



UNITED STATES  
NUCLEAR REGULATORY COMMISSION  
WASHINGTON, D.C. 20555-0001

October 18, 2012

Mr. Rafael Flores  
Senior Vice President and  
Chief Nuclear Officer  
Attention: Regulatory Affairs  
Luminant Generation Company LLC  
P.O. Box 1002  
Glen Rose, TX 76043

SUBJECT: COMANCHE PEAK NUCLEAR POWER PLANT, UNITS 1 AND 2 - ISSUANCE OF AMENDMENTS RE: LICENSE AMENDMENT REQUEST FOR CHANGES TO TECHNICAL SPECIFICATIONS 5.5.9 AND 5.6.9 REGARDING ALTERNATE STEAM GENERATOR REPAIR CRITERIA (TAC NOS. ME8374 AND ME8375)

Dear Mr. Flores:

The U.S. Nuclear Regulatory Commission (NRC) has issued the enclosed Amendment No. 158 to Facility Operating License No. NPF-87 and Amendment No. 158 to Facility Operating License No. NPF-89 for Comanche Peak Nuclear Power Plant (CPNPP), Units 1 and 2, respectively. The amendments consist of changes to the Technical Specifications (TSs) in response to your application dated March 28, 2012.

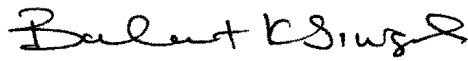
The amendments revise TS 5.5.9, "Unit 1 Model D76 and Unit 2 Model D5 Steam Generator (SG) Program," and TS 5.6.9, "Unit 1 Model D76 and Unit 2 Model D5 Steam Generator Tube Inspection Report," to permanently exclude portions of the CPNPP, Unit 2, Model D5 SG tube below the top of the SG tubesheet from periodic SG tube inspections and to provide permanent reporting requirements specific to CPNPP, Unit 2. The proposed alternate repair criteria would replace similar, interim criteria for CPNPP, Unit 2, that was applicable during Refueling Outage 12 (spring of 2011) and the subsequent (current) operating cycle approved by NRC by letter dated April 6, 2011.

R. Flores

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A copy of our related Safety Evaluation is enclosed. The Notice of Issuance will be included in the Commission's next biweekly *Federal Register* notice.

Sincerely,



Balwant K. Singal, Senior Project Manager  
Plant Licensing Branch IV  
Division of Operating Reactor Licensing  
Office of Nuclear Reactor Regulation

Docket Nos. 50-445 and 50-446

Enclosures:

1. Amendment No. 158 to NPF-87
2. Amendment No. 158 to NPF-89
3. Safety Evaluation

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UNITED STATES  
NUCLEAR REGULATORY COMMISSION  
WASHINGTON, D.C. 20555-0001

LUMINANT GENERATION COMPANY LLC

COMANCHE PEAK NUCLEAR POWER PLANT, UNIT NO. 1

DOCKET NO. 50-445

AMENDMENT TO FACILITY OPERATING LICENSE

Amendment No. 158  
License No. NPF-87

1. The Nuclear Regulatory Commission (the Commission) has found that:
  - A. The application for amendment by Luminant Generation Company LLC dated March 28, 2012, complies with the standards and requirements of the Atomic Energy Act of 1954, as amended (the Act), and the Commission's rules and regulations set forth in 10 CFR Chapter I;
  - B. The facility will operate in conformity with the application, as amended, the provisions of the Act, and the rules and regulations of the Commission;
  - C. There is reasonable assurance (i) that the activities authorized by this amendment can be conducted without endangering the health and safety of the public, and (ii) that such activities will be conducted in compliance with the Commission's regulations;
  - D. The issuance of this license amendment will not be inimical to the common defense and security or to the health and safety of the public; and
  - E. The issuance of this amendment is in accordance with 10 CFR Part 51 of the Commission's regulations and all applicable requirements have been satisfied.

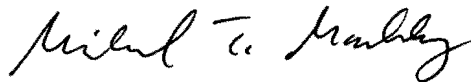
2. Accordingly, the license is amended by changes to the Technical Specifications as indicated in the attachment to this license amendment, and Paragraph 2.C.(2) of Facility Operating License No. NPF-87 is hereby amended to read as follows:

- (2) Technical Specifications and Environmental Protection Plan

The Technical Specifications contained in Appendix A as revised through Amendment No. 158 and the Environmental Protection Plan contained in Appendix B, are hereby incorporated into this license. Luminant Generation Company LLC shall operate the facility in accordance with the Technical Specifications and the Environmental Protection Plan as indicated in the attachment to this license amendment.

3. The license amendment is effective as of its date of issuance and shall be implemented prior to MODE 4 entry during startup from Unit 2 Refueling Outage 13.

FOR THE NUCLEAR REGULATORY COMMISSION



Michael T. Markley, Chief  
Plant Licensing Branch IV  
Division of Operating Reactor Licensing  
Office of Nuclear Reactor Regulation

Attachment:  
Changes to the Facility Operating  
License No. NPF-87 and  
Technical Specifications

Date of Issuance: October 18, 2012



UNITED STATES  
NUCLEAR REGULATORY COMMISSION  
WASHINGTON, D.C. 20555-0001

LUMINANT GENERATION COMPANY LLC

COMANCHE PEAK NUCLEAR POWER PLANT, UNIT NO. 2

DOCKET NO. 50-446

AMENDMENT TO FACILITY OPERATING LICENSE

Amendment No. 158  
License No. NPF-89

1. The Nuclear Regulatory Commission (the Commission) has found that:
  - A. The application for amendment by Luminant Generation Company LLC dated March 28, 2012, complies with the standards and requirements of the Atomic Energy Act of 1954, as amended (the Act), and the Commission's rules and regulations set forth in 10 CFR Chapter I;
  - B. The facility will operate in conformity with the application, as amended, the provisions of the Act, and the rules and regulations of the Commission;
  - C. There is reasonable assurance (i) that the activities authorized by this amendment can be conducted without endangering the health and safety of the public, and (ii) that such activities will be conducted in compliance with the Commission's regulations;
  - D. The issuance of this license amendment will not be inimical to the common defense and security or to the health and safety of the public; and
  - E. The issuance of this amendment is in accordance with 10 CFR Part 51 of the Commission's regulations and all applicable requirements have been satisfied.

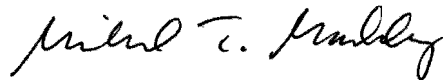
2. Accordingly, the license is amended by changes to the Technical Specifications as indicated in the attachment to this license amendment, and Paragraph 2.C.(2) of Facility Operating License No. NPF-89 is hereby amended to read as follows:

- (2) Technical Specifications and Environmental Protection Plan

The Technical Specifications contained in Appendix A as revised through Amendment No. 158 and the Environmental Protection Plan contained in Appendix B, are hereby incorporated into this license. Luminant Generation Company LLC shall operate the facility in accordance with the Technical Specifications and the Environmental Protection Plan.

3. The license amendment is effective as of its date of issuance and shall be implemented prior to MODE 4 entry during startup from Unit 2 Refueling Outage 13.

FOR THE NUCLEAR REGULATORY COMMISSION



Michael T. Markley, Chief  
Plant Licensing Branch IV  
Division of Operating Reactor Licensing  
Office of Nuclear Reactor Regulation

Attachment:  
Changes to the Facility Operating  
License No. NPF-89 and  
Technical Specifications

Date of Issuance: October 18, 2012

ATTACHMENT TO LICENSE AMENDMENT NO. 158  
TO FACILITY OPERATING LICENSE NO. NPF-87  
AND AMENDMENT NO. 158  
TO FACILITY OPERATING LICENSE NO. NPF-89  
DOCKET NOS. 50-445 AND 50-446

Replace the following pages of the Facility Operating License Nos. NPF-87 and NPF-89, and Appendix A Technical Specifications with the attached revised pages. The revised pages are identified by amendment number and contain marginal lines indicating the areas of change.

Facility Operating License No. NPF-87

<u>REMOVE</u>	<u>INSERT</u>
3	3

Facility Operating License No. NPF-89

<u>REMOVE</u>	<u>INSERT</u>
3	3

Technical Specifications

<u>REMOVE</u>	<u>INSERT</u>
5.5-6	5.5-6
5.5-7	5.5-7
5.6-5	5.6-5
5.6-6	5.6-6

- (3) Luminant Generation Company LLC, pursuant to the Act and 10 CFR Part 70, to receive, possess, and use at any time, special nuclear material as reactor fuel, in accordance with the limitations for storage and amounts required for reactor operation, and described in the Final Safety Analysis Report, as supplemented and amended;
- (4) Luminant Generation Company LLC, pursuant to the Act and 10 CFR Parts 30, 40 and 70, to receive, possess, and use, at any time, any byproduct, source, and special nuclear material as sealed neutron sources for reactor startup, sealed sources for reactor instrumentation and radiation monitoring equipment calibration, and as fission detectors in amounts as required;
- (5) Luminant Generation Company LLC, pursuant to the Act and 10 CFR Parts 30, 40 and 70, to receive, possess, and use in amounts as required, any byproduct, source, and special nuclear material without restriction to chemical or physical form, for sample analysis or instrument calibration or associated with radioactive apparatus or components; and
- (6) Luminant Generation Company LLC, pursuant to the Act and 10 CFR Parts 30, 40 and 70, to possess, but not separate, such byproduct and special nuclear materials as may be produced by the operation of the facility.

C. This license shall be deemed to contain and is subject to the conditions specified in the Commission's regulations set forth in 10 CFR Chapter I and is subject to all applicable provisions of the Act and to the rules, regulations, and orders of the Commission now or hereafter in effect; and is subject to the additional conditions specified or incorporated below:

(1) Maximum Power Level

Luminant Generation Company LLC is authorized to operate the facility at reactor core power levels not in excess of 3458 megawatts thermal through Cycle 13 and 3612 megawatts thermal starting with Cycle 14 in accordance with the conditions specified herein.

(2) Technical Specifications and Environmental Protection Plan

The Technical Specifications contained in Appendix A as revised through Amendment No. 158 and the Environmental Protection Plan contained in Appendix B, are hereby incorporated into this license. Luminant Generation Company LLC shall operate the facility in accordance with the Technical Specifications and the Environmental Protection Plan.



- (3) Luminant Generation Company LLC, pursuant to the Act and 10 CFR Part 70, to receive, possess, and use at any time, special nuclear material as reactor fuel, in accordance with the limitations for storage and amounts required for reactor operation, and described in the Final Safety Analysis Report, as supplemented and amended;
- (4) Luminant Generation Company LLC, pursuant to the Act and 10 CFR Parts 30, 40 and 70, to receive, possess, and use, at any time, any byproduct, source, and special nuclear material as sealed neutron sources for reactor startup, sealed sources for reactor instrumentation and radiation monitoring equipment calibration, and as fission detectors in amounts as required;
- (5) Luminant Generation Company LLC, pursuant to the Act and 10 CFR Parts 30, 40 and 70, to receive, possess, and use in amounts as required, any byproduct, source, and special nuclear material without restriction to chemical or physical form, for sample analysis or instrument calibration or associated with radioactive apparatus or components; and
- (6) Luminant Generation Company LLC, pursuant to the Act and 10 CFR Parts 30, 40 and 70, to possess, but not separate, such byproduct and special nuclear materials as may be produced by the operation of the facility.

C. This license shall be deemed to contain and is subject to the conditions specified in the Commission's regulations set forth in 10 CFR Chapter I and is subject to all applicable provisions of the Act and to the rules, regulations, and orders of the Commission now or hereafter in effect; and is subject to the additional conditions specified or incorporated below:

(1) Maximum Power Level

Luminant Generation Company LLC is authorized to operate the facility at reactor core power levels not in excess of 3458 megawatts thermal through Cycle 11 and 3612 megawatts thermal starting with Cycle 12 in accordance with the conditions specified herein.

(2) Technical Specifications and Environmental Protection Plan

The Technical Specifications contained in Appendix A as revised through Amendment No. 158 and the Environmental Protection Plan contained in Appendix B, are hereby incorporated into this license. Luminant Generation Company LLC shall operate the facility in accordance with the Technical Specifications and the Environmental Protection Plan.

(3) Antitrust Conditions

DELETED

## 5.5 Programs and Manuals

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### 5.5.9 Unit 1 Model D76 and Unit 2 Model D5 Steam Generator (SG) Program (continued)

- c. Provisions for SG tube repair criteria. Tubes found by inservice inspection to contain flaws with a depth equal to or exceeding 40% of the nominal tube wall thickness shall be plugged.
  - 1. The following alternate tube repair criteria shall be applied as an alternative to the 40% depth based criteria:
    - a. For Unit 2 only, tubes with service-induced flaws located greater than 14.01 inches below the top of the tubesheet do not require plugging. Tubes with service-induced flaws located in the portion of the tube from the top of the tubesheet to 14.01 inches below the top of the tubesheet shall be plugged upon detection.
- d. Provisions for SG tube inspections. Periodic SG tube inspections shall be performed. For Unit 1, the number and portions of the tubes inspected and methods of inspection shall be performed with the objective of detecting flaws of any type (e.g., volumetric flaws, axial and circumferential cracks) that may be present along the length of the tube, from the tube-to-tubesheet weld at the tube inlet to the tube-to-tubesheet weld at the tube outlet, and that may satisfy the applicable tube repair criteria. For Unit 2, the number and portions of the tubes inspected and methods of inspection shall be performed with the objective of detecting flaws of any type (e.g., volumetric flaws, axial and circumferential cracks) that may be present along the length of the tube from 14.01 inches below the top of the tubesheet on the hot leg side to 14.01 inches below the top of the tubesheet on the cold leg side and that may satisfy the applicable tube repair criteria. The tube-to-tubesheet weld is not part of the tube. In addition to meeting the requirements below, the inspection scope, inspection methods and inspection intervals shall be such as to ensure that SG tube integrity is maintained until the next SG inspection. An assessment of degradation shall be performed to determine the type and location of flaws to which the tubes may be susceptible and, based on this assessment, to determine which inspection methods need to be employed and at what locations.
  - 1. Inspect 100% of the tubes in each SG during the first refueling outage following SG replacement.
  - 2. For the Unit 2 model D5 steam generators (Alloy 600 thermally treated) inspect 100% of the tubes at sequential periods of 120, 90, and, thereafter, 60 effective full power months. The first sequential period shall be considered to begin after the first inservice inspection of the SGs. In addition, inspect 50% of the tubes by the refueling

## 5.5 Programs and Manuals

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### 5.5.9 Unit 1 Model D76 and Unit 2 Model D5 Steam Generator (SG) Program (continued)

outage nearest the midpoint of the period and the remaining 50% by the refueling outage nearest the end of the period. No SG shall operate for more than 48 effective full power months or two refueling outages (whichever is less) without being inspected.

3. For the Unit 1 model Delta-76 steam generators (Alloy 690 thermally treated) inspect 100% of the tubes at sequential periods of 144, 108, 72, and, thereafter, 60 effective full power months. The first sequential period shall be considered to begin after the first inservice inspection of the SGs. In addition, inspect 50% of the tubes by the refueling outage nearest the midpoint of the period and the remaining 50% by the refueling outage nearest the end of the period. No SG shall operate for more than 72 effective full power months or three refueling outages (whichever is less) without being inspected.
4. For Unit 1, if crack indications are found in any SG tube, then the next inspection for each SG for the degradation mechanism that caused the crack indications shall not exceed 24 effective full power months or one refueling outage (whichever is less). For Unit 2, if crack indications are found in any SG tube from 14.01 inches below the top of the tubesheet on the hot leg side to 14.01 inches below the top of the tubesheet on the cold leg side, then the next inspection for each SG for the degradation mechanism that caused the crack indications shall not exceed 24 effective full power months or one refueling outage (whichever is less). If definitive information, such as from examination of a pulled tube, diagnostic non-destructive testing, or engineering evaluation indicates that a crack-like indication is not associated with a crack(s), then the indication need not be treated as a crack.

- e. Provisions for monitoring operational primary to secondary LEAKAGE.

### 5.5.10 Secondary Water Chemistry Program

This program provides controls for monitoring secondary water chemistry to inhibit SG tube degradation and low pressure turbine disc stress corrosion cracking. The program shall include:

- a. Identification of a sampling schedule for the critical variables and control points for these variables;
- b. Identification of the procedures used to measure the values of the critical variables;

5.6 Reporting Requirements

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5.6.6 Reactor Coolant System (RCS) PRESSURE AND TEMPERATURE LIMITS REPORT (PTLR) (continued)

1. WCAP-14040-NP-A; "Methodology used to Develop Cold Overpressure Mitigating System Setpoints and RCS Heatup and Cooldown Limit Curves."
- c. The PTLR shall be provided to the NRC upon issuance for each reactor vessel fluence period and for any revision or supplement thereto.

5.6.7 Not used

5.6.8 PAM Report

When a report is required by the required actions of LCO 3.3.3, "Post Accident Monitoring (PAM) Instrumentation," a report shall be submitted within the following 14 days. The report shall outline the preplanned alternate method of monitoring, the cause of the inoperability, and the plans and schedule for restoring the instrumentation channels of the Function to OPERABLE status.

5.6.9 Unit 1 Model D76 and Unit 2 Model D5 Steam Generator Tube Inspection Report

A report shall be submitted within 180 days after the initial entry into MODE 4 following completion of an inspection performed in accordance with the Specification 5.5.9, Steam Generator (SG) Program. The report shall include:

- a. The scope of inspections performed on each SG,
- b. Active degradation mechanisms found,
- c. Nondestructive examination techniques utilized for each degradation mechanism,
- d. Location, orientation (if linear), and measured sizes (if available) of service induced indications,
- e. Number of tubes plugged during the inspection outage for each active degradation mechanism,
- f. Total number and percentage of tubes plugged to date, and
- g. The results of condition monitoring, including the results of tube pulls and in-situ testing,
- h. For Unit 2, the primary to secondary leakage rate observed in each SG (if it is not practical to assign the leakage to an individual SG, the entire primary to

5.6 Reporting Requirements

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5.6.9 Unit 1 Model D76 and Unit 2 Model D5 Steam Generator Tube Inspection Report  
(continued)

secondary leakage should be conservatively assumed to be from one SG) during the cycle preceding the inspection which is the subject of the report,

- i. For Unit 2, the calculated accident induced leakage rate from the portion of the tubes below 14.01 inches from the top of the tubesheet for the most limiting accident in the most limiting SG. In addition, if the calculated accident induced leakage rate from the most limiting accident is less than 3.16 times the maximum operational primary to secondary leakage rate, the report should describe how it was determined, and
  - j. For Unit 2, the results of monitoring for tube axial displacement (slippage). If slippage is discovered, the implications of the discovery and corrective action shall be provided.
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UNITED STATES  
NUCLEAR REGULATORY COMMISSION  
WASHINGTON, D.C. 20555-0001

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELATED TO AMENDMENT NO. 158 TO

FACILITY OPERATING LICENSE NO. NPF-87

AND AMENDMENT NO. 158 TO

FACILITY OPERATING LICENSE NO. NPF-89

LUMINANT GENERATION COMPANY LLC

COMANCHE PEAK NUCLEAR POWER PLANT, UNITS 1 AND 2

DOCKET NOS. 50-445 AND 50-446

1.0 INTRODUCTION

By letter dated March 28, 2012 (Reference 1), Luminant Generation Company LLC (the licensee), submitted a license amendment request (LAR) to revise the technical specifications (TSs) of Comanche Peak Nuclear Power Plant (CPNPP), Units 1 and 2. In its request, the licensee proposed changes to the inspection scope and repair requirements of TS 5.5.9, "Unit 1 Model D76 and Unit 2 Model D5 Steam Generator (SG) Program," and to the reporting requirements of TS 5.6.9, "Unit 1 Model D76 and Unit 2 Model D5 Steam Generator Tube Inspection Report."

The proposed changes would establish permanent alternate repair criteria for portions of the SG tubes within the tubesheet of the CPNPP, Unit 2 SGs. Because CPNPP, Units 1 and 2, have common TSs, the licensee docketed the LAR for both units. The proposed alternate repair criteria would replace similar, interim criteria for CPNPP, Unit 2, that was applicable during Refueling Outage 12 (spring of 2011) and the subsequent (current) operating cycle, which was approved by the U.S. Nuclear Regulatory Commission (NRC) staff on April 6, 2011, in License Amendment Nos. 154 and 154 for Units 1 and 2, respectively (Reference 2).

2.0 BACKGROUND

The four Model D5 SGs at CPNPP, Unit 2, were designed and fabricated by Westinghouse Electric Company, LLC (Westinghouse). There are 4,570 thermally treated Alloy 600 (Alloy 600TT) tubes in each SG, each with an outside diameter of 0.750 inches and a nominal wall thickness of 0.043 inches. The tubes are hydraulically expanded for the full depth of the 21-inch-thick tubesheet and are welded to the tubesheet at each tube end. Until the fall of 2004, no instances of stress-corrosion cracking (SCC) affecting the tubesheet region of Alloy 600TT tubing had been reported at any nuclear power plant in the United States.

In the fall of 2004, crack-like indications were found in tubes in the tubesheet region of Catawba Nuclear Station Unit 2 (Catawba), which has Westinghouse Model D5 SGs. Like CPNPP, Unit 2, the Catawba SGs use Alloy 600TT tubing that is hydraulically expanded against the tubesheet. The crack-like indications at Catawba were found in a tube overexpansion (OXP) that was approximately 7 inches below the top of the tubesheet (hot-leg side) in one tube, and just above the tube-to-tubesheet (T/TS) weld in a region of the tube known as the tack expansion region in several other tubes. Indications were also reported near the T/TS welds, which join the tube to the tubesheet. An OXP is created when the tube is expanded into a tubesheet bore hole that is not perfectly round. These out-of-round conditions were created during the tubesheet drilling process by conditions such as drill bit wandering or chip gouging. The tack expansion is an approximately 1-inch-long expansion at each tube end. The purpose of the tack expansion is to facilitate performing the T/TS weld, which is made prior to the hydraulic expansion of the tube over the full tubesheet depth.

Since the initial findings at Catawba in the fall of 2004, other nuclear plants with Alloy 600TT tubing have found crack-like indications in tubes within the tubesheet as well. These plants include CPNPP, Unit 2; Braidwood Station, Unit 2; Byron Station, Unit 2; Surry Power Station, Unit 2; Vogtle Electric Generating Plant, Unit 1; and Wolf Creek Generating Station. Most of the indications were found in the tack expansion region near the tube end welds and were a mixture of axial and circumferential primary-water SCC.

Over time, these cracks can be expected to become more and more extensive, necessitating more extensive inspections of the lower tubesheet region and more extensive tube plugging or repairs, with attendant increased cost and the potential for shortening the useful lifetime of the SGs. To avoid these impacts, the affected licensees and their contractor, Westinghouse, have developed proposed alternative inspection and repair criteria applicable to the tubes in the lowermost region of the tubesheets. These criteria are referred to as the "H\*" criteria. H\* is the minimum engagement distance between the tube and tubesheet, measured downward from the top of the tubesheet, that is proposed as needed to ensure the structural and leakage integrity of the T/TS joints. The proposed H\* proposal would exclude the portions of tubing below the H\* distance from inspection and plugging requirements on the basis that flaws below the H\* distance are not detrimental to the structural and leakage integrity of the T/TS joints.

Permanent H\* amendments were requested for a number of plants as early as 2005. The NRC staff identified a number of issues with these early LARs and in subsequent LARs submitted in 2009, including an LAR dated June 8, 2009, for CPNPP, Unit 2 (Reference 3), and the staff was, therefore, unable to approve these H\* LARs on a permanent basis pending resolution of these issues. The staff found it did have a sufficient basis to approve H\* amendments on an interim (temporary) basis, based on the relatively limited extent of cracking existing in the lower tubesheet region at the time the interim amendments were approved. The technical basis for approving the interim amendments is provided in detail in the NRC staff's safety evaluations accompanying issuance of these amendments. Interim H\* amendments were approved for CPNPP, Unit 2, as early as October 9, 2009 (Reference 4), and most recently on April 6, 2011 (Reference 2).

### 3.0 REGULATORY EVALUATION

In Title 10 of the *Code of Federal Regulations* (10 CFR) Section 50.36, "Technical specifications," the requirements related to the content of the TSs are established. Pursuant to 10 CFR 50.36, TSs are required to include items in the following five categories related to station operation: (1) safety limits, limiting safety system settings, and limiting control settings; (2) limiting conditions for operation (LCOs); (3) surveillance requirements; (4) design features; and (5) administrative controls. The rule does not specify the particular requirements to be included in a plant's TSs.

The regulations in 10 CFR 50.36(c)(2)(i) state, in part, that

Limiting conditions for operation are the lowest functional capability or performance levels of equipment required for safe operation of the facility.

For CPNPP, the pertinent LCOs for the subject LAR are in TS 3.4.17, "Steam Generator (SG) Tube Integrity."

The regulations in 10 CFR 50.36(c)(5) state, in part, that

Administrative controls are the provisions relating to organization and management, procedures, recordkeeping, review and audit, and reporting necessary to assure the operation of the facility in a safe manner.

This also includes the programs established by the licensee, and listed in the administrative controls section of the TSs, for the licensee to operate the facility in a safe manner. For CPNPP, the pertinent requirements for performing SG tube inspections and repair are in the administrative controls, TS 5.5.9, while the requirements for reporting the SG tube inspections and repair are also in the administrative controls, TS 5.6.9.

The TSs for all pressurized-water reactor (PWR) plants require that an SG program be established and implemented to ensure that SG tube integrity is maintained. For CPNPP, SG tube integrity is maintained by meeting the performance criteria specified in TS 5.5.9.b for structural and leakage integrity, consistent with the plant design and licensing basis. TS 5.5.9.a requires that a condition monitoring assessment be performed during each outage in which the SG tubes are inspected, to confirm that the performance criteria are being met. TS 5.5.9.d includes provisions regarding the scope, frequency, and methods of SG tube inspections. These provisions require that the inspections be performed with the objective of detecting flaws of any type that may be present along the length of a tube and that may satisfy the applicable tube repair criteria. The applicable tube repair criteria, specified in TS 5.5.9.c, are that tubes found during inservice inspection to contain flaws with a depth equal to or exceeding 40 percent of the nominal wall thickness shall be plugged, unless the tubes are permitted to remain in service through application of alternate repair criteria provided in TS 5.5.9.c.1, such as is being proposed for CPNPP, Unit 2. CPNPP TS 3.4.13, "RCS [Reactor Coolant System] Operational LEAKAGE," also includes a limit on operational primary-to-secondary leakage (of 150 gallons per day (gpd) through any one SG). Should a flaw exceeding the tube repair limit not be detected during the periodic tube surveillance required by the plant TSs, the operational leakage



limit provides added assurance of timely plant shutdown before tube structural and leakage integrity, established by the design and licensing bases, are impaired.

The SG tubes are part of the reactor coolant pressure boundary (RCPB) and isolate fission products in the primary coolant from the secondary coolant and the environment. For the purposes of this safety evaluation (SE), SG tube integrity means that the tubes are capable of performing this safety function in accordance with the plant design and licensing basis. The General Design Criteria (GDC) in Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50 provides the following regulatory requirements in GDCs 14, 15, 30, 31, and 32:

GDC 14, "Reactor coolant pressure boundary," states that

The reactor coolant pressure boundary shall be designed, fabricated, erected, and tested so as to have an extremely low probability of abnormal leakage, of rapidly propagating failure, and of gross rupture.

GDC 15, "Reactor coolant system design," states that

The reactor coolant system and associated auxiliary, control, and protection systems shall be designed with sufficient margin to assure that the design conditions of the reactor coolant pressure boundary are not exceeded during any condition of normal operation, including anticipated operational occurrences.

GDC 30, "Quality of reactor coolant pressure boundary," states that

Components which are part of the reactor coolant pressure boundary shall be designed, fabricated, erected, and tested to the highest quality standards practical. Means shall be provided for detecting and, to the extent practical, identifying the location of the source of reactor coolant leakage.

GDC 31, "Fracture prevention of reactor coolant pressure boundary," states, in part, that

The reactor coolant pressure boundary shall be designed with sufficient margin to assure that when stressed under operating, maintenance, testing, and postulated accident conditions (1) the boundary behaves in a nonbrittle manner and (2) the probability of rapidly propagating fracture is minimized.

GDC 32, "Inspection of reactor coolant pressure boundary," states that

Components which are part of the reactor coolant pressure boundary shall be designed to permit (1) periodic inspection and testing of important areas and features to assess their structural and leaktight integrity, and (2) an appropriate material surveillance program for the reactor pressure vessel.

The regulations in 10 CFR 50.55a, "Codes and standards," specify that components which are part of the RCPB must meet the requirements for Class 1 components in Section III, "Rules for Construction of Nuclear Facility Components," of the American Society of Mechanical Engineers

Boiler and Pressure Vessel Code (ASME Code), except as provided in 10 CFR 50.55a(c)(2), (3), and (4). Section 50.55a further requires that throughout the service life of PWR facilities like CPNPP, ASME Code Class 1 components meet the requirements of Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components," of the ASME Code to the extent practical, except for design and access provisions, and pre-service examination requirements. This requirement includes the inspection and repair criteria of Section XI of the ASME Code. The Section XI requirements pertaining to inservice inspection of SG tubing are augmented by additional requirements in the TSs.

As part of the plant's licensing bases, applicants for PWR licenses are required to analyze the consequences of postulated design-basis accidents (DBA), such as an SG tube rupture and a main steamline break (MSLB). These analyses consider primary-to-secondary leakage that may occur during these events and must show that the offsite radiological consequences do not exceed the applicable limits of 10 CFR 50.67 or 10 CFR Part 100 for offsite doses, GDC 19, "Control room" for control room operator doses (or some fraction thereof as appropriate to the accident), or the NRC-approved licensing basis (e.g., a small fraction of these limits). No accident analyses for CPNPP are being changed because of the proposed amendment and, thus, no radiological consequences of any accident analysis are being affected. The use of the proposed alternate repair criteria does not impact the integrity of the SG tubes, and the SG tubes, therefore, still meet the requirements of the GDC in Appendix A to 10 CFR Part 50, and the requirements for Class 1 components in Section III of the ASME Code. The proposed changes maintain the accident analyses and consequences that the NRC has reviewed and approved for the postulated DBAs for SG tubes.

By letter dated April 6, 2011, License Amendment Nos. 154 and 154 were approved for CPNPP, Units 1 and 2, respectively (Reference 2). These amendments modified TS 5.5.9, "Unit 1 Model D76 and Unit 2 Model D5 Steam Generator (SG) Program," and TS 5.6.9, "Unit 1 Model D76 and Unit 2 Model D5 Steam Generator Tube Inspection Report," incorporating interim alternate repair criteria and associated tube inspection and reporting requirements that are applicable to CPNPP, Unit 2 during Refueling Outage 12 (spring of 2011) and the subsequent operating cycle. Because CPNPP, Units 1 and 2, have common TSs, amendments were issued for both units. The proposed permanent amendments are similar to the currently approved interim amendments for CPNPP, Units 1 and 2. The specified H\* distance would be reduced (relaxed) to 14.01 inches under the proposed amendment from the currently specified value of 16.95 inches. In addition, words limiting the applicability of the amendment to an interim time period are deleted.

#### 4.0 TECHNICAL EVALUATION

##### 4.1 Proposed Changes to the TS

Current TS 5.5.9.c.1.a states:

For Unit 2 only during Refueling Outage 12 and the subsequent operating cycle, tubes with service-induced flaws located greater than 16.95 inches below the top of the tubesheet do not require plugging. Tubes with service-induced flaws located in the portion of the tube from the top of the tubesheet to 16.95 inches below the top of the tubesheet shall be plugged upon detection.

Revised TS 5.5.9.c.1.a would state:

For Unit 2 only, tubes with service-induced flaws located greater than 14.01 inches below the top of the tubesheet do not require plugging. Tubes with service-induced flaws located in the portion of the tube from the top of the tubesheet to 14.01 inches below the top of the tubesheet shall be plugged upon detection.

Current TS 5.5.9.d states, in part:

For Unit 2 during Refueling Outage 12 and the subsequent operating cycle, the number and portions of the tubes inspected and methods of inspection shall be performed with the objective of detecting flaws of any type (e.g., volumetric flaws, axial and circumferential cracks) that may be present along the length of the tube from 16.95 inches below the top of the tubesheet on the hot leg side to 16.95 inches below the top of the tubesheet on the cold leg side and that may satisfy the applicable tube repair criteria.

Revised TS 5.5.9.d would state, in part:

For Unit 2, the number and portions of the tubes inspected and methods of inspection shall be performed with the objective of detecting flaws of any type (e.g., volumetric flaws, axial and circumferential cracks) that may be present along the length of the tube from 14.01 inches below the top of the tubesheet on the hot leg side to 14.01 inches below the top of the tubesheet on the cold leg side and that may satisfy the applicable tube repair criteria.

Current TS 5.5.9.4 states, in part:

For Unit 2 during Refueling Outage 12 and the subsequent operating cycle, if crack indications are found in any SG tube from 16.95 inches below the top of the tubesheet on the hot leg side to 16.95 inches below the top of the tubesheet on the cold leg side, then the next inspection for each SG for the degradation mechanism that caused the crack indication shall not exceed 24 effective full power months or one refueling outage (whichever is less).

Revised TS 5.5.9.4 would state, in part:

For Unit 2, if crack indications are found in any SG tube from 14.01 inches below the top of the tubesheet on the hot leg side to 14.01 inches below the top of the tubesheet on the cold leg side, then the next inspection for each SG for the degradation mechanism that caused the crack indication shall not exceed 24 effective full power months or one refueling outage (whichever is less).

Current TS 5.6.9.h states:

- h. For Unit 2 only during Refueling Outage 12 and the subsequent operating cycle, the primary to secondary leakage rate observed in each SG (if it is not practical to assign the leakage to an individual SG, the entire primary to secondary leakage should be conservatively assumed to be from one SG) during the cycle preceding the inspection which is the subject of the report,

Revised TS 5.6.9.h would state:

- h. For Unit 2, the primary to secondary leakage rate observed in each SG (if it is not practical to assign the leakage to an individual SG, the entire primary to secondary leakage should be conservatively assumed to be from one SG) during the cycle preceding the inspection which is the subject of the report,

Current TS 5.6.9.i states:

- i. For Unit 2 only during Refueling Outage 12 and the subsequent operating cycle, the calculated accident induced leakage rate from the portion of the tubes below 16.95 inches from the top of the tubesheet for the most limiting accident in the most limiting SG. In addition, if the calculated accident induced leakage rate from the most limiting accident is less than 3.16 times the maximum operational primary to secondary leakage rate, the report should describe how it was determined; and

Revised TS 5.6.9.i would state:

- i. For Unit 2, the calculated accident induced leakage rate from the portion of the tubes below 14.01 inches from the top of the tubesheet for the most limiting accident in the most limiting SG. In addition, if the calculated accident induced leakage rate from the most limiting accident is less than 3.16 times the maximum operational primary to secondary leakage rate, the report should describe how it was determined; and

Current TS 5.6.9.j states:

- j. For Unit 2 only during Refueling Outage 12 and the subsequent operating cycle, the results of monitoring for tube axial displacement (slippage). If slippage is discovered, the implications of the discovery and corrective action shall be provided.

Revised TS 5.6.9.j would state:

- j. For Unit 2, the results of monitoring for tube axial displacement (slippage). If slippage is discovered, the implications of the discovery and corrective action shall be provided.

#### 4.2 NRC Staff Evaluation

The T/TS joints are part of the pressure boundary between the primary and secondary systems. Each T/TS joint consists of the tube, which is hydraulically expanded against the bore of the tubesheet, the T/TS weld located at the tube end, and the tubesheet. The joints were designed in accordance with the ASME Code, Section III, as welded joints, not as friction joints. The T/TS welds were designed to transmit the tube end-cap pressure loads, during normal operating and DBA conditions, from the tubes to the tubesheet with no credit taken for the friction developed between the hydraulically expanded tube and the tubesheet. In addition, the welds serve to make the joints leak-tight.

This design basis is a conservative representation of how the T/TS joints actually work, since it conservatively ignores the role of friction between the tube and tubesheet in reacting the tube end-cap loads. The initial hydraulic expansion of the tubes against the tubesheet produces an "interference fit" between the tubes and the tubesheet; thus, producing a residual contact pressure between the tubes and tubesheet, which acts normally to the outer surface of the tubes and the inner surface of the tubesheet bore holes. Additional contact pressure between the tubes and tubesheet is induced by operational conditions as will be discussed in detail below. The amount of friction force that can be developed between the outer tube surface and the inner surface of the tubesheet bore is a direct function of the contact pressure between the tube and tubesheet times the applicable coefficient of friction.

To support the proposed TS changes, the licensee's contractor, Westinghouse, has defined a parameter called  $H^*$  to be that distance below the top of the tubesheet over which sufficient frictional force, with acceptable safety margins, can be developed between each tube and the tubesheet under tube end-cap pressure loads associated with normal operating and DBA conditions to prevent significant slippage or pullout of the tube from the tubesheet, assuming the tube is fully severed at the  $H^*$  distance below the top of the tubesheet. For CPNPP, Unit 2, the proposed  $H^*$  distance is 14.01 inches. Given that the frictional force developed in the T/TS joint over the  $H^*$  distance is sufficient to resist the tube end-cap pressure loads, it is the licensee's and Westinghouse's position that the length of tubing between the  $H^*$  distance and the T/TS weld is not needed to resist any portion of the tube end-cap pressure loads. Thus, the licensee is proposing to change the TS to not require inspection of the tubes below the  $H^*$  distance and to exclude tube flaws located below the  $H^*$  distance (including flaws in the T/TS weld) from the application of the TS tube repair criteria. Under these changes, the T/TS joint would now be treated as a friction joint extending from the top of the tubesheet to a distance below the top of the tubesheet equal to  $H^*$  for purposes of evaluating the structural and leakage integrity of the joint.

The regulatory standard by which the NRC staff has evaluated the subject license amendment is that the amended TSs should continue to ensure that tube integrity will be maintained, consistent with the current design and licensing basis. This includes maintaining structural safety margins consistent with the structural performance criteria in TS 5.5.9.b.1 and the design basis, as is discussed in SE Section 4.2.1.1. In addition, this includes limiting the potential for accident-induced primary-to-secondary leakage to values not exceeding the accident-induced leakage performance criteria in TS 5.5.9.b.2, which are consistent with values assumed in the licensing basis accident analyses. Maintaining tube integrity in this manner ensures that the amended TSs are in compliance with all applicable regulations. The staff's evaluation of joint

structural integrity and accident-induced leakage integrity is discussed in SE Sections 4.2.1 and 4.2.2, respectively.

#### 4.2.1 Joint Structural Integrity

##### 4.2.1.1 Acceptance Criteria

Westinghouse has conducted extensive analyses to establish the necessary H\* distance to resist pullout under normal operating and DBA conditions. The NRC staff considers that pullout is the structural failure mode of interest since the tubes are radially constrained against axial fishmouth rupture by the presence of the tubesheet. The axial force which could produce pullout derives from the pressure end-cap loads due to the primary-to-secondary pressure differentials associated with normal operating and DBA conditions. Westinghouse determined the needed H\* distance on the basis of maintaining a factor of 3 against pullout under normal operating conditions and a factor of 1.4 against pullout under DBA conditions. The NRC staff considers that these are the appropriate safety factors to apply to demonstrate structural integrity. These safety factors are consistent with the safety factors embodied in the structural integrity performance criteria in TS 5.5.9.b.1 and with the design basis; namely, the stress limit criteria in the ASME Code, Section III.

The above approach equates tube pullout to gross structural failure which is conservative. Should the pullout load be exceeded, tube slippage would generally be limited by the presence of adjacent tubes and support structures such that the tube would not be expected to pull out of the tubesheet.

The licensee has committed in Reference 1 to monitor for tube slippage as part of the SG inspection program. Under the proposed license amendment, TS 5.6.9.j will require that the results of slippage monitoring be included as part of the 180-day report required by TS 5.6.9. TS 5.6.8.j will also require that should slippage be discovered, the implications of the discovery and corrective action shall be included in the report. The NRC staff concludes that slippage is not expected to occur for the reasons discussed in this safety evaluation. In the unexpected event if the slippage does occur, it will be important to understand why it occurred so that the need for corrective action can be evaluated. The NRC staff concludes that the commitment to monitor for slippage and the accompanying reporting requirements are acceptable.

##### 4.2.1.2 Three-dimensional Finite Element Analysis

A detailed three-dimensional (3-D) finite element analysis (FEA) of the lower SG assembly (consisting of the lower portion of the SG shell, the tubesheet, the channel head, and the divider plate separating the hot- and cold-leg inlet plenums inside the channel head) was performed to calculate tubesheet displacements due to primary pressure acting on the primary face of the tubesheet and SG channel head, secondary pressure acting on the secondary face of the tubesheet and SG shell, and the temperature distribution throughout the entire lower SG assembly. The calculated tubesheet displacements were used as input to the T/TS interaction analysis evaluated in SE Section 4.2.1.3.

The tubesheet bore holes were not explicitly modeled. Instead, the tubesheet was modeled as a solid structure with equivalent material property values selected such that the solid model

exhibited the same stiffness properties as the actual perforated tubesheet. This is a classical approach for analyzing perforated plates that the staff finds acceptable.

Two versions of the 3-D FEA model were used to support the subject LAR, a "reference model" documented in Westinghouse WCAP-17072P, Revision 0, "H\*: Alternate Repair Criteria for the Tubesheet Expansion Region in Steam Generators with Hydraulically Expanded Tubes (Model D5)," May 2009 (Reference 5), which was submitted to support a previous request dated June 8, 2009, for a permanent H\* amendment for CPNPP (Reference 3), and a "revised model" described in a technical support document, Westinghouse WCAP-17330-P, Revision 1, "H\*: Resolution of NRC Technical Issue Regarding Tubesheet Bore Eccentricity (Model F/Model D5)," June 2011 (Reference 6), referenced in the subject LAR (Reference 1). The reference 3-D FEA model was used to provide displacement input to the thick shell T/Ts interaction model described in SE Section 4.2.1.3.1. The revised 3-D FEA model was used to provide displacement input to the square cell T/Ts interaction model described in SE Section 4.2.1.3.2.

The revised 3-D model employs a revised mesh near the plane of symmetry (perpendicular to the divider plate) to be consistent with the geometry of the square cell model such that the displacement output from the 3-D model can be applied directly to the edges of the square cell model. In addition, the mesh near the top of the tubesheet was enhanced to accommodate high temperature gradients in this area during normal operating conditions. This allowed the temperature distributions throughout the lower SG assembly, including the tubesheet region, to be calculated directly in the 3-D FEA from the assumed plant temperature conditions (e.g., from the assumed primary and secondary water temperatures) for each operating condition. The NRC staff concludes that this a more realistic approach relative to the reference analysis where a linear distribution of temperature was assumed to exist through the thickness of the tubesheet in the 3-D FEA with an adjustment factor being applied to the H\* calculations for the case of normal operating conditions to account for the actual temperature distribution in the tubesheet based on sensitivity analyses.

Some non-U.S. units have experienced cracks in the weld between the divider plate and the stub runner attachment on the bottom of the tubesheet. Should such cracks ultimately cause the divider plate to become disconnected from the tubesheet, tubesheet vertical and radial displacements under operational conditions could be significantly increased relative to those for an intact divider plate weld. Although the industry believes that there is little likelihood that cracks such as those seen abroad could cause a failure of the divider plate weld, the 3-D FEA conservatively considered both the case of an intact divider plate weld and a detached divider plate weld to ensure a conservative analysis. The case of a detached divider plate weld was found to produce the most limiting H\* values. In the reference analyses (Reference 5), a factor was applied to the 3-D FEA results to account for a non-functional divider plate, based on earlier sensitivity studies. The revised 3-D FEA model assumes the upper 5 inches of the divider plate to be non-existent. The NRC staff concludes that this further improves the accuracy of the 3-D FEA for the assumed condition of a non-functional divider plate.

#### 4.2.1.3 T/Ts Interaction Model

##### 4.2.1.3.1 Thick-shell Model

The resistance to tube pullout is the axial friction force developed between the expanded tube and the tubesheet over the  $H^*$  distance. The friction force is a function of the radial contact pressure between the expanded tube and the tubesheet. In the reference analysis (Reference 5), Westinghouse used classical thick-shell equations to model the interaction effects between the tubes and tubesheet under various pressure and temperature conditions for purposes of calculating contact pressure (T/Ts interaction model). Calculated displacements from the 3-D FEA of the lower tubesheet assembly (see SE Section 4.2.1.2) were applied to the thick-shell model as input to account for the increment of tubesheet bore diameter change caused by the primary pressure acting on the primary face of the tubesheet and SG channel head, secondary pressure acting on the secondary face of the tubesheet and SG shell, and the temperature distribution throughout the entire lower SG assembly. However, the tubesheet bore diameter change from the 3-D FEA tended to be non-uniform (eccentric) around the bore circumference. The thick shell equations used in the T/Ts interaction model are axisymmetric. Thus, the non-uniform diameter change from the 3-D FEA had to be adjusted to an equivalent uniform value before it could be used as input to the T/Ts interaction analysis.

A two-dimensional (2-D) plane stress finite element model was used to define a relationship for determining a uniform diameter change that would produce the same change to average T/Ts contact pressure as would the actual non-uniform diameter changes from the 3-D finite element analyses.

In Reference 5, Westinghouse identified a difficulty in applying this relationship to Model D5 SGs under MSLB conditions. In reviewing the reasons for this difficulty, the NRC staff developed questions relating to the conservatism of the relationship and whether the tubesheet bore displacement eccentricities are sufficiently limited such as to ensure that T/Ts contact is maintained around the entire tube circumference. This concern was applicable to all SG models with Alloy 600TT tubing. By letter dated November 23, 2009 (Reference 7), the NRC staff documented a list of questions that would need to be addressed satisfactorily before the staff would be able to approve a permanent  $H^*$  amendment for Vogtle Electric Generating Plant, Units 1 and 2 (Vogtle). These questions related to the technical justification for the eccentricity adjustment, the distribution of contact pressure around the tube circumference, and a new model under development by Westinghouse to address the aforementioned issue encountered with the Model D5 SGs.

On June 14 and 15, 2010, the NRC staff conducted an audit at the Westinghouse Waltz Mill Site and provided a summary of the audit in a memorandum dated July 9, 2010 (Reference 8). The purpose of the audit was to gain a better understanding of the  $H^*$  analysis pertaining to eccentricity, to review draft responses to the staff's questions in Reference 7, and to determine which documents would need to be provided on the docket to support any future requests for a permanent  $H^*$  amendment. Based on the audit, including review of pertinent draft responses to the Reference 7, the staff concluded that eccentricity does not appear to be a significant variable affecting either average T/Ts contact pressure at a given elevation or calculated values of  $H^*$ . The NRC staff concluded that average contact pressure at a given elevation is primarily a function of average bore diameter change at that elevation associated with the pressure and temperature loading of the tubesheet. Accordingly, the NRC staff concluded that no adjustment of computed average bore diameter change considered in the thick-shell model is needed to account for eccentricities computed by the 3-D FEA. The material reviewed during the audit



revealed that computed  $H^*$  values from the reference analyses continued to be conservative when the eccentricity adjustment factor is not applied.

#### 4.2.1.3.2 Square Cell Model

Documentation for the square cell model (Reference 6) is referenced in the subject LAR for CPNPP, Unit 2 (Reference 1). The square cell model is a 2-D plane stress FEA model of a single square cell of the tubesheet with a bore hole in the middle and each of the four sides of the cell measuring one tube pitch in length. Displacement boundary conditions are applied at the edges of the cell, based on the displacement data from the revised 3-D FEA model. The model also includes the tube cross-section inside the bore. Displacement compatibility between the tube outer surface and bore inner surface is enforced except at locations where a gap between the tube and bore tries to occur.

The square cell model was originally developed in response to the above-mentioned difficulty encountered when applying the eccentricity adjustment to Model D5 SGs T/Ts interaction analysis under MSLB conditions using the thick-shell model. Early results with this model indicated significant differences compared to the thick-shell model, irrespective of whether the eccentricity adjustment was applied to the thick-shell model. The square cell model revealed a fundamental problem with how the results of the 3-D FEA model of the lower SG assembly were being applied to the tubesheet bore surfaces in the thick-shell model. As discussed in SE Section 4.2.1.2, the perforated tubesheet is modeled in the 3-D FEA model as a solid plate whose material properties were selected such that the gross stiffness of the solid plate is equivalent to that of a perforated plate under the primary-to-secondary pressure acting across the thickness of the plate. This approach tends to smooth out the distribution of tubesheet displacements as a function of radial and circumferential location in the tubesheet, and ignores local variations of the displacements at the actual bore locations. These smoothed-out displacements from the 3-D FEA results were the displacements applied to the bore surface locations in the thick-shell model. The square cell model provides a means for post-processing the 3-D FEA results such as to account for localized variations of tubesheet displacement at the bore locations as part of T/Ts interaction analysis. Based on these findings, square cell models were developed for each of the SG model types including the Model D5 SGs at CPNPP, Unit 2.

The square cell model is applied to nine different elevations, from the top to the bottom of the tubesheet, for each tube and loading case analyzed. The square cell slices at each elevation are assumed to act independently of one another. T/Ts contact pressure results from each of the nine slices are used to define the contact pressure distribution from the top to the bottom of the tubesheet.

The resisting force to the applied end-cap load, which is developed over each incremental axial distance from the top of the tubesheet, is the average contact pressure over that incremental distance times the tubesheet bore surface area (equal to the tube outer diameter surface area) over the incremental axial distance times the coefficient of friction. The NRC staff reviewed the coefficient of friction used in the analysis and concludes that it is a reasonable lower bound (conservative) estimate. The  $H^*$  distance for each tube was determined by integrating the incremental friction forces from the top of the tubesheet to the distance below the top of the tubesheet where the friction force integral equaled the applied end-cap load times the appropriate safety factor as discussed in SE Section 4.2.1.1. The square cell model assumes as

an initial condition that each tube is fully expanded against the tubesheet bore such that the outer tube surface is in contact with the inner surface of the tubesheet bore under room temperature, atmospheric pressure conditions, with zero residual contact pressure associated with the hydraulic expansion process. The NRC staff concludes that the assumption of zero residual contact pressure in all tubes to be a conservative assumption.

The limiting tube locations in terms of  $H^*$  were determined during the reference analysis to lie along the plane of symmetry perpendicular to the divider plate. The outer edges of the square cell model conform to the revised mesh pattern along this plane of symmetry in the 3-D FEA model of the lower SG assembly, as discussed in SE Section 4.2.1.2. Because the tubesheet bore holes were not explicitly modeled in the 3-D FEA, only the average displacements along each side of the square cell are known from the 3-D FEA. Three different assumptions for applying displacement boundary conditions to the edges of the square cell model were considered to allow for a range of possibilities about how local displacements might vary along the length of each side. The most conservative assumption, in terms of maximizing the calculated  $H^*$  distance, was to apply the average transverse displacement uniformly over the length of each edge of the square cell.

Primary pressure acting on the inside tube surface and crevice pressure<sup>1</sup> acting on both the tube outside surface and tubesheet bore surface are not modeled directly as in the case of the thick-shell model. Instead, the primary side (inside) of the tube is assumed to have a pressure equal to the primary pressure minus the crevice pressure. The crevice pressure varies as a function of the elevation being analyzed, as discussed in SE Section 4.2.1.4.

The NRC staff concludes that the square-cell model provides for improved compatibility between the 3-D FEA model of the lower SG assembly and the T/TTS interaction model, more realistic and accurate treatment of the T/TTS joint geometry, and added conservatism relative to the thick-shell model used in the reference analyses.

#### 4.2.1.4 Crevice Pressure Evaluation

The  $H^*$  analyses postulate that interstitial spaces exist between the hydraulically expanded tubes and tubesheet bore surfaces. These interstitial spaces are assumed to act as crevices between the tubes and the tubesheet bore surfaces. The NRC staff concludes that the assumption of crevices is conservative since the pressure inside the crevices acts to push against both the tube and the tubesheet bore surfaces, thus reducing contact pressure between the tubes and tubesheet.

For tubes which do not contain through-wall flaws within the thickness of the tubesheet, the pressure inside the crevice is assumed to be equal to the secondary system pressure. For tubes that contain through-wall flaws within the thickness of the tubesheet, a leak path is assumed to exist, from the primary coolant inside the tube, through the flaw, and up the crevice to the secondary system. Hydraulic tests were performed on several tube specimens that were hydraulically expanded against tubesheet collar specimens to evaluate the distribution of the

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<sup>1</sup> Although the tubes are in tight contact with the tubesheet bore surfaces, surface roughness effects are conservatively assumed to create interstitial spaces, which are effectively crevices, between these surfaces. See SE Section 4.2.1.4 for more information.

crevice pressure from a location where through-wall holes had been drilled into the tubes to the top of the crevice location. The T/TS collar specimens were instrumented at several axial locations to permit direct measurement of the crevice pressures. Tests were run for both normal operating and MSLB pressure and temperature conditions.

The NRC staff concludes that the use of the drilled holes, rather than through-wall cracks, is conservative since it eliminates any pressure drop between the inside of the tube and the crevice at the whole location. This maximizes the pressure in the crevice at all elevations, thus reducing contact pressure between the tubes and tubesheet.

The crevice pressure data from these tests were used to develop a crevice pressure distribution as a function of normalized distance between the top of the tubesheet and the H\* distance below the top of the tubesheet where the tube is assumed to be severed. These distributions were used to determine the appropriate crevice pressure at each axial location of the T/TS interaction model, which the NRC staff concludes are acceptable for this purpose.

Because the crevice pressure distribution is assumed to extend from the H\* location, where crevice pressure is assumed to equal primary pressure, to the top of the tubesheet, where crevice pressure equals secondary pressure, an initial guess as to the H\* location must be made before solving for H\* using the T/TS interaction model and 3-D finite element model. The resulting new H\* estimate becomes the initial estimate for the next H\* iteration.

#### 4.2.1.5 H\* Calculation Process

The calculation of H\* consists of the following steps for each loading case considered:

1. Perform initial H\* estimate (mean H\* estimate) using the T/TS interaction model and 3-D FEA models, assuming nominal geometric and material properties, and assuming that the tube is severed at the bottom of the tubesheet for purposes of defining the contact pressure distribution over the length of the T/TS crevice. Two sets of mean H\* estimates are pertinent to the proposed H\* value, mean H\* estimates calculated with the reference T/TS interaction and 3-D FEA models and mean H\* estimates calculated with the square cell T/TS interaction and revised 3-D FEA models. The maximum, mean H\* estimate (for the most limiting tube) from the reference analysis is 5.55 inches, for the most limiting case of normal operating conditions (with the associated factor of safety of 3 as evaluated in SE Section 4.2.1.1). This estimate includes the adjustments in items 2 and 3 below. The maximum, mean H\* estimate with the square cell model in conjunction with the revised 3-D lower SG FEA model is 10.89 inches. The most limiting loading case for this revised analysis is the MSLB (with its associated factor of safety of 1.4). The NRC staff concludes that the difference in mean H\* estimates between the reference analysis and the revised analysis is primarily due to the improved post-processing of the 3-D FEA model displacements for application to the T/TS interaction model.
2. In the reference analysis (Reference 5), a 0.3-inch adjustment was added to the initial H\* estimate to account for uncertainty in the bottom of the tube expansion transition (BET) location relative to the top of the tubesheet, based on an

uncertainty analysis on the BET for Model F SGs conducted by Westinghouse. This adjustment is not included in the revised H\* analysis accompanying the subject LAR, as discussed and evaluated in SE Section 4.2.1.5.1.

3. In the reference analysis (Reference 5) for normal operating conditions only, an additional adjustment was added to the initial H\* estimate to correct for the actual temperature distribution in the tubesheet compared to the linear distribution assumed in the reference 3-D FEA analysis. This adjustment is no longer necessary, as discussed in SE Section 4.2.1.2, since the temperature distributions throughout the tubesheet were calculated directly in the revised 3-D FEA supporting the current request for an H\* amendment.
4. Steps 1 through 3 yield a so-called "mean" estimate of H\*, which is deterministically based. Step 4 involves a probabilistic analysis of the potential variability of H\*, relative to the mean estimate, associated with the potential variability of key input parameters for the H\* analyses. This leads to a "probabilistic" estimate of H\*, which includes the mean estimate. The NRC staff's evaluation of the probabilistic analysis is provided in SE Sections 4.2.1.6 and 4.2.1.7.
5. Add a crevice pressure adjustment to the probabilistic estimate of H\* to account for the crevice pressure distribution which results from the tube being severed at the final H\* value, rather than at the bottom of the tubesheet. This step is discussed and evaluated in SE Section 4.2.1.5.2.
6. A new step, step 6, has been added to the H\* calculation process since the reference analysis to support the subject LAR. This step involves adding an additional adjustment to the probabilistic estimate of H\* to account for the Poisson contraction of the tube radius due to the axial end-cap load acting on each tube.

This step is discussed and evaluated in SE Section 4.2.1.5.3.

#### 4.2.1.5.1 BET Considerations

The diameter of each tube transitions from its fully expanded value to its unexpanded value near the top of the tubesheet. The BET region is located a short distance below the top of tubesheet so as to avoid any potential for over-expanding the tube above the top of the tubesheet. In the reference H\* analysis (Reference 5), a 0.3-inch adjustment was added to the mean H\* estimate to account for the BET location being below the top of the tubesheet based on an earlier survey of BET distances conducted by Westinghouse. This adjustment was necessary since the reference analysis did not explicitly account for the lack of contact between the tube and tubesheet over the BET distance.

BET measurements, based on eddy current testing, have subsequently been performed for all tubes at CPNPP, Unit 2. These measurements confirm that the original 0.3 inch BET assumption is bounding on a 95 percentile basis; but that maximum values at CPNPP, Unit 2 range to 0.72 inches.

However, the most recent  $H^*$  analyses using the square cell T/Ts interaction model (Reference 6) has made the need for a BET adjustment unnecessary, as the square cell model shows a loss of contact pressure at the top of the tubesheet that is greater than the possible variation in the BET location. The loss of contact pressure at the top of the tubesheet shown in the square cell model (which is unrelated to BET location) is compensated for by a steeper contact pressure gradient than was shown previously in the thick-shell model  $H^*$  analysis. The NRC staff concludes that the proposed  $H^*$  value adequately accounts for the range of BET values at CPNPP, Unit 2.

#### 4.2.1.5.2 Crevice Pressure Adjustment

As discussed in SE Section 4.2.1.5, steps 1 through 4 of the  $H^*$  calculation process, leading to a probabilistic  $H^*$  estimate are performed with the assumption that the tube is severed at the bottom of the tubesheet for purposes of calculating the distribution of crevice pressure as a function of elevation. If the tube is assumed to be severed at the initially computed  $H^*$  distance and steps 1 through 4 repeated, a new  $H^*$  may be calculated which will be incrementally larger than the first estimate. This process may be repeated until the change in  $H^*$  becomes small (convergence). Sensitivity analyses conducted with the thick-shell model showed that the delta between the initial  $H^*$  estimate and final (converged) estimate is a function of the initial estimate for the tube in question. This delta (i.e., the crevice pressure adjustment referred to in step 5 of SE Section 4.2.1.5) was plotted as a function of the initial  $H^*$  estimate for the limiting loading case and tube radial location. Although the sensitivity study was conducted with the thick-shell model, the deltas from this study were used in the Reference 6 (square cell model) analysis to make the crevice pressure adjustment to  $H^*$ . Updating this sensitivity study would have been very resource intensive, requiring many new 2-D FEA square cell runs. In response to an NRC staff question as to whether it is conservative to rely on the existing sensitivity study as opposed to updating it to reflect the square cell model, Westinghouse submitted an analysis, LTR-SGMMP-11-28-NP, "Response to USNRC Request for Additional Information Regarding the Catawba License Amendment Request for Permanent Application of the Alternate Repair Criterion,  $H^*$ ," included as Attachment 2 to Duke Energy letter regarding Catawba Nuclear Station, Units 1 and 2, dated January 12, 2012 (Reference 9), demonstrating that if the sensitivity study were updated, it would show that the crevice pressure adjustment  $H^*$  is negative, not positive as is shown by the existing study.

Although Reference 9 was submitted on the Catawba docket, it is referenced in subject LAR (Reference 1) as being applicable to CPNPP, Unit 2. This is because the square cell model predicts a much longer zone (6 inches) of no T/Ts contact below the top of the tubesheet than does the thick-shell model. Therefore, the crevice pressure must reduce from primary side pressure at the iterative  $H^*$  location to secondary side pressure 6 inches below the top of the tubesheet. This leads to higher predicted pressure differentials across the tube wall over the iterative  $H^*$  distance than exists during the initial iteration when crevice pressure is initially assumed to vary from primary pressure at the very bottom of the tubesheet to secondary pressure at the very top of the tubesheet. Based on its review of the Westinghouse analysis, the NRC staff concludes that the positive crevice pressure adjustment to  $H^*$  in the Reference 6 analysis, which is based on the existing sensitivity study, is conservative and that an updated sensitivity analysis based on use of the square cell model would show that a negative adjustment can actually be justified. Thus, the NRC staff concludes the crevice pressure

adjustment performed in support of the proposed H\* amendment is conservative and acceptable.

#### 4.2.1.5.3 Poisson Contraction Effect

The axial end-cap load acting on each tube is equal to the primary-to-secondary pressure difference times the tube cross-sectional area. For purposes of resisting tube pullout under normal and accident conditions, the end-cap loads used in the H\* analyses are based on the tubesheet bore diameter, which the NRC staff believes to be a conservative assumption. The axial end-cap load tends to stretch the tube in the axial direction, but causes a slight contraction in the tube radius due to the Poisson's Ratio effect. This effect, by itself, tends to reduce the T/TS contact pressure and, thus, to increase the H\* distance. The axial end-cap force is resisted by the axial friction force developed at the T/TS joint. Thus, the axial end-cap force begins to decrease with increasing distance into the tubesheet, reaching zero at a location before the H\* distance is reached. This is because the H\* distances are intended to resist pullout under the end-cap loads with the appropriate factors of safety applied as discussed in SE Section 4.2.1.1.

A simplified approach was taken to account for the Poisson radial contraction effect. First, thick-shell equations were used to estimate the reduction in contact pressure associated with application of the full end-cap load, assuming none of this end-cap load has been reacted by the tubesheet. The T/TS contact pressure distributions determined in Step 4 of the H\* calculation process in SE Section 4.2.1.5 were reduced by this amount. Second, the friction force associated with these reduced T/TS contact pressures were integrated with distance into the tubesheet, and the length of engagement necessary to react one times the end-cap loading (i.e., no safety factor applied) was determined. At this distance (termed attenuation distance by Westinghouse), the entire end-cap loading was assumed to have been reacted by the tubesheet, and the axial load in the tube below the attenuation distance was assumed to be zero. Thus, the T/TS contact pressures below the attenuation distance were assumed to be unaffected by the Poisson radial contraction effect. Finally, a revised H\* distance was calculated, where the T/TS contact pressures from Step 4 of SE Section 4.2.1.5 were reduced only over the attenuation distance.

The NRC staff concludes that the simplified approach for calculating the H\* adjustment for the Poisson contraction effect to contain significant conservatism relative to a more detailed approach. Regarding the safety factor of unity assumption, Westinghouse states that it is unrealistic to apply a safety factor to a physical effect such as Poisson's ratio. The NRC staff has not reached a conclusion on this point. However, irrespective of whether a safety factor is applied to the Poisson's contraction effect (consistent with SE Section 4.2.1.1), the NRC staff concludes that there is ample conservatism embodied in the proposed H\* distance to accommodate the difference.

#### 4.2.1.6 Acceptance Standard - Probabilistic Analysis

The purpose of the probabilistic analysis is to develop an H\* distance that ensures with a probability of 0.95 that the population of tubes will retain margins against pullout consistent with criteria evaluated in SE Section 4.2.1.1, assuming all tubes to be completely severed at their H\* distance. The NRC staff concludes that this probabilistic acceptance standard is consistent with

what the staff has approved previously and is acceptable. For example, the upper voltage limit for the voltage based tube repair criteria in NRC Generic Letter 95-05, "Voltage-Based Repair Criteria for Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking," dated August 3, 1995 (Reference 10), employs a consistent criterion. The NRC staff also notes that use of the 0.95 probability criterion ensures that the probability of pullout of one or more tubes under normal operating conditions and conditional probability of pullout under accident conditions is well within tube rupture probabilities that have been considered in probabilistic risk assessments NUREG-0844, "NRC Integrated Program for the Resolution of Unresolved Safety Issues A-3, A-4, and A-5 Regarding Steam Generator Tube Integrity," September 1988 (Reference 11), and NUREG-1570, "Risk Assessment of Severe Accident-Induced Steam Generator Tube Rupture," March 1998 (Reference 12).

In terms of the confidence level that should be attached to the 0.95 probability acceptance standard, it is industry practice for SG tube integrity evaluations, as embodied in industry guidelines, to calculate such probabilities at a 50 percent confidence level. The NRC staff has been encouraging the industry to revise its guidelines to call for calculating such probabilities at a 95 percent confidence level when performing operational assessments and a 50 percent confidence level when performing condition monitoring; see the summary of the January 8, 2009, NRC public meeting with the Nuclear Energy Institute and industry to discuss steam generator issues dated February 6, 2009 (Reference 13). In the meantime, the calculated H\* distances supporting the amendment currently being requested have been evaluated at the 95 percent confidence level, as recommended by the NRC staff.

Another issue relating to the acceptance standard for the probabilistic analysis is determining what population of tubes needs to be analyzed. For accidents such as MSLB or feed line break (FLB), the NRC staff and licensee agree that the tube population in the faulted SG is of interest, since it is the only SG that experiences a large increase in the primary-to-secondary pressure differential. However, normal operating conditions were found to be the most limiting in terms of meeting the tube pullout margins in SE Section 4.2.1.1. For normal operating conditions, tubes in all SGs at the plant are subject to the same pressures and temperatures. Although there is not a consensus between the NRC staff and industry on which population needs to be considered in the probabilistic analysis for normal operating conditions, the calculated H\* distances for normal operating conditions supporting the requested interim amendment are 0.95 probability/95 percent confidence estimates based on the entire tube population for the plant, consistent with the staff's recommendation.

Based on the above, the NRC staff concludes that the proposed H\* distance in the subject LAR is based on acceptable probabilistic acceptance standards evaluated at acceptable confidence levels.

#### 4.2.1.7 Probabilistic Analyses

##### 4.2.1.7.1 Reference Analyses

Sensitivity studies were conducted during the reference analyses (Reference 5) and demonstrated that H\* was highly sensitive to the potential variability of the coefficients of thermal expansion (CTE) for the Alloy 600 tubing material and the SA-508 Class 2a tubesheet material. Given that no credit was taken in the reference H\* analyses (Reference 5) for residual

contact pressure associated with the tube hydraulic expansion process<sup>2</sup>, the sensitivity of H\* to other geometry and material input parameters was judged by Westinghouse to be inconsequential and were ignored, with the exception of Young's modulus of elasticity for the tube and tubesheet materials. Although the Young's modulus parameters were included in the reference H\* analyses sensitivity studies, these parameters were found to have a weak effect on the computed H\*. Based on its review of the analysis models and its engineering judgment, the NRC staff concludes that the sensitivity studies adequately capture the input parameters which may significantly affect the value of H\*. This conclusion is based, in part, on no credit being taken for residual contact pressure during the reference H\* analyses.

These sensitivity studies were used to develop influence curves describing the change in H\*, relative to the mean H\* value estimate (see SE Section 4.2.1.5), as a function of the variability of each CTE parameter and Young's modulus parameter, relative to the mean values of CTE and Young's Modulus. Separate influence curves were developed for each of the four input parameters. The sensitivity studies showed that of the four input parameters, only the CTE parameters for the tube and tubesheet material had any interaction with one another. A combined set of influence curves containing this interaction effect were also created.

Two types of probabilistic analyses were performed independently in the reference analyses. One was a simplified statistical approach utilizing a "square root of the sum of the squares" method and the other was a detailed Monte Carlo sampling approach. The NRC staff's review of the reference analysis relied on the Monte Carlo analysis, which provides the most realistic treatment of uncertainties. The NRC staff reviewed the implementation of probabilistic analyses in the reference analyses and requested to justify if the H\* influence curves had been conservatively treated. To address this concern, new H\* analyses were performed as documented in Westinghouse LTR-SGMP-09-100-P (Proprietary), "Response to NRC Request for Additional Information on H\*; Model F and D5 Steam Generators," dated April 28, 2010 (Reference 14), and LTR-SGMP-09-104-P Attachment "White Paper on Probabilistic Assessment of H\*," dated August 13, 2009 (Reference 15). These analyses made direct use of the H\* influence curves in a manner the NRC staff finds to be acceptable.

The revised reference analyses in Reference 14 divided the tubes by sector location within the tube bundle and all tubes were assumed to be at the location in their respective sectors where the initial value of H\* (based on nominal values of material and geometric input parameters) was at its maximum value for that sector. The H\* influence curves discussed above, developed for the most limiting tube location in the tube bundle, were conservatively used for all sectors. The revised reference analyses also addressed a question posed by the NRC staff concerning the appropriate way to sample material properties for the tubesheet, whose properties are unknown but do not vary significantly for a given SG, in contrast to the tubes whose properties tend to vary much more randomly from tube to tube in a given SG. This issue was addressed by a staged sampling process where the tubesheet properties were sampled once and then held fixed, while the tube properties were sampled a number of times equal to the SG tube population. This process was repeated 10,000 times, and the maximum H\* value from each repetition was rank ordered. The final H\* value was selected from the rank ordering to reflect a 0.95 probability value at the desired level of confidence for a single SG tube population or all SG

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<sup>2</sup> Residual contact pressures are sensitive to variability of other input parameters.



population, as appropriate. The NRC staff concludes that this approach addresses the staff's question in a realistic fashion and is, therefore, acceptable.

The reference analyses in References 5 and 14 indicated normal operating conditions (with associated safety factor of 3) to be the limiting case for determining H\* for Model D5 SGs. As discussed earlier in SE Section 4.2.1.5, subsequent analyses with the more accurate square cell model and revised 3-D FEA model (due to the improved displacement compatibility between the two models) show the MSLB (with associated safety factor of 1.4) to be the limiting case for the Model D5 SGs. Accordingly, the reference analyses for the Model D5 SGs, including CPNPP, Unit 2, were rerun for the case of MSLB to support the subject LAR

#### 4.2.1.7.2 Revised Analyses to Reflect Square Cell and Revised 3-D FEA Models

New Monte Carlo analyses using the square cell model to evaluate the statistical variability of H\* due to the CTE variability for the tube and tubesheet materials were not performed. This was because such an approach would have been extremely resource intensive and because a simpler approach involving good approximation was available. The simplified approach involved using the results of the Monte Carlo analyses from the reference analysis, which are based on the thick-shell T/TS interaction model, to identify CTE values for the tube and tubesheet associated with the probabilistic H\* values near the desired rank ordering.

Tube CTE values associated with the upper 10 percent rank order estimates are generally negative variations from the mean value whereas tubesheet CTE values associated with the higher ranking order estimates are generally positive variations from the mean value. For the upper 10 percent of the Monte Carlo results ranking order, a combined uncertainty parameter, "alpha," was defined as the square root of the sum of the squares of the associated tube and tubesheet CTE values for each Monte Carlo sample. Alpha was plotted as a function of the corresponding H\* estimate and separately as a function of rank order. Each of these plots exhibited well-defined "break lines," representing the locus of maximum H\* estimates and maximum rank orders associated with a given values of alpha. From these plots, three paired sets of tube and tubesheet CTE values, located near the break line, were selected. One of these pairs was for the rank order corresponding to an upper 95 percent probability/95 percent confidence value for H\* on a per SG basis which the NRC staff concludes is appropriate for MSLB (see SE Section 4.2.1.6). These CTE values were then input to the lower SG assembly 3-D FEA model and the square cell model to yield probabilistic H\* estimates which approximate the H\* values for these same rank orderings had a full Monte Carlo been performed with the square cell and revised 3-D FEA models. These H\* estimates were then plotted as a function of rank ordering, allowing the interpolation of H\* values at the other rank orders. The resulting 95/95 upper bound H\* estimate is 11.52 inches, which compares to the mean estimate of 10.89 inches as discussed in SE Section 4.2.1.5. With adjustments for Poisson's contraction (SE Section 4.2.1.5.3) and crevice pressure (SE Section 4.2.1.5.2), the final 95/95 upper bound H\* estimate is 14.01 inches which is the value in the subject LAR.

The NRC staff believes that the above break line approach to be a very good approximation of what an actual Monte Carlo would show. A perfect approximation would mean that if hypothetically one were to perform a square cell analysis for each paired set of tube and tubesheet CTE values associated with the top 10 percent of rank orders and plot the resulting H\* values versus the original rank ordering associated with the CTE couple, the calculated

H\* values should monotonically increase from rank order to rank order. Westinghouse performed additional square cell analyses with CTE pairs for five consecutive rank orders for both Model D5 and Model F SGs. The results showed deviations from monotonically increasing values of H\* with rank order to be on the order of only 0.3 inches for the Model D5 SGs and 0.1 inches for the Model F SGs. The NRC staff concludes that use of the break line approach adds little imprecision to the probabilistic H\* estimates and, therefore, is acceptable.

#### 4.2.1.8 Coefficient of Thermal Expansion

During operation, a large part of contact pressure in an SG T/Ts joint is derived from the difference in CTE between the tube and tubesheet. As discussed in SE Section 4.2.1.7, the calculated value of H\* is highly sensitive to the assumed values of these CTE parameters. However, CTE test data acquired by an NRC contractor, Argonne National Laboratory (ANL), suggested that CTE values may vary substantially from values listed in the ASME Code for design purposes. By letter dated February 28, 2008, to Wolf Creek Nuclear Operating Corporation (Reference 16), the NRC staff highlighted the need to develop a rigorous technical basis for the CTE values, and their potential variability, to be employed in future H\* analyses.

In response, Westinghouse had a subcontractor review the CTE data in question, determine the cause of the variance from the ASME Code CTE values, and provide a summary report (Reference 17). Analysis of the CTE data in question revealed that the CTE variation with temperature had been developed using a polynomial fit to the raw data, over the full temperature range from 75 degrees Fahrenheit (°F) to 1300 °F. The polynomial fit chosen resulted in mean CTE values that were significantly different from the ASME Code values from 75 °F to about 300 °F. When the raw data was reanalyzed using the locally weighted least squares regression (LOWESS) method, the mean CTE values determined were in good agreement with the established ASME Code values.

Westinghouse also formed a panel of licensee experts to review the available CTE data in open literature, review the ANL-provided CTE data, and perform an extensive CTE testing program on Alloy 600 and SA-508 steel material to supplement the existing database. Two additional sets of CTE test data (different from those addressed in the previous paragraph) had CTE offsets at low temperatures that were not expected. Review of the test data showed that the first test, conducted in a vacuum, had proceeded to a maximum temperature of 1300 °F, which changed the microstructure and the CTE of the steel during decreasing temperature conditions. As a result of the altered microstructure, the CTE test data generated in the second test, conducted in air, was also invalidated. As a result of the large "dead band" region and the altered microstructure, both data sets were excluded from the final CTE values obtained from the CTE testing program. The test program included multiple material heats to analyze chemistry influence on CTE values and repeat tests on the same samples were performed to analyze for test apparatus influence. Because the tubes are strain hardened when they are expanded into the tubesheet, strain-hardened samples were also measured to check for strain hardening influence on CTE values.

The data from the test program was combined with the ANL data that was found to be acceptable and the data obtained from the open literature search. A statistical analysis of the data uncertainties was performed by comparing deviations to the mean values obtained at the applicable temperatures. The correlation coefficients obtained indicated a good fit to a normal

distribution, as expected. Finally, an evaluation of within-heat variability was performed due to increased data scatter at low temperatures. The within-heat variability assessment determined that the increase in data scatter was a testing accuracy limitation that was only present at low temperature. The CTE report is included as Appendix A to Reference 5.

The testing showed that the nominal ASME Code values for Alloy 600 and SA-508 steel were both conservative relative to the mean values from all the available data. Specifically, the CTE mean value for Alloy 600 was greater than the ASME Code value and the CTE mean value for SA-508 steel was smaller than the ASME Code value. Thus, the H\* analyses utilized the ASME Code values as mean values in the H\* analyses. The NRC staff concludes that this is conservative because it tends to lead to an over-prediction of the expansion of the tubesheet bore and an under-prediction of the expansion of the tube, thereby resulting in an increase in the calculated H\* distance. The statistical variances of the CTE parameters from the combined data base were utilized in the H\* probabilistic analysis.

Based on its review of the Westinghouse CTE program, the NRC staff concludes that the CTE values used in the H\* analyses are fully responsive to the concerns stated in Reference 16 and, therefore, are acceptable.

#### 4.2.2 Leakage Considerations

Operational leakage integrity is assured by monitoring primary-to-secondary leakage relative to the applicable TS LCO limits in TS 3.4.13, "RCS Operational LEAKAGE." However, it must also be demonstrated that the proposed TS changes do not create the potential for leakage during DBA to exceed the accident leakage performance criteria in TS 5.5.9.b.2, including the leakage values assumed in the plant licensing basis accident analyses.

If a tube is assumed to contain a 100 percent through-wall flaw some distance into the tubesheet, a potential leak path between the primary and secondary systems is introduced between the hydraulically expanded tubing and the tubesheet. The leakage path between the tube and tubesheet has been modeled by the licensee's contractor, Westinghouse, as a crevice consisting of a porous media. Using Darcy's model for flow through a porous media, the leak rate is proportional to differential pressure and inversely proportional to flow resistance. Flow resistance is a direct function of viscosity, loss coefficient, and crevice length.

Westinghouse performed leak tests of T/TS joint mockups to establish loss coefficient as a function of contact pressure. A large amount of data scatter, however, precluded quantification of such a correlation. In the absence of such a correlation, Westinghouse has developed a leakage factor relationship between accident-induced leak rate and operational leakage rate, where the source of leakage is from flaws located at or below the H\* distance.

Using the Darcy model, the leakage factor for a given type accident is the product of four quantities. The first quantity is ratio of the maximum primary-to-secondary pressure difference during the accident divided by that for normal operating conditions. The second quantity is the ratio of viscosity under normal operating primary water temperature divided by viscosity under the accident condition primary water temperature. The third quantity is the ratio of crevice length under normal operating conditions to crevice length under accident conditions. This ratio equals 1, provided it can be shown that positive contact pressure is maintained along the entire

H\* distance for both conditions. The fourth quantity is the ratio of loss coefficient under normal operating conditions to loss coefficient under the accident condition. Although the absolute value of these loss coefficients is not known, Westinghouse has assumed that the loss coefficient is constant with contact pressure such that the ratio is equal to 1. The staff concludes that this is a conservative assumption, provided there is a positive contact pressure for both conditions along the entire H\* distance and provided that contact pressure increases at each axial location along the H\* distance when going from normal operating to accident conditions. Both assumptions were confirmed to be valid in the H\* analyses.

Leakage factors were calculated for DBAs exhibiting a significant increase in primary-to-secondary pressure differential, including MSLB, FLB, locked rotor, and control rod ejection. The design basis FLB heat-up transient was found to exhibit the highest leakage factor, 3.16, meaning that it is the transient expected to result in the largest increase in leakage relative to normal operating conditions.

The latest H\* analyses by Westinghouse (Reference 6) did not show an increasing T/TS contact pressure when going from normal operating to MSLB conditions. The new analyses used the revised 3-D finite element model of the lower SG assembly and the new square cell model, discussed in SE Section 4.2.1.3.2. Although T/TS contact pressure increased over some sections of the tubing under MSLB conditions, it decreased over other sections within the H\* distance. This violated the assumed precondition for assuming that the ratio of loss coefficient under MSLB and normal operating conditions was at least equal to 1.

As discussed above, the large scatter of the loss coefficient versus contact pressure data prevented direct use of this data in applying Darcy's leakage model. Instead, Westinghouse considered a number of mathematical functions that represented the potential functional relationship between loss coefficient and contact pressure. For each potential functional relationship, Westinghouse evaluated the ratio of loss coefficient under MSLB and normal operating conditions, at each elevation and radial location within the tubesheet. For each tube, this ratio was integrated over the length of the H\* distance yielding a ratio of flow resistances for MSLB and normal operating conditions. This ratio, in conjunction with the differential pressure and viscosity ratios, was then used to compute the ratio of leakage under MSLB and normal operating conditions, at each radial location within the tubesheet. None of the potential functional relationships between loss coefficient and contact pressure considered by Westinghouse resulted in a leakage ratio value exceeding the value of 3.16 calculated for FLB.

Westinghouse performed additional analyses using parallel plate flow theory, benchmarked with the leak rate versus contact pressure data discussed above, to show that resistance to leakage under both normal operating and MSLB conditions is primarily developed in the lower portion of the H\* distance and that the leak rate ratio existing in this region dominates the overall leakage ratio existing over the entire H\* distance and that this ratio is less than 1.5. For the NRC staff, confidence that MSLB is not the limiting case for calculating leakage ratio derives from the fact that contact pressures are higher for MSLB than for normal operating conditions for the lower region of the H\* distance where most of the resistance to leakage is developed. The staff concludes that the calculated leakage factor of 3.16 for CPNPP, Unit 2 is a reasonably conservative bound for all relevant loading conditions.

In Reference 1, the licensee provided the following commitment for CPNPP, Unit 2 describing how the leakage factor will be used to satisfy TS 5.5.9.a for condition monitoring and TS 5.5.9.b.2 regarding performance criteria for accident induced leakage:

For the condition monitoring (CM) assessment, the component of operational leakage from the prior cycle from below the H\* distance will be multiplied by a factor of 3.16 and added to the total accident leakage from any other source and compared to the allowable accident induced leakage limit. For the operational assessment (OA), the difference between the allowed accident induced leakage and the accident induced leakage from sources other than the tubesheet expansion region will be divided by 3.16 and compared to the observed operational leakage. An administrative limit will be established to not exceed the calculated value.

The details of the condition monitoring and operational assessments are generally not included as part of the operating license, including the TSs. Extensive industry guidance on conducting condition monitoring and operational assessments is available as part of the industry NEI 97-06 initiative (Reference 18). The above commitments ensure that plant procedures address the above leakage factor issue as they do industry guidelines.

The subject LAR would include reporting requirements (TS 5.6.9.h and 5.6.9.i) relating to operational leakage existing during the cycle preceding each SG inspection and condition monitoring assessment, and the associated potential for accident induced leakage from the lower portion of the tubesheet below the H\* distance. These reporting requirements will allow the NRC staff to monitor how the leakage factor is actually being used, and are acceptable.

#### 4.3 Results of NRC Staff Evaluation

Since the initial proposal for a permanent H\* amendment in 2005, the supporting technical analyses have undergone substantial revision and refinement to address NRC staff questions and issues. The current analyses supporting the proposed permanent amendment still embody uncertainties and issues (e.g., should a factor of safety be applied to the Poisson's contraction effect) as discussed throughout this SE. However, it is important to acknowledge that there are significant conservatisms in the analyses. Some examples, also discussed elsewhere in this SE, include taking no credit for residual contact pressures associated with the hydraulic tube expansion process, the assumed value of 0.2 for coefficient of friction between the tube and tubesheet, and taking no credit for constraint against pullout provided by adjacent tubes and support structures. The NRC staff has evaluated the potential impact of the uncertainties and concludes that these uncertainties are adequately bounded by the significant conservatism within the analyses and proposed H\* distance.

Based on the above, the NRC staff concludes that the proposed changes to the CPNPP TSs ensure that tube structural and leakage integrity will be maintained with structural safety margins consistent with the design basis and with leakage integrity within assumptions employed in the licensing basis accident analyses, without undue risk to public health and safety. Based on this conclusion, the NRC staff further concludes that the proposed amendments meet 10 CFR 50.36 and, therefore, is acceptable.

## 5.0 REGULATORY COMMITMENTS

The licensee made the following regulatory commitments in support of the proposed LAR:

<b>Commitment No.</b>	<b>Regulatory Commitment</b>	<b>Due Date/Event</b>
4356629	Luminant Power commits to monitor for tube slippage as Implementation of Amendment part of the steam generator tube inspection program. Slippage monitoring will occur for each inspection of the Comanche Peak Unit 2 steam generators.	Implementation of Amendment
4356619	For the condition monitoring (CM) assessment, the component of operational leakage from the prior cycle from below the H* distance will be multiplied by a factor of 3.16 and added to the total accident leakage from any other source and compared to the allowable accident induced leakage limit. For the operational assessment (OA), the difference in the leakage between the allowed accident induced leakage and the accident induced leakage from sources other than the tubesheet expansion region will be divided by 3.16 and compared to the observed operational leakage. An administrative limit will be established to not exceed the calculated value.	Implementation of Amendment

The NRC staff considered these regulatory commitments as part of its review of the LAR and considers them acceptable. As stated earlier, the details of the condition monitoring and operational assessments are generally not included as part of the operating license, including the TSs.

## 6.0 STATE CONSULTATION

In accordance with the Commission's regulations, the Texas State official was notified of the proposed issuance of the amendments. The State official had no comments.

## 7.0 ENVIRONMENTAL CONSIDERATION

The amendments change a requirement with respect to installation or use of a facility component located within the restricted area as defined in 10 CFR Part 20. The NRC staff has determined that the amendments involve no significant increase in the amounts, and no significant change in the types, of any effluents that may be released offsite, and that there is no significant increase in individual or cumulative occupational radiation exposure. The Commission has previously issued a proposed finding that the amendments involve no

significant hazards consideration, and there has been no public comment on such finding published in the *Federal Register* on June 12, 2012 (77 FR 35074). Accordingly, the amendments meet the eligibility criteria for categorical exclusion set forth in 10 CFR 51.22(c)(9). Pursuant to 10 CFR 51.22(b), no environmental impact statement or environmental assessment need be prepared in connection with the issuance of the amendments.

## 8.0 CONCLUSION

The Commission has concluded, based on the considerations discussed above, that: (1) there is reasonable assurance that the health and safety of the public will not be endangered by operation in the proposed manner, (2) there is reasonable assurance that such activities will be conducted in compliance with the Commission's regulations, and (3) the issuance of the amendments will not be inimical to the common defense and security or to the health and safety of the public.

## 9.0 REFERENCES

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2. Singal, B. K., U.S. Nuclear Regulatory Commission, letter to Rafael Flores, Luminant Generation Company LLC, "Comanche Peak Nuclear Power Plant, Units 1 and 2 - Issuance of Amendments to Modify Technical Specifications to Establish Alternate Repair Criteria for Steam Generator Program (TAC Nos. ME5110 and ME5111)," dated April 6, 2011 (ADAMS Accession No. ML110770322).
3. Flores, R., Luminant Generation Company LLC, letter to U.S. Nuclear Regulatory Commission, "Comanche Peak Steam Electric Station, Docket Nos. 50-445 and 50-446, License Amendment Request 09-007, Model D5 Steam Generator Alternate Repair Criteria," dated June 8, 2009 (ADAMS Accession No. ML091670154).
4. Singal, B. K., U.S. Nuclear Regulatory Commission, letter to Rafael Flores, Luminant Generation Company LLC, "Comanche Peak Steam Electric Station, Units 1 and 2 - Issuance of Amendments to Modify Technical Specifications to Establish Alternate Repair Criteria and Include Reporting Requirements Specific to Alternate Repair Criteria for Steam Generator Program (TAC Nos. ME1446 and ME1447)," dated October 9, 2009 (ADAMS Accession No. ML092740076).
5. Westinghouse Electric Company LLC, WCAP-17072-P, Revision 0, "H\*: Alternate Repair Criteria for the Tubesheet Expansion Region in Steam Generators with Hydraulically Expanded Tubes (Model D5)," May 2009 (Proprietary). Non-proprietary version designated as WCAP-17072-NP, Revision 0, May 2009 (ADAMS Accession No. ML101730389).

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Principal Contributor: Emmett Murphy, NRR/DE/ESGB

Date: October 18, 2012

R. Flores

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A copy of our related Safety Evaluation is enclosed. The Notice of Issuance will be included in the Commission's next biweekly *Federal Register* notice.

Sincerely,

*/RA/*

Balwant K. Singal, Senior Project Manager  
Plant Licensing Branch IV  
Division of Operating Reactor Licensing  
Office of Nuclear Reactor Regulation

Docket Nos. 50-445 and 50-446

Enclosures:

- 1. Amendment No. 158 to NPF-87
- 2. Amendment No. 158 to NPF-89
- 3. Safety Evaluation

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**ADAMS Accession No. ML12263A036**

\*via email

\*\* via memo dated 9/13/12

OFFICE	NRR/DORL/LPL4/PM	NRR/DORL/LPL4/LA	NRR/DSS/STSB/BC	NRR/DE/ESGB/BC
NAME	BSingal	JBurkhardt	RElliott	GKulesa**
DATE	10/1/12	9/27/12	10/5/12	9/13/12
OFFICE	OGC	NRR/DORL/LPL4/BC	NRR/DORL/LPL4/PM	
NAME	AJones	MMarkley	BSingal	
DATE	10/12/12	10/18/12	10/18/12	

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