between curves of given tubesheet variations (number of standard deviations) from mean values (i.e., from the response surface).

The tubesheet is divided into nine regions, each with its own number of tubes and each with its own value of maximum mean H*. The maximum mean H* values for each region and the number of tubes in each region are shown on Table 5-1 (Reference 25). The sum of the number of tubes in all regions is the total number of tubes in the steam generator.

Only a single tubesheet encompasses all the tubes in each of the nine regions of one SG; therefore, it is not appropriate to separately sample the tubesheet properties for each of the tube samples in each sector.

The Monte Carlo program randomly samples from the tubesheet CTE distribution. For that tubesheet sample, the program randomly samples from the tube CTE distribution N times, where N is the number of tubes in the region of interest (see Table 5-1) and retains the maximum value of the estimated H* and the corresponding values of the significant variables in an external file. This process is defined as a "trial."

The sampling program repeats this process 10,000 times, each time retaining the maximum value of estimated H*. The result is a 10,000 row vector of maximum estimated H* values for the region of interest. This process is repeated for each of the nine regions of interest. For each region of interest, a 10,000 trial vector of maximum estimated H* values and associated values of the variables is retained.

The results vectors for each of the nine regions of interest are combined into a single vector of 90,000 entries. The 90,000 row vector is rank-ordered by estimated H* value in increasing order. From this, the upper 10,000 values are selected. The final 10,000 value vector represents the extreme values of estimated H* and is the basis for determining the estimated H* and associated variable values for the probabilistic values of H* desired. The 9500^{th} highest value in this list is identified as the 0.95 probability of the extreme values of estimated H* at 50% confidence. The 9536th in this list is identified as the 0.95 probability of the extreme values of estimated H* at 95% confidence (see discussion below).

A distinction is made between the "estimated" raw value of H* and the "final" raw value of H* prior to the adjustment for crevice length. The estimated probabilistic value of H* is determined based on the equations that represent the variability of H* to changes in the significant values as shown on Figure 5-1. The estimated values of H* are determined from linear interpolation between the curves in Figure 5-1. In contrast, the final raw value of H*, unadjusted for crevice pressure, is determined by inputting the specific values of the significant variables, determined in the Monte Carlo process, into the structural models, the lower SG assembly model and the 3DSM, to directly calculate the final raw value (without crevice pressure adjustment) of the probabilistic H*. Table 5-2 compares the estimated and the final raw H* values. The results of the estimated and calculated values of H* are very nearly the same; the difference between the estimated and calculated H* values is the result of the linear interpolation between the curves on the response surface (Figure 5-1). The calculated results are the more accurate values.

5.1 RESPONSE SURFACE

The sensitivity of H* to variations of the significant variables (tube and tubesheet CTEs) was calculated to determine the response surface (Figure 5-1) using the 3DSM for a range of material property variation and combinations. Prior experience has shown that the high probability values of H* always occur when the tube CTE varies negatively from its mean and the tubesheet CTE varies positively from its mean. It is intuitively obvious that the maximum probabilistic value of H* will occur when the tubesheet CTE varies from its mean in a positive manner and when the tube CTE varies from its mean in a negative manner because the contact forces, which depend primarily on differential thermal expansion, between the tube and tubesheet will be lowest.

It was not necessary to develop a complete response surface for the full range of both of the significant variables because it is known that the maximum H* value at the required level of confidence occurs when the tube CTE varies negatively and the tubesheet CTE varies positively from their respective mean. Based on prior experience, the ranges of CTE_{tube} and $CTE_{tubesheet}$ can be narrowed to limit the calculation effort.

Accordingly, a range of tubesheet CTEs and tube CTEs was selected to define the reduced response surface for subsequent sampling by the Monte Carlo process (Reference 11). It was previously determined in Reference 1 that the maximum value of H* occurs when the tube CTE varies from mean to mean minus **[ ]**^{a,c,e} σ and variations in the tubesheet CTE range from mean to mean plus **[ ]**^{a,c,e} (σ is the standard deviation of the variable's distribution). The resulting response surface is shown on Figure 5-1. The individual points on Figure 5-1 were calculated using the lower tubesheet assembly model and the 3DSM using a range of variations from the mean values of the significant variables. The results for each discreet value of tubesheet CTE were curve-fit to provide the mathematical relationships shown on Figure 5-1 that can be randomly sampled. As in the prior licensing basis, linear interpolation was used between the functions that represent discreet values of the tubesheet CTE.

In addition to the estimated values of H*, the results of Monte Carlo sampling from the response surface provide the specific combination of the significant variables that lead to the high probability values of H*, because the specific random sample values of the variables are saved in the calculation process along with the values of the resulting estimated H*. The results for the upper 10% tail of the H* distribution (e.g., rank order 9,000 to rank order 10,000 in 10,000 simulations) from the Monte Carlo analysis were output as a 4 column by 10,000 row matrix. The columns in the matrix are the rank order statistic (i.e., 9,001 to 10,000), the estimated H* value at the given rank order, the variation in the tubesheet CTE about its mean value in terms of $m\sigma_{TS}$, and the variation in the tube CTE about its mean value in terms of $n\sigma_T$ where m and n are the multipliers (positive or negative) on standard deviations added to the mean value of the respective CTEs.

As noted above, the output from the Monte Carlo sampling program includes the values of the significant variables that correspond to the specific rank-ordered H* values. Because the program randomly samples from the distribution of the variables, the identical values of the variables would not be expected for the same rank order if the analysis were repeated.

The absolute values of the coefficients of thermal expansion are shown on Table 5-3 for the tubesheet material and on Table 5-4 for the tube material for a range the multipliers on the standard distribution of the variables and for a range of temperatures. These are typical of the range of values that are input to the lower SG assembly model and the 3DSM to calculate the final raw H* values.

The values of tube and tubesheet CTE used in the final H* analysis are selected based on the required rank order statistics that met the probabilistic goals for H*. For the whole bundle analysis, the 95th percentile H* estimate at the 50th percentile confidence interval, for the H* distance in the tubesheet that would resist pull out during a postulated SLB, corresponds to a rank order statistic of 9500 out of 10000 trials ordered in increasing value (Reference 8). The order statistic for higher confidence intervals (e.g., 95%) is calculated using a method described in Reference 10. This method involves calculating the run-to-run variance in Monte Carlo order statistics and calculating a bounding order statistic to ensure a higher confidence. The run-to-run variance is shown in Equation 5-1:

$$\sigma^2 = np(1-p) \qquad \text{(Equation 5-1)}$$

Where n is the number of trials and p is the desired probability level. For 10,000 trials and a probability of 95%, the run-to-run variance, σ, is 22. For a confidence of 95%, the appropriate adjustment factor of 1.645 is multiplied by this value, giving an adjustment of 36. Therefore, the appropriate order statistic for 95/95 is 9536 (9500+36). In order to ensure that the final result is attained at 95% confidence, other sources of uncertainty must be bounded at 95% confidence. In this analysis, the other sources of uncertainty are the tube and tubesheet CTE standard deviations. Work documented in Reference 9 has shown that the values for the tube and tubesheet standard deviation for CTE conservatively bound 95% confidence values. Therefore, a high-confidence value can be obtained by simply moving to the higher rank order statistic by the method described above. Table 5-2 shows the actual values of the significant variables used to calculate the final raw value of H* for three rank order statistics including the required statistic for 0.95 probability at 95% confidence (9536).

Figure 5-2 shows the probabilistic values of H* for the entire range of ordered ranks from the Monte Carlo analysis. The H* values in this figure are the estimated values of H*, based on the sampling of the curve-fit equations that represent the response surface of H* from Figure 5-1.

Figure 5-3 is a narrow range of rank-ordered results in a range (9450 to 9650) that bounds the rank order statistics that represent the 0.95 probability at 95% confidence and the 0.95 probability at 95% confidence.

Both Figure 5-2 and Figure 5-3 show that the Monte Carlo analysis is well behaved and provides the expected result characteristic. Figure 5-2 shows the expected normal distribution of H* values because the input variables are also normally distributed natural properties of the materials. Figure 5-3 shows that there is an expected, but small, local variation in of the estimated H* values in the rank order owing to the random selection process, thus providing confidence that the results are accurate.

5.2 POINT BEACH UNIT 1 MODEL 44F RESULTS

For information, a comparison of rank order statistic and probability/confidence is provided in Table 5-5 for all of the models of SG that are in the H* population. Note that the plants for which the postulated SLB is the limiting condition, analysis of the whole plant is not required because the SLB affects only one SG.

The final H* value (without crevice pressure adjustment) is calculated starting from the tubesheet displacements obtained from the lower SG assembly model using the 9536 Rank Order values of tubesheet and tube CTE as input to the 3DSM model plus the crevice pressure adjustment as described in Section 6.0 of this report.

Table 5-1. Sector Definition for Point Beach Unit 1

Region Number	No. of Tubes	Mean H*
1		
2		
3		
4		
5		
6		
7		
8		
9		

a,c,e

Table 5-2. Estimated and Calculated Raw Values of H*

Rank Order	H* (Monte Carlo Estimated Results) (1)	Tube CTE	TS CTE	H* Length (From ANSYS)(2)
9500				
9536				
9550				

a,c,e

(1) Estimate based on response surface equations and interpolation (see Section 5.1)
(2) Calculated based on specific values of tube and tubesheet CTEs

Table 5-3. Absolute Values of TS CTE for a Representative Range of Variations about Its Mean

(Units of 10^{-6} in/in/°F)

Temp. °F	Mean	Multiplier on Standard Deviation					
		0.60	**0.76**	**0.82**	**0.984**	**1.159**	**1.885**
70	6.50	6.56	6.58	6.59	6.60	6.62	6.70
200	6.67	6.73	6.75	6.76	6.78	6.80	6.87
300	6.87	6.94	6.95	6.96	6.98	7.00	7.08
400	7.07	7.14	7.16	7.16	7.18	7.20	7.29
500	7.25	7.32	7.34	7.35	7.37	7.39	7.47
600	7.42	7.49	7.51	7.52	7.54	7.56	7.65
700	7.59	7.66	7.68	7.69	7.71	7.73	7.82

Table 5-4. Negative Variations about the Mean Tube CTE Used for Structural Analysis

(Units of 10^{-6} in/in/°F)

Temp. °F	Mean	Multiplier on Standard Deviation										
		3.12	**3.19**	**3.26**	**3.28**	**3.32**	**3.34**	**3.52**	**3.67**	**3.70**	**3.71**	**4.33**
212	7.22	6.70	6.68	6.67	6.67	6.66	6.66	6.63	6.60	6.60	6.60	6.49
300	7.40	6.86	6.85	6.84	6.83	6.83	6.82	6.79	6.77	6.76	6.76	6.65
420	7.60	7.05	7.04	7.02	7.02	7.01	7.01	6.98	6.95	6.94	6.94	6.83
500	7.70	7.14	7.13	7.12	7.11	7.10	7.10	7.07	7.04	7.04	7.03	6.92
600	7.82	7.25	7.24	7.23	7.22	7.22	7.21	7.18	7.15	7.15	7.14	7.03
628	7.85	7.28	7.27	7.25	7.25	7.24	7.24	7.21	7.18	7.17	7.17	7.06

Table 5-5. Rank Order Statistics for H* for Various Models of SG

Model SG	Whole Bundle Estimate		Whole Plant Estimate	
	95/50	95/95	95/50	95/95
F	9500	9536		
D5	9500	9536		
44F	9500	9536		
44F 2-loop	9500	9536		
51F	9500	9536		

a,c,e

Notes:

(1) Whole plant does not apply because SLB is limiting condition for H*.

(2) Values are the whole bundle rank orders based on whole plant rank order equivalent H* to recover the corresponding values of tube and tubesheet CTE.

a,c,e

Figure 5-1. Reduced Response Surface for the Point Beach Unit 1-Specific SLB Analysis

(Applicable only to 2-loop Model 44F)

a,c,e

Figure 5-2. Estimated H* Value in Rank Order from Monte Carlo Analysis

a,c,e

Figure 5-3. Narrow Range Monte Carlo H* Results

6 CREVICE PRESSURE ADJUSTMENT LENGTH

The determination of the final value of H* is necessarily iterative to address the axial distribution of crevice pressure. Initially, it is assumed that a crack exists at the bottom of the tubesheet and that the crevice pressure axial distribution applies over the entire thickness of the tubesheet. The H* value predicted based on this assumption is less than the full depth of the tubesheet. Because the effective crevice length is no longer the full depth of the tubesheet, the axial distribution of crevice pressure is applied over the initial prediction of H* and a new value of H* is calculated.

For Point Beach Unit 1, for which the SLB condition is limiting, it was necessary to re-create the crevice pressure adjustment curve in the expected range of initial predictions of H* because the crevice pressure axial profile depends on the limiting condition. The crevice pressure correction for Point Beach Unit 1 was developed using the lower SG assembly model and the 3DSM based on the SLB loading for the 2-loop Model 44F SGs. It was not necessary to consider the entire range of variation of the principal variables (tube and tubesheet CTE) because prior experience had established the range of interest for these variables as noted in Section 5.1. Figure 6-1 shows the crevice pressure adjustment calculation results for initial predictions of H* between 19 and 21 inches using variations in tube and tubesheet CTE values that bound the CTE variations for the inputs used in the 95/50 and 95/95 H* calculations for Point Beach Unit 1as discussed in Section 5. The calculated data points were fit with a polynomial curve whose equation is shown on Figure 6-1 (Reference 26). This equation was used to determine the crevice pressure adjustment value for the calculated value of H* at the required rank order statistic by inputting the calculated raw value of H* to determine the necessary adjustment for the final value of H*.

a,c,e

Figure 6-1. Model 44F (2-Loop Plant) Crevice Pressure Adjustment Curve

7 CALCULATION OF FINAL H* LENGTH

In prior calculations for the probabilistic H* using the C^2 model, two additional adjustments were required to determine the final H* length after H* was calculated: 1) effect of Poisson Contraction and 2) effect of crevice length as discussed in Section 6. As noted in Section 3, the Poisson contraction effect is directly included in the contact pressure calculations by application of the 3DSM because the end cap load is applied at the end of the tube extension in the 3DSM. Therefore, no post-calculation adjustment for Poisson contraction is needed for Point Beach Unit 1. However, the adjustment to the predicted (raw) probabilistic H* length (from Section 5) for crevice pressure length (from Section 6) is still required.

The final probabilistic values of H*, with the corresponding crevice pressure length adjustment taken from Figure 6-1, are shown on Table 7-1. It is noted that the incremental change in H* length from the 0.95 probability at 50% confidence value to the 0.95 probability at 95% confidence is less than 0.5 inch and well within the **[ ]**^{a,c,e} inch tubesheet thickness. This value applies, without exception, to all tubes in the Point Beach Unit 1 steam generators.

Table 7-1. Summary of 2-Loop Model 44F Probabilistic H* Calculations

Rank Order(1)	H* Length (Estimated) (in.)(2)	Tube CTE (mσ)(2)	TS CTE (nσ)(2)	H* Length (Calculated) (in.)(3)	Crevice Pressure Adjustment (in.)(4)	H* Length with Crevice Pressure Adj. (in.)(5)
9500						
9536						
9550						

a,c,e

(1) 9500 is 95/50; 9536 is 95/95; 9550 is higher confidence than 95% at 0.95 probability
(2) From sampling the sensitivity surface (Figure 5-1)
(3) Calculated using lower tubesheet assembly model and 3DSM with rank order-specific tube and tubesheet CTEs
(4) From equation on Figure 6-1
(5) All H* lengths are referenced from the top of the tubesheet.

8 LEAKAGE RATE FACTOR ASSESSMENT

8.1 RESISTANCE LEAKAGE MODEL ASSESSMENT

The model for calculating primary-to-secondary leakage applied in Reference 1, Equation 8-1, is the Darcy formulation for leakage through a porous medium. The Darcy equation is:

$$Q = \frac{\Delta p}{12\mu K l} \quad \text{(Equation. 8- 1)}$$

where,

> Δp is the driving potential (primary-to-secondary pressure difference)
> μ is the fluid dynamic viscosity
> K is the loss coefficient for flow through the porous medium
> l is the length of the porous medium

The Darcy formulation is used in Reference 1 to develop the ratio of leak rates between postulated accident-induced conditions (SLB) and normal operating conditions (NOP). The driving heads (Δp) at both of these conditions are known, as are the temperatures and pressures to define the fluid viscosity (μ). The contact length, l, is determined from the contact pressure calculations in Section 3. The resulting Darcy flow equation ratio can be separated into four "subfactors" as follows:

$$\frac{Q_{DBA}}{Q_{NOP}} = \frac{\Delta p_{DBA}}{\Delta p_{NOP}} \frac{\mu_{NOP}}{\mu_{DBA}} \frac{K_{NOP}}{K_{DBA}} \frac{l_{NOP}}{l_{DBA}} \quad \text{(Equation 8-2)}$$

The available data for hydraulically expanded tubes in tubesheet simulants (References 13 and 14), both at room temperature and at elevated temperature, are utilized in Reference 1 to show that no correlation between loss coefficient and contact pressure exists for conditions that simulate the Model D5 and Model F SG conditions. However, because the test data exhibit considerable scatter, confidence in this data analysis is low among the regulatory authorities. Engineering intuition could suggest that loss coefficient might be related to the absolute contact pressure between the tubes and the tubesheet. Hence, a requirement was applied to the H* leakage analysis by the regulatory authorities that it is necessary to show that the contact pressure at accident-induced conditions exceeds the contact pressure at normal operating conditions (P_{cSLB}:P_{cNOP}>1).

The calculated contact pressure results for all models of SGs are, to a large degree, dependent on the temperatures at a particular operating condition. The limiting accident leakage condition for H* for the Point Beach Unit 1 Model 44F SGs is the SLB condition, as documented in Reference 2. The Point Beach Unit 1 SLB transient includes a significantly lower temperature than even the Model 44F 3-loop SGs. As a result, it cannot be shown that the contact pressures at accident conditions exceed those at normal operating conditions, and the criterion for contact pressure (P_{cSLB}:P_{cNOP}>1) is not met.

Therefore, as noted by the USNRC in the prior licensing efforts for H*, the loss coefficient subfactor cannot be conservatively considered to be 1.0 during a postulated SLB and the standard approach for calculating leak rate factor cannot be used for Point Beach Unit 1. It is necessary to utilize a different approach for leakage analysis to show that the accident-induced leakage value assumed in the Updated Final Safety Analysis Report (UFSAR) is not exceeded.

Two alternate approaches are considered:

1. Parametric assumptions of loss coefficient dependency on contact pressure.
2. Application of parallel plate theory.

Both approaches rely on the existing Model D5 leak rate data from References 13 and 14 to varying degrees. No leak rate data are available for the Model 44F geometry. The use of the leak rate data developed for the Model D5 geometry for application to the Model 44F geometry is acceptable for this study because absolute leak rates are not in question; rather, the significance of a functional relationship between loss coefficient and contact pressure and the ratio of leak rates for NOP and SLB conditions are considered here. The approach of assuming various proportionality formulations between the loss coefficient and contact pressure and benchmarking them against the existing data is the most direct application. The parallel plate theory utilizes accepted theory to calculate a flow area based on the leakage test results and relates that flow area (and consequential leak rate) to the contact pressure conditions for the test specimens to develop leak rates for both SLB and NOP conditions.

As discussed in Reference 1, the design specification curves for the locked rotor and control rod ejection events apply for the leakage factors for these transients. These transients are of very short duration. Because of the short duration, as is also the case for the remainder of the H* fleet, no leakage factors are required for a postulated locked rotor and control rod ejection event for the Model 44F 2-loop SG.

The parametric proportionality approach utilizes the Darcy formulation for leakage through a porous medium and assumes various functional relationships between loss coefficient and contact pressure within the available test data. The mathematical relationships evaluated are not based on the actual leak test data but are simply assumed to test the hypothesis that loss coefficient is functionally related to contact pressure.

Consider an electrical analogy to the leakage through the crevice based on Ohm's law:

V (potential) = I(current) times R(Resistance), or in terms of flow:
$I = V/R$

where,

I, the current, is equivalent to leak rate, Q
V, voltage, is the driving potential, equivalent to Δp
R, resistance is equivalent to the flow resistance, ($12\mu Kl$), which must be calculated.

For an electrical system, with resistances in series, the total resistance is the sum of the individual resistances. Likewise, for a potential leak path that is divided into a number of sections, the total leakage through the entire path depends on the total resistance of the path, i.e., the sum of the resistances of the segments.

The leak rate through the crevice above H* can be considered a series related network of flow resistances in which the total resistance is the sum of the segment resistances, as for the electrical analogy. The calculations for H* for Point Beach Unit 1 divide the thickness of the tubesheet into eleven axial segments, although not of equal length. No attempt was made to evenly distribute the segments over the tubesheet thickness; the segment lengths are those defined by the structural model used in the original H* analysis in Reference 2. At the end-point of each segment, contact pressures are calculated as part of the normal H* calculations. The assumptions necessary for this approach are:

1. The local crevice length is the distance between the axial locations where contact pressures are calculated.
2. The contact pressure that applies over the local crevice length is the average of the contact pressures at the end-points of the local length.

The total resistance to leakage above the H* distance is the sum of the local resistances in the segments above H*.

If it is postulated that the loss coefficient is a function of the contact pressure as the criterion $P_{cSLB}:P_{cNOP}>1$ implies, a series of assumptions regarding the functional relationship can be made. The acceptance criteria for the relationships are based on engineering judgment. For example, a relationship that results in an inflection point so that, at some contact pressure, the slope of the relationship turns negative was rejected because it violates the basic premise that the loss coefficient should increase with increasing contact pressure. Relationships with a positive slope were considered which bound the data both as an upper bound of the K (loss coefficient) values and as a lower bound of the K values. If it is postulated that the loss coefficient increases with increasing contact pressure, intuitively, a bounding case would be a function that has the steepest slope of loss coefficient from low to high contact pressure based on the available data. Such a function was also considered even though it is considered unlikely that any data set would support such a function.

The underlying assumption of this approach is that the presumed relationship between loss coefficient and contact pressure is a continuous function and does not include any discontinuities over the range in which it is applied. For example, if exposure to a loading condition of interest permanently changes the characteristic of the flow path so that the slope of the loss coefficient to contact pressure relationship changes, this approach could not be used. All conditions of interest must lie on a continuous line represented by a single relationship.

Five arbitrary functional relationships were assumed to model the available test data, some with extreme slopes, and others that essentially envelope the upper and lower bounds of the available data (Reference 15). It should be noted that the K versus contact pressure data from the tests were used only as a benchmark for the assumed relationships. The absolute values of K shown on Figure 8-1 are not used in the analysis; only the value of K predicted by the assumed relationships is used in the calculations.

The assumed relationships, shown below in Figure 8-1, are not correlations to the data; they are, as stated, assumed relationships that meet the postulated criterion of increasing loss coefficient with increasing contact pressure. Different slopes of the relationships were investigated as well as various absolute positions relative to the available database. The purpose was to investigate to what degree a presumed function between loss coefficient and contact pressure would affect the leak rate ratio between SLB and NOP conditions.

a,c,e

Figure 8-1. Loss Coefficient vs. Contact Pressure Assumed Relationship

Table 8-1 provides a summary of the results of the leak rate ratios calculated between SLB and NOP conditions for the various assumed functions (Reference 15). For the relationships for loss coefficient as a function of contact pressure evaluated, the maximum leak rate factor occurs using the relationship that had the greatest slope (e.g., a cubic relationship between loss coefficient and contact pressure).
This relationship is not considered a realistic representation of the data because it artificially forces a fit from essentially the minimum value of K at the lowest contact pressure to the maximum at the highest contact pressure. Further, the Power-3 relationship for loss coefficient flattens out and is predicted to go negative (i.e., loss coefficient would decrease) if extrapolated to higher contact pressures; inconsistent

with the hypothesis that loss coefficient increases with increasing contact pressure. Therefore, the Power-3 relationship is not considered to be a physically realistic representation of the data.

The remaining four relationships evaluated, as shown on Table 8-1, result in a maximum leak rate factors less than 5.22 (Reference 16). Two of the 5 relationships result in maximum leak rate factors less than or equal to 1.0 for all radial locations on the tubesheet. It is important to note that only the assumed relationships that maximize the slopes result in leak rate factors greater than 3.

The smallest leakage rate ratio predicted in this study is 0.46 using the exponential relationship, 6E11*EXP(8E-05*P_c), which represents the lower bound of the data plotted in Figure 8-1.

Table 8-1. Resistance Leakage Model Calculated Leak Rate Factors

Assumed Loss Coefficient vs. Contact Pressure Relationship	Tubesheet Radius (in)				
	7.1256	28.1104	40.4544	47.08	51.564
6E11*EXP(8E-05*Pc)	[			]a,c,e	[ ]a,c,e
1.1E14*EXP(1.8E-04*Pc)					[ ]a,c,e
1E12*EXP(1.5E-03*Pc)					5.22
2E12*EXP(2E-04*C24)					[ ]a,c,e
1E4*Pc^3 (Power-3) (1)					[ ]a,c,e

1. For information only; does not meet criteria that satisfy the hypothesis of loss coefficient increasing with increased contact pressure for higher contact pressures.

It is Westinghouse's engineering judgment that the exponential relationship, 1E12*EXP (1.5E-03*Pc), represents a conservative relationship, consistent with the semi-logarithmic presentation of the data in Figure 8-1, for predicting loss coefficient as a function of contact pressure (and then, ultimately, the leak rate ratio). This relationship forces a significant slope through the data, consistent with the hypothesis of increasing loss coefficient with increasing contact pressure. However, it is not a mathematical correlation to the available data nor is any of the other assumed relationships in Table 8-1.

Conservatively, for the Point Beach Unit 1 steam generators, a maximum leakage rate factor of 5.22 was determined to establish an allowable primary-to-secondary leak rate limit following the implementation of H*. Appendix A provides additional details on the basis for the use of a leakage rate factor of 5.22.

A leakage rate factor of 5.22 represents a factor of 3.2 increase in leak rate factor for the SLB condition (5.22/[ ]a,c,e, where [ ]a,c,e is the ratio of the SLB to NOP pressure differential, (i.e., [ ]a,c,e psid/[ ]a,c,e psid) when the "four subfactor" Darcy flow equation (Equation 8.2) is used to calculate the leak rate factor assuming a loss coefficient subfactor of 1.0. Similarly, for the inner 3 radii, this same relationship results in a factor of 1.6 (5.22/[ ]a,c,e) increase in leak rate factor assuming a loss coefficient subfactor of 1 and an effective crevice length subfactor of 2. An effective crevice length subfactor of [ ]a,c,e of the distance of the thickness of the tubesheet during a postulated SLB for the inner radii of the tube bundle in the Point Beach Unit 1 steam generators.

For the Condition Monitoring (CM) Assessment, the operating leakage from the prior cycle from below the H* distance will be multiplied by a factor of 5.22 for the most limiting SG and then added to the total accident-induced leakage from any other source SG and compared to the allowed accident-induced leakage limit of 500 gallons per day (gpd) at operating conditions. Measurement of SG tube primary-to-secondary leakage is done at room temperature conditions. Therefore, the assumed accident-induced primary-to-secondary leakage of 500 gpd at 550°F in Reference 16 (or 1000 gm/min) must be converted to volumetric flow rate at room temperature conditions. This value equals the ratio of the density of water at 550°F (47 lbm/ft^3) divided by the density of water at 70°F (62.3 lbm/ft^3) times the allowable volumetric flow rate of 500 gpd at 550°F or 377 gpd at 70°F. For the Operational Assessment (OA), the difference in leakage between the allowable accident-induced leakage and the accident-induced leakage from all other sources other than the tubesheet expansion region will be divided by 5.22 and compared to the observed operational leakage. A new technical specification leakage limit will be established to not exceed the calculated value. The administrative limit for operational primary-to-secondary leakage can never exceed the current FSAR allowable limit for accident-induced primary-to-secondary leakage during a postulated SLB of 377gpd divided by the 5.22 leakage factor, equaling 72 gpd.

As noted, this evaluation is based on a conservative leak rate factor which is developed from an arbitrary functional fit of the leak rate data. It is highly likely that the actual leak rate factor is much smaller than the bounding leak rate factor. Whether a correlation between loss coefficient and contact pressure exists was a pivotal point in prior licensing activities for H* that was not uniquely resolved by the USNRC; however, an H* license was granted to a Model D plant which also did not meet the $P_{cSLB}:P_{cNOP}>1$ criterion.

8.2 FLOW THROUGH PARALLEL PLATES

A second approach to calculating leak rate ratio is an application of parallel plate flow theory, which provides a formulation for calculating steady, laminar flow between fixed, parallel plates. It is assumed that flow continuity applies and that the flow is unidirectional, constant and laminar. The use of this formulation for the tube in the tubesheet is appropriate because the direction of fluid particles can be assumed to be in a single direction along the tube-to-tubesheet bore crevice. Adapted to the geometry of concentric cylinders such as the tube in the tubesheet bore, the governing equation from Reference 15 is:

$$Q = \frac{\pi D \Delta p a^3}{12 \mu l}$$

where,

Q	is the flow rate of the fluid through the gap between the tube-to-tubesheet bore, in^3/sec
Δp	is difference in pressure (or driving head) acting to force the fluid through the gap, lbf/in^2
μ	is the viscosity of the fluid, lbf-sec/in^2
D	is the tubesheet bore inner diameter in inches
l	is the axial length of hydraulic expansion, in inches
a	is the gap between the tube and the tubesheet, in inches

The use of this relationship is acceptable for the tube-in-tubesheet case because the flow is continuous and laminar, and can conservatively be assumed to be in a single direction (axial) within the tubesheet crevice.

Analyses using the parallel plate theory approach show that the resistance to leakage under both normal operating and SLB leakage conditions is developed in the lower portion of the H* distance (see Figure 8-2). It is expected that the leak rate ratio existing in this region would dominate the overall leakage ratio existing over the entire H* distance. For leakage emanating below an H* distance of **[** **]**^{a,c,e} inches from the top of the tubesheet, the expected leak rate factor is less than 10 (the same order of magnitude as the resistance leakage model leakage rate factor) for all tube bundle radii evaluated (Reference 15).

a,c,e

Figure 8-2. Point Beach Leak Rate Ratio Comparison – Parallel Plate Theory Leakage Model

9 CONCLUSIONS

This report documents the calculations of H* for Point Beach Unit 1. This report is specifically applicable to the Point Beach Unit 1 Model 44F SGs, as they are unique among the population of Model 44F SGs that are candidates for application of H*in regard to their limiting operating condition, a postulated SLB defined for the 2-loop plant. The calculation methods used are the same as those used in prior H* analyses, with two exceptions:

1. A new 3D tube unit cell model (3DSM) replaces the C^2 model used in prior technical justifications of H*.

2. A conservative assumption made in prior H* analyses was shown not to apply for Point Beach Unit 1. That assumption is that the divider plate is not connected to the tubesheet. For Point Beach Unit 1, it was shown that a more conservative value of H* results when the divider plate is attached to the tubesheet.

The two principal requirements for H* are:

1. Assure that tube(s) do not pull out of the tubesheet under the most limiting loads during normal or accident conditions.

2. Assure that primary-to-secondary coolant leakage through the tube-to-tubesheet crevice is no greater than that assumed in the Final Safety Analysis Report (FSAR) for the most limiting accident.

Concerning Item 1, as discussed in Section 1.0 of this report, the current licensing basis C^2 model analysis is an independent method of modeling the contact pressure distribution between the tube and the tubesheet throughout the tubesheet thickness. For all plants in the original H* fleet except Point Beach Unit 1, satisfactory resolution of all USNRC technical issues is complete and H* has been applied on a permanent basis. For the reasons discussed in Section 1.0 above, application of the C^2 model did not result in a H* length for all tubes in the Point Beach Unit 1 SGs, therefore, a full 3DSM was developed. Unlike the C^2 model, the 3DSM factors in the contact pressure caused by the tube resistance to tubesheet bending and provides independent confirmation that the structural criteria are met for the all the Point Beach Unit 1 SG tubes. Probabilistic H* values were re-calculated based on application of the 3DSM. Together with documents provided under separate cover, (e.g., Reference 17) this document includes the response to the prior RAI provided in Reference 18.

The final 95/95 H* value is calculated to be 20.60 inches referenced from the top of the tubesheet (see Section 7). This length of hydraulic expansion represents the required engagement length to balance an end cap load caused by a differential pressure across the tubes of $1.4\Delta P_{SLB}$. It includes a distance of **[ ]**[a,c,e] inch of 0 psi tube-to-tubesheet contact pressure down to the BET from the top of the tubesheet for each tube. There is a 95 percent probability at a 95% confidence that a tube will not pull out of the tubesheet during a postulated SLB condition. This H* length exceeds the required NEI 97-06, Revision 3 (Reference 19) structural acceptance criteria.

Concerning Item 2, the impact of the new 3DSM results on the existing licensing basis leakage rate factors provided in Reference 8 for the Point Beach Unit 1 Model 44F steam generators was evaluated. It was determined that the 3DSM results affect the current licensing basis leakage rate factors. The driving heads (Δp) at NOP and SLB conditions are changed from the current licensing basis. The temperatures remain the same to define the fluid viscosity (μ).

A parametric study of assumptions of loss coefficient dependency on contact pressure (resistance leakage model) and an application of the parallel plate theory, both based on available leak test data discussed in Reference 15, were performed. As described in Section 8.0 above and Appendix A, both the resistance leakage model and parallel plate theory method support a conservative SLB leakage factor of 5.22.

Concerning all other design basis accidents that model accident condition leakage, as discussed in Reference 1, the design specification curves for the locked rotor and control rod ejection events apply for the leakage factors for these transients. These transients are of very short duration and the H* leakage calculations employ a time integrated leakage approach. The leakage factors for a postulated locked rotor and control rod ejection event remain less than 1.0 and, therefore, are not used.

Based on the above, with the use the leakage rate factor of 5.22, it is concluded that primary-to-secondary leakage through the tube-to-tubesheet crevice is bounded by the values assumed in the FSAR for the most limiting accident. For the Operational Assessment (OA), the difference in leakage between the allowable accident-induced leakage and the accident-induced leakage from all other sources other than the tubesheet expansion region will be divided by 5.22 and compared to the observed operational leakage. A new technical specification leakage limit will be established to not exceed the calculated value.
The administrative limit for operational primary-to-secondary leakage can never exceed the current FSAR allowable limit for accident-induced primary-to-secondary leakage during a postulated SLB of 377gpd divided by the 5.22 leakage factor, equaling 72 gpd.

10 REFERENCES

1. WCAP-17091-P, Revision 0, “H*: Alternate Repair Criteria for the Tubesheet Expansion Region in Steam Generators with Hydraulically Expanded Tubes (Model 44F),” June 2009.

2. WCAP-17378-P, Revision 1, “H*: Resolution of NRC Technical Issue Regarding Tubesheet Bore Eccentricity (Model 44F, 2-Loop),” June 2011.

3. CN-SGMP-14-14, Revision 0, “Benchmarking of New 3D Sub-Model for H*,” July 2015.

4. LTR-SGMP-15-10, Revision 0, “H* 3-D Steam Generator Tube Submodel: Peer Review Responses,” May 2015.

5. LTR-SGMP-15-11, “Point Beach Unit 1: Position of the Bottom of the Tubesheet Expansion Transition,” February 2015.

6. LTR-SGMP-15-12, Revision 0, “Peer Review Report for H* 3-D Steam Generator Tube Submodel,” March 2015.

7. CN-SGMP-15-4, Revision 0, “3D Submodel for H* Analysis and Point Beach Unit 1 H* Contact Pressure and Mean H* Results,” July 2015.

8. LTR-SGMP-09-100 P-Attachment, Revision 1, “Responses to NRC Request for Additional Information on H*; Model F and Model D5 Steam Generators,” September 2010.

9. LTR-SGDA-11-87, “High Confidence Variances for Tube and Tubesheet CTE for H*,” May 2011.

10. *Statistics, Probability and Reliability for Civil and Environmental Engineers*, Kottegoda, N. T., Rosso, R., McGraw-Hill, ©1997.

11. CN-SGMP-15-14, “Point Beach Unit 1 H*: Probabilistic Programs Considering Tubesheet Regions and Calculation of Crevice Pressure Adjustment and Final Probabilistic H* Length,” March 2016.

12. WCAP-17330-P, Revision 1, “H*: Resolution of NRC Technical Issue Regarding Tubesheet Bore Eccentricity (Model F/Model D5),” June 2011.

13. CN-SGDA-03-119, Revision 1, “Calculation of Loss Coefficient for Model D5 Steam Generators,” June 2004.

14. STD-MCE-03-49, “Determination of Model D5 Tube-to-Tubesheet Leakage Resistance for H-star program for CBE/CDE/DDP/TCX,” November 2003.

15. LTR-SGMP-11-54 P-Attachment, Revision 1, “Point Beach Unit 1, H* Determination of Leak Rate Ratio Based on Alternate Leakage Calculation Methods for H* for Situations When Contact Pressure at Normal Operating Conditions Exceed Contact Pressure at Accident Conditions,” July 2015.

16. LTR-SGMMP-15-9, “Point Beach Unit 1 H* Feasibility Study,” August 6, 2015.

17. LTR-SGMP-10-33 P-Attachment, “H*: Response to NRC Questions Regarding Tubesheet Bore Eccentricity,” September 2010.

18. US NRC Letter, “Vogtle Electric Generating Plant, Units 1 and 2 – Transmittal of Unresolved Issues Regarding Permanent Alternate Repair Criteria for Steam Generators (TAC Nos. ME 1339 and ME 1340),” November 23, 2009.

19. NEI 97-06, Revision 3, “Steam Generator Program Guidelines,” Nuclear Energy Institute, January 2011.

20. Not used.

21. Not used.

22. LTR-SGMMP-11-29, Rev. 1 P-Attachment, “Response to USNRC Request for Additional Information Regarding the Surry Units 1 and 2 License Amendment Request for Permanent Application of the ARC, H*,” January 2012.

23. LTR-CPS-08-19, Revision 1, “NSSS Design Transients for Point Beach Units 1 and 2 EPU Program,” October 2014.

24. PCWG-07-49,” Point Beach Units 1 and 2 (WEP/WIS): Approval of Category III PCWG Parameters to Support the EPU Program,” October 2007.

25. LTR-SGMP-09-92, Revision 3, “Tubesheet Sector Definition for H* Revised Probabilistic Analysis,” October 2015.

26. CN-SGMP-15-15, Revision 1, “Tube and Tubesheet Surface Sampling Verification for H-Star,” March 2016.

APPENDIX A BOUNDING LOSS COEFFICIENT

Bounding Loss Coefficient-Contact Pressure Correlation Discussion

The objective of Appendix A is to provide a quantifiable basis for why the use of a leak rate factor of 5.22 is conservative for the Point Beach Unit 1 H* criterion.

As noted in Section 8.0 of this report, no leak rate test data are available for the Model 44F geometry. However, the leak rate data developed for the Model D5 and Model F geometry, which comprises all the leak rate testing completed by Westinghouse, can be used for application to the Model 44F geometry. Since the Model D5 and F SGs have similar geometry along the crevice path, the Model D5 and Model F loss coefficients that were previously calculated in Reference A-1 can be scaled by the ratio of the outer diameter of either the Model D5 or Model F SG, as appropriate, divided by the outer diameter of the Model 44F steam generator tubes (**[ ]**[a,c,e] inch). By applying the scaling factor to the Model D5 and F loss coefficients, the results obtained are considered to be the loss coefficients that would have been obtained during the Model D5 and Model F testing if the Model D5 and Model F SGs had **[ ]**[a,c,e] inch tube outer diameters. Also, it is assumed that the Model D5 test data and Model F test data were collected under the same test conditions. The Model D5 and Model F tubes were prototypic tubes made to the drawing specifications and had the same surface condition.

The available Model D5 and Model F test results and the resultant loss coefficients, are documented in References A-1 and A-2. For convenience, all leakage test results with/without the scaling factor correction are reproduced in Table A-1.

Figure A-1 shows the loss coefficients calculated from Model D5 and Model F leak test data scaled to apply to the Model 44F SGs at Point Beach Unit 1. A regression analysis was completed for the adjusted data resulting in the following relationship between loss coefficient and contact pressure: loss coefficient = **[ ]**[a,c,e], where Pc is the contact pressure. Correlation coefficient ranges from 0 to 1. A value of 1 implies a linear equation describes a relationship between loss coefficient and contact pressure perfectly. A value of 0 implies that there is no correlation. The correlation coefficient for this data set was 0.22, indicating that there is not a significant correlation between loss coefficient and contact pressure in these data. For comparison, the second curve on Figure A-1 is the correlation discussed in Section 8 in the body of this report on which the conservative leakage rate factor is based.

Table A-1. Combined Model D and F Loss Coefficient Data

a,c,e

a,c,e

Figure A-1. Loss Coefficient versus Contact Pressure (All Model D and F Data – Corrected to Model 44F)

The loss coefficients shown on Table A-1 were calculated by the method of Reference A-1.

Because the contact pressure between the tube and the tubesheet was not measured in the leak tests, the contact pressures shown on Table A-1 were calculated based on application of thick shell equations such as were applied in Reference A-3 for the NOP conditions. The calculations for these tests assumed that the crevice pressure was at the saturation pressure for the secondary side temperature for the entire length of the specimens.

Examination of Figure A-1 leads to several observations:

1. The calculated loss coefficient exhibits significant variability at specific calculated contact pressures. This is not unexpected for a test in which the measured leakage rate is extremely small (drops per minute).

2. Similar data variability exists at all pressure conditions tested, suggesting that the data variability is, indeed, a measurement uncertainty, rather than a physical test specimen or process issue.

3. When the data are viewed collectively as shown on Figure A-1, within the range of pressure conditions represented, there is no evidence of a discontinuous relationship between loss coefficient and contact pressure. If a discontinuity existed within the range of test conditions, the median point of the data scatter should be at a discernibly different level at contact pressures greater than at the point of the discontinuity. If a discontinuity existed in the range of the contact pressures of the data, the statistical fit would be expected to exhibit a positive slope because of the higher loss coefficients at the higher contact pressures. It can be reasonably concluded that, within the range of contact pressures in the database, no discontinuity in a postulated relationship between K and P_c exists

4. The bounding functional relationship used to project the leakage factor of 5.22 for the Point Beach Unit 1 steam generators (1E12*EXP(1.5E-3*Pc) as discussed in Section 8 of this report has a steeper slope than the actual exponential mathematical relationship calculated for the Model F and Model D5 data (1E12*EXP(0.0005*Pc) discussed above. If it is postulated that the loss coefficient increases with increasing contact pressure, intuitively, a bounding case would be a function that has the steepest slope of loss coefficient from low to high contact pressure based on available data. Table A-2 shows a comparison of the calculated leak rate factors as a function of tube bundle radius between the assumed functional relationship (to determine the limiting leak rate factor of 5.22) for Point Beach Unit 1 and the leak rate factors calculated using the mathematical relationship determined for the Model D5 and F data. Referring to Table A-2, the limiting leak rate factor calculated using the resistance leakage model based on the mathematical correlation of the existing Model D5 and F steam generator data is determined to be **[ ]**^{a,c,e}, much less than the bounding leakage rate factor of 5.22 discussed in Section 8 of this report.

As discussed in Section 9.1.1 of Reference A-3, there has been general concurrence among the industry and the USNRC and its consultants that the Darcy model is the correct and conservative model for potential leakage in the tubesheet expansion region for hydraulically expanded tubing. It remains Westinghouse's position that loss coefficient and fluid viscosity remain constant under normal operating and accident conditions loadings. Any increase in primary-to-secondary leakage that may occur would be caused by the ratio of increased pressure differential across the tubesheet during a postulated steam line break compared to normal operating conditions (**[ ]**^{a,c,e} psid SLB/**[ ]**^{a,c,e} psid High T_{avg} NOP) times the ratio of effective crevice length during normal operating to steam line break conditions for the Point Beach Unit 1 SGs. Effective crevice length is defined as the length of positive contact pressure within the tubesheet region as a function of bundle radius during a plant condition. Based on a review of Figure 4-2 of this report, the maximum effective crevice length ratio is approximately **[ ]**^{a,c,e} at a tubesheet radius of 7.126 inches. This results in a maximum leak rate factor of **[ ]**^{a,c,e}.

Therefore, the use of a leak rate factor of 5.22 is conservative for the application of Point Beach Unit 1 H* versus the leak rate factor resulting from the analysis of the empirical data which results in a leakage rate factor of **[ ]**^{a,c,e} and application of engineering first principles using the accepted Darcy formulation which results in a leakage factor of **[ ]**^{a,c,e}.

Table A-2. Resistance Leakage Model Calculated Leak Rate Factors

	Radius (in)				
Loss Coefficient vs. Contact Pressure Relationship	7.1256	28.1104	40.4544	47.08	51.564
Selected Bounding Functional Relationship					
1E12*EXP(1.5E-03*Pc)	[ ]a,c,e	[ ]a,c,e	[ ]a,c,e	[ ]a,c,e	5.22
Actual Mathematical Relationship for Model D5 and Model F Data					
10^(2.167E-4*Pc+11.99)	[ ]a,c,e	[ ]a,c,e	[ ]a,c,e	[ ]a,c,e	[ ]a,c,e

References for Appendix A:

A-1 CN-SGDA-03-119, Revision 1, "Calculation f Loss Coefficient for Model D5 Steam Generators," Westinghouse Electric Company, June 2004.

A-2 STD-MCE-03-49, "Determination of Model D5 Tube-to-Tubesheet Leakage Resistance for H-star program for CBE/DCE/DDP/TCX," Westinghouse Electric Company, November 2003.

A-3 WCAP-17091-P, "H*: Alternate Repair Criteria for the Tubesheet Expansion Region in Steam Generators with Hydraulically Expanded Tubes (Model 44F)," Westinghouse Electric Company, June 2009.

ATTACHMENT 6

Responses to Information Requests from the Nuclear Regulatory Commission Staff (NRC) Concerning the Point Beach Unit 1 H* License Amendment Request Submittal (Non-Proprietary)

13 Pages follow

Westinghouse Electric Company

Responses to Information Requests from the Nuclear Regulatory Commission Staff (NRC) Concerning the Point Beach Unit 1 H* License Amendment Request Submittal

March 29, 2016

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A preliminary pre-application meeting for information only was held between NextEra Energy, the NRC Staff and Westinghouse on November 12, 2015 to obtain NRC feedback on their review of the Point Beach Unit 1 H* Feasibility Study Report (Reference 1). During the meeting, the NRC Staff identified six areas that will require "clear and complete description/resolution in the license amendment request (LAR) package." The NRC information requests were documented in a letter dated 12/16/15 (Reference 2) and are listed below along with the Westinghouse responses to each inquiry. The Westinghouse responses to Information Requests 1 through 4 and 6 below provide a road map to where the information is located in the technical support documentation for the license amendment request package. The response to Information Request 5 below is a stand-alone response.

1) The calculated H* distance was found to be longer when the functional divider plate was included in the 3D model of the lower SG complex, which is a different result from all previous 2D H* analyses. The NRC Staff expects any license amendment request (LAR) will explain why taking credit for the divider plate increases the H* distance, and will provide any supporting calculations that confirm the approach and results. We also anticipate any future license amendment will address why the 3D submodel result is valid, in light of the previous 2D model results.

   Response:

   Information responding to NRC Information Request No. 1 is contained in Section 3.3.2.3, "Connected Divider Plate Used in the Lower SG Assembly Model," of WCAP-18089-P (Reference 3) on Pages 3-37 through 3-42 which includes Figures 3-30, 3-31, 3-32 and 3-33 and Tables 3-6 and 3-7.

2) The NRC Staff noted that the tube-to-tubesheet contact pressures during the steam line break accident analysis were not always higher than the contact pressures during normal operation. This result was only encountered by one other H* plant and will be an area of the LAR that receives scrutiny from the Staff.

   Response:

   Information related to NRC Information Request No. 2 is contained in Section 4.2, "Contact Pressure Results," of WCAP-18089-P on Pages 4-3 through 4-10 which includes Figures 4-3, 4-4, 4-5, 4-6 and 4-7 and Tables 4-1, 4-2, 4-3 and 4-4.

3) The leakage factor proposed in the report reviewed by the NRC Staff was not the highest leakage factor result to come from the new analysis. It appears the selection of the proposed value required some judgment. The NRC Staff anticipates this portion of the LAR to be an area of focus for the review. Any technical information to support the determination of the leakage factor may assist the Staff in its review.

Response:

Appendix A, "Bounding Loss Coefficient," has been added to WCAP-18089-P on Pages A-1 through A-6 to address NRC Information Request No. 3. This appendix provides the conservative rationale for the selection of the recommended leakage factor.

4) In the 3D submodel, the tube was extended outside the thickness of the tubesheet. The importance of this assumption was not clear. We would expect any future license amendment will address the importance of this assumption and assumptions about the clearances at any tube support plates (including whether a locked/blocked tube support plate opening has any effect). In addition, the submittal should address where the expansion transition was modeled and how sensitive the results were to this assumption (i.e., was the expansion transition at the top of the tubesheet or one inch below the top of the tubesheet).

Response:

Information responding to the three-dimensional (3D) submodel (3DSM) tube extension beyond the tubesheet is addressed in Section 3.3.1.2, "3DSM: Tube" of WCAP-18089-P on Page 3-26 and Figures 3-25 and 3-26 on Pages 3-33 and 3-34.

Information responding to how the expansion transition is modeled is also addressed in Section 3.3.1.2 on Page 3-27, Tables 3-3, 3-4 and 3-5 on Pages 3-29 and 3-30 and Figures 3-27, 3-28 and 3-29 on Pages 3-35 and 3-36.

A sensitivity study addressing the elevation of the bottom of the expansion transition (BET) at the top of the tubesheet or 1 inch below the top of the tubesheet was not performed. It is Westinghouse's engineering judgment that the use of the 99th percentile position of the BET for the Point Beach Unit 1 steam generators of [ ][a,c,e] inches below the top of the tubesheet for all tubes is conservative during both normal operating and SLB conditions. As can be seen from Figures 4-3 through 4-7 of WCAP-18089 (Reference 3), the selection of the elevation for BET only matters at radii 47.861 inches and 51.564 inches, for the limiting plant condition, SLB. Tube-to-tubesheet contact pressure occurs up to the BET elevation near the top of the tubesheet contributing to the resistance to tube pull out at these two radii. For the smaller radii, the zero tube-to-tubesheet contact pressure elevation occurs well below an assumed BET elevation of 0 inches, [ ][a,c,e] inches or 1 inch from the top of the tubesheet during the postulated SLB condition. These smaller radii include the critical radius of 40.454 inches used to

determine the mean H* value of [ ]^{a,c,e} inches for Point Beach Unit 1 and ultimately the probabilistic H* value of 20.6 inches.

5) There appear to be some different trends in the contact pressure data between the 2D and 3D submodel results and in going from normal operating to steam line break conditions. We assume the trends in Tables 4.1 and 4.2 will be explained (the trends going from the 2D to 3D submodel, from the inside to outside radius of the steam generator, and in going from the normal operating to steam line break conditions).

<u>**Response**</u>**:**

Westinghouse understands that the NRC Staff's question regarding potential differences in contact pressure trends between the 3DSM and the prior two-dimensional (2D) square cell (C^2) model is based on Figures 4-1 and 4-2 of the Feasibility Study (Reference 1 and provided in this correspondence) reviewed by the Staff at the Westinghouse offices. Figures 4-3 through 4-5 show that 3DSM tube-to-tubesheet contact pressures calculated for these radii exceed those calculated using the square cell model. Tables 4-1 and 4-2 in Reference 1 are the tabular basis of all of the figures.

The NRC Staff concludes that the differences in calculated contact pressures represent a difference in trends between the 3DSM and the C^2 model. The figures and tables in the Feasibility Report (Reference 1) represent the solutions to the same problem using significantly different models. The results from application of both models show the same overall trends of contact pressures as a function of elevation in the tubesheet. It is expected that application of different models to the same problem will show the same trends but may lead to different local results. It is judged by Westinghouse that the local differences in contact pressures calculated using the 3DSM versus C^2 model do not represent a negative trend.

The local variations of contact pressures result primarily from three factors: 1) how tubesheet displacements are applied to the models, 2) the methods used to calculate the applied tubesheet displacement inputs to the 3DSM and the C^2 model, and 3) whether the tubesheet displacements are applied in two or three dimensions (the inputs to the C^2 model are 2D). Benchmarking analyses show that the use of the 3DSM results in tube-to-tubesheet contact pressures similar to the C^2 model when tube resistance to tubesheet bending is not considered. This is necessary because the C^2 model does not have the capability to consider tubesheet bending. The 3DSM includes the capability to include tubesheet bending and, therefore, simply provides a more accurate determination of tube-to-tubesheet contact pressures.

Further, the NRC Staff's concern does not apply to the analysis for Point Beach Unit 1, as the limiting plant condition for determining H* is a postulated steam line break (SLB). Referring to Figures 4-6 through 4-10 of Reference 1 (also included in this correspondence), a local cross-over in the contact pressure curves was not experienced

during a postulated SLB condition. The 3DSM always calculates the same or greater contact pressures compared to the C^2 model for the SLB condition, thus again demonstrating that there is not a difference in trends between the two models.

6) If a license amendment request is submitted, we would highly encourage highlighting all differences from what was previously approved. This will allow the NRC Staff to focus its review. A clear, definitive statement would be beneficial.

Response:

Please see Table 1 that follows which summarizes the differences between what was previously approved for the H* plants, versus the new H* LAR for Point Beach Unit 1 (and provides a road map to where additional information can be found in Reference 1).

Table 1. Point Beach Unit 1 H* Difference Matrix	
Topic **Tube-to-Tubesheet Contact Pressure Model Differences**	**WCAP-18089-P Section and Page Number**
1. The three-dimensional submodel (3DSM) replaces the quarter symmetry modeling of the two-dimensional square cell (C^2) model with a full tube and square tubesheet (TS) submodel that enables the direct import of the tubesheet displacement from the Lower SG Assembly Model. Displacement inputs to the C^2 model required post-processing and manual input. Also, there were only two displacements to consider for the C^2 model (both in the same plane), the X (perpendicular to the tube lane) and the Z (parallel to the tube lane) directions at the critical radii. The **ANSYS®**[1] generated displacements were then processed using a central difference method to calculate strain ($\varepsilon_{x, z}$), which is the first derivative of displacement. For calculation in the X direction, an average displacement from ANSYS from one tube pitch forward and backward from the radius of interest was used from the lower SG assembly model from the hot leg cut face to determine strain (ε_{x}). In the Z direction, an average displacement was used from <u>two</u> tube pitches back from the cut face. Because the cut face represents a symmetry condition in the Z direction (i.e., strain (ε_{z}) in the Z direction vanishes), and as the central difference method was used to calculate strain, the equation for strain was modified to calculate the strain one tube pitch back from the cut face. An average resultant displacement was then applied along the X and Z direction sides of the C^2 model at 12 discreet elevations within the thickness of the tubesheet in order to determine tube-to-tubesheet contact pressures. The final calculation of the applied displacements to the quarter symmetry C^2 model was the same in the X and Z direction (0.5 * tube pitch* $\varepsilon_{x, z}$). For the 3DSM, the exact resultant displacements (with components in the X, Y and Z direction) are directly imported from the lower SG assembly model along the cut face up to and including only <u>one</u> tube pitch back from the cut face at the radii of interest and applied along all the surfaces of the 3DSM within the thickness of the tubesheet (and at all elevations) to determine tube-to-tubesheet contact pressures using ANSYS.	Sections 3.1.2 and 3.3.1.1, Pages 3-1, 3-23 through 3-25 and Figures 3-1 (Page 3-4), Figures 3-20 and 3-21on Pages 3-24 and 3-25)
2. The 3DSM is effectively a three-dimensional (3D) version of the C^2 model that is a single structural unit cell model of the entire depth of the tubesheet, centered on the tube pitch, in which the previously uncoupled C^2 tubesheet segments are now coupled. (The thickness of the tubesheet was represented by twelve individual C^2 models at discreet elevations which are not coupled in the horizontal plane. This approach neglects the bending continuity of the tubesheet under pressure and thermal loads.)	Sections 3.1.1 and 3.1.2, Pages 3-1, Figures 3-2, 3-3, 3-4, 3-5, 3-6, 3-7 (on Pages 3-5, 3-6 and 3-8 through 3-11) and Table 3-1 (on Page 3-7).

[1] *ANSYS is a registered trademark of ANSYS, Inc. in the United States or other countries.*

Table 1. Point Beach Unit 1 H* Difference Matrix (continued)	
Topic	**WCAP-18089-P Section and Page Number**
Tube-to-Tubesheet Contact Pressure Model Differences	
3. The tube in the 3DSM extends beyond the top of the TS to enable direct application of the pull out force (end cap load) and direct calculation of the Poisson contraction effect while avoiding end effects at the top of the tubesheet that could affect the contact pressure calculation. The Poisson contraction effect was, of necessity, a separate calculation in prior analyses because the C^2 segments that represented the tubesheet thickness were not connected in the horizontal plane. Details of the description of the end cap loading on the tube to determine the Poisson effect as well as the details of the expansion transition zone used in the 3DSM model including tube and tubesheet temperatures and tube pressures are provided.	Sections 3.1.3, 3.3.1.2, 3.3.2.2 Pages 3-3, 3-26 through 3-28, and 3-37, Tables 3-3, 3-4 and 3-5 (on Pages 3-29 and 3-30) and Figures 3-23, 3-24, 3-25, 3-26, 3-27, 3-28 and 3-29 (on Pages 3-31 through 3-36).
Lower Steam Generator Assembly Model Differences	
1. A conservative assumption made in the current licensing basis for the H* fleet, disconnecting the divider plate from the tubesheet to avoid the potential effects of degradation of the divider plate-to-TS weld, was found not to be conservative for Point Beach Unit 1 in concert with using the 3DSM. A connected divider plate was used in the Lower SG Assembly Model.	Section 3.3.2.3, Pages 3-37 through 3-38, Figures 3-30, 3-31, 3-32, 3-33 (on Pages 3-39 through 3-41), and Tables 3-6 and 3-7 (on Page 3-42)
Calculation of Probabilistic H* Using the 3DSM	
1. In order to calculate a probabilistic value of H*, the variability of H* to changes in the principal variables must be known. A map of this variability is known as a "response surface." The initial calculations for H* were based on use of the thick-shell equations, a closed-form solution for contact pressures as a function of variation of the significant variables which enabled rapid development of the H* response to these variables. Subsequently, application of the C^2 model in the current licensing basis rendered it unfeasible to develop a variability surface due to the extreme number of calculations required; therefore, a rationale was developed and documented to use the original thick-shell equation based response surface. Development of the 3DSM to replace the C^2 model again enabled the calculation of the variability surface directly and efficiently using the 3DSM.	Section 5.1, Pages 5-2 through 5-3, Figure 5-1 (on page 5-8).

a,c,e

Figure 4-1. Contact Pressure vs. TS Elevation, 7.126 inch Radius, NOP

a,c,e

Figure 4-2. Contact Pressure vs. TS Elevation, 28.21 inch Radius, NOP

a,c,e

Figure 4-3. Contact Pressure vs. TS Elevation, 40.454 inch Radius

a,c,e

Figure 4-4. Contact Pressure vs. TS Elevation, 47.861 inch Radius

a,c,e

Figure 4-5. Contact Pressure vs. TS Elevation, 51.564 inch Radius

a,c,e

Figure 4-6. Contact Pressure vs. TS Elevation, 7.126 inch Radius, SLB

a,c,e

Figure 4-7. Contact Pressure vs. TS Elevation, 28.21 inch Radius, SLB

a,c,e

Figure 4-8. Contact Pressure vs. TS Elevation, 40.454 inch Radius, SLB

a,c,e

Figure 4-9. Contact Pressure vs. TS Elevation, 47.861 inch Radius, SLB

a,c,e

Figure 4-10. Contact Pressure vs. Elevation, 51.564 inch Radius, SLB

References

1. LTR-SGMMP-15-9, "Point Beach Unit 1 H* Feasibility Study," August 6, 2015.

2. "Summary of November 12, 2015 Closed Pre-Application Teleconference with NextEra Energy Point Beach Regarding Steam Generators H* License Amendment Request (CAC No. MF7001), Mahesh Chawla, Project Manager, Division of Operating Reactor Licensing, Office of Nuclear Reactor Regulation, December 16, 2015. (*Attached in EDMS*)

3. WCAP-18089-P, Revision 0, "Point Beach Unit 1 Steam Generator Tube Alternate Repair Criterion, H*," March 2016.

4. WCAP-17378-P, Revision 1, "H*: Resolution of NRC Technical Issue Regarding Tubesheet Bore Eccentricity (Model 44F, 2-Loop)," June 2011.

Attachment 7 Contains ~~Proprietary Information~~

Withhold Attachment 7 from Public Disclosure in Accordance with 10 CFR 2.390

ATTACHMENT 7

WCAP-18089-P, “Point Beach Unit 1 Steam Generator Tube Alternate Repair Criterion, H*” (Proprietary)

111 Pages follow

Attachment 8 Contains ~~Proprietary Information~~

Withhold Attachment 8 from Public Disclosure in Accordance with 10 CFR 2.390

ATTACHMENT 8

Responses to Information Requests from the Nuclear Regulatory Commission Staff (NRC) Concerning the Point Beach Unit 1 H* License Amendment Request Submittal" (Proprietary)

13 Pages follow