ATTACHMENT 3b
ULNRC 04861
CALLAWAY PLANT

Westinghouse Non-Proprietary Class 3

WCAP-15932-NP
Revision 1

May 2003

Improved Justification of Partial-Length RPC Inspection of Tube Joints of Model F Steam Generators of Ameren-UE Callaway Plant

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ABSTRACT

The evaluation of the application of an increased inspection scope of the tubes in the Callaway SGs has been reevaluated in light of a significant number of NRC RAIs on the justification documentation. There were no significant concerns relative to the structural integrity of the joint, although the approach was revised to develop H* values that explicitly addressed the 3·ΔP performance criterion for normal operation in Zones A B, C and D. The analyses were also revised to account for and to alleviate RAI implied concerns relative to the potential leak rate that could occur during a postulated accident.

The H* examination lengths are in accord with meeting both the 3·ΔP normal operation and 1.4·ΔP postulated accident condition performance criteria. The actual inspection depths used by AmerenUE were 9 inches for Zones D and C, 7 inches for Zone B, and 5 inches for Zone A, which exceed the values determined by the structural analysis by 1 to 1.5 inches. The H* values do not contain any margin for measurement error in the elevation of crack features.

The initial approach to evaluating leak rate integrity involved some very conservative assumptions relative to the behavior of the installed tube-to-tubesheet joints and resulted in an approach that relied on using the normal operation administrative limit leak rate to demonstrate that the allowable leakage during a postulated accident would remain below 1 gpm. In response to the implications posed by the RAIs the analysis methodology was revised to accurately predict the expected leak rate during postulated accident conditions. The results demonstrate that a significant number of tubes could be postulated to be severed within the tubesheet and the accident condition leak rate would remain less than the 1 gpm performance criterion. The leak rates predicted for 360° cracks at elevations of 8, 12, and 16 inches deep in the tubesheet are 0.01, 0.004, and 0.002 gpm respectively during a postulated steam line break accident. This leak translates into about 25, 100, or > 300 throughwall and leaking 360° cracks being necessary to achieve leak rates needed to approach the performance criterion value. In addition, the evaluation of prior test data in conjunction with the results from the in situ testing of the most severely cracked tubes in the Callaway SGs strongly support the conclusion that a small amount of oxidation of the tubesheet in the vicinity of a throughwall crack will significantly narrow the effective crevice area and could prevent meaningful primary-to-secondary leakage during normal operation and postulated accident conditions.

When the projected leak rates are taken in combination with the potential number of cracks likely to be present, the fact that the throughwall cracks tested did not leak at pressures greatly in excess of steam line break conditions, and the distribution of lengths in the circumferential direction is biased toward short cracks, it is quite unlikely that the leak rate during a postulated accident event would challenge the 1 gpm limiting value. A scoping check of the evaluation was performed which indicated that if all of the indications in the Callaway SGs were assumed to be in one SG during a postulated accident, the resulting primary-to-secondary leak rate is calculated to be 0.44 gpm.

In conclusion, there appears to be no technical reason that the plant should not enter power operation at the discretion of the operators. All of the foregoing arguments support the contention that the plant SGs will function as intended.

NOMENCLATURE

AFT	Away-From (Hydraulic Expansion) -Transition
ASME	American Society of Mechanical Engineers
AVB	Anti-Vibration Bars
BC	Bobbin Coil
BET	Bottom of (Hydraulic) Expansion Transition
CL	Cold Leg
CP	Contact Pressure
ECT	Eddy Current Test
EDM	Electro-Discharge Machined
FLB	Feed Line Break
gpd	Gallons per Day
gpm	Gallons per minute
H*	H-Star
HET	Hydraulic Expansion Transition
HL	Hot Leg
ID	Inside Diameter
Callaway	AmerenUE Callaway Plant
N/A	Not Applicable
NDD	Non-Detectable Degradation
NDE	Non-Destructive Examination
NOP	Normal Operation
NRC	Nuclear Regulatory Commission
OD	Outside Diameter
P*	P-Star
PRJ	Partial-Length RPC Justification
PLRPC	Partial-Length RPC
PWR	Pressurized Water Reactor
PWSCC	Primary Water Stress Corrosion Cracking
Q	Water Flow
R_O	Outboard Radius of a Zone Boundary
RAI	Request for Additional Information

NOMENCLATURE (Continued)

RCS	Reactor Coolant System
RHR	Residual Heat Removal
RPC	Rotating Pancake Coil
SG	Steam Generator
SLB	Steamline Break
TS	Tubesheet
TT	Thermally Treated
TTS	Top of Tubesheet
UFSAR	Updated Final Safety Analysis Report
V	Volts
W*	Alternate Plugging Criteria for Wextex Tubesheet SGs
γ_S	Inspection Depth Based on Structural Requirements (structural pull-out resistance)
γ_{ZCP}	Axial Extent of Joint with Zero Contact Pressure Between Tube and TS Hole Surface
$\gamma_{N,SLB}$	Inspection Depth for a given zone (N), SLB

1.0 INTRODUCTION

Several discussions have been held between AmerenUE and NRC staff personnel during the time period between mid-October 2002 and to the present aimed at resolving technical concerns for the RPC inspection lengths proposed for the tube-to-tubesheet joints in the Callaway SGs. These discussions have revolved around a series of 73 questions posed by the NRC staff to AmerenUE referred to as Requests for Additional Information (RAIs). The RAIs concentrate on seeking additional information regarding the implementation of the inspection scope increases, e.g., measurement distances, accounting for uncertainties, etc, information regarding the testing and analyses performed to determine the structural capability of the joint, and information regarding the testing and analyses performed to ascertain the leak resistance of a joint during both normal and postulated accident conditions. This WCAP report has been revised to address all identified issues arising from the review of the original WCAP report and the white paper of the same subject (Reference 8.16).

NRC Information Notice 98-27 noted that steam generator (SG) tube repair criteria often require licensees to consider the entire length of the tube in determining whether or not tubes are degraded or defective. The widely used bobbin coil nondestructive examination (NDE) process is not qualified for the detection and/or sizing of many types of degradation in the "full-depth" region of the tube-to-tubesheet joint and in the tube end region. However, the bobbin coil probe is capable of detecting deep axial indications within the tubesheet. Although the performance of an extensive rotating pancake coil (RPC) inspection of the tube within the tubesheet can be demonstrated to remedy the circumstance, its use is technically unnecessary. Performing RPC inspection over a significant extent of the full-depth of the tube joint requires excessive time during the plant outage. Developing and implementing an improved, rapid, reliable, non-RPC process is not practical with current inspection technology. Therefore, in lieu of using rotating pancake coil (RPC)[1] probes in the vicinity of the tube weld and/or to inspect for degradation at all elevations within the full-depth below the top of the tubesheet, it is recommended that partial-length RPC (PLRPC) inspection be performed only for distances reckoned down from the top of the tubesheet. Due to primary water stress corrosion cracking (PWSCC) already having been documented in the region below the hydraulic expansion transition bottom and within the 3 inch depth in the Callaway SGs, it is recommended to use the PLRPC justification developed herein and to inspect to the associated non-full-depth lengths determined in this evaluation.

The purpose of this report is to document the development of a technical justification for the application of PLRPC inspection of the tube within the tubesheet. There are two components, designated H* and P* (referred to as H-star and P-star respectively), of the technical rationale for application of PLRPC to address potential cracking below the elevation of the RPC zone for the Callaway Model F SGs.

H* is the sound length of tube-to-tubesheet joint required to prevent pullout of the tube from the tubesheet at the limiting SG condition for joint strength, 3 times the end cap load due to normal operating pressure differential and H* is the length of tube-to-tubesheet joint required to limit primary-to-secondary leakage to an acceptable level during a postulated steamline break condition. The implementation of H* involves performing PLRPC of the tube within the tubesheet to specified depths. In the case of Callaway,

[1] The RPC probe referred to herein is the Zetec™ +Point (plus point) probe.

PWSCC has been determined by NDE to exist below the bottom of the hydraulic expansion transition and the standard 3 inch inspection depth.

The mechanical features of the existing tube-to-tubesheet joint have been analyzed and have been shown able to perform the mechanical and hydraulic functions of the tube joint including and below the elevation of H*, including the function of the weld. The hydraulically expanded joint coupled with pressure and thermal tightening provides resistance to tube pullout and to primary-to-secondary leakage at the limiting conditions.

In the case of leakage resistance, cracks at various depths below H* are hypothesized and conservative leakage for types and numbers of cracks is projected. A similar approach has been demonstrated to be acceptable for use in cases of tube weld damage due to loose parts. In those cases, the entire length of the hydraulically expanded tube joint, above the weld (which is determined to be NDD along the entire length of the tubesheet), was demonstrated to be adequate to replace the potentially ineffective weld. For reasons to be discussed later, the numerical value of H* is a function of radial distance from the center of the tubesheet.

An examination of the inspection data for the Callaway SGs was used to determine the SG with the most indications as a function of time and then to predict the number of indications that would exist below H* at the end of the next cycle of operation. The morphology of the cracks is such that most of them would not be expected to grow in circumferential extent more than they are right now. The cracks form because of anomalies in the tubesheet holes resulting from the drilling process. The tube material flows into the anomaly when the tube is expanded leaving a localized stress concentration.

P* is based on the consideration that an affected tube will be captured by the [

]^{a,c,e}. The P* length is less than the H* length.

The improved justification approach to address tube PWSCC in the tube joint, the limiting or most severe case of which is circumferential in orientation, or tube weld failure, is a technical argument for inspecting SG tubes with only the bobbin coil eddy current test (ECT) probe below the RPC probe area in the tube joint. In the past, the RPC area typically extended downward approximately 3 inches from the top of the tubesheet. (It depends on customer definition in the outage ECT contract.) In this case, the lower, approximately 18 inches of the tube in the tubesheet is in what is referred to as the bobbin coil (BC) zone.

The intent of the P* portion of the justification is to show the acceptability, on the basis of [

]^{a,c,e}. P* and H* were developed as a contingency because tube PWSCC may be anticipated due to the relatively high T-hot of the Model F SGs, which may cause the tubing to be subject to potential degradation in the BC zone. Some of the logic and data used to develop H* were also used to clarify the features of P*.

2.0 PROGRAM OBJECTIVES

2.1 GENERAL

The purpose of this program is to define a tube inspection length in the SG tubesheet below which no special nondestructive examination of the SG tubes needs to be performed and, ultimately, to provide the basis for a Technical Specifications change to that effect should one be required. It is to be based on the development of partial-length RPC justification criteria referred to as H*.

Based on the results of this evaluation, and the results of several inspections during refueling outages wherein PWSCC (axial and circumferential) was indicated in the region below the hydraulic expansion transition bottom and within the 3 inch RPC inspection depth, it is recommended that the RPC inspection length of the tube within the tubesheet be the H* lengths.

It is assumed that the transition axial extent is taken as approximately 0.30 inches. [

]a,c,e

Because primary side tube cracking has already been found in the tubesheet region of the Callaway SGs, the inspection minimum axial extent should be the H* values (per Table 3-1) for the tubes to be inspected.

The H* inspection depth varies by radius from the vertical centerline of the TS, delineated into several separate zones. The number and boundaries of zones may vary, depending on the judgment of Callaway. A larger number of zones reduces over-inspection, i.e., inspection to a greater depth than required for roughly one-half of the tubes in a given zone. A smaller number of zones, such as one zone, set by the greatest H* in the SG, would mean that roughly 95 percent of the tubes in the inspection program would be inspected to a greater depth than required. The H* PLRPC is shown on Figures 2-1, 3-1 and 3-6 and P* is shown on Figures 2-2, 3-2 through 3-5.

2.2 EVALUATION TO ESTABLISH INSPECTION REGIMEN FOR H*/P*

Assumptions used for establishing H* and P*:

- Bobbin coil ECT is capable of detecting axial indications within the tubesheet. Bobbin probe eddy current from a 50% EDM notch population assembled for W*[2] program (Westinghouse Explosive Tube) have been examined to determine the detection performance for ID flaws in a straight expanded section in the tubesheet. A 0.5 inch long 100% EDM notch is expected to give approximately 74 volts signal amplitude (peak to peak) at the typical bobbin calibration settings (4 x 20% flat bottom holes set to give 4 volts in the prime frequency channel 1; the voltage of a crack of similar dimensions is expected to be approximately 20% of the EDM notch voltage, i.e.,

[2] The W stands for Wextex which refers to the Westinghouse explosive tube expansion process. Combustion Engineering used an explosive expansion process extensively and it is referred to as explansion.

approximately 15 volts. The response of 50% EDM notches is expected to be less than half expected for a 0.5 inch long crack. Therefore, it is concluded that, if the bobbin probe could reliably detect the 50% EDM notches, the detection of the limiting 100% crack would be assured.

The evaluations were conducted using typical bobbin probe analysis guidelines. A total of 9 tube specimens that contained 21 notches were analyzed; all of the notches present were successfully detected. The analysis team consisted of a primary analyst, a secondary analyst, and a resolution analyst, each functioning in a role identical to his field analysis function.

The amplitudes observed for these notches of various lengths range from a minimum of 1.98 volts to 7.20 volts. This result, 100% detection, is equivalent to 80% detection at 98% confidence, and provides confidence that ID cracks less severe than the 0.5 inch long 100% depth ID flaw will be detected.

- Tube cracking within the tubesheet is PWSCC.
- The separated tube condition for H* and P* is a low probability event for hydraulic expanded Alloy 600 mill annealed and thermally treated tubing.
- H* distances will restrict tube movement for all of the hot leg (HL) tubes for the limiting condition and will control leakage to within the UFSAR accident analysis assumptions.
- P* distances will prevent the probability of tube disengagement from the tubesheet hole in the case of separation and translation, based on the three-inch RPC inspection depth.
- The maximum allowable primary-to-secondary side leakage during the limiting accident condition, i.e., Steamline Break (SLB), through the affected SG is 1.0 gpm in the affected SG
- The plant primary side makeup capacity is on the order of 100 gpm.

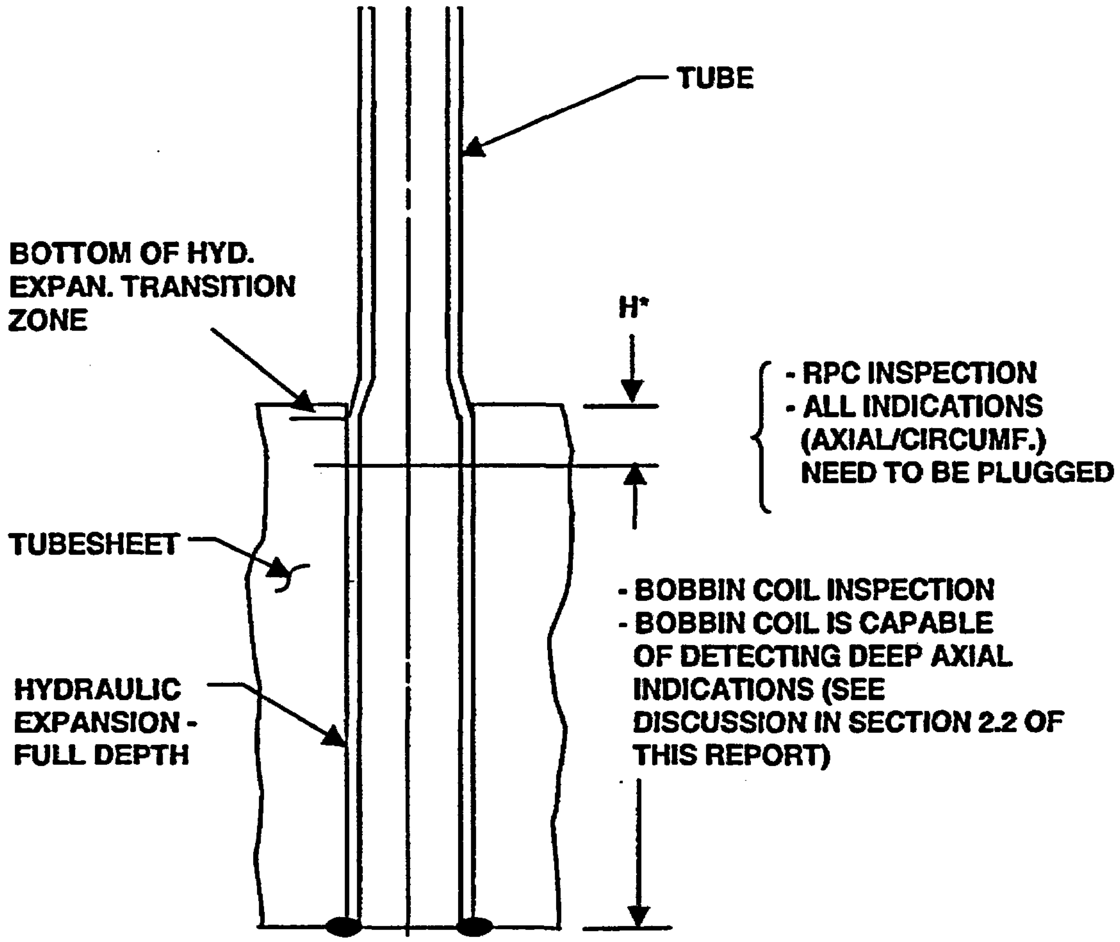

Figure 2-1
H* Tubesheet Region Partial-RPC Justification
for Steam Generators

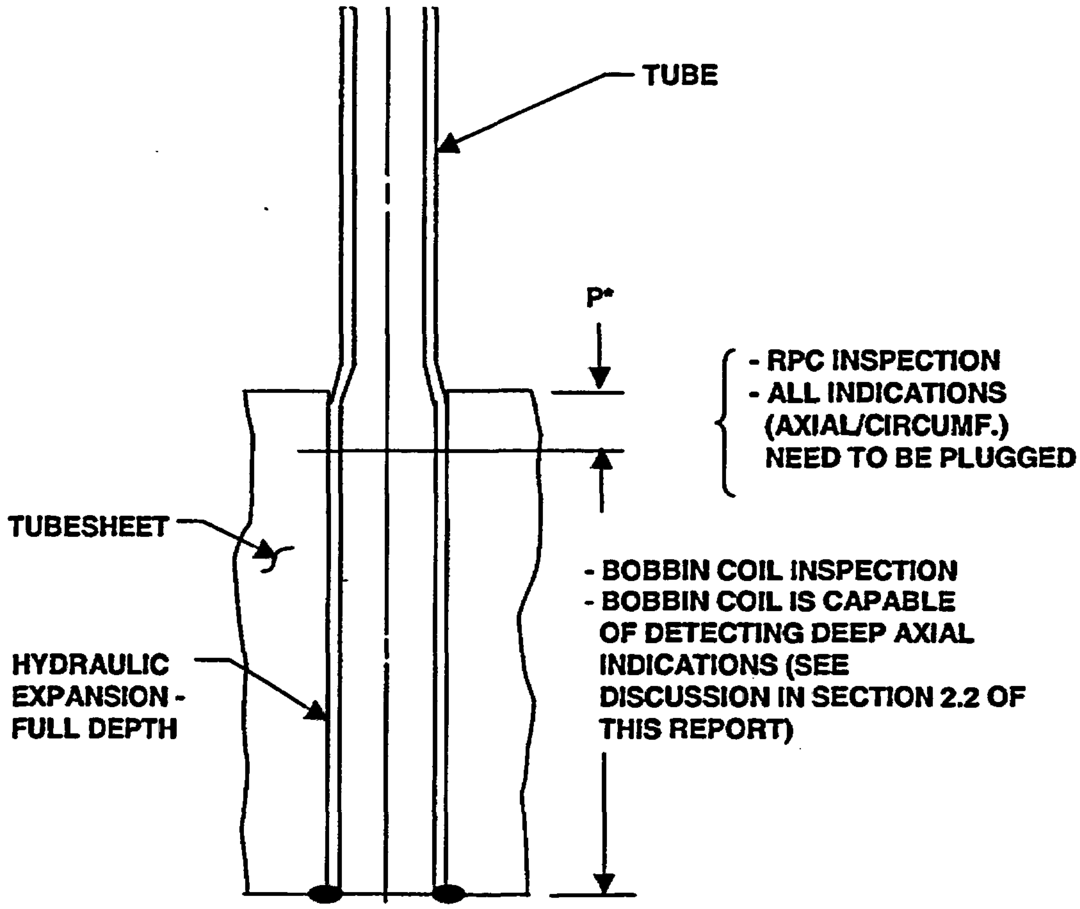

Figure 2-2
P* Tubesheet Region PLRPC Justification
for Steam Generators

3.0 ANALYSIS AND SUMMARY

3.1 ANALYSIS

3.1.1 Function of H* and P*

Because PWSCC has been indicated within the three-inch RPC inspection depth of the Callaway SGs, it is recommended to implement inspection to the H* depths. (Refer to Figures 2-1 and 3-1 and Table 3-1 determined in this evaluation.)

The P* justification, included in Appendix A of this report, addresses the very small likelihood of tube separation within the tubesheet for approximately 95% of the tubes on the HL. P* also applies to approximately 95% of the cold leg tubes. P* applies to interior tubes, i.e., tubes with outboard neighbors, to non-patchplate-area tubes and to non-stayrod-area tubes. It also applies to interior tubes which have non-plugged tubes in the next-larger-radius location in the same column. P* is shown on Figs. 2-2, 3-2 through 3-4 and the operating tube locations, with the exception of operating tubes adjacent to plugged tubes, where P* is permitted are shown on Fig. 3-5.

3.1.2 Features of H*

3.1.2.1 Leakage Resistance

The fundamental issue associated with the leak rate integrity is concerned with the potential leakage that could result from tube cracks located below the H* depths during a postulated accident condition event. Reference 8.17 provided information aimed at demonstrating under a number of assumptions that adopting a primary-to-secondary administrative leak rate limit of 75 gpd during normal operation would conservatively assure that the leak rate would remain less than 1 gpm during a postulated steam line or feed line break event. The reason this approach was taken stems from the anticipated performance of a tube which is postulated to contain a 360° circumferential crack within the tubesheet and for which there is no resistance to flow associated with the crack. Unlike hard rolled tube-to-tubesheet joints which are expected to result in zero leakage, the hydraulic expanded joints used at Callaway are expected to permit some leakage. This is similar to the situation with explosively expanded joints found at plants which have implemented a technology referred to as W*. The as-fabricated explosively expanded joint is not as tight as a hard rolled joint, but is somewhat tighter than a hydraulically expanded joint. The dominant interface pressure in a hydraulically expanded joint comes from the differential thermal expansion and the internal pressure in the tube. Multiple plants in the United States have already implemented inspection plans based on the structural and leak rate integrity of explosively expanded joints. In all cases the basis is the same, the installation process results in an interference fit between the tube and the tubesheet which has an associated residual pressure preload between the tube and the tubesheet. Thermal expansion and internal pressure both increase the magnitude of the interface pressure, and pressure induced deflection of the tubesheet leads to dilation of the tubesheet holes which acts to reduce the interface pressure. The hydraulic expansion process results in an as-fabricated interface pressure. The initial preload pressure is not the dominant factor in determining the length of engagement for structural integrity and the H* lengths are similar to the W* lengths in that respect. The evaluation of the leak rate resistance of the tube-to-tubesheet joints in the Callaway SGs is provided in further detail in section 6.0 of this report.

3.1.2.2 Tube Anchorage

Three determinations were made of the engagement lengths required to resist pullout during normal operation and under postulated accident conditions, Reference 8.17. Two of these were for anticipated normal operating conditions and the third was for the limiting accident condition. The area of the tubesheet was divided into four radial zones to account for the variation of H* with radius from the center of the tubesheet. These were designated as D, C, B, and A starting from the periphery of the tubesheet and had H* depths of 7.98, 7.50, 5.75, and 2.38 inches for radii extending to [ ]$^{a, c, e}$ respectively. Although the H* lengths calculated to meet the normal operation performance criterion exceeded those for the limiting postulated accident criterion, the H* values reported were based on the accident condition values. The rationale for this selection was based on anticipated leakage during normal operation leading to a shutdown of the plant before the degradation could progress to the state that the normal operation performance criterion would be violated.

During the course of preparing responses to the RAIs associated with the structural performance criteria, H* values based on the explicit use of the most limiting differential pressure during normal operation were reanalyzed. Although secondary side pressures of 908, the limiting value, and 970 psia were used for the calculation of the Reference 8.17 normal operating condition H* determinations, they were applied for the determination of the tube-to-tubesheet contact loads while the applied pullout load was based on the design specification differential pressure of 1600 psi. To obtain true limiting H* values for normal operation the analyses were repeated using the actual limiting normal operating differential pressure of 1342 psi based on the lower of the two secondary side pressures. It was also confirmed that the actual anticipated secondary side pressure during the current operating cycle is on the order of 950 psia, thus the analysis is conservative. The results of the evaluation were that H* lengths of 7.99, 7.43, 5.63, and 3.16 inches are required for Zones D, C, B, and A respectively (see Table 3-1). A length of 0.3 inches is added to the H* distances for Zones A and B as discussed below and included in Table 3.1. The H* lengths based on meeting the 3 times normal operation·ΔP performance criterion are essentially the same as those from the limiting accident condition except for the Zone A value.

A small crevice is formed at the top of the tubesheet during the tube hydraulic expansion process. This is because the top of the expansion tool is restricted to being slightly below the top of the tubesheet to prevent bulging of the tube above the top of the tubesheet. A transition from the expanded portion of the tube to the unexpanded portion of the tube exists which is referred to as the expansion transition. The bottom of the expansion transition is located below the top of the tubesheet. The H* values correspond to lengths of expansion engagement in the tubesheet while the measurement during the inspection is from the top of the tubesheet. Hence, an allowance is made based on the expected distance from the top of the tubesheet to the bottom of the expansion transition. This was estimated to be 0.15 inch from the analyses performed for Reference 8.16 and was the subject of an RAI. An investigation of the information from measurements of crevice depths from other hydraulically expanded units led to the finding that limiting values of crevice depth could range from about 0.15 to 0.30 inches depending on when the SGs were manufactured. The limiting value for the process used to make the Callaway SGs likely led to a limiting value closer to the former, but it was decided to implement a value of 0.30 inch for the Callaway inspections.

Whether or not the crevice depth value needs to be added to the H* value to determine the inspection length is a function of the tubesheet hole dilation. The contact pressure from the initial installation, thermal expansion, and pressure is reduced when the hole dilates. If the hole dilates too much the contact pressure becomes negligible and is referred to as loss of contact in Reference 8.17. However, the magnitude decreases with depth into the tubesheet because the dilation results from bending of the tubesheet in response to the application of the primary-to-secondary pressure difference. So, if loss of contact occurs, it is restricted to a small length below the bottom of the expansion transition. For two of the Zones, D and C, the no-contact length when reckoned from the top of the tubesheet is greater than the maximum expected distance of 0.30 inch, therefore, the H* values for those zones do not need to be increased to account for the depth of the hydraulic expansion crevice. But, the value for Zones A and B was increased to 3.46 inches and 5.93 inches to be inclusive of the transition distance.

In summary, the existing values initially determined based on postulated accident conditions were the same as those from the most limiting anticipated normal operating condition except for Zone A. The H* inspection distance for Zone A was increased to 3.46 inches, bounding the limiting performance criterion (end cap load from 3 times the normal operating pressure differential), as a result of the reanalysis. For implementation, the inspection depths were specified to be 9 inches for Zones D and C, 7 inches for Zone B, and 5 inches for Zone A, exceeding the values determined by the structural analysis.

3.1.2.3 Determination of H* for a Zone

H* for each zone is calculated to provide a portion of the tube pullout resistance necessary to meet the 3 times normal operating condition performance criteria.

The inspection depth-versus-R relationship is [

]a,c,e. The H* information is summarized in Tables 3.1 and 3.2.

The bobbin probe would be used to look for large axial indications within the tubesheet and below the RPC inspection depth. The signals identified by bobbin would be further interrogated by RPC in order to characterize them and to separate them from potential false positives (e.g. expansion anomalies). The bobbin probe capability of detecting cracks in the tubesheet is addressed in Section 2.2 of this report.

3.1.3 Features of P*

[

]a,c,e

[

]a,c,e. The details of the P* analysis are shown in Appendix A of this report.

The application of the P* criterion to any one tube requires that the [

]a,c,e.

3.2 SUMMARY

3.2.1 H* Summary

In this configuration, the following is assumed :

1. Consider multiple tubes in a given SG to be degraded (The incidence of ID cracking in the A600TT tube hydraulic expansion joints in Callaway SGs is very low and for the tubes in other plants of any diameter, such as 11/16 inch, 3/4 inch or 7/8 inch appears to be very low.)

2. For normal operation, the plant will operate as long as the leak rate stays within the technical specification allowable leakage limit and within the administrative limits of EPRI Report TR-104788, "PWR Primary-to-Secondary Leakage Guidelines".

3. For the accident condition (steamline break/feedline break – SLB):

   Q_{SLB} = 1.0 gpm for the affected SG

4. A significant number of tubes can be postulated to be severed within the tubesheet and the accident condition leak rate will remain below the 1.0 gpm performance criterion.

5. The evaluation of prior test data in conjunction with the results from in-situ testing or the most severely cracked tubes in the Callaway SGs strongly support the conclusion that a small amount of corrosion of the tubesheet in the vicinity of a throughwall crack will significantly narrow the

effective crevice area and could prevent meaningful primary-to-secondary leakage during normal operation and postulated accident condition.

6. A scoping check has been performed which indicates that if all the indications in the Callaway SGs were assumed to be in one SG during a postulated accident, the resulting leak rate would not exceed 0.44 gpm.

   Other assumptions include:

   - The distribution of indications in H* was representative of each respective depth in the tubesheet.
   - All of the indications were throughwall at their reported lengths.
   - All of the indications leaked.

Each leak rate was calculated using the 90th percentile lower bound loss coefficient and the total leak rate from all of the indications were summed.

Justifications were developed to reduce the RPC inspection length of the Model F steam generator tubes within the tubesheet from full-length to partial-length for the Callaway Plant. The criteria are referred to as partial-length RPC justifications and show that PWSCC below the H* depths (in a given zone) into the tubesheet from the tubesheet top will pose neither structural issues such as tube separation and pullout nor excessive leakage during the limiting accident condition, SLB.

An evaluation has been performed to develop the certain RPC inspection depth, known as H*, below which any type of PWSCC (axial and/or circumferential) can be accommodated. The determination of H* consists of analyses and testing programs which quantified the tube-to-tubesheet hole surface radial contact pressure of the Westinghouse Model F steam generator tubes for the bounding plant conditions. The tube within the H* length must be no-detectable-degradation (NDD) and is verified as such in the periodic RPC inspection programs. H* is reckoned downward from the TTS. The bottom of the hydraulic expansion transition is typically lower in elevation than the TTS. A small distance of approximately 0.30 inches may be added to account for the maximum distance between the bottom of the hydraulic expansion transition and the TTS. The calculated H* values do not contain any margin for measurement error in elevation of the crack features.

The tubes are grouped in four zones, based on distance from the bundle vertical centerline. Due to tubesheet upward bending during normal operation and during the limiting accident condition, the tube-to-tubesheet hole surface contact pressure varies through the thickness of the tubesheet. The resistance to leakage through a crack and through the tube-to-tubesheet interface to the secondary side is a function of fluid conditions and tube-to-tubesheet contact pressure. Therefore, leakage from a given crack in a given tube is a function of a crack tip distance from the tubesheet top and tube distance from the bundle (tubesheet) vertical centerline.

3.2.2 P* Summary

The P* value of 3 inches, [

]a,c,e. It also provides a contingency for any tube which was left out of the RPC inspection program during a given outage as well as all of the tubes in the SGs which were unopened in a given outage. The benefit it provides is a contingency against tube end disengagement from the TS hole in case of separation.

P* Evaluation Features - Summary

- Addresses case of separated tube at approximately three-inch depth.
- P* obviates the likelihood of developing a leak rate greater than the primary side makeup capacity of about 100 gpm.

Table 3-1

Depth into Tubesheet to Meet Structural Limits for Limiting Condition

	RPC Inspection Depth for Particular Zone, Inches (Outboard Boundary Distance of Zone from TS Vertical Centerline)			
	A (58.3 in.)	B (48.6 in.)	C (30.2 in.)	D (12.0 in.)
Axial Extent Req'd for Pullout Resistance includes a bounding distance for the location of the bottom of the hydraulic expansion transition within the tubesheet of 0.30 inch. A "no contact length" has been calculated for Zones C and D during normal operating conditions that exceeds the 0.30 inch distance, therefore, the 0.3 inch length is not added to the H* distance for Zones C and D.	3.46	5.93	7.43	7.99

Table 3-2

Callaway Leakage Limits (Per Steam Generator)

Operating Condition	Leakage Limits Maximum Per SG		
	Tech. Spec.	FSAR	Administrative
Normal Operation	150 gpd (0.35 gpm)	N/A	75 gpd (0.104 gpm)
SLB/FLB	N/A	[1]1440 gpd (1.00 gpm)	N/A

Notes:

1) The 1.0 gpm UFSAR leakage applies only to the faulted loop.
2) Negligible secondary-to-primary side leakage is acceptable during LOCA.

a,c,e

Figure 3-1
H* Concept Tube Constraint in Tubesheet Only

a,c,e

Figure 3-2
P* Concept for SG – As Built (Tube Constraint in U-Bend)

a,c,e

Figure 3-3
P* Concept Tube Constraint in U-Bend - Translated

a,c,e

Figure 3-4
P* Translated Tube Constraint in U-Bend at AVBs

a,c,e

Figure 3-5
Model F Tubesheet –P* Areas for Addressing Tube Separation Probability for Postulated Circumferential Cracking at Slightly More Than the RPC Depth of 3 In.

a,c,e

[ ]

Figure 3-6 H* Zones

A: H* = 3.46 In; B: H* = 5.43 In.; C: H* = 7.43 In.; D: H* = 7.99 In.

4.0 OPERATING CONDITIONS

Callaway Unit 1 is a four-loop plant with Model F steam generators.

4.1 NORMAL OPERATION CONDITIONS

Values of the plant thermal and hydraulic parameters during normal operation at 10 percent tube plugging conditions applicable to this study are tabulated below:

Parameter	Units	Normal Operation Conditions (1)	
		Case 2 (2)	Case 3 (3)
Power – NSSS	MWt	3579	3579
Reactor Vessel Outlet Temperature	°F	615.3	620.0
Reactor Coolant System Pressure	psia	2250	2250
SG Steam Temperature	°F	533.0	540.8
SG Steam Pressure	psia	908	970

(1) Reference 8.10

(2) Minimum Steam Temperature and Pressure in Reference 8.10

(3) Maximum Steam Temperature and Pressure in Reference 8.10

4.2 FAULTED CONDITIONS

In addition to the RG 1.121 criteria, it is necessary to satisfy the updated final safety analysis report (UFSAR) accident condition assumptions for primary-to-secondary leak rates. Calculated primary-to-secondary side leak rate during postulated events should: 1) not exceed the total charging pump capacity of the primary coolant system, and 2) be such that the off-site radiological dose consequences do not exceed title 10 of the Code of Federal Regulations (10 CFR) Part 100 guidelines.

The accident condition primary-to-secondary leakage must be limited to acceptable values established by plant specific UFSAR evaluations. The appropriate value for the Callaway SGs is 1.0 gpm for the affected SG. Pressure differentials associated with a postulated accident condition event can result in leakage from a throughwall crack through the interface between a hydraulically expanded tube in the tubesheet and the tube hole surface. Therefore, a steam generator leakage evaluation for faulted conditions is provided in this report. The accidents that are affected by primary-to-secondary leakage are those that include, in the activity release and off-site dose calculation, modeling of leakage and secondary steam release to the environment. Steamline break (SLB) is the limiting condition; the reasons that the SLB is limiting are: 1) the SLB primary-to-secondary leak rate in the faulted loop is assumed to be greater than the operating leak rate because of the sustained increase in differential pressure, and 2) leakage in the faulted steam generator is assumed to be released directly to the environment. For evaluating the radiological consequences due to a postulated SLB, the activity released from the affected SG (which is connected to the broken steam line) is released directly to the environment. The unaffected steam generators are assumed to continually discharge steam and entrained activity via the safety and relief valves up to the time when initiation of the RHR system can be accomplished. A 1.0 gpm (1440 gpd) primary-to-secondary leakage is assumed for the affected SG, which is significantly greater than that anticipated during normal operation. Furthermore, the radiological consequences evaluated, based on meteorological conditions, assumed that all of this flow goes to the affected steam generator. With this level of leakage, the resultant doses are well within the guideline values of 10 CFR 100.

5.0 TEST PROGRAM

The test program, see Reference 8.1, had two purposes:

1. To determine the [

]a,c,e.

Pullout test data were also obtained from a factory test program which was performed to investigate the various manufacturing steps for the tube joint. That test is described in Section 7.2.

A total of [

]a,c,e

The lower bound leakage resistance distribution for the collars with the nominal tubesheet hole diameter was used in the present leakage evaluation. This lower bound leakage resistance was made using data for the test conditions shown in the table below.

Table 5.1
Leak Test Program Matrix

a,c,e

5.1 TEST SAMPLE CONFIGURATION

The intent of the test samples was to model key features of the Model F tube-to-tubesheet joint for [ ]^{a,c,e}. The following hardware was used:

5.1.1 Tubesheet Simulant (Collar)

The collar simulates the circumferential stiffness of a Model F tubesheet unit cell, utilizing an appropriate outside diameter of approximately [

]^{a,c,e}.

5.1.2 Tubing

The yield strength for the SG Alloy 600 tubing ranges between [ ]^{a,c,e}. The Alloy 600 tubing used for these tests was from a certified heat and lot conforming to ASME SB163, Section III Class 1. It was obtained from a Quality Systems-controlled Storeroom. This material had a yield strength of [ ]^{a,c,e} ksi, making yield strength-sensitive test results appropriate.

5.1.3 Test Sample Design Configuration

The intent of the leakage portion of the test program was to determine the leakage resistance of simulated Model F tube-to-tubesheet joints, disregarding the effect of the tube-to-tubesheet weld and the [

]^{a,c,e}. (These welds were an artifact of the test design and did not affect the test condition because they made no contribution to hydraulic resistance from the tube-to-tubesheet weld or the tube tacking operation.)

5.1.4 Test Sample Assembly

5.1.4.1 Tube Tack Rolling Operation

The steam generator factory tubing drawing specifies a [ ]^{a,c,e}, to facilitate the weld to the cladding on the tubesheet face.

The assembly of the test samples required an appropriate roll expansion torque to bring the tube into light contact with the collar. Wall thinning calculations performed on the tacked region of the tube show values of no more than [ ]^{a,c,e}. This indicates a lack of significant contact with the collar, and conformance with the intent of the factory tacking operation.

5.1.4.2 Tube Hydraulic Expansion

The hydraulic expansion pressure range for the Callaway steam generators was approximately [

]^{a,c,e}. This value conservatively bounds the lower expansion pressure limit used for the Callaway steam generators.

The tube expansion tool used in the factory consisted of a pair of seals, spaced by a tie rod between them. The hydraulically expanded zone was positioned relative to the lower surface of the tubesheet, overlapping the upper end of the tack expanded region. It extended to within a short distance of the upper surface of the tubesheet. This produced a hydraulically expanded length of approximately [ ]^{a,c,e} inch nominal tubesheet depth.

The majority of the test samples were fabricated using [

]^{a,c,e}. These samples are described as "Segmented Expansion" types. A tube expansion schematic is shown in Figure 5-2.

A small group of the test samples were fabricated using a [ ]^{a,c,e} tool which was fabricated expressly for these tests. These samples were described as "Full Depth Expansion" types. The expansion method with regard to the segmented or full length aspect does not have a bearing on the test results.

5.2 TEST PROCEDURE

The testing reported herein was performed according to a test procedure which outlined two types of leak tests and one mechanical loading test. The tests performed are described below.

5.2.1 Room Temperature Primary-to-Secondary Leak Tests

Room temperature primary-to-secondary leak tests were performed on all test samples, using deionized water as a pressurizing medium. [

]^{a,c,e}, to simulate the lack of a tube weld.

5.2.2 Elevated Temperature Primary-to-Secondary Side Leak Tests

Elevated temperature primary-to-secondary side leak tests were performed using an [

]a,c,e.

These tests were performed following the room temperature primary-to-secondary side leak tests on the chosen samples. The test results showed a [

]a,c,e.

5.2.3 Mechanical Loading Tests

Mechanical loading, [

]a,c,e.

5.3 TEST SUMMARY

5.3.1 Leak Tests

The room temperature leak tests on nominal diameter segmented expansion collars averaged [

]a,c,e. (As a point of reference, there are approximately 75,000 drops in one gallon.)

5.3.2 Tube Pullout Tests

[

]a,c,e.

a,c,e

Figure 5-1
Leakage Test Schematic

a,c,e

Figure 5-2
Tube Hydraulic Expansion Process Schematic

6.0 LEAK RATE EVALUATION

The leak rate from a crack located within the tubesheet is governed by the crack opening area, the resistance to flow through the crack, and the resistance to flow provided by the tube-to-tubesheet joint. The path through the tube-to-tubesheet joint is also frequently referred to as a crevice, but is not to be confused with the crevice left at the top of the tubesheet from the expansion process. The presence of the joint makes the flow from cracks within the tubesheet much different from the flow to be expected from cracks outside of the tubesheet. The tubesheet prevents outward deflection of the flanks of cracks, a more significant effect for axial than for circumferential cracks, which is a contributor to the opening area presented to the flow. In addition, the restriction provided by the tubesheet greatly restrains crack opening in the direction perpendicular to the flanks regardless of the orientation of the cracks. The net effect is a large, almost complete reduction of the leak rate when the tube cracks are within the tubesheet.

The leak path through the crack and the crevice is very tortuous. The flow must go through several turns within the crack in order to pass through the tube wall, even though the tube wall thickness is relatively small. The flow within the crevice must constantly change direction in order to follow a path that is formed between the points of hard contact between the tube and the tubesheet as a result of the differential thermal expansion and the internal pressure in the tube. There is both mechanical dispersion and molecular diffusion taking place. The net result is that the flow is best described as primary-to-secondary weepage. At its base, the expression used to predict the leak rate from tube cracks through the tube-to-tubesheet crevice is the D'Arcy expression for flow rate, Q, through porous media, i.e.,

$$Q = \frac{1}{K\,\mu}\frac{dP}{dz}, \tag{1}$$

where μ is the viscosity of the fluid, P is the driving pressure, z is the physical dimension in the direction of the flow, and K is the "loss coefficient" which can also be termed the flow resistance if the other terms are taken together as the driving potential. The loss coefficient is found from a series of experimental tests involving the geometry of the particular tube-to-tubesheet crevice being analyzed, including factors such as surface finish, and then applied to the cracked tube situation. The flow through the crack is modeled separately and considered in series with the flow through the crevice. The loss coefficient is significantly affected by the contact pressure between the tube and the tubesheet because this affects the net contact area that is formed by the mating of asperities on both the tube and tubesheet surfaces at a microscopic level. The deflection of the tubesheet causes the contact pressure during normal or accident conditions to be an essentially linear function of the depth into the tubesheet. Thus, the estimation of the leak rate in service involves integrating the loss coefficient as a function of depth to calculate an effective loss coefficient for the joint. As noted earlier, the major factors affecting the contact pressure loss coefficient are differential thermal expansion and internal pressure in the tube. Although the fabrication preload does offer some contribution, it is important to note that all of the test specimens exhibited leakage at both room and elevated temperature conditions, with higher leak rates being measured at room temperature. These results strongly support the contention that throughwall cracks in the tubesheet of an operating SG should exhibit some leakage during an in situ test.

If a throughwall crack developed during operation, the loss coefficient would likely increase significantly with the initial introduction of primary water into the crevice between the tube and the tubesheet. A very small amount of primary water would be involved and any oxidant present would be quickly consumed by surface reactions with the tubesheet material wetted by the flow. This means the exposed microscopic crevices between mating asperities would be expected to narrow due to the expansion of the oxides formed; the oxides associated with corrosion in a SG occupy more space than the parent metals. There would be no meaningful further corrosion because of the lack of a mechanism for oxidant replenishment. In addition, any microscopic particulates that were transported through the crack would likely not be able to be transported through the crevice because of the torturous path involved. Although potentially not a big effect, they would nonetheless further narrow the crevice and retard the flow. An observation from the leak rate testing program was that subsequent tests on the same specimen at the same test pressures at elevated temperature with few exceptions demonstrated an increase in the loss coefficient with test number. The same effect was not observed on specimens for which repeated tests were run at room temperature using the same pressurizing medium, deionized water. Thus, supporting the argument that a small amount of oxidation takes place at elevated temperatures and leads to a closing or narrowing of the microscopic pathways between the tube and the tubesheet. The argument also explains why none of the in situ tests of tubes with likely throughwall cracks at Callaway resulted in detectable leakage and implies that there would have been no leakage in the event of a postulated accident.

In laboratory testing, at-temperature exposures of test units were very short (typically < 1 day) while at Callaway the at-temperature leakage may have occurred for hundreds of days before decreasing to less than detectable. Additionally, the pressure of boric acid in the reactor coolant would result in slightly higher low-alloy steel corrosion rates that would further accelerate blocking of the crevice to the point that flow would be limited. The impact of boric acid in the tubesheet due to the presence of a through-wall flaw in an SG tube is provided in previous F* reports like Reference 8.18 that have been submitted to the NRC staff.

The normal operation primary-to-secondary leak rate history measured at Callaway through the end of Cycle 11 is illustrated on Figure 6.1. The measured leak rate at the end of operating Cycle 12 was reported to be about 0.31 gpd. Although there were several tubes detected during the inspection that had circumferential cracks within the tubesheet that were very likely 100% throughwall, including one that was reported as being 360° in circumferential extent in situ tests performed during the outage of the cracks within the tubesheet found that they exhibited no leakage at pressures up to 4350 psi at room temperature.

6.1 IN SITU TESTED INDICATIONS

As noted in the introduction to this section, Callaway has performed a number of in situ tests of circumferential tube crack indications located within the tubesheet and has found none that exhibited any leakage (Reference 8.16). The in situ testing equipment is capable of measuring leak rates as small as 0.001 gpm or about 75 drops per minute. The detection capability is significantly improved if the pressure is monitored. Water is for all practical purposes an incompressible medium at the pressures of interest for in situ testing. Thus, if there is no detected drop in the pressure during a hold period, there has been zero leakage. For most of the tests performed at Callaway, especially those at refueling outage 12, there has been no decay in the pressure observed during the hold times. Examination of the ECT measured profiles implies that several were certainly 100% throughwall although there was no measured leak rate during the in situ testing.

A number of measured profiles are illustrated on Figures 6.2 through Figure 6.10. The cracks range in circumferential extent from about 30° to 360°. Regardless of the reported depths, they are all likely to be

100% throughwall or have most of their length at 100% throughwall. Examination of profiles from indications that were not in situ tested were used to glean information about the growth and progression of the cracks. A profile representative of the early stages of growth is shown on Figure 6.11. Likewise, a profile representative of, say, median stages of growth is illustrated on Figure 6.12, and finally, a profile indicative of the latter stage of growth is illustrated on Figure 6.13. What is apparent from the presented scenario is that the tendency is for the cracks to grow deeper without getting appreciably longer, in spite of the exception posed by the tube at R18C77 in SG C. The aspect ratio of depth over length reduces with time as the cracks get deeper. This means that future occurrences of 100% deep by 360° circumference is not likely, although the probability is not negligible.

The distribution of the locations of the cracks below the top of the tubesheet is illustrated on Figure 6.14, and the distribution of total angles is illustrated on Figure 6.15. A normal curve has been superposed on the distribution of locations below the top of the tubesheet, but it is apparent that the cumulative function for a uniform distribution would agree with the data as well. This means that projections of the number of cracks outside of the H* regions should be made using a uniform distribution.

The distribution of angles is approximately linear between 30 and 150°, however there was one crack with an angular extent of about 220° and one with an angular extent of 360°. The distribution is in keeping with expectations if the cause of the cracking is postulated to be residual stresses from local expansions of tube material into manufacturing depressions within the drilled holes in the tubesheet. It is also to be expected that the cracking would progress to a significant depth without necessarily extending 360° circumferentially. In other words, the large crack angles appear to be exceptions and most cracks would be expected to be in the range of less than 150°.

A further discussion of in situ testing of tube indications is located in Appendix D of this report.

6.2 PREDICTION OF ACTUAL LEAK RATES

The leak rate from a single circumferential indication is calculated using the Westinghouse computer code DENTFLO. The code was written to model the flow associated with cracks in series with the tube-to-tubesheet crevice based on maintaining continuity between the two physical elements through which the fluid must pass. To better respond to the concerns of the NRC staff relative to the potential leak rate from large indications, revisions of the previous analyses were developed and implemented. These are discussed in the following paragraphs.

The database for the curve fitting of the crevice loss coefficient as a function of the contact pressure was reviewed in detail. The examination of the test data revealed a bias to lower loss coefficients from the tests performed at room temperature relative to the tests performed at 600°F. In addition, it was found that crevice resistance increased with time at elevated temperature, i.e., the resistance consistently increased for subsequent tests using the same specimens. An examination of the data from the tests performed at room temperature revealed that the leak rate was constant with time, even though the repeated tests were performed using the same test equipment and the same test specimens. The consistent explanation for the behavior of the elevated temperature test results is that slight corrosion of the tubesheet simulant at elevated temperature resulted in a narrowing of the flow paths within the tube-to-tubesheet interface. The same effect as would be expected to occur in the tubesheet of an operating plant and supports the observation of no leakage from any of the in situ tests of cracks that surely were throughwall in the Callaway SGs. The regression analysis of the loss coefficient as a function of contact pressure was repeated using data more appropriate to the prediction of leak rate from an operating SG. Two modifications to the data base were made to effect the analysis. Firstly, most of the data obtained from room temperature tests was removed from analysis consideration. The inclusion of the data in prior analyses resulted in an artificial reduction of the loss coefficient regression curve and an artificial increase in the standard deviation of the regression residuals. Low contact pressure (1000 psi pressure differential equates to 790 psi contact pressure) room temperature data were retained in the database because there were no low contact pressure data obtained at elevated temperature. This is a conservative approach and has the effect of reducing predicted crevice resistance values. Although the data strongly indicated an increase in the crevice resistance with time, when multiple tests of the same specimen were available all of the data from the tests were included in the data base instead of retaining only the data from the last test. This has the effect of reducing the loss coefficient at higher contact pressures and increasing the standard deviation of the regression residuals, thus lowering the 95% simultaneous confidence curve. The final database and regression line are illustrated on Figure 6.18. There are 29 data points in the correlation and the coefficient of regression is 75%. Therefore, the loss coefficients used in the leakage calculations are based on a sound database, and no additional tests are deemed necessary.

In keeping with the analyses performed for other evaluations involving tube-to-tubesheet crevice resistance, a lower 95th percentile simultaneous confidence bound was fitted to the data for use in evaluating predicted leak rates. Monte Carlo simulations performed in support of the application of W* as an alternate repair criteria support the use of the confidence bound for making multiple predictions of the leak rate. Previously reported predictions of leak rate were done at a 95% prediction bound, normally a 95% confidence bound is used if multiple predictions are being made.

The crack opening area model was revised to properly account for the fact that the pressure acting on the flanks of the cracks is compressive relative to the material adjacent to the crack plane. Previous analyses considered a far-field tensile stress, which leads to an underestimate of the shear force resistance from the contact pressure between the tube and the tubesheet. The change resulted in a reduction of the predicted crack opening area on the order of 50% for cracks that are less than 360° in azimuthal extent. The theory of the crack opening model is provided in Appendix C.

An analysis procedure was also developed for dealing with the occurrence of a 360° throughwall crack. Prior discussions were based on postulating that the tube material below the crack ceased to exist and that only the tube-to-tubesheet crevice resisted the flow. In reality the crack faces will part slightly and the crack will continue to provide a resistance to primary-to-secondary leakage. The approach is based on considering the maximum area from an analysis which considers the primary pressure acting on the crack flanks and only the tube material acting as a spring to resist parting of the crack faces. The model predicts leak rate from a 360° crack at elevations of 8, 12, and 16 inches deep in the tubesheet during a postulated steam line break accident of 0.01, 0.004 and 0.002 gpm, respectively. These leak rates are predicted at the worst radial location for the elevations considered. Results from some of the calculations using the revised model and the model for a 360° crack are illustrated on Figure 6.19 for depths of 8, 12, and 16 inches into the tubesheet for the most severe locations in the SG.

6.3 MODELING OF FUTURE SG LEAK RATES

Modeling of future leak rates is a function of the number of cracks that are in the SGs at elevations below H* and their radial location from the centerline of the tubesheet. An examination of the inspection data for the Callaway SGs was used to determine the SG with the most indications as a function of time, and then to predict the number of indications below H* and the number of indications that would exist below H* at the end of the next cycle of operation. The morphology of the cracks is such that most of them would not be expected to grow in circumferential extent more than they are right now. The cracks form because of anomalies in the tubesheet holes resulting from the drilling process. The tube material flows into the anomaly when the tube is expanded leaving a localized stress concentration. This is somewhat akin to the denting process in carbon steel tube support plates which is azimuthally limited in extent and when cracks form within the dents they do not extend significantly outside of the dents. The situation is likely to be better within the tubesheet because the stress field associated with the internal pressure in the tube that is present outside of the tubesheet is not present within the tubesheet owing to the constraint afforded by the tubesheet.

6.4 POTENTIAL FOR NORMAL OR ACCIDENT CONDITION LEAKAGE

The total number of potentially significant indications within the tubesheet can be calculated from the number found during this outage. Here, significant is taken to be large enough to be tested in situ. It is apparent that most of the cracks are actually not significant from a structural standpoint nor from a leak rate standpoint given their tendency toward a small circumferential extent. The distribution of indications with depth was indicated to be uniform, thus the number of indications outside of the H* regions can be estimated by scaling the number by the relative depths into the tubesheet. The tubesheet is 21 inches thick and the inspection depths in Zones B and C were 7 inches and 9 inches respectively. This means that the number of cracks expected to be found outside of the H* depths in Zones B and C are 2.0 and 1.3 times the number found within H*. In Zone B the depth of the tubesheet below H* is 14 inches and the respective number in Zone C is 12 inches. Below H* and above 16 inches into the tubesheet the fractions for Zones B and C are 9/7 and 7/9 respectively, that is the expected number of indications is found by multiplying the found number of significant indications by the respective fractions. A summary of the number of indications expected outside of the H* region in the tubesheet is provided in Table 6.1 by SG.

The depth of 16 inches was chosen for the above comparison although the bowing of the tubesheet results in contraction of the tubesheet holes at a depth of 10.5 inches, the leak rate during a postulated steam line break is predicted to be less than the leak rate during normal operation for indications below 16 inches. The most severe indications were found in Zones B and C where the inspection depths were 7 and 9 inches respectively. There were no severe circumferential indications in Zones A and D. The number of severe indications are significantly less than the number of 360° throughwall cracks that would be necessary to cause excessive leakage during a postulated SLB event.

The projection of the future number of cracks to be present can be made by considering the cumulative number to follow either a lognormal or Weibull distribution function. These are the standard distributions assumed for SG cracking and Westinghouse is of the opinion that the lognormal distribution performs slightly better. The first cracks below the top of the tubesheet were observed in 1995 at Callaway after 8.6 years of effective operation. Projections were made for the total number of indications in all of the SGs and the number in the most seriously affected SG, i.e., SG A based on the number of indications.

The data from previous years during refueling outages (RFO) 7 through 11(identified in Tables 6.1, 6.2 and 6.3) involved an inspection depth of 3 inches. Using the numbers found from those inspections an estimate of the number of indications between 3 inches and 7 inches was made, i.e., an effective average H* depth. The number predicted for all of the SGs was 28 between 3 and 7 inches. Since the 3 to 7 inches depth was not being inspected by RPC during refueling outages RF07 through 11 this number represents the number likely to be found in active tubes during the current inspection outage. The actual number was found to be 18, or 64% of the predicted number.

Referring to Table 6.2, the number of indications within the H* distance is calculated as follows. For the 10/96 outage, 17 circumferential indications were found in the region from 0 to 3 inches below the top of the tubesheet. Therefore, it is conservatively projected that 4/3 x 13 = 17 indications would have been present in the tubesheet in the region ranging from 3 to 7 inches below the top of the tubesheet. However, referring to the October 2002 data discussed in the preceding paragraph, only 18 indications were found in that range out of the total of 28 indications in the tubesheet in the range of 3 to 7 inches predicted for RFO 7-11 for a ratio of 0.64. Therefore, 0.64 x 28 = 18 would be the real number of indications expected in this region for a total of 24 within the 0 to 7 inch length (i.e., 13 + 4/3 x 13 x 0.64 = 24).

Using the same approach, the anticipated number of circumferential indications in SG A at elevations from 3 to 7 inches below the top of the tubesheet would be 24, but only 6, or 25% of the predicted number, were present. The fractions from these two comparisons are greater than would have been obtained had an estimate of new indications been included in the analysis. These factors were then used to adjust the number of indications predicted to be in the H* length at prior outages which were then used for estimating the cumulative distributions of indications. The cumulative distributions of circumferential cracks within the tubesheet are illustrated on Figure 6.16 for all of the SGs and on Figure 6.17 for SG A. Both lognormal and Weibull distribution curves were fitted to the data and both fits are similar. A 90% confidence bound on the number of circumferential cracks is also illustrated for a lognormal distribution. The values used to develop the curves are listed in Table 6.2 for the cumulative of all the SGs and in Table 6.3 for SG A.

A summation of the leak rates to be expected from each indication projected within Table 6.3 could be made using the distribution of total angles as listed on Figure 6.15 and likely depths from the distribution of all indications found during the outage in combination with the prediction curves of Figure 6.19. However, the need to proceed with such an analysis is not seen as essential based on the actual number of cracks under consideration and the leak rate prediction information presented on Figure 6.19. A check of this assertion is provided following this discussion. The predicted leak rates were used to develop the number of allowable throughwall cracks as a function of depth in the tubesheet and crack extent. For example, at an 8 inch depth approximately 96 360° throughwall cracks would be needed to achieve a leak rate of 1 gpm. At 12 inches the number rises to 271 and at 16 inches depth the number is 465. Nearly half of the cracks are about 125° or less in azimuthal extent and the respective number needed to be throughwall and leaking, (which is not likely based on the results of the in situ tests) would be about 449, 1052, and 1095 respectively. The results for SG A show an expectation of about 77 cracks total in the range of 7 to 16 inches and 43 in the range of 16 to 21 inches at the end of the next cycle. Overall, it is seen to be unlikely that the combination of a large number of throughwall indications that would be capable of leaking in combination with the circumferential lengths necessary to provide meaningful leakage would be present.

However, to provide a check of the above assertion, the number of indications found between 3 inches and the average H* depth of 7 inches was taken as representative of the density of the total number of indications throughout the remaining depth of the tubesheet, i.e., 14 inches. This means that 3.5 times the number of cracks found between depths of 3 and 7 inches would be expected to be present between 7 and 21 inches, i.e., the region outside of H*. The leak rate from a crack of given size (angular extent) varies depending on the radial location of the tube containing the crack and the elevation of the crack within the tubesheet. For the purpose of calculating total leakage from a steam generator, the region outside H* was divided into three layers: 7" to 12", 12" to 16" and 16" to 21". In each layer, all cracks were placed at the top of the layer to maximize leakage. However, since the top of the first layer (7") is above the H* distances for Zones C and D, leakage was calculated at 8" depth. The DENTFLO code was used to examine the variation of the leakage with the radial location in the tubesheet. Figure 6.19 shows the results for a crack with 180° angular extent, and it is representative of other crack angles. It is evident that the leakage trend varies with elevation. At 8" elevation, leakage is highest close to the tubesheet center, and at the 16" elevation, highest leakage occurs at the outer end. To calculate total leakage from a steam generator, leakage at the worst radial location was used for each of the three layers: 5" radius at 8" depth, 48.6" radius at 12" depth and 58.3" radius at 16" depth. The variation of leakage at SLB conditions with angular extent is shown in Figure 6.20. The solid lines in Figure 6.20 represent polynominal fits to the discrete points from DENTFLO calculations. Second order log-log curves fit the data well. Using the polynomial relations shown in Figure 6.20, a very conservative prediction of the potential total leak rate for the Callaway SGs was made assuming:

1) all of the indications were in one SG,
2) the distribution of indications in H* was representative of each respective depth in the tubesheet,
3) the distribution of crack angles for all indications at each elevation interval was consistent with Figure 6.14, "Distribution of Severe Indication Total Angles"
4) all of the indications were throughwall at their reported lengths, and
5) all of the indications leaked.

Each leak rate was calculated using the 95th percentile lower confidence bound loss coefficient and the total leak rate from all of the indications summed. The result of the calculation was a total predicted leak rate of 0.44 gpm during a postulated accident condition.

6.5 LIGAMENT TEARING

One of the concerns that must be addressed in dealing with cracks in SG tubes is the potential for ligament tearing to occur during a postulated accident when the differential pressure is significantly greater than during normal operation. While this is accounted for in the strength evaluations that demonstrate a resistance to pullout in excess of $3 \cdot \Delta P$ for normal operation and $1.4 \cdot \Delta P$ for postulated accident conditions, the potential for ligament tearing to significantly affect the leak rate predictions needs to be accounted for.

Ligament tearing considerations for circumferential tube cracks that are located below the H* depths within the tubesheet are significantly different from those for potential cracks at other locations. The reason for this is that H* has been determined using a factor of safety of three relative to the normal operating pressure differential and 1.4 relative to the most severe accident condition pressure differential. Therefore, the internal pressure end cap loads which normally lead to an axial stress in the tube are not transmitted below about 2/3 of the H* depth. This means that the only source of stress acting to extend the crack is the primary pressure acting on the flanks of the crack. Since the tube is captured within the tubesheet, there are additional forces acting to resist opening of the crack. The contact pressure between the tube and tubesheet results in a friction induced shear stress acting opposite to the direction of crack opening, and the pressure on the flanks is compressive on the material adjacent to the plane of the crack, hence a Poisson's ratio radial expansion of the tube material in the immediate vicinity of the crack plane is induced which also acts to restrain the opening of the crack. In addition, the differential thermal expansion of the tube is greater than that of the carbon steel tubesheet, thereby inducing a compressive stress in the tube below the H* length.

A scoping evaluation of the [

]a,c,e.

In summary, considering the worst-case scenario, the likelihood of ligament tearing from radial circumferential cracks resulting from an accident pressure increase is small since at most, only 8% of the cross-sectional area is needed to maintain tube integrity. Also, since the crack face area will be less than the total cross-sectional area used above, the difference in the force applied as a result of normal operating and accident condition pressures will be less than the 35 lbs associated with the above numbers. Therefore, the potential for ligament tearing is considered to be a secondary effect of essentially negligible probability and should not affect the results and conclusions reported for the H* evaluation. The leak rate model does not include provisions for predicting ligament tearing and subsequent leakage, and increasing the complexity of the model to attempt to account for ligament tearing has been demonstrated to be not necessary.

Table 6.1
Distribution of Severe Circumferential Indications in Callaway SGs by SG and H* Zone

SG	Depth < H*		H* < Depth		H* < Depth < 16"	
	Zone B	Zone C	Zone B	Zone C	Zone B	Zone C
A	3	0	6	0	4	0
B	0	0	0	0	0	0
C	4	3	8	4	6	3
D	2	0	4	0	5	0
Totals	9	3	18	4	15	3

Table 6.2
Potential Number of Circumferential Indications Within the Tubesheet RPC Inspection Region, All SGs

Date	EFPY	No. of Circ.	Avg. Insp. Depth	No. In H* (≈7")	Cum. No. in H*	Outside of H*	Middle 9" of TS	Bottom 5" of TS
Apr 95	8.6	2	3	4	4	8	5	3
Oct-96	10.0	13	3	24	28	56	36	20
Apr-98	11.2	3	3	6	34	68	44	24
Oct-99	12.5	3	3	6	40	80	51	29
Apr-01	13.9	0	3	0	40	80	51	29
Oct-02	15.2	29	7	29	69	138	89	49
Apr-04	≈16.5			11	80	160	103	57
	90% Confidence			36	105	210	135	75

Table 6.3
Number of Circumferential Indications Within the Tubesheet RPC Inspection Region, SG A

Date	EFPY	No. of Circ.	Avg. Insp. Depth	No. In H* (≈7")	Cum. No. in H*	Outside of H*	Middle 9" of TS	Bottom 5" of TS
Apr 95	8.6	2	3	3	3	6	4	2
Oct-96	10.0	11	3	15	18	36	23	13
Apr-98	11.2	2	3	3	21	42	27	15
Oct-99	12.5	2	3	3	24	48	31	17
Apr-01	13.9	0	3	0	24	48	31	17
Oct-02	15.2	15	7	15	39	78	50	28
Apr-04	≈16.5		7	7	46	92	59	33
	90% Confidence			21	60	120	77	43

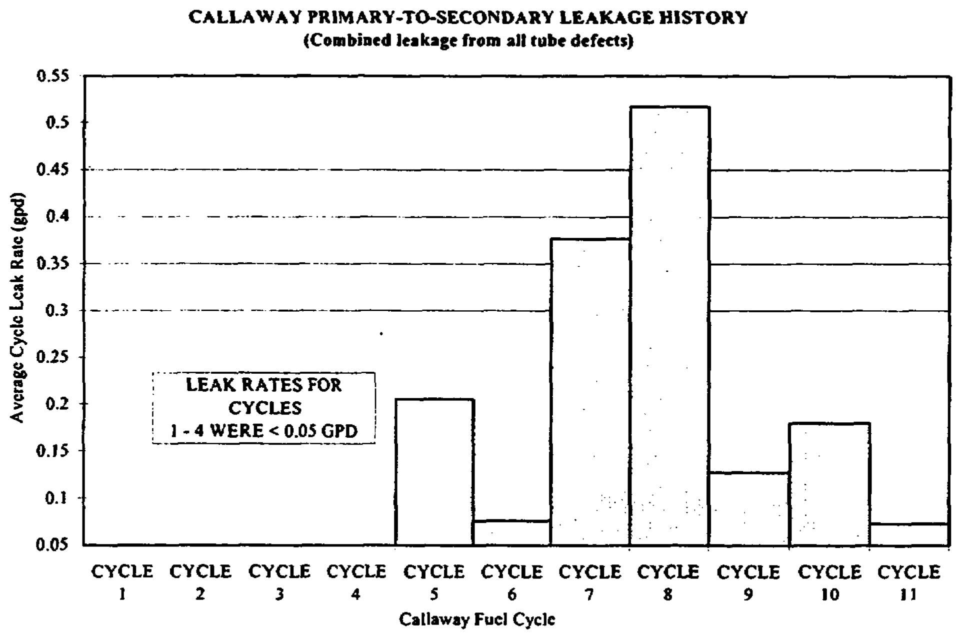

Figure 6.1
Callaway Leak Rate During Operation
The Leak Rate for Cycle 12 was 0.31 gpd.

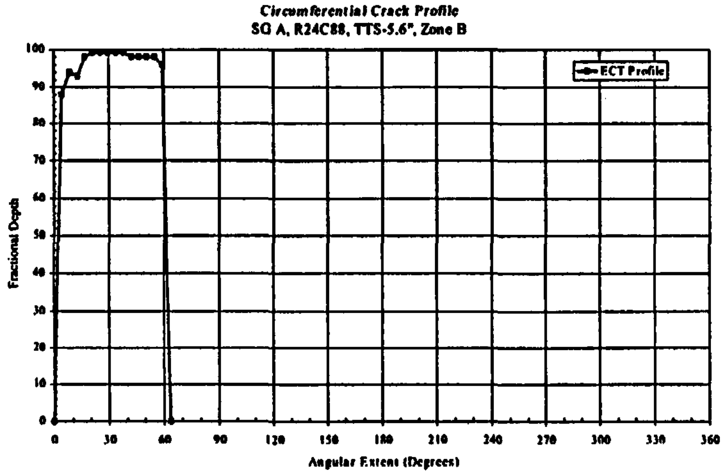

Figure 6.2
Short 60° by 100% TW Crack

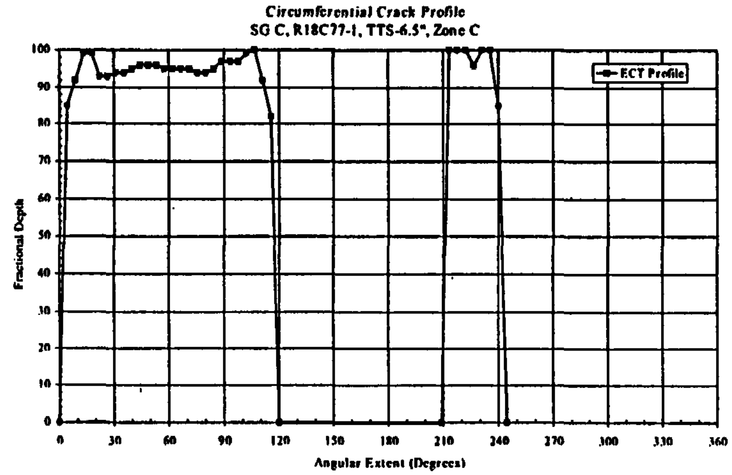

Figure 6.4
Multiple 100% TW Cracks, 150° Total

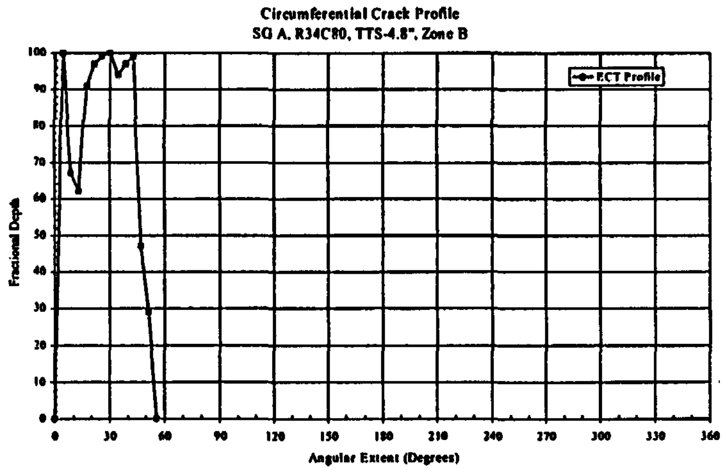

Figure 6.3
Short 50° Crack with Some 100% Depth

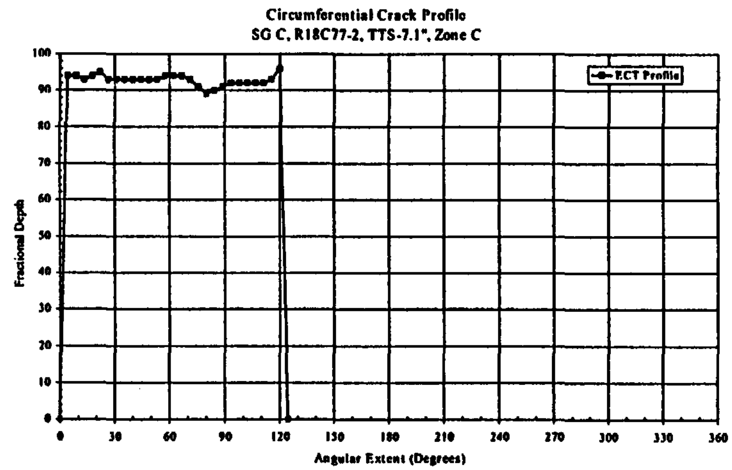

Figure 6.5
Single 120° by 95% TW Crack

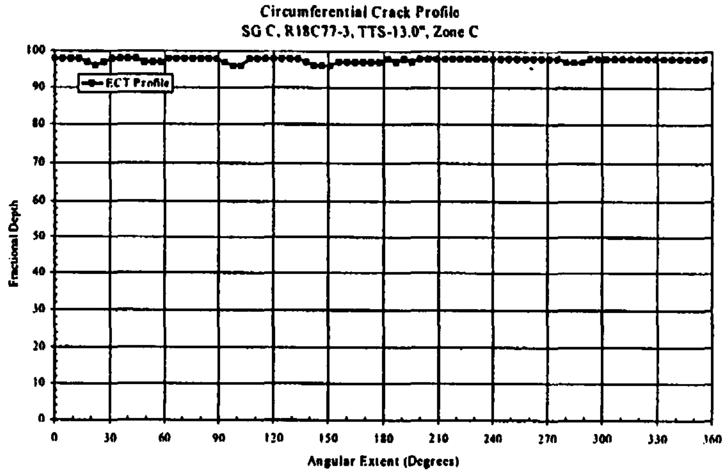

Figure 6.6
Large 360° by 100% TW Crack

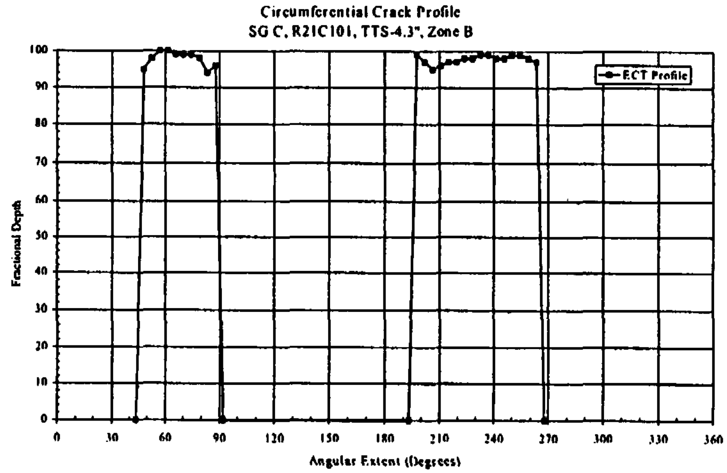

Figure 6.8
Multiple 100% TW Cracks, 120° Total

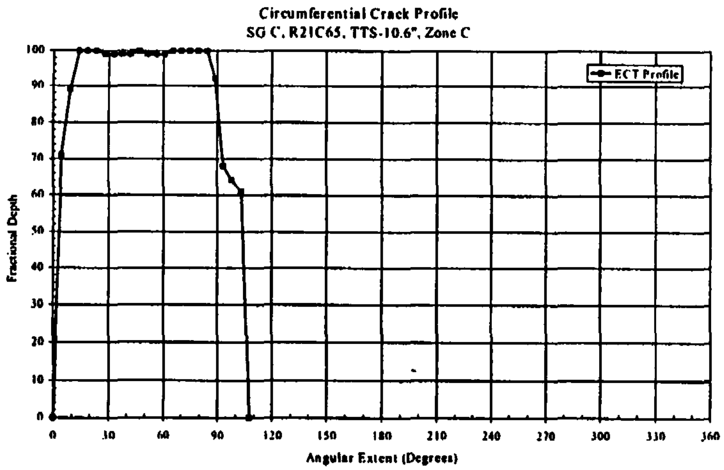

Figure 6.7
Single 90° by 100% TW Crack

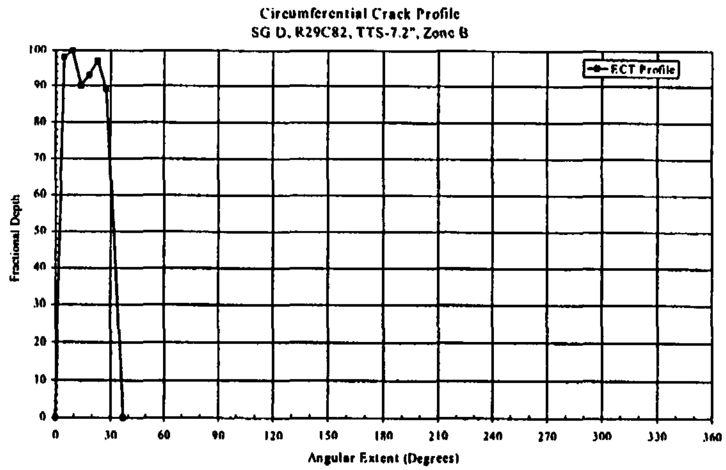

Figure 6.9
Short 30° by 95% TW Crack

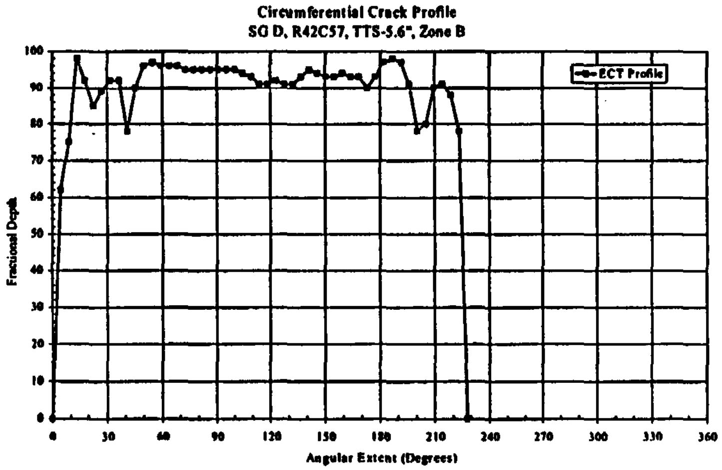

Figure 6.10
Long 100% Throughwall

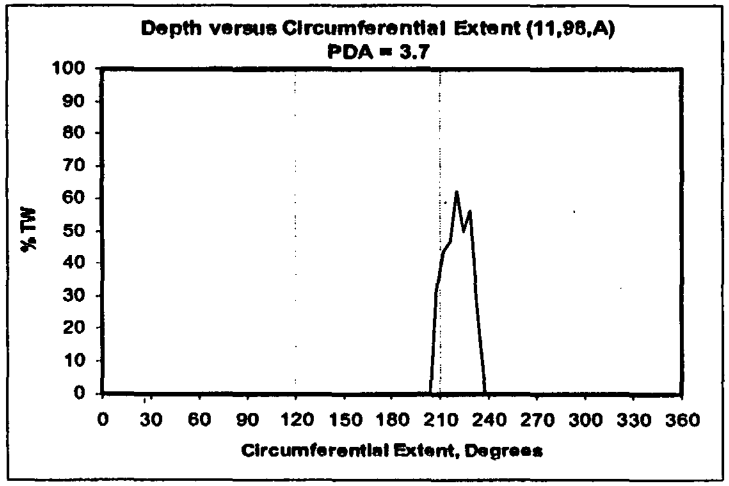

Figure 6.12
Median Stage of Growth

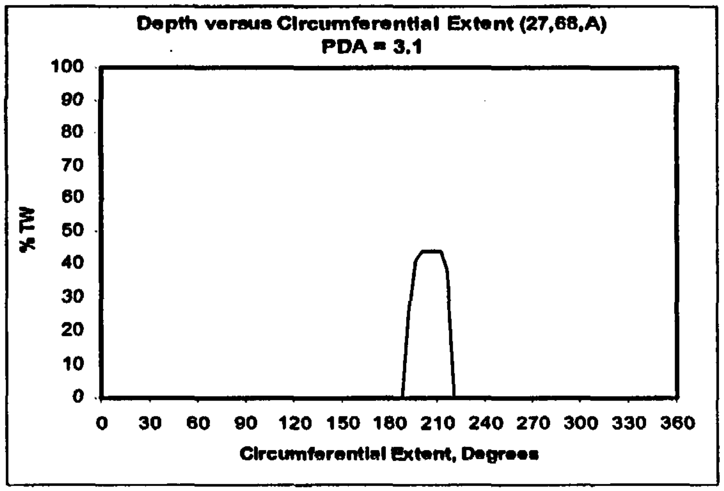

Figure 6.11
Initial Stage of Growth

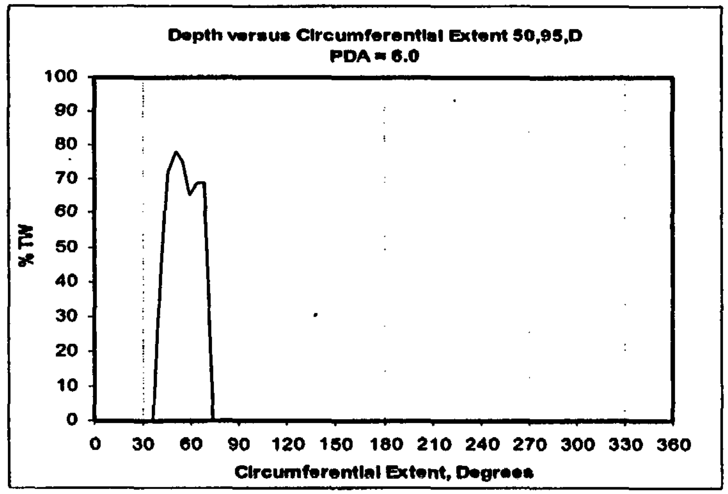

Figure 6.13
Latter Stage of Growth

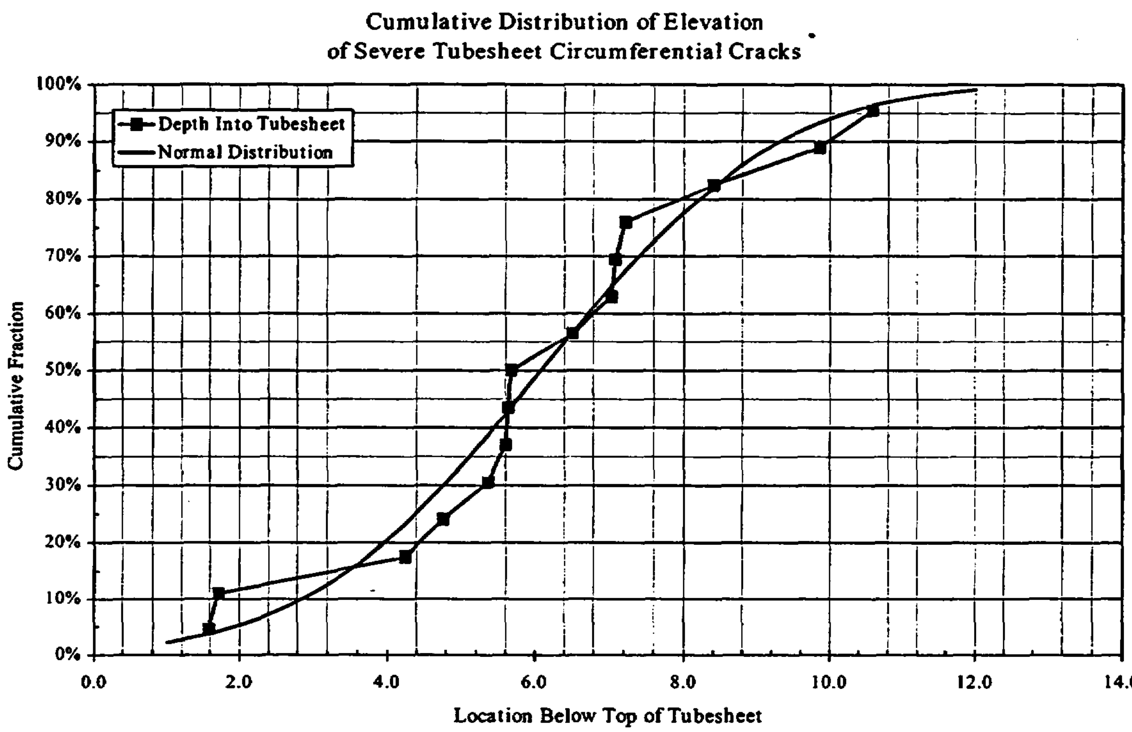

Figure 6.14. Distribution of Severe Indications Locations

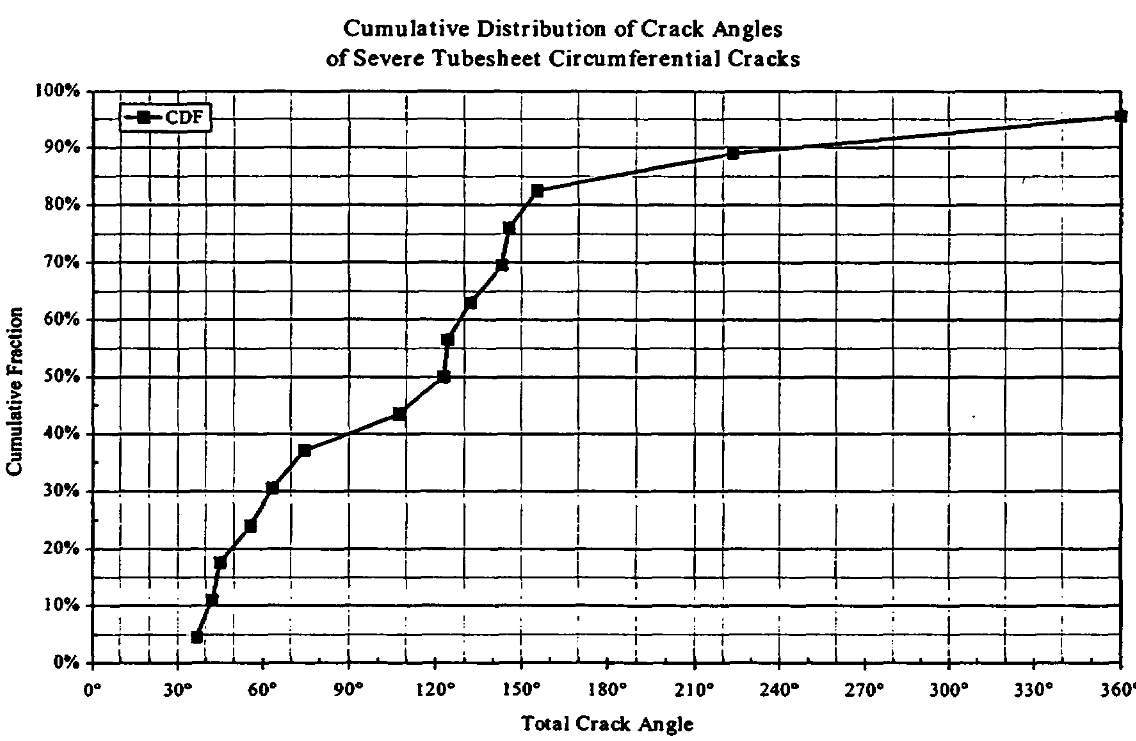

Figure 6.15: Distribution of Severe Indication Total Angles

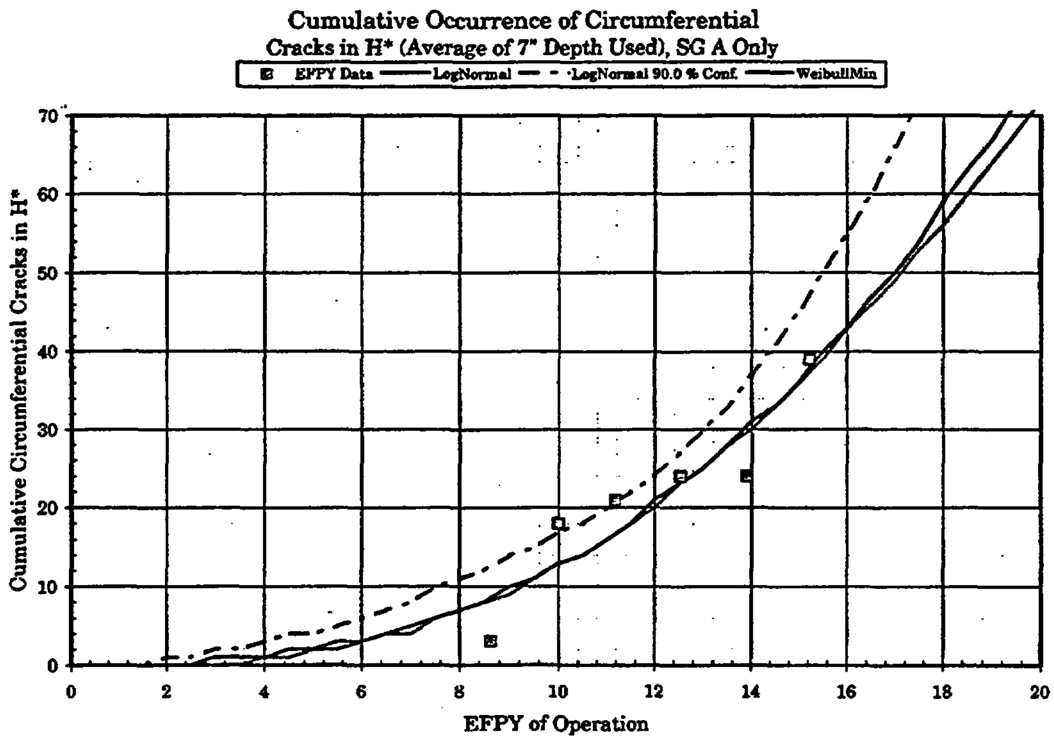

Figure 6.16: CDF of Circumferential Cracks in H* for All SGs

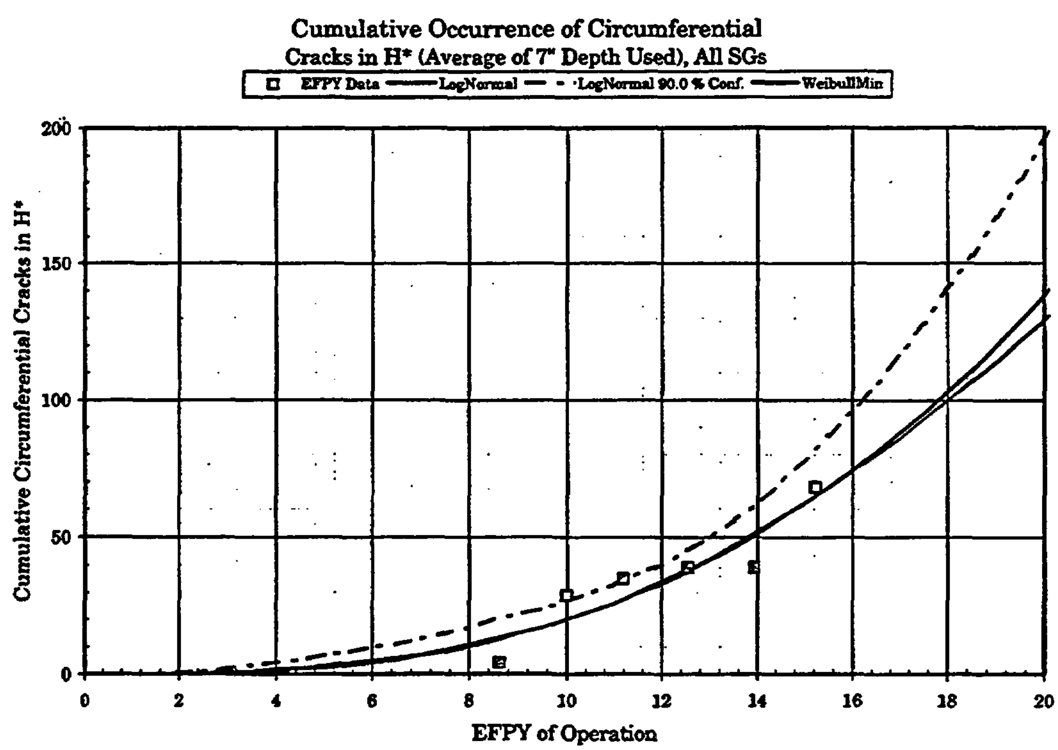

Figure 6.17: Distribution of Circumferential Cracks in H* in SG A

a, c, e

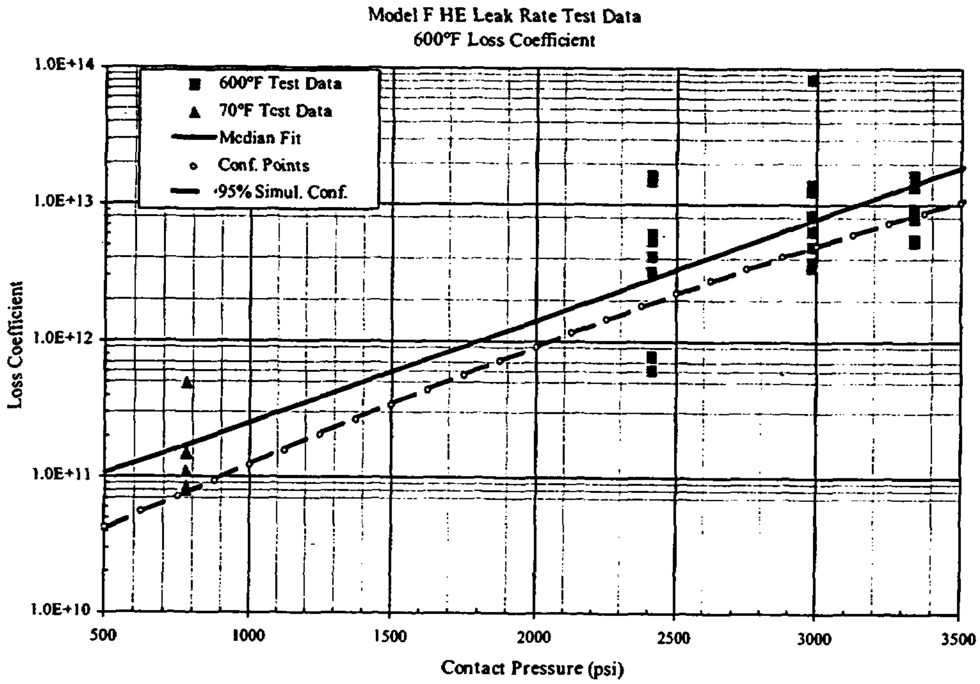

Figure 6.18: Loss Coefficient as a Function of Contact Pressure

a, c, e

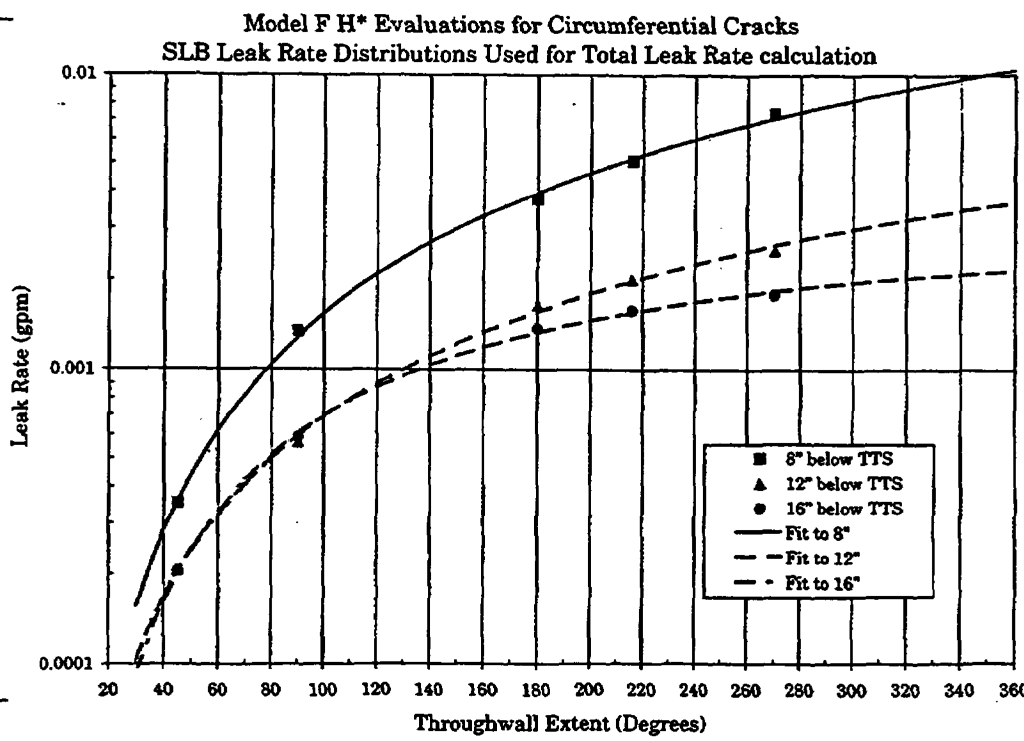

Figure 6.19: Predicted Leak Rates in GPM vs. Through-Wall Extent

a, c, e

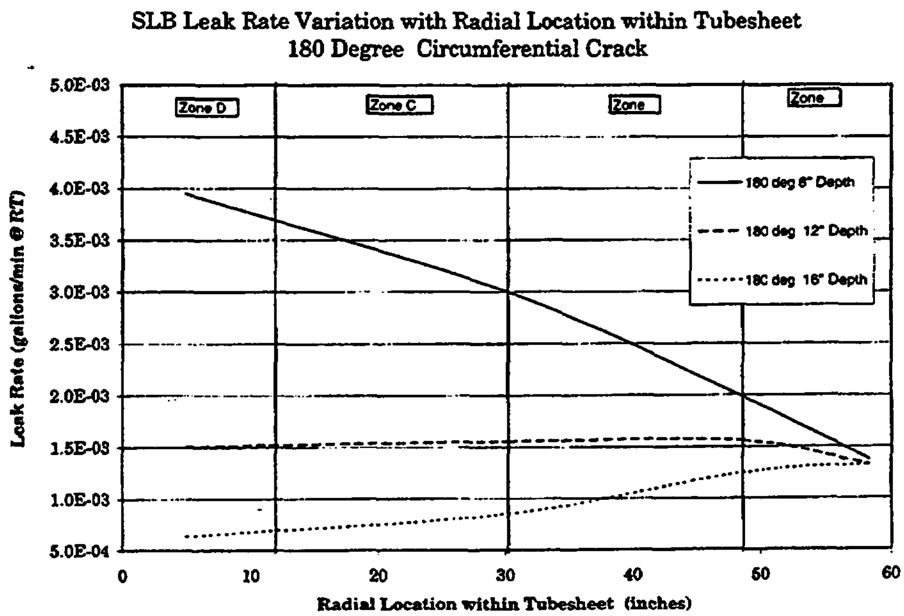

Figure 6.20: Curve Fits to Dentflo Leak Rate Predictions

7.0 STRUCTURAL ANALYSIS

An evaluation was performed to determine the contact pressures between the tubes and tubesheet in the Callaway steam generators as part of the H* analysis. The evaluation utilized [

]a,c,e, were determined.

The same contact pressure results were used [

]a,c,e were also included.

Because the P* analysis postulates that a [

]a,c,e for determination of P*.

7.1 EVALUATION OF TUBESHEET DEFLECTION EFFECTS FOR H* AND H* LEAKAGE

A finite element model developed previously for the Model F channelhead/tubesheet/shell region was used to determine the tubesheet hole dilations in the Callaway steam generators. [

]a,c,e loads in the tube.

7.1.1 Material Properties and Tubesheet Equivalent Properties

The material of construction for the tubing in the steam generators is a nickel base alloy, Alloy 600, most of the tubes are in a mill annealed condition and the remainder in the thermally treated (TT) condition. Summaries of the applicable mechanical and thermal properties for the tube material are provided in Table 7.1-1. The tubesheet material is SA-508, Class 2a, and its properties are in Table 7.1-2. The shell material is SA-533 Grade A Class 2, and its properties are in Table 7.1-3. The channelhead material is SA-216 Grade WCC, and its properties are in Table 7.1-4. The material properties are from Reference 8.4.

The perforated tubesheet in the Model F channelhead complex is treated [

]a,c,e in the perforated region of the tubesheet for the finite element model. The material properties of the tubes are not utilized in the finite element model, but are listed in Table 7.1-1 for use in the calculations of the tube/tubesheet contact pressures.

7.1.2 Tubesheet Rotation Effects

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

]^{a,c,e}.

Previous calculations performed [

]^{a,c,e}.

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

a,c,e

[ ]

This expression is used to determine the radial deflections along a line of nodes at a constant axial elevation (e.g. top of the tubesheet) within the perforated area of the tubesheet.

The expansion of a hole of diameter D in the tubesheet at a radius R is given by:

a,c,e

[ ]

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

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

]^{a,c,e}

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

a,c,e

[

]

These data were fit to the polynomial below:

[

]a,c,e

[ ]^a,c,e

The radial expansion of the hole ID is given by:

[

]^a,c,e

The resulting equation is:

[ ]a,c,e

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

$$\Delta R_{gap} = 0.5\left[\Delta D - 2\Delta R_t^{th} - 2\Delta R_t^{pr}\right]$$

The OD of the tubesheet cylinder is equal to that of the cylindrical (simulate) collars (1.632 inches) designed to provide the same radial stiffness as the tubesheet, which was determined from a finite element analysis of a section of the tubesheet (Reference 8.7).

The tube inside and outside radii within the tubesheet are obtained by assuming a nominal diameter for the hole in the tubesheet (0.7035 inch, selected as 0.703 inch in this case) and wall thinning in the tube equal to the average of that measured during hydraulic expansion tests. That thickness is 0.0366 inch for the tube. The table below lists the values used in the equations above, with the material properties evaluated at 600°F. (Note that the properties in the following sections are evaluated at the primary fluid temperature).

Parameter	Value
b, inside tube radius, in.	0.3149
c, outside tube radius, in.	0.3515
d, outside radius of cylinder w/ same radial stiffness as tubesheet, in.	[ ]a,c,e
α_t, coefficient of thermal expansion of tube, in/in °F	7.83×10^{-6}
E_t, modulus of elasticity of tube, psi	28.7×10^{6}
α_{TS}, coefficient of thermal expansion of tubesheet, in/in °F	7.42×10^{-6}
E_{TS}, modulus of elasticity of tubesheet, psi	26.4×10^{6}

7.1.3 Callaway Contact Pressures

7.1.3.1 Normal Operating Conditions

The loadings considered in the analysis are based on an umbrella set of conditions as defined in References 8.8, 8.9 and 8.10. The current operating parameters from Reference 8.10 are used. The temperatures and pressures for normal operating conditions at Callaway are therefore:

	Case 2 (1)	Case 3 (2)
Primary Pressure	= 2235 psig	2235 psig
Secondary Pressure	= 893 psig	955 psig
Primary Fluid Temperature (T_{hot})	= 615.3 °F	620.0 °F
Primary Fluid Temperature (T_{cold})	= 551.3 °F	556.6 °F
Secondary Fluid Temperature	= 533.0 °F	540.8°F

(1) Minimum Steam Temperature and Pressure in Reference 8.10

(2) Maximum Steam Temperature and Pressure in Reference 8.10

The primary pressure [

]a,c,e.

7.1.3.2 Faulted Conditions

Of the faulted conditions, Feedline Break (FLB) and Steamline Break (SLB) are the most limiting. FLB has a higher ΔP across the tubesheet, and requires a slightly longer length of engagement to resist pull out, while the lower temperature of SLB results in a higher leak rate. Both cases are considered in this section. The impact of a postulated loss of coolant accident is also considered below.

7.1.3.2.1 Feedline Break

The temperatures and pressures for Feedline Break, using the guidelines from Reference 8.9, are:

	Case 2 (1)	Case 3 (2)
Primary Pressure	= 2650 psig	2650 psig
Secondary Pressure	= 0 psig	0 psig
Primary Fluid Temperature (Thot)	= 591.3 °F	596.0 °F
Secondary Fluid Temperature	= 533.0 °F	540.8 °F

(1) Minimum Steam Temperature and Pressure in Reference 8.9

(2) Maximum Steam Temperature and Pressure in Reference 8.9

The Feedline Break condition [

]a,c,e.

7.1.3.2.2 Steam Line Break

As a result of SLB, the faulted SG will rapidly blow down to atmospheric pressure, resulting in a large ΔP across the tubes and tubesheet. The entire flow capacity of the auxiliary feedwater system would be delivered to the dry, hot shell side of the faulted SG. The primary side re-pressurizes to the pressurizer safety valve set pressure. The pertinent parameters are listed below. The combination of parameters yielding the most limiting results is used.

Primary Pressure	=	2560 psig
Secondary Pressure	=	0 psig
Primary Fluid Temperature (Thot)	=	420°F
Secondary Fluid Temperature	=	260°F

For this set of primary and secondary side pressures and temperatures, the equations derived in Section 7.1.2 are solved for the selected elevations in the tubesheet to obtain the contact pressures between the tube and tubesheet as a function of tubesheet radius for both the hot leg and cold leg.

7.1.3.2.3 LOCA Condition

Following rupture of a reactor coolant pipe resulting in a large loss of coolant, the primary system pressure decreases rapidly causing the primary system temperature to decrease. Because of the rapid blowdown of coolant from the system and the comparatively large heat capacity of the metal sections of the components, it is likely that the metal will remain at or near the operating temperature during the blowdown. This event may initiate from either 100% power or hot standby (0% power) conditions. Zero percent power conditions are more conservative with respect to contact pressures in that the primary temperature is lower, the secondary temperature is higher, and the pressure drop across the tubesheet is higher than for 100% power conditions.

Although the maximum secondary to primary ΔP during the LOCA condition is 793 psi (Reference 8.8) the temperatures and pressure for the LOCA condition are conservatively:

Primary Pressure	=	0 psig
Secondary Pressure	=	1092 psig
Primary Fluid Temperature (Thot)	=	557 °F
Secondary Fluid Temperature	=	557 °F

For this set of primary and secondary side pressures and temperatures, the equations derived in Section 7.1.2 are solved for the selected elevations in the tubesheet to obtain the contact pressures between the tube and tubesheet as a function of tubesheet radius for both the hot leg and cold leg.

7.1.4 Summary of Results

For Callaway, the contact pressures between the tube and tubesheet for various plant accident conditions are plotted versus radius in Figures 7.2-2a through 7.2-3b.

7.2 DETERMINATION OF TUBE-TO-TUBESHEET CONTACT PRESSURE FOR H*

The H* partial-length RPC justification relies on knowledge of the tube-to-tubesheet interfacial mechanical interference fit contact pressure at all elevations in the in the tube joint especially in the upper half of the tube joint. The contact pressure is used for both anchorage of the tube in the tubesheet in the H* evaluation and for determining the leakage effects for H*.

For the tube anchorage effect, it is necessary to demonstrate that the [

]a,c,e

[

]^{a,c,e}

The end cap loads for Normal and Faulted conditions are:

Normal: $\pi * 1600 * (0.71)^2 /4 = 633.47$ lbs.

Faulted (FLB): $\pi * 2650 * (0.71)^2 /4 = 1049.19$ lbs.

Faulted (SLB): $\pi * 2560 * (0.71)^2 /4 = 1013.55$ lbs.

Thus, based on the guidelines of RG 1.121, the critical end cap load is 1900 lbs., which is three times the normal load and is greater than 1.43 times the accident operation loads of 1500 lbs. (FLB) and 1449 lbs. (SLB).

[

]^{a,c,e}

[

]a,c,e

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

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

Where:

F_{HE} = Resistance to pull out due to the initial hydraulic expansion = 118.85 lb/in

P = Contact pressure acting over segment dh

μ = Coefficient of friction between the tube and tubesheet, conservatively assumed to be 0.2

The contact pressure is assumed to vary linearly between adjacent elevations in the top part of Tables 7.2-2a , 7.2-2b and 7.2-3, so that between elevations L_1 and L_2,

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

or,

a,c,e

[ ]

so that,

a,c,e

[ ]

This equation is used to accumulate the force resisting pullout from the TTS to each of the elevations listed in the lower parts of Tables 7-2a through 7-2b. The above equation is also used to find the minimum contact lengths needed to meet the pullout force requirements. This length is 7.99 inches for the limiting 3 times normal operating pressure performance criterion which corresponds to a pullout force of 1900 lbs in the Hot Leg (Case 1).

The top part of Table 7.2-3 lists the contact pressures through the thickness at each of the radial sections for Faulted (SLB) condition. The last row [ ]^{a,c,e} of this table lists the maximum tubesheet elevation at which the contact pressure is greater than or equal to zero. The above equation is used to accumulate the force resisting pull out from the top of the tubesheet to each of the elevations listed in the lower part of Table 7.2-3. The above equation is also used to find the minimum contact lengths needed to meet the pull out force requirements. This length is 7.83 inches for Faulted (SLB) condition. The minimum contact length needed to meet the pullout force requirement for Faulted (FLB) condition is less.

Therefore, the bounding condition for the determination of the H* length is the NOP performance criterion. The minimum contact length for this normal operating condition is 7.99 inches in Zone D.

a,c,e

Figure 7-1
Finite Element Model of Model F Tubesheet Region

a,c,e

Figure 7.2-2a
Contact Pressures for Normal Condition at Callaway, Psec = 893 psig

a,c,e

Figure 7.2-2b
Contact Pressures for Normal Condition at Callaway, Psec = 955 psig

a,c,e

Figure 7.2-3a
Contact Pressures for FLB and SLB Conditions at Callaway, Tsec = 533.0 °F

a,c,e

Figure 7.2-3b
Contact Pressures for FLB and SLB Conditions at Callaway,
Tsec = 540.8 °F

Table 7.1-1
Summary of Material Properties
Alloy 600 Tube Material

PROPERTY	TEMPERATURE (°F)						
	70	**200**	**300**	**400**	**500**	**600**	**700**
Young's Modulus psi x 1.0 E06	31.00	30.20	29.90	29.50	29.00	28.70	28.20
Coefficient of Thermal Expansion in/in/°F x 1.0 E-06	6.90	7.20	7.40	7.57	7.70	7.82	7.94
Density lb-sec²/in⁴ x 1.0E-04	7.94	7.92	7.90	7.89	7.87	7.85	7.83
Thermal Conductivity Btu/sec-in-°F x 1.0E-04	2.01	2.11	2.22	2.34	2.45	2.57	2.68
Specific Heat Btu-in/lb-sec²-°F	41.2	42.6	43.9	44.9	45.6	47.0	47.9

Table 7.1-2
Summary of Material Properties
SA-508 Class 2a Tubesheet Material

PROPERTY	TEMPERATURE (°F)						
	70	200	300	400	500	600	700
Young's Modulus psi x 1.0 E06	29.20	28.50	28.00	27.40	27.00	26.40	25.30
Coefficient of Thermal Expansion in/in/°F x 1.0 E-06	6.50	6.67	6.87	7.07	7.25	7.42	7.59
Density lb-sec^2/in^4 x 1.0E-04	7.32	7.30	7.29	7.27	7.26	7.24	7.22
Thermal Conductivity Btu/sec-in-°F x 1.0E-04	5.49	5.56	5.53	5.46	5.35	5.19	5.02
Specific Heat Btu-in/lb-sec^2-°F	41.9	44.5	46.8	48.8	50.8	52.8	55.1

Table 7.1-3
Summary of Material Properties
SA-533 Grade A Class 2 Shell Material

PROPERTY	TEMPERATURE (°F)						
	70	**200**	**300**	**400**	**500**	**600**	**700**
Young's Modulus psi x 1.0 E06	29.20	28.50	28.00	27.40	27.00	26.40	25.30
Coefficient of Thermal Expansion in/in/°F x 1.0 E-06	7.06	7.25	7.43	7.58	7.70	7.83	7.94
Density lb-sec^2/in^4 x 1.0E-04	7.32	7.30	7.283	7.265	7.248	7.23	7.211

Table 7.1-4
Summary of Material Properties
SA-216 Grade WCC Channelhead Material

PROPERTY	TEMPERATURE (°F)						
	70	**200**	**300**	**400**	**500**	**600**	**700**
Young's Modulus psi x 1.0 E06	29.50	28.80	28.30	27.70	27.30	26.70	25.50
Coefficient of Thermal Expansion in/in/°F x 1.0 E-06	5.53	5.89	6.26	6.61	6.91	7.17	7.41
Density lb-sec^2/in^4 x 1.0E-04	7.32	7.30	7.29	7.27	7.26	7.24	7.22

Table 7.2-2a
Cumulative Forces Resisting Pull Out from the Top of the Tubesheet
Callaway – Hot Leg Normal Conditions – Axial Load Included, Psec = 893 psig

a,c,e

Table 7.2-2b
Cumulative Forces Resisting Pull Out from the Top of the Tubesheet
Callaway – Hot Leg Normal Conditions – Axial Load Included, Psec = 955 psig

a,c,e

Table 7.2-3
Cumulative Forces Resisting Pull Out from the Top of the Tubesheet
Callaway–Faulted (SLB) Conditions, Axial Load Included, P_{sec} = 0 psig

a,c,e

Table 7.2-4a: Large Displacement, ≈ 0.2 to 0.3 in., Pullout Test Data
(Assume μ of 0.3 for contact pressure determination.)

a,c,e

Table 7.2-4b: Initial Slip Data

a,c,e

8.0 REFERENCES

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8.3 "Formulas for Stress and Strain", Fifth Edition, Table 32, Cases 1a – 1d, by R. J. Roark and W.C. Young, McGraw-Hill Book Company, New York, NY, 1975

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8.6 Calculation Note SM-94-58, Rev. 1, A. L. Thurman, Westinghouse, NSD, October, 1994 (Proprietary Report)

8.7 Report DE-LAN-765(80), "Determination of Contact Stress Between Tube and Tubesheet of a Hydraulically Expanded Joint", by L. A. Nelson, Westinghouse NTS, January 1980. (Proprietary Report)

8.8 General Design Specification 953236, Rev. 1, "Model F Steam Generator Reactor Coolant System", Westinghouse Energy Systems, March 6, 1981 (Proprietary Report)

8.9 Systems Standard 1.3F, Rev. 0, "Nuclear Steam Supply System - Reactor Coolant System Design Transients for Standard Plants with Model F Steam Generators", Westinghouse Energy Systems, March, 1978 (Proprietary Report)

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8.17 WCAP-15932, Rev. 0, "Improved Justification of Partial-Length RPC Inspection of Tube Joints of Model F Steam Generators of Ameren-UE Callaway Plant."

8.18 WCAP-11228, Rev. 1, "Tubesheet Region Plugging Criterion for the South Carolina Electric and Gas Company V.C. Summer Units 1 and 2 Steam Generators," October 1986.

APPENDIX A
RESISTANCE TO PULLOUT – P*

P* theory assumes that a tube, which is postulated to become fully separated below the secondary face of the tubesheet, will be retained within the tubesheet, because the resulting primary to secondary pressure differential (ΔP) vertical thrust from the separated tube leg will be reacted and supported by the next row (outboard) adjacent tube. The maximum upward displacement of the separated tube end plus at least ¼ inch (to retain the separated tube end in the tubesheet hole) is required to determine P*. This upward displacement is calculated using various finite element (FE) models of the separated tubes and row adjacent supporting tubes as described in this section for the overall maximum ΔP load. Based on these calculations, P* is less than [ ]^{a,c,e} inches for all locations in the tube bundle that have an outer next row, both hot leg and cold leg. In addition, the calculated stresses in the supporting tubes are shown to satisfy the structural criteria of the ASME Code, Reference 8.4 for the ΔP loads specified in References 8.8 and 8.9.

A.3.1 Major Assumptions

The major assumptions made in the P* analysis concern U-bend out-of-plane effects, dynamic effects and the selection of representative locations in the Model F tube bundle for evaluation.

U-bend Out-of-Plane Effects

The extrados of the separated tube will initially strike the intrados of the row-adjacent intact tube. [

]^{a,c,e}.

Figure A.3-3 is a typical cross-section, [

]^{a,c,e}.

The elastic strain energy required to establish the snap through mode shapes may be calculated using the 3D FE pipe models of the tubes discussed in Section A.3.5. The minimum strain energy occurs for the largest (most-flexible) U-bend radii, Rows 57, 58 and 59. The initial contact for Row 58 is calculated to occur at node 84 near node 85 (see Section A.3.6 and Table A.3-7). Thus, it is conservative to assume snap through occurs only at nodes 85, 77 and 68. Figures 7.3-4A and 4B show the resulting FE deformed geometry plots for this case. The resulting FE calculated elastic strain energy is over [ ]^{a,c,e} Actually, the total strain energy would be significantly higher than [ ]^{a,c,e} since the bending stresses in the separated tube greatly exceed yield resulting in plastic flow-work, which is unaccounted for in the elastic solution. Also unaccounted for are the torsion strain energy and the energy lost to sliding friction at the tube-TSP, tube-AVB and tube-tube contacts.

The maximum kinetic energy of the Row 58 separated tube (at impact with Row 59) is about [ ]^{a,c,e}, as calculated in Section A.3.6 and listed in Table A.3-9. Actually, the kinetic energy available at impact would be less (than [ ]^{a,c,e}) since the effects of sliding friction and strain energy of the separated tube in bending have been neglected. It is unlikely that sufficient energy is available to cause out-of-plane snap through, even at Row 58, the most flexible separated tube location. Therefore, it is assumed that the separated and intact tubes remain essentially in-plane after contact, and that out-of-plane effects are limited to considering the stresses in the supporting intact tube due to the out-of-plane contact forces, shown in Figure A.3-1.

Dynamic Effects

The separated tube has kinetic energy when it strikes the intact tube, and it is necessary to consider dynamic amplification of the separated tube displacement for the P* calculation. Because of the complex nonlinear nature of the surface-to-surface contact, such effects are best simulated assuming [ ]^{a,c,e}, as shown in Figure A.3-6 and as discussed in Section A.3.5.

Thermal Effects

It is reasonable to assume that the average temperatures of two active row adjacent tubes (i.e., in the same column) are essentially [ ]^{a,c,e}. Further, it is conservative to assume the material properties and structural strengths are evaluated at the [ ]^{a,c,e}. Thus, P* analysis results apply to either the hot leg or cold leg.

Tube Rows Selected for P* Evaluation

In order to cover the tube bundle, Rows 4/5, Rows 30/31 and Rows 58/59 are selected for the P* evaluation. The small radius rows (4/5) have [ ]^{a,c,e}, but are relatively stiff in both in-plane and out-of-plane bending. The largest P* radius combination is Rows 58/59, which are very flexible in bending and have [ ]^{a,c,e}, as shown in Figure A.3-2. Rows 30/31 are assumed to have [ ]^{a,c,e} and represent the middle of the tube bundle. In addition, Row 57, which [ ]^{a,c,e}, is considered in the out-of-plane energy analysis, as discussed above.

A.3.2 Loads

P* requires that the next row-adjacent tube provide support for a postulated fully separated tube inside the tubesheet. P* is the maximum lift-distance of the postulated separated tube at the secondary face of the tubesheet plus at least ¼ inch to assure the separated tube end remains in the tubesheet. Therefore, the maximum separated tube lift-distance should be calculated for the specified overall maximum primary-to-secondary pressure differential (ΔP) and should include dynamic amplification effects for a suddenly applied load.

The overall maximum pressure differential occurs for the [ ]a,c,e for a Model F plant, which is over [ ]a,c,e for Callaway. In addition, a dynamic amplification factor, which is as high as [ ]a,c,e (Table A.3-10), is used giving a combined safety factor on the order of 3 with respect to the normal operation ΔP. This approach compares well to the static pullout load used for determination of H* based on 3 × normal operating ΔP, as required by RG 1.121. Finally, the next row-adjacent supporting tube must meet the rules in Section III, Subsection NB of the ASME Code, for all specified loading conditions, design, normal, upset, test, emergency and faulted.

The load conditions, used in the P* analysis, are listed in Table A.3-1. P* is determined by [ ]a,c,e. Again, the intact tube must meet the ASME Code structural criteria for all of the loading conditions specified in Table A.3-1.

A.3.3 Material Properties

Table A.3-2 lists the material properties used for the SB-163 TT Alloy 600 tube material in the P* analysis. All properties are conservatively taken at [ ]a,c,e.

A.3.4 Acceptance Criteria

The ASME Code stress intensity limits, used in the P* analysis, are listed in Table A.3-3. These limits apply to the intact tube supporting the separated tube.

The maximum kinetic energy of the Row 58 separated tube (at impact with Row 59) is about [ ]a,c,e, as calculated in Section A.3.6 and listed in Table A.3-9. Again, the actual kinetic energy available at impact would be less (than [ ]a,c,e since the effects of sliding friction and strain energy of the separated tube in bending have been neglected. The local dynamic effects at impact may be evaluated by comparison with the kinetic energy of the [ ]a,c,e. From page 2-48 of Reference 8.12, the puncture kinetic energy was estimated to exceed [ ]a,c,e. Therefore, based on both the energy level required for local fracture and the more favorable geometries of the impacting surfaces, no deleterious local effects are expected due to the impact of the postulated separated tube's extrados with the intact tube's intrados in the P* model.

Since the tubes are ductile, the limits in Table A.3-3 are applied to stresses calculated statically for the load conditions listed in Table A.3-1. Thus, no shock factors are required in the stress evaluation since the peak dynamic loads act for a very small time period. However, dynamic amplification factors are employed to calculate the displacements for P* as discussed in Section A.3.6.

The fatigue usage factor due to P*, when added to the maximum fatigue usage factor calculated for a Model F tube in Reference 8.14, must not cause the combined overall usage factor to exceed the ASME Code limit of one. At most, the P* stress range for cycling loading is assumed to occur [

]a,c,e. Since the limit on the upset range is $3S_m$, the maximum amplitude would be $1.5S_m$ or 39.9 ksi. Conservatively assuming a maximum stress riser of 2, returns the peak stress to 79.8, say 80 ksi. From the fatigue design curve in Reference 8.4 for Alloy 600, the allowable cycles are over 4000, giving at most an additional usage factor of [ ]a,c,e. From Table 1-1 of Reference 8.14, the maximum cumulative usage factor in the Model F U-bend region is only about [ ]a,c,e. Thus, any additional fatigue usage due to P* is negligible.

A.3.5 Finite Element Models

The displacements of the separated tubes and row adjacent supporting tubes are calculated using the FE models described below.

Static Models

The separated and intact tubes are modeled using [

]a,c,e.

Dynamic effects are considered using amplification factors obtained with the dynamic models, as discussed below.

Figures A.3-5A, 5B and 5C show details of the [

]a,c,e.

Dynamic Models

The separated tube has kinetic energy when it strikes the intact tube, and it is necessary to consider dynamic amplification of the separated tube displacement for the P* calculation. [

]a,c,e

[

]^a,c,e.

A.3.6 Displacement Results

The maximum displacement results at the selected tube row combination locations in the bundle are required to calculate P*. In turn, this requires simulation of the [

]^a,c,e.

<u>Initial Surface-to-Surface Contact</u>

Figure A.3-7 shows schematically the geometric logic employed to calculate the upward displacement of the tangent point A due to initial surface-to-surface contact. [

]^a,c,e

[

]a,c,e. The resulting tangent point lift from A to A′ is also the vertical upward displacement of the separated tube straight leg at top of the tubesheet due to the initial surface-to-surface contact.

Subsequent Point-to-Point Contact

The subsequent displacements due to point-to-point contact are [

]a,c,e. These are added to the initial surface-to-surface results (from Table A.3-7) to give the combined statically calculated displacements of the separated tube at the top of the tubesheet, also listed in Table A.3-8. These combined static results are increased for dynamic effects as discussed next.

Dynamic Amplification

Prior to performing FE time-history solutions using the [

]a,c,e

[

]^{a,c,e}. At impact, the maximum kinetic energy for Row 58 is about [ ]^{a,c,e} for an impact velocity of [ ]^{a,c,e}. (Note: The use of the term δ in this section is unrelated to the use of it in another section of this report.)

The dynamic displacement amplification factor (λ) is defined as [

]^{a,c,e}.

A.3.7 Structural Evaluation Results

Primary Membrane Stress Evaluation

The P* primary stress evaluation of the intact tube conservatively neglects the remaining intact leg of the separated tube and assumes that all of the resulting pressure differential thrust from the separated tube leg is carried equally by each leg of the row adjacent intact tube. Table A.3-11 lists the resulting calculated axial primary stresses in the intact tube straight legs for the specified Model F load conditions. Table A.3-12 shows the P* primary stress evaluation, which considers the combined total axial stress from Table A.3-11, the hoop stress due to the primary to secondary ΔP, the radial stress, and the resulting primary membrane stress intensity P_m. Minimum tube cross section properties are employed to calculate the primary stresses. [

]^{a,c,e}. As seen in Table A.3-12, the ratio of P_m to the allowable stress intensity is less than one for all specified load conditions indicating that the ASME Code primary stress limits are satisfied for the intact tube.

Out-of-Plane Load Cases

It is assumed that out-of-plane effects are limited to considering the stress (mostly bending) in the supporting intact tubes due to the out-of-plane contact forces, i.e., the H component of the contact force N, shown in Figure A.3-1. The vertical component (V) of the contact force N is the compression force in the contact elements obtained from the FE models considering in-plane loading only. The resulting out-of-plane horizontal force (H), acting in opposite directions on the separated and intact tubes, is obtaining using the geometric relationship shown in Figure A.3-1. This relationship depends on [
]^{a,c,e}:

[

]a,c,e.

Using the above conservative misalignment assumptions and the in-plane 1st pass results that calculate the vertical contact forces (V) it is possible to determine the resulting out of plane forces (H) at each contact point between the separated and intact tubes. These H reactions are applied as equal and opposite FZ forces on the end nodes defining the contact elements shown in Figure A.3-5B. Note that some of the gaps are open, and there is no contact (V = 0) and there is no out-of-plane force (H = 0). In each in-plane (pass 1) and out-of-plane (pass 2) 3D pipe element models, four load steps are used corresponding to the design (or test), upset, emergency and faulted loads listed in Table A.3-5. The resulting 2nd pass stresses in the intact tube are used to evaluate the bending stresses as discussed below.

Primary Membrane plus Bending Stress Evaluation

In most bundle locations, the P* bending stresses, due to both in-plane and out-of-plane loads, occur in the [ ]a,c,e. The overall maximum in-plane plus out-of-plane stresses result from the [ ]a,c,e. Assuming the overall worst case minimum cross-sectional properties for primary loading (see Tables A.3-11 and 12), [ ]a,c,e. The resulting primary plus secondary stress intensity for the FLB load is $P_m + P_b$ = [

]a,c,e all primary plus bending stress limits for the Row 59 intact tube, due to out-of-plane loads, are satisfied with positive structural margins. Since the margins are substantial, significantly larger tube misalignments at contact (than the assumed [ ]a,c,e could be tolerated.

Secondary Stress Evaluation

The P* bending stresses in the intact tube are [ ]a,c,e. There are no secondary stress limits for the emergency and faulted load conditions. The overall maximum bending stresses occur in the [ ]a,c,e. The resulting maximum primary plus secondary stress intensity range is 35 ksi, which is less than the $3S_m$ allowable of 79.8 ksi, indicating that the ASME Code secondary stress limits are satisfied.

Table A.3-1
Model F Primary to Secondary ΔP Loads Used in P* Analysis

ASME Code Classification	P_p Primary Side Pressure (psia)	P_s Secondary Side Pressure (psia)	$\Delta P = P_p - P_s$ Primary to Secondary Pressure Differential (psi)	Reference
Design	[		]a,c,e	Reference 8.8
Max-Upset	[		]a,c,e	Table K-30 of Reference 8.15
Test	[		]a,c,e	Limited to Design ΔP by Section XI (IWA 4700, IWA 500, IWB 5000), Reference 8.11.
Emergency	[		]a,c,e	Small Steam Line Break, Systems Standard 1.3F, Reference 8.9
Faulted	[		]a,c,e	Feed Line Break, Systems Standard 1.3F, Reference 8.9

Table A.3-2
Material Properties Used in P* Analysis

Property	Value [ ]a,c,e	Reference
Elastic Modulus	28.45×10^6 psi	Table I-6.0 of Reference 8.4
Thermal Expansion Coefficient	7.9×10^{-6} °F^{-1}	Table I-5.0 of Reference 8.4
Poisson's Ratio	0.3	Assumed
Metal Weight Density	0.307 lbf/in^3	Page 4-9 of Reference 8.14
Effective Mass Density*	0.001076 lbf-sec^2/in^4	Page 4-10 of Reference 8.14
S_m Primary Membrane Limit	26.6 ksi	Table 6-1 of Reference 8.14
S_y Yield Strength	35.2 ksi	Table 6-1 of Reference 8.14
S_u Ultimate Tensile Strength	80.0 ksi	Table 6-1 of Reference 8.14

* Used in dynamic analysis and includes metal, internal water and external hydrodynamic masses based on the nominal cross section area of a Model F tube.

Table A.3-3
Stress Intensity Limits Used in P* Analysis

ASME Code Classification	Basis for Stress Intensity Limit	P_m Limit (ksi)	$P_m + P_b$ Limit* (ksi)	$P_m + P_b + Q$ Limit (ksi)
Design	S_m	26.6	35.6	N/A
Upset	$3S_m$	N/A	N/A	79.8
Test	$0.9S_y$	31.7	42.5	N/A
Emergency	S_y	35.2	47.2	N/A
Faulted	$0.7S_u$	56.0	75.0	N/A

* Using a shape factor of 1.34 for the Model F tube.

Table A.3-4

[

]a,c,e

Tube Row	U-bend Radius (inch)	Straight Leg* (inch)	[AVB Out-of-Plane Support Location Angles (°) Measured from U-bend Tangent of Separated Leg]a,c,e					
			# 1	# 2	# 3	# 4	# 5	# 6
4	[							]a,c,e
5	[							]a,c,e
30	[							]a,c,e
31	[							]a,c,e
57	[							]a,c,e
58	[							]a,c,e
59	[							]a,c,e

* Straight leg length is from the top of the tubesheet to U-bend tangent.

Table A.3-5
Vertical Forces Acting on Separated Tube Leg
Applied in P* FE Models (See Figures 7.3-5A, 5B and 5C)

Load Condition	ΔP (psi)	F_1 = Force on Tube Expansion (lbf)	F_{65} = Force at Tangent to U-bend (lbf)	Total Vertical Force (lbf)
Design or Test	[			]a,c,e
Upset	[			]a,c,e
Emergency	[			]a,c,e
Faulted	[			]a,c,e
Unit	[			]a,c,e

Table A.3-6

[ ]a,c,e

Tube Rows	Lump Masses[A] (lbf-sec2/in)		Effective Spring Rates (lbf/in)		4% Damping Coefficient (lbf-sec/in)		Gap Stiffness (lbf/in)	Initial Gap[B] (inch)
	M_1	M_2	K_1	K_2	C_1	C_2	K_{GAP}	δ_{GAP}
4/5	[							]a,c,e
30/31	[							]a,c,e
58/59	[							]a,c,e

A. Mass 1 is the separated tube, mass 2 is the next outer row-adjacent intact tube.

B. Initial gap is assumed to be UY_B vertical displacement at 1st contact from Table A.3-7.

Table A.3-7
Results of Initial Surface-to-Surface Contact Displacement Analysis

Tube Rows	1st Node in FE Model to Contact (B)	θ Polar Angle to B (°)	ΔP_C Min ΔP For 1st Contact (psi)	α Arc A′-B′ Angle (°)	ϕ Solution Angle (°)	ψ Polar Angle to A′ (°)	Tangent Lift (A to A′) L + Yo (inch)	UY_B Vertical Disp at 1st Contact (inch)
4/5	[							]a,c,e
30/31	[							]a,c,e
58/59	[							]a,c,e

Table A.3-8
Total Combined Static Surface-to-Surface and Point-to-Point Contact Displacement Analysis Results for the Separated Tube Straight Leg at the Top of the Tubesheet

Tube Rows	Point-to-Point FE Calculated Vertical Displacement at the Top of Tubesheet Due to FLB Load Applied Statically (inch)	Surface-to-Surface Tangent Lift (A to A′) L + Yo from Table A.3-7 (inch)	Total Combined Static Displacement at Top of Tubesheet (inch)
4/5	[		]a,c,e
30/31	[		]a,c,e
58/59	[		]a,c,e

Table A.3-9
Calculation of Maximum Kinetic Energy of Separated Tube at Impact With Adjacent Intact Tube for [ ]^{a,c,e}

Tube Rows	Separated Tube Mass M_I (lbf-sec^2/in)	Initial Acceleration $A_o = F_{SLB} / M_I$ (in/sec^2)	δ_{GAP} Vertical Disp At 1st Contact (inch)	V_c Contact Velocity (in/sec)	KE Kinetic Energy At 1st Contact (in-lbf)	T_c Time to Initial Contact (sec)
4/5	[					]^{a,c,e}
30/31	[					]^{a,c,e}
58/59	[					]^{a,c,e}

Table A.3-10
Dynamic Displacement Amplification Factors for [ ]^{a,c,e} of Figure A.3-6

Tube Rows	UY_D Maximum Dynamic Displacement Of Separated Tube (inch)	Time of Maximum Dynamic Displacement (second)	UY_S Maximum Static Displacement Of Separated Tube (inch)	$\lambda = UY_D / UY_S$ Dynamic Displacement Amplification Factor	$(UY_I)_S$ Total Combined Static Displacement at Top of Tubesheet from Table A.3-8 (inch)	$(UY_I)_D = \lambda\ (UY_I)_S$ Maximum Dynamic Displacement at Top of Tubesheet (inch)
4/5	[					]^{a,c,e}
30/31	[					]^{a,c,e}
58/59	[					]^{a,c,e}

Table A.3-11
Total Axial Primary Stress in Intact Tube Straight Legs
Model F Steam Generators

[

]a,c,e

Load Condition	Pp (psia)	Ps (psia)	ΔP = Pp –Ps (psi)	Po Separated Tube Thrust (lbf)	Axial Stress Due to Po (ksi)	Axial Stress Due to ΔP (ksi)	Total Axial Stress (ksi)
Design	[						]a,c,e
Upset	[						]a,c,e
Test	[						]a,c,e
Emergency	[						]a,c,e
Faulted	[						]a,c,e

Table A.3-12
P* Primary Stress Evaluation of Intact Tube
Model F Steam Generators

[

]a,c,e

Load Condition	ΔP (psi)	Total Axial Stress (ksi)	Hoop Stress Due to ΔP (ksi)	Radial Stress (ksi)	P_m Stress Intensity (ksi)	Allowable Intensity Stress (ksi)	Ratio P_m To Allowable
Design	[						]a,c,e
Upset	[						]a,c,e
Test	[						]a,c,e
Emergency	[						]a,c,e
Faulted	[						]a,c,e

a,c,e

Figure A.3-1
Schematic Showing Misalignment Between
Separated and Intact Tubes at Contact.

a,c,e

Figure A.3-2
U-bend Region Showing AVBs and
Postulated Snap Through Mode Shape

a,c,e

Figure A.3-3
Minimum Required Out-of-Plane Motion Between AVB Support Points for Postulated Snap Through

a,c,e

Figure A.3-4A
In-Plane View FE Deformed Geometry Plot of Postulated Snap Through at Nodes 68, 77 and 85 Used to Obtain Minimum Strain Energy Required to Establish Snap Through

a,c,e

Figure A.3-4B
Out-of Plane View FE Deformed Geometry Plot of Postulated Partial Snap Through at Nodes 68, 77 and 85 Used to Obtain Minimum Strain Energy Required to Establish Snap Through

a,c,e

Figure A.3-5A

FE Model – [

]a,c,e

a,c,e

Figure A.3-5B

FE Model – [

]a,c,e

a,c,e

Figure A.3-5C

FE Model – [

][a,c,e]

a,c,e

[

]

Figure A.3-6

[

]a,c,e

a,c,e

Figure A.3-7
Geometry of Initial (1st) Surface-to-Surface Contact
Between Separated and Intact Tubes

[ ]a,c,e

a,c,e

Figure A.3-8
Static Pont-to-Point In-plane Displacement Vectors
of Rows 4/5 U-bend Region Separated and
Intact Tubes For [
]a,c,e

a,c,e

[

]

Figure A.3-9
Static Pont-to-Point In-plane Displacement Vectors of Rows 30/31 U-bend Region Separated and Intact Tubes For [

]a,c,e

a,c,e

[

]

Figure A.3-10
Static Pont-to-Point In-plane Displacement Vectors of Rows 58/59 U-bend Region Separated and Intact Tubes For [

]a,c,e

[ ]a,c,e

Figure A.3-11
Time History Displacement Response of Rows 4/5
Separated and Intact Tubes [ ]a,c,e

a,c,e

[

]

Figure A.3-12
Time History Displacement Response of Rows 30/31
Separated and Intact Tubes For [

][a,c,e]

a,c,e

Figure A.3-13
Time History Displacement Response of Rows 58/59
Separated and Intact Tubes for [
]a,c,e

APPENDIX B
TUBE-TO-TUBESHEET JOINT STRENGTH ANALYSIS

B.1 INTRODUCTION

The geometry of a tube with a circumferential crack located within the tubesheet is illustrated on Figure B.1. Specimens made for pull testing are severed at various locations within a tubesheet simulating collar as illustrated on Figure B.2.

B.2 ANALYSIS

The analysis follows the method published [

]^{a,c,e}

The analysis presented herein considers two cases, the first for a constant residual contact pressure as would be the case for pullout testing of a tube element in a collar and the second for a linearly increasing contact pressure as would be the case for a tube in a tubesheet bowed by the primary-to-secondary pressure. The problem is solved by considering the equations of [

]^{a,c,e}

B.2.1 FORCE EQUILIBRIUM

The load carrying capability of the joint, *F*, is calculated by considering force equilibrium for a [

]^{a,c,e}

The axial force equilibrium for an element of the tube with a length of dz and a cross-section area of A, illustrated on Figure 4, is given by,

a,c,e

[ ] (1)

where b is the outside radius of the tube, μ is the coefficient of friction between the tube and the tubesheet, and p_c is the contact pressure between the tube and tubesheet. So,

a,c,e

[ ] *Force Equilibrium* (2)

is the differential equation of equilibrium. Note that the contact pressure is not known at this point. The contact pressure is the net value from the initial installation of the tube, thermal expansion and internal pressure associated with operation, and relaxation associated with dilation of the tubesheet holes as the result of bowing from the primary-to-secondary pressure differential.

B.2.2 COMPATIBILITY

The compatibility condition is that the reduction in the radius of the tubesheet due to the decrease in contact pressure must be equal to the expansion of the tube as a result of the decrease in contact pressure minus the Poisson contraction of the tube due to the application of the axial load. The magnitudes of the terms to be considered for compatibility come from the force-deformation relations.

B.2.3 FORCE-DEFORMATION

The force-deformation relations will be used next to develop expressions for the respective deformations of the tube and tubesheet radii. If p_0 is the initial contact pressure, the decrease in TS radius from the decrease in the contact pressure can be found from,

a,c,e

[ ] *TS Radius Decrease* (3)

where the subscript on the radius indicates it is for the tubesheet collar. Absolute relations are considered since the accounting of the directions of movement can be accounted later. The flexibility of the inside radius of the collar relative to an internal pressure is given by,

a,c,e

[ ] *Collar Flexibility* (4)

where ν is Poisson's ratio for the tubesheet and E is the modulus of elasticity. This is obtained from the application of the theory of elasticity to a thick-walled, open ended cylinder, see Reference B.2 for example. For a first analysis it is assumed that both Poisson's ratio and the modulus of elasticity of the tube and the tubesheet can be considered to be equal without a significant effect on the results of the analysis.

The corresponding relation for the effect of the change in pressure on the outside radius of the tube is given by,

[ ]a,c,e *Tube Radius Increase* (5)

Because of the application of the axial tensile stress, there is a radial contraction (Poisson effect) of the tube given by the following expression,

[ ]a,c,e *Tube Radius Decrease* (6)

If the axial stress is compressive, the radius of the tube increases due to the Poisson effect.

B.2.4 SOLUTION

Applying the compatibility condition that the tube must remain in contact with the tubesheet leads to the following solution for the average axial stress acting on the tube element, i.e.,

[ ]a,c,e (7)

B.2.4.1 Constant Contact Pressure

If the initial contact pressure, p_0, is a constant, then,

[ ]a,c,e (8)

and the differential equation for the contact pressure between the tube and tubesheet becomes,

[ ]a,c,e (9)

The solution is straightforward. The boundary conditions (BC) are: [

]a,c,e

[

$]^{a,c,e}$ *For constant p_0* (11)

For pullout testing programs the axial force is measured and the equation is rearranged as,

[$]^{a,c,e}$ *Contact Pressure* (12)

to solve for the unknown contact pressure. Note that the [

$]^{a,c,e}$

B.2.4.2 Linear Contact Pressure

The differential equation for equilibrium is different when the contact pressure is not constant with depth, e.g., when the tubesheet is bowed from the primary-to-secondary pressure. From Reference B.3 it is known that the interface pressure or load is approximately linear, especially in the range of interest at the top of the tubesheet. In addition, there may be a *loss of contact* between the tube and the tubesheet at the top of the tubesheet. Hence, the discussions in this section consider the loss of contact point to be the origin for the Z axis as opposed to the top of the tubesheet per se. If the contact pressure is linear, then the magnitude of the initial contact pressure as a function of distance below the loss of contact point is,

[$]^{a,c,e}$ *Linear Contact Pressure* (14)

where L is any point within the tubesheet at which the initial contact load, p_c, can be calculated, that is, it is simply a slope and the dimensions chosen do not have any special meaning. Since the origin is taken at the point of loss of contact, where the interface pressure is zero, there is no intercept needed in the equation. The compatibility and force-deformation relations yield the following for the axial stress,

a,c,e

Axial Stress (15)

The equilibrium equation is unchanged from Equation 2. The derivative of the stress with respect to depth into the tubesheet is now given by,

a,c,e

(16)

[

(17)

(18)

(19)

(20)

a,c,e

(21)

[

Linear P_c (22)

Linear P_c (23)

]a,c,e

B.2.4.3 Adjustments for Test or Operating Conditions

B2.4.3.1 Difference in Material Properties

If the modulus of elasticity of the tube and the tubesheet, or collar, are not the same, the expression for the pullout force becomes,

$$\left[\qquad\qquad\qquad\qquad \right]^{a,c,e} \qquad (24)$$

Here Δf is the difference in radial flexibilities between the tubesheet and the tube relative to the application of the interface pressure, i.e., $\Delta f = f_c - f_t$ where the respective flexibility expressions are,

$$\left[\qquad\qquad\qquad\qquad \right]^{a,c,e} \qquad (25)$$

Note that f_t [

]a,c,e

B.2.4.3.2 Application of a Pushout Load

As previously note, the strength of the joint is different depending on whether or not the applied load is tensile of compressive. In the case of a compressive load, the required force to push the tube out of the tubesheet or collar when the preload pressure is constant with depth is given by,

Pushout Force [ ]a,c,e *For constant p_0* (26)

For a prescribed force the length required to resist being pushed out is,

Pushout Length [ ]a,c,e *For constant p_0* (27)

It is noted that if $\mu\alpha L$ is small, the pullout and pushout loads and lengths are nearly equal in magnitude. This is demonstrated by performing a series expansion of the terms.

B.3 ANALYSIS RESULTS

Data from two series of tests performed at two different locations by two different Westinghouse organizations and separated by almost 10 years in time, see References 4 and 5, were analyzed to determine the effective residual contact pressure from the hydraulic installation process. [

]a,c,e

B.4 REFERENCES

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B.2 *Formulas for Stress and* Strain, Fifth Edition, Roark, R., and Young, W., McGraw-Hill Book Company, New York, New York, USA (1975).

B.3 CN-SGDA-02-127, Westinghouse Electric Company, Madison, PA, USA (September, 2002).

B.4 NCE-88-271, Westinghouse Electric Company, Pensacola, FL, USA (November, 1988).

B.5 STD-DP-1997-8015, Westinghouse Electric Company, Pittsburgh, PA, USA (1997).

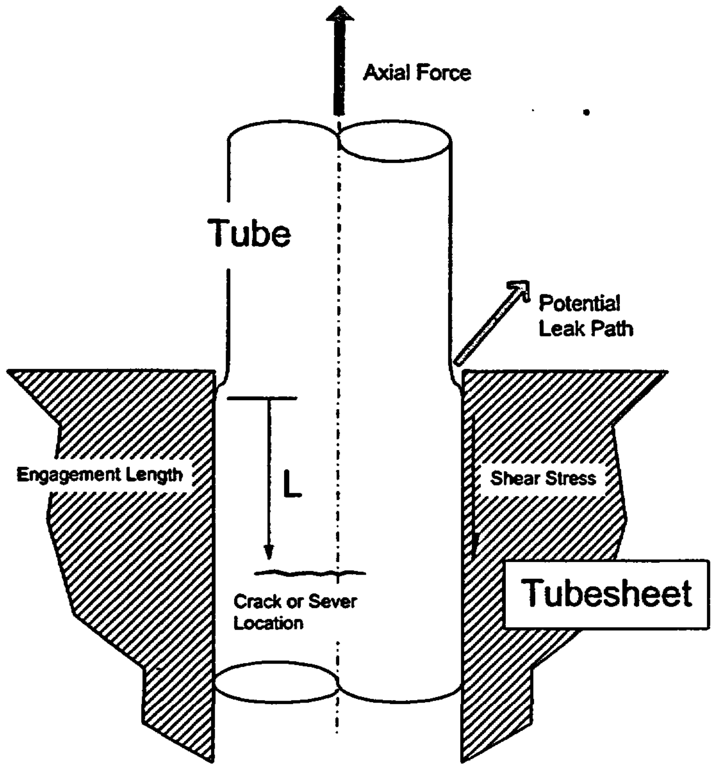

Figure B.1: Tube with Circumferential Crack or Sever Within the Tubesheet.

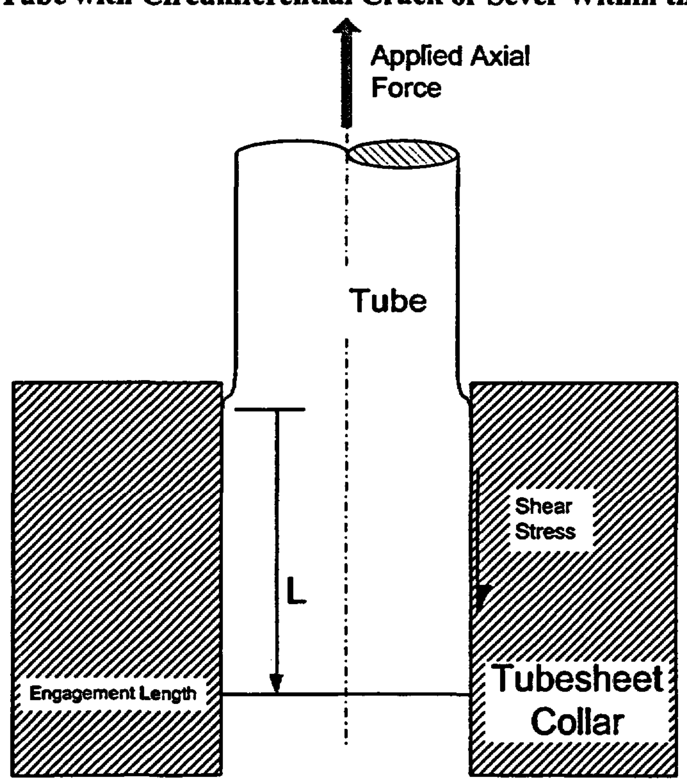

Figure B.2: Tube-to-Tubesheet Pullout Testing

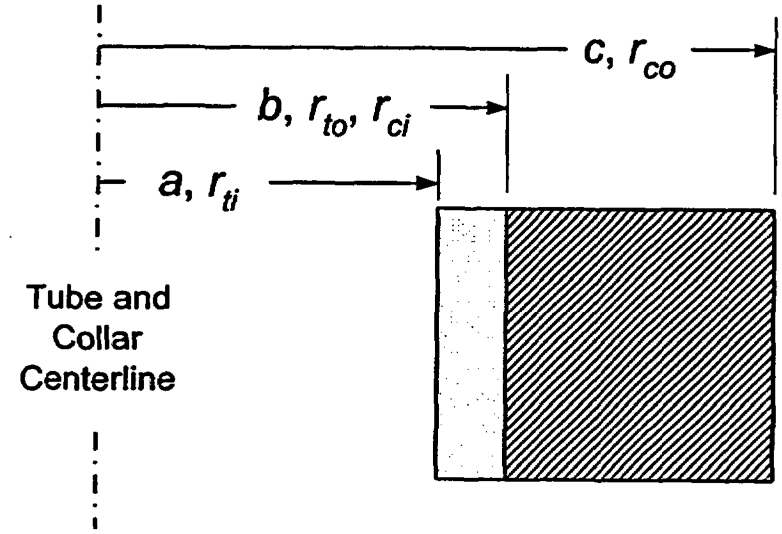

Figure B.3: Tube & Collar Radii Designations

a,c,e

Figure B.4: Tube Wall Element for Elastic Analysis.

APPENDIX C
CRACK OPENING AREA ANALYSIS

C.1 INTRODUCTION

The potential leak rate through circumferential cracks located in steam generator tubes is of interest when the cracks are located in the portion of the tube within in the tubesheet (TS). This is of special interest when the tubes have been expanded over the full thickness of the TS and it is desired to limit the length of rotating pancake coil (RPC) eddy current test (ECT) inspections to less than the full depth of the tubesheet. The geometry of a tube with a circumferential crack located within the tubesheet is illustrated on Figure C.1. The potential leak rate would be expected to be small if the distance from the top of the tubesheet, or bottom of the expansion transition, to the crack is significant. The purpose of this evaluation is to document the development of crack opening area (COA) expressions to be used for the calculation of leak rates from circumferential cracks in the expanded region of steam generator (SGs) tubes.

Expressions exist in the literature for calculating the COA of a circumferentially cracked pipe, for example see Volume 1 of the EPRI Ductile Fracture Handbook, Reference C.1, or Section 33.1 of The Stress Analysis of Cracks Handbook, Reference C.2. The given expressions do not account for [

]a,c,e

There are two sources for the loads that are to be considered for the evaluation of the COA, the end cap load from the differential pressure across the tube at the U-bend, and the internal pressure acting on the flanks of the crack. No further transmission of the pullout force from the pressure end cap load would be expected below a certain distance within the tubesheet because the tubes are expanded into a radial interference fit with the tubesheet, and because differential thermal expansion of the tube and tubesheet materials and internal pressure in the tube will increase the interface pressure in the tube-to-tubesheet joint. This is clearly demonstrated to be the case for the tube analysis for Westinghouse Model F SGs in Reference C.4. The only forces acting to open the crack below the critical distance would be due to internal pressure acting on the crack flanks. The radial interference force between the tube and the tubesheet will be acting to retard the crack opening area in that case through friction of the joint. An expression is developed herein for use that accounts for the contact pressure resisting load.

C.2 EVALUATION & ANALYSIS

There are a few assumptions associated with the performance of the evaluation, i.e., [

]a,c,e

The situation to be analyzed is illustrated on Figure C.1. Here a circumferential crack is located effectively deep within the tubesheet. There are two sources of loading on the crack, the end cap load due to the primary-to-secondary pressure differential at the U-bend of the tube and the load due to the application of the primary pressure on the flanks of the crack. Near the top of the tubesheet the primary axial stress acting to open the crack will be the end cap load. Because of the interface pressure between the tube and the tubesheet, the magnitude of the axial stress acting on the tube cross section will diminish with elevation into the tubesheet. At some elevation no further axial stress will be transmitted. In what follows this location is referred to as the nil transmittal elevation or may be identified by the variable designation T^* (T-star). Note that T^* is not a criterion like H^* because there is no safety factor considered. It is simply the elevation below which there is no axial stress due to the application of the end cap load on the tube.

Handbook solutions for cracked pipes (tubes) are available for the application of internal pressure, application of an axial load and application of a bending moment. The internal pressure solution includes consideration of the bending moment induced by the geometry, that is, the centroid of the cracked section is not coincident with the far-field axis of the pressure load. Another factor to consider relative to published solutions is that the presence of the tubesheet prevents local out-of-plane or surface deformation that leads to an increase in the COA. The aim of this analysis is to provide expressions for the calculation of the crack opening area of a circumferential crack located at various elevations within the tubesheet. There were two approaches considered for the solution of the engineering problem, the first being more conservative than the second. The final approach to the solution is to [

]a,c,e

The expressions contained in the EPRI Ductile Fracture Handbook, Reference C.1, form the basis for all of the COA expressions developed. These are in Section 7 of Chapter 1 of that reference. The expressions are identical to those contained in the Stress Analysis of Cracks Handbook, Reference C.2, Cases 33.1 and 33.2 for an applied axial load and an applied bending moment respectively. The equations are the same as those presented in Reference C.3 for the analysis of circumferential cracks in reactor piping systems. A solution for the crack opening area of a circumferential crack in a guided tube must be developed because there was no solution found in the public literature. There are however, solutions for the combined axial and bending load case. Finally, a check of the solution is performed by assuming that the restriction of deformation effected by the presence of the tubesheet means that the tube can be treated as a flat plate.

C.2.1 FAR-FIELD BENDING STRESS

The cross-section centroid of a circumferentially cracked tube section with a crack half-angle of θ is located at a distance of

$$\bar{x} = -\frac{R \sin \theta}{\pi - \theta} \qquad \textit{Centroid Location} \quad (1)$$

from the axis of the tube (an easy derivation using the mensuration formulae in Reference C.5) where R is the mean radius of the tube. The application of an internal pressure in the SG tube results in a far-field axial force, F, because of the end cap pressure at the U-bend. This load acts along the axis of the tube and its line of action is thus displaced relative to the centroid. This creates a far-field bending moment, M, applied to the cracked section of the tube given by the following expression,

$$M = \frac{F R \sin \theta}{\pi - \theta} = \frac{\pi R^3 \Delta P \sin \theta}{\pi - \theta}. \qquad \textit{End Cap Moment} \quad (2)$$

where ΔP is the pressure differential acting across the tube wall. The application of the bending moment results in a far-field bending stress given by the following,

$$\sigma_b = \frac{M\,R}{\pi R^3 t} = \frac{\Delta P\,R\,\sin\theta}{t(\pi-\theta)} = \sigma_z\,\frac{2\sin\theta}{\pi-\theta}, \qquad \textit{Bending Stress}\ \ (3)$$

where σ_z is the far-field axial stress in the tube due to the pressure difference given by,

$$\sigma_z = \frac{\Delta P\,R}{2t}. \qquad \text{Axial Stress}\ \ (4)$$

Note that the moment of inertia for the far-field bending stress equation is calculated as,

$$I = 2\,t\,R^3 \int_0^{\pi} \cos^2\phi\, d\phi = \pi R^3 t. \qquad \textit{Moment of Inertia}\ \ (5)$$

C.2.2 CRACK OPENING AREA FOR APPLIED AXIAL AND BENDING LOADS

Per Section 7.1 of Chapter 1 of Reference C.1, the crack opening area, A_c, of a circumferential crack in a tube with far-field axial load induced stress of σ_z and a far-field bending moment induced stress of σ_b is given by,

$$A_c = \frac{\pi R^2}{E} B_6\left[\sigma_z + \sigma_b\left(\frac{3+\cos\theta}{4}\right)\right], \qquad \textit{Axial} + \text{Bending}\ \ (6)$$

where,

$$B_6 = 2\theta^2\left\{1+\left(\frac{\theta}{\pi}\right)^{3/2}\left[8.6-13.3\left(\frac{\theta}{\pi}\right)+24\left(\frac{\theta}{\pi}\right)^2\right]+\right.$$
$$\left.\left(\frac{\theta}{\pi}\right)^3\left[22.5-75\left(\frac{\theta}{\pi}\right)+205.7\left(\frac{\theta}{\pi}\right)^2-247.5\left(\frac{\theta}{\pi}\right)^3+242\left(\frac{\theta}{\pi}\right)^4\right]\right\} \qquad (7)$$

[

]a,c,e

[

, (9)

(10)

. (11)

]a,c,e

C.2.3 INTERNAL PRESSURE SOLUTION

Sections 7.3 and 7.4 of Chapter 1 of Reference C.1 provide crack opening area solutions for circumferential cracks with internal pressure in the tube. These solutions are more in line with the problem being solved, but were not initially selected for use because of the apparent ease with which the bending load could be accounted for in the Section 7.1 (all references are to the same chapter) solution. Since this accounting was not put into practice, equations based on the internal pressure solution were derived.

Section 7.3 presents the linear elastic fracture mechanics solution and Section 7.4 presents a solution for small scale yielding. The only difference between the two sections is that Section 7.4 adds the use of a crack half-angle that has been adjusted for the plastic zone at the tips of the crack based on the standard Irwin plastic zone adjustment approach. The crack opening area is given by,

[,]a,c,e *Internal Pressure COA* (12)

where,

$$B_7 = \begin{cases} \lambda^2\left(1+0.16\lambda^2\right) & 0 \le \lambda \le 1 \\ 0.02+\lambda^2\left[0.81+\lambda(0.30+0.03\lambda)\right] & 1 < \lambda \le 5 \end{cases} \tag{13}$$

and the normalized crack length is determined as a function of the crack half-angle as,

$$\lambda = \theta\sqrt{\frac{R}{t}}. \tag{14}$$

Here, R is the mean radius of the tube. The solution for small scale yielding is identical except that an effective half-angle (to account for the effect of the plastic zone at each of the crack tips) is calculated as,

$$\theta_e = \theta\left[1+\frac{1}{\beta}\left(\frac{F_m\sigma_z}{\sigma_y}\right)^2\right], \qquad \textit{Effective Crack Angle} \tag{15}$$

where,

$$F_m = \begin{cases} 1+0.1501\lambda^{1.5} & 0 \le \lambda \le 2 \\ 0.8875+0.2625\lambda & 2 < \lambda \le 5 \end{cases}, \tag{16}$$

where λ is calculated here using the initial crack half-length and in the previous equation using the effective crack half-length.

Using the above expressions, and Model F tube dimensions, an internal pressure of 2560 psi expansion in the tubesheet and a yield stress of 80 ksi (judged to be reasonable for an expended tube), crack opening areas for the elastic and small scale yielding cases were calculated. [

]a,c,e

a,c,e

[ ] *Adjustment Factor* (17)

Also, the two solutions are illustrated on Figure C.6, along with an adjusted value which accounts for the guidance provided by the tubesheet. The adjustment factor is derived in the following section.

C.2.4 THE EFFECT OF THE GUIDANCE PROVIDED BY THE TUBESHEET

The internal pressure solution does not provide a means by which the effect of the guidance provided by the tubesheet has on the crack opening area can be directly calculated. However, [

]a,c,e

[

(18)

(19)

(20)

]a,c,e

C.2.5 MOMENT DUE TO PRESSURE ON THE CRACK FLANKS

The adjustment [

(21)

(22)

a,c,e

] (23)

[

]a,c,e

C.2.6 FLAT PLATE SOLUTION

The flat plate equivalent configuration to the circumferentially crack tube configuration is illustrated on Figure C.3. The total width of the plate is equal to the circumference of the tube, $2b$, and the half length of the crack, a, is calculated from the half-crack angle, θ. The solution for the crack opening area is taken from the Stress Analysis of Cracks Handbook, Reference 2, Case 2.1, the Center Crack Test Specimen. The crack opening area for a flat plate, A_p, is calculated as,

$$A_p = \delta_c 2b \tag{24}$$

where δ_c is the displacement associated with the presence of the crack, given by,

$$\delta_c = \frac{4 a \sigma}{E} V_2(\zeta) \tag{25}$$

where $\zeta = a/b$, and the function of the crack length, V_2, is given by,

$$\begin{aligned} V_2 = &-1.071 + 0.250\,\zeta - 0.357\,\zeta^2 + 0.121\,\zeta^3 \\ &- 0.047\,\zeta^4 + 0.008\,\zeta^5 - \frac{1.071}{\zeta}\ln(1-\zeta). \end{aligned} \tag{26}$$

A comparison of the areas calculated using Equation 24 shows them to be comparable to the areas obtained from Equations 20 and 23. This solution also does not include any consideration of [

]a,c,e

C.3 AXIAL STRESS IN THE TUBE

The analysis of the axial stress in the tube as a function of distance into the tubesheet in response to an applied axial load, e.g., the end cap load, is provided in Appendix B of this report. Resistance to the axial force is provided by the frictional contact pressure between the tube and the tubesheet. The pullout resistance incrementally decreases with depth because Poisson contraction of the tube radius diminishes the tube-to-tubesheet contact pressure. Not all of the axial load is transmitted downward into the tubesheet because of the resistance provided by the joint, hence, the Poisson contraction is progressively less with distance into the tubesheet. At a calculated depth, L, no further axial load is transmitted to lower tube material. The axial stress as a function of depth into the tubesheet when the initial contact pressure linearly increases with depth is calculated as,

^{a,c,e}

[ ] (27)

A is the cross section area of the tube, μ is the coefficient of friction, ν is Poisson's ratio. The distance to the nil stress transmission point, L, is roughly one-third of criterion length . The derivation of the above equation assumes that the moduli of elasticity for the tube and tubesheet are similar. A discussion of the effect of different moduli is presented in Appendix B.

C.4 CRACK OPENING AREA BELOW H* (PRESSURE ON THE CRACK FLANKS)

If a circumferential crack occurs below H*, the above equations would indicate that there is no crack opening area because H* is defined as the length below which no load is transmitted further down the tube. H* is calculated for two operating conditions, normal plant operation and postulated main steam line or feed line break. In addition, a factor of safety of three is imposed on the load for the determination made for normal operation and a factor of 1.4 is imposed on the load for the determination of the required length during postulated accident conditions. The final value of H* is the greater of the two. The elevation below which no load is transmitted is higher than the specified value of H* because each of these conditions include consideration of a multiplying factor on the load. The configuration illustrated on Figure 1 for a circumferential crack still applies, but without a far-field loading from the end cap pressure imbalance. The principle of superposition can be used to demonstrate that the solution to the fracture mechanics problem of imposing of a pressure on the flanks of the crack is the same as the solution based on applying the pressure as a far-field stress. So, a solution is available for the crack opening area, the same equation as before, in which the far-field stress, σ_z, is simply the pressure acting on the flanks of the crack. However, the direct application of the solution associated with far-field loading would ignore the resisting force from the tube to tubesheet interface pressure. The resisting force from the tube-to-tubesheet joint acts like a stiff spring in parallel with and in addition to the resisting force associated with deformation of the tube material itself. The stiffness of the joint can be determined and added to the stiffness of the tube material to determine the opening area for a circumferential crack located below the H* elevation.

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(28)

]^{a,c,e}

[

(29)

(30)

(31)

(32)

(33)

(34)

]a,c,e

[

]a,c,e

The resistance to movement of the tube material provided by the tube-to-tubesheet joint significantly reduces the crack opening area and is expected to greatly retard the potential for leakage from the joints.

C.5 REFERENCES

C.1 NP-6301-D, *Ductile Fracture Handbook*, Volume 1, EPRI (formerly the Electric Power Research Institute), 3412 Hillview Ave., Palo Alto, CA (June 1989).

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C.3 NUREG/CR-3464, "The Application of Fracture Proof Design Methods Using Tearing Instability Theory to Nuclear Piping Postulating Circumferential Through Wall Cracks," U. S. Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation, Washington, DC, USA (February, 1979).

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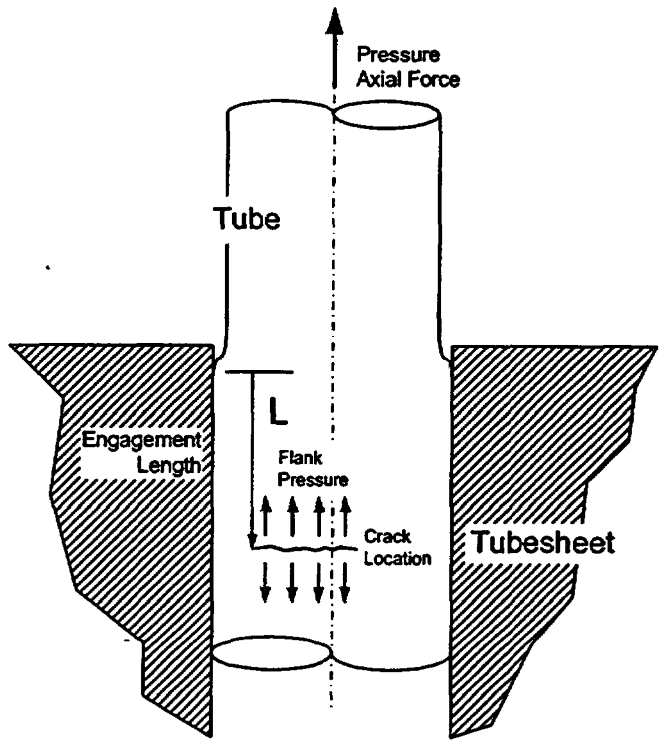

Figure C.1: Tube with circumferential crack within the tubesheet.

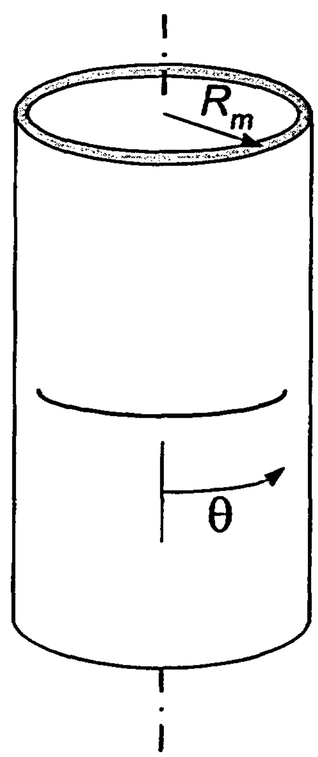

Figure C.2: Circumferential crack in a tube

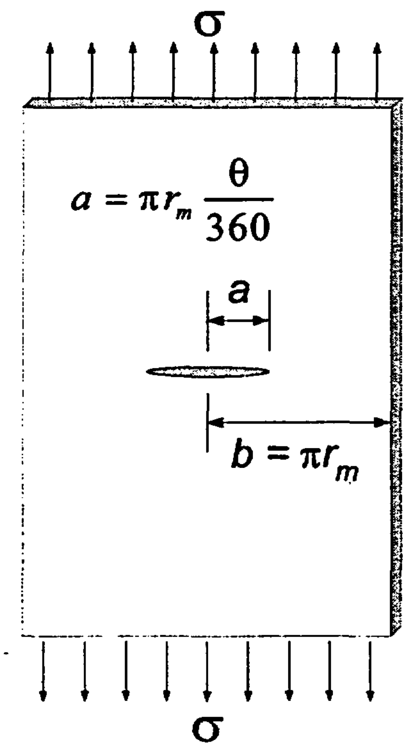

Figure C.3: Flat plate equivalent to a guided tube.

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Figure C.4: Various Crack Opening Area Solutions

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Figure C.5: Ratio of Plastic to Elastic Area for Internal Pressure

a,c,e

Figure C.6: Effect of Guiding on the Crack Opening Area for Internal Pressure

APPENDIX D
IN SITU TESTING OF TUBE INDICATIONS LOCATED IN THE TUBESHEET

D.1 INTRODUCTION

There have been a number of concerns raised by the NRC staff regarding in situ leak and pressure testing of tube indications located within the tubesheet of nuclear power plant steam generators (SGs). There are three primary requirements for degraded SG tubes. The burst pressure must be greater than three times the normal operating pressure difference, the burst pressure must be greater than 1.4 times the accident condition with the largest primary-to-secondary differential pressure, and the plant leak rate during postulated accident conditions, e.g., steam line break (SLB), must be met. In most cases the limiting structural requirement is that associated with the differential pressure during normal operation. A number of analyses have been performed which support the contention that the structural requirements are met by specific engagement lengths of the tube-to-tubesheet joint. For example, a hard rolled joint engagement length of less than one inch is required to achieve structural adequacy. Other such engagement lengths have been determined for tube-to-tubesheet joints effected by explosive expansion and by hydraulic expansion. Testing performed on hard rolled joints also demonstrated that the joints do not leak, thus the leak rate requirement is also met. Explosive and hydraulic expansion joints are not as tight as hard rolled joints and some leakage through 100% throughwall cracks may be expected during postulated accident conditions. Testing programs have been performed to demonstrate that such leakage would be expected to be small. In addition, analysis models have been developed with which potential leak rates can be predicted.

The first such model was developed for explosively expanded joints and consisted of integrating test results from tubes with freespan cracks and from tubes with 360° by 100% throughwall volumetric degradation within the tubesheet. Because the integrated model was analytic instead of testing cracked tubes in simulated tubesheets, the NRC staff required that in situ testing of cracks found within the tubesheet of one operating plant be performed with the intent of obtaining data with which to verify the model. The engineering expectation is that the model would be demonstrated to be conservative simply because the presence of the tubesheet restricts bulging of the tube, and it is that bulging that leads to the dominant portion of the crack opening area. Moreover, the presence of the tubesheet prevents any significant opening of the cracks in the hoop direction because that would necessitate an increase in the diameter of the tube. Hence. it is not surprising that none of the tests have ever resulted in any measurable leakage. In situ tests performed at a plant with hydraulic tube-to-tubesheet joints led to similar results. There was very strong nondestructive examination (NDE) evidence that most of the indications tested were throughwall. Although no tube sections removed for physical examination, one of the indications was judged to be severed within the tubesheet. The NDE result for that tube provides compelling evidence that the tube is indeed severed. There was also no primary-to-secondary operating leakage at that plant prior to the refueling outage in which the degradation was discovered and tested.

The NRC staff responded to the in situ test information by noting that the indication may not have leaked because:

(a) it was not as severe as eddy current data indicated,

(b) the in situ pressure test may be limited in its ability to provide results representative of a SLB, and/or

(c) it does not represent the worst-case scenario.

The staff further opined that while a full-length tube pressure test performed at a pressure of three times the normal operating pressure may result in simulating three times the axial pressure load, it also increases the interface pressure between the tube and the tubesheet by a factor 3. It was also noted that the in situ pressure test does not include the effect of the tubesheet bow that is present during normal operating or postulated accident conditions. The comment was made that an ideal test would result in the more limiting of the following conditions:

(a) imparting 3 times the axial load on the tube at normal operating pressure and temperature with a hole dilation consistent with that observed during normal operation; or

(b) imparting 1.4 times the axial loads on the tube at the SLB differential pressure and temperature with a hole dilation consistent with that observed during a SLB.

These postulated ideal test conditions correspond to the expected conditions during normal operation of the plant or during a postulated SLB event. Such conditions cannot be duplicated for testing in situ. The temperature of operation is on the order of 600°F and the tubesheet bow occurs because of the pressure difference that exists from the primary to secondary faces of the tubesheet. The differential pressure during normal operation is on the order of 1300 psid and about 2560 psid during a postulated SLB event.

There are two reasons for performing in situ tests; to ascertain whether or not condition monitoring structural requirements were met by degraded tubes and whether or not condition monitoring leak rate requirements were met by those same degraded tubes. For degradation within the tubesheet the structural requirements are inherently satisfied and the only purpose of such testing is with regard to leak rate requirements. For circumferential degradation the in situ tests may be performed with the intent of demonstrating compliance with structural and/or leak rate requirements. If the degradation is located below the specified H* distance there is no rationale for performing in situ tests aimed at demonstrating structural adequacy because the such has already been demonstrated in determining the value to be used for H*.

For circumferential degradation located above the H* elevation within the tubesheet the demonstration of structural adequacy can be best effected by determining the circumferential extent of the degradation and calculating the strength of any remaining ligaments. Structural in situ tests should only be considered in the unlikely event that the analysis fails to confirm that the structural requirement was met. An appropriate test in that circumstance would need to be performed with a part-tube testing tool capable of imparting a tensile axial load in the tube without pressurizing the inside of the tube to the extent that the test would be invalidated for reasons cited in the NRC staff query. It is not known whether or not a test tool capable of apply an axial load to the tube corresponding to three times the end cap load associated with from normal operation without also applying a radial pressure load to the inside of the tube currently exists. However, because the tube material within the H* region is to be inspected frequently with rotating pancake coil technology the occurrence of such indications may be expected to be extremely rare.

Regardless, the dilation of the tubesheet holes during a postulated SLB event is a function of location on the tubesheet and elevation below the top of the tubesheet. The holes experiencing the most dilation tend to be towards the center of the tubesheet. The holes at tube locations farther than about 46" from the center of the tubesheet contract during a SLB event as a result of tubesheet bow. To quantify the magnitude of the concern expressed by the NRC staff, the results from the finite element model (FEM) analysis of the tubesheet were interrogated. The primary-to-secondary pressure acting on the tubesheet causes it to deflect upwards in the center. This results in tensile hoop and radial stresses above the mid-plane of the tubesheet and compressive stresses below the mid-plane. The effect of the tensile stresses is to dilate or increase the diameter of the tubesheet holes above the mid-plane, reducing the interface pressure between the tube and the tubesheet. A summary of the maximum dilation values as a function of tubesheet elevation is provided in Table D.4. The most appropriate numbers to consider are those for an elevation of 15" or about 6" below the top of the tubesheet (TTS). The dilation during normal operation is about 0.29 mil. The corresponding value during a postulated SLB event is 0.42 mil, or an increase of 0.13 mil.

D.2 INTERFERENCE LOADS

There are four source terms that must be considered relative to the determination of the interface pressure between the tube and the tubesheet. These are,

1. the initial preload from the installation of the tube,
2. internal pressure in the tube that is transmitted from the ID to the OD,
3. thermal expansion of the tube relative to the tubesheet, and
4. bowing of the tubesheet that results in dilation of the tubesheet holes.

The initial preload results from the plastic deformation of the tube material relative to that of the tubesheet. The material on the inside diameter experiences more plastic deformation than the material on the outside and thus has a deformed diameter which is incrementally greater. Equilibrium of the hoop forces and moments in the tube means that the OD is maintained in a state of hoop tension at a diameter greater than a stress free state. The model for the determination of the initial contact pressure between the tube and the tubesheet, P_c, is illustrated on Figure D.2. Both the tube and the tubesheet behave as elastic springs after the expansion process is applied. The normal stress on the tube must be equal in magnitude to the normal stress on the tubesheet and the sum of the elastic springback values experienced by each must sum to the total interference.

As long as the tube and the tubesheet remain in contact the radial normal stresses must be in equilibrium. Thus, the problem of solving for the location of the interface and the contact pressure is determinate. The elements considered in the analysis are illustrated on Figure D.3 for all operating and postulated accident conditions; the centerline of the tube and tubesheet hole are to the left in the figure. Each source of deformation of the tube outside surface starting from the installed equilibrium condition can be visualized starting from the top left side of the figure. The sources of deformation of the tubesheet inside surface can be visualized starting from the lower left side of the figure. As illustrated, although not to scale, the tube material has a coefficient of thermal expansion that is greater than that of the tubesheet. The radial flexibility[3], f, of the tube relative to that of the tubesheet determines how much of the pressure is actually transmitted to the interface between the tube and the tubesheet. Positive radial deformation of the tube in response to an internal pressure is found as the product of the pressure, P_p, and the tube flexibility associated with an internal pressure, discussed in the next section. Thus, the tube gets tighter in the tubesheet hole as the temperature of the tube and tubesheet increase. The deformation of the tube in response to an external pressure, P_s, is the product of the pressure times the flexibility associated with an external pressure. The normal operation contact pressure, P_N, is found from compatibility and equilibrium considerations. The deformation of the tubesheet hole in response to an internal pressure, P_s, is found as the product of the pressure and the flexibility of the tubesheet associated with an internal pressure. The opening or closing of the tubesheet hole, δr_i, resulting from bow induced by the primary-to-secondary pressure difference is in addition to the deformations associated with temperature and internal pressure.

[3] Flexibility is the ratio of deformation to load and is the inverse of the stiffness.

Once the tube has been installed, the deformations of the tube and tubesheet associated thermal expansion, internal pressure, and tubesheet bow remain linearly elastic.

Because of the potential for a crack to be present and the potential for the joint to be leaking, the pressure in the crevice is assumed to vary linearly from the primary pressure at the crack elevation to the secondary pressure at the top of the tubesheet. If the joint is not leaking, it would be expected that there was no significant fluid pressure in the crevice. The pressure assumption is considered to be conservative because it ignores the pressure drop through the crack, and the leak path is through the crevice will not normally be around the entire circumference of the tube. In addition, the leak path is believed to be between contacting microscopic asperities between the tube and the tubesheet, thus the pressure in the crevice would not be acting over the entire surface area of the tube and tubesheet. In any event, pressure in the crevice is always assumed to be present for the analysis.

There is no bow induced increase in the diameter of the holes during normal operation or postulated accident conditions above the mid span elevation within the tubesheet, hence most analyses concentrate on locations near the top of the tubesheet. The tubesheet bow deformation under postulated accident conditions will increase because of the larger pressure difference between the bottom and top of the tubesheet. The components remain elastic and the compatibility and equilibrium equations from the theory of elasticity remain applicable. Below the mid span elevation within the tubesheet the tubesheet holes will contract. The edges of the tubesheet are not totally free to rotate and there is some suppression of the contraction near the outside radius. This also means that the dilation at the top of the tubesheet is also suppressed near the outside radius of the tubesheet. The maximum hole dilations occur near the center of the tubesheet.

The application of the theory of elasticity means that the individual elements of the analysis can be treated as interchangeable if appropriate considerations are made. The thermal expansion of the tube can be thought of as the result of some equivalent internal pressure by ignoring Poisson effects, or that tubesheet bow could be analytically treated as an increase in temperature of the tubesheet while ignoring associated changes in material properties.

D.3 FLEXIBILITY

Flexibility, f, is defined as the ratio of deflection relative to applied force. It is the inverse of stiffness which commonly used to relate force to deformation. There are four flexibility terms associated with the radial deformation of a cylindrical member depending on the surface to which the loading is applied and the surface for which the deformation is being calculated, e.g., for transmitted internal pressure one is interested in the radial deformation of the OD of the tube and the ID of the tubesheet. The deformation of the OD of the tube in response to external pressure is also of interest. The geometry of the tube-to-tubesheet interface is illustrated on Figure 1. The flexibility of the tubesheet, designated herein by the subscript c, in response to an internal pressure, P_{ci}, is found as,

a,c,e

[ ] *Tubesheet (1)*

where, r_{ci} = inside radius of the tubesheet and outside radius of the tube,
r_{co} = outside radius of the tubesheet hole unit cell,
E_c = the elastic modulus of the carbon steel tubesheet material, and
υ = Poisson's ratio for the tubesheet material.

Here, the subscripts on the flexibility stand for the component, *c* for tubesheet (and later *t* of tube), the surface being considered, *i* for inside or *o* for outside, and the surface being loaded, again, *i* for inside and *o* for outside. The superscript designates whether the cylinder is open, *o*, or closed, *c*, of interest in dealing with the tube. The former case is a state of plane stress and the latter is not since a closed cylinder has an end cap load. The flexibility of the tube in response to the application of an external pressure, P_{ro}, e.g., the contact pressure within the tubesheet, is,

a,c,e

[ ] *Open Tube (2)*

Poisson's ratio is the same for the tube and the tubesheet. When the external pressure can act on the end of the tube,

a,c,e

[,] *Closed Tube (3)*

where E_t is the elastic modulus of the tube material. The flexibility of the tube in response to an external pressure is different when the secondary side pressure is present because that pressure also acts to compress the tube in the axial direction giving rise to a Poisson expansion effect, resisting the radial compression due to the pressure.

Finally, the flexibility of the outside radius of the tube in response to an internal pressure, P_{ti}, is,

a,c,e

[ ] *Closed Tube (4)*

where r_{ti} is the internal radius of the tube and the tube is assumed to be closed. For an open tube the term in parentheses in the numerator is simply 2. A closed tube expands less due to Poisson contraction associated with the end cap load from the internal pressure. A summary of the applicable flexibilities is provided in Table D.2. Note that during normal operation there is an end cap load on the tube from the secondary pressure but not from that associated with the fluid in the crevice if the joint is leaking. Both flexibilities would then be involved in calculating the radial deformation of the outside of the tube. Only the open tube flexibility is used with the pressure in the crevice for postulated accident conditions.

When the inside of the tube is pressurized, P_{ti}, some of the pressure is absorbed by the deformation of the tube within the tubesheet and some of the pressure is transmitted to the OD of the tube, P_{to}, as a contact pressure with the ID of the tubesheet. The magnitude of the transmitted pressure is found by considering the relative flexibilities of the tube and the tubesheet as,

a,c,e

[ ] (5)

Note that the tube flexibility in response to the contact pressure is for an open tube because there is no end cap load associated with the contact pressure. The denominator of the fraction is also referred to as the interaction coefficient between the tube and the tubesheet. About 85 to 90% of the pressure internal to the tube is transmitted through the tube in Westinghouse designed SGs. However, the contact pressure is not increased by that amount because the TS acts as a spring and the interface moves radially outward in response to the increase in pressure. The net increase in contact pressure is on the order of 56.4% of the increase in the internal pressure. For example, the contact pressure between the tube and the tubesheet is increased by about 1970 psi during normal operation relative to ambient conditions. Likewise, the increase in contact pressure associated with SLB conditions is about 2250 psi relative to ambient conditions.

When the temperature increases from ambient conditions to operating conditions the differential thermal expansion of the tube relative to the tubesheet increases the contact pressure between the tube and the tubesheet. The mismatch in expansion between the tube and the tubesheet, δ, is given by,

$$\delta = \left(\alpha_t \, \Delta T_t - \alpha_c \, \Delta T_c\right) r_{to} \qquad \textit{Thermal Mismatch} \quad (6)$$

where: α_t, α_c = thermal expansion coefficient for the tube and tubesheet respectively,
ΔT_t, ΔT_c = the change in temperature from ambient conditions for the tube and tubesheet respectively.

During normal operation the temperature of the tube and tubesheet or effectively identical to within a very short distance from the top of the tubesheet and the individual changes in temperature can usually be replaced by ΔT_t, thus,

$$\delta = \left(\alpha_t - \alpha_c\right)\Delta T_t b \, . \quad (7)$$

The change in contact pressure due to the increase in temperature relative to ambient conditions, P_T, is given by,

a,c,e

[ ] (8)

Likewise, the same equation can be used to calculate the reduction in contact pressure resulting from a postulated reduction the temperature of the tube during a postulated SLB event.

The net contact pressure, P_C, between the tube and the tubesheet during operation or accident conditions is given by,

Net Contact Pressure $$P_C = P_0 + P_P + P_T - P_B \quad (9)$$

where P_B is the loss of contact pressure due to dilation of the tubesheet holes, P_0 is the installation preload, P_P is the pressure induced load, and P_T is the thermal induced contact load. There is one additional term that could be considered as increasing the contact pressure. When the temperature increases the tube expands more in the axial direction than the tubesheet. This is resisted by the frictional interface between the tube and the tubesheet and a compressive stress is induced in the tube. This in turn results in a Poisson expansion of the tube radius, increasing the interface pressure. The effect is not considered to be significant and is essentially ignored by the analysis.

D.4 ANALYSIS

From the preceding discussions it is apparent that the contact pressure during normal operation can be found by equating the total deformation of the outside radius of the tube, r_{to}, to the total deformation of the inside radius of the tubesheet hole, r_{ci}, where the net deformation of the outside of the tube, δ_{to}, is given by,

Tube Deformation $$\delta_{to} = \alpha_t \Delta T_t r_{to} + P_p f_{toi}^c + P_s f_{too}^c + P_N f_{too}^o \tag{10}$$

and the net deformation of the tubesheet hole, δ_{ci}, is given by,

TS Deformation $$\delta_{ci} = \alpha_c \Delta T_c r_{ci} + P_s f_{cii}^o + \delta r_i + P_N f_{cii}^o . \tag{11}$$

The inclusion of the P_N terms assures compatibility and the two net deformations must be equal. It can usually be assumed that the secondary fluid pressure does not penetrate the tubesheet hole and the terms involving P_s may be ignored. All of the terms except for the final contact pressure, P_N, are known and the tubesheet bow term, δr_i, is found from the finite element model analysis of the tubesheet. The total contact pressure during operation is then found as P_N plus P_c, the installation contact pressure. For postulated SLB conditions the solution is obtained from,

$$\alpha_t \Delta T_t r_{to} + P_p f_{toi}^c + P_N f_{too}^o = \alpha_c \Delta T_c r_{ci} + \delta r_i + P_N f_{cii}^o , \tag{12}$$

or, the total contact pressure during a postulated SLB event is given by,

SLB Contact Pres. $$P_T = P_c + \frac{\alpha_t \Delta T_t r_{to} - \alpha_c \Delta T_c r_{ci} + P_p f_{toi}^c - \delta r_i}{f_{cii}^o - f_{too}^o} , \tag{13}$$

where $r_{to}=r_{ci}$. A similar expression with more terms is used to obtain the contact pressure during normal operation. The denominator of the above equation is referred to as the tube-to-tubesheet influence coefficient because it related deformations associated with the interfacing components to the interface pressure. The influence coefficient for Westinghouse Model F SG tubes is calculated using the information tabulated in Table D.2 as $3.33 \cdot 10^{-6}$ psi/inch.

By taking partial derivatives with respect to the various terms on the right the rate of change of the contact pressure as a function of changes in those parameters can be easily calculated. For example, the rate of change of the contact pressure with the internal pressure in the tube is simply,

$$\frac{\Delta P_N}{\Delta P_p} = \frac{f_{toi}^c}{f_{cii}^o - f_{too}^o} . \tag{14}$$

Thus, the rate of change of contact pressure with internal pressure in the tube is 0.564 psi/psi. Likewise, the rate of change of the contact pressure with change in the tube temperature or tubesheet temperature is given by,

$$\frac{\Delta P_N}{\Delta T_t} = \frac{\alpha_t r_{to}}{f^o_{cii} - f^o_{too}} \text{ and } \frac{\Delta P_N}{\Delta T_c} = -\frac{\alpha_c r_{ci}}{f^o_{cii} - f^o_{too}}, \tag{15}$$

respectively. Again using the values in Table D.2, the rate of change of contact pressure with tube temperature is 18.3 psi/°F if there is no increase in tubesheet temperature. The corresponding change with an increase in tubesheet temperature without an increase in tube temperature is –17.36 psi/°F leave a net increase in contact pressure of 0.94 psi/°F with a uniform increase in temperature of the tube and the tubesheet.

Finally, the rate of change of contact pressure with tubesheet bow is calculated as,

$$\frac{\Delta P_N}{\Delta \delta r_{ci}} = \frac{1}{f^o_{cii} - f^o_{too}}. \tag{16}$$

The effect of the dilation associated with the tubesheet bow can be calculated using the information tabulated in Table 2. For each 0.1 mil of diameter dilation the interface pressure is reduced on the order of 380 psi. A summary of all of the contact pressure influence factors is provided in Table 3. A summary of tubesheet bow induced hole dilation values is provided in Table 4.

D.5 IN SITU TESTING

Eddy current information pertaining to the most severe indication in the Callaway SGs is provided as Figure 4. The indication at 10.26" is so large that it almost appears to be background to the figure itself. There is no question that the non-destructive examination information indicates that not only is the indications throughwall, but it is throughwall for 360°. Considering that the image looks like that of a tube end, there is no doubt that the indication is less severe than indicated.

D.5.1 IN SITU LEAK TESTING PRESSURE

The NRC staff has queried whether or not in situ leak rate testing at the maximum SLB differential pressure would be conservative relative to testing at a lower pressure. The intuitive expectation would be that increasing the pressure will always result in an increase in the leak rate. However, an evaluation was performed using the information available from the leak rate testing program and the structural analysis of the tube-to-tubesheet joint. The leak rate testing demonstrated that the leak rate could be correlated to the primary-to-secondary pressure gradient as,

$$Q = \frac{1}{\mu K}\frac{\Delta P}{L} \tag{17}$$

where the pressure gradient, ΔP, through the crevice is assumed to be approximately linear, L is the length of the joint, μ is the viscosity of the fluid, and K is a loss coefficient obtained from the analysis of the test data. The results for the testing program were that the loss coefficient was related to the joint contact pressure, P_c, as,

$$K = a_0 \ e^{a_1 P_c} \tag{18}$$

where $a_0$and a_1 are obtained from a regression analysis of the data. Noting that the contact pressure can be expressed as a function of the internal pressure in the tube as $P_c = \xi P_i$, the derivative of the leak rate with respect to the internal pressure becomes,

$$\frac{dQ}{dP_i} = \frac{a_0}{\mu L} e^{-a_1 \xi P_i} \left(1 - a_1 \xi P_i\right). \tag{19}$$

Hence, the leak rate increases with pressure if the term in parentheses is positive and decreases if the term is negative because the intercept coefficient is positive. The value of ξ was calculated to be 0.564 psi/psi for the Model F tube-to-tubesheet joint (see the previous discussion). The analysis for the loss coefficient obtained a nominal value for the slope of the regression equation of $7.486 \cdot 10^{-4}$ with a standard deviation of $8.139 \cdot 10^{-5}$ for leak rate data at 600°F. The slope of the leak rate changes from positive to negative at an internal pressure of 2370 psig using the nominal value for the slope. This result is counter to expectation and is an artifact of the approach taken to add conservatism to the analysis. The loss coefficient equation results from the regression analysis of test data obtained from specimens tested at 70 and 600°F. Because it is impractical to try obtain high temperature, low contact pressure test data, and such data were not available for the analysis, the low temperature, low contact pressure test data were used to anchor the left end of the curve. This means that the slope of the curve was artificially increased in order to underestimate the loss coefficient and overestimate the attendant calculated leak rate at lower contact pressures. The pressure at which the slope of the leak rate in Equation 19 becomes negative increases to 3950 psi when the 70°F data are removed from the regression analysis. The corresponding value for an upper 95% confidence bound on the slope is 2780 psi. These latter results indicate that in situ leak rate testing at 2560 psi provides results in measured values that are greater than those at lower pressures. The loss coefficient data that were obtained from room temperature testing exhibited little dependence on the internal pressure in the tube and there was no indication that the leak rate could be higher at a lower pressure, i.e., the driving pressure term in Equation 17 dominates the determination of the leak rate.

D.5.2 EFFECT OF TUBESHEET BOW ON LEAK RATE TESTING

In situ leak rate tests are conducted at ambient conditions and there is no differential pressure across the tubesheet. Thus, there are two conditions that are atypical of normal operating and postulated accident conditions. In summary, the increase in temperature tends to make the joint tighter, and the increase in differential pressure across the tubesheet tends to make the joint looser. In addition, for structural integrity testing the increase in pressure internal to the tube will act to tighten the joint and increase the strength of the joint. Thus, the act of testing may bias the results in a nonconservative manner. However, it is likely that structural in situ testing of tubesheet indications will be very infrequently indicated because of the ease with which the strength of the joint can be demonstrated analytically. It is desired to obtain information regarding the tendency of one condition to compensate for the other with regard to leak rate testing. Because the bowing dilation decreases with depth, being effectively zero at the mid plane of the tubesheet, ambient conditions are conservative at that elevation. A summary of pressure changes with tubesheet bow between normal operation and postulated accident conditions is provided in Table 4.

For example, in situ testing at a differential pressure of 2560 psi results in an increase in the contact pressure between the tube and the tubesheet of about 1640 psi. For a R18C77 tube, at about 24" from the center of the tubesheet, the contact pressure at the mid span of the tubesheet increases by about 2200 psi. During normal operation the contact pressure increase is about 1700 psi. However, at the top of the tubesheet the contact pressure during a postulated SLB event increases by only about 235 psi relative to ambient conditions, i.e., the leak path is less resistant than during an in situ leak test. This observation brings into question the validity of in situ leak testing for indications located within the tubesheet.

Although the actual measurements cannot be directly related to performance during operation, the results from the tests performed to characterize the leak resistance of the joint do provide an indirect validation of the results of in situ tests in which none of the joints leaked. The length of the joints for those tests was greater than 16" and the tests were performed at elevated temperature. As noted, the eddy current depiction of the R18C77 tube is provided on Figure D.4. There can be no doubt that the tube is severed at a depth of 10.3". The contact pressure during the in situ leak test was about 2140 psi while the contact pressure during the laboratory tests was about 2700 psi. Thus, the in situ leak test provided a similar pressure drop in the presence of significantly less contact pressure. The test of the R18C77 tube resulted in no measurable leak rate while all of the laboratory specimens, with longer engaged lengths, leaked.

D.6 CONCLUSIONS

The results of this evaluation indicate that in situ structural testing is not likely to be meaningful in demonstrating compliance with performance criteria, i.e., demonstrating a resistance to pullout of greater than three times the normal operating pressure difference. Moreover, the difference in contact pressure during in situ testing means that the leak rate data cannot be used directly to quantify potential leak rates. This does not mean that an analytic procedure could not be developed to deal with such quantification, that is the basis for correlating the leak rate to the inverse of the loss coefficient and further correlating the loss coefficient to the contact pressure between the tube and the tubesheet.

The results listed in Table D.4 indicate that the effect of bow can result in a significant average decrease in the contact pressure during postulated accident conditions for Model F SG tubes. For the most severe indication in the Callaway SGs, i.e., R18C77, in situ testing resulted in no measurable leakage. However, the contact pressure during the performance of the in situ test was meaningfully less than the contact pressure present when the laboratory leak rate tests were performed, all of which leaked. Thus, the leak rate tests performed in situ are relevant to demonstrating whether or not an indication leaks. Although the leak rate from a leaking indication may not lend itself to a precise quantified prediction of the leak rate during operation, it can be used to estimate whether or not the leak rate would be significant during operation or postulated accident conditions.

a,c,e

a,c,e

a,c,e

a.c.e

a,c,e

Figure D.3: Determination of Contact Pressure, Normal or Accident Operation

(As illustrated, the bow does not result in a loss of contact, however, there are situations where the bow is sufficient to result in a loss of contact between the tube and the tubesheet at the top of the tubesheet.)

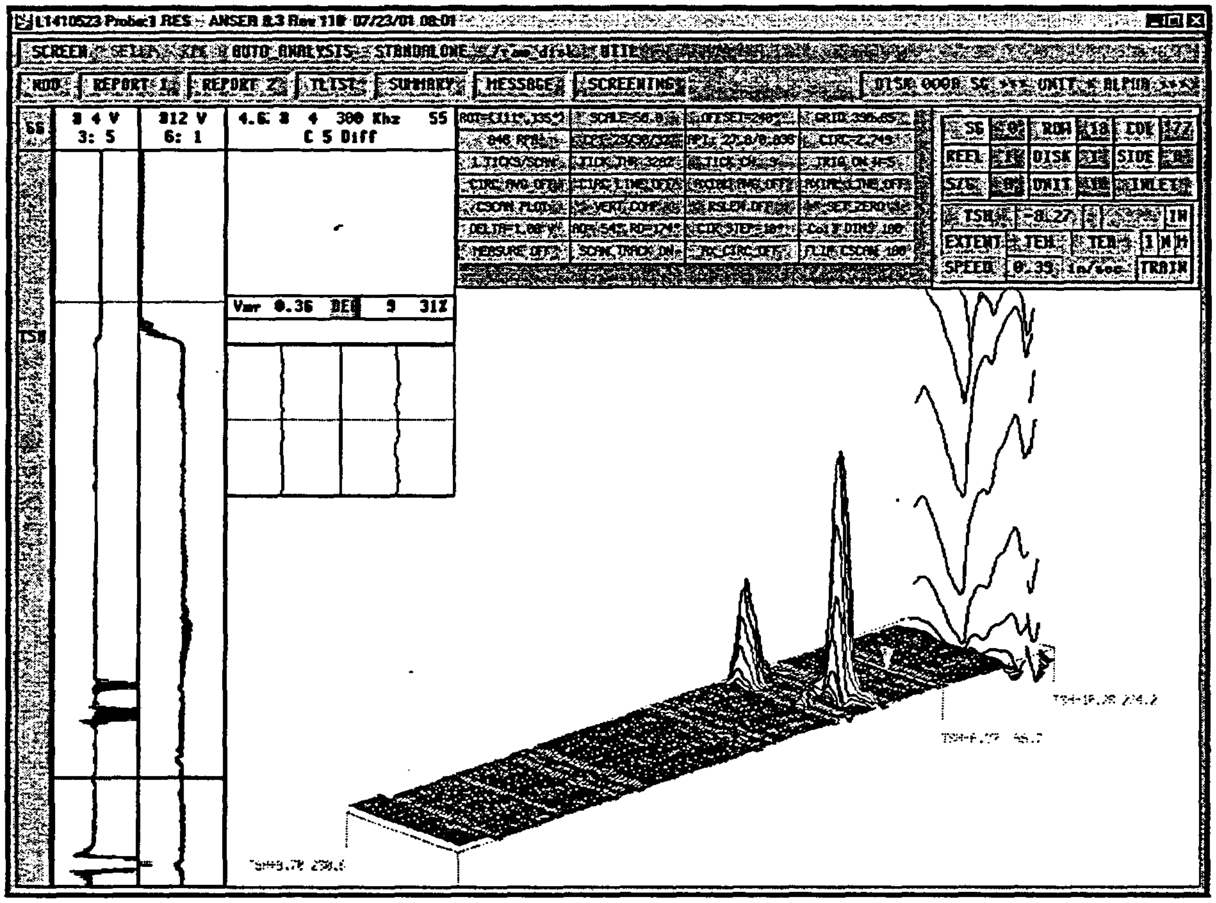

Figure D.4: Severed Tube Eddy Current Image (at 10.26")

ATTACHMENT 3c
ULNRC 04861
CALLAWAY PLANT

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Our ref: CAW-03-1650

June 3, 2003

APPLICATION FOR WITHHOLDING PROPRIETARY INFORMATION FROM PUBLIC DISCLOSURE

Subject: WCAP-15932-P, Rev. 1, "Improved Justification of Partial Length RPC Inspection of Tube Joints of Model F Steam Generators of AmerenUE Callaway Plant (Proprietary)

The proprietary information for which withholding is being requested in the above-referenced report is further identified in Affidavit CAW-03-1650 signed by the owner of the proprietary information, Westinghouse Electric Company LLC. The affidavit, which accompanies this letter, sets forth the basis on which the information may be withheld from public disclosure by the Commission and addresses with specificity the considerations listed in paragraph (b)(4) of 10 CFR Section 2.790 of the Commission's regulations.

Accordingly, this letter authorizes the utilization of the accompanying affidavit by AmerenUE.

Correspondence with respect to the proprietary aspects of the application for withholding or the Westinghouse affidavit should reference this letter, CAW-03-1650 and should be addressed to the undersigned.

Very truly yours,

H. A. Sepp, Manager
Regulatory Compliance and Plant Licensing

Enclosures

cc: S. J. Collins
D. Holland
B. Benney

CAW-03-1650

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF ALLEGHENY:

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

H. A. Sepp

H. A. Sepp, Manager
Regulatory Compliance and Plant Licensing

Sworn to and subscribed
before me this 3rd day
of June, 2003

Sharon L. Fiori
Notary Public

SHARON L. FIORI
COMMONWEALTH OF PENNSYLVANIA
NOTARY PUBLIC

Notarial Seal
Sharon L. Fiori, Notary Public
Monroeville Boro, Allegheny County
My Commission Expires January 29, 2007
Member, Pennsylvania Association Of Notaries

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

(2) I am making this Affidavit in conformance with the provisions of 10 CFR Section 2.790 of the Commission's regulations and in conjunction with the Westinghouse application for withholding accompanying this Affidavit.

(3) I have personal knowledge of the criteria and procedures utilized by the Westinghouse Electric Company LLC in designating information as a trade secret, privileged or as confidential commercial or financial information.

(4) Pursuant to the provisions of paragraph (b)(4) of Section 2.790 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld.

(i) The information sought to be withheld from public disclosure is owned and has been held in confidence by Westinghouse.

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

Under that system, information is held in confidence if it falls in one or more of several types, the release of which might result in the loss of an existing or potential competitive advantage, as follows:

(a) The information reveals the distinguishing aspects of a process (or component, structure, tool, method, etc.) where prevention of its use by any of

Westinghouse's competitors without license from Westinghouse constitutes a competitive economic advantage over other companies.

(b) It consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), the application of which data secures a competitive economic advantage, e.g., by optimization or improved marketability.

(c) Its use by a competitor would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing a similar product.

(d) It reveals cost or price information, production capacities, budget levels, or commercial strategies of Westinghouse, its customers or suppliers.

(e) It reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

(f) It contains patentable ideas, for which patent protection may be desirable.

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

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

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

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

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

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

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

(iii) The information is being transmitted to the Commission in confidence and, under the provisions of 10 CFR Section 2.790, it is to be received in confidence by the Commission.

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

(v) The proprietary information sought to be withheld in this submittal is that which is appropriately marked in WCAP-15932-P, Rev. 1, "Improved Justification of Partial Length RPC Inspection of Tube Joints of Model F Steam Generators of AmerenUE Callaway Plant" (Proprietary), dated May 2003. The information is provided in support of a submittal to the Commission, being transmitted by the AmerenUE letter and Application for Withholding Proprietary Information from Public Disclosure, to the Document Control Desk. The proprietary information as submitted for use by Westinghouse Electric Company LLC for the Callaway Plant is expected to be applicable for other licensee submittals in response to certain NRC requirements for justification of a reduction of rotating pancake coil (RPC) inspection length of Model F steam generator tubes within the tubesheet from full-length to partial length.

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

(a) Justify the use of the H* criterion as a basis for limiting the length of eddy current inspection of hydraulically expanded tubes in the tubesheet region of steam generators.

(b) Discuss analysis and testing programs used in support of the development of the H* criterion.

Further this information has substantial commercial value as follows:

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

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

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

Public disclosure of this proprietary information is likely to cause substantial harm to the competitive position of Westinghouse because it would enhance the ability of competitors to provide similar licensing support documentation and licensing defense services for commercial power reactors without commensurate expenses. Also, public disclosure of the information would enable others to use the information to meet NRC requirements for licensing documentation without purchasing the right to use the information.

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

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

Further the deponent sayeth not.

PROPRIETARY INFORMATION NOTICE

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

In order to conform to the requirements of 10 CFR 2.790 of the Commission's regulations concerning the protection of proprietary information so submitted to the NRC, the information which is proprietary in the proprietary versions is contained within brackets, and where the proprietary information has been deleted in the non-proprietary versions, only the brackets remain (the information that was contained within the brackets in the proprietary versions having been deleted). The justification for claiming the information so designated as proprietary is indicated in both versions by means of lower case letters (a) through (f) located as a superscript immediately following the brackets enclosing each item of information being identified as proprietary or in the margin opposite such information. These lower case letters refer to the types of information Westinghouse customarily holds in confidence identified in Sections (4)(ii)(a) through (4)(ii)(f) of the affidavit accompanying this transmittal pursuant to 10 CFR 2.790(b)(1).

COPYRIGHT NOTICE

AmerenUE

Letter for Transmittal to the NRC

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

Enclosed are:

1. 2 copies of WCAP-15932-P, Rev. 1, "Improved Justification of Partial Length RPC Inspection of Tube Joints of Model F Steam Generators of AmerenUE Callaway Plant" (Proprietary)

2. 2 copies of WCAP-15932-NP, Rev. 1, "Improved Justification of Partial Length RPC Inspection of Tube Joints of Model F Steam Generators of AmerenUE Callaway Plant" (Non-Proprietary)

Also enclosed are a Westinghouse authorization letter, CAW-03-1650, accompanying affidavit, Proprietary Information Notice, and Copyright Notice.

As Item 1 contains information proprietary to Westinghouse Electric Company, it is supported by an affidavit signed by Westinghouse, the owner of the information. The affidavit sets forth the basis on which the information may be withheld from public disclosure by the Commission and addresses with specificity the considerations listed in paragraph (b) (4) of Section 2.790 of the Commission's' regulations.

Accordingly, it is respectfully requested that the information which is proprietary to Westinghouse be withheld from public disclosure in accordance with 10 CFR Section 2.790 of the Commission's regulations.

Correspondence with respect to the copyright or proprietary aspects of the items listed above or the supporting Westinghouse Affidavit should reference CAW-03-1650 and should be addressed to H. A. Sepp, Manager of Regulatory Compliance and Plant Licensing, Westinghouse Electric Company, P.O. Box 355, Pittsburgh, Pennsylvania 15230-0355.

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

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ATTACHMENT 5
ULNRC-04861
CALLAWAY PLANT

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CALLAWAY DATA

"A" S/G: Tube: 25 - 71

RPC: **SG1AHCAL00069 and SG1AHCAL00073**

Bobbin: **SG1ACCAL00060 and SG1AHCAL00059**

"C" S/G: Tube 18 - 77

RPC: **SG1CHCAL00006 and SG1CHCAL00076**

Bobbin: **SG1CCCAL00040** ***(April 2001 Data)***

"C" S/G: Tube 21 - 101

RPC: **SG1CHCAL00044 and SG1CHCAL00076**

Bobbin: **SG1CCCAL00043** ***(April 2001 Data)***

"C" S/G: Tube 29 - 69

RPC: **SG1CHCAL00007 and SG1CHCAL00081**

Bobbin: **SG1CCCAL00051** ***(April 2001 Data)***

"D" S/G: Tube 42 - 57

RPC: **SG1DHCAL00049 and SG1DHCAL00055**

Bobbin: **SG1DCCAL00013**

All primary, secondary, and resolution setups are provided for each calibration group. Calibration standard drawings are provided.

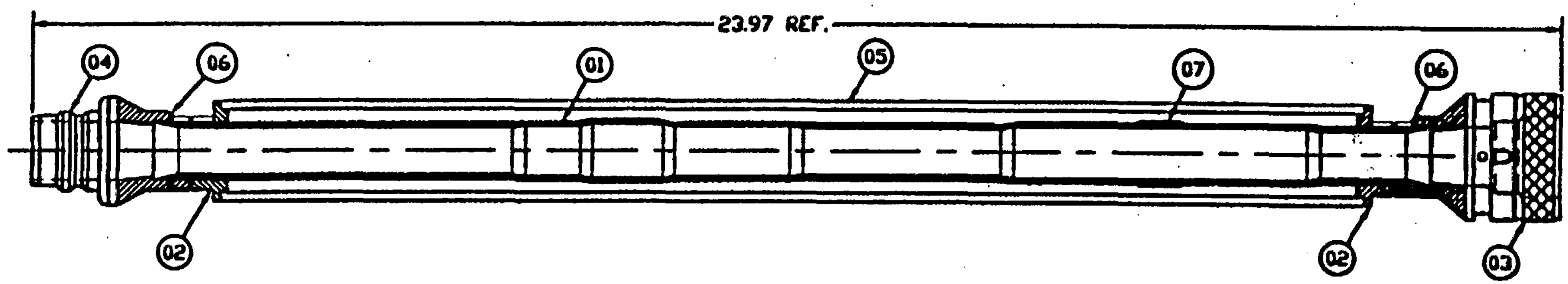
All raw data was acquired during the November 2002 outage unless otherwise noted.

BILL OF MATERIAL

GROUP 03	GROUP 02	GROUP 01	ITEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MATL SIZE CO PART NUMBER OR REF DWG
		1	01		STANDARD		11/16" X .040 TUBE/.580 X .035 SLEEVE	1B79057G0
		2	02		TUBING END CAP		11/16" TUBING	1B79327H1
		1	03		FEMALE COUPLER		11/16" TUBING	1B79327G0
		1	04		MALE COUPLER		11/16" TUBING	1B79327G0
		1	05		TUBING		1.5" X .125" WALL (CLEAR) LEXAN	
		2	06	A	RETAINING RING		11/16" DIA X .04 THK ST. STEEL. 02-68	
		1	07	B	MARKER TAG		WHT W/ BLK CHARACTERS .25 PT MAX. #2141516	

VENDORS:

A: WINFRED M. BERG INC, E.ROCKAWAY, NY 11518
B: KROY CORP., SCOTTSDALE, AZ 85261



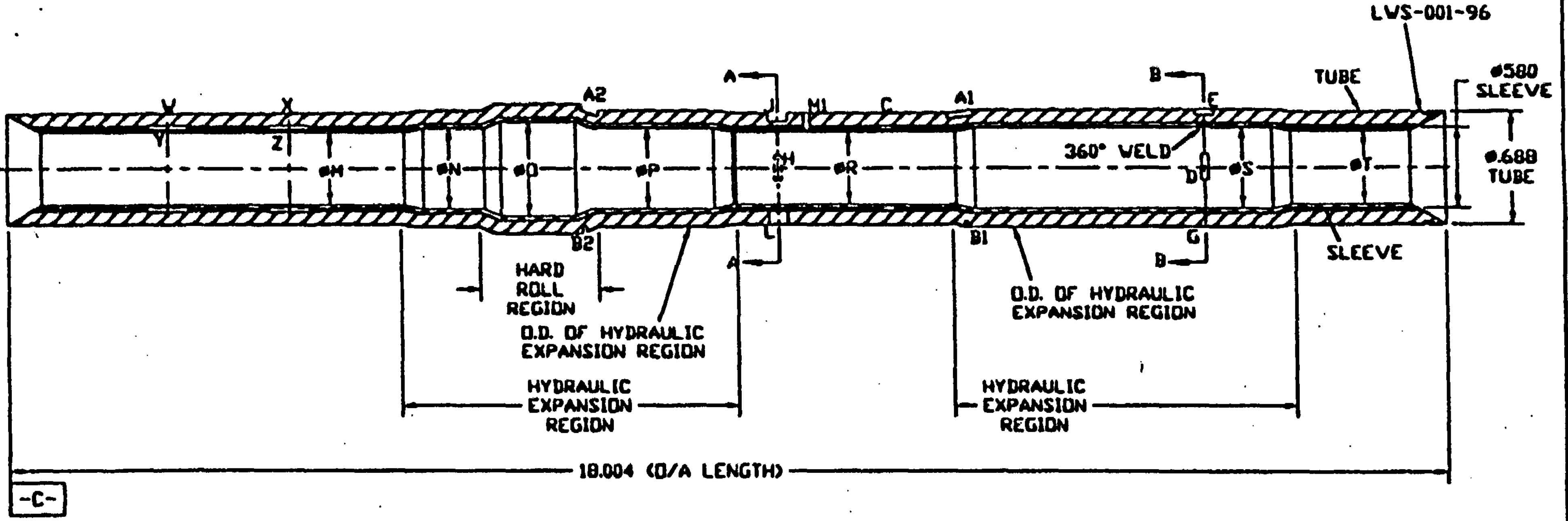
Westinghouse Electric Corporation
NUCLEAR SERVICES DIVISION - MADISON, PA, USA

LASER WELDED SLEEVE
STANDARD ASSEMBLY
(AS-BUILT) (11/16)

AJF 3/31/98

B | 1B80299 | 3/4:1 | 1 of 3

1 REVISION



TUBE
MATERIAL: INCONEL 600
SPECIFICATION: SB-163
SERIAL NO.: LWS-001-96
HEAT NO.: NX 9815
AVG. WALL THICKNESS: .038

SLEEVE
MATERIAL: INCONEL 690
SPECIFICATION: PS803145O REV.B
SERIAL NO.: LWS-001A-96
HEAT NO.: NX 8959
AVG. WALL THICKNESS: .035

CHARACTERIZATION FREQ.: 100KHZ-310KHZ
WORK ORDER NO.: 181175

NR N/A
DN N/A

SECTION A-A

SECTION B-B (CONTAINS 360° WELD)

NUCLEAR SERVICES DIVISION
MADISON, PA, USA

AJF 3/31/96 B 1B80299 0
1:1 2 3

DETAIL LOC.	A1	B1	C	M1	A2	B2	W	X	Y	Z	D	E	F	G	H	J	K	L
DETAIL TYPE	NOTCH	NOTCH	NOTCH	HOLE	NOTCH	GROOVE	GROOVE	GROOVE	GROOVE	GROOVE	NOTCH	NOTCH	NOTCH	HOLE	NOTCH	NOTCH	NOTCH	NOTCH
ORIENTATION	AXIAL	CIRC	CIRC	N/A	AXIAL	CIRC	CIRC	CIRC	CIRC	CIRC	CIRC	AXIAL	CIRC	FT BOT	CIRC	AXIAL	CIRC	AXIAL
DEPTH	.025	.022	.004	THRU	.024	.023	.007	.014	.008	.014	.017	.024	.022	THRU	.018	.021	THRU	THRU
DEPTH % OF (1) AVG. WALL TK.	66% P	58% P	11% S	100% B	63% P	61% P	18% P	37% P	23% S	40% S	49% S	63% P	58% P	100% S	47% P	55% P	100% P	100% P
WIDTH	.006	.005	.127	.052	.006	.005	.500	.500	.500	.500	.005	.005	.006	.033	.005	.006	.006	.006
LENGTH	.250	.251	360°	N/A	.250	.250	360°	360°	360°	360°	.250	.250	.251	N/A	.250	.251	.251	.251
LOCATION FROM DATUM -C-	7.228	7.228	12.000	11.000	13.500	13.500	2.000	3.500	2.000	3.500	15.000	15.000	15.000	15.000	10.000	10.000	10.000	10.000

Weld Area Unexpanded

NOTE:

1. P, S AND B REFER TO PARENT TUBE, SLEEVE AND BOTH, RESPECTIVELY.

MEASURED DIMENSIONS			
DIA.	0°	90°	AVG.
⌀H	.510	.510	.510
⌀N	.545	.545	.545
⌀O	.555	.555	.555
⌀P	.546	.546	.546
⌀R	.510	.510	.510
⌀S	.545	.545	.545
⌀T	.510	.510	.510

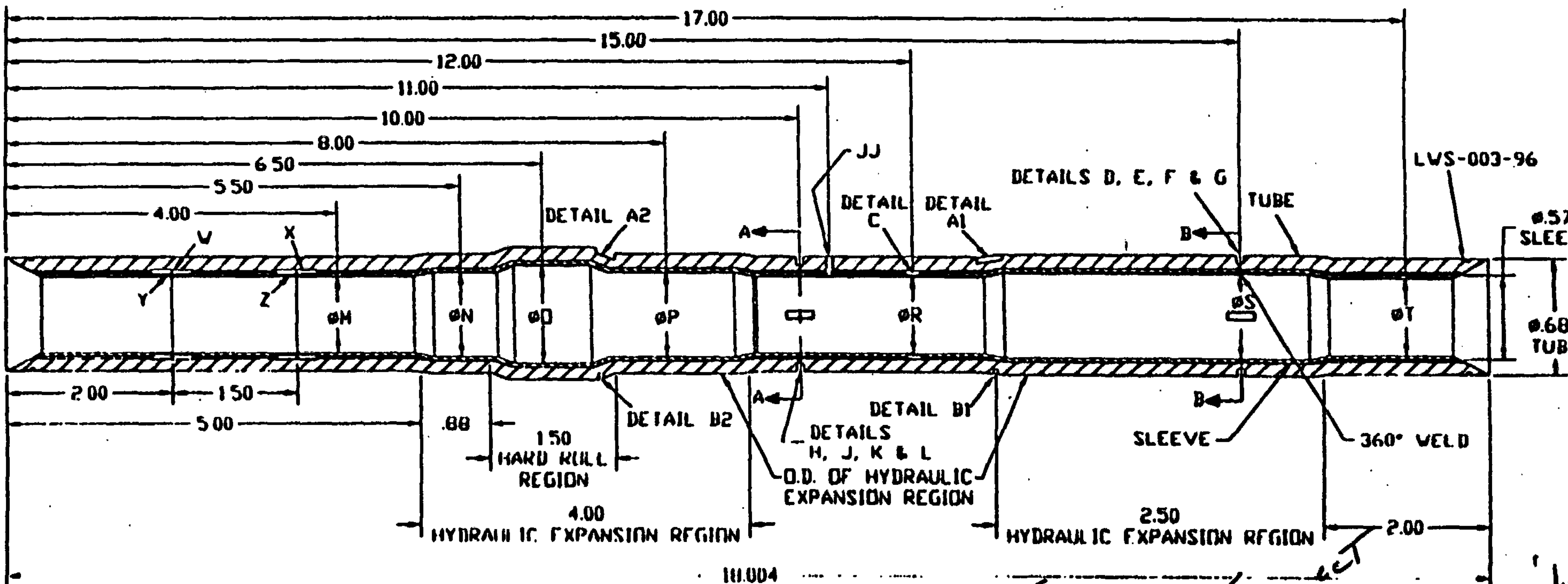
NUCLEAR SERVICES DIVISION MADISON, PA. USA

A.J.F. 3/31/90 B

1:1

1B80299

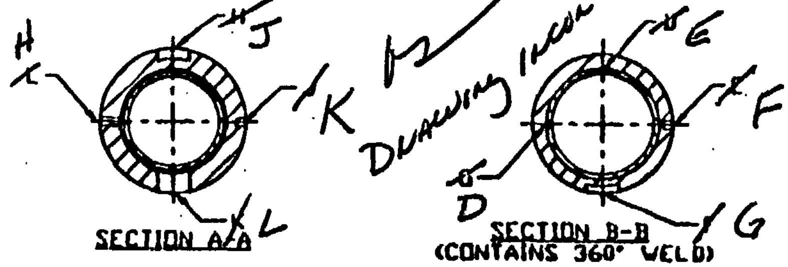
3 of 3



TUBE
MATERIAL: INCONEL 600
SPECIFICATION SB 163
SERIAL NO: LWS-003-96
HEAT NO: NX9815
AVG. WALL THICKNESS: .038

SLEEVE
MATERIAL: INCONEL 690
SPECIFICATION: PS00314SD REV. B
SERIAL NO: LWS-003A-96
HEAT NO: NX8959
AVG. WALL THICKNESS: .035

CHARACTERIZATION FREQ: 630KHZ
WORK ORDER NO: 470034



K B2 Drawing incorrect

Verified visually 10/7/99

JEB	9/4/96
[signature]	9/16/96
[signature]	9/16/96
[signature]	9/16/96
[signature]	9/6/96

Westinghouse Electric Corporation
NUCLEAR SERVICES DIVISION – MADISON, PA, USA

LASER WELDED SLEEVE STANDARD (AS-BUILT)

B | 1B79683 | 1
SCALE 1:1 | SHEET 1 OF 2

DSPEC 340 | REVISION 1

4 3 2 1

DETAIL LOC	A1	B1	C	JJ	A2	B2	W	X	Y	Z	D	E	F	G	H	J	K	L
DETAIL TYPE	NOTCH	NOTCH	NOTCH	HOLE	NOTCH	GROOVE	GROOVE	GROOVE	GROOVE	GROOVE	NOTCH	NOTCH	NOTCH	HOLE	NOTCH	NOTCH	NOTCH	NOTCH
ORIENTATION	AXIAL	CIRC	CIRC	N/A	AXIAL	CIRC	CIRC	CIRC	CIRC	CIRC	CIRC	AXIAL	CIRC	FT BOT	CIRC	AXIAL	CIRC	AXIAL
DEPTH	.024	.023	.004	THRU	.023	.022	.008	.016	.007	.014	.016	.022	.022	THRU	.019	.019	THRU	.037
DEPTH % OF ① AVG. WALL TK	63%P	61%P	11%S	100%B	61%P	58%P	21%P	42%S	20%S	40%S	46%S	58%P	58%P	100%S	50%P	50%P	100%P	97%P
WIDTH	.006	.005	.125	ø.051	.006	.005	.500	.500	.500	.500	.005	.006	.005	ø.032	.005	.005	.006	.006
LENGTH	.251	.251	360°	N/A	.251	.252	360°	360°	360°	360°	.249	.251	.251	N/A	.251	.250	.252	.251

~~HYD EXP~~ ~~WELD AREA~~

NOTE:
1. P, S AND B REFER TO PARENT TUBE, SLEEVE AND BOTH, RESPECTIVELY.

WELD AREA UNEXPANDED

MEASURED DIMENSIONS			
DIA	0°	90°	AVG.
M	.510	.510	.510
N	.547	.546	.547
O	[illegible]	[illegible]	[illegible]
P	.547	.547	.547
R	.510	.510	.510
S	.547	.546	.547
T	.510	.510	.510

B

A

NUCLEAR SERVICES DIVISION
MADISON, PA, USA

JEB 9/4/96
[illegible] 9/16/96

B

1B79683 1

1:1

2 2

DWG NO 1280785 B

FRAMATOME TECHNOLOGIES

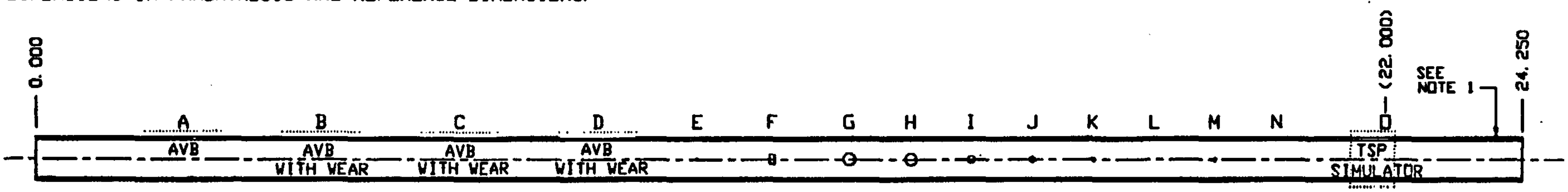
REVISIONS			
REV	DESCRIPTION	DATE	APPROVAL

FLAW LABEL	FLAW TYPE	SURFACE OF ORIGIN	AXIAL LOCATION	AZIMUTHAL LOCATION	LENGTH/ WIDTH OR DIAMETER	DEPTH IN INCHES	DEPTH IN %TW	
A	AVB	N/A	(2.375")	0°	(1.250)	N/A	N/A	
B	AVB WEAR	OD	4.623"	0°	1.250	(.009)	22 %TW	
C	AVB WEAR	OD	6.875"	0°	1.250	(.017)	41 %TW	
D	AVB WEAR	OD	9.127"	0°	1.250	(.026)	63 %TW	
E1	THRU HOLE	OD	10.753"	0°	ø.026	THROUGH	100 %TW	
E2	THRU HOLE	OD	10.753"	90°	ø.026	THROUGH	100 %TW	
E3	THRU HOLE	OD	10.753"	180°	ø.026	THROUGH	100 %TW	
E4	THRU HOLE	OD	10.753"	270°	ø.026	THROUGH	100 %TW	
F	DENT	OD	12.005"	0°	.086	(.008)	N/A	
G1	FBH	OD	13.252"	0°	ø.186	(.008)	20 %TW	AVERAGE DEPTH .0083" 20.5 %TW
G2	FBH	OD	13.252"	90°	ø.186	(.009)	22 %TW	
G3	FBH	OD	13.252"	180°	ø.186	(.008)	20 %TW	
G4	FBH	OD	13.252"	270°	ø.186	(.008)	20 %TW	
H	FBH	OD	14.252"	0°	ø.186	(.015)	37 %TW	
I	FBH	OD	15.252"	0°	ø.110	(.024)	59 %TW	
J	FBH	OD	16.252"	0°	ø.078	(.032)	78 %TW	
K	PW HOLE	OD	17.252"	0°	ø.052	THROUGH	100 %TW	
L	PW HOLE	OD	18.250"	90°	ø.052	THROUGH	100 %TW	
M	PW HOLE	OD	19.250"	180°	ø.052	THROUGH	100 %TW	
N	PW HOLE	OD	20.250"	270°	ø.052	THROUGH	100 %TW	
O	TSP	N/A	(22.000")	360°	(1.200)	N/A	N/A	

DIMENSIONS IN PARENTHESIS ARE REFERENCE DIMENSIONS.

NOTES:

1. THE MATERIAL HEAT NUMBER, HT 765502 AND THE AS BUILT NUMBER, 1280785B, ARE ETCHED AT THE RIGHT TUBE END.
2. THIS STANDARD WAS MADE VIA PA 83-799885-00 AND FTI WORK ORDER 11505, FROM DESIGN DRAWING 1280476D-0, FOR FTI.
3. THE AS BUILT DIMENSIONS WERE OBTAINED FROM QCIR 99-01453.
4. EACH FLAW IS CENTERED ABOUT THE SPECIFIED AXIAL AND AZIMUTHAL LOCATIONS.
5. THE DEPTHS IN PERCENT THROUGH WALL (%TW) ARE BASED UPON THE ACTUAL MEAN WALL THICKNESS (MWT) OF THE TUBING, .041".
6. WHEN PLACED IN HOLDER (1280802D-0), A TSP SIMULATOR RING IS CENTERED NEAR AXIAL LOCATION O (22.000"). THEIR AZIMUTHAL LOCATION IS 360°. ALSO, AVB BARS ARE CENTERED AT LOCATIONS A (2.375"), B (4.625"), C (6.875") AND D (9.125). THEY ARE ALIGNED, AND PLACED OVER THE WEAR FLAWS AT B, C AND D.



(1) 6875 BY 041 ASME CALIBRATION STANDARD

MAT'L: ALLOY 600, .6875" OD, .041" WALL.

FILENAME: 1280785.DWG
DISK No.: OPTICAL

DWN BY M.H. COWELL	CHK'D BY D. PROKITY	.6875 X .040 ASME CALIBRATION STANDARD AS BUILT DRAWING	SCALE 9/16	DATE 9/22/99
PASSED BY V.F. NEWMAN	APP'D BY R.L. NEWMAN		DWG NO	1280785 B-0

82159 (12/93)

DWG NO 1280786 B

FRAMATOME TECHNOLOGIES

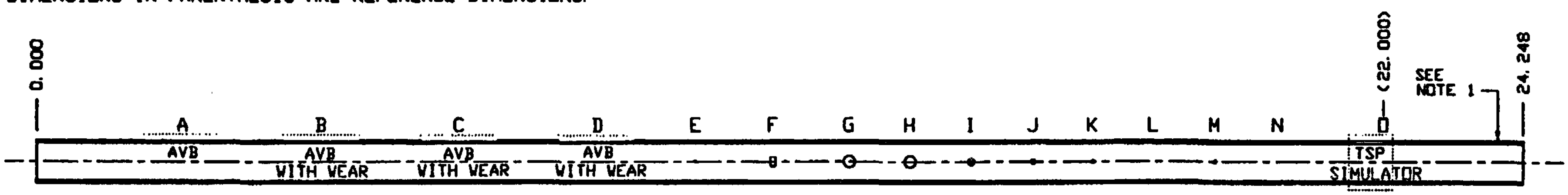
REVISIONS			
REV	DESCRIPTION	DATE	APPROVAL

FLAW LABEL	FLAW TYPE	SURFACE OF ORIGIN	AXIAL LOCATION	AZIMUTHAL LOCATION	LENGTH/ WIDTH OR DIAMETER	DEPTH IN INCHES	DEPTH IN %TW	
A	AVB	N/A	(2.375")	0°	(1.250)	N/A	N/A	
B	AVB WEAR	OD	4.625"	0°	1.250	(.008)	20 %TW	
C	AVB WEAR	OD	6.875"	0°	1.250	(.016)	39 %TW	
D	AVB WEAR	OD	9.125"	0°	1.250	(.024)	59 %TW	
E1	THRU HOLE	OD	10.752"	0°	ø.026	THROUGH	100 %TW	
E2	THRU HOLE	OD	10.752"	90°	ø.026	THROUGH	100 %TW	
E3	THRU HOLE	OD	10.752"	180°	ø.026	THROUGH	100 %TW	
E4	THRU HOLE	OD	10.752"	270°	ø.026	THROUGH	100 %TW	
F	DENT	OD	12.000"	0°	.084	(.008)	N/A	
G1	FBH	OD	13.252"	0°	ø.186	(.008)	20 %TW	AVERAGE DEPTH .0083" 20.5 %TW
G2	FBH	OD	13.252"	90°	ø.186	(.009)	22 %TW	
G3	FBH	OD	13.252"	180°	ø.186	(.008)	20 %TW	
G4	FBH	OD	13.252"	270°	ø.186	(.008)	20 %TW	
H	FBH	OD	14.249"	0°	ø.187	(.016)	36 %TW	
I	FBH	OD	15.248"	0°	ø.110	(.024)	59 %TW	
J	FBH	OD	16.248"	0°	ø.078	(.032)	78 %TW	
K	PW HOLE	OD	17.250"	0°	ø.052	THROUGH	100 %TW	
L	PW HOLE	OD	18.250"	90°	ø.052	THROUGH	100 %TW	
M	PW HOLE	OD	19.250"	180°	ø.052	THROUGH	100 %TW	
N	PW HOLE	OD	20.250"	270°	ø.052	THROUGH	100 %TW	
O	TSP	N/A	(22.000")	360°	(1.200)	N/A	N/A	

DIMENSIONS IN PARENTHESIS ARE REFERENCE DIMENSIONS.

NOTES:

1. THE MATERIAL HEAT NUMBER, HT 765502 AND THE AS BUILT NUMBER, 1280786B, ARE ETCHED AT THE RIGHT TUBE END.
2. THIS STANDARD WAS MADE VIA PA 83-799885-00 AND FTI WORK ORDER 11505, FROM DESIGN DRAWING 1280476D-0, FOR FTI.
3. THE AS BUILT DIMENSIONS WERE OBTAINED FROM QCIR 99-01455.
4. EACH FLAW IS CENTERED ABOUT THE SPECIFIED AXIAL AND AZIMUTHAL LOCATIONS.
5. THE DEPTHS IN PERCENT THROUGH WALL (%TW) ARE BASED UPON THE ACTUAL MEAN WALL THICKNESS (MWT) OF THE TUBING, .041".
6. WHEN PLACED IN HOLDER (1280802D-0), A TSP SIMULATOR RING IS CENTERED NEAR AXIAL LOCATION O (22.000"). THEIR AZIMUTHAL LOCATION IS 360°. ALSO, AVB BARS ARE CENTERED AT LOCATIONS A (2.375"), B (4.625"), C (6.875") AND D (9.125). THEY ARE ALIGNED, AND PLACED OVER THE WEAR FLAWS AT B, C AND D.



1 6875 BY 041 ASME CALIBRATION STANDARD

MAT'L: ALLOY 600, .6875" OD, .041" WALL.

FILENAME: 1280786.DWG
DISK No.: OPTICAL

DWN BY M.H. COWELL	CHK'D BY D. PROKOPY	.6875 X .040 ASME CALIBRATION STANDARD AS BUILT DRAWING	SCALE 9/16	DATE 9/22/99
PASSED BY V.P. NEWMAN	APP'D BY R.L. NEWMAN		DWG NO. 1280786 B-0	

22159 (12/93)

DWG NO 1280787 B

FRAMATOME TECHNOLOGIES

REVISIONS			
REV	DESCRIPTION	DATE	APPROVAL

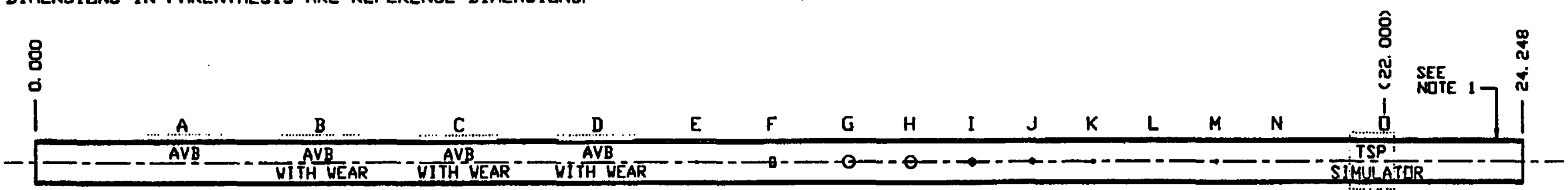
FLAW LABEL	FLAW TYPE	SURFACE OF ORIGIN	AXIAL LOCATION	AZIMUTHAL LOCATION	LENGTH/ WIDTH OR DIAMETER	DEPTH IN INCHES	DEPTH IN %TW
A	AVB	N/A	(2.375")	0°	(1.250)	N/A	N/A
B	AVB WEAR	OD	4.625"	0°	1.250	(.008)	20 %TW
C	AVB WEAR	OD	6.875"	0°	1.250	(.017)	41 %TW
D	AVB WEAR	OD	9.126"	0°	1.250	(.024)	59 %TW
E1	THRU HOLE	OD	10.752"	0°	ø.026	THROUGH	100 %TW
E2	THRU HOLE	OD	10.752"	90°	ø.026	THROUGH	100 %TW
E3	THRU HOLE	OD	10.752"	180°	ø.026	THROUGH	100 %TW
E4	THRU HOLE	OD	10.752"	270°	ø.026	THROUGH	100 %TW
F	DENT	OD	12.000"	0°	.086	(.008)	20 %TW
G1	FBH	OD	13.248	0°	ø.186	(.008)	20 %TW
G2	FBH	OD	13.249"	90°	ø.186	(.009)	22 %TW
G3	FBH	OD	13.248"	180°	ø.186	(.008)	20 %TW
G4	FBH	OD	13.248"	270°	ø.186	(.008)	20 %TW
H	FBH	OD	14.249"	0°	ø.187	(.017)	41 %TW
I	FBH	OD	15.248"	0°	ø.109	(.024)	59 %TW
J	FBH	OD	16.250"	0°	ø.079	(.032)	78 %TW
K	PW HOLE	OD	17.250"	0°	ø.052	THROUGH	100 %TW
L	PW HOLE	OD	18.250"	90°	ø.052	THROUGH	100 %TW
M	PW HOLE	OD	19.250"	180°	ø.052	THROUGH	100 %TW
N	PW HOLE	OD	20.250"	270°	ø.052	THROUGH	100 %TW
O	TSP	N/A	(22.000")	360°	(1.200)	N/A	N/A

AVERAGE DEPTH .0083" 20.5 %TW

DIMENSIONS IN PARENTHESIS ARE REFERENCE DIMENSIONS.

NOTES:

1. THE MATERIAL HEAT NUMBER, HT 765502 AND THE AS BUILT NUMBER, 1280787B, ARE ETCHED AT THE RIGHT TUBE END.
2. THIS STANDARD WAS MADE VIA PA 83-799885-00 AND FTI WORK ORDER 11505, FROM DESIGN DRAWING 1280476D-0, FOR FTI.
3. THE AS BUILT DIMENSIONS WERE OBTAINED FROM QCIR 99-01458.
4. EACH FLAW IS CENTERED ABOUT THE SPECIFIED AXIAL AND AZIMUTHAL LOCATIONS.
5. THE DEPTHS IN PERCENT THROUGH WALL (%TW) ARE BASED UPON THE ACTUAL MEAN WALL THICKNESS (MWT) OF THE TUBING, .041".
6. WHEN PLACED IN HOLDER (1280802D-0), A TSP SIMULATOR RING IS CENTERED NEAR AXIAL LOCATION O (22.000"). THEIR AZIMUTHAL LOCATION IS 360°. ALSO, AVB BARS ARE CENTERED AT LOCATIONS A (2.375"), B (4.625"), C (6.875") AND D (9.125). THEY ARE ALIGNED, AND PLACED OVER THE WEAR FLAWS AT B, C AND D.



(1) 6875 BY 041 ASME CALIBRATION STANDARD

MAT'L: ALLOY 600, .6875" OD, .041" WALL.

FILENAME: 1280787.DWG
DISK No.: OPTICAL

DWN BY M.H. COWELL	CHK'D BY D. PROKOTY	.6875 X .040 ASME CALIBRATION STANDARD AS BUILT DRAWING	SCALE 9/16	DATE 9/22/99
PASSED BY V.F. NEWMAN	APP'D BY R.I. NEWMAN		DWG NO.	1280787 B-0

22159 (12/95)

DWG NO 1280788 B

FRAMATOME TECHNOLOGIES

REVISIONS			
REV	DESCRIPTION	DATE	APPROVAL

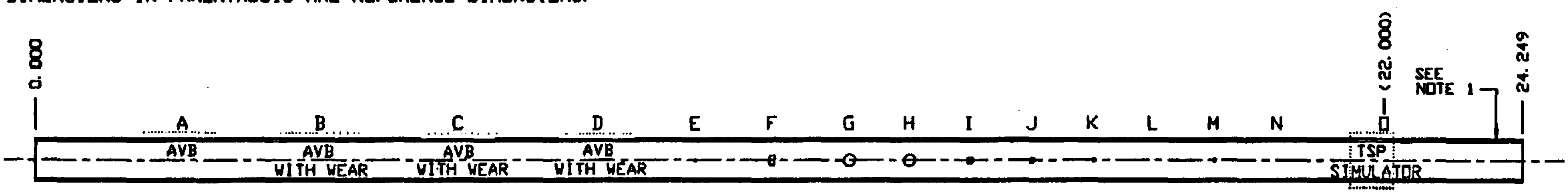
FLAW LABEL	FLAW TYPE	SURFACE OF ORIGIN	AXIAL LOCATION	AZIMUTHAL LOCATION	LENGTH/ WIDTH OR DIAMETER	DEPTH IN INCHES	DEPTH IN %TW
A	AVB	N/A	(2.375')	0°	(1.250)	N/A	N/A
B	AVB WEAR	OD	4.627'	0°	1.251	(.009)	22 %TW
C	AVB WEAR	OD	6.878'	0°	1.252	(.017)	41 %TW
D	AVB WEAR	OD	9.127'	0°	1.250	(.026)	63 %TW
E1	THRU HOLE	OD	10.754'	0°	ø.026	THROUGH	100 %TW
E2	THRU HOLE	OD	10.754'	90°	ø.026	THROUGH	100 %TW
E3	THRU HOLE	OD	10.754'	180°	ø.026	THROUGH	100 %TW
E4	THRU HOLE	OD	10.754'	270°	ø.026	THROUGH	100 %TW
F	DENT	OD	12.000'	0°	.086	(.008)	N/A
G1	FBH	OD	13.247	0°	ø.186	(.009)	22 %TW
G2	FBH	OD	13.247'	90°	ø.186	(.009)	22 %TW
G3	FBH	OD	13.247'	180°	ø.186	(.009)	22 %TW
G4	FBH	OD	13.247'	270°	ø.186	(.009)	22 %TW
H	FBH	OD	14.247'	0°	ø.187	(.017)	41 %TW
I	FBH	OD	15.248'	0°	ø.107	(.025)	61 %TW
J	FBH	OD	16.248'	0°	ø.079	(.032)	78 %TW
K	PW HOLE	OD	17.251'	0°	ø.052	THROUGH	100 %TW
L	PW HOLE	OD	18.251'	90°	ø.052	THROUGH	100 %TW
M	PW HOLE	OD	19.251'	180°	ø.052	THROUGH	100 %TW
N	PW HOLE	OD	20.251'	270°	ø.052	THROUGH	100 %TW
O	TSP	N/A	(22.000')	360°	(1.200)	N/A	N/A

AVERAGE DEPTH .009' 22 %TW (G1–G4)

DIMENSIONS IN PARENTHESIS ARE REFERENCE DIMENSIONS.

NOTES:

1. THE MATERIAL HEAT NUMBER, HT 765502 AND THE AS BUILT NUMBER, 1280788B, ARE ETCHED AT THE RIGHT TUBE END.
2. THIS STANDARD WAS MADE VIA PA 83-799885-00 AND FTI WORK ORDER 11505, FROM DESIGN DRAWING 1280476D-0, FOR FTI.
3. THE AS BUILT DIMENSIONS WERE OBTAINED FROM QCIR 99-01459.
4. EACH FLAW IS CENTERED ABOUT THE SPECIFIED AXIAL AND AZIMUTHAL LOCATIONS.
5. THE DEPTHS IN PERCENT THROUGH WALL (%TW) ARE BASED UPON THE ACTUAL MEAN WALL THICKNESS (MWT) OF THE TUBING, .041'.
6. WHEN PLACED IN HOLDER (1280802D-0), A TSP SIMULATOR RING IS CENTERED NEAR AXIAL LOCATION O (22.000'). THEIR AZIMUTHAL LOCATION IS 360°. ALSO, AVB BARS ARE CENTERED AT LOCATIONS A (2.375'), B (4.625'), C (6.875') AND D (9.125). THEY ARE ALIGNED, AND PLACED OVER THE WEAR FLAWS AT B, C AND D.



(1) 6875 BY 041 ASME CALIBRATION STANDARD

MAT'L: ALLOY 600, .6875" OD, .041" WALL.

FILENAME: 1280788.DWG
DISK No.: OPTICAL

DWN BY M.H. COWELL	CHK'D BY D. PROKITY	.6875 X .040 ASME CALIBRATION STANDARD AS BUILT DRAWING	SCALE 9/16	DATE 9/22/99
PASSED BY V.F. NEWMAN	APP'D BY R.L. NEWMAN		DWG NO. 1280788 B-0	

22159 (12/95)

DWG NO 1280789 B

FRAMATOME TECHNOLOGIES

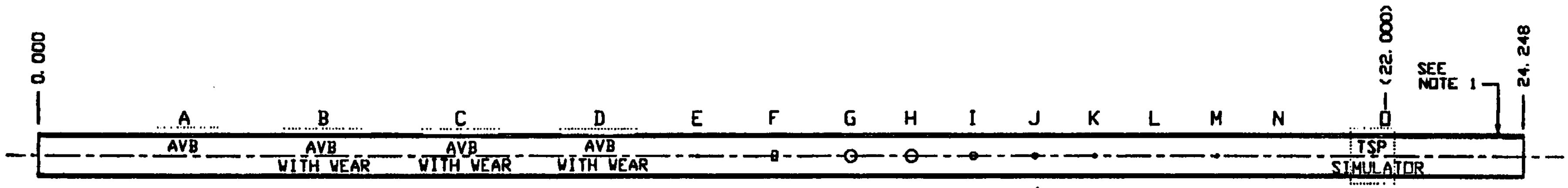
REVISIONS			
REV	DESCRIPTION	DATE	APPROVAL

FLAW LABEL	FLAW TYPE	SURFACE OF ORIGIN	AXIAL LOCATION	AZIMUTHAL LOCATION	LENGTH/ WIDTH OR DIAMETER	DEPTH IN INCHES	DEPTH IN %TW	
A	AVB	N/A	(2.375")	0°	(1.250)	N/A	N/A	
B	AVB WEAR	OD	4.626"	0°	1.252	(.009)	22 %TW	
C	AVB WEAR	OD	6.876"	0°	1.250	(.017)	41 %TW	
D	AVB WEAR	OD	9.126"	0°	1.250	(.026)	63 %TW	
E1	THRU HOLE	OD	10.751"	0°	ø.026	THROUGH	100 %TW	
E2	THRU HOLE	OD	10.751"	90°	ø.026	THROUGH	100 %TW	
E3	THRU HOLE	OD	10.751"	180°	ø.026	THROUGH	100 %TW	
E4	THRU HOLE	OD	10.751"	270°	ø.026	THROUGH	100 %TW	
F	DENT	OD	12.000"	0°	.086	(.009)	N/A	
G1	FBH	OD	13.246"	0°	ø.186	(.009)	22 %TW	AVERAGE DEPTH .009" 22 %TW
G2	FBH	OD	13.246"	90°	ø.186	(.009)	22 %TW	
G3	FBH	OD	13.246"	180°	ø.186	(.009)	22 %TW	
G4	FBH	OD	13.246"	270°	ø.186	(.009)	22 %TW	
H	FBH	OD	14.246"	0°	ø.187	(.016)	39 %TW	
I	FBH	OD	15.247"	0°	ø.108	(.025)	61 %TW	
J	FBH	OD	16.247"	0°	ø.079	(.032)	78 %TW	
K	PW HOLE	OD	17.251"	0°	ø.052	THROUGH	100 %TW	
L	PW HOLE	OD	18.251"	90°	ø.052	THROUGH	100 %TW	
M	PW HOLE	OD	19.251"	180°	ø.052	THROUGH	100 %TW	
N	PW HOLE	OD	20.251"	270°	ø.052	THROUGH	100 %TW	
O	TSP	N/A	(22.000")	360°	(1.200)	N/A	N/A	

DIMENSIONS IN PARENTHESIS ARE REFERENCE DIMENSIONS.

NOTES:

1. THE MATERIAL HEAT NUMBER, HT 765502 AND THE AS BUILT NUMBER, 1280789B, ARE ETCHED AT THE RIGHT TUBE END.
2. THIS STANDARD WAS MADE VIA PA 83-799885-00 AND FTI WORK ORDER 11505, FROM DESIGN DRAWING 1280476D-0, FOR FTI.
3. THE AS BUILT DIMENSIONS WERE OBTAINED FROM QCIR 99-01461.
4. EACH FLAW IS CENTERED ABOUT THE SPECIFIED AXIAL AND AZIMUTHAL LOCATIONS.
5. THE DEPTHS IN PERCENT THROUGH WALL (%TW) ARE BASED UPON THE ACTUAL MEAN WALL THICKNESS (MWT) OF THE TUBING, .041".
6. WHEN PLACED IN HOLDER (1280802D-0), A TSP SIMULATOR RING IS CENTERED NEAR AXIAL LOCATION O (22.000"). THEIR AZIMUTHAL LOCATION IS 360°. ALSO, AVB BARS ARE CENTERED AT LOCATIONS A (2.375"), B (4.625"), C (6.875") AND D (9.125). THEY ARE ALIGNED, AND PLACED OVER THE WEAR FLAWS AT B, C AND D.



① 6875 BY 041 ASME CALIBRATION STANDARD

MAT'L: ALLOY 600, .6875" OD, .041" WALL.

FILENAME: 1280789.DWG
DISK No.: OPTICAL

DWN BY M.H. GOWELL	CHK'D BY D. PROKIT	.6875 X .040 ASME CALIBRATION STANDARD AS BUILT DRAWING	SCALE 9/16	DATE 9/22/99
PASSED BY V.F. NEWMAN	APP'D BY R.L. NEWMAN		DWG NO. 1280789 B-0	

22159 (12/95)

DWG NO 1280790 B

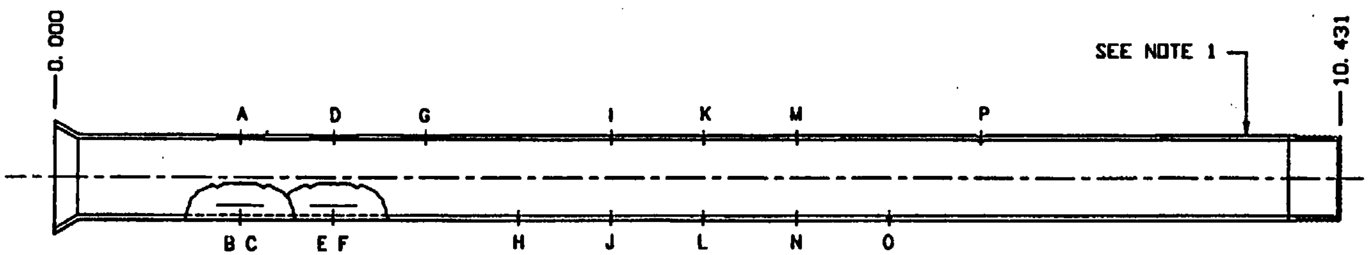
FRAMATOME TECHNOLOGIES

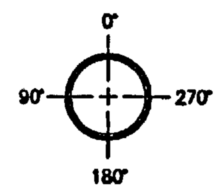
REVISIONS			
REV	DESCRIPTION	DATE	APPROVAL

FLAW LABEL	FLAW TYPE	SURFACE OF ORIGIN	AXIAL LOCATION	AZIMUTHAL LOCATION	FLAW LENGTH	WIDTH OR DIAMETER	DEPTH	DEPTH IN %TW	FLAW LABEL
A	AXIAL EDM	ID	1.500"	0°	.380"	.005"	.025"	61% TW	A
B	AXIAL EDM	ID	1.500"	120°	.380"	.005"	.017"	41% TW	B
C	AXIAL EDM	ID	1.500"	240°	.380"	.005"	.009"	22% TW	C
D	AXIAL EDM	OD	2.248"	0°	.379"	.005"	.025"	61% TW	D
E	AXIAL EDM	OD	2.249"	120°	.379"	.005"	.017"	41% TW	E
F	AXIAL EDM	OD	2.249"	240°	.379"	.005"	.010"	24% TW	F
G	AXIAL EDM	OD	3.003"	0°	.380"	.005"	THROUGH	100% TW	G
H	CIRC EDM	OD	3.750"	180°	.380"	.005"	THROUGH	100% TW	H
I	CIRC EDM	ID	4.500"	0°	.380"	.005"	.025"	61% TW	I
J	CIRC EDM	OD	4.501"	180°	.380"	.005"	.025"	61% TW	J
K	CIRC EDM	ID	5.250"	0°	.380"	.005"	.017"	41% TW	K
L	CIRC EDM	OD	5.250"	180°	.380"	.005"	.017"	41% TW	L
M	CIRC EDM	ID	6.000"	0°	.380"	.005"	.009"	22% TW	M
N	CIRC EDM	OD	5.999"	180°	.380"	.005"	.009"	22% TW	N
O	HOLE	OD	6.752"	180°	N/A	.052"	THROUGH	100% TW	O
P	DENT	OD	7.500"	0°	N/A	(.054")	.006"	15% TW	P

NOTES:

1. THE MATERIAL HEAT NUMBER, HT NX0888 , AND THE AS BUILT NUMBER, 1280790B, ARE ETCHED AT THE RIGHT TUBE END.
2. THIS STANDARD WAS MADE VIA PA 83-799886-02, FTI WO 11482 AND FROM DESIGN DRAWING 1280475D-01, FOR FTI.
3. THE AS BUILT DIMENSIONS WERE OBTAINED FROM FTI SHOP DATA SHEETS, QCIR 99-00999 AND QCIR 99-01285.
4. EACH FLAW IS CENTERED ABOUT THE SPECIFIED AXIAL AND AZIMUTHAL LOCATIONS.
5. THE DEPTHS IN PERCENT THROUGH WALL (%TW) ARE BASED UPON THE ACTUAL MEAN WALL THICKNESS (MWT) OF THE TUBING, .041".





(1) RPC GT CALIBRATION STANDARD

MAT'L: ALLOY 600, .682" O.D., .041" MEAN WALL

FILENAME: 1280790.DWG

DISK No.: OPTICAL

DWN BY MH GOVELL	CHK'D BY D PROKITT	.684 BY .042 RPC GT CALIBRATION STANDARD AS BUILT DRAWING	SCALE FULL / DATE 9-15-99
PASSED BY VE NEYMAN	APP'D BY RL NEYMAN		DWG NO. 1280790 B-0

DWG NO 1280791 B

FRAMATOME TECHNOLOGIES

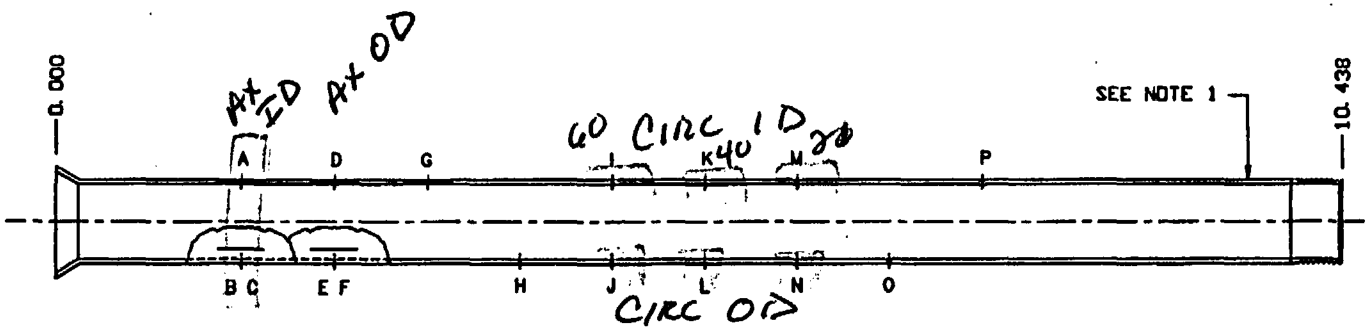
REVISIONS			
REV	DESCRIPTION	DATE	APPROVAL

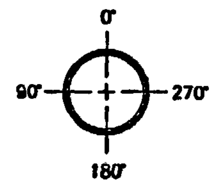
FLAW LABEL	FLAW TYPE	SURFACE OF ORIGIN	AXIAL LOCATION	AZIMUTHAL LOCATION	FLAW LENGTH	WIDTH OR DIAMETER	DEPTH	DEPTH IN %TW	FLAW LABEL
A	AXIAL EDM	ID	1.500"	0°	.380"	.005"	.025"	60% TW	A
B	AXIAL EDM	ID	1.500"	120°	.380"	.005"	.017"	40% TW	B
C	AXIAL EDM	ID	1.500"	240°	.380"	.005"	.009"	21% TW	C
D	AXIAL EDM	OD	2.256"	0°	.380"	.005"	.025"	60% TW	D
E	AXIAL EDM	OD	2.255"	120°	.380"	.005"	.017"	40% TW	E
F	AXIAL EDM	OD	2.252"	240°	.380"	.005"	.009"	21% TW	F
G	AXIAL EDM	OD	3.003"	0°	.380"	.006"	THROUGH	100% TW	G
H	CIRC EDM	OD	3.750"	180°	.380"	.005"	THROUGH	100% TW	H
I	CIRC EDM	ID	4.500"	0°	.380"	.005"	.025"	60% TW	I
J	CIRC EDM	OD	4.500"	180°	.380"	.005"	.025"	60% TW	J
K	CIRC EDM	ID	5.250"	0°	.380"	.005"	.017"	40% TW	K
L	CIRC EDM	OD	5.252"	180°	.380"	.005"	.017"	40% TW	L
M	CIRC EDM	ID	6.000"	0°	.380"	.005"	.009"	21% TW	M
N	CIRC EDM	OD	6.000"	180°	.380"	.005"	.009"	21% TW	N
O	HOLE	OD	6.754"	180°	N/A	.052"	THROUGH	100% TW	O
P	DENT	OD	7.502"	0°	N/A	(.054")	.005"	12% TW	P

6.754
1.500
5.254

NOTES:

1. THE MATERIAL HEAT NUMBER, HT NX0888, AND THE AS BUILT NUMBER, 1280791B, ARE ETCHED AT THE RIGHT TUBE END.
2. THIS STANDARD WAS MADE VIA PA 83-799886-02, FTI WO 11482 AND FROM DESIGN DRAWING 1280475D-01, FOR FTI.
3. THE AS BUILT DIMENSIONS WERE OBTAINED FROM FTI SHOP DATA SHEETS, QCIR 99-00999 AND QCIR 99-01288.
4. EACH FLAW IS CENTERED ABOUT THE SPECIFIED AXIAL AND AZIMUTHAL LOCATIONS.
5. THE DEPTHS IN PERCENT THROUGH WALL (%TW) ARE BASED UPON THE ACTUAL MEAN WALL THICKNESS (MWT) OF THE TUBING, .042".





① RPC GT CALIBRATION STANDARD
MAT'L: ALLOY 600, .683" O.D., .042" MEAN WALL

FILENAME: 1280791.DWG
DISK No.: OPTICAL

DWN BY MT COVELL	CHK'D BY D PRORITY	.684 BY .042 RPC GT CALIBRATION STANDARD AS BUILT DRAWING	SCALE FULL	DATE 9/15/99
PASSED BY VF NEWMAN	APP'D BY RL NEWMAN		DWG NO.	1280791B-0

22159 (12/95)

DWG NO 1280792 B

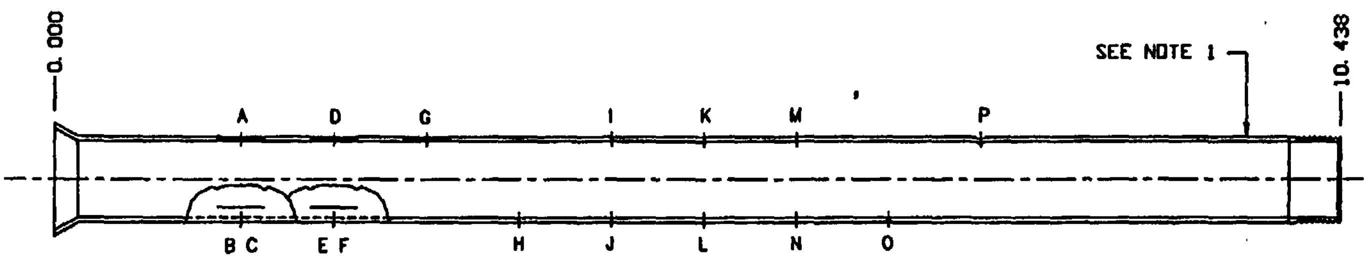
FRAMATOME TECHNOLOGIES

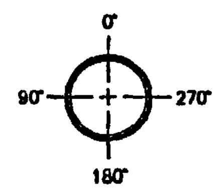
REVISIONS			
REV	DESCRIPTION	DATE	APPROVAL

FLAW LABEL	FLAW TYPE	SURFACE OF ORIGIN	AXIAL LOCATION	AZIMUTHAL LOCATION	FLAW LENGTH	WIDTH OR DIAMETER	DEPTH	DEPTH IN %TW	FLAW LABEL
A	AXIAL EDM	ID	1.500"	0°	.380"	.005"	.025"	61% TW	A
B	AXIAL EDM	ID	1.500"	120°	.380"	.005"	.017"	41% TW	B
C	AXIAL EDM	ID	1.500"	240°	.380"	.005"	.009"	22% TW	C
D	AXIAL EDM	OD	2.256"	0°	.379"	.005"	.025"	61% TW	D
E	AXIAL EDM	OD	2.256"	120°	.379"	.005"	.017"	41% TW	E
F	AXIAL EDM	OD	2.250"	240°	.378"	.006"	.009"	22% TW	F
G	AXIAL EDM	OD	3.001"	0°	.379"	.006"	THROUGH	100% TW	G
H	CIRC EDM	OD	3.750"	180°	.380"	.005"	THROUGH	100% TW	H
I	CIRC EDM	ID	4.500"	0°	.380"	.005"	.025"	61% TW	I
J	CIRC EDM	OD	4.505"	180°	.380"	.005"	.025"	61% TW	J
K	CIRC EDM	ID	5.250"	0°	.380"	.005"	.017"	41% TW	K
L	CIRC EDM	OD	5.255"	180°	.380"	.005"	.017"	41% TW	L
M	CIRC EDM	ID	6.000"	0°	.380"	.005"	.009"	22% TW	M
N	CIRC EDM	OD	6.002"	180°	.380"	.005"	.009"	22% TW	N
O	HOLE	OD	6.756"	180°	N/A	.052"	THROUGH	100% TW	O
P	DENT	OD	7.501"	0°	N/A	(.054")	.005"	12% TW	P

NOTES:

1. THE MATERIAL HEAT NUMBER, HT NX0888 , AND THE AS BUILT NUMBER, 1280792B, ARE ETCHED AT THE RIGHT TUBE END.
2. THIS STANDARD WAS MADE VIA PA 83-799886-02, FTI WO 11482 AND FROM DESIGN DRAWING 1280475D-01, FOR FTI.
3. THE AS BUILT DIMENSIONS WERE OBTAINED FROM FTI SHOP DATA SHEETS, QCIR 99-00999 AND QCIR 99-01289.
4. EACH FLAW IS CENTERED ABOUT THE SPECIFIED AXIAL AND AZIMUTHAL LOCATIONS.
5. THE DEPTHS IN PERCENT THROUGH WALL (%TW) ARE BASED UPON THE ACTUAL MEAN WALL THICKNESS (MWT) OF THE TUBING, .041".





(1) RPC GT CALIBRATION STANDARD

MAT'L: ALLOY 600, .682" O.D., .041" MEAN WALL

FILENAME: 1280792.DWG
DISK No.: OPTICAL

DWN BY MH GOVEC	CHK'D BY D PROKITY	.684 BY .042 RPC GT CALIBRATION STANDARD AS BUILT DRAWING	SCALE FULL	DATE 9/15/99
PASSED BY VF NEYMAN	APP'D BY RL NEYMAN		DWG NO. 1280792 B- 0	

22159 (12/95)

DWG NO 1280793 B

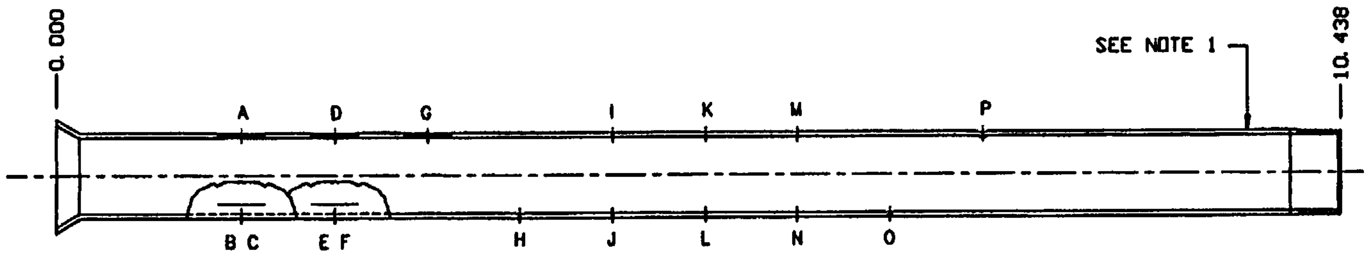
FRAMATOME TECHNOLOGIES

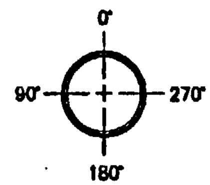
REVISIONS			
REV	DESCRIPTION	DATE	APPROVAL

FLAW LABEL	FLAW TYPE	SURFACE OF ORIGIN	AXIAL LOCATION	AZIMUTHAL LOCATION	FLAW LENGTH	WIDTH OR DIAMETER	DEPTH	DEPTH IN %TW	FLAW LABEL
A	AXIAL EDM	ID	1.500"	0°	.380"	.005"	.025"	60% TW	A
B	AXIAL EDM	ID	1.500"	120°	.380"	.005"	.017"	40% TW	B
C	AXIAL EDM	ID	1.500"	240°	.380"	.005"	.009"	21% TW	C
D	AXIAL EDM	OD	2.252"	0°	.379"	.005"	.025"	60% TW	D
E	AXIAL EDM	OD	2.254"	120°	.379"	.005"	.017"	40% TW	E
F	AXIAL EDM	OD	2.254"	240°	.379"	.005"	.009"	21% TW	F
G	AXIAL EDM	OD	3.001"	0°	.380"	.005"	THROUGH	100% TW	G
H	CIRC EDM	OD	3.750"	180°	.380"	.005"	THROUGH	100% TW	H
I	CIRC EDM	ID	4.500"	0°	.380"	.005"	.025"	60% TW	I
J	CIRC EDM	OD	4.502"	180°	.380"	.005"	.022"	52% TW	J
K	CIRC EDM	ID	5.250"	0°	.380"	.005"	.017"	40% TW	K
L	CIRC EDM	OD	5.252"	180°	.380"	.005"	.016"	38% TW	L
M	CIRC EDM	ID	6.000"	0°	.380"	.005"	.009"	21% TW	M
N	CIRC EDM	OD	6.000"	180°	.380"	.005"	.009"	21% TW	N
O	HOLE	OD	6.754"	180°	N/A	.052"	THROUGH	100% TW	O
P	DENT	OD	7.500"	0°	N/A	(.055")	.005"	12% TW	P

NOTES:

1. THE MATERIAL HEAT NUMBER, HT NX0888 , AND THE AS BUILT NUMBER, 1280793B, ARE ETCHED AT THE RIGHT TUBE END.
2. THIS STANDARD WAS MADE VIA PA 83-799886-01, FTI WO 11482 AND SI 39-5005364-00, FROM DESIGN DRAWING 1280475D-00, FOR FTI.
3. THE AS BUILT DIMENSIONS WERE OBTAINED FROM FTI SHOP DATA SHEETS, QCIR 99-00734 AND QCIR 99-01090.
4. EACH FLAW IS CENTERED ABOUT THE SPECIFIED AXIAL AND AZIMUTHAL LOCATIONS.
5. THE DEPTHS IN PERCENT THROUGH WALL (%TW) ARE BASED UPON THE ACTUAL MEAN WALL THICKNESS (MWT) OF THE TUBING, .042".





1 RPC GT CALIBRATION STANDARD

MAT'L: ALLOY 600, .684" O.D., .042" MEAN WALL

FILENAME: 1280793.DWG
DISK No.: OPTICAL

DWN BY MH GUWELL	CHK'D BY JD PROKITY	.684 BY .042 RPC GT CALIBRATION STANDARD AS BUILT DRAWING	SCALE FULL	DATE 8/25/99
PASSED BY RG KROIKE	APP'D BY TA RIBART		DWG NO. 1280793 B-0	

82159 (12/93)

DWG NO 1280794 B

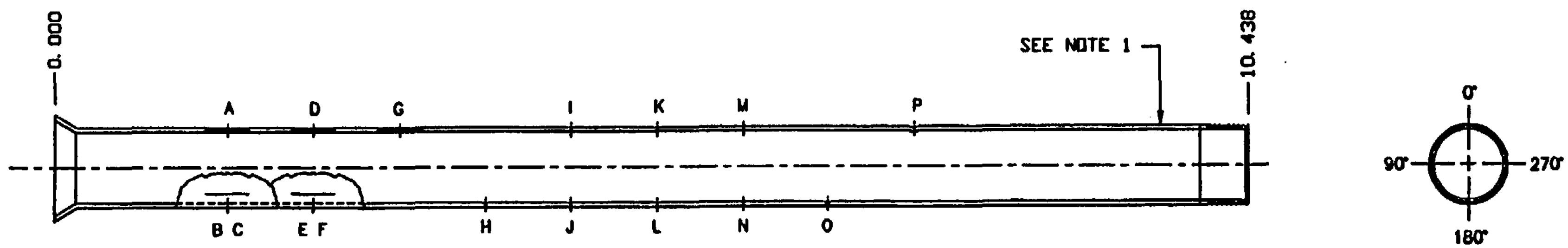
FRAMATOME TECHNOLOGIES

REVISIONS				
REV	DESCRIPTION	DATE	APPROVAL	NF

FLAW LABEL	FLAW TYPE	SURFACE OF ORIGIN	AXIAL LOCATION	AZIMUTHAL LOCATION	FLAW LENGTH	WIDTH OR DIAMETER	DEPTH	DEPTH IN %TW	FLAW LABEL
A	AXIAL EDM	ID	1.500"	0°	.380"	.005"	.025"	60% TW	A
B	AXIAL EDM	ID	1.500"	120°	.380"	.005"	.017"	40% TW	B
C	AXIAL EDM	ID	1.500"	240°	.380"	.005"	.009"	21% TW	C
D	AXIAL EDM	OD	2.252"	0°	.379"	.006"	.025"	60% TW	D
E	AXIAL EDM	OD	2.252"	120°	.379"	.006"	.017"	40% TW	E
F	AXIAL EDM	OD	2.253"	240°	.379"	.006"	.009"	21% TW	F
G	AXIAL EDM	OD	3.004"	0°	.380"	.006"	THROUGH	100% TW	G
H	CIRC EDM	OD	3.752"	180°	.380"	.005"	THROUGH	100% TW	H
I	CIRC EDM	ID	4.500"	0°	.380"	.005"	.025"	60% TW	I
J	CIRC EDM	OD	4.505"	180°	.380"	.005"	.023"	55% TW	J
K	CIRC EDM	ID	5.250"	0°	.380"	.005"	.017"	40% TW	K
L	CIRC EDM	OD	5.256"	180°	.380"	.005"	.016"	38% TW	L
M	CIRC EDM	ID	6.000"	0°	.380"	.005"	.009"	21% TW	M
N	CIRC EDM	OD	6.004"	180°	.380"	.005"	.009"	21% TW	N
O	HOLE	OD	6.754"	180°	N/A	.052"	THROUGH	100% TW	O
P	DENT	OD	7.500"	0°	N/A	(.054")	.005"	12% TW	P

NOTES:

1. THE MATERIAL HEAT NUMBER, HT NX0888 , AND THE AS BUILT NUMBER, 1280794B, ARE ETCHED AT THE RIGHT TUBE END.
2. THIS STANDARD WAS MADE VIA PA 83-799886-01, FTI WO 11482 AND SI 39-5005364-00, FROM DESIGN DRAWING 1280475D-00, FOR FTI.
3. THE AS BUILT DIMENSIONS WERE OBTAINED FROM FTI SHOP DATA SHEETS, QCIR 99-00734 AND QCIR 99-01091.
4. EACH FLAW IS CENTERED ABOUT THE SPECIFIED AXIAL AND AZIMUTHAL LOCATIONS.
5. THE DEPTHS IN PERCENT THROUGH WALL (%TW) ARE BASED UPON THE ACTUAL MEAN WALL THICKNESS (MWT) OF THE TUBING, .042".



(1) RPC GT CALIBRATION STANDARD

MAT'L: ALLOY 600, .684" O.D., .042" MEAN WALL

FILENAME: 1280794.DWG
DISK No.: OPTICAL

DWN BY: MH GOWELL	CHK'D BY: JD PROKITY	.684 BY .042 RPC GT CALIBRATION STANDARD AS BUILT DRAWING	SCALE FULL	DATE 8/25/99
PASSED BY: RG KROTHE	APP'D BY: TA RIBARIC		DWG NO. 1280794 B-0	

22159 (12/95)

DWG NO 1280795 B

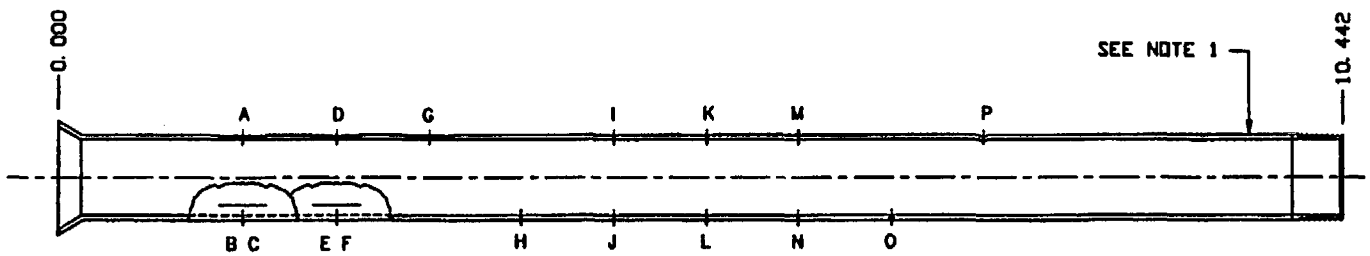
FRAMATOME TECHNOLOGIES

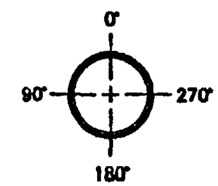
REVISIONS			
REV	DESCRIPTION	DATE	APPROVAL

FLAW LABEL	FLAW TYPE	SURFACE OF ORIGIN	AXIAL LOCATION	AZIMUTHAL LOCATION	FLAW LENGTH	WIDTH OR DIAMETER	DEPTH	DEPTH IN %TW	FLAW LABEL
A	AXIAL EDM	ID	1.500"	0°	.380"	.005"	.025"	60% TW	A
B	AXIAL EDM	ID	1.500"	120°	.380"	.005"	.017"	40% TW	B
C	AXIAL EDM	ID	1.500"	240°	.380"	.005"	.009"	21% TW	C
D	AXIAL EDM	OD	2.248"	0°	.378"	.006"	.024"	57% TW	D
E	AXIAL EDM	OD	2.249"	120°	.378"	.006"	.016"	38% TW	E
F	AXIAL EDM	OD	2.252"	240°	.378"	.006"	.008"	19% TW	F
G	AXIAL EDM	OD	3.000"	0°	.380"	.006"	THROUGH	100% TW	G
H	CIRC EDM	OD	3.750"	180°	.380"	.005"	THROUGH	100% TW	H
I	CIRC EDM	ID	4.500"	0°	.380"	.005"	.025"	60% TW	I
J	CIRC EDM	OD	4.501"	180°	.380"	.005"	.025"	60% TW	J
K	CIRC EDM	ID	5.250"	0°	.380"	.005"	.017"	40% TW	K
L	CIRC EDM	OD	5.251"	180°	.380"	.005"	.016"	38% TW	L
M	CIRC EDM	ID	6.000"	0°	.380"	.005"	.009"	21% TW	M
N	CIRC EDM	OD	6.000"	180°	.380"	.005"	.009"	21% TW	N
O	HOLE	OD	6.750"	180°	N/A	.053"	THROUGH	100% TW	O
P	DENT	OD	7.497"	0°	N/A	(.056")	.006"	14% TW	P

NOTES:

1. THE MATERIAL HEAT NUMBER, HT NX0888 , AND THE AS BUILT NUMBER, 1280795B, ARE ETCHED AT THE RIGHT TUBE END.
2. THIS STANDARD WAS MADE VIA PA 83-799886-01, FTI WO 11482 AND SI 39-5005364-00, FROM DESIGN DRAWING 1280475D-00, FOR FTI.
3. THE AS BUILT DIMENSIONS WERE OBTAINED FROM FTI SHOP DATA SHEETS, QCIR 99-00999 AND QCIR 99-01086.
4. EACH FLAW IS CENTERED ABOUT THE SPECIFIED AXIAL AND AZIMUTHAL LOCATIONS.
5. THE DEPTHS IN PERCENT THROUGH WALL (%TW) ARE BASED UPON THE ACTUAL MEAN WALL THICKNESS (MWT) OF THE TUBING, .042".





1 RPC GT CALIBRATION STANDARD

MAT'L: ALLOY 600, .684" O.D., .042" MEAN WALL

FILENAME: 1280795.DWG
DISK No.: OPTICAL

DWN BY MH GOWELL	CHK'D BY D PROKITY	.684 BY .042 RPC GT CALIBRATION STANDARD AS BUILT DRAWING	SCALE FULL	DATE 8/25/99
PASSED BY RG KROTKE	APP'D BY TA RIBARIC		DWG NO. 1280795 B- 0	

22159 (12/95)

DWG NO 1280796 B

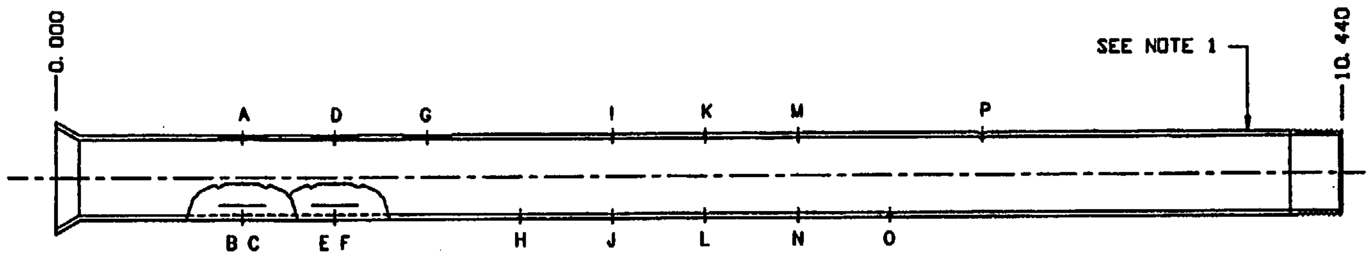
FRAMATOME TECHNOLOGIES

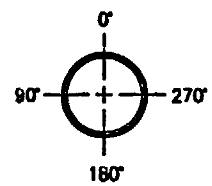
REVISIONS			
REV	DESCRIPTION	DATE	APPROVAL

FLAW LABEL	FLAW TYPE	SURFACE OF ORIGIN	AXIAL LOCATION	AZIMUTHAL LOCATION	FLAW LENGTH	WIDTH OR DIAMETER	DEPTH	DEPTH IN %TW	FLAW LABEL
A	AXIAL EDM	ID	1.500"	0°	.380"	.005"	.025"	60% TW	A
B	AXIAL EDM	ID	1.500"	120°	.380"	.005"	.017"	40% TW	B
C	AXIAL EDM	ID	1.500"	240°	.380"	.005"	.009"	21% TW	C
D	AXIAL EDM	OD	2.249"	0°	.379"	.006"	.024"	57% TW	D
E	AXIAL EDM	OD	2.247"	120°	.378"	.006"	.017"	40% TW	E
F	AXIAL EDM	OD	2.250"	240°	.378"	.006"	.009"	21% TW	F
G	AXIAL EDM	OD	2.999"	0°	.378"	.006"	THROUGH	100% TW	G
H	CIRC EDM	OD	3.747"	180°	.379"	.005"	THROUGH	100% TW	H
I	CIRC EDM	ID	4.500"	0°	.380"	.005"	.025"	60% TW	I
J	CIRC EDM	OD	4.498"	180°	.379"	.005"	.025"	60% TW	J
K	CIRC EDM	ID	5.250"	0°	.380"	.005"	.017"	40% TW	K
L	CIRC EDM	OD	5.249"	180°	.379"	.005"	.016"	38% TW	L
M	CIRC EDM	ID	6.000"	0°	.380"	.005"	.009"	21% TW	M
N	CIRC EDM	OD	5.997"	180°	.379"	.005"	.009"	21% TW	N
O	HOLE	OD	6.748"	180°	N/A	.052"	THROUGH	100% TW	O
P	DENT	OD	7.498"	0°	N/A	(.056")	.004"	10% TW	P

NOTES:

1. THE MATERIAL HEAT NUMBER, HT NX0888 , AND THE AS BUILT NUMBER, 1280796B, ARE ETCHED AT THE RIGHT TUBE END.
2. THIS STANDARD WAS MADE VIA PA 83-799886-01, FTI WO 11482 AND SI 39-5005364-00, FROM DESIGN DRAWING 1280475D-00, FOR FTI.
3. THE AS BUILT DIMENSIONS WERE OBTAINED FROM FTI SHOP DATA SHEETS, QCIR 99-00999 AND QCIR 99-01087.
4. EACH FLAW IS CENTERED ABOUT THE SPECIFIED AXIAL AND AZIMUTHAL LOCATIONS.
5. THE DEPTHS IN PERCENT THROUGH WALL (%TW) ARE BASED UPON THE ACTUAL MEAN WALL THICKNESS (MWT) OF THE TUBING, .042".





1 RPC GT CALIBRATION STANDARD

MAT'L: ALLOY 600, .684" O.D., .042" MEAN WALL

FILENAME: 1280796.DWG
DISK No.: OPTICAL

DWN BY MH GOWELL	CHK'D BY D PROKITY	.684 BY .042 RPC GT CALIBRATION STANDARD AS BUILT DRAWING	SCALE FULL	DATE 8/25/99
PASSED BY RG KROTKOL	APP'D BY TA RIBARIC		DWG NO. 1280796 B-0	

22159 (12/93)

DWG NO 1280797 B

FRAMATOME TECHNOLOGIES

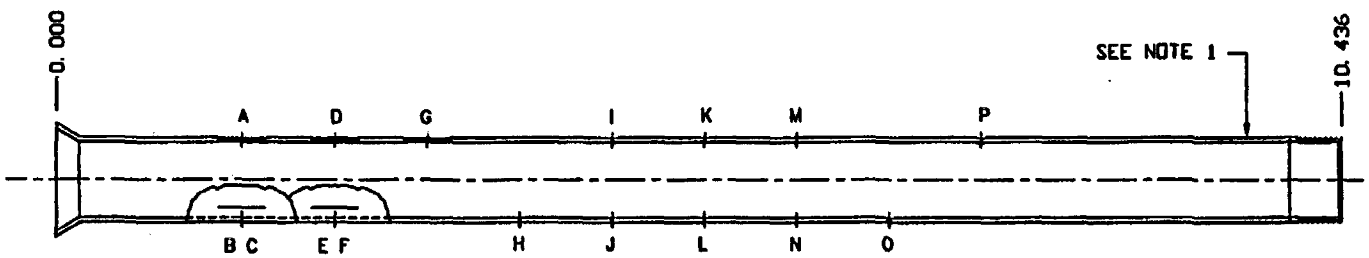
REVISIONS

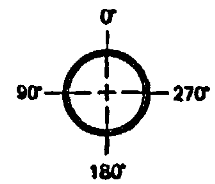
REV	DESCRIPTION	DATE	APPROVAL

FLAW LABEL	FLAW TYPE	SURFACE OF ORIGIN	AXIAL LOCATION	AZIMUTHAL LOCATION	FLAW LENGTH	WIDTH OR DIAMETER	DEPTH	DEPTH IN %TW	FLAW LABEL
A	AXIAL EDM	ID	1.500"	0°	.380"	.005"	.025"	60% TW	A
B	AXIAL EDM	ID	1.500"	120°	.380"	.005"	.017"	40% TW	B
C	AXIAL EDM	ID	1.500"	240°	.380"	.005"	.009"	21% TW	C
D	AXIAL EDM	OD	2.248"	0°	.380"	.006"	.024"	57% TW	D
E	AXIAL EDM	OD	2.248"	120°	.380"	.006"	.017"	40% TW	E
F	AXIAL EDM	OD	2.249"	240°	.380"	.006"	.009"	21% TW	F
G	AXIAL EDM	OD	2.999"	0°	.378"	.006"	THROUGH	100% TW	G
H	CIRC EDM	OD	3.748"	180°	.380"	.005"	THROUGH	100% TW	H
I	CIRC EDM	ID	4.500"	0°	.380"	.005"	.025"	60% TW	I
J	CIRC EDM	OD	4.498"	180°	.380"	.005"	.025"	60% TW	J
K	CIRC EDM	ID	5.250"	0°	.380"	.005"	.017"	40% TW	K
L	CIRC EDM	OD	5.250"	180°	.380"	.005"	.017"	40% TW	L
M	CIRC EDM	ID	6.000"	0°	.380"	.005"	.009"	21% TW	M
N	CIRC EDM	OD	6.001"	180°	.380"	.005"	.010"	24% TW	N
O	HOLE	OD	6.750"	180°	N/A	.052"	THROUGH	100% TW	O
P	DENT	OD	7.499"	0°	N/A	(.055")	.005"	12% TW	P

NOTES:

1. THE MATERIAL HEAT NUMBER, HT NX0888, AND THE AS BUILT NUMBER, 1280797B, ARE ETCHED AT THE RIGHT TUBE END.
2. THIS STANDARD WAS MADE VIA PA 83-799886-01, FTI WO 11482 AND SI 39-5005364-00, FROM DESIGN DRAWING 1280475D-00, FOR FTI.
3. THE AS BUILT DIMENSIONS WERE OBTAINED FROM FTI SHOP DATA SHEETS, QCIR 99-00999 AND QCIR 99-01093.
4. EACH FLAW IS CENTERED ABOUT THE SPECIFIED AXIAL AND AZIMUTHAL LOCATIONS.
5. THE DEPTHS IN PERCENT THROUGH WALL (%TW) ARE BASED UPON THE ACTUAL MEAN WALL THICKNESS (MWT) OF THE TUBING, .042".





1 RPC GT CALIBRATION STANDARD

MAT'L: ALLOY 600, .684" O.D., .042" MEAN WALL

FILENAME: 1280797.DWG
DISK No.: OPTICAL

DWN BY MH GOVELL	CHK'D BY TD PROKITY	.684 BY .042 RPC GT CALIBRATION STANDARD AS BUILT DRAWING	SCALE FULL / DATE 8/25/99
PASSED BY RG KROLIK	APP'D BY TA RIBART		DWG NO. 1280797 B-0

82159 (12/95)

DWG NO 1280798 B

FRAMATOME TECHNOLOGIES

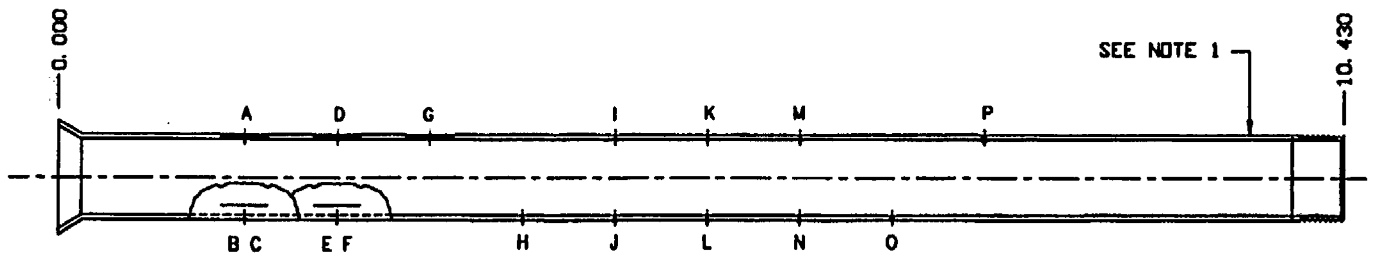
REVISIONS

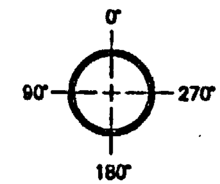
REV	DESCRIPTION	DATE	APPROVAL

FLAW LABEL	FLAW TYPE	SURFACE OF ORIGIN	AXIAL LOCATION	AZIMUTHAL LOCATION	FLAW LENGTH	WIDTH OR DIAMETER	DEPTH	DEPTH IN %TW	FLAW LABEL
A	AXIAL EDM	ID	1.500"	0°	.380"	.005"	.025"	60% TW	A
B	AXIAL EDM	ID	1.500"	120°	.380"	.005"	.017"	40% TW	B
C	AXIAL EDM	ID	1.500"	240°	.380"	.005"	.009"	21% TW	C
D	AXIAL EDM	OD	2.252"	0°	.379"	.005"	.025"	60% TW	D
E	AXIAL EDM	OD	2.248"	120°	.379"	.005"	.017"	40% TW	E
F	AXIAL EDM	OD	2.250"	240°	.379"	.005"	.009"	21% TW	F
G	AXIAL EDM	OD	3.003"	0°	.378"	.006"	THROUGH	100% TW	G
H	CIRC EDM	OD	3.752"	180°	.380"	.005"	THROUGH	100% TW	H
I	CIRC EDM	ID	4.500"	0°	.380"	.005"	.025"	60% TW	I
J	CIRC EDM	OD	4.502"	180°	.380"	.005"	.025"	60% TW	J
K	CIRC EDM	ID	5.250"	0°	.380"	.005"	.017"	40% TW	K
L	CIRC EDM	OD	5.252"	180°	.380"	.005"	.017"	40% TW	L
M	CIRC EDM	ID	6.000"	0°	.380"	.005"	.009"	21% TW	M
N	CIRC EDM	OD	6.000"	180°	.380"	.005"	.009"	21% TW	N
O	HOLE	OD	6.754"	180°	N/A	.052"	THROUGH	100% TW	O
P	DENT	OD	7.500"	0°	N/A	(.055")	.006"	14% TW	P

NOTES:

1. THE MATERIAL HEAT NUMBER, HT NX0888 , AND THE AS BUILT NUMBER, 1280798B, ARE ETCHED AT THE RIGHT TUBE END.
2. THIS STANDARD WAS MADE VIA PA 83-799886-01, FTI WO 11482 AND SI 39-5005364-00, FROM DESIGN DRAWING 1280475D-00, FOR FTI.
3. THE AS BUILT DIMENSIONS WERE OBTAINED FROM FTI SHOP DATA SHEETS, QCIR 99-00999 AND QCIR 99-01161.
4. EACH FLAW IS CENTERED ABOUT THE SPECIFIED AXIAL AND AZIMUTHAL LOCATIONS.
5. THE DEPTHS IN PERCENT THROUGH WALL (%TW) ARE BASED UPON THE ACTUAL MEAN WALL THICKNESS (MWT) OF THE TUBING, .042".





(1) RPC GT CALIBRATION STANDARD

MAT'L: ALLOY 600, .684" O.D., .042" MEAN WALL

FILENAME: 1280798.DWG
DISK No.: OPTICAL

DWN BY MH GOWELL	CHK'D BY D PROKITY	.684 BY .042 RPC GT CALIBRATION STANDARD AS BUILT DRAWING	SCALE FULL	DATE 8/25/99
PASSED BY RG KROTKE	APP'D BY TA RIBARIC		DWG NO. 1280798 B-0	

82159 (12/95)

DWG NO 1280799 B

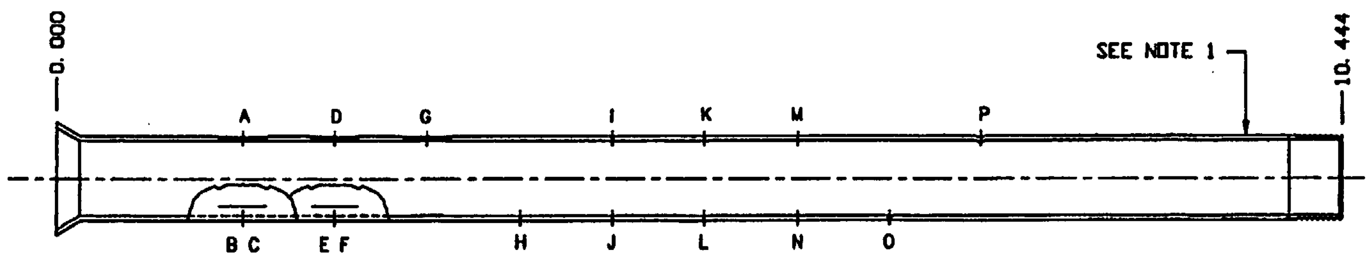
FRAMATOME TECHNOLOGIES

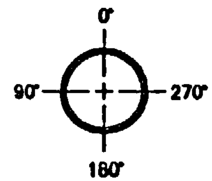
REVISIONS			
REV	DESCRIPTION	DATE	APPROVAL

FLAW LABEL	FLAW TYPE	SURFACE OF ORIGIN	AXIAL LOCATION	AZIMUTHAL LOCATION	FLAW LENGTH	WIDTH OR DIAMETER	DEPTH	DEPTH IN %TW	FLAW LABEL
A	AXIAL EDM	ID	1.500"	0°	.380"	.005"	.025"	60% TW	A
B	AXIAL EDM	ID	1.500"	120°	.380"	.005"	.017"	40% TW	B
C	AXIAL EDM	ID	1.500"	240°	.380"	.005"	.009"	21% TW	C
D	AXIAL EDM	OD	2.254"	0°	.379"	.006"	.025"	60% TW	D
E	AXIAL EDM	OD	2.254"	120°	.380"	.006"	.017"	40% TW	E
F	AXIAL EDM	OD	2.252"	240°	.380"	.006"	.009"	21% TW	F
G	AXIAL EDM	OD	3.002"	0°	.379"	.006"	THROUGH	100% TW	G
H	CIRC EDM	OD	3.750"	180°	.380"	.005"	THROUGH	100% TW	H
I	CIRC EDM	ID	4.500"	0°	.380"	.005"	.025"	60% TW	I
J	CIRC EDM	OD	4.503"	180°	.380"	.005"	.025"	60% TW	J
K	CIRC EDM	ID	5.250"	0°	.380"	.005"	.017"	40% TW	K
L	CIRC EDM	OD	5.251"	180°	.380"	.005"	.018"	43% TW	L
M	CIRC EDM	ID	6.000"	0°	.380"	.005"	.009"	21% TW	M
N	CIRC EDM	OD	6.003"	180°	.380"	.005"	.009"	21% TW	N
O	HOLE	OD	6.752"	180°	N/A	.051"	THROUGH	100% TW	O
P	DENT	OD	7.500"	0°	N/A	(.055")	.006"	14% TW	P

NOTES:

1. THE MATERIAL HEAT NUMBER, HT NX0888 , AND THE AS BUILT NUMBER, 1280799B, ARE ETCHED AT THE RIGHT TUBE END.
2. THIS STANDARD WAS MADE VIA PA 83-799886-01, FTI WO 11482 AND SI 39-5005364-00, FROM DESIGN DRAWING 1280475D-00, FOR FTI.
3. THE AS BUILT DIMENSIONS WERE OBTAINED FROM FTI SHOP DATA SHEETS, QCIR 99-00999 AND QCIR 99-01162.
4. EACH FLAW IS CENTERED ABOUT THE SPECIFIED AXIAL AND AZIMUTHAL LOCATIONS.
5. THE DEPTHS IN PERCENT THROUGH WALL (%TW) ARE BASED UPON THE ACTUAL MEAN WALL THICKNESS (MWT) OF THE TUBING, .042".





1 RPC GT CALIBRATION STANDARD

MAT'L: ALLOY 600, .684" O.D., .042" MEAN WALL

FILENAME: 1280799.DWG
DISK No.: OPTICAL

DWN BY MH GOWELL	CHK'D BY D PROKITY	.684 BY .042 RPC GT CALIBRATION	SCALE FULL · DATE 8/25/99
PASSED BY RG KROIN	APP'D BY TA RIBART	STANDARD AS BUILT DRAWING	DWG NO. 1280799 B- 0

22159 (12/95)

CALLAWAY PLANT

ENGINEERING TECNICAL PROCEDURE

ETP-BB-01309

STEAM GENERATOR EDDY CURRENT TESTING ACQUISTION AND ANALYSIS GUIDELINES

RESPONSIBLE DEPARTMENT Engineering

PROCEDURE OWNER Brad Corder

WRITTEN BY Brad Corder

PREPARED BY Brad Corder

APPROVED BY T. E. Herrmann

DATE ISSUED 1-23-03

This procedure contains the following:

Pages	1	through	22
Attachments	1	through	18
Tables		through	
Figures		through	
Appendices		through	
Checkoff Lists		through	

This procedure has 0 checkoff list(s) maintained in the mainframe computer.

Conversion of commitments to TRS reference/hidden text completed by Revision Number:

Non-T/S Commitments ______

67

DEFICIENCY LIST

Section	Deficiency Description	Constraints

TABLE OF CONTENTS

TABLE OF CONTENTS

STEAM GENERATOR EDDY CURRENT TESTING ACQUISTION AND ANALYSIS GUIDELINES

1 PURPOSE AND SCOPE

1.1 The purpose of this guideline is to provide instructions for the acquisition and analysis of steam generator eddy current data at AmerenUE's Callaway Nuclear Power Plant, and to define the technique and specific requirements applicable to that analysis.

1.2 This guideline is to be followed for any eddy current testing of any of the four steam generators. Deviation from this guideline is only allowed at the discretion of the Callaway Steam Generator Activity Coordinator.

1.3 This procedure satisfies the surveillance requirements set forth in Technical Specifications. **T/S SR 3.4.13.2 T/S AC 5.5.9**

1.4 In general, it is AmerenUE's intent to adhere to the guidance provided in the EPRI PWR Steam Generator Examination Guidelines, Revision 5, including inspection scope and expansion criteria (**COMN 5846**)). Specific examination criteria and points of deviation from these guidelines are provided in the S/G Strategic Plan for Callaway (Nuclear Division Policy UEND-STRATEGY-02).

2 NOTES AND PRECAUTIONS

2.1 Callaway's steam generators are Westinghouse Model F. They are designated by the plant as E-BB-01A, B, C, and D (Westinghouse serial numbers SAGT-2234, 2231, 2232, and 2233 respectively). Specific details of the steam generator design are provided as Attachment 1, Westinghouse Model F Steam Generator General Information.

2.2 Callaway began commercial operation December 19, 1984 and has operated through eleven fuel cycles. In addition to a 100% pre-service inspection, there have been ten previous in-service inspections. Results of these examinations are detailed in Attachment 2, Previous Inspection History.

2.3 All techniques used **SHALL** be qualified in accordance with Appendix H of the EPRI PWR Steam Generator Examination Guidelines, Revision 5. **(COMN 43346)**) The primary vendor **SHALL** supply documentation of Appendix H equivalency for all anticipated techniques prior to the inspection.

2.4 There have been numerous industry events associated with leaking tube plugs. Each time the primary channel head is opened, a remote visual inspection of all installed tube plugs should be performed to look for any indication of leakage. Results of this inspection should be documented on Attachment 8, Installed Steam Generator Tube Plug Inspection, and filed at E170.0110.

2.4.1 Personnel signing Attachment 8 for the plug visual inspection will be knowledgeable in the area of tube plug leakage and be certified in accordance with ANSI 45.2.6 Visual/Mechanical certification.

2.5 Foreign objects have damaged tubes at a number of plants, including Callaway. For this reason, Foreign Object Search and Retrieval (FOSAR) is generally performed for the secondary tubesheet each outage. Results of these inspections should be documented on Attachment 9, Steam Generator Secondary Side Foreign Object Search and filed at E170.0110.

3 PERSONNEL QUALIFICATIONS

3.1 All personnel involved with the acquisition and interpretation of steam generator eddy current data during this inspection **SHALL** be qualified per ASME Section XI to the appropriate level of ASNT Recommended Practice No. SNT-TC-1A-1984, Nondestructive Testing Personnel Qualifications and Certification. **(COMN 5594)**

3.2 In addition to the above, all personnel involved in data analyses MUST have received specific training in the identification and evaluation of steam generator damage mechanisms and be qualified to Level IIA or higher.

3.3 All analysts evaluating Callaway data **MUST** be currently qualified as a Qualified Data Analyst (QDA), in accordance with Appendix G of the EPRI PWR Steam Generator Examination Guidelines, Revision 5. In addition, the analysts are required to successfully complete a site specific performance demonstration and test to be conducted in accordance with directions provided by the AmerenUE Contract Administrator. Results of the analyst performance demonstration are to be provided to the Contract Administrator, who will forward them to the appropriate file (E170.0110).

3.4 <u>SSPD REQUIREMENTS</u>

To be considered qualified to analyze data at Callaway the analyst **MUST** pass a written, a bobbin practical and an RPC practical exam. If the student fails the first test, then a second exam will be available. If the student fails both written tests, they will not be permitted to analyze data. If they fail two practical exams, they will not be allowed to analyze data of this probe type. For instance, if an analyst passes the written and bobbin practical exams, but fails two RPC practical exams, they will be limited to only performing bobbin analysis.

3.4.1 A grade of at least 80% is required to pass the written exam.

1.1.2 The following criteria are required to pass the bobbin practical exam:

3.4.2.1 A POD of at least 80%, at a 90% confidence level for $\geq$ 38% throughwall indications

3.4.2.2 Detection of at least 80% of I-codes, PLP's and <38% throughwall indications

3.4.2.3 The number of overcalls can be no more than 10% of the total number of intersections.

3.4.3 The following criteria are required to pass the RPC practical exam:

3.4.3.1 A POD of at least 80%, at a 90% confidence level for axial, circumferential and volumetric indications

3.4.3.2 The number of overcalls can be no more than 10% of the total number of unflawed intersections. An overcall is defined as a call or calls at an unflawed intersection. Multiple calls at a given intersection will not be counted as additional overcalls.

3.4.3.3 The correct orientation must be reported on at least 80% of the indications.

4 ACQUISITION GUIDELINES

All steam generator eddy current data is to be acquired per the applicable Examination Technique Specification Sheet (ETSS). A typical ETSS sheet can be found in Attachment 10. No technique can be used without the prior approval of the Callaway Steam Generator Activity Coordinator or his designee. Prior to implementation, each technique MUST be reviewed by, and receive the concurrence of, an independent QDA.

The calibration standards and setup parameters to be used for each acquisition technique SHALL be specified on the ETSS.

4.1 BOBBIN COIL PROBES

4.1.1 Optimal probe size is 0.560 inch with 0.540 or 0.520 inch allowed for tight U-bend tubes or where a 0.560 inch probe has difficulty transversing. No probe smaller than 0.520 inch should be used without the prior approval of the Callaway Steam Generator Activity Coordinator or his designee.

4.1.2 Calibration runs should be made using specified standards.

4.1.3 Calibration standard runs are required every 4 hours. Calibration standard runs should be made at the beginning and end of each data set and anytime a piece of equipment (i.e. probe, cable, ten footer) is replaced such that the signal path from the probe to the computer is affected.

4.1.4 All tubes should be tested full length from tube end-hot to tube end-cold. Those hot leg portions inaccessible from the cold leg should be tested from 07H to tube end hot from the hot leg. Full length testing from the hot leg may be performed with prior approval of the Callaway Steam Generator Activity Coordinator.

4.1.5 DATA QUALITY (NOISE)

The following systematic approach to evaluate probe related noise is to ensure a degree of data quality which allows for the detection of small amplitude signals.

4.1.5.1 Analysts, using their experience and system knowledge, can elect to have a bobbin probe replaced if they determine the ability to detect and/or size indications has been hindered due to signal quality.

4.1.5.2 "Control tubes" within the steam generator should be used for signal quality determinations. These tubes are to be identified for each region of the inspection plan to facilitate ease of access without major impact on robot manipulations. The Lead Analyst or his designee will select the control tubes.

4.1.5.3 The following steps are repeated for each new bobbin probe. These steps may be performed by either primary data analysis or acquisition personnel, at the primary inspection vendor's option.

4.1.5.3.1 Data from a control tube should be recorded to a minimum of two support plate elevations at the nominal inspection speed.

4.1.5.3.2 Control tube entries are to be recorded at the start and end of each data set with a new probe, and at the end of each subsequent data set for that probe.

4.1.5.3.3 Set a location scale for the tube. This may be done manually or with an auto-locate feature.

4.1.5.3.4 The area for measuring signal quality is defined by the Level III.

4.1.5.3.5 Verify that this section of tube is free from degradation, denting and permeability variations. If not, designate an alternative portion of the tube for measuring signal quality.

4.1.5.3.6 Record the location chosen for measurements on the Control Tube Log Sheet, Attachment 11.

4.1.5.3.7 At the designated location perform a volts peak-to-peak, Vpp, measurement using the prime differential channel.

4.1.5.3.8 Ensure the expanded strip chart window is completely open prior to assigning the measurement dots.

4.1.5.3.9 Record the measured value on the Control Tube Log Sheet.

4.1.5.3.10 Perform a volts vertical maximum, Vvm, measurement from the prime frequency differential channel.

4.1.5.3.11 Again, ensure the expanded strip chart window is completely open prior to assigning the measurement dots.

4.1.5.3.12 Record the measured value on the Control Tube Log Sheet.

4.1.5.3.13 Calculate the limit values for the two measurements using the equations below. Record the values in the appropriate columns on the control tube log sheet.

4.1.5.3.14 $Vpp_{limit} = (2.0) \times Vpp_{initial}$

4.1.5.3.15 $Vvm_{limit} = 0.3 + Vvm_{initial}$

4.1.5.3.16 When subsequent checks of signal quality, for a given probe, exceed the calculated limits, a bobbin probe change is required.

4.1.5.3.17 Should plant conditions, external to the eddy current system, exist which negate the above equations, these equations may be modified by the Lead Analyst, with written approval of the Callaway Steam Generator Activity Coordinator or his designee. Any such revision will be noted on the Control Tube Log Sheet.

4.1.5.4 Compare the end calibration standard responses to the initial settings for each data set. Changes in phase shall be limited to +/- 5 degrees and changes in amplitude shall be limited to +/- 20%. (If there is no end calibration, use support structures in tubes for verification.)

4.1.5.5 The data should remain within the dynamic range of the tester, i.e. no saturation.

4.1.5.6 Spiking **SHALL** be limited to ≤ 1 spike per 12 inches and on < 2 frequencies.

4.2 ROTATING COIL (RPC) PROBES

4.2.1 ROTATING COIL CALIBRATION STANDARDS

The minimum rotating coil calibration standard requirements for inspection of non-sleeved tube regions are defined below. The inspection of sleeved tube regions require alternative calibration standards, which are based on the anticipated mode(s) of degradation.

4.2.1.1 Electro-discharge machining (EDM) notch standards are used to establish setup conditions for rotating probe techniques. The following notches **SHALL** be used as a minimum.

4.2.1.1.1 100% axial and circumferential notches with a minimum length of 0.375" and a width of 0.005" (+.001" -.002")

4.2.1.1.2 40% inside diameter (ID) axial and circumferential notches with a minimum length of 0.375" and a width of 0.005" (+.001" -.002")

4.2.1.1.3 40% outside diameter (OD) axial and circumferential notches with a minimum length of 0.375" and a width of 0.005" (+.001" -.002")

4.2.1.2 If depth sizing of circumferential indications is performed utilizing fit curves, the following additional notches are required:

4.2.1.2.1 60% ID circumferential notch with a minimum length of 0.375" and a width of 0.005" (+.001" -.002")

4.2.1.2.2 20% ID circumferential notch with a minimum length of 0.375" and a width of 0.005" (+.001" -.002")

4.2.1.2.3 60% OD circumferential notch with a minimum length of 0.375" and a width of 0.005" (+.001" -.002")

4.2.1.2.4 20% OD circumferential notch with a minimum length of 0.375" and a width of 0.005" (+.001" -.002")

4.2.1.3 If depth sizing of axial indications is performed utilizing fit curves, the following additional notches are required:

4.2.1.3.1 60% ID axial notch with a minimum length of 0.375" and a width of 0.005" (+.001" -.002")

4.2.1.3.2 20% ID axial notch with a minimum length of 0.375" and a width of 0.005" (+.001" -.002")

4.2.1.3.3 60% OD axial notch with a minimum length of 0.375" and a width of 0.005" (+.001" -.002")

4.2.1.3.4 20% OD axial notch with a minimum length of 0.375" and a width of 0.005" (+.001" -.002")

4.2.1.4 It is preferable that standards include a lift-off reference signal to facilitate evaluation of signals influenced by local profile changes.

4.2.2 DATA QUALITY

4.2.2.1 The responses from the notches in section 4.2.1.1 should be clearly discernable from background noise for all mid-range coils (pancake or +point). If 20% OD circumferential and axial notches are present on the standard, these should also be clearly discernable with a mid-range +point coil. If noise is present to the extent that it prevents meeting this requirement, logical troubleshooting should be performed to eliminate or reduce the noise to acceptable levels.

4.2.2.2 For multiple coil probe heads, all coils used in the referenced Appendix H qualification ETSS's are required to be active for the data acceptable.

4.2.2.3 The following limitations are applicable to both the standard runs and to the area of interest as defined on the ETSS.

4.2.2.3.1 Electrical noise or spiking shall be limited to ≤ 1 spike per 10 consecutive revolutions on < 2 frequencies.

4.2.2.3.2 No more than one skip or rotational stop per 30 scan lines.

4.2.2.3.3 The data should remain within the dynamic range of the tester, i.e. no saturation.

4.2.2.4 Compare the end calibration standard responses to the initial settings for each data set. Changes in phase shall be limited to +/- 5 degrees and changes in amplitude shall be limited to +/- 20%.

4.2.2.5 Analysts, using their experience and system knowledge, can elect to have an RPC probe replaced if they determine the ability to detect indications has been hindered due to signal quality.

4.2.3 RPC PROBE REQUIRED TEST EXTENTS

4.2.3.1 To ensure the area of interest is tested, supplemental RPC inspections of free span bobbin I-code indications will be conducted from steam generator landmark to steam generator landmark.

4.2.3.2 For Westinghouse Laser Welded Sleeves, data will be acquired 2.00" above and below the sleeve ends.

4.2.3.3 For tubesheet examinations, the minimum required test extent shall be in accordance with the Degradation Assesssment.

4.2.3.4 For tube support plate examinations, the minimum required test extent shall be from TSP –1.50" to TSP +1.50".

4.3 PROBE AUTORIZATION

4.3.1 Only probe types authorized via an approved ETSS are to be used for a given inspection plan.

4.3.2 No probe type may be used without the prior approval of the Callaway Steam Generator Activity Coordinator or his designee.

4.4 SAMPLE RATES

4.4.1 Digitization Rate (Samples/inch) =

Sample Rate(Samples/Second) / Probe Speed (inches/Second)

4.4.2 Bobbin Coil Probes

4.4.2.1 Minimum Digitization Rate = 33 Samples/Inch (axial direction).

4.4.3 RPC Probes

4.4.3.1 Rotating coil minimum digitization rates MUST be 30 samples per inch circumferentially and 25 samples per inch axially.

4.4.3.2 Refer to Attachment 7 for digitization rate requirements for RPC sizing.

4.5 LOST TIME

4.5.1 The Contractor should notify the steam generator shift coordinator any time that problems arise (due to Contractor or AmerenUE) which cause "lost time" greater than one hour. This and lost time less than one hour should be logged by Contractor and a summary provided to AmerenUE upon completion of the work.

5 ANALYSIS GUIDELINES

5.1 RESPONSIBILITIES

5.1.1 LEAD ANALYST

5.1.1.1 The Lead Analyst is the lead contractor representative responsible for the data analysis performed by the analysts. The Lead Analyst is the primary point of contact to AmerenUE for eddy current data analysis services.

5.1.1.2 The Lead Analyst will document any clarifications necessary to the Analysis Guidelines and obtain approval from the Callaway Steam Generator Activity Coordinator. The Analysis Guidelines Clarification Form in Attachment 13 should be used to document these items.

5.1.1.3 The Lead Analyst is responsible for notifying and receiving acknowledgement of guideline changes from all the data analysts by attaching the Guidelines Clarification Acknowledgement Form (Attachment 14) to the Analysis Guidelines Clarification Form. This form is used to document that all data analysts are aware of any modifications to the Analysis Guidelines.

5.1.1.4 The Lead Analyst coordinates data resolution analysis and may act as a Resolution or Primary Analyst.

5.1.1.5 The Lead Analyst or his designee reviews all repairable indications that were accepted or overruled by resolution analysts.

5.1.1.6 The Lead Analyst provides input for tube-pull and in-situ pressure testing as directed by AmerenUE.

5.1.2 RESOLUTION ANALYST

5.1.2.1 The primary and secondary Resolution Analysts are responsible for resolving data analysis discrepancies between the Primary and Secondary Analysts.

5.1.2.2 Resolution Analysts are responsible for alerting the Lead Analyst to conditions present in the data, which are not addressed in the guidelines. This may be accomplished via the Analyst Concerns Form (Attachment 15).

5.1.2.3 Resolution Analysts may act as Primary or Secondary Analysts, but are not allowed to resolve data for which they were one of the production analysts. (Unless given special permission by the Callaway Steam Generator Activity Coordinator for special situations).

5.1.3 PRIMARY/SECONDARY ANALYST

5.1.3.1 Primary/Secondary Analysts are responsible for evaluating the data in accordance with these Guidelines.

5.1.3.2 Primary/Secondary Analysts are responsible for alerting the Shift Lead Analyst to conditions present in the data, which are not addressed in the guidelines. This may also be accomplished via the Analyst Concerns Form (Attachment 15).

5.1.3.3 Primary/Secondary Analysts are responsible for addressing history (prior inspection results) except INR or INF which need not be addressed.

5.1.4 SHIFT LEAD ANALYST AT REMOTE ANALYSIS SITE

5.1.4.1 Shift Lead Analysts are designated for each shift at the primary and secondary analysis sites. The Shift Lead Analyst is responsible for coordination of data analysis on their work shift.

5.1.4.2 Shift Lead Analysts act as either a Primary or Secondary Analyst when evaluating data at their respective remote sites.

5.1.4.3 Shift Lead Analysts ensure that all analysts on their shift are informed of any guideline changes.

5.1.4.4 Shift Lead Analysts are responsible for alerting the Lead Analyst to conditions present in the data, which are not addressed in the guidelines. This may also be accomplished via the Analyst Concerns Form (Attachment 15).

5.1.5 <u>INDEPENDENT QDA</u>

5.1.5.1 AmerenUE **MUST** assign an Independent QDA to oversee aspects of the steam generator inspection. The Independent QDA will review any acquisition technique prior to implementation.

5.1.5.2 The Independent QDA **MUST** randomly sample the inspection results to ensure that the resolution process was properly performed and that the field calls were properly reported.

5.1.6 <u>PRIMARY&SECONDARY VENDOR</u>

5.1.6.1 Both the primary and secondary vendors working at Callaway and at remote analysis sites MUST provide an environment conducive to effective human performance. To achieve this goal, each vendor SHALL develop a written policy and conspicuously post it in the data room.

5.1.6.2 The Lead Analyst is responsible for enforcing the data room policy on site.

5.1.6.3 The Shift Lead Analysts are responsible for enforcing the data room policy at the remote analysis sites.

5.2 <u>CALIBRATION</u>

All steam generator eddy current data is to be analyzed per the applicable ETSS. As stated in Step 2.3, all techniques used **MUST** be qualified in accordance with Appendix H of the EPRI PWR Steam Generator Examination Guidelines, Revision 5. No technique may be used without the prior approval of the Callaway Steam Generator Activity Coordinator or his designee. **(COMN 43346)**)

5.2.1 Phase angle and voltage measurements should be performed as follows:

5.2.1.1 Phase angle measurements should be made utilizing volts peak to peak or max rate. Selection should be based on whichever technique assigns an angle along the signal transition line more accurately.

5.2.1.2 Voltage measurements for AVBs should be performed utilizing vertical max for calibration and sizing based on amplitude.

5.2.1.3 The use of guess angle should be kept to a minimum and only used when volts peak to peak or max rate do not give a good representation of the signal phase angle.

5.2.2 Other mixes not specified on the ETSS may be set up as required by the data analyst to further evaluate indications.

5.2.3 All calibration curves should be established using "as built" dimensions. The use of artificial curves (set 4.1) is prohibited.

5.3 EVALUATION (BOBBIN COIL)

5.3.1 The evaluation should consist of reviewing lissajous and strip chart displays to the extent that all tube wall degradation and other signals as defined by this document are reported and dispositioned in accordance with the requirements of this guideline.

5.3.2 Set lissajous to display channel 1 or P1. Set strip charts to display the vertical component of P1 and the vertical component of channel 6. Additional strip chart and lissajous displays may be employed at the analyst's discretion.

5.3.3 Any indication should be evaluated using other frequencies to ensure proper phase rotation.

5.3.4 Phase angle and voltage measurements should be consistent with Section 5.2.1.

5.3.5 Indications should be evaluated as follows:

NOTE:	The assignment of bobbin through-wall percentages MUST be limited to AVB wear indications only.

5.3.5.1 AVB Wear - AVB wear can be detected by using P1 or P2. AVB wear will be reported as a percent using P2 vertical max. If a bobbin inspection is performed without an AVB wear standard, indications of AVB wear should be reported as RWS, (Retest AVB Wear Standard). All RWS indications should be retested with an AVB wear standard. P4 should be used to size AVB wear calls that measure greater than 40%.

5.3.5.2 Indications in the tube free span - ODSCC or IGA has been detected in free span tubing at a few plants with Westinghouse model steam generators. Although, ODSCC or IGA has not been detected in the free span at Callaway, analysts must evaluate closely all free span areas of the tubes. Channel 3 should be used to locate free span indications. If a free span indication is indicative of ODSCC or IGA, it should be reported as NQI, using channel 1 or P1. Also, the Free Span Bobbin Coil Indication Flow Chart (Attachment 16) should be consulted when reporting DFI or ADI.

5.3.5.2.1 If there is a previous MBM, DFS, MBH, or FSH call at a current ADI or DFI's location then the history review should compare to RF9 for steam generators B and C and to RF10 for steam generators A and D. If no previous call exists then compare to data from RF5 for steam generators B and C, and to data from RF6 for steam generators A and D. The setup calibration for the historical data may need to be altered to match the current ETSS, prior to comparison of signals.

5.3.5.2.2 When a signal being subjected to a history review has changed, but the signal's change does not meet the parameters specified on the Free Span Bobbin Indication Flow Chart, the analyst may still report the signal with the appropriate I-code, if he feels the change is significant enough to warrant further testing.

5.3.5.2.3 Volts peak-to-peak (Vpp) is the preferred measurement type for free span indications. Volts max rate (Vmr) is only permitted on differential channels when straight transition signals are evaluated. Vmr should never be used on an absolute channel.

5.3.5.2.4 Ranging of ADI and DFI calls is permitted when multiple signals are present.

5.3.5.3 Tube support plate intersections should be evaluated using channel 3 and P1. Indications in this region should be reported as DSI from P1.

5.3.5.4 PWSCC or ODSCC in tubesheet and at the top of tubesheet - Indications at the top of tubesheet and within the tubesheet will be reported as DTI using P1. Indications above the top of tubesheet will be reported as NQI using P1. The bobbin indications above the top of tubesheet in the sludge region may be influenced by deposit signals. For this reason, these indications should be reported as NQI from P1.

5.3.5.5 Free span ding signals should be scrutinized for distortions indicative of possible degradation. Any ding-like signal measuring $\leq$ 155 degrees on channel 5 should be reported as DDI. Also, the Ding Signal Disposition Flow Chart (Attachment 18) should be consulted when reporting DDI's. The reporting of DDI's should be limited to the mill-annealed tubes, row 11 and higher. ODSCC at dings has only been observed in mill-annealed tubing. In thermally-treated tubing, dings undergo a localized permeability change during the early operating cycles which cause the signal to rotate up off horizontal.

5.3.5.6 Loose parts and damage from loose parts have been observed during previous inspections at Callaway. The lower frequency absolute channels 6 and 8 should be reviewed for evidence of possible loose parts (report as PLP from channel 8). Loose part damage should be reported as LPI from channel 1 or P1, whichever best represents the indication.

5.3.5.7 Indications for which the analyst feels there is no specific criteria in this document should be noted as LAR (Lead Analyst Review). The Resolution Analysts must resolve this indication appropriately, with assistance from the Lead Analyst as required.

5.3.6 All bobbin I-code indications (i.e. DDI, DSI, DTI, NQI), that are not dispositioned via a history review will be RPC tested. The probe type(s) to be used for these special interest inspections will be specified on the ETSS sheets.

5.3.7 Axial locations in the hot leg should be reported in a positive direction from supports, AVBs, tube sheet, and tube end up to but not including 07C.

5.3.8 Axial location in the cold leg should be reported in a positive direction from supports, tubesheet, and tube end up to 07C.

5.3.9 Indications MUST be measured from the center of tube supports, AVB intersections, top-of-tubesheet or tube end, as appropriate. Negative measurements are permitted within 2.0 inches of the centerline of a landmark.

5.4 RECORDING CRITERIA

5.4.1 The following information will be recorded for the final analysis report:

5.4.1.1 For each tube evaluated an entry must be made that, as a minimum, contains SG, ROW, COL and EXTENT tested.

5.4.1.2 Each indication reported MUST contain SG, ROW, COL, VOLTS, DEG, % or applicable three letter code, CH#, LOCATION and EXTENT tested.

5.4.1.3 The extent tested for a restricted tube (report as RRT) should be reported as the last complete support location. A message from the data collector is the only way to call a tube restricted.

5.4.2 All indications of tube wall degradation meeting the following criteria should be recorded:

5.4.2.1 There is no minimum voltage requirement for reporting of indications.

5.4.2.2 Dents and dings greater than or equal to 2.0 volts peak to peak should be recorded. At tube support plate intersections with two dent indications (top and bottom) both dents should be recorded. Dings (DNG) should be called in free span areas using channel 1, and dents (DNT) should be called in tube support plate or tubesheet areas using P1. At a minimum, 20% of the dents and dings 2.0 volts and greater will be RPC inspected.

5.4.2.3 Permeability variations (PVN) greater than or equal to 5.0 volts peak to peak should be recorded using channel 1. Care should be taken when evaluating permeability variation signals to ensure that they are not masking an indication of through-wall degradation.

5.4.2.4 Sludge (SLG) depth (when present) should be recorded using the 30 kHz absolute response.

5.4.2.5 Copper (CUD) residual greater than or equal to 2.0 volts peak to peak should be recorded using channel 1.

5.4.2.6 Inside diameter chatter (IDC) greater than or equal to 5.0 volts peak to peak should be recorded using channel 1.

5.4.2.7 All other indications or signals which are considered to be distorted, non-quantifiable, undefined and/or damage precursors should be recorded. This includes but is not limited to those indications listed in Attachment 4, Indication Codes.

5.4.3 Actual tested extents should be recorded as the beginning landmark code followed by the end landmark code. For example, TEHTEC would be the test extent for a full length test acquired from the cold leg.

5.4.4 All locations and/or length measurements should be recorded in one-hundredths (0.00) of an inch.

5.4.5 The requirements for graphics plots will be determined by the Lead Analyst, with the approval of the Callaway Steam Generator Activity Coordinator.

5.5 <u>EVALUATION AND RECORDING CRITERIA(ROTATING COIL)</u>

5.5.1 The evaluation will consist of reviewing lissajous, strip charts and C-Scan displays to the extent that all tube wall degradation is identified. Specific evaluation instructions are divided, as follows, by probe model.

5.5.1.1 <u>+Point-560-115-36-S80 or M+Point-560-115-36-S80</u> C-Scan plotting is required for the 300kHz raw channel and the 300kHz process channel over the entire data collected. For signals of interest, the corresponding lissajous display should be reviewed. Additionally, C-Scan plots of the .115" pancake coil's 300kHz channel and the .080" HF pancake coil's 600kHz channel should be reviewed in the area of interest.

5.5.1.2 <u>M+Pt-500/520-MRPC-FH-52PH</u> C-Scan plotting is required for the 300kHz raw channel and the 300kHz process channel over the entire data collected. For signals of interest, the corresponding lissajous display should be reviewed.

5.5.1.3 M+Pt-500/520-MRPC-HFMB-+Pt-FH/PH C-Scan plotting is required for the 300kHz raw channel and the 800/600/300kHz process channel over the entire data collected. For signals of interest, the corresponding lissajous display should be reviewed.

5.5.1.4 0.115MRPC-560-3C C-Scan plotting is required for the .115" pancake coil's 300kHz channel over the entire data collected. For signals of interest, the corresponding lissajous display should be reviewed. Additionally, C-Scan plots of the axial and circumferential directional coils should be reviewed in the area of interest.

5.5.1.5 M+PT-460-GPP-3PH C-Scan plotting is required for the 240/170/80 kHz raw channel and the 240/170/80 kHz process channel over the entire data collected. For signals of interest, the corresponding lissajous display should be reviewed.

5.5.1.6 0.480 (608/504) 2 Coil Delta P/H (0.115/+Point) C-Scan plotting is required for the +point 300kHz raw and the 300 kHz process channels over the entire data collected. For signals of interest, the corresponding lissajous display should be reviewed. Review of additional coils shall be performed as appropriate in order to assure adequate evaluation of the complete data record.

5.5.1.7 0.500 1 coil +PT (Self-Referencing) Refer to the ETSS for specific data screening instructions.

5.5.2 Probe travel and rotational speeds should be checked by the data analyst for all tubes collected.

5.5.3 The following information will be recorded for the final analysis report:

5.5.3.1 For each tube evaluated an entry must be made that, as a minimum, contains SG, ROW, COL and EXTENT tested.

5.5.3.2 Each indication reported should contain SG, ROW, COL, VOLTS, DEG, % or applicable three letter code, CH#, LOCATION and EXTENT tested.

5.5.3.3 The extent tested for a restricted tube (report as RRT) should be reported as the last complete support location. A message from the data collector is the only way to call a tube restricted.

5.5.4 Any indication of tube wall degradation should be recorded.

5.5.5 Rotating Coil indications will not be reported as a percent through-wall depth, but will be assigned an acronym indicative of the orientation and number of flaws in a given location plane. A list of acceptable acronyms can be found in Attachment 4.

5.5.6 The requirements for graphics plots will be determined by the Lead Analyst, with the approval of the Callaway Steam Generator Activity Coordinator.

5.5.7 Length and depth sizing of crack-like indications may be required as supplemental information. In this case, sizing instructions can be found in Attachment 7.

5.6 DATA FLOW AND RESOLUTIONS

A data flow diagram can be found in Attachment 6.

5.6.1 All eddy current data sets are subject to two separate independent analyses (primary and secondary).

5.6.2 Discrepancies, between the two analysis parties, as defined in Attachment 3, **MUST** be resolved by a joint review of the data by two Resolution Analysts.

5.6.3 One of the Resolution Analysts will represent the primary analysis team, while the other Resolution Analyst will represent the secondary analysis team.

5.6.4 The resolution of any reported indication of degradation (I-Codes and greater than or equal to 20% TWD), whether accepted or rejected, must have the concurrence of both Resolution Analysts. When an indication of degradation is accepted or overruled, both Resolution Analysts will initial the compare sheet.

5.6.5 All repairable indications that are accepted by the Resolution Analysts will be reviewed by the Lead Analyst or his designee.

5.6.6 The Independent QDA will review all repairable indications accepted or overruled by the Lead Analyst.

5.6.7 If the Resolution Analysts can not agree upon an indication's disposition, then the Lead Analyst will perform the resolution with the concurrence of the Independent QDA.

5.7 ANALYSIS FEEDBACK REQUIREMENTS

5.7.1 This process is not intended to change the resolution process, but to improve the consistency of the data analysts and provide direct feedback to the resolution process.

5.7.2 The final resolved analysis results will be compared with the primary results and the secondary results. The comparison MUST identify missed indications and overcalls.

5.7.3 Each analyst MUST review their missed indications and a sample of their overcalls. The sample will consist of at least 20% of their overcalls.

5.7.4 If the Primary or Secondary Analyst disagrees with the Resolution Analysts' call, either analyst may request that the Lead Analyst reconsider the call.

5.7.5 Calls requested to be reconsidered, which the Lead Analyst feels should remain as originally reported, will be reviewed by the Independent QDA and appropriate action taken.

5.8 REPORTING CRITERIA

5.8.1 All completed data should be submitted to AmerenUE at 0600 daily.

5.8.2 Status reports of tubes acquired and evaluated the previous 24 hours should be submitted to AmerenUE at 0600 daily.

5.8.3 A log of the Compare Sheets should be maintained for the review of the Independent QDA.

5.9 DATA REQUIRED FOR TURNOVER (PRIMARY CONTRACTOR)

5.9.1 Copies of all graphics plots made are to be turned over at the end of the inspection.

5.9.2 One copy of the optical disks should be turned over at the end of the inspection.

5.9.3 Documentation as specified in Specification S-1032(Q). The final field reports, which contain the complete examination record, will be filed at E170.0110.

5.9.4 Color coded tubesheet map graphical presentations should be provided by the primary vendor as follows:

1. AVB Indications in each steam generator.

   <20% #tubes
   20-29% #tubes
   30-39% #tubes
   > 40% #tubes

2. Tubes plugged this outage for each steam generator, with existing plugs.

3. Non-quantifiable indications

   DSI ADI SCI MVI MAI DDI

   DTI SAI MCI NQI SVI

6 RECORDS

6.1 QA RECORDS

6.1.1 Analyst performance demonstration results (E170.0110)

6.1.2 Final examination field report and original copies of data media (E170.0110)

6.1.3 Attachment 8, Installed Steam Generator Tube Plug Inspection (E170.0110)

6.1.4 Attachment 9, Steam Generator Secondary Side Foreign Object Search (E170.0110)

7 ATTACHMENTS

7.1 Attachment 1, Westinghouse Model F Steam Generator General Information

7.2 Attachment 2, Previous Inspection History

7.3 Attachment 3, Criteria for Identification of Discrepancies and Errors

7.4 Attachment 4, Indication Codes and Definitions

7.5 Attachment 5, has been deleted

7.6 Attachment 6, Steam Generator Eddy Current Testing Data Flow

7.7 Attachment 7, Length and Depth sizing of Crack-like Indications

7.8 Attachment 8, Installed Steam Generator Tube Plug Inspection

7.9 Attachment 9, Steam Generator Secondary Side Foreign Object Search

7.10 Attachment 10, Typical Examination Technique Specification Sheet (ETSS)

7.11 Attachment 11, Control Tube Log Sheet

7.12 Attachment 12, has been deleted

7.13 Attachment 13, Analysis Guidelines Clarification Form

7.14 Attachment 14, Analysis Guidelines Clarification Acknowledgement Form

7.15 Attachment 15, Analyst Concerns Form

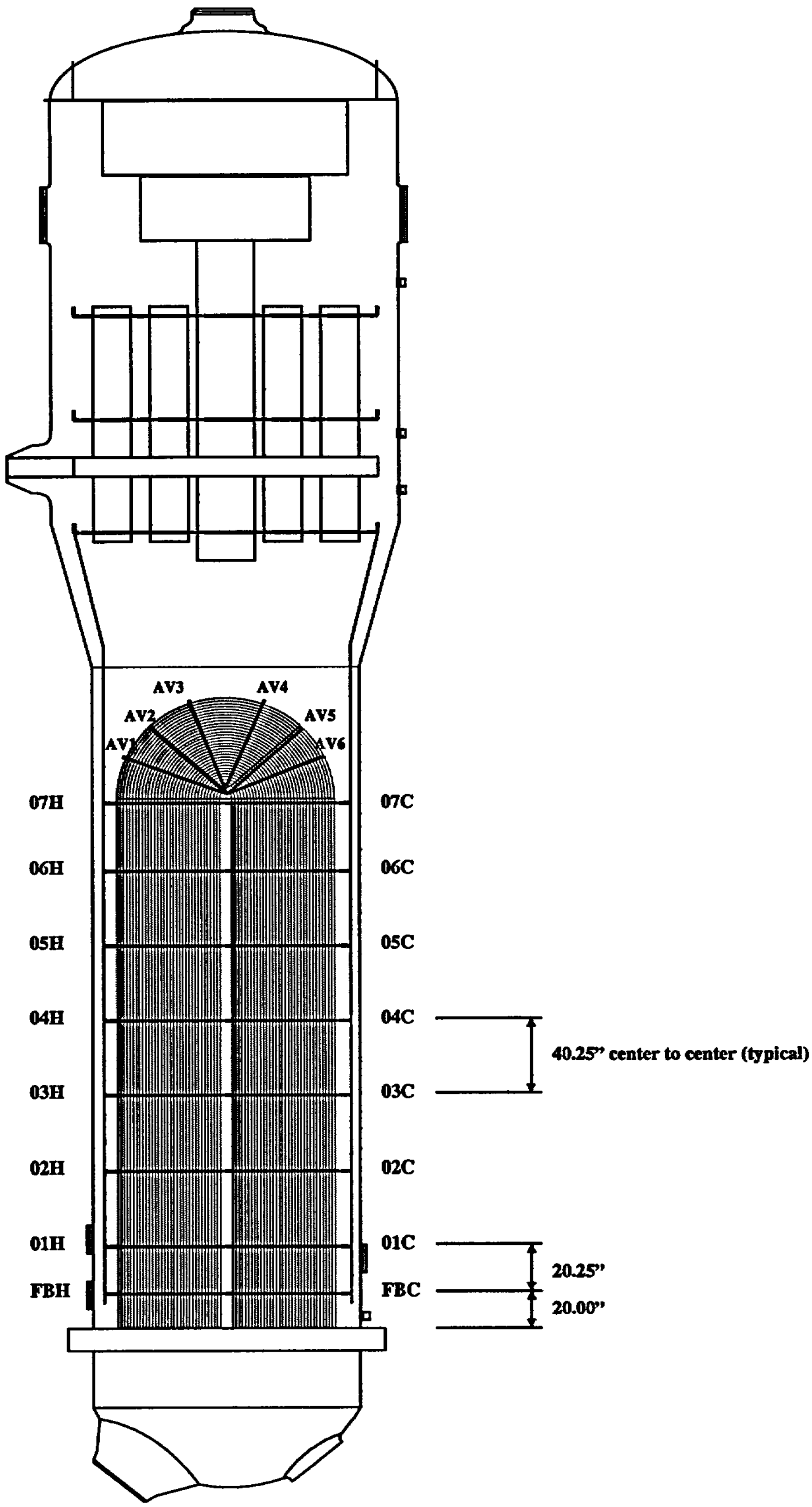
7.16 Attachment 16, Free Span Bobbin Coil Indication Flow Chart

7.17 Attachment 17, Geometry Change Disposition Flow Chart

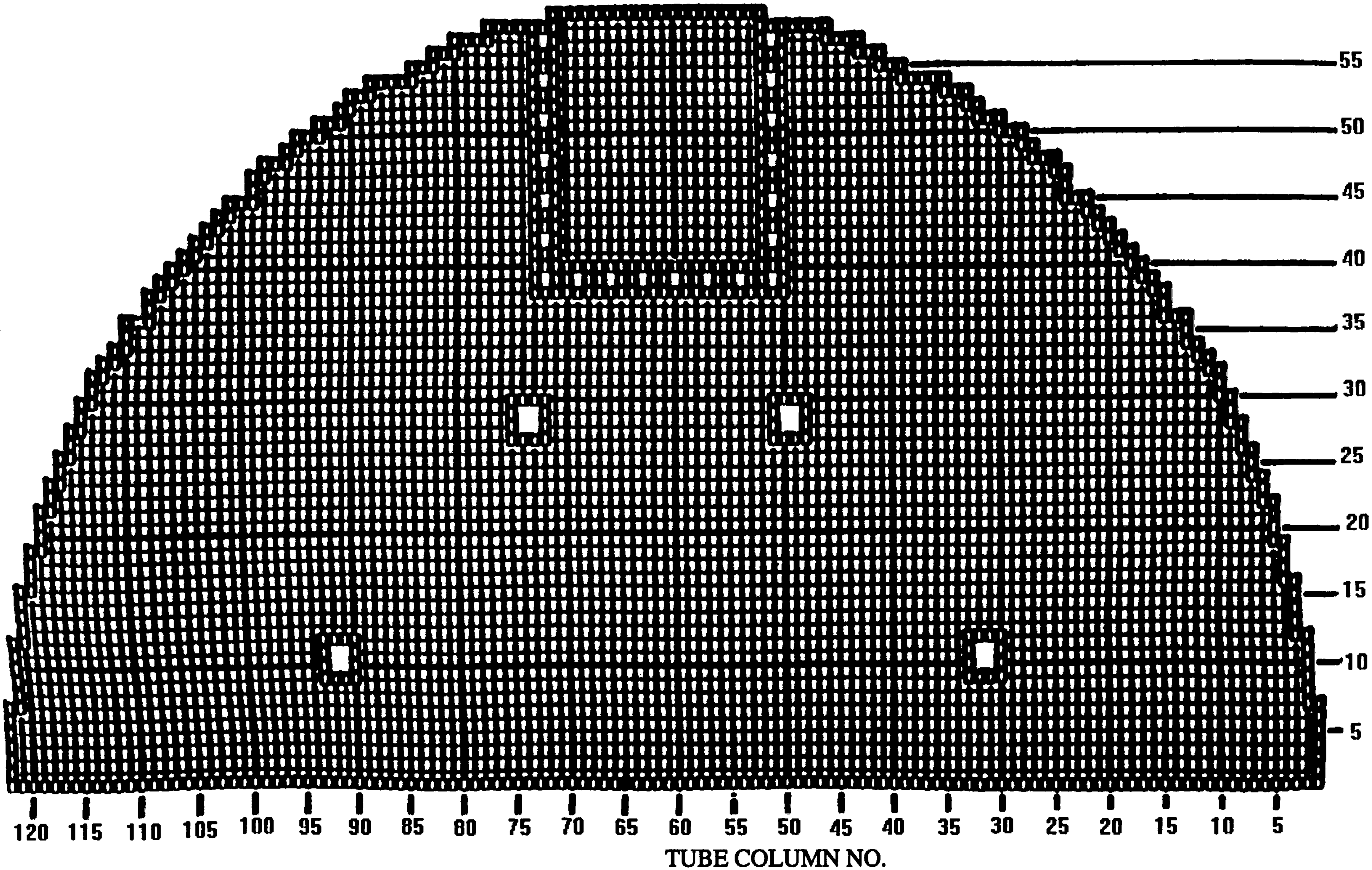
7.18 Attachment 18, Ding Signal Disposition Flow Chart

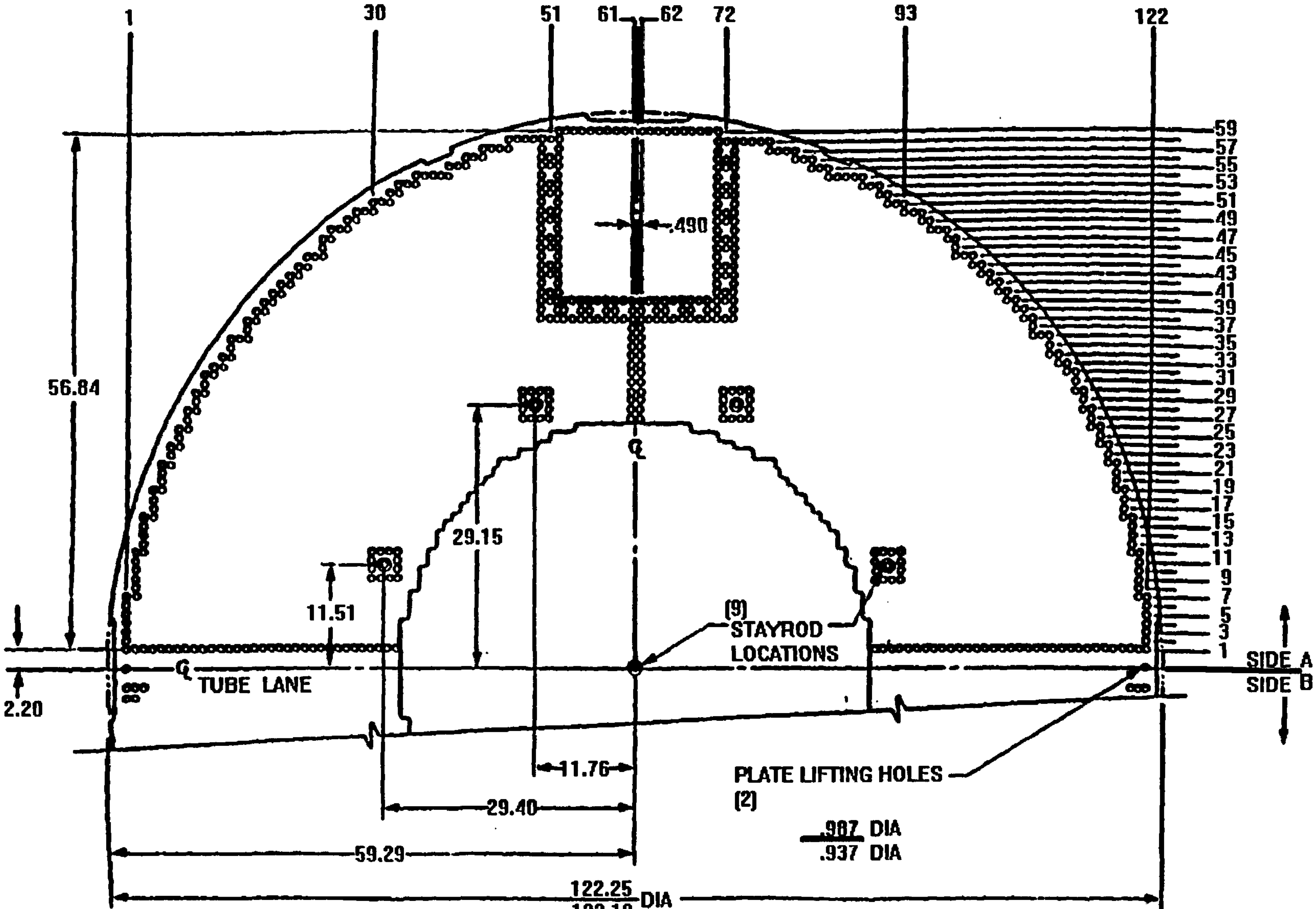
WESTINGHOUSE MODEL F STEAM GENERATOR GENERAL INFORMATION

Number of Tubes	5626
Tube Material	Inconel 600 Mill Annealed (Tubes above row 10) Inconel 600 Thermally Treated (Tubes row 10 and below)
OD of Tubes	0.688 Inches
Tube Wall Thickness	0.040 Inches
Height of Bundle	343.85 Inches
Number of Support Plates	7 (Excluding Flow Distribution Baffle)
Support Plate Material	SA-240, Type 405 SS
Support Plate Tube Hole Design	Quatrefoil
Number of Anti-Vibration Bars	6
Anti-Vibration Bar Material	Inconel 600
Tubesheet Thickness	21.23 Inches
Expansion Method	Hydraulic
Extent of Expansion	Full through Tubesheet



ATTACHMENT 1


55
50
45
40
35
30
25
20
15
10
5
120 115 110 105 100 95 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5
TUBE COLUMN NO.



MODEL F
FLOW DISTRIBUTION BAFFLE

STEAM GENERATOR INSPECTION HISTORY

PREVIOUS INSPECTION HISTORY

Below is a summary of pre-service and in service eddy current inspections performed to date at Callaway, specific Callaway concerns, and the plugging history for each steam generator.

JUNE, 1983 (PRE-SERVICE INSPECTION) – A 100% examination of all four steam generators was performed by Westinghouse prior to placing them in service. A handful of tubes were plugged, but no serious concerns were identified.

MAY, 1986 (REFUEL I) – 1136 (20%) tubes were inspected in steam generator D and 401 (7%) were inspected in steam generator A. Few indications were found and no adverse trends were identified. No tubes were plugged.

APRIL, 1987 (MAINTENANCE OUTAGE) – 1147 (20%) tubes were inspected in steam generator B and 1165 (21%) were inspected in steam generator C. At this time, an adverse trend of wear at the AVB intersections was identified. Although the Tech. Spec. plugging limit (48%) was not exceeded, five tubes were plugged (2 in B; 3 in C), all due to AVB indications. No other adverse trends were identified.

SEPTEMBER, 1987 (REFUEL II) –3507 (62%) tubes were inspected in steam generator A and 3506 (62%) were inspected in steam generator D. The trend of AVB indications continued to be apparent, though not overly severe. Again, no tubes exceeded the plugging limit, but eight (3 in A; 5 in D) were plugged as a precaution. One tube was plugged in steam generator A (17,55) due to a dent at the top of the tube sheet similar to those found at another unit (see Specific Concerns). An 8x1 multi-array probe was run on several AVB indications which found all to be one sided wear.

APRIL, 1989 (REFUEL III) – 5621 (100%) tubes were inspected in steam generator B and 5616 (100%) were inspected in steam generator C. We continued to see growth in previously identified AVB wear as well as a considerable number of new indications. A few indications exceeded the Tech. Spec. plugging limit. Thirteen tubes were plugged (4 in B; 9 in C). Twelve tubes were plugged for AVB wear and one tube in S/G C was plugged for a DSI/SAI at the cold leg flow baffle. MRPC testing was performed in the sludge pile region (rows 11-20, columns 51-75) at the tubesheet and hot leg tangent areas. No significant indications were found.

STEAM GENERATOR INSPECTION HISTORY

<u>OCTOBER, 1990 (REFUEL IV)</u> – 5616 (100%) tubes were inspected in steam generator A and 5614 (100%) were inspected in steam generator D. A relatively larger number of tubes (138) had some sort of AVB wear, with 49 tubes having indications greater than 20% throughwall. The sixteen pluggable indications in steam generator D were tested with an 8x1 probe which revealed all to be one sided wear. MRPC testing was performed on 624 tubes (mostly in the sludge pile region) at the expansion transitions to attempt to identify any PWSCC initiation that may be occurring. No cracking was found. Twenty-two tubes were plugged (6 in A; 16 in D), all due to AVB wear.

<u>APRIL, 1992 (REFUEL V)</u> – All hot leg tubes for each steam generator were shot peened through the expanded zone. 100% of the tubes in steam generators B and C were inspected. In addition, a sample of 600 tubes were examined with a RPC probe at the expansion transition. A total of 188 tubes with AVB indications were found, of which 113 had at least one indication of 20% or greater. A 79% (34.5 volt) indication was found on a periphery tube in S/G C. No cracking was found. In addition to the 29 tubes plugged based on the examination (15 in B; 14 in C), two tubes were plugged in S/G C due to indications from the Refuel 4 inspection which were of a similar nature as the 79% indication found this outage.

<u>OCTOBER, 1993 (REFUEL VI)</u> – 100% of the tubes in steam generators A and D were inspected. Again, a sample of approximately 600 tubes were examined with a RPC probe at the expansion transition. A total of 199 tubes with AVB indications were found, of which 104 had at least one indication greater than or equal to 20 percent throughwall. A total of 37 tubes were plugged (19 in A, 18 in D). Five of those plugged in steam generator A were damaged as a result of a loose part, which was removed.

<u>APRIL, 1995 (REFUEL VII)</u> – The initial scope was 100% bobbin coil examination of steam generators B and C, plus a sample of 600 tubes with the RPC at the top of the tubesheet. Near the end of the inspection, a tube with an apparent TTS crack was discovered in Steam Generator C. The TTS RPC examination was eventually expanded to include 100% of the mill annealed (non-thermally treated) tubing. Twenty nine tubes (A - 11, B – 0, C –15, and D –3) were found with top of tubesheet indications. Of these, ten (A – 6, C – 3, and D – 1) appeared to have circumferential cracks. In the end, a total of 40 tubes were plugged. Those with circumferential cracks were staked on the hot leg side. Plugging due to AVB wear was significantly reduced (7 tubes). Two tubes were plugged due to loose part damage, and two were plugged after they were damaged by Westinghouse equipment installed for chemical cleaning.

STEAM GENERATOR INSPECTION HISTORY

OCTOBER, 1996 (REFUEL VIII) - The initial scope was 100% bobbin coil examination of steam generators A and D, 100% +Point examination in all four steam generators of the hot leg top of tubesheet (+2"/-3"), and 100% +Point examination of SG C's row 1 U-Bend region. Eight of the row 1 U-Bends were not tested due to the motor stalling in the U-Bend. These tubes were tested with a bobbin coil probe to complete the inspection. One hundred and twenty one tubes (A - 47, B - 8, C - 44 and D - 22) were found with top of tubesheet indications. Of these, seventy eight (A - 30, B - 3, C - 29 and D - 16) appeared to have circumferential cracks. A total of 44 of these tubes were plugged, the rest (A - 44 and C - 33) were sleeved with 12" elevated laser-welded tubesheet sleeves. All of the plugged circumferential indications were staked on the hot leg side prior to plugging. Again, plugging due to AVB wear was reduced (3 tubes in SG D). One tube in SG A had an NQI, which RPC confirmed as an SVI and was subsequently plugged.

APRIL, 1998 (REFUEL IX) – The initial scope was 100% bobbin coil examination of steam generators B and C, 100% + point examination in all four steam generators of the hot leg top of tubesheet (+2"/-3"), and 100% + Point examination of SG A's row 1 U-Bend region. Sixty-five tubes (A-32, B-4, C-36 and D-5) were found with top of tubesheet indications. Of these, thirty-nine (A-17, B-0, C-17 and D-5) appeared to have circumferential cracks. All sixty-five tubes were plugged. All those with circumferential cracks were also stabilized. Twelve tubes (B-3 and C-9) were plugged due to AVB wear that exceeded the plugging limit.

OCTOBER, 1999 (REFUEL X) – The initial scope was 100% bobbin coil examination of steam generators A and D, 100% + Point examination in all four steam generators of the hot leg top of tubesheet (+2"/-3"), and 100% + Point examination of SG D's row 1 and 2U-Bend region. One of the row 1 U-Bends was not tested due to the motor stalling in the U-Bend. This tube was tested with a bobbin coil probe to complete the inspection. Ninety-one tubes (A41, B-15, C-30, and D-5) were found with top of tubesheet indications. Of these, thirty-eight (A-23, B-4, C-10, and D-1) appeared to have circumferential cracks. A total of 34 of these tubes were plugged, the rest (A-31 and C-26) were sleeved with 8" tubesheet electrosleeves. All of the plugged circumferential indications were stabilized on the hot leg side prior to plugging. One tube in SG D was plugged due to AVB wear. One tube in SG A had a DSI, which RPC confirmed as an SVI and was subsequently plugged. A loose part was recovered from above the cold leg tubesheet in SG D. Four tubes had loose part indications (LPI's), which RPC confirmed as SVI's and were subsequently plugged.

STEAM GENERATOR INSPECTION HISTORY

APRIL, 2001 (REFUEL XI) – The initial scope was 100% bobbin coil examination of steam generators B and C, 100% + Point examination in all four steam generators of the hot leg top of tubesheet (+2"/-3"), and 100% + Point examination of SG B's row 1 and 2 U-Bend region. Four of the row 1 and 2 tubes were not tested with a + Point probe due to the motor stalling in the U-Bend. These tubes were tested with a bobbin coil probe to complete the inspection. Forty-five tubes (A-26, B-0, C-13 and D-6) were found with top of tubesheet indications. Of these, seven (A-3, C-1 and D-3) appeared to have circumferential cracks. All forty-five tubes were plugged. All those with circumferential cracks were also stabilized. Two tubes (B-1 and C-1) were plugged due to AVB wear that exceeded the plugging limit. One tube in SG B had a volumetric indication detected by bobbin and confirmed by + Point at 04C+0.47". The indication appeared to have been caused by land contact wear. This tube was also plugged.

SPECIFIC CONCERNS

Loose Part Damage - One of the main contributors to tube repairs in F model steam generators continues to be damage from foreign materials on the secondary side. The free span areas above the top of tubesheet and above the tube support plates should be scrutinized for the presence of loose parts or loose part damage.

AVB Wear – The Model F has been found to be particularly susceptible to AVB induced wear. Any measurable indication would be recorded as measured to develop a database for growth rate. The Model F utilizes AVBs only down to the seventh row.

PWSCC/ODSCC at Top of Tubesheet – In Refuel 7 (April 1995), apparent PWSCC and ODSCC were identified at Callaway. The cracking was found in both the axial and circumferential directions. Particular attention should be directed at the expansion transition regions.

Unique Design – Callaway is unique among F models since it contains both Inconel 600TT tubing (row 10 and below) and Inconel 600MA tubing (row 11 and above). Inconel 600MA has been found to be susceptible to free span cracking in Westinghouse Pre-Heater design plants, i.e. McGuire and South Texas. Though this condition has not been diagnosed at Callaway, care should be taken when dispositioning free span signals in Inconel 600MA tubes.

Different Sleeving Processes – SG's A and C contain both electrosleeved and laser-welded sleeves. Sleeving history details are presented later in this section.

Flow Distribution Baffle Cut-out – The flow distribution baffle does not intersect every tube. (See Attachment 1, Page 4) This should be considered when verifying locations of special interest exams.

STEAM GENERATOR INSPECTION HISTORY

ODSCC at Quatrefoil Support Plate Intersections – One other Westinghouse model F plant recently reported ODSCC-like indications at their quatrefoil support plate intersections. These indications were initially detected with a bobbin probe and confirmed with a + point probe. These indications were also subsequently confirmed with a UT inspection. Several intersections were pulled and final metallurgical analysis is pending. This other plant's experience should be considered when analyzing and dispositioning signals at the support plates.

CRITERIA FOR IDENTIFICATION OF DISCREPANCIES AND ERRORS

1. Flaw wall loss differs by more than 10% through-wall.
2. Either analyst or both (primary-secondary) reports a flaw as greater than or equal to 20%.
3. Either analyst or both (primary-secondary) reports an undefined-type indication in which the data suggests a reasonable probability that a flaw exists.
4. One analyst reports a tube not reported by the other analyst. In these cases, the appropriate resolution analyst will perform an independent review of the tube to ensure that all data has had both a primary and secondary analysis.
5. One analyst reports a flaw indication not reported by the other analyst.
6. The reported extents of test are not in agreement.
7. Flaw locations reported by analyst must be within 0.5 inches of each other to be considered the same flaw.
8. The reported row number is something other than 1 through 59.
9. The reported column number is something other than 1 through 122.
10. The reported flaw location is beyond the reported extent of test.
11. Any negative values for flaw location except within the tubesheet and support plates.
12. Tubes reported as restricted which do not have a corresponding extent of test.
13. Use of a three letter code with no established definition.
14. One analyst reports "retest bad data" not reported by the other analyst.

INDICATION CODES AND DEFINITIONS

I. GENERAL

CODE	DEFINITION
ADI	Absolute Drift Indication – Signal which has a positive "Y" and negative "X" component. This type of a signal indicates the possible presence of IGA (non-quantifiable) in the tube sheet crevice, tube support plate crevice, or sludge pile regions.
ADS	Absolute Drift Signal – An ADI which has been confirmed to be a non-flawed condition by a RPC inspection.
BLG	Bulge – Condition where the tubing inside diameter is greater than nominal.
CUD	Copper Deposit – Indicates the presence of copper.
DDI	Distorted Ding Signal with Indication - Condition where a ding signal forms abnormally and is indicative of degradation which is non-quantifiable. DDI calls should be limited to the mill-annealed tubes, row 11 and higher.
DDS	Distorted Ding Signal – A DDI which either has been confirmed to be a non-flawed condition by a RPC inspection or has undergone a history review and the signal has not changed.
DEP	Deposit – Indicates presence of a non-copper deposit.
DFI	Differential Free Span Indication - Free Span indication with a differential response, which requires history review or RPC testing for final disposition.
DFS	Differential Free Span Signal - A DFI which has undergone a history review, and has been ruled as "not changed". No further action is required, however, this indication will be tracked during future inspections.
DNF	Degradation Not Found - Code used to indicate an alternate or retest was performed and that the area of interest contained no degradation. Enter DNF in the percent field with the location of the previous call.
DNG	Ding – Any free span dent signal greater than or equal to 2.0 volts, which shows no evidence of degradation, shall be reported as DNG.

INDICATION CODES AND DEFINITIONS

I. GENERAL

CODE	DEFINITION
DNT	Dent – Condition where the tubing inside diameter is less than nominal at a structure. Any dent signals at a structure with magnitude greater than or equal to 2.0 volts shall be reported as DNT.
DSI	Distorted Support Signal with Indication – Condition where the support signal forms abnormally and has mix output indicative of degradation which is non-quantifiable.
DSS	Distorted Support Signal – A DSI which either has been confirmed to be a non-flawed condition by a RCP inspection or has undergone a history review and the signal has not changed.
DTI	Distorted Tube Sheet Signal with Indication – Condition where the tube sheet signal forms abnormally and has mix output indicative of degradation which is non-quantifiable.
DTS	Distorted Tubesheet Signal – A DTI which has been confirmed to be a non-flawed condition by a RPC inspection or has undergone a history review and the signal has not changed.
IDC	Inside Diameter Chatter – Condition where horizontal noise caused by wall variation could mask indications or degradations.
INF	Indication Not Found – Condition where a previously reported indication or anomaly cannot be detected within 1.00 inches of the previously reported indication.
INR	Indication not Reportable – Condition where a previously reported signal (indication and/or distorted) is detectable, but with current test results does not meet the reporting level.
LAR	Lead Analyst Review - The LAR code may be used in instances where the analyst feels there is no specific criteria in the Analysis Guidelines or the analyst is unsure how to disposition a signal.
LPI	Loose Part with Indication – Condition where a non-quantifiable indication occurs coincidental with the presence of a loose part.

INDICATION CODES AND DEFINITIONS

I. GENERAL

CODE	DEFINITION
LPS	Loose Part Signal – A LPI which either has been confirmed to be a non-flawed condition by a RPC inspection or has undergone a history review and the signal has not changed.
MBM	Manufacturer's Burnish Mark – An ADI which has undergone a history review, and has "not changed". No further action is required, however, this indication WILL be tracked during future inspections.
NDD	No Detectable Degradation – Condition where no signal responses of degradation or damage precursors exist.
NHE	No Hydraulic Expansion – Used to indicate rework may be required.
NHT	No Heat Treat – Used to indicate rework may be required.
NQI	Non-Quantifiable Indication – To be used when an analyst detects a signal that cannot be quantified, but which is believed to be a flaw.
NQS	Non-quantifiable Signal – A NQI which either has been confirmed to be a non-flawed condition by a RPC inspection or has undergone a history review and the signal has not changed.
NTE	No Tubesheet Expansion – Indicates tube is not fully expanded in the tubesheet. A comment should be added indicating depth of unexpanded tube in the tubesheet.
NWS	No Weld Signal – Used to indicate rework may be required.
OBS	Obstructed – Indicates restricted tube preventing the passage of the test probe. Analysis is required for position of test completed. Also requires message from collector that tube is restricted.
OXP	Overexpansion – Indicates tube is expanded above the top of the tubesheet to an outside diameter greater than the drilled tubesheet hole.

INDICATION CODES AND DEFINITIONS

I. GENERAL

CODE	DEFINITION
PBC	Previous Bobbin Call – Used when a tube is retested with a bobbin probe to indicate that the previously reported bobbin call(s) are correct.
PID	Positive Identification – Indicates verification of a pluggable defect previously reported. This condition SHALL be recorded and confirmed for each call with the same channel previously used.
PLG	Plugged – Indicates a tube that has been plugged.
PLP	Possible Loose Part - Indicates the possibility of foreign material on the secondary side of the steam generator.
PTE	Partial Tube Expansion – Used to indicate that the tubesheet region was not fully expanded.
PVN	Permeability Variation – Condition where the test coil impedance changes due to a change in the tubing's inherent willingness to conduct magnetic flux lines.
RAD	Retest Analyst Discretion – Retest code used when the data quality is acceptable but a retest may clarify a tube condition or a signal of interest.
RBD	Retest Bad Data – Used to signify that the data for a particular tube cannot be analyzed for one or more reasons; e.g., noise, level, bad probe, etc.
RBI	Retest Bad Data with Indication – Used to signify that the data for a particular tube is not acceptable but a possible indication has been detected by the analyst. During the retest of this tube, the analysts should pay particular attention to the RBI's location. All RBI calls must be dispositioned to either a call or a DNF when retested. Volts, phase, channel and location information SHALL be recorded for all RBI calls.

INDICATION CODES AND DEFINITIONS

I. GENERAL

CODE	DEFINITION
	The following quality codes SHALL be assigned whenever an RBD or RBI is reported to assist the resolution analysts with their disposition. The quality code should be reported in the UTIL2 field.
QUALITY CODE	DESCRIPTION
QET	Insufficient extent tested
QDO	Data drop out
QDR	Less than the required digitization rate
QPB	Probe is out of balance
QPN	Spiking or parasitic noise
QPS	No eddy current signal on one or more of the required channels
QRN	Excessive Rotational Noise
QSS	Saturated signals in the tube
QSV	Unacceptable probe speed variation
QED	Other bad data condition
RID	Retest questionable tube ID - To be used when the tube encoding is in question.
RND	Retest No Data - To be used when a tube is encoded on the T-List but no data was recorded.
RFX	Retest Fixture – Retest code used when a positioning fixture prevents a complete test.
RRT	Retest Restricted Tube – Retest Code used to schedule the tube for inspection with a smaller diameter probe. Requires a message from the date collector that the tube is restricted.

INDICATION CODES AND DEFINITIONS

I. GENERAL

CODE	DEFINITION
RWS	Retest with AVB Wear Standard - Used to flag indications of AVB wear, when a bobbin inspection is performed without an AVB wear standard.
SLG	Sludge - Indication of a buildup of contaminants on top of the tubesheet or tube support plates. This condition, when present, shall be recorded with 30 kHz absolute.
SLV	Indicates a tube that has been sleeved.
TBP	To Be Plugged – Used to signify a tube is to be plugged.
WZI	Weld Zone Indication - -Condition where a non-quantifiable indication occurs within the weld zone area of a sleeved tube.
WZS	Weld Zone Signal – A WZI which either has been confirmed to be a non-flawed condition by a RPC inspection or has undergone a history review and the signal has not changed.
Degradation	Service induced cracking, wastage, pitting, general corrosion, or wear on either the inside or outside of a tube.
Repairable	A tube at or exceeding the repair limit of 40% through wall depth or a tube containing a Category V indication.

INDICATION CODES AND DEFINITIONS

II. RPC PROBE SPECIFIC

CODE	DEFINITION
GEI	Geometry Indication – Any GEO signal that showed significant change from previous inspections. The lead analyst or his designee SHALL review and disposition all GEI calls.
GEO	Geometry Signal – A signal caused by a localized geometry change at the top of tubesheet intersection. Similar signals have been confirmed by tube pulls at another hydraulically expanded plant. These signals are to be reported to allow future historical reviews via a DSR database.
MAI	Multiple Axial Indications – Same definition as SAI, except more than one indication is present.
MCI	Multiple Circumferentially Oriented Indication – Same definition as SCI, except more than one indication is present.
MMI	Mixed Mode Indication – Used to signify both axial and circumferentially orientated indications are present.
MVI	Multiple Volumetric Indication - Same definition as SVI except more than one indication is present.
PRC	Previous RPC Call – Used when a tube is retested with an RPC probe to indicate that the previously reported RPC call(s) are correct.
RMB	Retest Mag-Bias Probe – Retest code used when a permeability variation is present that the analyst feels could mask an indication.
SAI	Single Axial Indication – When displayed in an isometric plot, the indication will have an <u>axial extent</u> that is <u>greater</u> than its circumferential extent. The "base" of the indication will also normally have minimal circumferential extent. This indication is normally immediately adjacent to transitions (or dents) and may run into or through the transition (or dent).
SCI	Single Circumferentially Oriented Indication – To be used when the isometric plot depicts an indication whose <u>axial extent</u> is <u>less</u> than its circumferential extent. These type indications are normally located within transition area and normally do not extend axially beyond the transition area.
SVI	Single Volumetric Indication - To be used for an indication that exhibits both axial and circumferential characteristics. Indicative of general localized intergranular attack or associated with wear, thinning or pitting.

NOTE: Indication codes other than those documented above may be added if condition warrant, subject to agreement by the Callaway Steam Generator Activity Coordinator.

Notation	Description	Category
	Blank – No Indication (No Detectable Degradation)	I
CUD	Copper Deposit	I
DEP	Deposit (non-Copper)	I
DNF	Degradation Not Found	I
PBC	Previous Bobbin Call	I
PID	Positive Identification	I
PLG	Plugged	I
PRC	Previous RPC Call	I
SLG	Sludge Height Measurement	I
SLV	Sleeved	I
RAD	Retest Analyst Discretion	II
RBD	Retest Bad Data	II
RBI	Retest Bad Data with Indication	II
RFX	Retest Fixture is Blocking Probe	II
RID	Retest Questionable Tube ID	II
RMB	Retest Mag-Bias Probe	II
RND	Retest No Data	II
RRT	Restricted Tube (retest with smaller probe)	II
RWS	Retest Tube with Anti-Vibration Bar (AVB) Wear Standard	II
ADI	Absolute Drift Indication	III
DFI	Differential Free Span Indication	III
DDI	Distorted Dent Indication	III
DSI	Distorted Support Indication	III
DTI	Distorted Tubesheet Indication	III
LPI	Loose Part with Indication	III
NQI	Non-quantifiable Indication	III
WZI	Weld Zone Indication	III

Notation	Description	Category
ADS	Absolute Drift Signal	IV
DFS	Differential Free Span Signal	IV
DDS	Distorted Dent Signal	IV
DSS	Distorted Support Signal	IV
DTS	Distorted Tubesheet Signal	IV
LPS	Loose Part Signal	IV
NQS	Non-quantifiable Signal	IV
WZS	Weld Zone Signal	IV
GEI	Geometry Indication	V
MMI	Mixed Mode Indication	V
MAI	Multiple Axial Indication	V
MCI	Multiple Circumferential Indication	V
MVI	Multiple Volumetric Indication	V
OBS	Obstructed	V
SAI	Single Axial Indication	V
SCI	Single Circumferential Indication	V
SVI	Single Volumetric Indication	V
TBP	To be plugged	V
NHT	No Heat Treatment	VI
NHE	No Hydraulic Expansion	VI
NWS	No Weld Signal	VI
BLG	Bulge	VII
DNG	Ding	VII
DNT	Dent	VII
GEO	Geometry Signal	VII
INF	Indication Not Found	VII
INR	Indication Not Reportable	VII

Notation	Description	Category
IDC	Inside Diameter Chatter	VII
LAR	Lead Analyst Review	VII
MBM	Manufacturing Burnish Mark	VII
NTE	No Tubesheet Expansion	VII
OXP	Over Expansion	VII
PTE	Partial Tubesheet Expansion	VII
PVN	Permeability Variation	VII
PLP	Possible Loose Part	VII

Indication Category:

I - Non Flaw condition with no further action required

II - Retest with the same or smaller diameter probe, as appropriate.

III - These "I" codes represent possible flaw signals where no qualified sizing technique is being utilized or does not exist. They require diagnostic testing or evaluation.

IV - These "S" codes are assigned when an indication previously reported as an "I" code receives a diagnostic test which confirms a non-flaw condition or when a historical review has been performed to compare to the current signal and the signal has not changed.

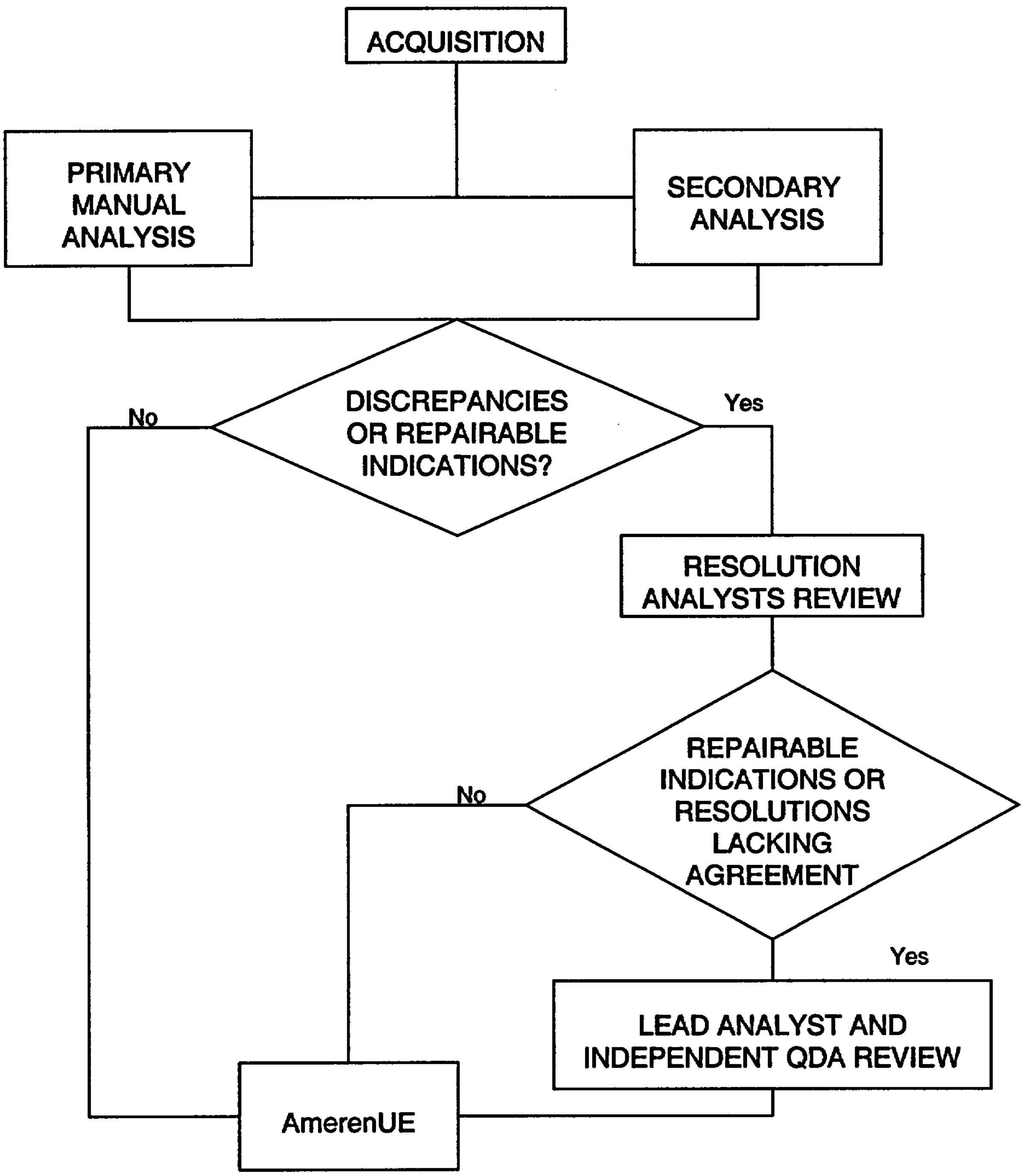
V - These codes designate a repairable condition or an engineering evaluation which may use an alternate repair criteria (ARC).

VI - These codes designate incomplete repairs and may require rework depending upon the acceptance criteria.

VII - These codes require additional reviews (historical), additional diagnostic sampling or engineering evaluations. MBM is only entered after historical review.

Attachment 5 has been deleted.

STEAM GENERATOR EDDY CURRENT TESTING DATA FLOW



LENGTH AND DEPTH SIZING CRACK-LIKE INDICATIONS

I. SCOPE AND PURPOSE

A. The guidelines herein are intended to provide instructions on the length and depth measurement of axially and circumferentially oriented PWSCC.

B. The mid-range +Point coil excited at 300 kHz is to be used for sizing PWSCC.

II. DATA ACQUISITION

The following parameters are additions or modifications to the appropriate ETSS.

A. The data **SHALL** be acquired to achieve a minimum digitizing rate of 30 samples/inch in both the axial and circumferential directions.

B. Refer to sections 4.2.1.2 and 4.2.1.3 for calibration standard requirements.

C. The combined motor unit and cable lengths should be equivalent to an 83 foot motor unit with a 50 foot "low loss" extension cable.

D. The gain (or sensitivity) setting for the eddy current test instrument should be such that no signal saturation occurs at any time. If saturation occurs, the tester configuration should be adjusted via an ETSS sheet revision.

E. The prime frequency should be 300 kHz. Auxiliary frequencies, such as 200 kHz and 100 kHz, may be included in the test configuration.

III. DATA ANALYSIS CALIBRATION

The following parameters are additions or modifications to the appropriate ETSS. Note, all phase angles should be measured peak to peak and on the entrance leg of the signal.

A. Phase Rotation

1. Rotate the raw 300 kHz +Point channel to 15 degrees on the 40%ID axial EDM notch signal.

2. Create an unmodified process channel for the 300kHz +Point raw channel. Rotate the process channel to 15 degrees on the 40% ID Circumferential EDM notch signal.

B. Volts Scale

1. Set the 100% axial EDM notch signal to 20 volts peak to peak for the raw channel.

2. Set the 100% circumferential EDM notch signal to 20 volts peak to peak for the process channel.

C. Span Setting (These are the minimum span settings used for the EPRI qualifications, the analyst may increase them as desired.)

1. Set the response from the 40% OD axial notch to 1 screen division for the raw channel.

2. Set the response from the 40% ID circumferential notch to 1 screen division for the process channel.

D. Calibration Curves

1. Set a phase curve utilizing the circ lissajous on the axial 100%, 60%ID and 40%ID EDM notches for the ID portion of the raw channel's curve.

2. Use the 100% axial notch along with the 60%OD and 40%OD EDM notches for the OD portion of the raw channel's curve.

3. Set a phase curve utilizing the axial lissajous on the circ 100% 60%ID and 40%ID EDM notches for the ID portion of the process channel's curve.

4. Use the 100% circ notch along with the 60%OD and 40%OD EDM notches for the OD portion of the process channel's curve.

5. Use the center hit within each EDM notch to measure the phase angle.

IV. DATA ANALYSIS EVALUATION (AXIAL PWSCC)

All measurements should be made with the 300 kHz +Point coil raw channel.

A. Beginning at the lower end of the crack, find the first hit of the crack. Scroll one rotation backward. Enter 0% at that location in the report.

B. Scroll up to the first hit. Measure the phase angle. Enter the % through-wall depth measurement at that location into the report.

C. Continue the line-by-line measurements until all hits have been entered into the report.

D. Scroll one rotation past the last hit at the upper end of the crack. Enter 0% at that location into the report.

E. The above steps should be repeated if multiple cracks exist.

F. The crack length should be determined from the line-by-line depth measurements. A from-to technique should not be used. The crack length is determined by subtracting the beginning location from the ending location.

G. The average crack depth is determined by adding all the line-by-line % through-wall depths and dividing by the number of lines including the 0% lines.

H. The percent degraded area (PDA) may be determined by using post processing applications, such as EPRI Draw or Microsoft Excel.

I. Corrections for Field Spread

At the completion of the initial analysis process, adjustments for data points at the ends of the cracks is required. Data points within 0.2" of the indicated crack ends will be adjusted as follows:

1. Ignore data points from the 1st reading to the point at which phase angles change from ID to OD. The adjusted end of the crack SHALL be defined as less than or equal to 0.03" beyond the last accepted data point. When the phase angles are largely OD over most of the crack, this guideline cannot be applied.

2. Less than 1 volt data points, with ID phases indicating 85% through-wall and greater will be ignored from the first reading to that point provided within 0.2" from the first reading. The adjusted end of the crack SHALL be defined as less than or equal to 0.03" beyond the last accepted data point.

3. Less than 1 volt, ID phase data points exhibiting depth increases of greater than 10% through-wall over approximately a 0.05" span will be ignored. The adjusted end of the crack SHALL be defined as less than or equal to 0.03" beyond the last accepted data point.

J. Reporting Requirements

1. The sizing data should be saved in a SIZING analysis group report.

2. Crack profiles may be plotted using applications such as the EPRI Draw program or Microsoft's Excel.

V. DATA ANALYSIS EVALUATION (CIRCUMFERENTIAL PWSCC)

All measurements should be made with the 300 kHz +Point coil process channel.

A. The % through-wall depth should be measured in increments of approximately 4 degrees (maximum is 10 degrees).

B. Find the first hit of the crack in the Axial lissajous window. Scroll one increment backwards. Enter 0% at that circumferential position into the report.

C. Click the mouse button to the first hit. Measure the phase angle. Enter the % through-wall depth at that circumferential position into the report.

D. Continue the incremental depth measurements until around the tube circumference until all hits have been entered into the report.

E. Click the mouse button one increment past the last hit of the crack. Enter 0% at that circumferential position into the report.

F. The above steps should be repeated if multiple cracks exist.

G. The circumferential crack extent should be determined from the incremental depth measurements. A from-to measurement technique should not be used.

H. Depth measurements using an amplitude curve may also be required.

1. At the peak amplitude signal response measure the % through-wall using the phase angle curve established per the instructions in Section III.

2. Create a new process channel, which is the duplicate of the previously made 300 kHz process channel, with the circumferential notch responses going in the positive direction. In the new process channel establish a two-point linear curve using the amplitude and % through-wall values, from section 1, and extrapolate to zero.

3. Note: Do not use the 1pt magnitude curve in the Eddynet95 software to create the amplitude curve.

4. Each crack should be measured using the new linear peak to peak amplitude curve.

5. If the voltage at the peak amplitude from the indication exceeds the voltage of the 100% circumferential notch set at 20 volts in the axial lissajous window, then use a curve where 20 volts equals 100%.

I. Reporting Requirements

1. The sizing data should be saved in a SIZING analysis group report.

2. Crack profiles may be plotted using applications such as the EPRI Draw program or Microsoft's Excel.

VI. REFERENCES

A. EPRI PWR Steam Generator Examination Guidelines Appendix H, ETSS #96701

B. EPRI PWR Steam Generator Examination Guidelines Appendix H, ETSS #96702

C. EPRI PWR Steam Generator Examination Guidelines Appendix H, ETSS #96703

INSTALLED STEAM GENERATOR TUBE PLUG INSPECTION

Visually inspect all previously installed tube plugs for indication of leaking or other deficiencies.

Steam Generator A	Signature/Date	Steam Generator B	Signature/Date
Hot Leg	______________	Hot Leg	______________
Cold Leg	______________	Cold Leg	______________
Steam Generator C	**Signature/Date**	**Steam Generator D**	**Signature/Date**
Hot Leg	______________	Hot Leg	______________
Cold Leg	______________	Cold Leg	______________

Steam Generator	Hot or Cold Leg	Row	Col	Deficiency Found and Action Taken	Tracking Document

______________________________/____________

Signature Date

E170-0110

STEAM GENERATOR SECONDARY SIDE FOREIGN OBJECT SEARCH

Use this form to document the Foreign Object Search and Retrieval (FOSAR) results for the steam generator secondary tubesheet.

STEAM GENERATOR A

____
____
____
____
____

STEAM GENERATOR B

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____
____

STEAM GENERATOR C

____
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____
____
____

STEAM GENERATOR D

____
____
____

____________________/__________

E170.0110 Signature Date

Examination Technique Specification Sheet

ETSS # :	Revision 0	Page: 1 of 6
Site: CALLAWAY		

Examination Scope

Applicability:

Instrument	Tubing
Manufacturer/Model:	Material Type: Inconel 600 TT or Inconel 600 MA
Data Recording Equipment	OD/Wall (inch): 0.688 OD X 0.041 Wall
Manuf./Media:	**Calibration Standards**
Software	Type:
Manufacturer:	**Analog Signal Path**
Version/Revision:	Probe Extension Manuf.:
Examination Procedure	Extension Type & Length:
Number/Revision:	Slip Ring Model Number:

Scan Parameters

Scan Direction:

Digitization Rate, Samples Per Inch (minimum):	Axial Direction	

Probe Speed	Sample Rate	Direction

Probe

Description (Model/Diameter/Coil Dimensions)	Manufacturer:Part Number	Length

Data Acquisition

Channel Setup Differential

Channel & Frequency	Channel 1	Channel 3	Channel 5	Channel 7
Phase Rotation				
Span Setting Minimum				

Channel Setup Absolute

Channel & Frequency	Channel 2	Channel 4	Channel 6	Channel 8
Phase Rotation				
Span Setting Minimum				

Examination Technique Specification Sheet		
ETSS # :	Revision 0	Page: 2 of 6
Configuration Board Settings		
Acquisition Notes and Special Instructions		
Calibration Method		

Examination Technique Specification Sheet

ETSS # :	Revision 0	Page: 3 of 6

Data Analysis (See Analysis Notes)

Channel Setup Bobbin Differential

Channel & Frequency	Channel 1	Channel 3	Channel 5	Channel 7
Phase Rotation				
Span Setting				
Volts				

Channel Setup Bobbin Absolute

Channel & Frequency	Channel 2	Channel 4	Channel 6	Channel 8
Phase Rot				
Span Setting				
Volts				
Curve				

Channel Setup Bobbin Process

Channel & Frequency	Channel P1 .	Channel P2		
Phase Rot				
Span Setting Minimum				
Mix @				
Volts				
Curve				

Data Screening

Left Strip Chart	Right Strip Chart	Lissajous

Reporting Requirements
(See Acceptable Reporting Acronyms and Callaway Guidelines for others and more detail)

Condition/Region	Report	Ch	Comment

Examination Technique Specification Sheet

ETSS # :	Revision 0	Page: 4 of 6

Acceptable Reporting Acronyms

Notation	Description	Category
	Blank – No Indication (No Detectable Degradation)	I
CUD	Copper Deposit	I
DEP	Deposit (Non-Copper)	I
DNF	Degradation Not Found	I
PBC	Previous Bobbin Call	I
PID	Positive Identification	I
PLG	Plugged	I
PRC	Previous RPC Call	I
SLG	Sludge Height Measurement	I
SLV	Sleeved	I
RAD	Retest Analyst Discretion	II
RBD	Retest Bad Data	II
RFX	Retest Fixture is Blocking Probe	II
RID	Retest Questionable Tube ID	II
RMB	Retest Mag-Bias Probe	II
RND	Retest No Data	II
RRT	Restricted Tube (retest with smaller probe)	II
RWS	Retest Tube with Anti-Vibration Bar (AVB) Wear Standard	II
ADI	Absolute Drift Indication	III
DFI	Differential Freespan Indication	III
DDI	Distorted Dent Indication	III
DSI	Distorted Support Indication	III
DTI	Distorted Tubesheet Indication	III
LPI	Loose Part with Indication	III
NQI	Non-quantifiable Indication	III
WZI	Weld Zone Indication	III
ADS	Absolute Drift Signal	IV
DFS	Differential Freespan Signal	IV
DDS	Distorted Dent Signal	IV
DSS	Distorted Support Signal	IV
DTS	Distorted Tubesheet Signal	IV
LPS	Loose Part Signal	IV
NQS	Non-quantifiable Signal	IV
WZS	Weld Zone Signal	IV
MMI	Mixed Mode Indication	V
MAI	Multiple Axial Indication	V
MCI	Multiple Circumferential Indication	V
MVI	Multiple Volumetric Indication	V
OBS	Obstructed	V
SAI	Single Axial Indication	V
SCI	Single Circumferential Indication	V
SVI	Single Volumetric Indication	V
TBP	To be plugged	V

Continued on next page

Examination Technique Specification Sheet

ETSS # :	Revision 0	Page: 5 of 6

Acceptable Reporting Acronyms-continued

Note:

Notation	Description	Category
NHT	No Heat Treatment	VI
NHE	No Hydraulic Expansion	VI
NWS	No Weld Signal	VI
BLG	Bulge	VII
DNG	Ding	VII
DNT	Dent	VII
INF	Indication Not Found	VII
INR	Indication Not Recordable	VII
IDC	Inside Diameter Chatter	VII
LAR	Lead Analyst Review	VII
MBM	Manufacturing Burnish Mark	VII
NTE	No Tubesheet Expansion	VII
OXP	Over Expansion	VII
PTE	Partial Tubesheet Expansion	VII
PVN	Permeability Variation	VII
PLP	Possible Loose Part	VII

Indication Category:

I - Non-flaw condition with no further action required

II - Retest with the same or smaller diameter probe, as appropriate

III – These "I" codes represent possible flaw signals where no qualified sizing technique is being utilized or does not exist. They require diagnostic testing or evaluation.

IV – These "S" codes are assigned when an indication previously reported as an "I" code receives a diagnostic test which confirms a non-flaw condition or when a historical review has been performed to compare to the current signal and the signal has not changed.

V - These codes designate a repairable condition or an engineering evaluation which may use an alternate repair criteria (ARC)

VI - These codes designate incomplete repairs and may require rework depending upon the acceptance criteria

VII- These codes require additional reviews (historical), additional diagnostic sampling or engineering evaluations. MBM is only entered after historical review.

Examination Technique Specification Sheet		
ETSS # :	Revision 0	PAGE: 6 OF 6
Analysis Notes		

Level III Approval Signature / Date	Customer Approval Signature / Date

Control Tube Log Sheet

S/G: ________ Leg: ________ Control Tube: ____________ Measurement Location: ____________

Acceptance Criteria: (a) $VPP_{limit} = (2.0) \times VPP_{initial}$ (b) $VVM_{limit} = 0.3 + VVM_{initial}$

Probe SN #	Data Set #	$VPP_{initial}$	$VVM_{initial}$	VPP_{limit}	VVM_{limit}	Subsequent Readings		Accept ? Y or N
						VPP	VVM	

Attachment 12 has been deleted.

Analysis Guidelines Clarification Form

Change No: ____________________

Effective Date: ____________________

Description of Update:

____
____
____
____
____
____
____

Reason for Update:

____
____
____
____
____
____
____

Technical Basis:

____
____
____
____
____

Authorizations:

______________________________ **Lead Analyst**	**Date:** ______________
______________________________ **Callaway Steam Generator Activity Coordinator**	**Date:** ______________
______________________________ **Independent QDA**	**Date:** ______________

Analysis Guidelines Clarification Acknowledgement Form

Change No: ____________________

Effective Date: ____________________

Description of Update:

____
____
____
____
____

Analyst Signature	Date	Analyst Signature	Date

Analyst Concerns Form

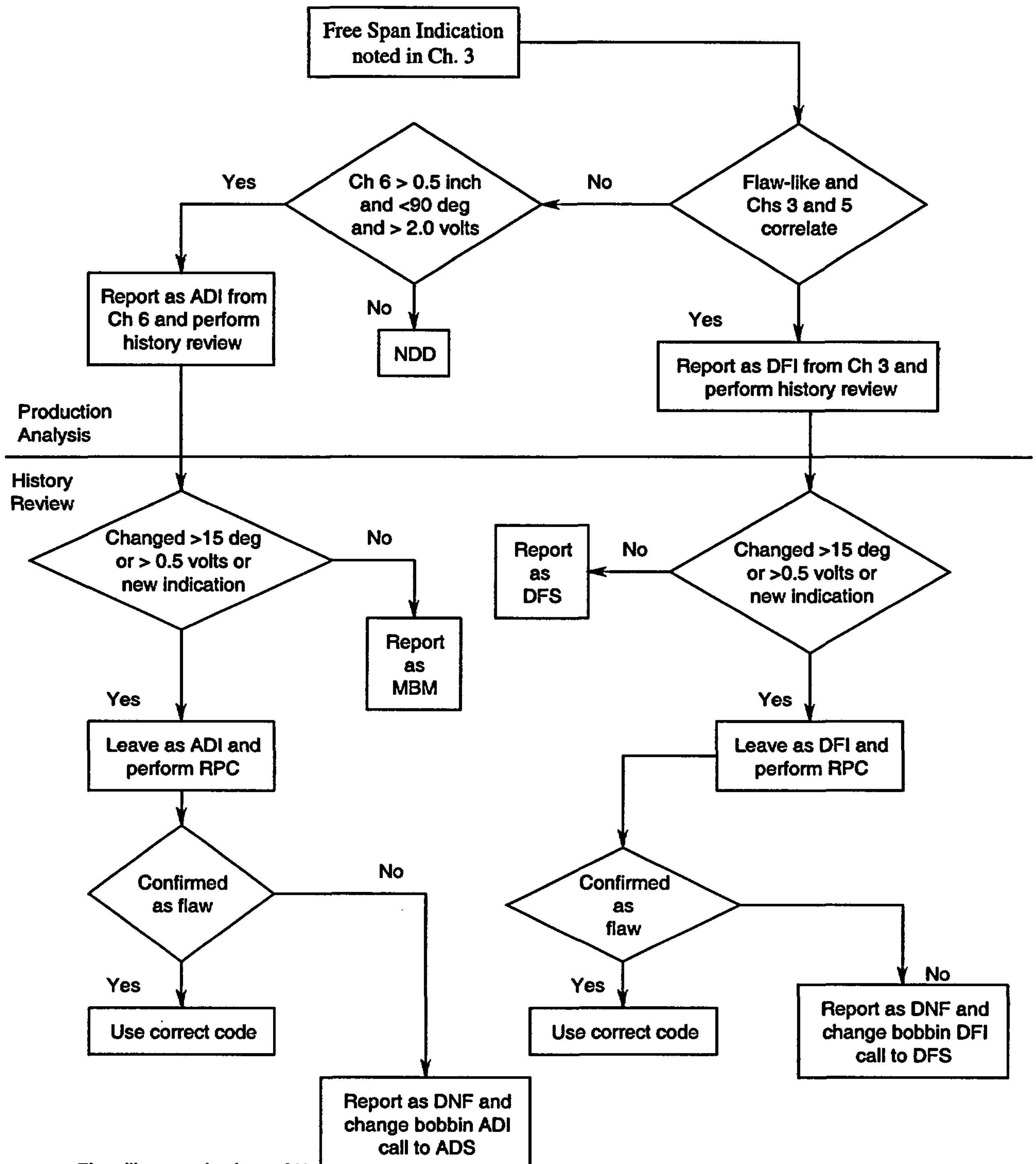
Date:__________________

Description of Concern:

Response from Lead Analyst:

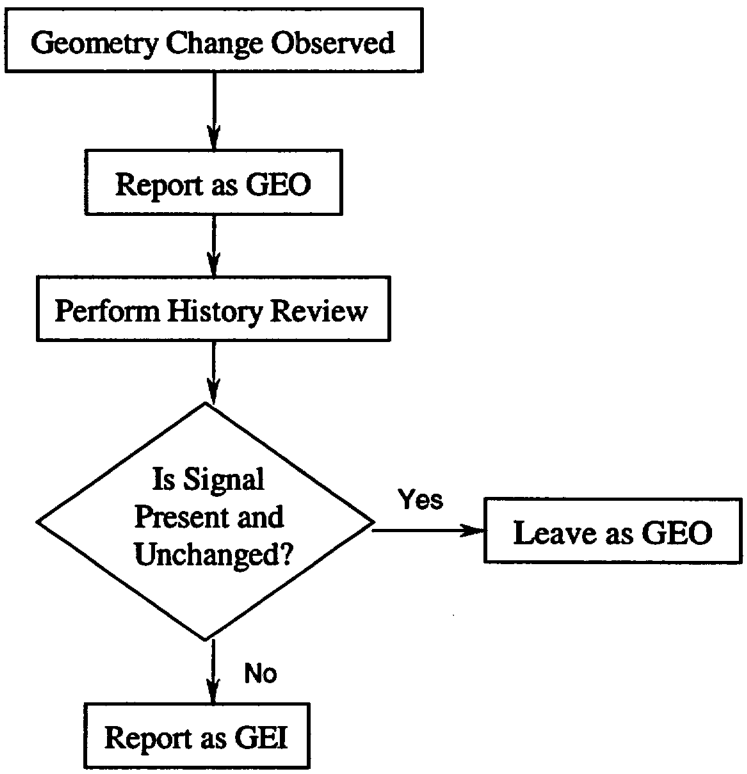
________________________ **Concerned Analyst**	**Date:** __________
________________________ **Lead Analyst**	**Date:** __________
________________________ **Callaway Steam Generator Activity Coordinator**	**Date:** __________
________________________ **Independent QDA**	**Date:** __________

FREE SPAN BOBBIN COIL INDICATION FLOW CHART



Flaw-like: reads above 0%
Correlate: both chs 3 and 5 read above 0%
If there's a previous call at the current location, the history review will be performed using RF9 for SG's B and C, and RF10 for SG's A and D. New calls will be reviewed using RF5 data for SG's B and C, and RF6 data for SG's A and D.

GEOMETRY CHANGE DISPOSITION FLOW CHART

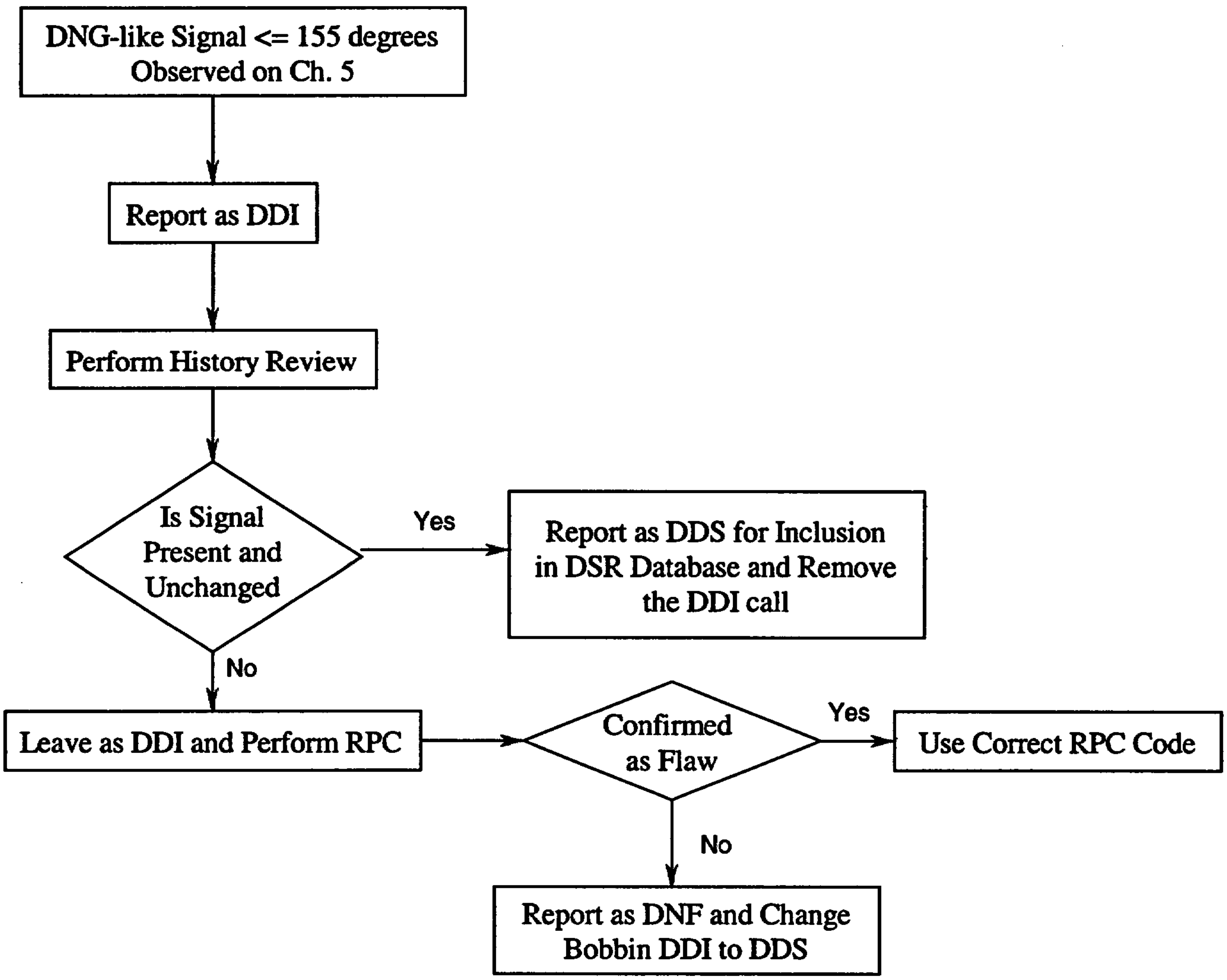


History Review will be performed using RF10 data for all four SG's. If RF10 data is not available RF9 or RF8 data can also be used.

Note: When reviewing signals for change allow for some differences in phase and amplitude on the +Point channels. Due to the differential nature of the +Point coils, variations in the roataional and push speeds can result in changes in the phase and amplitude of signals produced by localized geometry changes.

All GEI calls will be reviewed and dispositioned by the Lead Analyst or his designee.

DING SIGNAL DISPOSITION FLOW CHART



If there's a previous DDS call at the current location, the history review will be performed using RF9 for SG's B and C, and RF10 for SG's A and D. New calls will be reviewed using RF5 data for SG's B and C, and RF6 data for SG's A and D.

June 27, 2003
NRC:03:042

Document Control Desk
ATTN: Chief, Planning, Program and Management Support Branch
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

Release of Drawings Related to Callaway

Ref.: 1. Letter, Ameren UE (Dave Shafer) to NRC, June 5, 2003, ULNRC 04861.

Ameren issued a letter to the NRC on June 5, 2003, that included numerous attachments (Reference 1). Attachment 6 to that letter contained copies of drawings developed by Framatome ANP that were noted to be the property of Framatome ANP and were not to be copied or further distributed. These drawings are not proprietary.

This letter authorizes the NRC to place copies of these drawings (that is, the drawings in Attachment 6 to the referenced letter) in the Public Document Room or ADAMS, as appropriate, and make other distribution of the information as needed to fulfill its regulatory review function.

Very truly yours,

James F. Mallay kh

James F. Mallay, Director
Regulatory Affairs

cc: J. N. Donohew
D. E. Shafer
Docket 50-483

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