St. Lucie Unit 2
Docket No. 50-389
L-2005-012 Enclosure 2

Enclosure 2

Non Proprietary Version

Responses to NRC Requests for Additional Information on WCAP-16208-P, Revision 0, *NDE Inspection Length for CE Steam Generator Tubesheet Region Explosive Expansions*

(66 Pages)

Enclosure 1 contains 2.390(a)(4) Proprietary Information

Responses to NRC Requests for Additional Information on WCAP-16208-P, Rev. 0, "NDE Inspection Length for CE Steam Generator Tubesheet Region Explosive Expansions"

February 2005

Revision 1

Prepared by: Thomas Magee 2/10/05
Thomas Magee, Principal Engineer
Chemistry, Diagnostics & Materials Engineering

Reviewed by: Peter Nelson 2/10/05
Peter Nelson, Advisory Engineer
Chemistry, Diagnostics & Materials Engineering

Westinghouse Electric Company LLC
P.O. Box 355
Pittsburgh, PA 15230-0355

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

DEFINITIONS

ARC – Alternate repair criteria are approvals by NRC to utilize specific criteria for repair decisions based on detection of flaws.

AVT – All Volatile Treatment.

BET – Bottom of the explansion transition.

BTA – Bore Trepanning Association process for machine boring. A process improvement employed for tubesheet drilling applicable to Plant CE2 (only one steam generator), Plant CE3 and the Plant CG replacement steam generators

Collar - Tubesheet mockups were fabricated from tubesheet bar stock material SA-508, Class 3. The machined bar stock in which a tube was explosively expanded was referred to in this project as a collar.

C* - The CE design explansion joint inspection distance.

EDM - Electrical discharge machining.

EOC – End of the operating cycle.

Explansion – Explosive expansion of tubing into a Combustion Engineering steam generator tubesheet.

F* - The Westinghouse design rolled joint inspection distance.

FPL - Florida Power & Light.

Joint – The tube and tubesheet contact surface area created by the explansion process.

H* - The Westinghouse design hydraulic expansion joint inspection distance.

Leakage criteria – The generic technical specifications LCO for accident induced leakage value is 0.5 gpm per steam generator. The leak limit is reduced by one-fifth (i.e. 0.1 gpm) to provide margin for leaks from other potential degradation types. The criterion conservatively assumes that the leakage is from 100% of the tubes in the steam generator that have throughwall flaws present at the threshold length below the hot leg BET.

LCO – Technical specifications limiting condition for operation.

MDM - Metal Disintegration Machining.

NODP – Normal operating differential pressure = RCS pressure minus SG pressure at normal full power operating conditions.

Pullout force - The force required to overcome the joint static and sliding friction such that tube movement within the tubesheet may occur.

POD – Probability of detection based on the ability of an NDE technique to indicate the presence of a flaw.

RAI - Request for additional information.

Rough Bore – The machined surface on the inside diameter of each rough bore collar was drilled on a lathe to a surface roughness not greater than 250 micro-inches (AA) to mockup the gun-drilled tubesheet hole surface.

SLB or MSLB – The design basis event known as main steam line break.

STD – The Science and Technology Division of Westinghouse.

Smooth Bore - The machined surface on the inside diameter of each smooth bore collar was drilled on a lathe to a surface roughness not greater than 250 micro-inches (AA) and then reamed to increase smoothness to mockup the BTA process tubesheet hole surface.

Taper – The theoretically incomplete contact near the top of the joint just below the explansion transition. The W* topical report increased the threshold length to account for an approximately 0.7" taper.

Threshold length – The tube to tubesheet joint length below the BET that provides a sufficient contact force to preclude Pullout at 3NODP and leakage at SLB pressures.

TTS – Top of the tubesheet.

W* - The Westinghouse design explosive expansion joint inspection distance.

1.0 INTRODUCTION

1.1 BACKGROUND

The Westinghouse Owner's Group program to provide recommended tubesheet region inspection lengths, for plants with Combustion Engineering supplied steam generators with explosive expansions, was documented in report WCAP-16208-P, Reference 1. This inspection length is commonly referred to as C* ("C-Star"). Reference 1 was submitted by Florida Power & Light (FPL) to the NRC as part of their request for a license amendment.

The NRC has reviewed the Reference 1 document, and has compiled a list of requests for additional information (RAIs), Reference 2. This document provides the responses to those RAIs.

1.2 QUALITY ASSURANCE

This work was completed under the requirements of the Westinghouse Quality Assurance Program (Reference 3).

2.0 RESPONSES TO REQUESTS FOR ADDITIONAL INFORMATION

2.1 RAI #1

Please provide the expected normal operating differential pressure for the length of time that this amendment will be implemented.

Response:

FPL provided the following response: The current plugging levels for St. Lucie Unit 2 Cycle 14 are 8.0% in SG 2A and 10.4% in SG 2B. The tube plugging levels are expected to remain between 10% and 30% over the next two cycles of operation when this amendment will be implemented. Based upon a pressurizer pressure setpoint of 2250 psia, the calculated normal operating differentials for 10% and 30% tube plugging levels are 1404 psid and 1461 psid, respectively.

The 1461 psid is marginally greater than the value cited in WCAP 16208 but only increases the burst based inspection length by approximately 0.1 inches. The NODP difference has no impact on the leakage based inspection length which is based on the MSLB differential pressure. NDE inspection length is based on the leakage based length and therefore is not impacted by a change in NODP.

2.2 RAI #2

Please discuss the expected condition of your tube-to-tubesheet joint. For example, discuss whether you would expect minor corrosion at the top-of-the-tubesheet (similar to what might have been present in some of the test specimens) or whether there is any sludge buildup at the top of the tubesheet.

Response:

The following response was provided by FPL:

The tube-to-tubesheet joint in the St. Lucie Unit 2 steam generators is expected to contain corrosion at the top-of-tubesheet similar to or exceeding the extent of corrosion that may have been present in the test specimens. This expectation is based on the following:

- Bundle flushing and tubesheet sludge lancing have removed almost 8,800 pounds of feed train corrosion products from the Unit 2 steam generators through the end of Cycle 13. While these processes have removed significant quantities from the steam generators, the triangular pitch and large size of the tube bundles are problematic for complete cleaning. Limited inner bundle inspections following sludge lancing of the tubesheet show that sludge remains on the tubesheet (secondary face) within the bundle.

- Sludge acts as a harbor for concentration of impurities that can lead to corrosion degradation of the carbon steel tubesheet and tubing. Since 1994, approximately 188 tubes have been plugged for axial or circumferential outer diameter stress corrosion cracking (ODSCC) at or near the secondary face of the tubesheet. This tube plugging confirms that corrosion processes are active at the top-of-tubesheet and supports the expectation that corrosion is also present in the tube-to-tubesheet joint.

- During refueling outages, the top-of-tubesheet is exposed to an oxygen atmosphere for several days for completion of maintenance activities, similar to conditions experienced with the test specimens. It is expected that these conditions would add to the probability that corrosion has developed within the tube-to-tubesheet joint.

2.3 RAI #3

It was assumed that the tubesheet joints on the cold-leg side would not leak since less stress corrosion cracking is expected on the cold-leg side due to the lower temperatures. Given that stress corrosion cracking could potentially occur on the cold-leg side, discuss the need to modify the methodology such that leakage from cracks on the cold-leg side would be accounted for once cracking begins to develop.

Response:

The inspection of the top of the tubesheet regarding +Point inspection of hot and cold leg side is consistent with the industry practice. This is based on history of hot leg versus cold leg side cracking. PWSCC is strongly temperature dependent. The temperature differential between hot and cold leg exceeds 50°F. The history of hot leg PWSCC at CE units with T_{hot} in the range of 585°F to 595°F is that little or no PWSCC would be expected at or below 550°F for the life of the steam generators.

It would be excessively conservative to employ the C* inspection depth methodology to the cold leg tubesheet. If necessary, expansion of testing into the cold leg will follow NEI 97-06 program guidance and leakage from any cracking identified on the cold leg would be considered accordingly. The bounding leakage would be projected based on an assumed set of flaws in the operational assessment. The leak rate used would be based on the leak rate as a function of joint length curve provided in the C* report (Reference 1) and corrected for the lower cold leg temperature using the factors provided in Section 2.27.

2.4 RAI #4

Please clarify whether the proprietary value for the uncorrected joint length listed on page 4-8 is correct.

Response:

The value provided (6.2 inches) is incorrect. This value is a simple summary of the Table 4-8 values. The values provided in Table 4-8 are correct, thus the value on page 4-8 should be 6.6 inches, not 6.2 inches. In addition, this value is not proprietary, as are the other values in Table 4-8.

The value of 6.2 inches is the result when a 90% upper confidence bound is considered. The decision was made, during subsequent revisions to the report, to use the 95% upper confidence bound. The value of 6.2 inches was not updated during the revision. The Table 4-8 results are used in subsequent calculations, not the summary result. Thus, the rest of the report is unaffected.

2.5 RAI #5

Please clarify whether the last sentence in section 2.1 should indicate that the referenced joint lengths were "corrected" for tubesheet dilation and non-destructive examination positional uncertainty.

Response:

The last sentence in Section 2.1 (of Reference 1) should state that the 3NODP burst limit based joint length is corrected for NDE positional uncertainty and tubesheet dilation.

2.6 RAI #6

Please clarify the statement on page 3-9 which indicates that the "average load was determined by normalizing the load to a one inch engagement length and averaging the total data." The staff was under the impression that the pullout force was determined from Figures 5-1 through 5-3 using a lower 95% bound to the data.

Response:

Westinghouse concurs with the staff's understanding; the lower 95% bound of the 50% regression (average) of the data was used to determine the pullout load.

2.7 RAI #7

Did slipping occur at any locations (e.g., in the grips) other than the tube-to-collar joint during the pullout testing? If so, discuss the effect on the results.

Response:

Slipping of the gripper performed in the tests conducted in the Chattanooga tests was noted in the "first move" and accounted for in the results by use of the maximum pull force result after movement of the tube in the tubesheet collar was noted. The Windsor tests were conducted with threaded fasteners and no slippage in the pull test equipment occurred. Gripper slippage in general would result in lower pull force and is therefore conservative even if it had been mistakenly ignored.

2.8 RAI #8

Was the simulated tubesheet (collar) hole surface finish measured for the test samples? If so, compare the measured surface finish for the smooth and rough bore samples. How do these surface finishes compare to those expected for smooth and rough bore steam generator tubesheet holes?

Response:

The simulated tubesheet (collar) hole surface finish was not directly measured in the C* program, nor is there any known database of installed tubesheet hole surface roughness with which to compare such measurements. However, several observations suggest that the specimens tested in the C* program were representative of operating steam generator tubesheet hole surface roughness. These observations include:

- Figure 5-1 of Reference 1 shows a number of points taken from CEOG Task 1154 (Reference 4). They include pullout data from pullout tests conducted on a retired Boston Edison steam generator, several collar tests from CEOG Task 1154, and one blowout sample from the C* program. The Boston Edison steam generators were manufactured using the gun drill process. Figure 5-1 of Reference 1 shows a good linear correlation between joint length and pullout load between most of the samples. This suggests a similarity in surface roughness between the C* collars, the CEOG Task 1154 collars and the Boston Edison tubesheet.

- A bobbin coil technique was used, as described in Section 7.5 of WCAP-16208-P (Reference 1), to characterize tubesheet hole surface roughness using a bobbin coil probe. Table 7-4 of Reference 1 showed that the technique was generally able to segregate the rough bore from the smooth bore samples; samples with greater than 1.5 volts (peak-to-peak) of noise were rough bore samples while those with less than 1.5 volts (peak-to-peak) of noise were smooth bore samples.

- Arizona Public Service (APS) provided data (on an information-only basis) from a similar study that was conducted on their original steam generators at the Palo Verde site. Palo Verde NDE data indicates that bobbin measurements can differentiate between the tubesheet bore hole boring processes of BTA (smooth) and gun-drilled (rough). Palo Verde-1 is a rough bore plant, Palo Verde-3 is a smooth bore plant and the original steam generators from Palo Verde-2 were a mix of both; one Palo Verde-2 steam generator was all rough bore and the other was all smooth bore. Discussions with knowledgeable Combustion Engineering personnel confirmed that, the BTA process was used in fabrication of the Palo Verde Unit 2, steam generator 1 tubesheet (Reference 4). Based on a 10 tube sample from each generator, the average horizontal channel noise voltages are summarized in Table 2-1. Although these voltages were reported as root-mean-square rather than peak-to-peak, the results show the difference between rough and smooth bore tubesheet holes that was shown in Section 7.5 of Reference 1.

Table 2-1
Palo Verde Tubesheet Region Bobbin Coil Noise Summary

Unit 1 (Rough Bore)		Unit 2 (Smooth and Rough Bore)		Unit 3 (Smooth Bore)	
SG 1	SG 2	SG 1	SG 2	SG 1	SG 2
1.233 volts (RMS)	1.162 volts (RMS)	0.655 volts (RMS)	1.707 volts (RMS)	0.873 volts (RMS)	0.489 volts (RMS)

(This table is provided for information only)

2.9 RAI #9

Contact loads were calculated from the pullout load and coefficient of friction as part of the tubesheet deflection analysis. Was the coefficient of friction determined from testing performed on prototypical Combustion Engineering design samples? Discuss whether this coefficient of friction applies to both smooth bore and rough bore tubesheets.

Response:

The estimation of the coefficient of friction between the tubes and the tubesheet dates to the mid 1980s.
[

]^{a,b,c}.

Subsequently, an analysis was performed to demonstrate that [ ]^{a,b,c} was a conservative value for calculating the required length of engagement for rolled tube to tubesheet joints. There are several WCAP reports that were submitted to the NRC staff for license amendments for plants with rolled tube joints. In the analyses supporting those documents it was demonstrated that the actual factor of safety obtained during operation and under postulated accident conditions was well in excess, by factors of 1.5 to 2, of the requirements of RG 1.121, e.g., a factor of safety of 5 instead of 3 for normal operating conditions. The coefficient of friction used in the C* analyses was selected independent from the F* development work using similar general literature references. In both cases, a coefficient of friction of [ ]^{a,b,c} is conservative for estimating the strength of the tube to tubesheet joint.

The coefficient of friction of [ ]^{a,b,c} applies to both rough and smooth tubesheet bore surfaces. It is likely that an effective coefficient of friction would be greater for rough relative to smooth bore samples if the explansion process results in coining of the tubesheet asperities into the tube material such that a mechanical interference would also be active. However, the use of consistent values in performing the force balance negates any potential error in the estimate. [

]^{a,b,c}

2.10 RAI #10

In the evaluation of the required joint length to resist tube pullout, the slope of the bounding (95%) regression line illustrated in Figures 5-1 through 5-3 were used. Given that all tubes should resist pullout from the tubesheet, confirm that if the force per unit length for the most limiting specimen were used to determine the required length of expanded tube needed to resist pullout that this length would still be less than the proposed inspection distance (10.1 inches).

<u>Response:</u>

Figure 5-1 of Reference 1, is reproduced as Figure 2-1, applicable to St. Lucie. The SG tube pullout force relation for St. Lucie is provided in Figure 2-1 because the tubes are 0.048 inch thick and the tubesheet bore has a rough finish. The relationship used for determining the necessary length of engagement from the relation provided on the chart for a 95% lower bound is,

$$\left[\qquad \qquad \right]^{a,b,c} \qquad (3)$$

Where *L* is the length of engagement in inches and the pullout force is in pounds. This relationship establishes the necessary length of engagement to resist the end cap load with a safety factor of three. Thus, all tubes would be expected to be able to resist pullout from the tubesheet. However, the most limiting specimen exhibited a pullout strength of [ ].[a,b,c] Repeating the analysis of Table 6-4 of Reference 1 yields a required engagement length of less than 3 inches to resist a 3NODP pullout load of [ ][a,b,c] (1461 psid basis).

a,b,c

Figure 2-1
Pullout Force for 48 mil Wall Rough Bore Samples (Figure 5-1 from WCAP-16208-P)

2.11 RAI #11

In several places, the basis for selecting 600°F for the leak rate testing was discussed (e.g., pages 3-1 and 4-3). The basis appears to rely on past precedent for a degradation mechanism at a different location. Given the differences in the location of the degradation and the effect that pressure and temperature can have at sealing the crevice between the tube and the tubesheet, it would appear that in this case, consideration must be given to the range of temperatures and pressures that could occur during the various design basis accidents. To this end, please confirm that the combination of pressure and temperature used in determining the "accident induced leakage per joint" (i.e., 2560 pounds per square inch at 600°F) bounds the leakage from other combinations of pressure and temperature that may be experienced during your design basis accidents.

Response:

The response to this RAI is provided in Section 2.27 of this report and is based on the experimentally determined effects of temperature and pressure that are discussed in Section 4.6 of Reference 1.

2.12 RAI #12

In determining the "cumulative no-dilation joint length," the effects of pressure and temperature were addressed analytically. Discuss whether the actual pullout and leak rate data support the magnitude of this analytical adjustment. For example, do the pullout test data indicate that the pullout strength for the hot, pressurized samples is greater than the ambient pressure, room temperature tests by the amount of the analytical adjustment?

Response:

The effects of pressure and temperature are addressed analytically using the results from a finite element model of the tube in the tubesheet.

The pullout data supports the adjustment because it is derived from the data. The pullout force model is a simplification of a more complex theory of elasticity solution. The elasticity solution accounts for the reduction in contact pressure due to Poisson contraction of the tube and leads to an integral solution for the pullout force as a function of initial contact pressure. The overall strength of the joint is asymptotic to a constant value as the length of the joint increases. For short to medium joint lengths the linear approximation is adequate and reasonably accurate. Both models are based on the axial force needed to move the tube section being the product of the radial contact force, i.e., the normal force, times the coefficient of friction, which is assumed to be relatively constant over the length of the joint. The normal force per unit length of joint is found as the product of the contact pressure times the circumference at the tube-to-tubesheet interface. The pullout force data presented in WCAP-16208 were all obtained from tests performed at room temperature. There were some pullout tests performed in which the specimen was pressurized internally, leading to an increase in the radial contact pressure between the tube and the tubesheet simulation collar.

[

]a,b,c

The results from two screening tests for smooth bore specimens are presented in Table 5-1 of of WCAP-16208-P (Reference 1). [

]a,b,c.

The temperature effect on leak rate is discussed in RAI #27 (Section 2.27).

2.13 RAI #13

It was indicated that during the leak testing program that the pump stroke volume was measured periodically and that the exact pump stroke volume was used for each test. Please provide the pump stroke volume for each test. In addition, for each leak rate test performed at the Churchill facility, please indicate whether the leak rates were measured through condensing the leakage or whether they were calculated based on pressure changes on the secondary side environment.

Response:

The measured pump stroke that was used for each test is provided in Table 2-2, Table 2-3 and Table 2-4. The tables also include the method of leak rate measurement at the Churchill facility. In the tables, [

]a,b,c

Table 2-2
Summary of Room Temperature Windsor Lab Leak Test Results

a,b,c

(Table continued on next page)

Table 2-2
Summary of Room Temperature Windsor Lab Leak Test Results (Continued)

a,b,c

(Table continued on next page)

Table 2-2
Summary of Room Temperature Windsor Lab Leak Test Results (Continued)

a,b,c

Table 2-3
Summary of Room Temperature STD Lab Leak Test Results

a,b,c

Table 2-4
Summary of Elevated Temperature Leak Test Results

a,b,c

(Table continued on next page)

Table 2-4
Summary of Elevated Temperature Leak Test Results (Continued)

a,b,c

(Table continued on next page)

Table 2-4
Summary of Elevated Temperature Leak Test Results (Continued)

a,b,c

(Table continued on next page)

Table 2-4
Summary of Elevated Temperature Leak Test Results (Continued)

a,b,c

(Table continued on next page)

Table 2-4
Summary of Elevated Temperature Leak Test Results (Continued)

a,b,c

2.14 RAI #14

Please describe the Churchill facility and provide additional detail of how the leak rates were determined. In particular, address how the density of superheated steam was used in determining the leak rate.

Response:

[

]a,b,c

2.14.1 Leak Rate Test Specimen

[

]a,b,c

2.14.2 Primary Water and Deionized Water Solution Reservoirs

[

]a,b,c

2.14.3 Bladder Accumulator

[

][a,b,c]

2.14.4 Solution Preheater

[

][a,b,c]

2.14.5 316 SS Autoclave

[

][a,b,c]

2.14.6 Mass Balance

[

][a,b,c]

[

][a,b,c]

2.14.7 Determination of Leak Rates for Tests Conducted at Westinghouse STD

[

[

] [a,b,c]

[

]a,b,c

Table 2-5
Autoclave Water Inventory for Normal Operation Leak Rate Tests for Specimen 7

a,b,c

a,b,c

Figure 2-2
Schematic of the Test Loop Used for Room and Elevated Temperature Leak Rate Tests at STD

a,b,c

[ ]

Figure 2-3
A Typical Output from a Room Temperature Leak Rate Test

[

]a,b,c

a,b,c

[

]

Figure 2-4
A Typical Output From an Elevated Temperature, SLB Leak Rate Test

[

][a,b,c]

a,b,c

[ ]

Figure 2-5
Typical Output From an Elevated Temperature, Normal Operation Leak Rate Test

[ ]a,b,c

2.15 RAI #15

In several instances, it was indicated that all samples were tested at room temperature before testing at elevated temperatures (e.g., pages 4-2 and 4-3). Please clarify this statement. For example, specimen 1 was tested at room temperature, elevated temperatures, and then again at room temperature (see bottom of page 4-1). In addition, several joint lengths were made from each specimen (e.g., sample 2 had joint lengths of 3, 2, and 1.5-inches). As a result, it is not clear how the room temperature tests of the 1.5-inch joint could have been performed before the elevated temperature test of the 3-inch joint. See related questions regarding whether the elevated temperatures may have affected the leak rates of subsequent room temperature tests.

Response:

[

]a,b,c

[

]a,b,c

2.16 RAI #16

On page 4-3, it was indicated that a few tests had pressures and temperatures outside the targeted range and were not included in Appendix B. Please provide this data. In addition, please discuss whether any of this excluded data would have resulted in a more conservative leak rate estimate (e.g., were the leak rates for any of the excluded data points significantly greater than the bulk of the data retained given the actual conditions of the test).

Response:

Table 2-6 provides a summary of the data that was excluded from Appendix B and was not used in any analysis. The excluded data for samples 2, 5 and 6 were tests that were conducted at the Windsor, CT facilities. In all of the Windsor excluded tests, a steady state leak rate was never achieved; the leak rates, temperatures and pressures reported in the table are the average over the length of the test. These leak rates are not comparable to those used to determine the C* inspection length; the C* inspection lengths were derived from leak rate data with established leak rates. The leak rates provided in Table 2-6 for the

Windsor tests do not represent the leak rate at any given condition and the assignment of a leak rate would be arbitrary.

The excluded data for sample 7 were tests that were conducted at the Churchill, PA facilities. These data were excluded for falling outside of temperature specifications. Few of the STD excluded tests achieved a stable leak rate, however the range of leakage, temperature and pressures experienced during the test were not quite as large as the Windsor tests. Assuming that the average leak rates provided in Table 2-6 for sample 7 are somewhat representative of the leak rate from each of the tests, then a rough comparison can be made with test data that was taken under controlled conditions of temperature and pressure. Table 2-12 provides the established leak rate data taken from Sample 7, with a joint length of 2 inches.

At a pressure differential of 1255 psid (roughly NODP), Sample 7 had a leak rate of [ ]^{a,b,c} All of the excluded Sample 7 NODP tests shown in Table 2-6 were conducted at temperatures higher than the target temperature; all of the Sample 7 NODP leak rates shown in Table 2-6 are less than [ ]^{a,b,c}

At a pressure differential of 2619 psid (roughly SLB), Sample 7 had a leak rate of [ ]^{a,b,c} One of the excluded Sample 7 SLB tests shown in Table 2-6 was conducted at a temperature higher than the target temperature; that one leak rates shown in Table 2-6 is less than [ ]^{a,b,c} Three of the excluded Sample 7 SLB tests shown in Table 2-6 were conducted at a temperature lower than the target temperature; those leak rates shown in Table 2-6 are all greater than [ ]^{a,b,c}

These observations are consistent with the general observation that, near 600°F, a decrease in temperature will cause an increase in the leak rate and vice versa. The excluded Sample 7 data is not very different from the Sample 7 (joint length of 2 inches) data that was used in the analysis.

The excluded data would not have significantly altered the conclusions of the C* report.

Table 2-6
Excluded Leak Rate Data

a,b,c

2.17 RAI #17

In section 4.6, the effects of temperature change on the leak rate at constant pressure were discussed. Please explain the trends in the Figures 4-3 through 4-6. In particular, discuss why during the cooldown phase of some of the specimens the leak rate was higher than during the heatup phase and for other specimens the opposite trend was noted.

Response:

At sample temperatures of greater than [ ]^{a,c,e} the four figures indicate a decrease in leak rate with increasing temperature (and visa versa). This trend was observed in most tests where the temperature and pressures were held constant for enough time to establisha constant leak rate. This trend was attributed to the differential thermal expansion between the tube and the tubesheet. At these elevated temperatures, the viscosity of the leakage remains relatively constant and the temperatures are well above the corrosion regime discussed in Section 2.19. At temperatures below [ ]^{a,c,e} the leak rate response to temperature becomes a complex function of several factors (corrosion products, viscosity, contact pressure). Section 2.27 provides further discussion of this trend.

Figure 3-3 of Reference 1 shows that the water that was injected into the sample was heated by means of a long coil of tubing within the oven. The pre-heater coil also passes through the bottom of a secondary-side vessel, which was heated by the oven and coils separate from the oven. This long coil has a large heat transfer area. The sample thermocouple was attached to the outside of the tubesheet collar, which was located within a vessel to contain a secondary side environment. The water pre-heat coil passed through the bottom of the vessel. With this configuration, the water would be expected to react to an oven temperature change quicker than the sample.

The cooldown phase of Sample 2, shown in Figure 4-3 of Reference 1, began at about [ ]^{a,b,c} when the leak rate was about [ ]^{a,b,c} Sample 2 continued to heatup for another 25°F after the cooldown phase was started. The cooldown phase of Sample 3, shown in Figure 4-4 of Reference 1, began at about [ ]^{a,b,c} when the leak rate was about [ ]^{a,b,c} Several extra pump strokes were noted when cooldown began. Sample 3 continued to heatup for another [ ]^{a,b,c} after the cooldown phase was started. The cooldown phase of Sample 6, shown in Figure 4-6 of Reference 1, began at about [ ]^{a,b,c} when the leak rate was about [ ]^{a,b,c} Sample 6 began to cool immediately after the cooldown phase was started.

In the case of a low leak rate, such as that shown in Figure 4-3 of Reference 1, the heatup phase would [

]^{a,c,e}

[

]^{a,c,e}

[

]a,c,e

2.18 RAI #18

Please provide a plot of the leak rate versus time for the 3.5-inch joint length of specimen 37. It does not appear to be included in Appendix C. Regarding the leak rate assigned to the 3-inch joint length of specimen 3, it is not clear that a conservative leak rate was assigned to this specimen given the leak rate versus time plot in Appendix C. Please discuss.

Response:

The leak rate plot requested for specimen 37 (3.5 inch joint length) is provided in Figure 2-6.

A conservative leak rate was assigned to the 3-inch joint length of specimen 3 as seen by note 5 of Table 4-1 (page 4-10 of Reference 1). Figure 2-7 shows that same plot from Appendix C without the pressure line smoothing. The plot also includes lines through the pressure and leak rate data to clarify the engineering judgment that was used to select the leak rate. From a period of 33 to 35 minutes, the pressure and the leak rate were relatively stable. Prior to 33 minutes, the leak rates were either unsteady or less conservative. After the 35 minute point in the test, the pressure began to increase and the leak rate followed the pressure. [

]a,c,e

a,b,c

Figure 2-6
Sample 37 Leak Rate vs. Time (x=3.5", P=SLB)

a,b,c

Figure 2-7
Leak Rate vs. Time (Sample 3, x=3", P=SLB) Showing Pressure Before Smoothing

2.19 RAI #19

Discuss any theories on why the leak rate is independent of tubesheet hole roughness. The pullout tests are dependent on roughness.

Response:

The dependence of the pullout force on the surface roughness was addressed in Section 2.10. Effectively, the coefficient of friction would increase with increasing roughness because of plastic deformation of the tube material into space between the tubesheet surface asperities. This would have a direct effect on the pullout strength in the as-fabricated condition.

[

]a,c,e

Reference 5 presents the results of an experimental study of the effect of leakage from a cracked pressurizer heater sleeve on the pressurizer shell. Although the gap between the heater sleeve and the pressurizer shell is significantly larger (on the order of 1 mil) than the gap between a tube and the tubesheet, there are some items in that report that are applicable to the tube-tubesheet scenario.

[

]^{a,c,e}

2.20 RAI #20

Provide a history for the test samples including the dates for sample fabrication, time between fabrication, subsequent leak tests and pullout tests, and the storage conditions between each step. Identify any samples other than samples 7 and 37 that had an extended period between initial and final tests? Was any testing (e.g., visual, destructive analysis) performed to characterize the initial condition or final condition of the samples with respect to the presence and amount of oxides?

Response:

The test samples for the C* program are samples that were archived from the CEOG Task 1154 program. The C* samples were never tested in the CEOG Task 1154 program. These samples were fabricated in December 1999. Samples 36 and 37 were made into NDE standards when EDM holes were made in March 2000. All of the C* samples were stored in a humidity and temperature controlled office environment. Samples 36 and 37 were sent to the Arizona Public Service Company, where they were used in multiple rotating pancake coil, bobbin, and array probe examinations to validate detection and comparison in various probe types. As Table 2-7 and Table 2-8 show, none of the samples had an extended period between initial and final tests.

The samples were retained for the bobbin coil characterization of surface roughness, as described in Section 7.5 of Reference 1 and were not destructively examined to characterize the oxides within the annular gap between the tube and the tubesheet.

Table 2-7
Dates of Tests Conducted in Windsor

Sample	Date of First Leak Test	Date of Last Leak Test	Date of Last Pullout Screening Test
1	7/31/2003	8/8/2003	8/8/2003
2	8/4/2003	9/12/2003	9/18/2003
3	8/18/2003	9/23/2003	9/24/2003
4	8/19/2003	9/16/2003	9/18/2003
5	8/6/2003	9/7/2003	9/8/2003
6	8/13/2003	9/15/2003	9/18/2003
7	9/11/2003	9/22/2003	9/24/2003
36	11/19/2003	11/25/2003	N/A
37	11/18/2003	11/21/2003	N/A

Table 2-8
Dates of Tests Conducted in Churchill

Sample	Date of First Leak Test	Date of Last Leak Test
7	3/22/2004	5/11/2004
37	3/24/2004	5/14/2004

2.21 RAI #21

Section 4.4 of WCAP-16208 states that there was an effect of time in the leak rate data and that the higher leak rates were typically observed at the start of testing. Discuss whether this observation is consistent with previous leak rate testing programs and to what this effect is attributed to? Discuss the basis for the statement that this is uncharacteristic of leakage that would be observed in an operating steam generator.

Response:

An example of the time effect in the leak rate from the C* program is provided in Figure 2-8. Under a relatively constant temperature and pressure, the leak rate was measured as half its initial value after [ ]a,b,c of leaking. Often the effect is difficult to discern because the temperature of the test, or even the pressure, varied during the time of the test.

A similar effect was observed during similar laboratory testing for the H* program in 2003. Figure 2-9 shows the integrated leakage from specimen 16, with an expansion length of 3 inches that was measured in August of 2003. [ ]a,c,e

In 1991, a series of leak rate tests were performed on four heater sleeve – pressurizer shell configurations (Reference 5). The annular gap in this configuration is larger (on the order of a mil wide), but other dimensions and materials are similar to the tube-tubesheet joint. In these tests, leak rates from a cracked heater sleeve into the sleeve-shell annulus were observed to drop as a function of time. [ ]a,b,c

The statement provided in WCAP-16208 (Reference 1) was also intended to mean that the behavior of the test specimens are best compared to steam generator performance after each test had reached a pseudo steady state condition. [ ]a,c,e

a,b,c

Figure 2-8
Example of the Time Effect on Leak Rate

a,b,c

Figure 2-9
Example of H* Leak Rate Effect of Time

Note the y-axis is the integrated mass of leakage from this H* sample. This graph show that the leakage slows down with time.

2.22 RAI #22

Provide the criteria used to determine if leak rate data was valid and should be included in Table 4-1 (i.e., the elevated temperature leak rate data). Identify which leak rate tests were determined not to be valid.

Response:

The term "valid leak rate" is defined in Section 4.4 of Reference 1 as [

]a,c,e

Table 2-6 provides a list of test data that were determined not to be valid.

2.23 RAI #23

A comparison of the room temperature leak rates from sample 1 to the CEOG Task 1154 leak rates was made to conclude storage for 3 years did not have a significant effect on the samples. The room temperature test performed after a high temperature test had a much lower leak rate than the initial room temperature test. Discuss whether these results suggest that the elevated temperature leak rate test performed between the initial and final room temperature leak rate tests may have influenced the results through the formation of oxides in the crevice (annular gap) or by some other mechanism.

Response:

Table 2-9 provides a summary of the sample 1 data which shows that the leak rate was much lower after the elevated temperature tests. The leak rate data after the elevated temperature tests also exhibits a drop in the leak rate even though the pressure was increased. The NODP pressure leak rate was repeated in the post-elevated temperature leak rate tests and it showed a leak rate that was approximately 25% of that measured approximately half an hour earlier.

It is unclear whether or not the elevated temperature tests influenced these results. Although the leak rates following the elevated temperature tests were lower than before, it was found that the leak rates continued to drop even during the last set of room temperature tests.

Section 2.21 discussed the time effect on leak rate; portions of that discussion are applicable to this RAI.

[

]a,c,e

Table 2-9
Sample 1 (3 inch Joint Length) Room Temperature Leak Rate Results Before and After Elevated Temperature Testing

a,b,c

2.24 RAI #24

Provide the sequence in which the leak rate tests shown in the Table of Page A-5 were performed (i.e., the sequence of the tests performed at the Westinghouse Science and Technology Division in Churchill). From this table, it appears that sample 7 was tested in the Churchill facilities in the following order: deionized water with low oxygen levels, deionized water with high oxygen levels, and primary water (low oxygen). The leak rate for the primary water tests (performed after the high oxygenated tests) is higher than the original low oxygen tests. Given the theory that the original 1154 test program results are invalid because the oxygenated water used during these tests resulted in "blocking the leak path", please discuss the trend in the Sample 7 leak rate (i.e., higher leak rate following the oxygenated test). In addition, given the uncertain initial condition of the samples (with respect to the presence of oxides within the crevice) and considering that testing in a higher oxygen containing environment occurred prior to testing in simulated primary water tests, doesn't the presence of oxides complicate the evaluation of water chemistry effects?

<u>Response:</u>

The table on page A-5 of Reference 1 provides the chronological order in which the tests were conducted on each sample.

[

]^{a,c,e}

2.25 RAI #25

The effects of temperature and differential pressure on leak rates seem inconsistent. For example, in some cases the room temperature leak rates increase with increasing differential pressure (e.g., the first set of normal operating and steam line break leak rate values for specimen 1) and in other cases the leak rates stay the same or decrease with increasing differential pressure (e.g., the second set of normal operating and steam line break leak rate values for specimen 1). Data from the room temperature leak tests at the Science and Technology Division (STD) show a consistent increasing leak rate with increasing differential pressure. Please provide any insight into this apparent discrepancy in the leak rate data. In your response, discuss the type of pump used during the Windsor tests and whether any check valves were in the supply lines.

An example of inconsistent trends with temperature is: the leak rate for specimen 1 with a joint length of 3-inches increases at steam line break pressure when the temperature was changed from 400 to 600 degrees; however, the leak rate for specimen 2 with a joint length of 2-inches decreases at steam line break pressure when the temperature was changed from 400 to 600 degrees.

The elevated temperature leak rates determined at the Churchill facility are always greater than the corresponding room temperature tests. Please discuss any insights on this trend since the analysis provided in Section 4.6 would indicate that the leak rate should decrease with increasing temperature.

Response:

[

]^{a,c,e}

[

]^{a,c,e}

2.26 RAI #26

Room temperature leak rates measured at the Windsor facility (Samples 7 and 37) are higher compared to the room temperature leak rates measured at the STD facility. Given that oxides may have influenced the STD test results, how can effects in test water chemistry differences or test facility differences be discerned?

Response:

[

]^{a,c,e}

2.27 RAI #27

The effects of temperature and pressure were estimated from the data in Table 4-5. What criteria were used to select the data in Table 4-5? Does the median value change if all data are included?

Response:

The data presented in Table 4-5 (of Reference 1) was used to provide a rough estimate of the effects of temperature and pressure on the leak rate. Figure 4-7 (of Reference 1) presented a plot of the data, and the median values were presented in Section 4.6 (of Reference 1).

The data presented in Table 4-5 (of Reference 1) represents a portion of the entire data set. This sampling of the data includes all data taken up to August 19, 2003, or about half of all the data. Within that sample set, certain criteria were used to select data for comparison:

[

]a,c,e

The slopes calculated and presented in the upper part of Table 4-5 have been revised, thus the value for pressure presented in Figure 4-7 is changed. The revised version of Table 4-5 is presented in Table 2-10 and the revised version of Figure 4-7 is presented in Figure 2-10. Under the revised version (using a partial data set) the pressure factor was determined as [ ]a,c,e

If the entire data set is considered, then an additional 14 pressure comparisons can be considered. Only one more temperature comparison is considered (from Figure 4-5 of Reference 1). Using the full data set, the criteria above and the method used in Reference 1, the factor can be estimated from the data in Table 2-11, which is plotted in Figure 2-11. Using the full data set, the pressure factor was determined as [ ]a,c,e No significant difference in these factors result from the use of the additional data.

The approach that was used in Reference 1 provided independent estimates of the effects of temperature and pressure. The pressure comparisons provided in Table 2-10 and Table 2-11 were made possible by choosing data with two different pressures where the temperatures were approximately the same, but not exactly the same. A similar process was used for temperature comparisons. The median was used as the representative temperature and pressure factors. Upon further consideration of the staff's RAI, an alternate approach was used to determine the effect of temperature and pressure simultaneously, which did not rely on comparisons between data with only approximately similar conditions, and used the average rather than the median of the data.

[

]a,c,e

[ ]a,c,e

[

]a,c,e

This alternate approach used the data that is summarized in Appendix B of Reference 1. [

]a,c,e

[

]a,c,e

[

]a,c,e

These temperature and pressure effects can be used to determine how leakage might change following a SLB accident. Reference 7 includes the temperature and pressure responses following a steam line break accident for St. Lucie Unit 2. These responses are provided in Figure 2-12.

Figure 2-12 also shows an example of how the leak rate from a single tube might change during a SLB event. Figure 2-12 shows a single tube-tubesheet joint with a characteristic leak rate of [

]a,c,e

[

]a,c,e

Time frames longer than 500 seconds have not been considered directly. Temperature and pressure projections following a steam line break have only been performed to 500 seconds because the expense of performing MSLB projections has not been warranted. The affected steam generator would be isolated and the plant would be shutdown after a MSLB event. At St. Lucie Unit 2, it is projected that significant concerns such as Peak Heat Flux, Minimum DNBR and Peak Linear Heat Rate from the fuel, will have been achieved by 305 seconds.

It is not known how the pressure and temperature of the joints in the faulted steam generator will proceed after the 500 second time frame. The large mass of the tubesheet would likely keep the joint at a relatively high temperature (higher than the coolant inlet temperature) for an extended period of time. During the accident, higher concentrations of boron are injected into the primary side, which has the effect of reducing leakage through the joint from the deposition of boric acid in the leak path (see the discussion in Section 2.19).

[

]a,c,e

Table 2-10

Revised Table 4-5: Data Used to Estimate Effect of Temperature and Pressure on Leak Rate (Partial Data Set)

a,b,c

Table 2-11
Data Used to Estimate Effect of Temperature and Pressure on Leak Rate (Full Set)

a,b,c

Table 2-12
Determination of Temperature and Pressure Effect on Leak Rate by Normalization

a,b,c

(Table continued on next page)

Table 2-12
Determination of Temperature and Pressure Effect on Leak Rate by Normalization (Continued)

a,b,c

a,b,c

Figure 2-10
Revised Figure 4-7: CDF of Temperature and Pressure Effects on Leakage (Partial Data Set)

a,b,c

Figure 2-11
CDF of Temperature and Pressure Effects on Leakage (Full Data Set)

a,b,c

Figure 2-12
Example of Calculated Leak Rate Response Under Accident Conditions (St. Lucie Unit 2)

2.28 RAI #28

Metallography was performed to evaluate the potential for blockage of the tube-to-collar crevice as a result of the EDM cutting process (refer to page 7-4). How many cross sections of the tube-to-collar sample were examined with the microscope? Were all areas observed similar to that shown in Figure 7-5?

Response:

Section 7.2 of Reference 1, as written, suggests that only a single EDM notch was examined, whereas two similar cuts were actually made. These EDM cuts were made [

][a,c,e]

2.29 RAI #29

Fittings were cut off and welded on the ends of the samples as necessary to make new EDM cuts to shorten the joint length. In addition, welding was used to repair any leaks at the fittings prior to leak testing. Were the tube or collar temperatures monitored during welding? If so, indicate the peak temperature reached at the tube collar interface during welding. Discuss whether sample heating from welding could result in mechanical loosening of the joint or promote oxide growth on the samples?

Response:

The tube and collar temperatures were not monitored during welding. It is unlikely that the localized sample heating from welding would result in mechanical loosening of the joint or promote oxide growth in the vicinity of the EDM notch. The welding of fittings to the collar was only performed once (after the first EDM cut was made). [

][a,c,e] [

][a,c,e]

2.30 RAI #30

Please discuss your plans to submit the following information concerning indications found in the tubesheet region (including the expansion transition) within 90 to 120 days after each inspection: Number of total indications, location of each indication (e.g., TTS –1.0), orientation (axial, circumferential, volumetric) of each indication, severity of each indication (e.g., near through-wall or not through-wall), and whether the indications initiated from the inside or outside diameter.

In addition, discuss your plans to provide the cumulative number of indications detected in the tubesheet region as a function of elevation within the tubesheet (e.g., 12 indications at expansion transition (TTS), 6 indications within 1 inch of TTS, 3 indications from 1 inch to 2 inches below the TTS, etc.).

Response:

The following response was provided by FPL:

FPL will provide the information requested, including cumulative numbers of indications, in the report required by NEI 97-06, *Steam Generator Program Guidelines*, Rev. 1 (Reference 8), Section 3.1.7 following each inspection and within 120 days after the plant reenters MODE 4. This information will be provided for the period of time that the requested license amendment is in effect (i.e., until the original steam generators are replaced). The NEI 97-06 report is required if the results of the steam generator inspection indicate greater than 1% of the inspected tubes in any steam generator exceed the repair criteria. In the event that the NEI report is not required due to more favorable inspection results, the requested information will be provided in a separate special report within 120 days after the plant reenters MODE 4.

Undetected flaws and the potential for new flaws will be assessed in the Operational Assessment. These flaws will be assessed for both pullout and leakage integrity. Growth rate and POD are important considerations in the undetected population of cracks. The POD and growth rate of TTS and below TTS cracking has resulted in a manageable flaw population without reduced leakage or burst margin to-date. No change in the undetected flaw population is expected over the course of the next two cycles. The undetected flaw population will be used in conjunction with the leakage vs. joint length curve provided in WCAP-16208-P (Reference 1) to derive a leakage assessment. More conservative methods of assessing leakage, such as assuming that the tubesheet joint is not present, may also be used. If significant circumferential flaws are projected or remain undetected, they will be assessed for the potential for pullout. Based on the history of St. Lucie, the population of new indications would not affect pullout