

RS-09-117
August 31, 2009

10 CFR 50.90

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

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

Byron Station, Units 1 and 2
Facility Operating License Nos. NPF-37 and NPF-66
NRC Docket Nos. STN 50-454 and STN 50-455

Subject: Additional Information Supporting License Amendment Request to
Revise Technical Specifications (TS) for Steam Generator
Permanent Alternate Repair Criteria

- References:
1. Letter from P. R. Simpson (Exelon Generation Company, LLC) to U. S. Nuclear Regulatory Commission, "License Amendment Request to Revise Technical Specifications (TS) for Permanent Alternate Repair Criteria," dated June 24, 2009
 2. Letter from M. J. David (U. S. Nuclear Regulatory Commission) to C. G. Pardee (Exelon Generation Company, LLC), "Braidwood Station, Units 1 and 2, and Byron Station, Unit Nos. 1 and 2 – Request for Additional Information Related to Steam Generator Permanent Alternate Repair Criteria (TAC Nos. ME1613, ME1614, ME1615, and ME1616)," dated July 20, 2009
 3. Email from M. J. David (U. S. Nuclear Regulatory Commission) to P. Simpson and L. Schofield (Exelon Generation Company, LLC), "Braidwood & Byron Request for Additional Information Related to Steam Generator Permanent Alternate Repair Criteria (TAC Nos. ME1613 - ME1616)," dated August 6, 2009
 4. Letter from P. R. Simpson (Exelon Generation Company, LLC) to U. S. Nuclear Regulatory Commission, "Additional Information Supporting License Amendment Request to Revise Technical Specifications (TS) for Steam Generator Permanent Alternate Repair Criteria," dated August 14, 2009

In Reference 1, Exelon Generation Company, LLC (EGC), requested a license amendment for Braidwood Station, Units 1 and 2, and Byron Station, Units 1 and 2, to revise Technical Specifications (TS) 5.5.9, "Steam Generator (SG) Program," to exclude portions of the tube below the top of the steam generator tubesheet from periodic steam generator tube inspections and

plugging or repair, and TS 5.6.9, "Steam Generator (SG) Tube Inspection Report," to revise the reporting requirements. Westinghouse Electric Company, LLC, (Westinghouse) WCAP-17072-P, Revision 0, "H*: Alternate Repair Criteria for the Tubesheet Expansion Region in Steam Generators with Hydraulically Expanded Tubes (Model D5)," was submitted with Reference 1 and provided the basis for the proposed change.

In References 2 and 3, the NRC requested that EGC provide additional information in support of their review of Reference 1. Attachments 1 and 2 of Reference 4 provided the requested information, with the exception of Question 4 of Reference 2 and Question 1 of Reference 3. As discussed with the NRC on August 11, 2009 and documented in Reference 4, those responses would be provided in a separate submittal.

Attachments 1 and 2 of this submittal provide the requested information for Question 4 of Reference 2 and Question 1 of Reference 3.

Attachment 2 provides the proprietary Westinghouse letter LTR-SGMP-09-109 P-Attachment, "Response to NRC Request for Additional Information on H*; RAI #4; Model F and Model D5 Steam Generators," dated August 25, 2009.

As Attachment 2 contains information proprietary to Westinghouse, it is supported by an affidavit signed by Westinghouse, the owner of the information. The affidavit sets forth the basis on which the information may be withheld from public disclosure by the NRC and addresses with specificity the considerations listed in paragraph (b)(4) of 10 CFR 2.390, "Public inspections, exemptions, requests for withholding." Accordingly, it is requested that the information that is proprietary to Westinghouse be withheld from public disclosure in accordance with 10 CFR 2.390. This affidavit is provided in Attachment 3. Attachment 4 to this letter provides a non-proprietary version of Attachment 2.

EGC has reviewed the information supporting a finding of no significant hazards consideration that was previously provided to the NRC in Reference 1. The additional information provided in this submittal does not affect the bases for concluding that the proposed license amendment does not involve a significant hazards consideration.

In accordance with 10 CFR 50.91, "Notice for public comment; State consultation," paragraph (b), a copy of this letter and its non-proprietary attachments are being provided to the designated State of Illinois official.

There are no regulatory commitments contained in this letter.

Should you have any questions concerning this letter, please contact Ms. Lisa A. Schofield at (630) 657-2815.

I declare under penalty of perjury that the foregoing is true and correct. Executed on the 31st day of August 2009.

Respectfully,

A handwritten signature in black ink, appearing to read "Patrick R. Simpson", with a long, sweeping horizontal flourish extending to the right.

Patrick R. Simpson
Manager – Licensing
Exelon Generation Company, LLC

Attachments:

1. Additional Information Supporting License Amendment Request to Revise Technical Specifications for Steam Generator Permanent Alternate Repair Criteria
2. Westinghouse LTR-SGMP-09-109 P-Attachment, Revision 0 (Proprietary)
3. Westinghouse Affidavit and Authorization Letter CAW-09-2663
4. Westinghouse LTR-SGMP-09-109 NP-Attachment, Revision 0 (Non-Proprietary)

cc:

NRC Regional Administrator, Region III
NRC Senior Resident Inspector, Braidwood Station
NRC Senior Resident Inspector, Byron Station

ATTACHMENT 1
Additional Information Supporting License Amendment Request to
Revise Technical Specifications for Steam Generator
Permanent Alternate Repair Criteria

In a letter dated July 20, 2009, and an email dated August 6, 2009, the NRC requested that EGC provide additional information related to the application for a permanent alternate repair criteria. Attachments 1 and 2 provide the requested information for Question 4 of the July 20, 2009, letter and Question 1 of the August 6, 2009, email.

Response to Request for Additional Information Dated July 20, 2009

Question 4

Reference 1, Page 6-70. In Section 6.2.5.3, it is concluded that the tube outside diameter and the tubesheet tube bore inside diameter always maintain contact in the predicted range of tubesheet displacements. However, for tubes with through-wall cracks at the H^* distance, there may be little or no net pressure acting on the tube for some distance above H^* . In Tables 6-18 and 6-19, the fourth increment in the step that occurs two steps prior to the last step suggests that there may be no contact between the tube and tubesheet, over a portion of the circumference, for a distance above H^* . Is the conclusion in 6.2.5.3 valid for the entire H^* distance, given the possibility that the tubes may contain through wall cracks at that location.

Reference:

1. WCAP-17072-P, Rev. 0, " H^* : Alternate Repair Criteria for the Tubesheet Expansion Region in Steam Generators with Hydraulically Expanded Tubes (Model D5)," dated May 2009

Response to Request for Additional Information Dated August 6, 2009

Question 1

In addition to the information requested in RAI Question 4, please address the following questions:

- a. Clarify the nature of the finite element model ("slice" model versus axisymmetric SG assembly model) used to generate the specific information in Tables 6-1, 2, and 3 (and accompanying graph entitled "Elliptical Hole Factors") of Reference 6-15. What loads were applied? How was the eccentricity produced in the model? (By modeling the eccentricity as part of the geometry? By applying an axisymmetric pressure the inside of the bore?) Explain why this model is not scalable to lower temperatures.
- b. Provide a table showing the maximum eccentricities (maximum diameter minus minimum diameter) from the 3-dimensional finite element analysis for normal operating and steam line break (SLB), for Model D5.
- c. In Figure 6-70, add a plot for the original relationship between reductions in contact pressure and eccentricity as given in Reference 6-15 in the graph accompanying Table 6-3. Explain why this original relationship remains conservative in light of the new relationship. Explain the reasons for the differences between the curves.
- d. When establishing whether contact pressure increases when going from normal operating to SLB conditions, how can a valid and conservative comparison be made if

ATTACHMENT 1
Additional Information Supporting License Amendment Request to
Revise Technical Specifications for Steam Generator
Permanent Alternate Repair Criteria

the normal operating case is based on the original delta contact pressure versus eccentricity curve and the SLB case is based on the new curve?

Response

The response to Question 4 of the July 20, 2009, letter and Question 1 of the August 6, 2009, email is provided in Attachment 2 to this submittal.

ATTACHMENT 3

Westinghouse Affidavit and Authorization Letter

CAW-09-2663



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

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

Direct tel: (412) 374-4643
Direct fax: (412) 374-3846
e-mail: greshaja@westinghouse.com

Our ref: CAW-09-2663

August 27, 2009

APPLICATION FOR WITHHOLDING PROPRIETARY
INFORMATION FROM PUBLIC DISCLOSURE

Subject: LTR-SGMP-09-109 P-Attachment, "Response to NRC Request for Additional Information on H*; RAI # 4: Model F and Model D5 Steam Generators," dated August 2009 (Proprietary)

The proprietary information for which withholding is being requested in the above-referenced report is further identified in Affidavit CAW-09-2663 signed by the owner of the proprietary information, Westinghouse Electric Company LLC. The affidavit, which accompanies this letter, sets forth the basis on which the information may be withheld from public disclosure by the Commission and addresses with specificity the considerations listed in paragraph (b)(4) of 10 CFR Section 2.390 of the Commission's regulations.

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

Correspondence with respect to the proprietary aspects of the application for withholding or the Westinghouse affidavit should reference this letter, CAW-09-2663, and should be addressed to J. A. Gresham, Manager, Regulatory Compliance and Plant Licensing, Westinghouse Electric Company LLC, P.O. Box 355, Pittsburgh, Pennsylvania 15230-0355.

Very truly yours,

A handwritten signature in black ink, appearing to read 'J.A. Gresham'.

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

Enclosures

cc: G. Bacuta, (NRC OWFN 12E-1)

bcc: J. A. Gresham (ECE 4-7A) 1L
R. Bastien, 1L (Nivelles, Belgium)
C. Brinkman, 1L (Westinghouse Electric Co., 12300 Twinbrook Parkway, Suite 330, Rockville, MD 20852)
RCPL Administrative Aide (ECE 4-7A) 1L (letter and affidavit only)
G. W. Whiteman, Waltz Mill
H. O. Lagally, Waltz Mill
C. D. Cassino, Waltz Mill
J. T. Kandra, Waltz Mill
F. D. Garofalo, ECE 561B

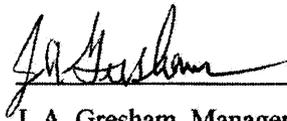
AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

SS

COUNTY OF ALLEGHENY:

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



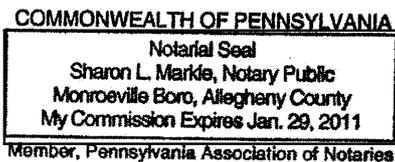
J. A. Gresham, Manager

Regulatory Compliance and Plant Licensing

Sworn to and subscribed before me
this 27th day of August, 2009



Notary Public



- (1) I am Manager, Regulatory Compliance and Plant Licensing, in Nuclear Services, Westinghouse Electric Company LLC (Westinghouse), and as such, I have been specifically delegated the function of reviewing the proprietary information sought to be withheld from public disclosure in connection with nuclear power plant licensing and rule making proceedings, and am authorized to apply for its withholding on behalf of Westinghouse.
- (2) I am making this Affidavit in conformance with the provisions of 10 CFR Section 2.390 of the Commission's regulations and in conjunction with the Westinghouse "Application for Withholding" accompanying this Affidavit.
- (3) I have personal knowledge of the criteria and procedures utilized by Westinghouse in designating information as a trade secret, privileged or as confidential commercial or financial information.
- (4) Pursuant to the provisions of paragraph (b)(4) of Section 2.390 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld.
 - (i) The information sought to be withheld from public disclosure is owned and has been held in confidence by Westinghouse.
 - (ii) The information is of a type customarily held in confidence by Westinghouse and not customarily disclosed to the public. Westinghouse has a rational basis for determining the types of information customarily held in confidence by it and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The application of that system and the substance of that system 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.

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

- (a) The use of such information by Westinghouse gives Westinghouse a competitive advantage over its competitors. It is, therefore, withheld from disclosure to protect the Westinghouse competitive position.
- (b) It is information that is marketable in many ways. The extent to which such information is available to competitors diminishes the Westinghouse ability to sell products and services involving the use of the information.
- (c) Use by our competitor would put Westinghouse at a competitive disadvantage by reducing his expenditure of resources at our expense.

- (d) Each component of proprietary information pertinent to a particular competitive advantage is potentially as valuable as the total competitive advantage. If competitors acquire components of proprietary information, any one component may be the key to the entire puzzle, thereby depriving Westinghouse of a competitive advantage.
 - (e) Unrestricted disclosure would jeopardize the position of prominence of Westinghouse in the world market, and thereby give a market advantage to the competition of those countries.
 - (f) The Westinghouse capacity to invest corporate assets in research and development depends upon the success in obtaining and maintaining a competitive advantage.
- (iii) The information is being transmitted to the Commission in confidence and, under the provisions of 10 CFR Section 2.390, it is to be received in confidence by the Commission.
- (iv) The information sought to be protected is not available in public sources or available information has not been previously employed in the same original manner or method to the best of our knowledge and belief.
- (v) The proprietary information sought to be withheld in this submittal is that which is appropriately marked in LTR-SGMP-09-109 P-Attachment, "Response to NRC Request for Additional Information on H*;RAI # 4; Model F and Model D5 Steam Generators," dated August 2009 (Proprietary), for submittal to the Commission, being transmitted by Exelon Generation Company, LLC letter and Application for Withholding Proprietary Information from Public Disclosure to the Document Control Desk. The proprietary information as submitted for use by Westinghouse for Braidwood Unit 2 and Byron Unit 2 is expected to be applicable to other licensee submittals in support of implementing an alternate repair criterion, called H*, that does not require an eddy current inspection and plugging of steam generator tubes below a certain distance from the top of the tubesheet.

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

- (a) Provide documentation of the analyses, methods, and testing which support the implementation of an alternate repair criterion, designated as H*, for a portion of the tubes within the tubesheet of the Braidwood Unit 2 and Byron Unit 2 steam generators.
- (b) Assist the customer in obtaining NRC approval of the Technical Specification changes associated with the alternate repair criterion.

Further this information has substantial commercial value as follows:

- (a) Westinghouse plans to sell the use of similar information to its customers for the purposes of meeting NRC requirements for licensing documentation.
- (b) Westinghouse can sell support and defense of the technology to its customers in the licensing process.

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

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

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

Further the deponent sayeth not.

PROPRIETARY INFORMATION NOTICE

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

In order to conform to the requirements of 10 CFR 2.390 of the Commission's regulations concerning the protection of proprietary information so submitted to the NRC, the information which is proprietary in the proprietary versions is contained within brackets, and where the proprietary information has been deleted in the non-proprietary versions, only the brackets remain (the information that was contained within the brackets in the proprietary versions having been deleted). The justification for claiming the information so designated as proprietary is indicated in both versions by means of lower case letters (a) through (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).

COPYRIGHT NOTICE

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

Exelon Generation Company, LLC
Letter for Transmittal to the NRC

The following paragraphs should be included in your letter to the NRC:

Enclosed are:

1. 1 copy of LTR-SGMP-09-109 P-Attachment, "Response to NRC Request for Additional Information on H*; RAI # 4; Model F and Model D5 Steam Generators," dated August 2009 (proprietary).
2. 1 copy of LTR-SGMP-09-109 NP-Attachment, "Response to NRC Request for Additional Information on H*; RAI # 4; Model F and Model D5 Steam Generators," dated August 2009 (non-proprietary).

Also enclosed is Westinghouse authorization letter CAW-09-2663 with accompanying affidavit, Proprietary Information Notice, and Copyright Notice.

As Item 1 contains information proprietary to Westinghouse Electric Company LLC, it is supported by an affidavit signed by Westinghouse, the owner of the information. The affidavit sets forth the basis on which the information may be withheld from public disclosure by the Commission and addresses with specificity the considerations listed in paragraph (b)(4) of Section 2.390 of the Commission's regulations.

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

Correspondence with respect to the copyright or proprietary aspects of the items listed above or the supporting Westinghouse affidavit should reference CAW-09-2663 and should be addressed to J. A. Gresham, Manager, Regulatory Compliance and Plant Licensing, Westinghouse Electric Company LLC, P.O. Box 355, Pittsburgh, Pennsylvania 15230-0355.

ATTACHMENT 4

**Westinghouse LTR-SGMP-09-109 NP-Attachment
(Non-Proprietary)**

Westinghouse Electric Company

**Response to
NRC Request for Additional Information on H*; RAI #4;
Model F and Model D5 Steam Generators**

August 25, 2009

Westinghouse Electric Company LLC
P.O. Box 158
Madison, PA 15663

© 2009 Westinghouse Electric Company LLC
All Rights Reserved

**Response to
NRC Request for Additional Information on H*; RAI #4;
Model F and Model D5 Steam Generators**

References:

1. NL-09-0547, Vogtle Electric Generating Plant License Amendment Request to Revise Technical Specification(TS) Sections 5.5.9, "Steam Generator (SG) Program" and TS 5.6.10, "Steam Generator Tube Inspection Report for Permanent Alternate Repair Criteria," Southern Company, May 19, 2009.
2. RS-09-071, "License Amendment Request to Revise Technical Specifications (TS) for Permanent Alternate Repair Criteria," Exelon Nuclear, June 24, 2009.
3. CP-200900748, Log # TXX-09075, "Comanche Peak Steam Electric Station (CPSES) Docket Nos. 50-445 and 50-446, License Amendment Request 09-007, Model D5 Steam Generator Alternate Repair Criteria," Luminant, June 8, 2009.
4. SBK-L-09118, "Seabrook Station: License Amendment Request 09-03; Revision to Technical Specification 6.7.6.k, "Steam Generator (SG) Program," for Permanent Alternate Repair Criteria (H*)," May 28, 2009.
5. Vogtle Electric Generating Plant, Units 1 and 2, Request for Additional Information Regarding Steam Generator Program (TAC Nos. ME1339 and ME1340)," United States Nuclear Regulatory Commission, July 10, 2009.
6. Braidwood Station, Units 1 and 2, and Byron Station, Unit Nos. 1 and 2 – Request for Additional Information Related to Steam Generator Permanent Alternate Repair Criteria (TAC Nos. ME1613, ME1614, ME1615, and ME1616)," United States Nuclear Regulatory Commission, July 20, 2009.
7. Comanche Peak Steam Electric Station, Units 1 and 2 – Request for Additional Information Regarding the Permanent Alternate Repair Criteria License Amendment Request (TAC Nos. ME1446 and ME1447)," United States Nuclear Regulatory Commission, July 23, 2009.
8. WCAP-17071-P, "H*: Alternate Repair Criteria for the Tubesheet Expansion Region in Steam Generators with Hydraulically Expanded Tubes (Model F)," Westinghouse Electric LLC, April 2009.
9. WCAP-17072-P, "H*: Alternate Repair Criteria for the Tubesheet Expansion Region in Steam Generators with Hydraulically Expanded Tubes (Model D5)," Westinghouse Electric LLC, May 2009.
10. "Vogtle Electric Generating Plant, Units 1 and 2, Request for Additional Information Regarding Steam Generator Program (TAC Nos. ME1339 and ME1340)," United States Nuclear Regulatory Commission, August 5, 2009

11. LTR-SGMP-09-100, "Response to NRC Request for Additional Information on H*; Model F and Model D5 Steam Generators," August 2009
12. LTR-NRC-09-26, "LTR-SGMP-09-66 P-Attachment, "White Paper: Low Temperature Steam Line Break Contact Pressure and Local Tube Bore Deformation Analysis for H* (Proprietary)," Westinghouse Electric Company LLC, May 13, 2009.
13. Seabrook Station, Unit No. 1- Request for Additional Information Regarding Steam Generator Program (TAC Nos. ME1386)," United States Nuclear Regulatory Commission, August 13, 2009

Introduction

In response to formal requests for technical specification amendments, References 1, 2, 3 and 4, the USNRC formally requested additional information in References 5, 6, 7 and 13. The Vogtle, Seabrook, Byron/Braidwood and Comanche Peak requests for a permanent license amendment to implement H* represent the Model F and Model D5 steam generators for which the H* technical justification is provided in References 8 and 9.

Subsequent to the initial issue of the RAI (References 5, 6, 7 and 13), the NRC issued follow-up questions (Reference 10) to questions numbers 4, 20 and 24 and an additional request regarding a technical specification (TS) commitment for applying the leakage factors. Except for RAI#4, responses to all of the RAIs, including the follow-up questions in Reference 10, were provided in Reference 11. The affected licensees provided separate responses in regard to the commitment for applying leakage factors.

The response to RAI#4 required additional explanation as discussed with the NRC staff on August 11, 2009 and was, therefore, not included in Reference 11. The additional questions related to RAI#4 that were identified during the August 11, 2009 telephone conference were summarized by Westinghouse and were the basis of the discussion at a meeting among the NRC, several licensees and Westinghouse on August 17 and 18, 2009. These additional questions are reproduced in the response to RAI#4, below. Specific discussion is included in the response to address the additional questions.

To summarize, this document provides the response to the initial RAI#4 as included in References 5, 6, 7 and 13, response to the follow-up question relating to RAI#4 in Reference 10 and response to the additional questions raised during the conference call on August 11, 2009.

Utilities, other than referenced in this document, have requested amendments to their licensees in parallel with the response to these RAI's. The technical RAIs are generic in nature because the analysis methods are the same for all affected plants. Therefore, this response to RAI#4 is generic for all Models of SGs that are candidates for application of H*. However, this letter

specifically augments Reference 11 to complete the responses to NRC RAIs for WCAP-17071-P (Model F H*) and WCAP-17072-P (Model D5 H*).

RAI Part A	Vogtle	4. <i>Reference 1, page 6-69: In Section 6.2.5.3, it is concluded that the tube outside diameter and the tubesheet tube bore inside diameter always maintain contact in the predicted range of tubesheet displacements. However, for tubes with through-wall cracks at the H* distance, there may be little or no net pressure acting on the tube for some distance above H*. In Tables 6-18 and 6-19, the fourth increment in the step that occurs two steps prior to the last step suggests that there may be no contact between the tube and tubesheet, over a portion of the circumference, for a distance above H*. Is the conclusion in Section 6.2.5.3 valid for the entire H* distance, given the possibility that the tubes may contain through-wall cracks at that location?</i>
	WCGS	4. <i>Reference 1, page 6-69: In Section 6.2.5.3, it is concluded that the tube outside diameter and the tubesheet tube bore inside diameter always maintain contact in the predicted range of tubesheet displacements. However, for tubes with through-wall cracks at the H* distance, there may be little or no net pressure acting on the tube for some distance above H*. In Tables 6-18 and 6-19, the fourth increment in the step that occurs two steps prior to the last step suggests that there may be no contact between the tube and tubesheet, over a portion of the circumference, for a distance above H*. Is the conclusion in 6.2.5.3 valid for the entire H* distance, given the possibility that the tubes may contain through-wall cracks at that location?</i>
	B/B	4. <i>Reference 1, Page 6-7: In Section 6.2.5.3, it is concluded that the tube outside diameter and the tubesheet tube bore inside diameter always maintain contact in the predicted range of tubesheet displacements. However, for tubes with through-wall cracks at the H* distance, there may be little or no net pressure acting on the tube for some distance above H*. In Tables 6-18 and 6-19, the fourth increment in the step that occurs two steps prior to the last step suggests that there may be no contact between the tube and tubesheet, over a portion of the circumference, for a distance above H*. Is the conclusion in 6.2.5.3 valid for the entire H* distance, given the possibility that the tubes may contain through-wall cracks at that location.</i>

CPSES	4. Reference 1, page 6-70: In Section 6.2.5.3, it is concluded that the tube outside diameter and the tubesheet tube bore inside diameter always maintain contact in the predicted range of tubesheet displacements. However, for tubes with through-wall cracks at the H^* distance, there may be little or no net pressure acting on the tube for some distance above H^* . In Tables 6-18 and 6-19, the fourth increment in the step that occurs two steps prior to the last step suggests that there may be no contact between the tube and tubesheet, over a portion of the circumference, for a distance above H^* . Is the conclusion in Section 6.2.5.3 valid for the entire H^* distance, given the possibility that the tubes may contain through-wall cracks at that location?
Seabrook	4. Reference 1, page 6-69: In Section 6.2.5.3, it is concluded that the tube outside diameter and the tubesheet tube bore inside diameter always maintain contact in the predicted range of tubesheet displacements. However, for tubes with through-wall cracks at the H^* distance, there may be little or no net pressure acting on the tube for some distance above H^* . In Tables 6-18 and 6-19, the fourth increment in the step that occurs two steps prior to the last step suggests that there may be no contact between the tube and tubesheet, over a portion of the circumference, for a distance above H^* . Is the conclusion in 6.2.5.3 valid for the entire H^* distance, given the possibility that the tubes may contain through-wall cracks at that location?

Part B: The additional questions relating to RAI#4 as provided in Reference 10 are:

Address following questions as part of response to RAI#4 (Vogtle):

- a. Clarify the nature of the finite element model (“slice” model versus axisymmetric SG assembly model) used to generate the specific information in Tables 6-1, 2, and 3 (and accompanying graph entitled “Elliptical Hole Factors”) of Reference 6-15. What loads were applied? How was the eccentricity produced in the model? (By modeling the eccentricity as part of the geometry? By applying an axisymmetric pressure the inside of the bore?) Explain why this model is not scalable to lower temperatures.
- b. Provide table showing maximum delta diameters (total diameter distortion) and maximum eccentricities (maximum diameter minus minimum diameter) from the 3 dimensional (3-D) finite element analysis for normal operating and steam line break (SLB), for model F and D5.
- c. In Figure 2 of the White Paper, add plot for original relationship between reductions in contact pressure and eccentricity as given in Reference 6-15 in the graph accompanying Table 6-3. Explain why this original relationship remains conservative

in light of the new relationship. Explain the reasons for the differences between the curves.

- d. When establishing whether contact pressure increases when going from normal operating to steam line break conditions, how can a valid and conservative comparison be made if the normal operating case is based on the original delta contact pressure versus eccentricity curve and the SLB case is based on the new curve?*

Part C: Additional Questions Provided in the August 11, 2009 telephone conference:

a. Overall High Level Question

1. *Discuss if the eccentricity effect on contact pressure is occurring as described. It is the opinion of the NRC staff that the eccentricity effect may not be as significant as being reported by Westinghouse.*

b. Other Key Questions

1. *The eccentricities included in Table RAI 4-4 appear larger than anticipated. Need to confirm that positive contact pressure exists around the entire circumference of the tube and state this clearly in the response.*
2. *The difference between initial and final eccentricity included in Table RAI4-2 needs to be explained. In particular, the exclusive use of the relationship between initial eccentricity and scale factor in calculating contact pressure needs to be justified.*
3. *The basis for applying the correlation for scale factor outside an "eccentricity" range of between 1E-3 to 1E-4 inch in the calculation of contact pressure needs to be further explained. Values for displacements included in Table 6-18 (of WCAP-17071) suggest that contact pressure may be lost at displacement ranging between 1E-3 in to 1E-4 inch.*
4. *Provide the calculation basis for the upper and lower curves provided in Figure RAI 4-2*
5. *Resolve the apparent inconsistency between Item 4 on page 25 and the statement below Figure RAI4-1 regarding how the model in Figure RAI4-1 is loaded.*

c. Key Remaining Issues

1. *Provide the basis for why the ΔD_{hole} adjustment for contact pressure made using the old model remains conservative.*
2. *Provide an appropriate basis for demonstrating that joints tighten during a postulated SLB event. Why is it acceptable to compare the contact pressures calculated using the original model for NOP to the contact pressures calculated using the new model for SLB for the Model D5 SGs?*
3. *If both old and new models are conservative, is there an appropriate basis to show the relative conservatism of the methods?*

To facilitate a continuous response to the total RAI#4 questions, the questions received originally (Part A), those received as follow-up questions (Part B) and those identified during the 8/11/09 telephone conference (Part C) are re-arranged as noted below. The location of responses to specific questions is shown in bold type after the question. Also, in the responses, the specific questions addressed by the responses are repeated in bold type in the box at the start of the response.

Part C: Sub a.

Discuss if the eccentricity effect on contact pressure is occurring as described. It is the opinion of the NRC staff that the eccentricity effect may not be as significant as being reported by Westinghouse. (See Section 1.0)

Part B

Address following questions as part of response to RAI#4 (Vogtle):

a. Clarify the nature of the finite element model ("slice" model versus axisymmetric SG assembly model) used to generate the specific information in Tables 6-1, 2, and 3 (and accompanying graph entitled "Elliptical Hole Factors") of Reference 6-15. What loads were applied? How was the eccentricity produced in the model? (By modeling the eccentricity as part of the geometry? By applying an axisymmetric pressure the inside of the bore?) Explain why this model is not scalable to lower temperatures. (See Section 1.2)

b. Provide table showing maximum delta diameters (total diameter distortion) and maximum eccentricities (maximum diameter minus minimum diameter) from the 3 dimensional (3-D) finite element analysis for normal operating and steam line break (SLB), for model F and D5. (See Section 1.1)

c. In Figure 2 of the White Paper, add plot for original relationship between reductions in contact pressure and eccentricity as given in Reference 6-15 in the graph accompanying Table 6-3. Explain why this original relationship remains conservative in light of the new relationship. Explain the reasons for the differences between the curves. (See Section 4.1)

d. When establishing whether contact pressure increases when going from normal operating to steam line break conditions, how can a valid and conservative comparison be made if the normal operating case is based on the original delta contact pressure versus eccentricity curve and the SLB case is based on the new curve? (See Section 4.2)

Part C: Sub b. Other Key Questions

1. *The eccentricities included in Table RAI 4-4 appear larger than anticipated. Need to confirm that positive contact pressure exists around the entire circumference of the tube and state this clearly in the response. (See Section 3)*
2. *The difference between initial and final eccentricity included in Table RAI4-2 needs to be explained. In particular, the exclusive use of the relationship between initial eccentricity and scale factor in calculating contact pressure needs to be justified. (See Section 1.2)*
3. *The basis for applying the correlation for scale factor outside an “eccentricity” range of between 1E-3 to 1E-4 inch in the calculation of contact pressure needs to be further explained. Values for displacements included in Table 6-18 (of WCAP-17071) suggest that contact pressure may be lost at displacement ranging between 1E-3 in to 1E-4 inch. (See Section 2.0)*
4. *Provide the calculation basis for the upper and lower curves provided in Figure RAI 4-2. (See Section 2.1)*
5. *Resolve the apparent inconsistency between Item 4 on page 25 and the statement below Figure RAI4-1 regarding how the model in Figure RAI4-1 is loaded. (See Section 1.2)*

Part C: Sub c. Key Remaining Issues

1. *Provide the basis for why the ΔD_{hole} adjustment for contact pressure made using the old model remains conservative. (See Section 2.2)*
2. *Provide an appropriate basis for demonstrating that joints tighten during a postulated SLB event. Why is it acceptable to compare the contact pressures calculated using the original model for NOP to the contact pressures calculated using the new model for SLB for the Model D5 SGs? (See Section 2.3)*
3. *If both old and new models are conservative, is there an appropriate basis to show the relative conservatism of the methods? (See Section 2.4)*

Part A: (Original RAI#4 from Reference 5)

Reference 1, Page 6-69: In Section 6.2.5.3, it is concluded that the tube outside diameter and the tubesheet tube bore inside diameter always maintain contact in the predicted range of tubesheet displacements. However, for tubes with through-wall cracks at the H^ distance, there may be little or no net pressure acting on the tube for some distance above H^* . In Tables 6-18 and 6-19, the fourth increment in the step that occurs two steps prior to the last step suggests that there may be no contact between the tube and tubesheet, over a portion of the circumference, for a distance above H^* . Is the conclusion in 6.2.5.3 valid for the entire H^* distance, given the possibility that the tubes may contain through-wall cracks at that location? (See Section 5.0)*

1.0 General Background on Approach and Models

Discuss if the eccentricity effect on contact pressure is occurring as described. It is the opinion of the NRC staff that the eccentricity effect may not be as significant as being reported by Westinghouse.

Response:

The reference structural model for the H^* calculation as described in References 8 and 9 is a 3D FEA model that utilizes the equivalent properties approach for perforated plates in accordance with Reference 6-15 of the H^* WCAP reports. This model provides the tubesheet displacements that are utilized in the calculation of H^* . Included in the displacement output from the 3D FEA model are the radius and depth dependent x- and y- axis displacements for the tubesheet. These displacements are the input to the H^* integrator model that uses the inputs to calculate contact pressures based on thick-shell equations. The tubesheet displacements from the FEA model indicate that the tubesheet bores become eccentric after application of all thermal and pressure loads. The displacement results from the 3D FEA model are the difference between the completely unloaded case and the fully loaded case for the conditions of interest (i.e., NOP, SLB).

The information from the 3D FEA model, that the tubesheet bores become eccentric, led to a question regarding continued tube-to-tubesheet contact in the eccentric tubesheet bore. The impact of tubesheet bore hole out-of-roundness (eccentricity) on the calculation of tube to-tubesheet contact pressures was originally addressed using a scale factor approach as described below and in Reference 6-15 of the H^* WCAP reports. The fit developed in Reference 6-15, a third order polynomial, was appropriate for the conditions for which it was developed but it provided physically impossible results when extrapolated significantly outside its data basis such as was the case for the SLB conditions for the Model D5 SGs.

To resolve this issue, a separate model, was developed as described in Section 6.2.5 and shown in Figure 6-48 of Reference 8 and 9, to assess tube-to-tubesheet contact under the fully loaded condition (e.g., ΔP and thermal loading) for the small eccentricities that were calculated during the much "colder" temperature postulated SLB conditions for the Model D5 SGs than for the Model F SGs. To properly represent the tube in tubesheet condition, this model considered a tubesheet equivalent cell (the local TS material around a tubesheet bore) and a tube. To address the question if continued contact would exist between the tube and tubesheet after the tubesheet bore becomes eccentric, the tube expansion was analytically simulated to provide a condition of tube to tubesheet contact in a non-eccentric tubesheet bore. This condition was the reference condition for the subsequent loading of the model by pressure loads (thermal loads were not included) and by applying displacement boundary conditions (e -bar) to simulate the expected range of tubesheet bore eccentricity. The unloaded, post-tube expansion simulation conditions of the model was the reference condition for the displacements provided in Tables 6-18 and 6-19 of the H^* reports, References 8 and 9.

While eccentricity was the specific focus of this study because of the question raised about continued tube to tubesheet contact in an eccentric condition, the analytical model naturally also provided information on tubesheet bore dilation, the diametral growth of the tubesheet bore represented by the average of the maximum and minimum diameters of the eccentric tubesheet bore. Examination of the results from this model, as is discussed further below, resulted in two significant conclusions:

1. For the tubesheet bore eccentricities and dilation due to the applied loading in the limiting plants in the models of SG considered, the tube remains in contact with the tubesheet bore.
2. While tubesheet bore eccentricity contributes to the reduction in contact pressure between the tube and the tubesheet, tubesheet bore dilation appears to be the principal cause of reduction of contact pressure between the tube and the tubesheet.

1.1 Discussion of 3D FEA Model for H* Analysis

Provide table showing maximum delta diameters (total diameter distortion) and maximum eccentricities (maximum diameter minus minimum diameter) from the 3 dimensional (3-D) finite element analysis for normal operating and steam line break (SLB), for model F and D5.

Response:

The 3D FEA Model and its application for determining the tubesheet displacements are extensively described in Section 6 of the H* WCAP reports (References 8 and 9). It is important to note that the 3D FEA model includes the entire tubesheet complex (i.e., tubesheet, stub barrel, channelhead and divider plate) but excludes the tubes. The model utilizes an equivalent material approach from Reference 6-5 in the WCAP reports to represent the deformation of the tubesheet under the applied loading conditions (NOP, SLB/FLB). Displacements in Cartesian coordinates are calculated for these conditions at any location on the tubesheet. The displacements calculated are the changes from an unstressed, room temperature condition after all thermal and pressure loads appropriate to the operating conditions are applied. Application of a uniform temperature increase causes uniform dilation at each tubesheet bore. Application of pressure loads causes distortions in the structure due to bending. The 3D FEA model provides integrated total displacements of each tubesheet bore location.

Table RAI4-1 is a summary of the maximum eccentricities and ΔD s for the Model F and Model D5 limiting plants as calculated based on the U_R (tubesheet radial displacement) results from the 3-D lower SG complex model.

Table RAI4-1: Summary of Model D5 and Model F NOP and SLB Eccentricity Results

SG Model	Elev.	Avg. Eccentricity Data			Max. Eccentricity Data			Avg. Δ D			Max. Δ D		
		Above BTS ⁽¹⁾	NOP	SLB	NOP	SLB	in/in	NOP	SLB	in	NOP	SLB	in
-	in	in/in	in/in	in/in	in/in	in/in	in	in	in	in	in	in	
F													
F													
F													
D5													
D5													
D5													
F													
D5													

Notes:
1. BTS is Bottom of the Tubesheet

The original Table RAI4-4 is provided here for convenience

Plant	Condition	Value	Eccentricity, e	Δ D, 0°	Δ D, 90°
Byron	SLB	MAX			
Byron	SLB	MIN			
Byron	SLB	AVG			
Millstone	SLB	MAX			
Millstone	SLB	MIN			
Millstone	SLB	AVG			
Byron	NOP	MAX			
Byron	NOP	MIN			
Byron	NOP	AVG			
Millstone	NOP	MAX			
Millstone	NOP	MIN			
Millstone	NOP	AVG			

1.2 Discussion of the “Slice” Model

Clarify the nature of the finite element model (“slice” model versus axisymmetric SG assembly model) used to generate the specific information in Tables 6-1, 2, and 3 (and accompanying graph entitled “Elliptical Hole Factors”) of Reference 6-15. What loads were applied? How was the eccentricity produced in the model? (By modeling the eccentricity as part of the geometry? By applying an axisymmetric pressure the inside of the bore?) Explain why this model is not scalable to lower temperatures.

The difference between initial and final eccentricity included in Table RAI4-2 needs to be explained. In particular, the exclusive use of the relationship between initial eccentricity and scale factor in calculating contact pressure needs to be justified.

Resolve the apparent inconsistency between Item 4 on page 25 and the statement below Figure RAI4-1 regarding how the model in Figure RAI4-1 is loaded.

Response:

The “slice model” is shown in Figure 6-9 of Reference 6-15 in WCAP-17071-P, WCAP-17072-P, WCAP-17091-P, and WCAP-17092-P.

The data in Tables 6-1, 6-2, and 6-3 of Reference 6-15 of the H* WCAP reports, are derived from this plane stress model (“slice model”) developed in WECAN/PLUS and the contact pressure equation identified on page 6-87 of WCAP-17071-P, page 6-95 of WCAP-17072-P, page 6-91 of WCAP-17091-P and page 6-84 of WCAP-17092-P as described below.

For convenience Tables 6-1, 6-2, and 6-3 of Reference 6-15 are replicated below and re-named as follows: Table 6-1 is renamed as Table RAI4-2, Table 6-2 is renamed as Table RAI 4-3, and Table 6-3 is renamed as Table RAI4-4.

The “initial” eccentricities (defined as $D_{MAX} - D_{MIN}$) applied in the “slice” model in Table RAI4-3 and Table RAI4-4 are directly incorporated into the model geometry. That is, the initial eccentricity is built into the model geometry. The eccentricity values in the model were assumed values for tubesheet tube bore deformation based on engineering judgment and prior experience.

In the “slice” model analysis, the tubesheet is assumed to have a thermal expansion coefficient of zero (0) in/in/°F and the tube material is assumed to have the appropriate ASME Code thermal expansion coefficient values. (The TS coefficient of thermal expansion is set to zero to provide a loading mechanism for the model. When a temperature is applied, the tube “grows” into the tubesheet collar. The temperature difference applied to the tube in the “slice” model was 500°F, for a total tube temperature of 570°F. [Applied 500°F + 70°F assumed room temperature]). The sole purpose of the development of the “slice” model was to provide a sensitivity study to relate the effects of assumed eccentricity ($D_{MAX} - D_{MIN}$) conditions to contact pressures from which the contact pressure ratios were developed. No attempt was made to

reproduce the contact pressures that would be calculated by the 2-D axisymmetric model that was previously used to develop the tubesheet displacements.

The “final” eccentricity ($D_{MAX} - D_{MIN}$) values in Table RAI4-3 and Table RAI4-4 were also determined using the “slice model”: The final eccentricity values are the ($D_{MAX} - D_{MIN}$) results of applying the loading conditions on the slice model: The loads applied to the “slice” model were thermal loads only as follows:

- 0 psig - Primary Side Pressure
- 0 psig - Secondary Side Pressure
- 500 °F- Tubesheet ΔT
- 500 °F- Channel Head ΔT
- 500 °F- Shell ΔT

As discussed in Reference 6-15, Table RAI4-3 was constructed using the displacement results from the plane stress model analysis for the elliptical holes along with the contact pressure equations. The effective change in hole diameter was calculated as follows using a series of assumed scale factors:

$$\left[\frac{\Delta D_{MAX}}{D_{MAX}} \text{ and } \frac{\Delta D_{MIN}}{D_{MIN}} \right]^{a,c,e} \quad (RAI4-1)$$

The ΔD_{MAX} and ΔD_{MIN} were taken from the radial and circumferential change in tube bore diameter in the “slice” model.

The corresponding contact pressure for each scale factor was then determined as follows:

$$\left[\frac{P_{CONTACT}}{P_{CIRCULAR}} \right]^{a,c,e} \quad (RAI4-2)$$

Equation RAI4-2 is a generic representation of how tube to tubesheet contact pressure is calculated in the H* integrator spreadsheet analysis. The equation is equivalent to the equation for P2 shown on page 6-87 in WCAP-17071-P, page 6-95 in WCAP-17072-P, page 6-91 in WCAP-10791-P and page 6-84 in WCAP-17092-P.

The scale factors for a given input eccentricity in Table RAI 4-3 result in contact pressure ratios using the thick shell equations that are equal to the contact pressure ratios calculated using the “slice” model for initial eccentricities (defined as $D_{MAX} - D_{MIN}$) equivalent to 0.0002, 0.0004, 0.0006 and 0.0008 inches, respectively, compared to the contact pressures for a circular hole ($D_{MAX} - D_{MIN} = 0$). These scale factors are identified in bold print in Table RAI4-3. The data for the scale factors as a function of “initial” eccentricity was fit by a third order polynomial equation provided on page 6-85 of WCAP-17071-P and page 6-86 of WCAP-17072-P.

Based on a review of Table RAI4-3 and Table RAI4-4, the scale factor []^{a,c,e} is the appropriate scale factor for calculating a reduction factor for contact pressure of []^{a,c,e} associated with an initial eccentricity of []^{a,c,e} ((D_{MAX} - D_{MIN})/ []^{a,c,e} inch) from the “slice” model. The scale factor of []^{a,c,e} relates to a contact pressure reduction factor of []^{a,c,e} and corresponds to an initial eccentricity of []^{a,c,e} inch, and so forth.

The “final eccentricity” values corresponding to the same scale factors highlighted in bold in Table RAI 4-3 (and Table RAI4-4) are not used in determining the reduction in contact pressure because the resulting third order polynomial relationship between scale factor and eccentricity is bounded by the relationship for “initial eccentricity”, i.e., the resultant scale factors, and hence the reduction in contact pressure due to eccentricity, would be less using the third order fit resulting from the “final” eccentricity values from Table RAI 4-3. For example, for an eccentricity of 1E-3 in/in, the scale factor is []^{a,c,e} as compared to []^{a,c,e} for the trend line associated with the “initial” eccentricity results. Figure RAI 4-1 illustrates this. This figure shows a comparison of the trend line analysis for “initial” eccentricity and “final” eccentricity. Referring to Equation RAI 4-1, larger scale factors result in a greater reduction in contact pressure due to eccentricity.

Table RAI4-2
Reproduced Table 6-1 of Reference 6-15

Eccentricity (inch)	Sleeve O.D.			Tube O.D.		
	Average ⁽¹⁾	Ratio ⁽³⁾	Delta ⁽¹⁾⁽²⁾	Average ⁽¹⁾	Ratio ⁽³⁾	Delta ⁽¹⁾⁽²⁾
0.0000						
0.0002						
0.0004						
0.0006						
0.0008						

a,c,e

Notes: This table is developed from the model shown in Figure RAI4-1, below.

- The units of these columns are stress in psi.
- The “delta” in this table refers to the maximum deviation from a constant value of the mean linearized radial stress around the tube bore.
- The ratio is calculated by dividing the contact pressure between the tube and the tubesheet at a given eccentricity by the contact pressure between the tube and the tubesheet in a round tube bore (e=0.0). For example, the ratio of []^{a,c,e} calculated in Table 6-1 is a ratio of the average contact pressure at an eccentricity of 0.0002 in of []^{a,c,e} psi divided by the average contact pressure at an eccentricity of []^{a,c,e} psi.

Table RAI4-3

Reproduction of Table 6-2 of Reference 6-15

Primary Pressure	0	psig
Secondary Pressure	0	psig
Tubesheet Delta T	500	°F
Shell Delta T	500	°F
Channel Head Delta T	500	°F
Sleeve OD Delta D	[] ^{a,c,e}	in
Tube ID Delta D	[] ^{a,c,e}	in
Tube OD Delta D (Thermal)	[] ^{a,c,e}	in
Sleeve/Tube Interaction Coefficients	[] ^{a,c,e}	
Tube/Tubesheet Interaction Coefficients	[] ^{a,c,e}	

Eccentricity		(1)	(2)	(3)	(4)	(5)	(6)
Initial (inch)	Final (inch)	Max/Min Combination _{a,c,e}	Hole Delta D (0 Deg)	Hole Delta D (90 Deg)	S/T Contract Pressure	T/TS Contact Pressure	Ratio
0.0000		Minimum Average Maximum					_{a,c,e}
0.0002		Minimum Average _{a,c,e} <div style="border: 1px solid black; height: 100px; width: 100%;"></div> Maximum					
0.0004		Minimum Average _{a,c,e} <div style="border: 1px solid black; height: 100px; width: 100%;"></div> Maximum					

Table RAI4-3 (Cont'd.)

<i>Eccentricity</i> ^{a,c,e}	(1)	(2)	(3)	(4)	(5)	(6)
0.0006	<i>Minimum</i>					
	<i>Average</i> ^{a,c,e}					
	<i>Maximum</i>					
0.0008	<i>Minimum</i>					
	<i>Average</i> ^{a,c,e}					
	<i>Maximum</i>					

*Note: The values in **Bold** identify the source data for Table RAI4-3*

Table RAI4-4

Reproduction of Table 6-3 of Reference 6-15

Initial Delta Dia (in)	Eccentricity ⁽¹⁾		Max/Min Factor	Pressure Ratio
	Initial (in/in)	Final (in/in)		
0.0000				
0.0002				
0.0004				
0.0006				
0.0008				

(1) These values are the values for initial and final eccentricity from Table RAI4-2 are divided by the nominal tubesheet hole diameter [] ^{a,c,e}

[] ^{a,c,e}

a,c,e



Figure RAI4-2: Scale Factor Comparison (Initial versus Final Eccentricity)

The method for calculating the contact pressure for using the “old” method for the Model F SGs (all plant conditions) and the Model D5 SGs (NOP and FLB conditions) and the “new” method for calculating the contact pressure the Model D5 SGs only (SLB conditions) are described below:

Old Method (Reference 6-15):

1. The U_R used in the calculation of the circumferential and radial ΔD is based on the linearly scaled 2D axisymmetric FEA model (3-D model for the current H^* analysis) of the lower SG complex
2. The circumferential and radial ΔD 's are used in the scale factor (SF) equation to determine the ΔD_{hole} (see equation RAI4-1) that is used to determine the reduction in contact pressure as a function of eccentricity (e), equation RAI4-2.
3. The relationship between 11D and e is based on the 2-D plane model shown in Figure 6-9 of SM-94-58, Rev.1.

4. The model in Figure 6-9 of SM-94-58, Rev.1 includes the initial applied eccentricities ($D_{MAX} - D_{MIN}$) geometry definition of the model.
5. The “slice” model provides the input for using the SF relationship (Eqn. RAI4-1). The SF is determined by comparing the “slice” model results to the axisymmetric model results for a TS collar and tube model at a given radius in the TS over the full thickness of the TS.
6. The result is then used to calculate the reduction in contact pressure as a function of TS elevation and radius due to TS displacement and tube bore eccentricity. This is appropriate because the conditions for the Model F SG and Model D5 SG (NOP and FLB conditions) are within the range of data for which the scale factor relationship is applicable.

New Method (WCAP-17071-P, WCAP-17072-P):

1. The U_R used in the calculation of the circumferential and radial ΔD comes from a 3-D FEA model of the lower SG complex with condition-specific inputs applied.
2. The circumferential and radial ΔD 's are compared to determine the maximum ΔD that will give the maximum reduction in contact pressure as a function of eccentricity (e).
3. The relationship between ΔD and e is based on the 2-D []^{a,c,e} model shown in WCAP-17071-P and WCAP-17072-P, section 6.2.5. The model is shown in Figure 6-49 of the WCAP reports. The range of eccentricity used in this study conservatively exceeds the values of tube bore eccentricity calculated from the perforated TS model in Section 6.2.4.
4. The model in Figure 6-49 of the H* WCAP reports applies boundary conditions to the outer edge of the tube pitch material and does not directly affect the material that is deforming in the tube and tubesheet cell.
5. The TS deformations and tube to tubesheet contact pressure results that produce the maximum reduction in contact pressure at the minimum value of TS tube bore eccentricity are then fit with a linear relationship.
6. The result of the linear relationship is used to determine the reduction in contact pressure between the tube and the tubesheet directly. There are no intermediate equations or results.

A correct prediction of contact pressure loss requires the knowledge of both the proper values of D_{MAX} and D_{MIN} associated with the different pressure and temperature conditions at a given tubesheet radius and elevation as well as the value of eccentricity. The values of D_{MAX} and D_{MIN} are a function of the radial deflection of the tubesheet, U_R , as determined by the finite element analysis model (which previously was a 2-D axisymmetric model of the SG lower

assembly and at present, is a 3-D model of the SG lower assembly). The results from the “slice” model cannot be linearly scaled to lower temperatures because the method of superposition has been shown during the development of the current H* analysis to not apply to the non-linear combination of materials and loading in the lower SG complex. This conclusion led to the development of the 3D FEA model that is the reference model for the H* analysis. A discussion of this is provided in Section 6.1.2 of WCAP-17071-P and WCAP-17072-P.

1.3 Discussion of the Unit Cell Model to Calculate Contact Pressures

The “Unit Cell” model is extensively discussed in Section 6.2.5 of the H* WCAPs (References 8 and 9). The specific goal of this model was to determine if tube to tube contact would remain when the tubesheet is deformed due to operating loads. An equivalent tubesheet cell is modeled, that is, a tubesheet bore with surrounding tubesheet material, and a tube in the tubesheet bore (see Figure 6-48 of the H* WCAPs). For the primary purpose of this model – to study if tube-to-tubesheet contact is present during the limiting tubesheet deformations – the model was initialized by simulating the tube expansion process. The expansion process was conservatively simulated by applying a low value of expansion pressure []^{a,c,e} inside the tube, resulting in initial tube to tubesheet contact, and then removing the tube expansion internal pressure. The calculated dilation of the tubesheet bore due to the simulation of the tube expansion is []^{a,c,e} inch for all models of SG considered.

As discussed in Section 6.2.5 of the H* WCAP reports, the operating pressure loads, were applied to the initialized model in a sequential manner, and the resulting contact pressures were calculated when a range of displacements (termed “E-bar”) were applied as boundary conditions to the model. Figure RAI4-2 shows the updated sequential loading (includes application of thermal loads) of the model and relates it to the steps discussed in Section 6.2.5 and Tables 6-18 and 6-19 of the H* WCAPs. The “E-bar” values shown as the displacement inputs on Tables 6-18 and 6-19 in the H* WCAP reports are uni-directional displacements (in inches) that are NOT the same as eccentricity and also not the same as ΔD . (Eccentricity is defined as the difference between the maximum and minimum diameters of a bore divided by the nominal diameter of the bore. The units of eccentricity are inch/inch.) The displacement inputs applied to the unit cell model are assumed values that based on prior analyses that envelope the expected tubesheet displacement for all of the applicable operating conditions. It is important to note that the unit cell model as described in Section 6.2.5 of the H* WCAP reports utilizes boundary conditions chosen to minimize the tube-to-tubesheet contact pressures for the applied relative displacements.

To interpret the results from the unit cell model properly, the following must be observed:

- To address if tube to tubesheet contact continues for all the assumed tubesheet displacements, the appropriate reference condition is the initialized condition (after Step 4) of the model that simulates a tube expanded in the tubesheet bore.

- To compare the results of the unit cell model with the 3D FEA model, the appropriate reference condition of the unit cell model is the initial model (Step 0) without the tube expansion simulated and thermal loads must be included.

Figures RAI4-3 and RAI4-4 show the average tubesheet bore dilation (ΔD) as a function of tubesheet relative displacement (E-bar) for the Model F and Model D5. The average tube bore dilation at zero E-bar input is the result of the temperature and pressure loading of the unit cell model. Initially, application of the displacement input “E-bar” results in more significant hole dilation, but rapidly takes on a shallower slope as the applied displacement increases. The curves are characteristically the same for the Model F and Model D5 steam generators and also for the different operating conditions, NOP and SLB, for the different models of SGs.

Similarly, Figures RAI4-5 and RAI4-6 show the tubesheet bore eccentricity “e” as a function of tubesheet relative displacement (E-bar) for the Model F and Model D5. Eccentricity initially increases with application of the displacement boundary condition (E-bar) simulating the load due to pressure differential across the tubesheet, but the rate of increase decays with increasing E-bar. A significant difference is noted between NOP and SLB conditions at large values of E-bar. This difference reflects the fact that the uniform growth of the tube bore hole due to increased temperature overwhelms the effect of application of the displacement boundary condition (E-bar) on tubesheet bore eccentricity. During the SLB event, the temperature is decreased and the differences in D_{MAX} and D_{MIN} remain more significant as the displacement boundary condition is increased, although the rate of increase in the difference between D_{MAX} and D_{MIN} is reduced at some point. . Eventually, at NOP conditions, the difference between D_{MAX} and D_{MIN} tends to become decrease even though a greater displacement (E-bar) is applied, leading to a reduction of eccentricity “e.”

Figures RAI4-7 and RAI4-8 show the contact pressure as a function of tubesheet relative displacement (E-bar) for the Model F and Model D5 for both NOP and SLB conditions based on the unit cell model. As expected, both NOP and SLB contact pressure decrease with increasing displacement inputs, ultimately going to zero at a very large value of applied displacements. It is to be noted that the maximum displacement assumed is significantly greater than would be predicted by the 3D FEA model. Over the entire range of assumed displacement conditions, the SLB contact pressure exceeds that for NOP conditions.

Table RAI4-5 summarizes the eccentricity, ΔD and predicted contact pressure using the unit cell model for various values of applied displacement (E-bar) for both the model F and Model D5 SGs. The true eccentricity ($[D_{max}-D_{min}]/D_{nom}$) is shown for the applied displacement, E-bar. Table RAI4-5 also provides a comparison of the ΔD predicted by the unit cell model for the two reference conditions noted above, that is, for the total ΔD from the model without the simulated tube expansion (reference step 0 in Table 6-18) and for the initialized case with the tube expansion simulated (reference step 4 in Table 6-18).

Further, Table RAI4-5 provides a summary of contact pressures between the tube and the tubesheet for various applied values of E-bar for the Model F and Model D5 SGs. The “Modified Contact Pressure” is the “Raw Contact Pressure” from the unit cell model adjusted for the actual tube expansion process ([]^{a,c,e} psi compared to the simulation at []^{a,c,e} psi) real Model F and Model D5 geometry and more realistic operating conditions of pressures and temperatures. For all cases of applied displacement, positive contact pressure remains between the tube and tubesheet. It should be noted that the largest value of applied displacement (E-bar) is well in excess of the displacement predicted by the 3D FEA model.

Table RAI4-6 provides similar data to that in Table RAI4-5, except that the data is based on the 3D FEA model.

Comparison of Tables RAI4-5 and RAI4-6 leads to the following observations:

1. The ΔD s from the 3D FEA model are significantly less than the corresponding ΔD s from the unit cell model from the unloaded to the fully loaded condition (i.e., from step 0 to step 9) for both NOP and SLB conditions. This leads to the conclusion that the unit cell model displacement results and contact pressure predictions conservatively represent the reference 3D FEA model results.
2. The eccentricities from the unit cell model are generally comparable to those from the 3D FEA model. A more exact comparison is difficult based on the available data; however, it is clear that the actual range of eccentricities from the 3D FEA model was adequately addressed by the unit cell model.
3. The method of Reference 6-15 of the H* WCAP report for adjusting contact pressure provides acceptable results for all conditions except the SLB condition for the Model D5 SGs. The method of Reference 6-15 significantly under-predicts contact pressure for the Model D5 SLB conditions. Referring to Figure RAI4-6, the method for calculating the reduction in contact pressure defined by the White Paper, when adjusted for temperature effects, shows that SLB contact pressure is increased relative to normal operating conditions.

**Table RAI4-5
Eccentricity, Contact Pressure and ΔD Results from Unit Cell Model**

SG Model	"E bar" in	Square Cell Results			Square Cell Results			Square Cell - Average Delta D			
		Eccentricity	Raw Contact Pressure ⁽¹⁾	Modified Contact Pressure ⁽¹⁾	Step 0 ⁽²⁾ - Step 9 ⁽³⁾	Step 4 ⁽⁴⁾ - Step 9 ⁽³⁾	Step 0 ⁽²⁾ - Step 9 ⁽³⁾	Step 4 ⁽⁴⁾ - Step 9 ⁽³⁾			
-	in/in	NOP	SLB	psi	NOP	SLB	psi	NOP	SLB	in	in
F											
F											
F											
F											
D5											
D5											
D5											
D5											

a,c,e

Notes:

1. Accounts for expansion pressure and geometry.
2. See Section 6.2.5 H* WCAP. Step 0 is the condition of the unit-cell model prior to any modifications for tube expansion, loading, etc.
3. See Section 6.2.5 H* WCAP. Step 9 is the condition of the unit cell model after all loading conditions have been applied.
4. See Section 6.2.5 H* WCAP. Step 4 is the initialized condition of the Unit Cell model after tube expansion has been simulated.

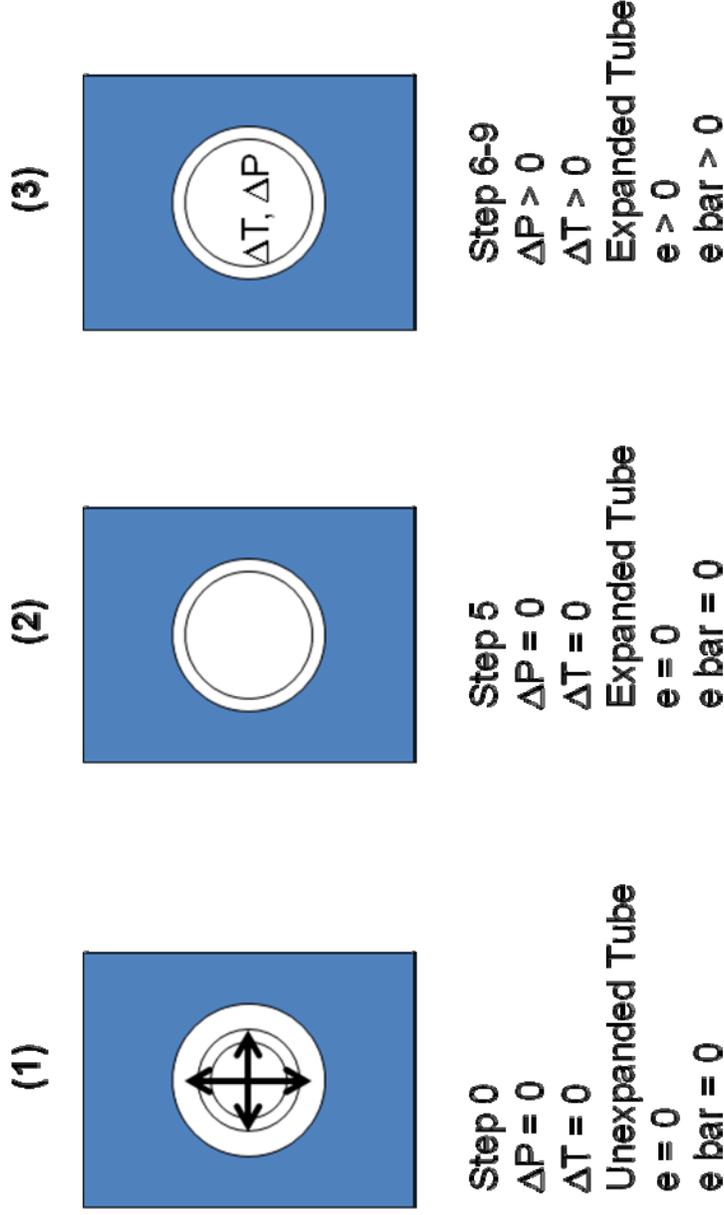
**Table RAI4-6
Eccentricity, Bore Dilation and Contact Pressure from 3D FEA Model**

	Hstar Analysis Eccentricity		Hstar Analysis Avg. Contact Pressure		Hstar Analysis - Avg. Δ D No Load to Operating	
	NOP	SLB	NOP	SLB	NOP	SLB
	in/in	in/in	psi	psi	in	in
SG Model and Contact Pressure Reduction Model						
F - Ref. 6-15						
Limiting Radius - F - Ref. 6-15						
D5 - Ref. 6-15						
D5 - White Paper						
Limiting Radius - D5 - Ref. 6-15						
Limiting Radius - D5 - White Paper						
F - Updated Model ⁽¹⁾						
D5 - Updated Model ⁽¹⁾						

a,c,e

⁽¹⁾: Updated Model Results based on estimates from approximate values in finite element analysis and do not reflect the result of a regression analysis.

Figure RAI4-2
Unit Cell Model and Loading Sequence



Loading Steps:

0. Initial Model
1. Initial Tube to TS gap
2. Pressurize tube to 16ksi
3. Pressurize tube to 28ksi
4. Release Pressure on Tube
5. Apply $\Delta T^{(1)}$
6. Apply "E-bar"
7. Apply $\Delta P = []^{a,c,e}$ psi
8. Apply $\Delta P = []^{a,c,e}$ psi
9. Apply $\Delta P = []^{a,c,e}$ psi

Notes: (1) The application of the unit cell model in support of Tables 6-18 and 6-19 does not include application of ΔT .



Figure RAI4-3
Relationship between "E-bar" and ΔD ; Model F



Figure RAI4-4
Relationship between "E-bar" and ΔD ; Model D5



**Figure RAI4-5
Relationship between "E-bar" and Eccentricity "e"; Model F**



**Figure RAI4-6
Relationship between "E-bar" and Eccentricity "e"; Model D5**



Figure RAI4-7
Relationship between "E-bar" and Contact Pressure; Model F



Figure RAI4-8
Relationship between "E-bar" and Contact Pressure; Model D5

2.0 Comparison of Slice Model and Unit Cell Model Results

The basis for applying the correlation for scale factor outside an “eccentricity” range of between 1E-3 to 1E-4 inch in the calculation of contact pressure needs to be further explained. Values for displacements included in Table 6-18 (of WCAP-17071) suggest that contact pressure may be lost at displacement ranging between 1E-3 in to 1E-4 in.

Response:

Interpretation of the displacements noted in Table 6-18 of the WCAP reports was clarified in the prior response, Section 1.3. The values noted in the column titled “Displacement Total” refer to the condition of the unit cell model after Step 4 of the loading sequence (See Figure RA14-2). When the true reference condition (Step 0) for total displacement is considered, the values of total displacement are significantly larger as noted previously.

Westinghouse agrees that the derivation of the fit in Reference 6-15 is non-intuitive and limited in its application. However, the results of applying the fit described in reference 6-15 are acceptable relative to a best case finite element model (unit cell with thermal and ΔP loading) for the reasons described below.

Westinghouse also agrees that the fit that describes the reduction in contact pressure for the steam line break condition in the Model D5 White Paper does not account for the reduction in contact pressure due to tube bore dilation in the same manner as the fit described in Reference 6-15. The results of using the fit described in Reference 6-15 also match the expected trend from a best case finite element model. See the response to b.4 below for more details.

A series of tubesheet tube bore eccentricities were applied to the tubesheet cell model and combined with different pressure and temperature loads. The average, maximum and minimum values of the tube-to-tubesheet (T/TS) contact pressures around the circumference of the tube were reported. The values of tubesheet relative displacement, pressure and temperature that were used in the analysis are summarized in the table below.

Input Conditions for Unit Cell Model (no correlation implied)		
\bar{e}	Internal Pressure	Temperature Difference
in	ΔP , psi	ΔT , °F _{a,c,e}
0.00	[]
2.0E-04	[]
4.0E-04	[]

Normal operating (NOP) conditions in the Model D5 and Model F steam generators are represented by a ΔP of []^{a,c,e} psi and a ΔT of []^{a,c,e} °F. Main steam line break (SLB) conditions in the Model D5 are represented by a ΔP of []^{a,c,e} psi and a ΔT of []^{a,c,e} °F. The value of ΔP in the tubesheet cell can change as a function of elevation in the tubesheet due to the distribution of crevice pressure. The results of the study include the data for a depth ratio of 0.9 which is an elevation roughly 2 inches below the top of the tubesheet. The values of ΔP represented in this study account for the region of interest near the top of the tubesheet where the maximum eccentricity in the tubesheet is expected and where the crevice fluid is transitioning from the crevice conditions to the secondary side fluid conditions. The region roughly 2 inches below the top of the tubesheet is also where a significant portion of the T/TS contact pressure develops so it is a good indicator of trends in the effect that different operating conditions have on the contact pressure.

The original results in section 6.2.5 of WCAP-17071-P were used to verify that the reduction in T/TS contact pressure as a function of tubesheet tube bore eccentricity was appropriate for the Model F SG. The original relationship that is used to define the reduction in T/TS contact pressure as a function of eccentricity is described in section 6.3 of WCAP 17071-P and WCAP 17072-P. However, the result of applying the fit described in section 6.3 to the Model D5 SG during SLB was shown to be inconsistent with the expected trend from the more detailed analysis described in section 6.2.5. The results of section 6.2.5 were then used to define a new relationship between the reduction in T/TS contact pressure and tube bore eccentricity. This new relationship is described in the Model D5 White Paper (Reference 12). Figure RAI4-8 shows the result of applying the new relationship to the Model D5 SLB conditions (i.e., White Paper results, Reference 12) in comparison with the results from the old 3rd order polynomial relationship. Because the tubesheet temperature induced hole dilation, potentially the most significant factor in contact pressure reduction, was not considered in the Model D5 condition results, a third curve was added to the figure titled "Model D5 FEA trend." This curve represents the most accurate calculation of the contact pressure ratio.

Figure RAI4-9 shows the contact pressure ratio (PC_{SLB}/PC_{NOP}) as a function of tubesheet relative displacement, E-bar. It is clear from Figure RAI4-9 that the results of using the old fit for the Model D5 SLB are inconsistent with the more detailed analysis. At SLB conditions, the tubesheet bore dilation is relatively larger than at NOP conditions due to the increased bending of the TS and decreased thermal expansion. Therefore, it is expected that the T/TS contact pressure ratio should increase by a factor of at least []^{a,c,e} (see Figure RAI4-9) when going from NOP to SLB. It is also expected that the tube to tubesheet contact pressure should decrease with increasing tube bore eccentricity. The H* results using the old fit for the Model D5 clearly do not follow either expectation from the detailed analysis. However, when the new fit results are applied to the H* calculation process the relationship between T/TS contact pressure in the Model D5 is much more reasonable and follows the expected trend from the more detailed analysis.

The Model F H* contact pressure results, using the old fit, are well within the range predicted by the more detailed analysis in section 6.2.5 and the additional work described in this RAI response. See Figure RAI 4-10 below. This means that the old fit is appropriate to use for the

Model F NOP and SLB conditions and the NOP condition in the Model D5 SG. The results of using the fit described in Reference 6-15 match the expected trend from a best case finite element model for the NOP and SLB conditions for the Model F SGs and NOP conditions for the Model D5 SG.

To further address the concern that contact pressure may be lost at displacements ranging between 1E-3 in and 1E-4 in, the "Unit Cell" model is extensively discussed in Section 1.3 of this response above.



a,c,e

Figure RAI 4-9



a,c,e

Figure RAI 4-10

2.1 Calculation Basis for Contact Pressure Reduction Factors

Provide the calculation basis for the upper and lower curves provided in Figure RAI 4-2

Response:

The original figure RAI4-2, referred to in the question, is reproduced here as RAI4-10 to provide the foundation for the question and the response. Note that the scale of the y-axis has been corrected as discussed in the meeting on August 17, 2009.

a,c,e



Figure RAI4-10 (original Figure RAI4-2)

The upper curve in the figure above is based on the data from the following table:

Eccentricity ($\Delta D_{max} - \Delta D_{min}$) (in)	Reduction in Contact Pressure (psi)(1)	Normalization Basis (psi)	Contact Pressure Reduction Factor(psi/psi)
0	0	1200	0
2E-4	[] ^{a,c,e} psi		[] ^{a,c,e}
4E-4	[] ^{a,c,e} psi		[] ^{a,c,e}
5E-4	[] ^{a,c,e} psi		[] ^{a,c,e}
6E-4	[] ^{a,c,e}		[] ^{a,c,e}
Notes: (1) Contact stress reductions are based on the values on Table RAI4-3			

Referring to Table RAI 4-3, the contact pressure for a round tube bore hole is calculated to be []^{a,c,e} psi (Ratio = 1.0). The contact pressure for a tube bore hole that results in a contact pressure ratio reduction of []^{a,c,e} (Ratio = []^{a,c,e}), which corresponds to an eccentricity of 2E-4 inch, is []^{a,c,e} psi. The absolute reduction in contact pressure is []^{a,c,e} psi.

The total reduction in contact pressure using the new model is approximately []^{a,c,e} psi (see Figure 6-69 of WCAP-17072-P). To plot the absolute reduction in contact pressure of []^{a,c,e} psi for an eccentricity of 2E-4 on Figure RAI4-10, the value is normalized by the total reduction in contact pressure of []^{a,c,e} psi from the new method. This value represents a reduction in contact pressure of []^{a,c,e}.

Again, referring to Table RAI 4-3, the contact pressure for a round tube hole is calculated to be []^{a,c,e} psi. The contact pressure for a tube bore hole that results in a contact pressure ratio reduction of []^{a,c,e} (Ratio = []^{a,c,e}), which corresponds to be eccentricity of 4E-4 inch, is []^{a,c,e} psi. The absolute reduction in contact pressure is []^{a,c,e} psi.

Again, the total reduction in contact pressure using the new model is approximately []^{a,c,e} psi (see Figure 6-69 of WCAP-17072-P). To plot the absolute reduction in contact pressure of []^{a,c,e} psi for an eccentricity of 4E-4 on Figure RAI4-10, the value is normalized by the total reduction in contact pressure of []^{a,c,e} psi from the new method. This value represents a reduction in contact pressure of []^{a,c,e}.

The same calculation was completed for an eccentricity of 6E-4 in. The value for 5E-4 in is an interpolated value between 4 E-4 in and 6E-4 in.

The bottom curve in the figure above is generated using the 3rd order polynomial fit. The results are summarized in the following table:

E, eccentricity (in)	T/TS Contact Pressure Reduction (psi)	Normalized Contact Pressure Reduction
6.36E-07	[] ^{a,c,e}	[] ^{a,c,e}
5.53E-05	[] ^{a,c,e}	[] ^{a,c,e}
3.16E-04	[] ^{a,c,e}	[] ^{a,c,e}
5.69E-04	[] ^{a,c,e}	[] ^{a,c,e}
9.07E-04	[] ^{a,c,e}	[] ^{a,c,e}

2.2 Conservatism of 3rd Order Polynomial Fit from WCAP Reference 6-15

Provide the basis for why the ΔD_{hole} adjustment for contact pressure made using the old model remains conservative.

Response:

The key conclusions from the comparison of the Reference 6-15 analysis, the WCAP results and the results of the square cell tubesheet model are:

- 1.) The fit described in Reference 6-15 of the H* WCAP reports is conservative when applied to the NOP condition in both the Model D5 and Model F SG. The fit tends to underestimate the contact pressure during NOP by as much as []^{a,c,e} psi to []^{a,c,e} psi for the Model F SG and as much as []^{a,c,e} % for the Model D5 SG ([]^{a,c,e} psi to []^{a,c,e} psi) (see Table RAI4-6).
- 2.) The fit described in Reference 6-15 of the H* WCAP reports is comparable when applied to the SLB condition in the Model F SG. The fit described in the Model D5 White Paper tends to over-estimate the contact pressure, by as much as []^{a,c,e} %, during SLB ([]^{a,c,e} psi to []^{a,c,e} psi) because the White Paper does not fully account for the change in tube bore diameter during the transient.
- 3.) The fit described in Reference 6-15 of the H* WCAP reports significantly under-estimates the contact pressure, by as much as []^{a,c,e} %, during the D5 SLB condition (from []^{a,c,e} psi to []^{a,c,e} psi).
- 4.) The square cell tubesheet finite element model shows an increase in contact pressure when going from NOP to SLB conditions in both the D5 and F SGs.

- 5.) Using the results from the square cell model to estimate the magnitude of the contact pressure reduction from the change in tube bore diameter calculated using the 3D finite element results from the lower SG tubesheet complex model show that the contact pressure still increases when going from NOP to SLB conditions in both the Model F and Model D5 SG.

The results of this analysis show that NOP contact pressures that define H^* in the Model F and Model D5 SG are conservative and that a more realistic model of contact pressure reduction as a function of tube bore deformation (including both dilation and eccentricity) would predict an increase in tube to tubesheet contact pressure at SLB conditions compared to NOP conditions.

(See also Section 2.3)

2.3 SLB vs. NOP Contact Pressures

Provide an appropriate basis for demonstrating that joints tighten during a postulated SLB event. Why is it acceptable to compare the contact pressures calculated using the original model for NOP to the contact pressures calculated using the new model for SLB for the Model D5 SGs?

Response:

Table RAI4-5 provides a summary of contact pressures between the tube and the tubesheet for various applied values of E-bar for the Model F and Model D5 SGs. Comparison of the eccentricity values calculated using the unit cell model (see Table RAI4-5) with the eccentricity values calculated from the 3D FEA model (see Table RAI4-1) shows that the eccentricities from both models are comparable. It is not reasonable to expect exact matches of numbers between the two models, however, the order of magnitude of the calculated eccentricities is the same. Given that the two structural models provide similar eccentricities, the unit cell model shows that for these eccentricities, positive contact pressure exists between the tubes and the tubesheet for the entire range of displacements considered. Further, the results show that the contact pressures at SLB conditions exceed those at NOP conditions (See Table RAI4-6). See also the discussion in Section 2.4 below.

2.4 Relative Conservatism of “Old” and “New” Fit

If both old and new models are conservative, is there an appropriate basis to show the relative conservatism of the methods?

Response:

As noted above in Section 1.3 of this response, tube bore dilation is a more significant factor in determining tube-to-tubesheet contact pressure at higher temperatures and the effect of eccentricity on contact pressure is reduced at higher temperatures. The methodology for addressing the effect of eccentricity on contact pressure discussed in Reference 6-15 and utilized in WCAP-17071-P, WCAP-17072-P, WCAP-17091-P and WCAP-17092-P reflects this fact and it, therefore, provides acceptably accurate contact pressure results at higher temperatures (i.e., for all conditions except the “colder” SLB condition). This includes NOP, SLB (higher temperature, > 400°F, and FLB, where appropriate).

Also, as noted in Section 1.3 of this report, the effect of eccentricity on contact pressure loss is a more significant factor at the lower SLB temperatures for the Model D5 SG, but tube bore dilation due to temperature and pressure needs to be considered (which was not addressed in the “new” method, a.k.a the White Paper method discussed in WCAP-17072-P or 17091-P). Moreover, the original 3rd order polynomial fit significantly over-predicts contact pressure loss during the “colder” Model D5 SLB transient (and Model 44F two loop plant SLB).

Therefore, a more detailed model for contact pressure during a postulated SLB was developed. Referring to Table RAI4-6, it shows that contact pressure increases during a SLB event ([]^{a,c,e} psi) relative to NOP ([]^{a,c,e} psi) with primary and secondary side temperatures as low as 212°F when comparing contact pressures for NOP conditions for the unit cell to contact pressures for SLB for the unit cell.

Again, referring to Table RAI4-6, it has been shown when comparing contact pressures for NOP conditions for the unit cell to contact pressures for SLB for the unit cell for the Model F SG (higher temperature SLB conditions), that contact pressure increases during a postulated SLB (from []^{a,c,e} psi at NOP to []^{a,c,e} psi at SLB).

3.0 Comparison of 3D FEA and Unit Cell Model Results

The eccentricities included in Table RAI 4-4 appear larger than anticipated. Need to confirm that positive contact pressure exists around the entire circumference of the tube and state this clearly in the response.

Response:

Comparison of the eccentricity values calculated using the unit cell model (see Table RAI4-5) with the eccentricity values calculated from the 3D FEA model (see Table RAI4-1) shows that the eccentricities from both models are comparable. It is not reasonable to expect exact matches of numbers between the two models, however, the order of magnitude of the eccentricities calculated is the same. Given that the two structural models provide similar eccentricities, the unit cell model shows that for these eccentricities, positive contact pressure exists between the tubes and the tubesheet for the entire range of displacements considered. Further, the results show that the contact pressures at SLB conditions exceed those at NOP conditions.

4.0 Additional Background Information For Key Questions and Issues

RAI#4 evolved in several stages, each stage building on the prior stage. Reference 10 provided additional questions to augment those that were provided by Reference 5. Responses were prepared and were discussed in a telephone conference on August 11, 2009. During this telephone conference, additional questions were raised as identified in the introduction of this document. The following are responses that were provided in response to Reference 10 that were discussed in the August 11, 2009 telephone conference. They are historical in nature and are provided to complete the record of information provided in response to the NRC request for additional information.

4.1 Comparison of “Old and New” Relationship for Reduction in Contact Pressure and Eccentricity

In Figure 2 of the White Paper, add a plot for original relationship between reductions in contact pressure and eccentricity as given in Reference 6-15 in the graph accompanying Table 6-3. Explain why this original relationship remains conservative in light of the new relationship. Explain the reasons for the differences between the curves.

In order to superimpose the results of the “old” and “new” analyses for reduction in contact pressure related to eccentricity, the data for the “old” method must be normalized in the same fashion that Figure 2 has been normalized. The plot of contact pressure reduction included in

Figure 2 of the White Paper represents the total reduction in contact pressure associated with a given eccentricity. The information from Table 6-3 represents the ratio of the contact pressure calculated at a given eccentricity divided by the contact pressure calculated for a tubesheet bore with no eccentricity. For the new analysis, the total reduction in contact pressure for the eccentricities ($D_{MAX} - D_{MIN}$) for a range of up to []^{a,c,e} inch is determined to be []^{a,c,e} psi. For the old analysis, the total reduction in contact pressure for eccentricities in the same range is calculated to be []^{a,c,e} psi. The normalization basis is the same for both curves on the figure.

Figure RAI4-11, showing the normalized results as discussed during the August 17, 2009 meeting, is provided below. (Figure RAI4-11 is the same as Figure RAI4-10 in Section 2.1 of this document, except that the values of the “Old Polynomial Results” have been corrected on Figure RAI4-10 by a factor of 2 as discussed in the August 17, 2009 meeting.) The curve labeled “Old” Model Results is based on the data from Table RAI4-3 (Table 6-2 of Reference 15 of the WCAP report). The curve labeled “New” Model reproduces Figure 2 in the White Paper (Reference 12). The curve labeled “D5 SLB Polynomial Fit” are the results when the eccentricity data and ΔD_{hole} for the Model D5 SLB condition are applied directly to the polynomial fit, equation 6-8 in WCAP-17072-P and similar equation on page 6-85 in WCAP-17071-P. The latter curve is based on the maximum displacement conditions at the top of the tubesheet for the Model D5.

The curve labeled “Old Model Results” (top curve on Figure RAI4-11) is misleading relative to making an assessment of the conservatism of the new analysis method compared to the old analysis method. Unlike the new analysis method, which is only applied to the SLB case for the Model D5 SGs, the old analysis method has not been applied as a linear function as represented in the figure as the uppermost curve (solid squares). In reality, the old data fit (top curve on Figure RAI4-11), which is a 3rd order polynomial fit, when extrapolated significantly outside its supported data range (i.e., at temperatures either significantly above or below 500°F), provides physically unrealistic results as shown on Figure RAI4-11 (bottom curve, Δ -symbols). The Model D5 SLB condition puts the tubesheet at a nearly uniform temperature of less than 300°F, which is far outside of the range for which the eccentricity relationship was developed in Reference 6-15 in the WCAP reports.

The original relationship remains conservative because it predicts greater reduction of tube to tubesheet contact pressure than the new method for all operating conditions. However, the original relationship is only valid when ΔD_{min} and ΔD_{max} are within []^{a,c,e} % and eccentricity is within []^{a,c,e} inch to []^{a,c,e} inch range, (i.e., the basis of the original fit).

The maximum tube bore distortions occur at the top of the tubesheet. The results from applying the old fit for the relationship versus the new fit for the relationship for the Model D5 SLB tubesheet displacements and contact pressures are shown in Table RAI4-7. The tube-to-tubesheet (T/TS) contact pressure result due to thermal expansion of the tube and the pressure expansion of the tube including the effect of the crevice pressure distribution, is the same in the both the “old” and “new” cases in the Table RAI4-7 .

**Table RAI4-7
Summary of Model D5 SLB Contact Pressure Results for
Different Eccentricity Fit Relationships**

Model D5	Value	Eccentricity	T/TS P _{CON} Reduction		T/TS P _{CON}	
			Old	New	Old	New
SLB	Avg					
SLB	Max					
SLB	Min					

The results in Section 6.2.4 of WCAP-17071-P and WCAP-17072-P show that the average expected tubesheet-tube-bore eccentricity is on the order of []^{a,c,e} inch. The results in Table RAI4-7 show that the old method of calculating the reduction in contact pressure due to tubesheet-tube-bore eccentricity and change in diameter is conservative for larger values of eccentricity and ΔD (predicts greater decrease in contact pressure) than the new fit. However, it is inappropriate to use the old method at smaller values of eccentricity and ΔD because it provides physically impossible results (see Table RAI4-7). For example, the “old” method predicts a larger decrease in contact pressure for a smaller eccentricity on the order of 10⁻⁷ inch than for a larger eccentricity on the order of 10⁻³ inch. The “new” method, by comparison, predicts a slightly positive increase in contact pressure for an eccentricity of 10⁻⁷ inch and a large reduction in contact pressure for an eccentricity of 10⁻⁴ inch or greater, a physically realistic result. The reason that the “old” method predicts such a different reduction in contact pressure for small values of eccentricity is that these small eccentricity values are well outside the range of the data upon which the “old” relationship was developed. However, when used within its intended range of eccentricities and tubesheet bore displacement, the “old” method provides valid and conservative results. The “new” method of calculating the reduction in T/TS contact pressure is linear and directly accommodates small calculated values of eccentricity. It is also clear from the results in Table RAI4-7 that the results from the old method when used in its supported eccentricity range are highly conservative compared to the “new” method.

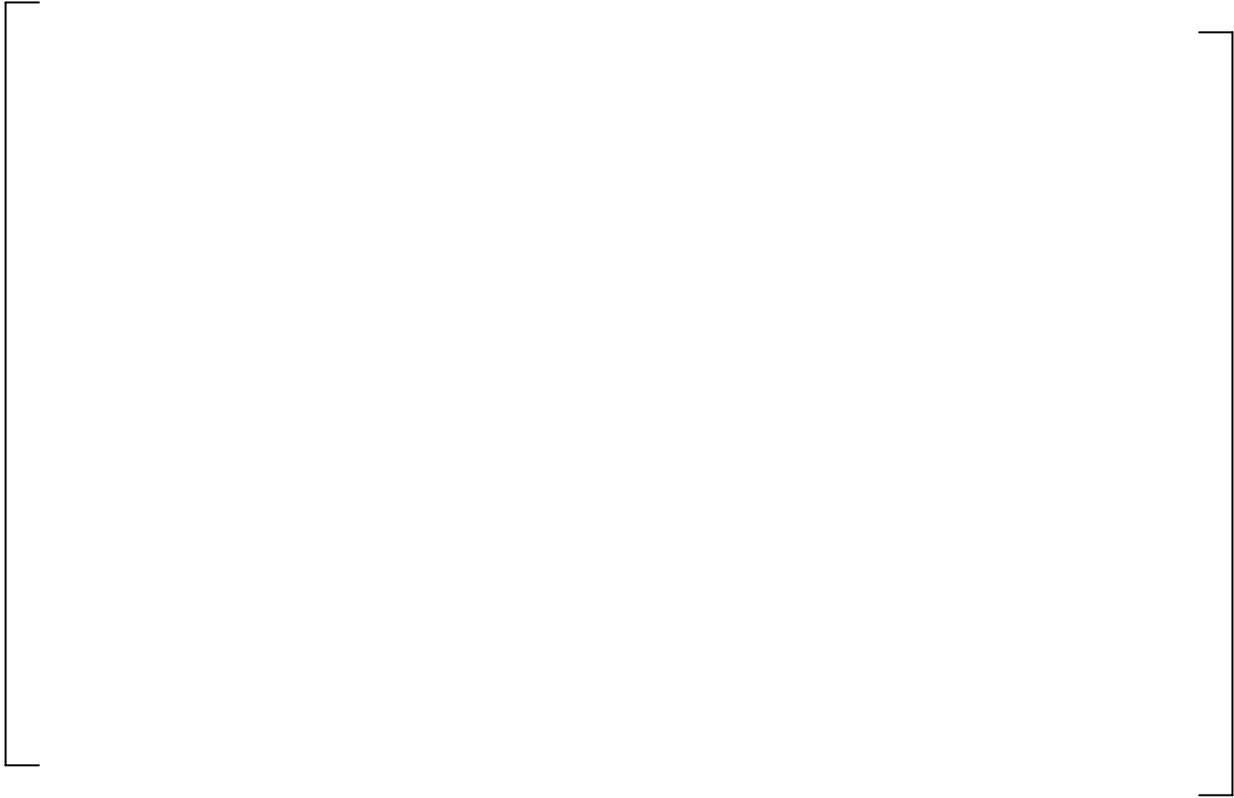


Figure RAI4-11
Original Figure RAI4-2 Discussed at the August 17, 2009 Meeting

4.2 Use of Both “Old” and “New” Fit

When establishing whether contact pressure increases when going from normal operating to steam line break conditions, how can a valid and conservative comparison be made if the normal operating case is based on the original delta contact pressure versus eccentricity curve and the SLB case is based on the new curve?

Response:

It is important to note that the new analysis method is only used for the SLB condition for the Model D5 steam generators. Comparison of contact pressures between the normal operating condition and the SLB condition is made for the Model F steam generators in the H* fleet in WCAP-17071-P on a consistent basis.

It is Westinghouse’s engineering judgment that the old methodology provides an accurate determination of contact pressures during normal operating conditions and postulated accident conditions (FLB and SLB) when peak temperatures range between []^{a,c,e} °F and eccentricities are between []^{a,c,e} inch and []^{a,c,e} inch and D_{max} and D_{min} are within []^{a,c,e} % of each other.

Application of the new method to calculate eccentricities and values of D_{max} and D_{min} that fall outside the above noted range provides conservative results because the plane strain model upon which it is based over-estimates the stiffness of the tube and tubesheet structure leading to lower contact pressure results as a function of eccentricity. The new method also excluded the effect of temperature and therefore, conservatively bounds the lower temperatures of the Model D5 SLB transient. The T/TS contact pressure results during SLB are still expected to bound the T/TS contact pressure results during NOP because, even though the tube bore eccentricity during SLB is generally greater than that during NOP, the overall growth of the tube bore during NOP is greater than that during SLB. Larger magnitudes of tube bore growth are directly related to decreasing tube-tubesheet contact pressure regardless of the value of calculated tube bore eccentricity.

It is appropriate to compare the Model D5 SLB contact pressure results from the “new” method to the Model D5 NOP results from the “old” method because each condition uses the appropriate fit to conservatively determine the reduction in T/TS contact pressure due to tube bore eccentricity and tube bore growth.

The sole purpose of the new methodology was to develop a more accurate way of calculating contact pressures during a postulated SLB for the Model D5 steam generators. The comparison provided in Figure 6-83 of WCAP-17072-P remains a valid comparison.

5.0 Part A (Original RAI#4)

Reference 1, Page 6-69: In Section 6.2.5.3, it is concluded that the tube outside diameter and the tubesheet tube bore inside diameter always maintain contact in the predicted range of tubesheet displacements. However, for tubes with through-wall cracks at the H^* distance, there may be little or no net pressure acting on the tube for some distance above H^* . In Tables 6-18 and 6-19, the fourth increment in the step that occurs two steps prior to the last step suggests that there may be no contact between the tube and tubesheet, over a portion of the circumference, for a distance above H^* . Is the conclusion in 6.2.5.3 valid for the entire H^* distance, given the possibility that the tubes may contain through-wall cracks at that location?

The following response to RAI#4 was included in Reference 11. The same response is included here to complete the record of information provided in regard to RAI#4 of References 5, 6 and 7.

Response:

The conclusions reached in Section 6.2.5.3 of WCAP-17071-P are valid for the entire H^* distance because of the following considerations:

1. The primary source of contact pressure between the tube and the tubesheet is differential thermal expansion between the tubes and the tubesheet. The analysis in Section 6.2.5.3 specifically excludes the effect of thermal expansion of the tube from the analysis. The tubesheet is assumed to deform due to the combination of pressure and thermal loads which produces the tube bore ovalization and leads to the displacements applied in this model. Only the residual effects from installation are considered for the tube in steps 1 through 5. The tube internal pressure applied in these steps only simulates the hydraulic expansion pressure to establish the initial conditions for the following step. The conditions assumed for this study are not possible during any operating condition in the steam generator but are conservative relative to actual SG conditions. (Note: Residual contact pressure is not used in the calculation of H^* values in Section 6. The residual effects of installation are included in the results of Section 6.2.5.3 so that the sensitivity of a strain hardened tube to tubesheet tube bore deformation can be studied.)
2. Step 5 on Tables 6-18 and 6-19 is not representative of any condition in the steam generator because it assumes that the tubesheet is at operating temperature with an applied primary-to-secondary pressure differential while the tubes remain at room temperature and are not pressurized. That is why Steps 1 through 5 are described as "initializing" steps in the process. It is physically impossible for these conditions to occur simultaneously in the same steam generator.

3. Because no pressure loading is applied to the tube in Step 5 of the analysis discussed in section 6.2.5, the results presented in Tables 6-18 and 6-19 are applicable regardless of whether, or not, a through-wall crack exists at the H^* location. The more representative case is Step 6 shown on Tables 6-18 and 6-19 in which tube internal pressure is included. For that case, the potential point of zero contact pressure is at an applied displacement a factor of 5 greater than for Step 5, and far in excess of what is reasonably predicted for the actual tubesheet deformation. The factor of 5 difference in required displacement to cause the contact pressure to reduce to zero more than adequately covers the postulated potential local reduction in crevice pressure due to a circumferential separation at the location of H^* . Recall also, that no thermal expansion of the tube is considered in this analysis.

It is also noted that tables 6-18 and 6-19 are the results of a sensitivity study that is not intended to represent the integrated calculation for H^* . The integrated H^* analysis is a complex process that combines the effects of several types of loading and deformation into an integrated estimate of the tube-to-tubesheet contact pressure. Therefore, it is not appropriate to consider a sensitivity study out of the context of the greater analysis. The integrated analysis presented in the complete Section 6 shows that for the combined case of the thermal effects, pressure effects, and tubesheet displacement there is tube-to-tubesheet contact pressure throughout the tubesheet.

It is acknowledged that the cut end of a tube is radially less stiff than a tube that is radially loaded at a point away from the tube end, and that the presumption of a tube sever at the H^* distance may represent the case of a tube end. The decreased tube-end stiffness is referred to as "compliance." In other words, a tube that is loaded at the cut end provides less resistance to the load than a tube with equal load applied a distance removed from the tube-end. Thus, conceptually, a local "end effect" could be expected to occur due to the increased compliance of the tube-end.

The calculation process for H^* shown in Figure 1-1 of the H^* WCAP reports and discussed in several places in the report notes that an adjustment is made to the initial prediction of H^* to account for the distributed crevice pressure referenced to the predicted H^* position. Thus, the greatest crevice pressure is always located at the final value of H^* . Increased tube compliance cannot result in a higher local crevice pressure than is already included in the analysis because, at the point of sever, the primary side pressure is the crevice pressure.

It may be postulated that the increased tube compliance results in reduced contact pressure because the net differential pressure across the tube wall is zero. At the tube-end, the current analysis already includes a zero differential pressure due to the adjustment process for distributed crevice pressure. Therefore, the net reduction in contact pressure would be limited to the axial length of the local effect and would further depend on the slope of the decrease in crevice pressure.

For the Model F and Model D5 SGs, the bounding value of isolation distance above the tube end is 0.6 inch based on classical solutions for the design of pressure vessels (Timoshenko).

The isolation distance is the generically applicable minimum separation distance from an applied load to a point of interest in order to safely assume that the load is in the far field relative to the point of interest. Specific structures and load cases may have different isolation distances but the classical result by Timoshenko for a pressure vessel will conservatively bound any specific cases. For this length, the slope of the contact pressure curve would have to decrease by a factor of at least $[]^{a,c,e}$ before the value of H^* is affected by more than $[]^{a,c,e}$ inch. If the tube is conservatively modeled as a center-loaded beam on an elastic foundation compared to an end-loaded beam on an elastic foundation, the resulting worst case change in structural compliance and the resulting contact pressure slope could be a factor of up to 2. Alternatively, similar analyses for the cross sections of curved beams suggest that the change in compliance of the structure could be as high as a factor of 6. Neither case approaches the factor of $[]^{a,c,e}$ required based on classical pressure vessel analysis to impact the value of H^* ; therefore, no additional adjustments to H^* are necessary to address the potential end effects.

6.0 Summary of the Response to RAI #4

A summary of the response to the original RAI# 4 and additional questions related to RAI 4 are provided below:

1. No additional adjustment to the value for H^* is necessary to address the potential for end effects. This is because the greatest crevice pressure is always located at the final value of H^* . At the H^* distance, the current analysis already includes a zero pressure differential due to the adjustment process for the distributed crevice pressure. Therefore, the net reduction in contact pressure would be limited to the axial length of the local effect and would further depend on the slope of the decrease in crevice pressure. It is judged that the slope of the contact pressure curve would not decrease at a rate such that the value of H^* would be affected.
2. Tube bore dilation is a more significant factor in determining tube-to-tubesheet contact pressure at higher temperatures and the effect of eccentricity on contact pressure is reduced at higher temperatures. The methodology for addressing the effect of eccentricity on contact pressure discussed in Reference 6-15 and utilized in WCAP-17071-P, WCAP-17072-P, WCAP-17091-P and WCAP-17092-P reflects this fact and, therefore, it provides acceptably accurate contact pressure results at higher temperatures (i.e., for all conditions except the "colder" SLB condition). This includes NOP, SLB (higher temperature, > 400°F, and FLB, where appropriate).
3. The results of using the fit described in Reference 6-15 match the expected trend from a best case finite element model for the NOP and SLB conditions for the Model F SGs and NOP conditions for the Model D5 SG.
4. The ΔD s from the 3D FEA model are significantly less than the corresponding ΔD s from the unit cell model from the unloaded to the fully loaded condition (i.e.,

from step 0 to step 9) for both NOP and SLB conditions. This leads to the conclusion that the unit cell model displacement results and contact pressure predictions conservatively represent the reference 3D FEA model results.

5. The eccentricities from the unit cell model are generally comparable to those from the 3D FEA model. A more exact comparison is difficult based on the available data; however, it is clear that the actual range of eccentricities from the 3D FEA model was adequately addressed by the unit cell model.
6. Based on items 4) and 5) which demonstrate the acceptability of the use of the unit cell model for benchmarking the 3-D FEA model, the method for calculating the reduction in contact pressure defined by the unit cell model, when adjusted for temperature effects, shows that SLB contact pressure is increased relative to normal operating conditions for the Model D5 steam generators.
7. It has also been shown when comparing contact pressures for NOP conditions for the unit cell to contact pressures for SLB for the unit cell for the Model F SG (higher temperature SLB conditions), that contact pressure increases during a postulated SLB.
8. Given that the two structural models provide similar eccentricities, the unit cell model shows that for these eccentricities, positive contact pressure exists between the tubes and the tubesheet for the entire range of displacements considered.

Based on the above, it is concluded that the NOP contact pressures that define H^* in the Model F and Model D5 SG are conservative and that a more realistic model of contact pressure reduction as a function of tube bore deformation (including both dilation and eccentricity) would predict positive contact pressure around the entire circumference of the tube and an increase in tube to tubesheet contact pressure at SLB conditions compared to NOP conditions.

The conclusions reached in the response to RAI#4 apply equally for the Model 44F and Model 51F SGs.