Westinghouse Non-Proprietary Class 3

WCAP-15164
Addendum
Revision 1

South Texas Unit 2: 3V Alternate Repair Criteria Application of Bounding Analysis and Tube Expansions

Westinghouse Electric Company LLC

Westinghouse Non-Proprietary Class 3

Addendum to
WCAP-15164, Rev 1

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SOUTH TEXAS UNIT 2;

3V ALTERNATE REPAIR CRITERIA

APPLICATION OF BOUNDING ANALYSIS

AND TUBE EXPANSIONS

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1. Introduction

WCAP 15163, Revision 1 provided the technical basis for proposed 3V Alternate Repair Criteria (ARC) for ODSCC at tube support plate (TSP) intersections in the South Texas Plant Unit 2 steam generators (SG). The technical basis justifying the 3 V ARC was based on analyses that showed that TSP displacement during main steam line break (MSLB) accident conditions would not exceed 0.15" maximum at the TSPs for which the ARC were proposed. It was calculated that the probability of burst (POB) was much less than the 10^{-2} limit established by GL 95-05 (Reference 1). Leak rate tests data were included that provided a bounding leak rate for indications at TSP intersections that were predicted to be sufficiently large that they would burst if they occurred in the freespan of the tube, based on the freespan burst correlation included in the licensed 1 Volt ARC according to Reference 1.

This report is an addendum to WCAP 15163, Revision 1 that provides additional information to support the proposed ARC, specifically with regard to the conservatism of the hydraulic loading on which the TSP displacements are based, and documents the added conservatism provided by 16 tubes at each of three TSPs to lock the TSPs in place.

The basis of the TSP displacement analyses in WCAP 15163, Rev 1 was input transient hydraulic loads calculated using RELAP5. During review of the technical report, WCAP 15163, Rev 1, the NRC provided a request for additional information (RAI) (Reference 2), which was further clarified by the NRC during subsequent discussions. The staff noted that the application of RELAP5 to determine TSP loading during a MSLB was not considered inappropriate, but that validation of the code version utilized against available test data was necessary prior to its application to provide input hydraulic loading for the TSP displacement analysis for STP Unit 2.

In response to the NRC position, a bounding analysis was initiated, based on conservative first-principles assumptions, to determine bounding hydraulic loads and TSP deflections that do not depend on the use of RELAP5. The objective of this analysis was to demonstrate the significant margins for POB that exist for the 3V ARC. Section 3 of this report presents the bounding hydraulic analysis methods and the resulting TSP pressure drops.

The proposed application of the 3V ARC is limited to the hot leg of the three TSPs above the flow distribution baffle (FDB) in the STP-2 SGs to reduce uncertainties in the calculation of the TSP loading. In addition, to add conservatism, expansion of 16 tubes at each of the three TSPs to lock them in place is added to the proposed ARC by this supplement. The tube expansion process and the restraint loading provided by the tube expansions are discussed in Section 5.

TSP displacement analysis is discussed in Section 4. The analysis is a static, elastic analysis that assumes unit loading. The results of this analysis can be extrapolated within defined limits because the analysis is an elastic analysis.

The probability of burst (POB) analysis methods are addressed in WCAP 15163, Rev 1, Section 9. Section 6 of this Addendum addresses the incremental POB from application of the 3V ARC at the hot leg of plates C,F, and J. The total POB is shown to be $<10^{-2}$, the limit specified in Reference 1.

Section 6 of this Addendum discusses the Alternate Repair Criteria based on the bounding hydraulic loads and on the addition of TSP locking by expansion of tubes at each of the hot leg support plates (C,F, and J) for which the 3-Volt ARC are intended to apply. Section 6 also discusses the inspections that are required to support implementation of the 3V ARC.

Table 1-1 summarizes the applicability of the sections of this Addendum report and of the WCAP 15163 report. It is noted that WCAP 15163 provides significant background and logic for the 3V ARC and, therefore, cannot be completely divorced from the technical justification of the ARC. Table 1-1 is intended to facilitate review of the original WCAP and of this Addendum report by noting the sections of the reports that apply and sections that have been superseded by this addendum report.

References:

1. "Voltage-Based Repair Criteria for Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking," Generic Letter 95-05, dated August 3, 1995
2. NRC Letter, T. Kim to W. Cottle, "South Texas Project, Unit 2 – Request for Additional Information re: Licensing Amendment Request Associated with Modifying Alternate Repair Criteria of Steam Generator Tubes at Certain Intersections of the Tubes and Tube Support Plates (TAC No. MA8271)", AE-NOC-00000699, dated October 31,2000.

Table 1-1
Applicability of Addendum to WCAP-15163, Rev. 1

Section	Addendum Report	WCAP 15163, Rev 1
1	Applies - Provides background rationale for the Addendum Report and limits of applicability of the ARC to TSPs C,F and J	Applies Provides the background for the 3V ARC; references to RELAP are superseded by the Addendum Report
2	Applies -Summarizes the 3V ARC for plates C, F, and J based on bounding loads and application of tube expansions	Generally Applies -References to limiting displacement of 0.15" do not apply -References to RELAP5 do not apply - References to application of 3V ARC to TSPs L and M do not apply -Inspection requirements are superseded by the Addendum Report -Exclusion of 15 tubes in SG-D applies -SG Internals Inspection requirements are superseded by Addendum Report
3	Applies - Supersedes Section 5 of WCAP 15163	Applies There is no corresponding section in the Addendum Report that describes the Model E2 design
4	Applies - Generally supersedes Sections 6 and 7 of WCAP 15163	Partially Applies -References to RELAP5 do not apply -Model E operating conditions apply -Flow loss coefficient data apply -Description of sensitivity analyses does not apply

Table 1-1 (continued)

Applicability of Addendum to WCAP 15163, Rev 1

Section	Addendum Report	WCAP 15163, Rev 1
5	Applies - New section for tube expansion development and parameters; no equivalent section in WCAP 15163, Rev 1	Generally superseded by Addendum Report Section 3
6	Applies -Supersedes Section 10 of WCAP 15163 -Augments Section 11 of WCAP 15163	Generally superseded by Addendum Report Section 4 -General methodology description applies -Material properties apply
7	N/A	Generally superseded by Addendum Report Section 4
8	N/A	Applies -Provides the discussion and results for the IRB tests; no equivalent section on the Addendum Report
9	N/A	Applies -Augmented by discussion of burst probability in section 6 of Addendum Report -Provides tube burst and leakage methodology -References to limited displace-ment of 0.15" do not apply
10	N/A	Generally Does Not Apply - Superseded by Section 6 of Addendum Report - References to industry experience apply
11	N/A	Partially Applies - Augmented by Section 6 of Addendum Report - Discussion of applicability of GL-95-05 to all intersections not covered by the proposed 3V ARC applies.

2.0 Summary and Conclusions

WCAP 15163, Revision 1 documented the technical support for 3-Volt Alternate Repair Criteria (ARC), applicable to the hot leg intersections of tube support plates (TSP) C through M. This addendum to WCAP 15163, Rev. 1 provides additional information to address issues that arose during review of the proposed ARC. The additional information provided addresses the following key areas:

A. Application of the 3V ARC to Only the Hot Leg (HL) Intersections of TSPs C, F and J

Although WCAP 15163, Rev 1 justifies application of the 3-Volt ARC to hot leg TSP intersections at plates C through M, the currently proposed application of the ARC is limited to the HL intersections of plates C, F and J only. Limiting the application of the 3-Volt ARC to these three plates eliminates potential uncertainties in the Thermal/Hydraulic analyses that could enter due to the mixing of the hot leg flow with the cold leg flow above plate L (see Figure 3.2, WCAP 15163, Rev.1).

It is noted that application of the 3-Volt ARC is proposed for only one 18 months operating cycle, prior to the scheduled replacement of the steam generators at South Texas Unit 2.

B. Basis of the Input Hydraulic Loads to the TSP Structural Analysis

WCAP 15163, Rev 1 described the development TSP loading data (pressure drop across the TSP) using RELAP5. To address questions regarding the validation of the application of RELAP5 to the problem of predicting pressure drop across the TSP during a postulated SLB event, an independent <u>bounding</u> analysis was performed that is based on first principles and does not rely on RELAP5. The analysis is discussed in Section 3 and is summarized below in Section 2.1.

C. Addition of Tube Expansions to "Lock" the TSPs

Although TSP displacements can be shown to be acceptable to limit the probability of burst and leakage to within the specified limits, even under the bounding loads, the hydraulic expansion of 16 tubes in the HL at each of TSPs C, F and J to lock the TSPs in place is proposed to provide added margin against TSP displacement.

Tube expansions were previously utilized at Byron and Braidwood for three cycles of operation as part of the licensed 3-volt ARC at these plants, prior to replacement of the SGs. The proposed tube expansions at the TSPs, described in Section 5 and summarized in 2.3 below for STP Unit 2, are the same as those utilized at Byron and Braidwood, except that the expansion bulge diameter was reduced to minimize

tube axial stresses and a full-section internal sleeve (i.e., not a thinned sleeve) is utilized to improve the axial load capacity of the expanded tube.

Addition of tube expansions limits the maximum deflection of the TSPs under bounding T/H loading conditions and provides a significant additional factor of safety above the bounding loads. The TSP structural analysis is described in Section 4 and is summarized below in Section 2.2. The margins above the bounding loads are summarized in Section 2.4, below.

2.1 Bounding Thermal/Hydraulic Analysis

For a postulated SLB, depressurization of the SG causes void formation due to steam flashing in the SG. This causes the coolant volume to swell, pushing the coolant through the tube support plates and upward through the downcomer to depressurize the SG. The flow split between the bundle and the downcomer is determined by the relative flow resistance through these paths. The elevation of the flow split, up vs. down, is approximately at mid-bundle. A simplified model, using mass and energy balance for the fluid contained in the bundle region, was employed to calculate the flow rate through the bundle during depressurization of the SG.

Conservative assumptions were made to assure that the calculated flow, and therefore, pressure drop, across the TSPs was a bounding value:

1. The assumption was made that all of the flow would exit through the TSP by setting the flow through the downcomer to zero. This is conservative for the mid and upper tube support plates, since the depressurization flow actually passes through both the bundle and the downcomer as noted above. The analysis case with this assumption provides conservative peak differential pressure (Δp) across the mid and upper tube support plates.

2. The assumption was made that half the flow passes through the downcomer, and half the flow passes through the bundle. Since the flow path through the downcomer is known to have greater resistance to flow than the flow path through the tube bundle, causing the actual flow to be predominantly through the bundle, this assumption results in conservative pressure drop values for the lower tube support plates. Therefore, the analysis case with this "split flow" assumption provides conservative bounding Δp across the lower TSPs.

3. The assumption was made that the entire depressurization flow would escape through the downcomer. Although this assumption is physically unrealistic, it is useful to confirm that assumption 2 for the "split flow" case is conservative and bounding since it demonstrates the considerably higher pressure drops associated with "downflow" than with "upflow" when the flows are comparable.

4. In all cases, the flow resistance due to the upper internals components of the SG (primary and secondary separators, deck plates, etc.) was conservatively neglected.

The results of the bounding analyses are as follows:

1. For the assumption that all of the flow escapes through the bundle ("up-flow" with the downcomer blocked), the maximum Δp across plates C, F and J is 1.76 psid at plate J. The maximum Δp across any of the TSP is 3.56 psid at plate R, the uppermost plate in the bundle.
2. For the assumption of 50/50 split flow through the downcomer and through the bundle, the maximum Δp across any of the plates (except the Flow Distribution Baffle, Plate A) is –2.35 psid at plate C.

For comparison purposes, the normal operating Δp across the TSPs is <1 psid. The maximum Δp predicted for the hot leg tube support plates based on the RELAP5 analysis was 1.67 psid at plate R. Thus, application of these bounding loads, based on first principles analyses using conservative assumptions, provides high confidence, conservative TSP deflection results.

In addition to the bounding thermal hydraulic analysis discussed above, the effect that pressure fluctuations in the steam line might have on tube support plate loads in the tube bundle was evaluated by calculating the transfer function for pressure oscillations in the steam line to pressure oscillations in the tube bundle. The method of analysis and the calculated results are provided in Section 3.4 and apply only to moderately sized steam line breaks for which the break area is less than the flow area of the flow restrictor in the steam line nozzle. For large area breaks, the flow restrictor will choke and isolate the steam generator from any pressure fluctuations in the steam line. On the other hand, if the break area is much smaller than the flow area of the flow restrictor, the steam flow will be less than that experienced under normal operating conditions and would not be expected to result in concern for the steam generator.

The transfer function results indicate that at high frequencies (pressure oscillations in the steam line that exceed about 30 Hertz) the pressure response in the tube bundle will be very small. For lower frequencies, the relative amplitude in the tube bundle region will be less than about 10 per cent of the amplitude of the oscillations in the steam line. This pressure reduction effect is primarily due to the large flow areas located in the upper part of the steam generator which act as an accumulator when compared to the flow area of the flow restrictor. In addition, the flow resistances associated with the steam separators and the two-phase conditions in the steam generator which occur during depressurization from a steam line break help to mitigate any sonic waves from propagating from the steam line into the tube bundle region. As discussed in Section 3.4, the resulting loads on the tube support plates due to these oscillations are expected to be small.

2.2 TSP Deflection Analysis

A static, elastic model of the SG tube bundle was utilized that included the same components of the model described in Section 4 of WCAP 15163, Rev. 1. The tube support plates, stayrods, backup bars, wedges, wrapper, etc. are included in this model. Also included in the model are 16 expanded tubes and the structural characteristics of the tube expansions at the TSPs. While all of the support structures for the TSPs are active elements in the model, only support plates C, F and J were loaded for these analyses.

The factors of safety above the peak bounding Δp were developed from a single plate loading case. A sensitivity analysis was performed, which considered simultaneous loading of TSPs C, F and J. Application of the same conservative, bounding load to multiple TSPs is physically unrealistic, since, although the maximum loading occurs during the initial swell following a postulated SLB, the times of maximum loading of the plates after initiation of the transient are not coincident. Further, the peak bounding Δp used in this bounding analysis is the peak value of 3.56 psid calculated for the up direction at TSP R (see Section 3). The bounding value calculated for TSP J is in the up direction at approximately half the value for TSP R, and the values for TSPs F and C in the up direction are approximately 1/6 and 1/20, respectively, the value for TSP R.

Both "up" loads and "down" loads were considered, since the structural response of the system is different for these loadings. In the "up" direction, the loads are transmitted to the stayrods via the spacers between the TSPs, and the TSP wedges provide active support. In the "down" direction, the spacers transmit the loads to the tubesheet, the stayrods provide no support, and the wedges provide no support. The results of the unit load analyses showed that the "up" loading was limiting, that is, resulted in larger TSP deflections and component stresses. TSPs F and C can be expected to be loaded in the down direction with a bounding load of 2.35 psid at TSP C.

Since the model was an elastic model, unit loads were applied to the TSPs, so that the displacement and stress results could be ratio-ed to other loads. To preserve the validity of the model, the elements of the model were required to be within their respective yield strengths. Thus, the limits that apply for the validity of the model are:

- TSP stress must be below the TSP yield stress.
- Stayrod and spacer stresses must be less than the respective component yield strength.
- The axial deflection in the TSP expansions must be less than 0.10"
- Expanded tube stress must be within the yield strength of the tubes

Provided these criteria are met, the Δp across the TSP can be derived from the unit load deflection results for any desired deflection or stress limit.

The following are the key results from this analysis for 16 expanded tubes at TSPs C, F and J:

- For the planned tube expansion and the bounding load of 3.56 psid assumed to apply at TSPs C, F and J, the maximum TSP displacements would be only 0.048".
- The maximum Δp across the TSP to maintain structural members within elastic limits is 13.3 psid. This represents a factor of safety of 3.74 to the peak bounding Δp of 3.56 psid. The limiting Δp is determined by stress in the expanded tubes. For the bounding up direction Δp of 1.76 psid at TSP J, the factor of safety is 7.57, and for the bounding down direction Δp of 2.35 psid, the factor of safety is 5.66.
- For the very conservative case of simultaneous loading of plates C,F and J, the limiting Δp is 4.59 psid (factor of safety = 1.29), determined by the stress in the expanded tubes.
- The maximum TSP displacement at the maximum acceptable Δp of 13.3 psid for single plate loading is 0.180". This maximum displacement is confined to a local area of the TSP.
- The stayrods and spacers are very lightly stressed and exhibit large margins at the limiting loads.

This analysis also showed that without implementing tube expansions and without violating any of the established stress criteria, the TSP maximum local deflection for the applicable ARC TSPs would be –0.133" for the bounding downward load of –2.35 psid at TSP C, 0.142" for the bounding upward load of 1.76 psid at TSP J and would be only 0.31" at the peak bounding load of 3.56 psid obtained at TSP R.. The limiting criterion for this case is the TSP ligament stress.

2.3 Tube Expansion Joint Process and Capabilities

The tube expansion at the TSPs is performed by a hydraulic expansion process that expands the parent tube and a sleeve stabilizer at the same time. Expansions are performed below and above each TSP intersection that requires expansion. The design requirement for the tube expansion process, as developed to restrain TSP displacement, is a minimum expanded tube stiffness of [.] a,c,e. The process development tests (Section 5) show that an expanded tube minimum diameter increase of [ ]a,c,e provides a stiffness exceeding the required tube stiffness. The sleeve stabilizer expanded with the parent tube increases the expansion stiffness at a given diametral expansion. After expansion of a tube in the field, bobbin coil profilometry is used to confirm that acceptable expanded tube diameters have been achieved and that the expansions are properly located relative to the TSP.

The TSP expansion process for STP-2 will be targeted toward obtaining approximately [ ] a,c,e bulges in low yield strength tubing and approximately [ ] a,c,e bulges in high yield strength tubing. For TSP expansions, the minimum bulge diametral increase is [ ] a,c,e independent of material yield strength. Based upon the load displacement data developed for the TSP expansions, expansions produced at the target value of [ ] a,c,e in low yield strength tubing provide approximately [ ] a,c,e resistive load, resulting in an axial stiffness of approximately [ ] a,c,e of TSP displacement.

2.4 Margins

WCAP 15163, Rev. 1, Section 11 discussed the probability of burst as a function of the TSP displacement. For an assumed displacement of all of the HL intersections at all of the TSPs (C through R) of 0.3", a negligible burst probability of $<10^{-5}$ was calculated. Application of the peak bounding Δp, 3.56 psid, to the results of the unit loading analysis for single plate loading results in a maximum local TSP deflection of 0.048" at the peak bounding Δp. This represents a factor safety of 6.41 to the very conservative probability of burst analysis. Consequently, probability of burst under bounding load conditions is much less than 10^{-5}.

WCAP 15163, Rev. 1, Section 8 discusses the testing to develop the bounding leak rate for indications restricted from burst (IRB) and notes that the range of applicability of the IRB test data is a support plate deflection of 0.21". For leak rate calculation, the methods discussed in WCAP 15163, Rev.1 will be utilized for defining whether an indication is an IRB. The TSP deflection calculated based on the peak bounding Δp across a single plate is 0.048" as noted above; thus, the factor of safety for application of the bounding IRB leak rate is 4.38.

For single plate loading, the minimum factor of safety over the peak bounding loading is 3.76. For this case, the limiting criterion is the expanded tube stress.

For the unrealistically conservative case of simultaneous loading of TSPs C, F and J, the minimum factor of safety over the peak bounding load is 1.29. The limiting criterion is the stress in the expanded tubes.

Table 2.1 summarizes the key displacements of the TSPs that were predicted during the bounding loading analyses, together with the displacements that identify limits for applicability of supporting test data and probability of burst analyses.

2.5 Summary of ARC

The overall ARC objective is to have limited TSP displacements such that the tube burst probability is negligible for indications at TSPs C, F and J under the 3-volt ARC. For the 3 TSPs under the 3 volt ARC, a maximum TSP displacement of 0.3" results in a tube burst probability contribution of $< 10^{-5}$. The TSP displacement goal of 0.3" and the resulting tube burst probability of $<10^{-5}$ is satisfied with, or without, tube expansions for the peak bounding loads. With 16 tubes expanded to lock the TSPs, the maximum TSP displacement is approximate 0.048" at the peak bounding pressure drop across the TSPs, compared to the 0.3" design requirement for negligible probability of burst (defined as 10^{-5}). Even for a postulated pressure drop margin of 13.3 psid, which maintains the structural components within elastic limits, the maximum TSP displacement would be about 0.18" and less than the 0.3" displacement goal. The maximum calculated TSP displacement at the limiting load occurs at only a small fraction (about 10% of tubes within 20% of largest deflection) of the HL intersections. Thus, the probability of burst for the limiting loading will be much less than 10^{-5} for the contribution from TSPs C, F and J.

There have been in excess of 210 tube-to-TSP intersections (from pulled tubes) destructively examined since the beginning of the ARC program. Seven indications have been found with crack indications extending outside of the TSP. The exposed lengths have ranged from 0.025 to 0.27" with average depths up to 25% (for an indication with an exposed length of 0.11") and maximum depths up to 50% (for the same indication). If the likelihood of existence of such cracks is taken to be 7 in 200, the number of affected intersections would be 7 in 200 times 14,553 hot leg intersections or approximately 509. If the depth of each crack is conservatively assumed to be 100% TW for approximately half of the maximum observed length of the crack (0.15" assumed for each), and the lengths are added to the maximum predicted TSP displacement (0.18"), the cumulative probability of at least one burst during a postulated SLB event is 1.2×10^{-6}. Even unrealistically conservative assumptions still lead to predicted POB significantly less than 10^{-2}; thus, assumed crack growth outside the TSP meets the GL 95-05 probability of burst limits.

An incremental POB of 10-5 will be conservatively assigned for the 3V ARC at the hot legs of plates C, F, and J for the total probability of burst calculation.

Although an indication inside the TSP cannot burst, the flanks of a crack that could burst at SLB conditions can open up within the confines of the TSP. This condition has been labeled as an indication restricted from burst, or an IRB. Conceptually, the IRB leak rate can vary with TSP displacement that exposes part of the throughwall crack. A leak test program was performed to determine a leak rate that conservatively envelops the leak rate from an IRB. For South Texas-2, the applicable SLB pressure differential is 2405 psid, based on the pressurizer PORVs for pressure relief. At this pressure differential, the bounding IRB leak rate is 5.0 gpm. The IRB leak rate, as compared to the much larger leak rate from a freespan burst, is dependent upon the TSP hole limiting the crack opening at or near the center of the crack. This crack opening constraint leads to a limit on TSP displacement. Tests were performed up to a maximum TSP displacement of 0.21" in developing the bounding IRB leak rate of 5.0 gpm. Since the throughwall crack lengths that led to the 5.0 gpm IRB leak rate were on the order of 0.6" or longer, the center of the crack limiting the crack opening would be inside the TSP for displacements up to about 0.3". For assessing conservative design margins such as the acceptable 13.3 psid value, displacements up to about 0.3" are reasonable and satisfied for application of the IRB leak rate. For the predicted bounding TSP loads, the maximum TSP displacement of 0.048" is much less than the ≤ 0.21" that maintains the displacements within the database used to develop the 5.0 gpm IRB leak rate.

Table 2.1 summarizes the key limiting TSP displacements and the TSP displacements predicted using the bounding loads.

The following provides a summary of the 3.0 volt alternate tube repair criteria (ARC), as developed in Section 6, to be applied at South Texas-2 tube support plates C, F and J with limited SLB displacement. Tube expansions at 16 locations on TSPs C, F and J are required to support these ARC.

South Texas-2 Tube Repair Limits

- For hot leg TSP indications at plates C, F and J, bobbin flaw indications >3.0 volts shall be repaired independent of rotating pancake coil (RPC) (or equivalent) confirmation.

- For indications at hot leg plates L through R, at the FDB and at cold leg TSP intersections, bobbin flaw indications >1.0 volt and confirmed by RPC inspection shall be repaired per the requirements of NRC GL 95-05. Bobbin flaw indications greater than the upper voltage repair limits for South Texas-2 indications at these intersections shall be repaired independent of RPC confirmation. The upper voltage repair limits for hot leg plates L through R, for the FDB and for cold leg TSP intersections shall be updated at each inspection based on the latest database, correlations and plant specific growth rate information.

- All indications found to extend outside of the TSP and all circumferential crack indications shall be repaired and the NRC shall be notified of these indications prior to returning the SGs to service.

- All flaw indications found in the RPC sampling plan for mechanically induced dents (corrosion denting is not present with stainless steel TSPs at South Texas-2) at TSP intersections and bobbin mixed residuals potentially masking flaw indications shall be repaired.

- For the South Texas-2 Model E SGs, no intersections near TSP wedge supports are excluded from application of ARC repair limits due to potential deformation of these tube locations under combined LOCA + SSE loads.

Inspection Requirements for Expanded Tubes

- The bobbin coil inspection shall include 100% of all hot leg FDB and TSP intersections and cold leg TSP intersections down to the lowest cold leg TSP with ODSCC indications. The lowest cold leg TSP with ODSCC indications shall be determined from an inspection of at least 20% of the cold leg TSP intersections.

- All bobbin flaw indications exceeding 3.0 volts for hot leg TSP intersections at plates C to J, and 1.0 volt for hot leg intersections at plates L through R, for all FDB intersections and for all cold leg TSP intersections shall be RPC (or equivalent probe) inspected. In addition, a minimum of 100 hot leg TSP intersections at plates C through J with bobbin voltages less than or equal to 3.0 volts shall be RPC inspected. The RPC data shall be evaluated to confirm responses typical of ODSCC within the confines of the TSP. A RPC inspection shall be performed for intersections with mechanically induced dent signals >5.0 volts and for bobbin mixed residual signals that could potentially mask flaw responses near or above the voltage repair limits.

- Prior to the tube expansion, tubes selected for expansion will be bobbin inspected; potential indication at TSPs C, F and J found by the bobbin inspection will be +Point inspected, and a +Point inspection will be performed for the tube sheet expansion transition. The tubes to be expanded must have no circumferential indication at the expansion transition, no indications within one inch above or below the TSP and no +Point confirmed bobbin indications greater than one bobbin volt within the confines of the TSP. Following implementation of the tube expansion process, the tube expansions are inspected to confirm that the expansion process resulted in the minimum acceptable bulge size as described in Section 2.3 above.

Inspection Requirements for SG Internals

Visual inspections of the stayrods or peripheral supports are judged not to be required to adequately limit TSP displacements and maintain structural integrity based on the following considerations:

- The stayrods are very lightly loaded; a minimum factor of safety of 26.5 on the peak bounding Δp is predicted for the stayrod and spacer stresses for the single plate loading case when all stayrods are active. The TSP expansions at TSPs C, F and J provide for large margins on the TSP hydraulic loads while obtaining acceptable TSP displacements and maintaining structural component stresses within elastic limits. The tube expansions more than compensate for an assumed loss of one stayrod or one peripheral support, either of which is a very low likelihood event over the planned one operating cycle with the 3 volt ARC at South Texas-2.

- Various visual inspections of the secondary side components have been performed by STP-2 without any reported anomalies (see Section 6.4 of this addendum). The wedges and backup bars have been confirmed undamaged during inspections of the lower TSPs (including TSP C) in the bundle. No SG internals loss of structural integrity has been observed in several inspections of them at STP Units 1 and 2 since the SGs were placed in service in 1989. Backup bars and wedges have been confirmed to be in place for the lower TSPs, including plate C, during inspections at STP 1 and 2.

- No loss of structural integrity of the stayrod nuts, backup bars and wedges has been observed in prior visual inspection of similar components during application of 3V ARC at Byron 1 and Braidwood 1.

- No mechanism has been identified for degradation of the structural components during operation. No mechanism has been identified to unthread the stayrod nuts, particularly working against the force of gravity.

- The proposed operating time for application of the 3V ARC is limited to one 18-months operating cycle.

- The real cost, \$440,000, and the personnel dose, 12Rem, required to perform these inspections are not justified by the added information that could be obtained by performing the inspections.

SLB Leak Rate and Tube Burst Probability Analyses

- SLB leak rates and tube burst probabilities shall be evaluated for the actual voltage distribution found by inspection and for the projected next EOC distribution.

- Based on the voltage distribution obtained at the inspection, the SLB leak rate shall be compared to the South Texas-2 allowable. The SLB tube burst probability for FDB and cold leg TSP intersections and the hot leg intersections at plates L through R shall be evaluated according to the requirements of GL 95-05. A burst probability of 10^{-5} for the hot leg intersections of TSPs where the 3 V ARC apply will be included in the total burst probability, which will be compared to the reporting value of 10^{-2}. The NRC shall be notified prior to returning the SGs to service if the allowable limits are exceeded. If the allowable limits are exceeded for the projected EOC distribution, the NRC shall be notified and an assessment of the significance of the results shall be performed. A report shall be prepared that includes inspection results and the SLB analyses within 90 days following return to power.

- SLB leak rate analyses for indications at TSPs C, F and J shall apply the IRB leak rate methods while the freespan GL 95-05 methods apply for all other locations. An IRB leak rate of 5.0 gpm shall be used for sample indications predicted to burst under freespan conditions in the IRB Monte Carlo leak rate analyses.

Table 2.1
Summary of Key TSP Displacement Values

Displacement From Bounding Analysis	Explanation
0.048" (Upper bound on expected displacements; TSP Δp=3.56 psid)	This displacement value results from application of the bounding Δp predicted for all TSPs (i.e., 3.56 psid for plate R (See Table 3.2) to the single plate unit loading case (Case 112, Table 4.14). E.g., 3.56 psid x 0.0135 In./psid = 0.048 in. This displacement provides a conservative reference number for predicted TSP displacement, in that the bounding Δp for all plates is used when the predicted bounding Δp for plates C, F and J are much less than 3.56 psid (see Table 3.2)
0.18" (Displacement of record for upper limit analysis; TSP Δp=13.3 psid)	This displacement value results from application of the limiting Δp, 13.3 psid, that meets all of the applicable displacement and stress criteria, to the single plate unit loading case (Case 112, Table 4.14). E.g., 13.3 psid x 0.0135 In./psid = 0.18 in. This displacement is a conservative number since it is a factor of 3.74 greater than the largest bounding Δp of 3.56 psid (at plate R), a factor of 7.57 greater than the Δp of 1.76 psid at plate J and a factor of 5.66 greater than the Δp of 2.35 at plate C.
0.21" (Comparative displacement value for applicability of IRB bounding leak rate)	This value is the upper limit on test data supporting the bounding leak rate (5 gpm) for Indications Restricted from Burst (IRB). Larger displacements are likely acceptable for the applied bounding IRB leak rate of 5.0 gpm, but were not included in the EPRI tests. This value is documented in EPRI report TR-107625.

Table 2.1 (continued)
Summary of Key TSP Displacement Values

0.3" (Comparative displacement value for incremental Probability of Burst <10-5)	This displacement, when applied to all HL intersections at all TSPs (except the FDB) results in an incremental probability of burst of 10^{-5} if it is assumed that a throughwall crack exists at every intersection with its tip located at the edge of the TSP. This displacement provides a comparison basis for incremental probability of burst resulting from TSP displacement. Thus, if the TSP displacement is less than this value, and if the displacement occurs at fewer than ALL of the intersections, the incremental probability of burst must be $<10^{-5}$ for that condition.
General Note: None of these displacements will be directly used to calculate the leak rate from the flawed tubes. Leak rate calculations will be based on the freespan leakage correlation of GL-95-05, except for indications that are predicted to be Indications Restricted from Burst (IRB). For an IRB, a fixed, bounding leak rate of 5 gpm will be used, based on the tests documented in EPRI TR-107625 and section 8 of WCAP-15163, Revision 1. An IRB is defined as an indication that, after application of uncertainties and growth rates, would be predicted to burst in the freespan according to the burst correlation of GL 95-05. For these cases, the bounding leak rate from the IRB tests will be used.	

3.0 THERMAL/HYDRAULIC ANALYSIS

3.1 Steam Line Break Characteristics

A schematic of a Westinghouse Model E steam generator is shown in Figure 3-1. The steam generator utilizes a venturi flow restrictor in the main steam line nozzle to limit the magnitude of the break flow during a steam line break accident. In the top of the steam generator just below the steam line nozzle, there are several open volumetric regions in the flow paths with cross-sectional areas that vary between 75 times and 145 times the size of the flow area of the flow restrictor. These large flow areas act as accumulators that tend to absorb pressure fluctuations from the steam line and result in relatively low steam velocities near the top of the steam generator inside the main steam nozzle. In addition, there are two sets of steam separators that the steam flow must pass through prior to entering the steam outlet nozzle. These steam separators act in series and provide resistance to the steam flow as it approaches the main steam nozzle.

The water in the steam generator resides primarily in the region below the primary separators. When the steam generator is operating at power, the water in most of the tube bundle region is a two-phase mixture of steam and water with increased quality in the higher regions of the tube bundle. Typically, subcooled water will be present in the preheater section of the bundle with slight subcooling in the lower regions of the bundle just above the tube sheet depending on the operating power level. The flow in the bundle region will be upwards due to natural convection effects arising from differences in density between the two-phase fluid in the heated tube bundle and the single phase fluid in the unheated downcomer. The flow in the tube bundle is upwards and two-phase. Almost all the liquid entrained in the flow leaving the tube bundle is separated by gravity in the steam separators and is returned to the bundle via the downcomer annulus. The ratio of the total flow in the bundle to the steam flow escaping the main steam nozzle is known as the circulation ratio and is about 2.35 (Ref. Section 4.3, WCAP 15163, Rev 1) for the Model E steam generator when it is operating at full power. Consequently, at full power operating conditions the upward flow in the tube bundle is about 2.35 times the steam flow that exits the main steam nozzle. Under these operating conditions, the largest pressure drop across a tube support plate is less than 1 psid.

When a steam line break occurs from full power operating conditions, the flow from the steam nozzle increases by about a factor of 3 until the flow restrictor chokes. Due to the resulting flow imbalance, a depressurization of the large volume at the top of the steam generator occurs. The decrease in pressure acts to disrupt the circulation flow as the flow in the downcomer slows down and reverses to help supply the flow to the break. Consequently, when a steam line break occurs from full power operating conditions, there will be only a moderate increase in flow in the bundle itself that is directly attributable to the break. However, there is a secondary, more substantial contribution to flow in the tube bundle caused by the swelling of the fluid in the tube bundle region due to flashing as the steam generator pressure decreases. This swelling effect in the tube bundle generates the peak loads on the tube support plates during the early part of a steam line break. Since the tube bundle region already contains substantial voids when the steam generator is operating, the surge associated with swelling in the tube bundle from a steam line break from hot standby conditions will result in the worst case tube support plate loads for the steam generator.

3.2 Methods

To determine the peak loads that could occur during a steam line break, a simplified calculation was employed to estimate the peak loads on the tube support plates that would occur as a result of the surge associated with depressurization of the steam generator due to a steam line break. This simplified method utilizes a mass and energy balance of the fluid contained within the tube bundle region of the steam generator to determine the volumetric swell that would occur as a result of depressurization due to the postulated break. Since the increased volume must be removed from the bundle region as flow through the tube support plates, the calculation can be used to determine the flow across each tube support plate and the resulting load that will be applied. The technique employed and the results obtained are discussed in Section 3.3 below.

In addition to considering the loads on the tube support plates that result from the relatively steady depressurization of the steam generator associated with the steam line break, the effect that pressure fluctuations in the steam line would have on the internals in the tube bundle was also investigated. These results are discussed in Section 3.4 below.

3.3 Simplified Analysis for Peak Loads due to Swell

During hot standby conditions, the tube bundle region will contain stagnant, essentially saturated, water slightly subcooled with depth due to the gravitational head from the water level. When a steam line break occurs, the steam generator will begin to depressurize and the hot water in the tube bundle will begin to flash. This results in a sudden swell that forces the fluid in the tube bundle to expand through the tube support plates. There are two exit paths from the tube bundle that the expanding fluid can take. The fluid can escape by flowing up through the U-bends and into the primary separators or it can escape by flowing down towards the tubesheet and up the downcomer annulus. The ratio of the flow for these two escape paths will depend on the relative resistances involved.

Since the flow will escape the tube bundle in two opposite directions, there will be a stagnation region located at a particular height in the tube bundle where the flow will be very small. The fluid above this stagnation region will go up towards the U-bends whereas the fluid below this stagnation region will go down towards the tubesheet and up through the downcomer. By making conservative assumptions regarding the escape flow path, conservative values for the peak pressure drops across each tube support plate can be obtained once the magnitude of the volumetric expansion is defined.

3.3.1 Assumptions

The load on a particular tube support plate will result from the accumulation of flow from the expansion of all the fluid between the stagnation region and that tube support plate. Therefore, an assumption that the stagnation region is too low will result in conservative loads on the upper tube support plates and non-conservative loads for the lower support plates. Similarly, an assumption that the stagnation region is too high will result in conservative loads on the lower tube support plates and non-conservative loads on the upper tube support plates. The assumptions used for this simplified analysis are summarized below:

- Homogeneous equilibrium conditions are assumed for the analysis. The assumption of equilibrium conditions results in instantaneous flashing in reaction to a drop in pressure and will overestimate the rate of fluid expansion. In addition, the assumption of homogeneous flow will limit the ability of the steam to escape from the tube bundle and will also result in an overestimate of the expansion.

- For estimating the load on the upper tube support plates, it is assumed that the flow path through the downcomer is blocked. For this case, all the expansion of fluid in the tube bundle is forced upwards through the tube support plates.

- For estimating the load on the lower tube support plates, it is assumed that only half the flow expands up through the U-bends. The increased resistance associated with obstruction of flow by the preheater in the cold leg and the flow path up the downcomer is significantly higher than that for flow up through the U-bends so the flow stagnation region will be lower in the bundle than assumed here. For example, the flow area of the downcomer is about 9.8 square feet which is about half the flow area available through the upper tube support plates. In addition, the minimum area in the flow path through the separators from the tube bundle is 14.1 square feet whereas the minimum area through the separators from the downcomer is about 4 square feet. Consequently, much higher velocities would be required for the same flow rate to pass through the downcomer as compared to the upper tube support plates. Requiring that all the flow due to expansion go up the downcomer would be overly conservative.

- All resistance in flow between the tube bundle and the main steam outlet nozzle is ignored. This is conservative as it overestimates the pressure at the nozzle that results in an overestimate of the break flow. The effect is small early in the transient when the highest tube support loads are calculated.

3.3.2 Method

The steam generator is assumed to be at hot standby conditions (1200 psia stagnant saturated steam and water) and is divided into upper and lower regions. The upper region includes the part of the steam generator that is above the water level and includes only saturated steam. The lower region includes the part of the steam generator that is below the water level and initially includes only saturated water.

Based on the initial conditions, the total mass and energy are determined for each region using the properties for saturated steam and water from the ASME steam tables and the initial volumes of each region.

$$M = V / v$$

$$U = M (h - P v)$$

Where:
- M is the total mass in each region
- U is the total energy in each region
- V is the volume of the region
- v is the specific volume from the steam tables
- h is the specific enthalpy from the steam tables
- P is the pressure

When the steam line break occurs, the flow at the break is determined from the critical mass flux for saturated steam as a function of pressure as provided by the ASME steam tables. For a particular time step, the mass and energy in the upper region will be reduced as a result of flow out the steam nozzle:

$$\in M = - W_{crit} \in t$$

$$\in U = - h\, W_{crit} \in t$$

where: W_{crit} is the critical mass flow from the break
$\in t$ is the time step

The mass and energy of the lower region are unchanged as the boundary of this region is selected such as to contain the original mass. This requires that the lower region expand and the upper region contract to maintain pressure equilibrium between the two regions. An iterative technique is employed to obtain the appropriate volumes for the upper and lower regions that maintain the total volume constant and result in the pressures in the two regions being the same. As a result, vapor will be formed in the lower region since the specific volume increases but the total mass remains constant. Once the new volume of the lower region is determined, a new specific volume for the expanded fluid in that region can be calculated.

As a result of the reduced pressure and the expansion of fluid in the lower region, the volume of the steam generator between the tubesheet and the top tube support plate will lose mass.

$$\in M_B = V_B(t+\in t)/\ v_B(t+\in t) \quad - V_B(t)/\ v_B(t)$$

where: M_B is the mass in the bundle between the tubesheet and the upper tube support plate
V_B is the volume in the bundle between the tubesheet and the upper tube support plate
v_B is the specific volume in the bundle between the tubesheet and the upper tube support plate

The rate of change of mass in the tube bundle from one time step to the next provides a measure of the total flow leaving the tube bundle during the time step.

$$W_B = \in M_B/\in t$$

By making conservative assumptions regarding the path that this flow must take as it flows out of the tube bundle region, a conservative measure of the pressure drop on each tube support plate can be obtained.

By making conservative assumptions regarding the path that this flow must take as it flows out of the tube bundle region, a conservative measure of the pressure drop on each tube support plate can be obtained.

$$\in P = K\,W^2 / (\Delta\,A^2)$$

where:

where:	K	is the loss coefficient for the tube support plate based on the flow area through the plate
	W	is the portion of the mass flow rate that passes through the tube support plate
	Δ	is the density of the fluid flowing through the plate
	A	is the flow area through the plate

For example, if one assumes that all the flow from expansion of the fluid in the tube bundle must flow upwards, the top tube support plate must pass all the flow while the bottom tube support plate will only pass the expanded flow from the region below it. Consequently, the load on the top tube support plate will be conservatively overestimated for this assumption while the load on the bottom tube support plate may be underestimated.

3.3.3 Results of Simplified Analysis

The technique described above was employed to obtain a conservative estimate of the loads that would occur on the tube support plates of the model E steam generator as a result of a steam line break. The technique was programmed for a personal computer using computerized steam tables. Parameters used for the analysis are summarized in Table 3.1.

The results indicate that for the conservative equilibrium assumption, the peak pressure drops for the tube support plates occur when flashing in the tube bundle initiates. Voids already present in the tube bundle region act to reduce the expansion effect associated with further pressure decreases so the calculated loads on the tube support plates diminish with time for a constant depressurization rate.

In order to obtain conservative results for all tube support plates, three separate assumptions on flow distribution were employed. The results of these analyses are summarized in Table 3.2 and are discussed below.

For the first case, it was assumed that no flow can escape up the downcomer and all flow must pass up through the tube bundle. This assumption provides conservative results for the upper tube support plates as they experience the full expansion flow, some of which would normally escape up the downcomer.

The second case assumed that half the flow escapes upwards through the tube bundle and half the flow escapes through the downcomer. Due to the higher resistance for the flow path through the downcomer, the tube bundle flow will necessarily be higher than the downcomer flow so the assumption of an equal flow split is conservative for calculating the pressure drops for the lower tube support plates.

Assuming the full flow escapes through the downcomer in a manner opposite to that used for Case 1 will result in overly conservative results for the lower tube support plates. Nevertheless, this case was also run as Case 3 and is included in the results in Table 3.2. The pressure drops that were obtained for the lower tube support plates for Case 3 are very high when compared to those for the upper tube support plates from the comparable Case 1. This confirms that the path of least resistance would be out the top of the tube bundle and helps justify that Case 2 results are conservative for the lower tube support plates.

For the sake of comparison, Table 3.2 also includes the results obtained from the analysis from hot standby conditions using the RELAP program.

Figures 3-2 through 3-5 provide plots of the calculated results for the first two seconds of the simplified transient analysis. Figure 3-2 shows the pressure inside the steam generator which is calculated from the remaining mass and energy existing inside the steam generator at each time step as previously discussed in Section 3.3.2. The calculated critical mass flow rate at the nozzle is shown in Figure 3-3 and was determined from the calculated pressure using the data from the ASME steam tables. Saturated steam was assumed at the nozzle location as little moisture will reach the nozzle until after the swell inside the steam generator is high enough to flood the steam separators.

Figure 3-4 shows the calculated volumes for the upper (steam only) region of the steam generator and the lower (two-phase mixture) region of the steam generator as utilized for the iterative pressure calculation. When the volume of the upper region that contains only steam disappears, moisture will arrive at the nozzle and the critical mass flow rate will increase due to increased fluid density. However, the pressure drop across the tube support plates due to the swell of the fluid will be significantly reduced by this time.

Figures 3-5 shows the calculated flow rate that must be removed from the volume beneath the top support plate as a result of the expansion of the fluid due to the depressurization. The mass flow due to swell that occurs early in the transient is almost an order of magnitude higher the critical mass flow at the break. The manner in which this flow is distributed between up-flow and down-flow determines the load on each tube support plate.

3.4 Effect of Steam Line Pressure Fluctuations

The effects of a steam line break will diminish with time as the steam generator depressurizes and the flow from the break decreases. As long as the pressure in the steam generator is high enough and the break large enough to choke the flow restrictor in the steam outlet nozzle, pressure fluctuations in the steam line downstream of the nozzle will not be able to propagate into the steam generator. If the area of the break is small enough (less than about 0.45 square feet or about 1/3 of the area of the flow restrictor), the break flow will be less than that normally experienced during operation. The internals of the steam generator should not be significantly affected since there is considerable operating experience at this level of flow. Nevertheless, it may be possible that for a medium sized break for which the break area is smaller than the nozzle area, the break flow could exceed the full power operating flow and the flow restrictor could not be choked. Under these conditions, pressure fluctuations in the steam line could possibly propagate into the steam generator and affect the internals. Nevertheless, the significant change in area and the presence of the compressible steam in the large volume at the top of the steam generator combine to act as an accumulator and will help to isolate the lower internals from the effect of sudden pressure changes in the steam line.

Additional isolation for the tube bundle region is provided by significant resistance that exists across the two levels of steam separators and the presence of large amounts of saturated liquid that can flash to maintain the pressure near saturation pressure. As a result, any sudden depressurization in the steam line leads to a much slower depressurization of the steam generator as a whole and relatively small pressure gradients would be expected inside the tube bundle. The pressure gradients that are established are primarily a result of "steady flow" rather than dynamic imbalance due to flow acceleration. In fact, the dominant loads on the tube support plates in the tube bundle result from the swell of the fluid trapped by the support plates as the steam generator begins to depressurize rather than from the propagation of sonic waves from the main steam nozzle.

To estimate the extent to which pressure fluctuations in the steam line could propagate into the tube bundle of the steam generator, a two-phase thermal-hydraulic analysis was conducted for which a sinusoidal pressure oscillation was imposed at the steam line boundary. The steam generator was assumed to be at hot standby. The pressure response in the tube bundle region was determined as a function of the applied oscillatory pressure in the steam line. The analyses were run until steady state oscillating conditions were achieved. Several such analyses were conducted using several different frequencies for the pressure oscillations to determine the frequency transform for the pressure oscillations between the steam line and the tube bundle region.

3.4.1 Method

The steam generator was divided into control volumes that contain mass and energy. The control volumes are connected together by fluid connectors that transfer mass and energy between the control volumes. The integrated form of the momentum, mass, and energy conservation equations were solved for the control volumes and connectors to obtain transient pressures and flows. Computerized steam tables were used to represent the properties of the fluid and rigorous mass and energy conservation was imposed. Results from the technique have been compared to analytic solutions for wave propagation in piping systems with good agreement.

3.4.2 Results

Results obtained from five separate runs with pressure oscillation frequencies between 10 and 50 Hertz are summarized in Table 3-3 and are plotted in Figure 3-6. These results provide the relative amplitude of the calculated response of pressure at the inside of the steam nozzle, at the top of the tube bundle, and at the region just above the tubesheet as compared to the amplitude of the pressure oscillations imposed at the steam line boundary. At low frequency, the calculated amplitude of the pressure oscillations at the tubesheet is about 7 per cent of the amplitude of the applied pressure oscillations in the steam line whereas the amplitude of the pressure oscillations at the U-bends is about 2 per cent of the applied amplitude. There appears to be some frequency dependence for the response at low frequencies, particularly near the steam nozzle. This may indicate an acoustic resonance effect at the top of the steam generator since the response is about 90 degrees out of phase with the applied pressure. However, the response in the tube bundle remains low for all the analyzed frequencies. For frequencies above 30 Hertz, the calculated response in the tube bundle is negligible.

Figures 3-7, 3-8, and 3-9 show the detailed transient pressures for the 10 Hertz, 30 Hertz, and 50 Hertz cases, respectively. At low frequency, there is distortion of the signal between the applied pressure and the response. This may be due to resistances in the flow paths that tend to generate reflections in the pressure signal. These distortions disappear at the higher frequencies analyzed.

Figure 3-10 shows the calculated oscillating pressures at several elevations in the hot leg region for the 20 Hertz analysis case. The peak-to-peak amplitude of the pressure oscillations is about 6 psi for an applied peak-to-peak magnitude in the steam line of 100 psi. The pressures at the different elevations in the hot leg oscillate in phase and the difference in pressure observed in the plot is primarily due to differences in elevation head. Consequently, there is little load on the tube support plates associated with these oscillations.

A further indication that the pressure oscillations apply little load to the tube support plates is provided by Figure 3-12 which shows the calculated flow in the tube bundle region associated with these pressure oscillations. In the figure, W38 is the total flow just above the divider plate and represents the flow through the full tube support plate whereas W39 is the total flow at the top of the hot leg that includes only half the steam generator cross sectional area. The amplitude of the flow oscillations is less than 200 lbs/sec and corresponds to a flow velocity through the minimum area of the support plates of less than 0.25 feet per second. This flow amplitude would be imposed on top of the flow in the tube bundle from the steam line break that was calculated previously to be in the order of 20,000 lbs/sec. Since the loads on the tube support plates vary by the square of the flow rate, the loads on the tube support plate generated by pressure oscillations in the steam line will be negligible when compared to those generated by the steam line break. This would be true even if the amplitude of the pressure oscillations in the steam line is well in excess of the 100 psi peak-to-peak value used for this analysis.

Pressure oscillations in the steam line would normally be of smaller amplitude than the 100 psi used in this analysis. The only way such large amplitude oscillations could be sustained in the piping would be through acoustic waves which reinforce themselves as they propagate back and forth between the break and the steam generator nozzle. The frequency of such acoustic oscillations is dependent on the speed of sound and the length of pipe involved. For the steam outlet piping, acoustic oscillations in the steam line will probably be at a low enough frequency so that any response inside the tube bundle of the steam generator will be in phase. As was demonstrated previously, low frequency oscillations (below 30 Hertz) will not apply a significant load to the tube support plate since the same pressure is applied to both sides of the plate simultaneously. As was also demonstrated previously, if the frequency of these pressure oscillations exceeds 30 Hertz, they will not propagate into the steam generator tube bundle.

additional energy to the secondary side fluid. Since the peak pressure drops across the tube support plates occur on initial flashing of the secondary side early in the transient, these peak pressure drops will not be significantly affected by heat transfer when the steam line break occurs from hot standby.

The effect of heat transfer later in the transient results in two compensating effects. On the one hand, the additional heat transfer will tend to generate additional voids due to the increased energy. On the other hand, the increased energy will tend to maintain pressure that results in a slower rate of depressurization and the corresponding swell that accompanies it. This is one of the reasons why the steam line break from full power operating conditions is less severe than that from hot standby conditions. Preliminary calculations which incorporated the heat transfer from the metal by adding the appropriate term to the energy equation of the secondary fluid indicate the effect on tube support plates pressure drops is small.

3.6 Potential for Water Slugs Contributing to Tube Support Plate Loads

Water slugs impacting on structures is usually associated with low pressure two phase flow conditions in contrained sections of horizontal piping. Slug flow is limited to low velocities under these conditions because higher velocities result in turbulent or annular flow regimes.

At low flow velocities, the possibility may exist that voids could coalesce in the tube bundle and form water slugs that might impact the tube support plates. Clearly discernable slug flow is rare in diabatic systems and is not considered to be a problem for the steam generator during normal operation due to the distributed formation of voids during the heat transfer process. Although a depressurization transient also forms distributed voids due to flashing of the hot fluid, due to lack of experience we can not totally rule out slug flow during the steam line break transient. Consequently, an estimate of the magnitude of the forces that would be involved is provided below.

For vertical slug flow, the terminal rise velocity is given by the following expression:

$$U_t = k_1 [g D_b (\kappa_l - \kappa_g)/ \kappa_l]^{1/2}]$$

where: k_1 is an empirical constant and is equal to 0.345.

D_b is conservatively taken as the diameter of the steam generator (about 10 feet)

g is the acceleration of gravity

κ_l , κ_g are the densities of the liquid and vapor phases

The terminal rise velocity represents the relative velocity between voids and water slugs which could form and be present in vertical flow. As such, it is a good estimate of the peak slug velocities that could be obtained for unconstrained flow in the tube bundle. Since the rise velocity is proportional to the square root of the diameter of the water slug, the worst possible case would occur if a slug formed which fills the complete cross-section of the steam generator. At hot standby conditions of 1200 psi, the terminal rise velocity for such a slug will be about 6.0 feet/sec. The dynamic head associated with liquid flowing at this velocity will be about 0.17 psi. Similarly, at 600 psi the terminal rise velocity of such a slug will be about 6.1 psi with a dynamic head of about 0.19 psi.. Obviously, smaller slugs that occur between tubes would have much lower terminal rise velocities. Since the pressures associated with slug flow are very small compared to the bounding Δp, slug flow in the tube bundle is not considered significant for the tube support plates during a steam line break.

TABLE 3.1
Parameters used for Simplified Analysis

Input Parameter	Value	Comment
Initial Pressure	1200 psia	Hot Standby Conditions
Total Volume	7585 Cubic Feet	
Water Volume	4500 Cubic Feet	
Flow Area in Bundle	68.1 Square Feet	Full Cross Section
Distance to Top Plate	31.86 Feet	
Break Flow Area	1.338 Square Feet	Area of Venturi

Tube Support Plate	Flow Area (Square Feet)	Resistance Coefficient
A	9.01	1.23
C	10.45	1.07
F	10.45	1.07
J	8.98	1.17
L	16.83	1.18
M	19.13	1.13
N	19.11	1.13
P	19.13	1.13
Q	19.11	1.13
R	20.99	1.06

TABLE 3.2

Calculated Peak Pressure Drops for Hot Leg Tube Support Plates

Plate	Up-Flow Only (psid)	Split Flow (psid)	Down Flow Only (psid)	RELAP Results (psid)
A	0.013	-5.068	-21.330	-0.97
C	0.139	-2.346	-11.800	-0.88
F	0.534	-1.376	-9.467	-0.66
J	1.756	-0.983	-10.940	-0.71
L	1.011	-0.056	-2.182	0.68
M	1.254	0.003	-1.035	0.63
N	1.893	0.094	-0.583	0.95
P	2.653	0.314	-0.259	1.31
Q	3.553	0.665	-0.068	1.64
R	3.559	0.890	0.000	1.67

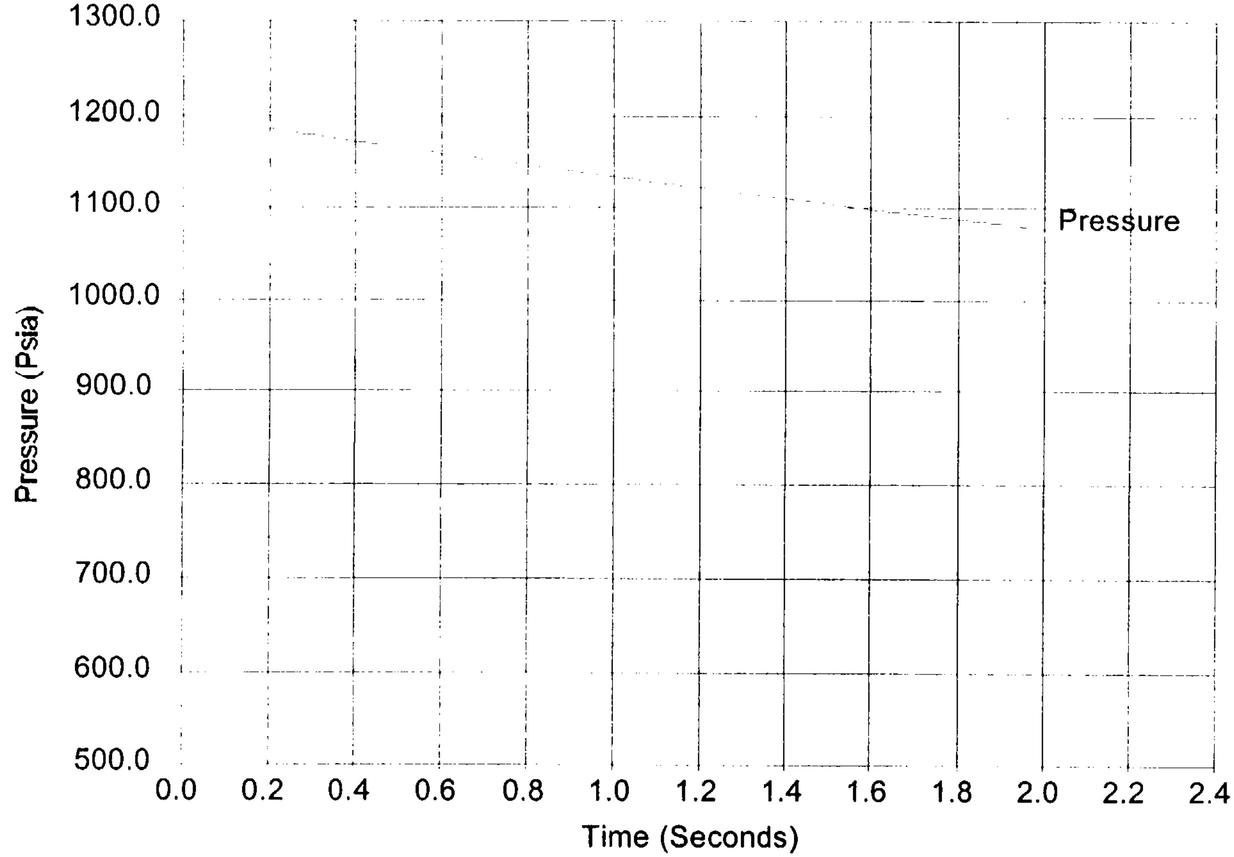
TABLE 3.3
Results of Frequency Response Analysis for Pressure Oscillations in Steam Line

Frequency	Relative Response in Per Cent		
	Inside Nozzle	U-Bends	Tubesheet
10	7.2	1.9	6.7
20	4.2	4.9	8.0
30	16.9	0.8	1.1
40	5.5	0.1	0.1
50	3.0	0.05	0.05

Figure 3.1

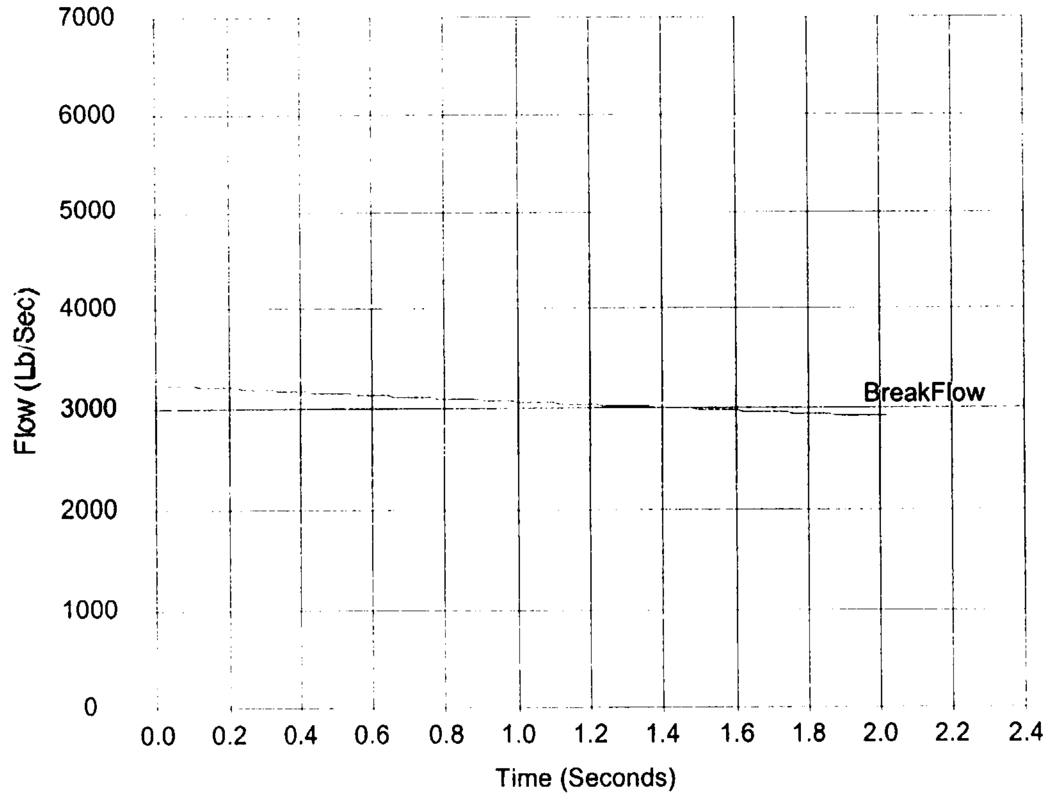
Model E2 Steam Generator Layout

a,c



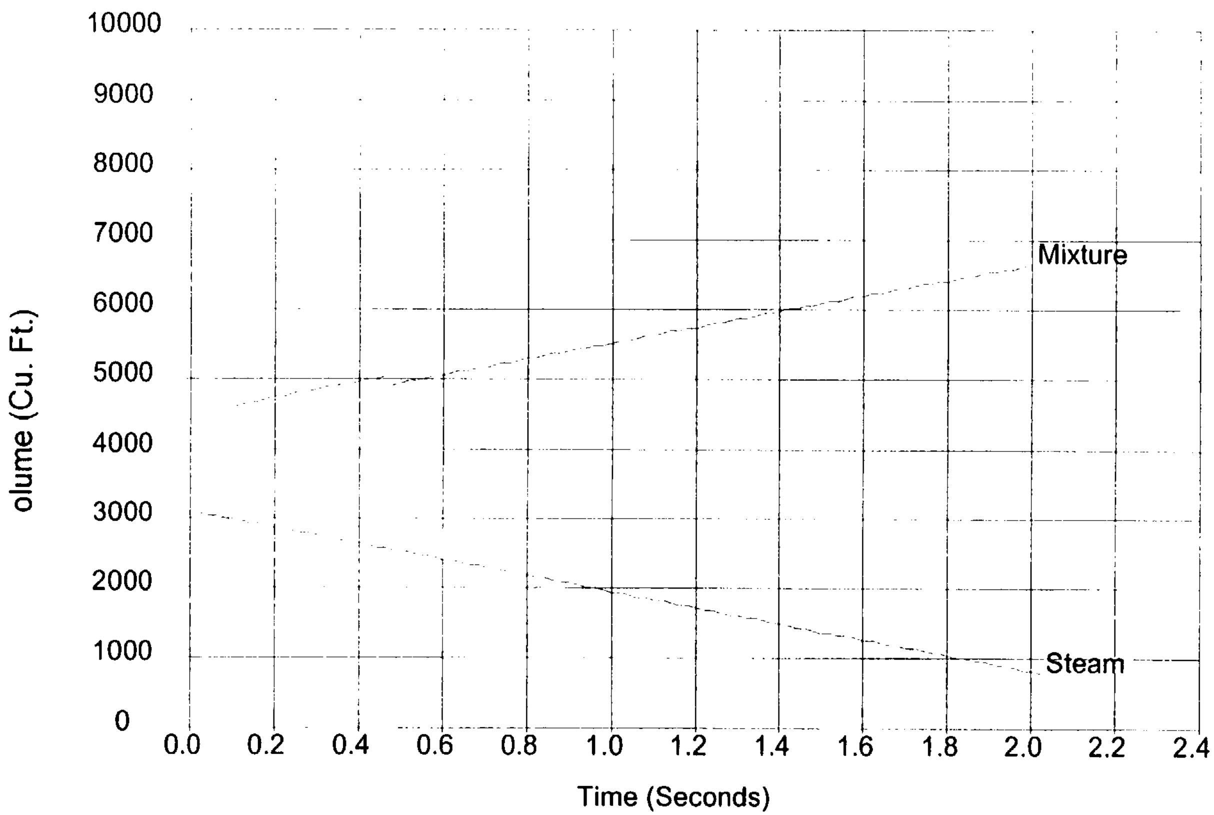
Simplified Conservative Analysis - Calculated Steam Generator Pressure

FIGURE 3-2



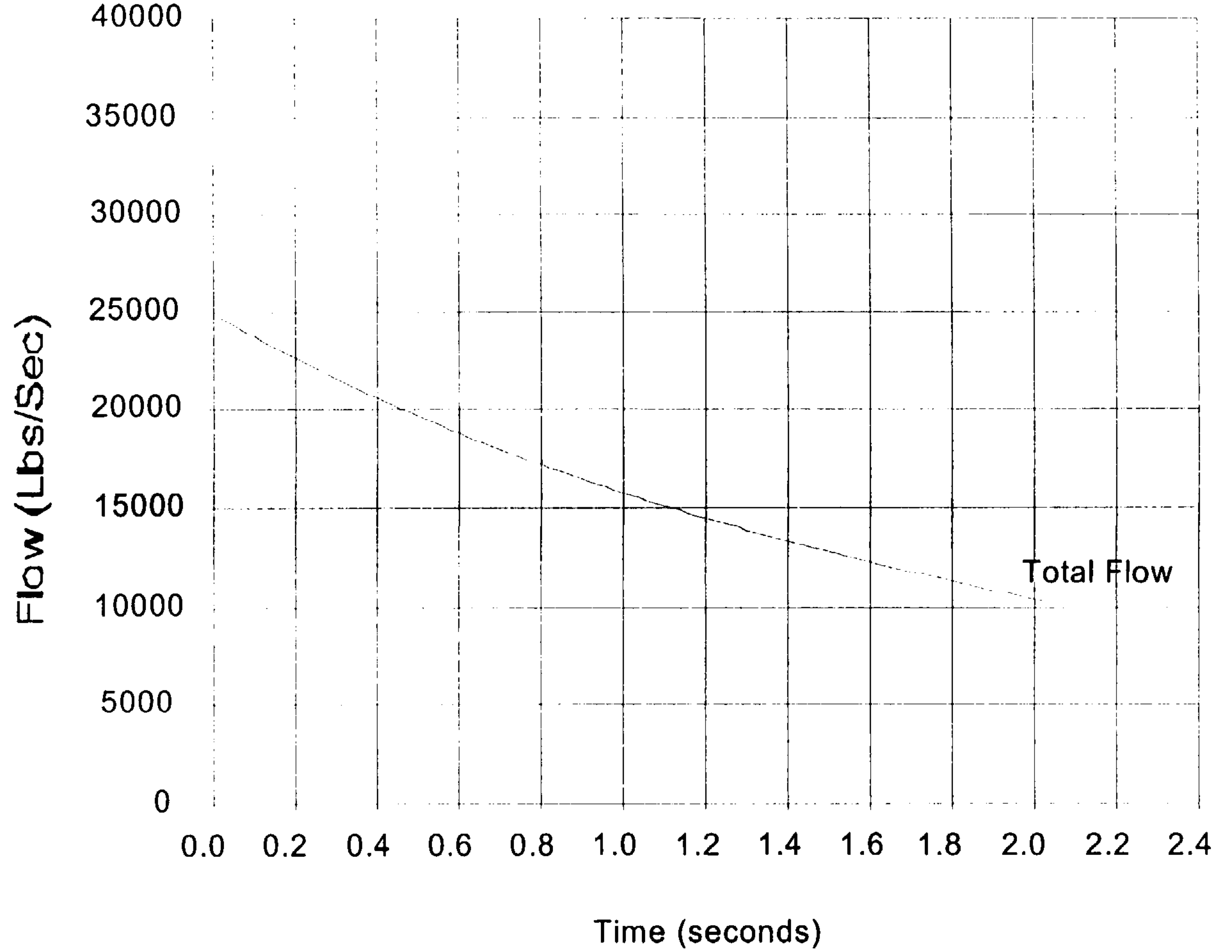
Simplified Conservative Analysis - Calculated Critical Break Mass Flow Rate

FIGURE 3-3



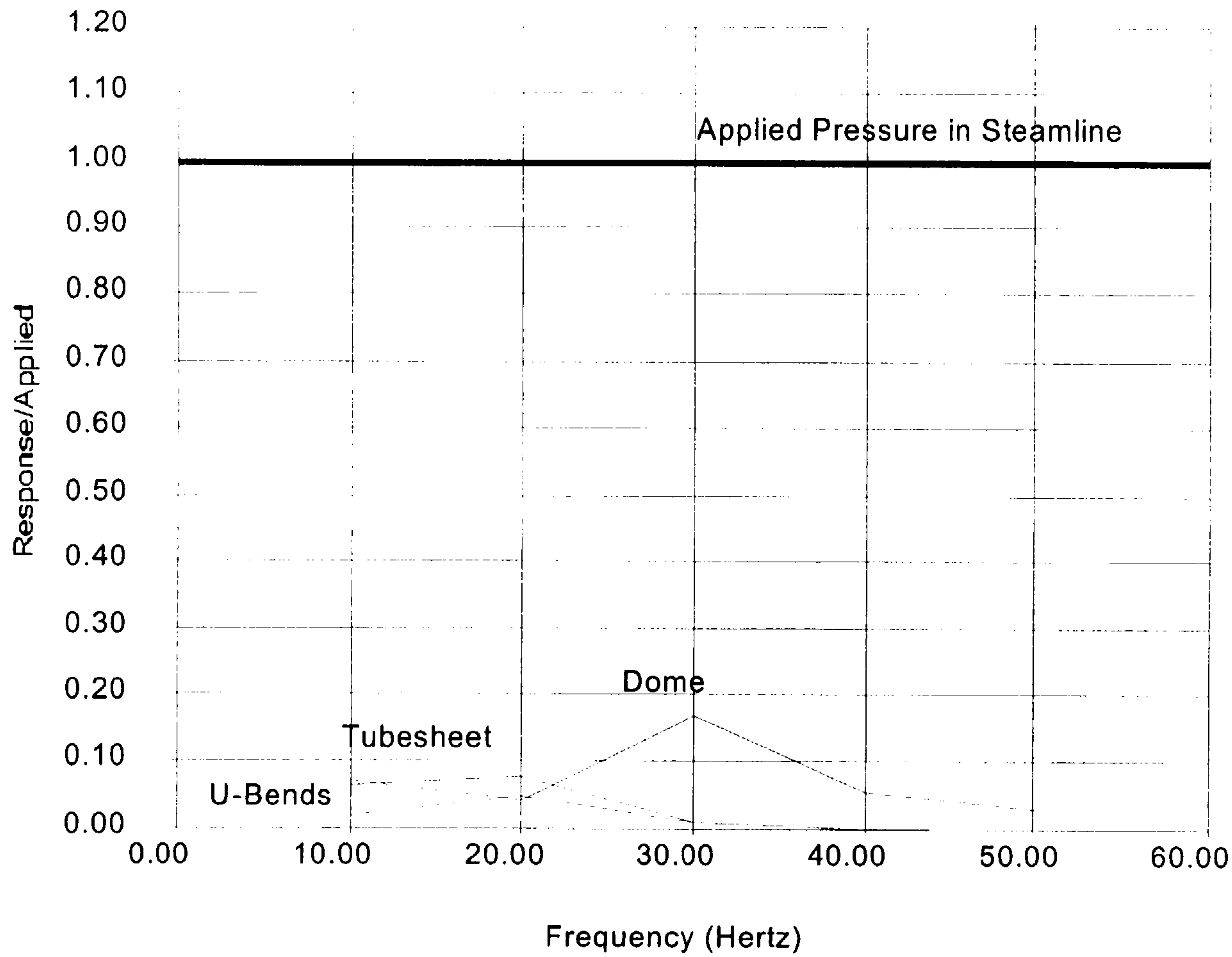
Simplified Conservative Analysis - Calculated Volumes for Regions

FIGURE 3-4



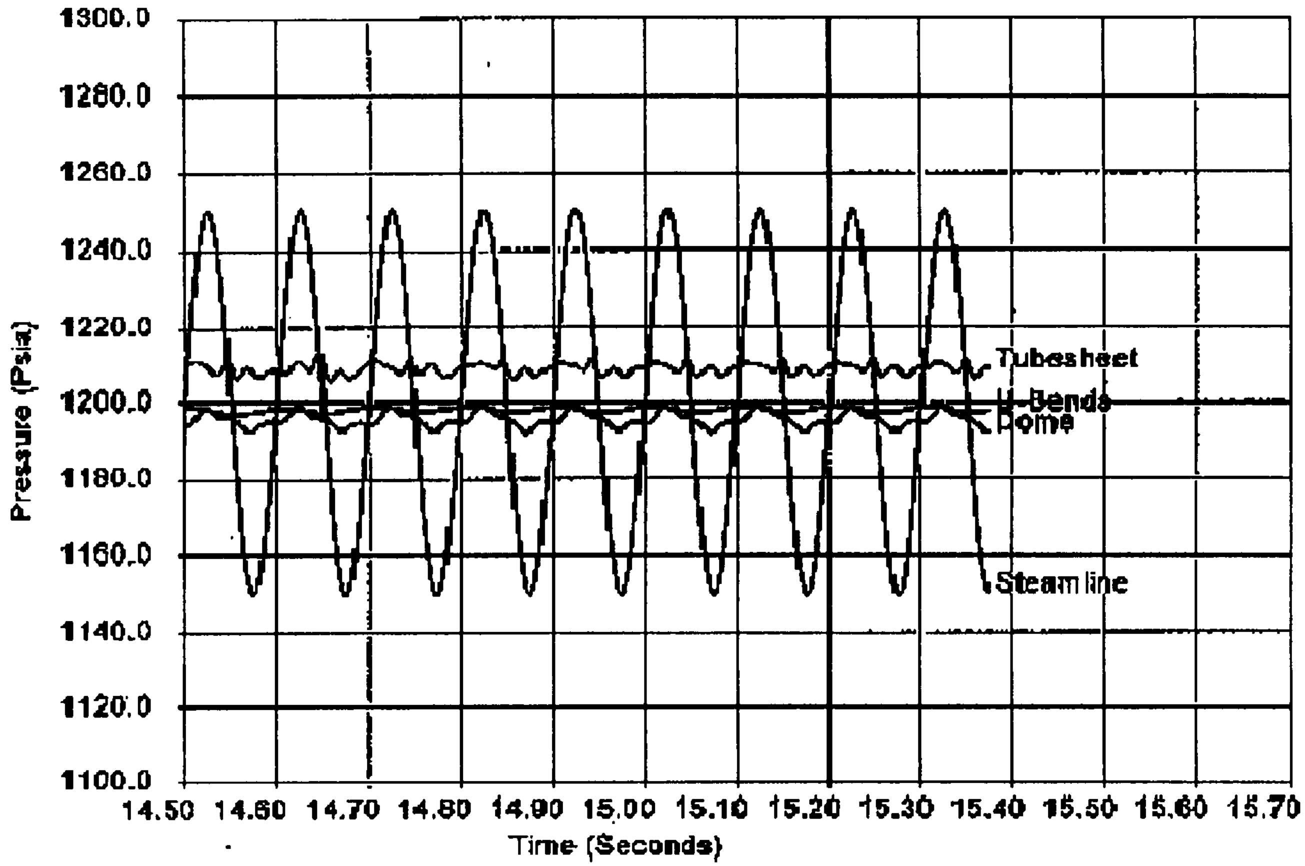
Simplified Conservative Analysis - Total Flow Due to Swell

FIGURE 3-5



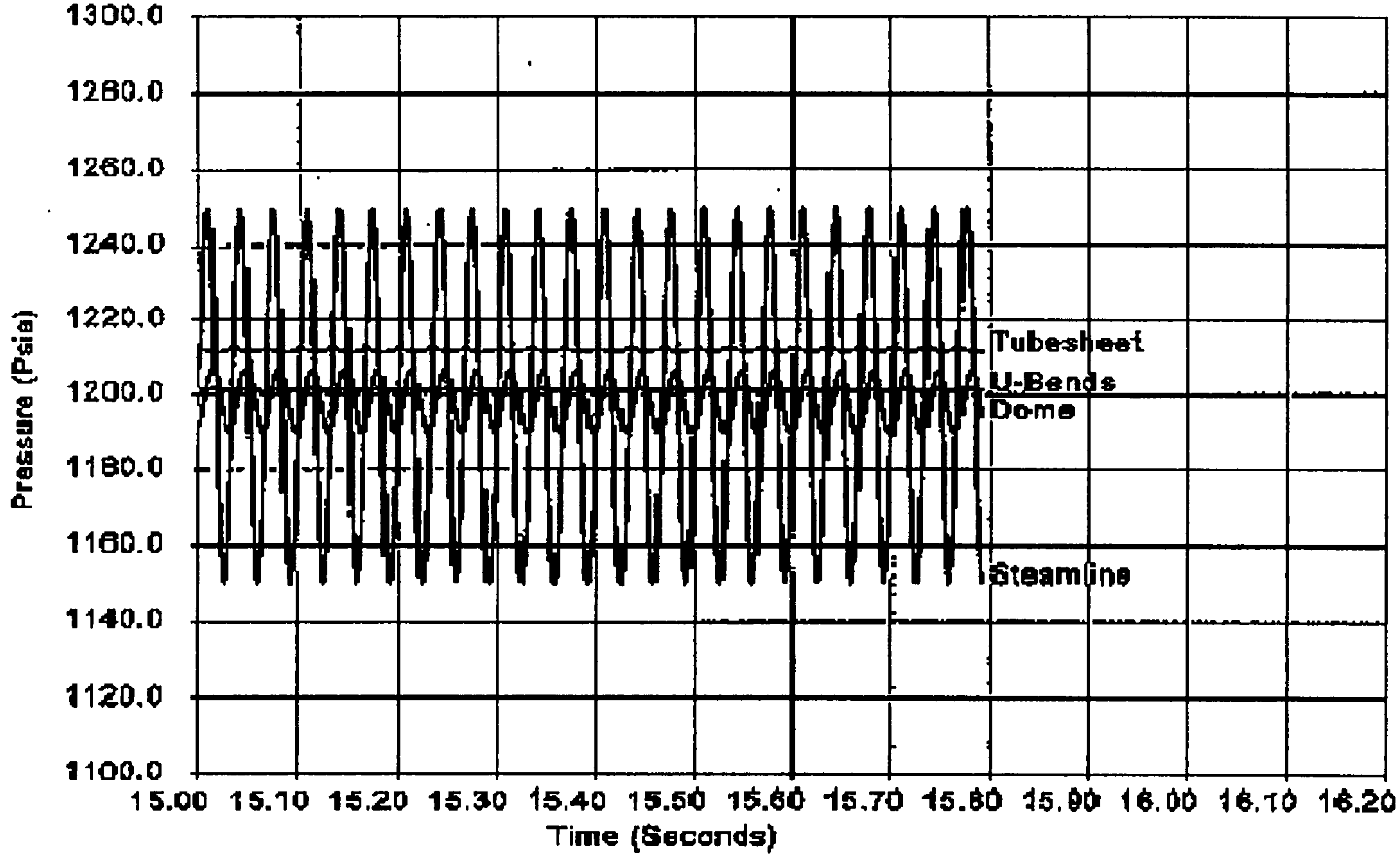
Summary of Results for Steam Line Oscillations at Hot Standby Conditions

FIGURE 3-6



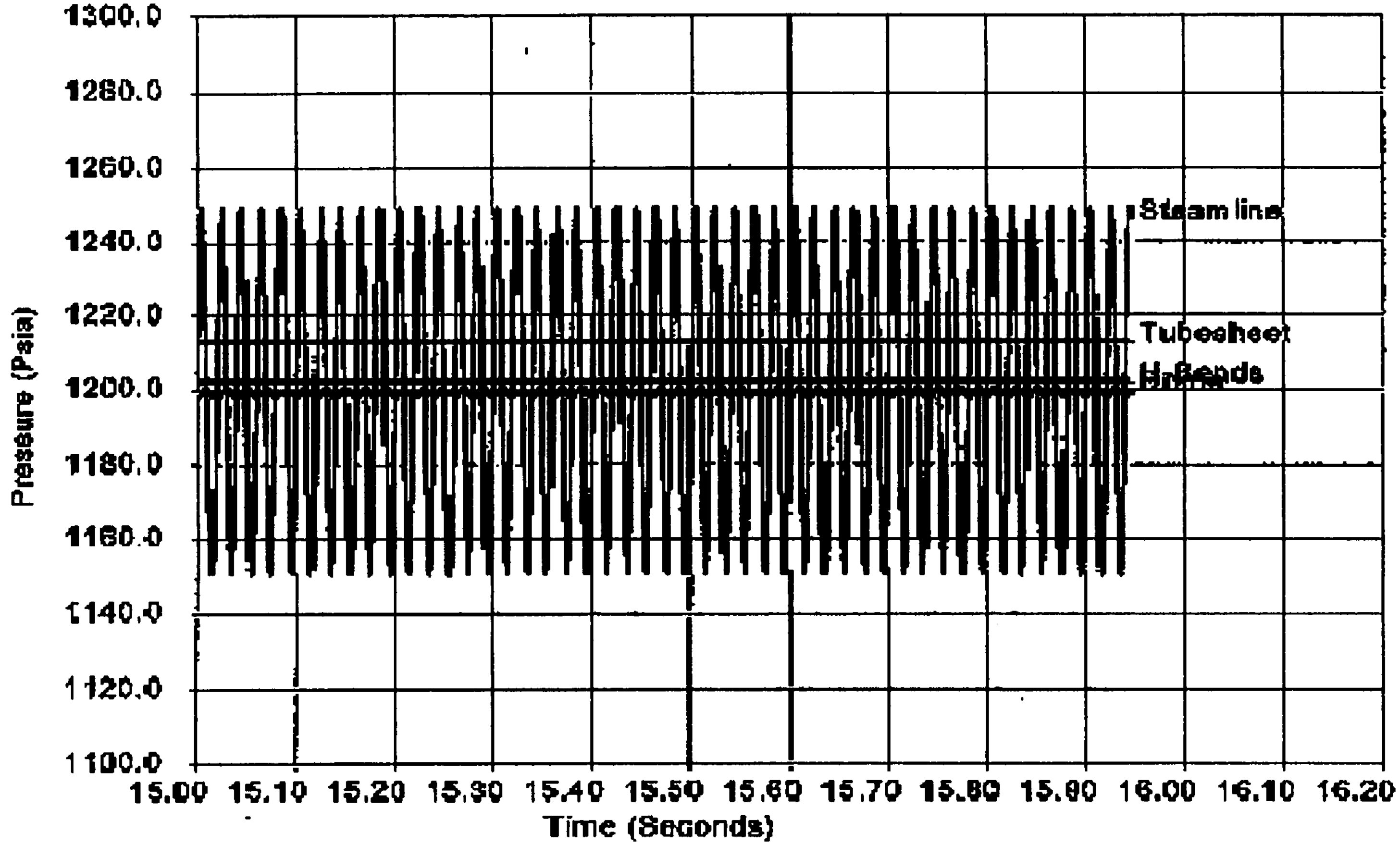
Results at 10 Hertz - Steam Line Oscillations at Hot Standby Conditions

FIGURE 3-7



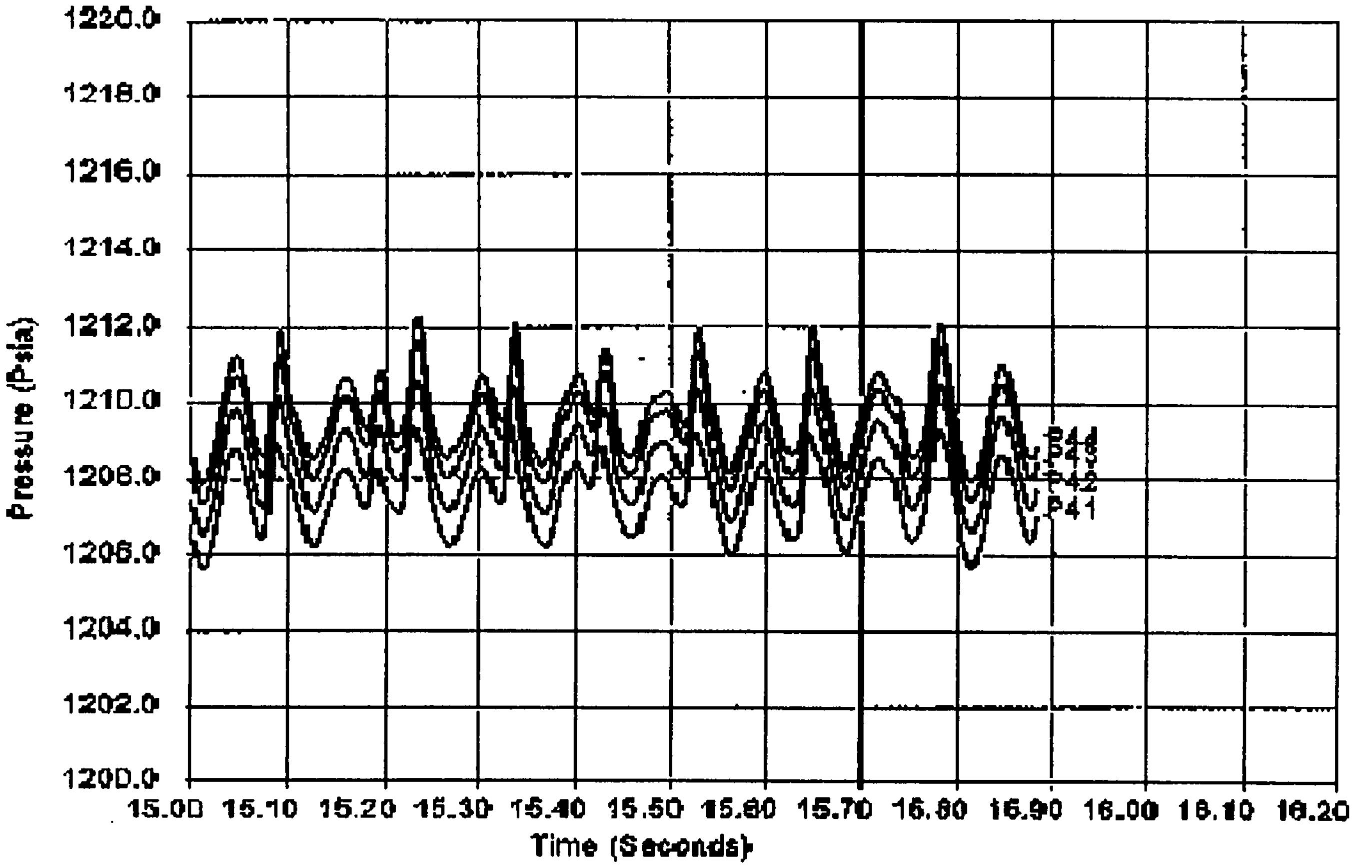
Results at 30 Hertz - Steam Line Oscillations at Hot Standby Conditions

FIGURE 3-6



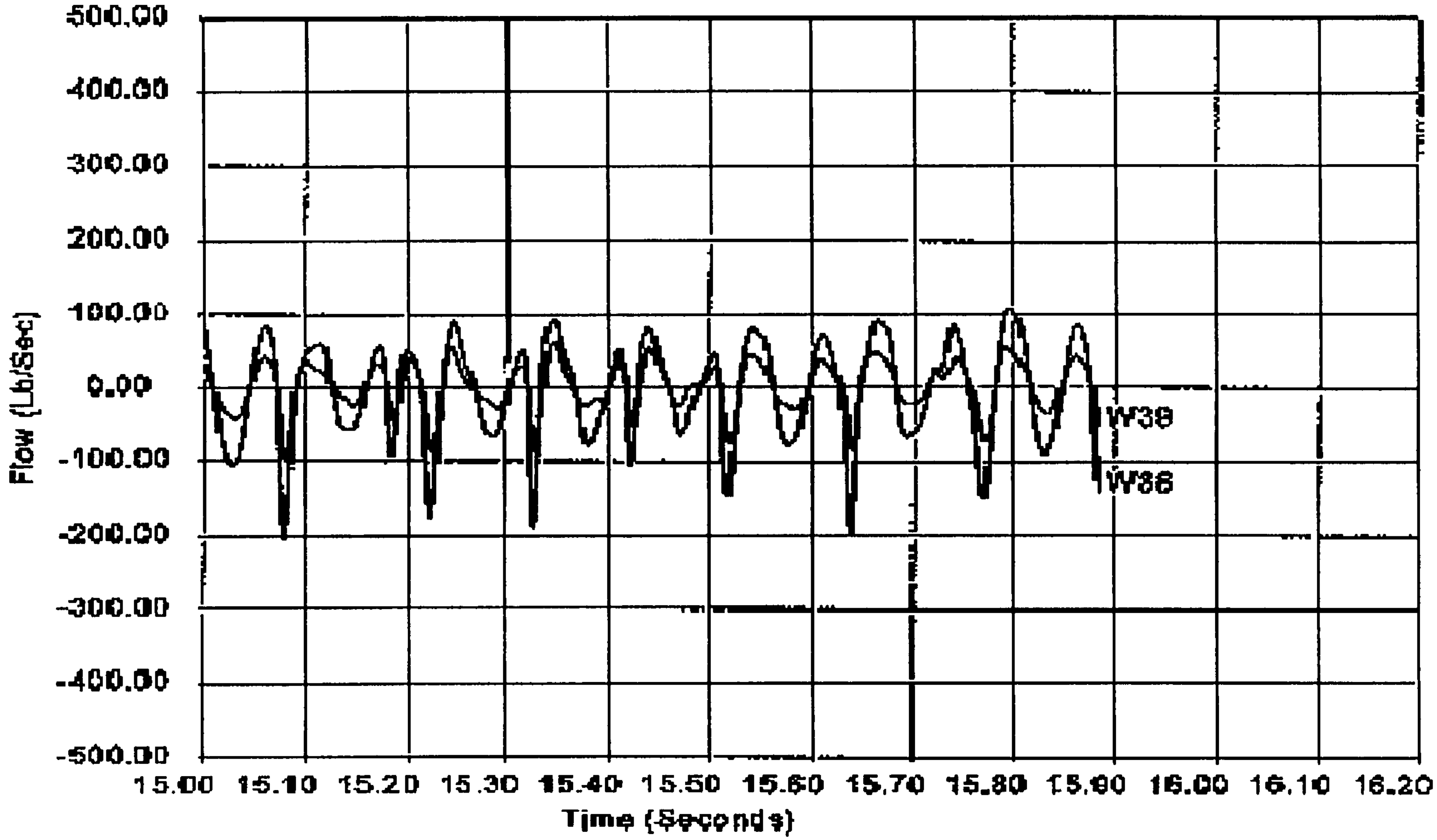
Results at 50 Hertz - Steam Line Oscillations at Hot Standby Conditions

FIGURE 3-9



Results at 20 Hertz - Oscillating Pressures in Hot Leg

FIGURE 3-10



Results at 20 Hertz - Oscillating Flow in Bundle

FIGURE 3-11

4. TSP Deflection Analysis

4.1 Static Analysis

4.1.1 Analysis Overview

As a precursor to performing a full bundle dynamic analysis to determine relative tube / TSP displacements for the bounding SLB loads, a preliminary analysis was performed using statically applied pressure loads. The preliminary analysis was performed to identify the number and location of expanded tubes within the lower region of the tube bundle hot leg for limiting TSP displacements under SLB loads.

The analysis was performed using the finite element model shown in Figure 6.15 of WCAP-15163, Revision 1 (hereafter referred to as the WCAP). However, for the preliminary analysis only the tube support plates of interest, Plates C, F, and J (see Figure 6.1 of the WCAP) are loaded. All remaining structures are active in the model, thus maintaining the interaction effects between the plates, wrapper, shell, tubesheet, stayrods and spacers.

Because this is an elastic static calculation, a reference load of 1 psid is applied to the tube support plates and the results scaled to higher loads as applicable. For the initial runs to identify the number and location of the expanded tubes, only Plate C was active in the model, with Plates F and J active for the final runs. Load cases were evaluated for pressure drops in both the upward and downward directions. For the case of upward loads, the wedge supports at the plate / wrapper interface were active. However, for the downward loads the wedge supports were not active as the wedges do not provide any restraint to plate motion in the down direction.
Relative to the interface between the plates and the stayrods and spacers, the plates were coupled to the stayrods through the spacers for upward loads. For loads in the downward direction, the plates were coupled to the spacers which transmitted the load to the tubesheet.

In determining the number and location of the expanded tubes, the objective was to show that for pressure loads significantly above the bounding pressure load of 3.56 psid that the structural response would remain elastic, and that the peak plate displacements would not exceed 0.3".

4.1.2 Expansion Zone Stiffness

When incorporating the restraining effect of the expanded tubes in the structural model, it is necessary to accurately represent the stiffness of the TSP expansion joint. The stiffness of the expansions is based on test data for prototypic expansions. Initially, the structural model conservatively used a stiffness of [ ] a,b,c lb/in for the TSP expansion joint; however, for later analysis cases, a more realistic stiffness value of [ ] a,b,c lb/in was used. A schematic of the stiffness representation for the tube support plate intersection is shown in Figure 4.1.

4.1.3 Cases Analyzed

A number of different load cases were considered, varying the number and location of the expanded tubes, as well as the expansion stiffness of the tube expansion zone, single and multiple plate loading and examining the unlikely effects of an inactive stayrod. The results for the initial cases without expansions and the cases with the final tube expansion locations are provided on the following pages. A summary of the input parameters for the final cases is provided in Table 4.1. It should be noted that the number of tube expansions in Table 4.1 corresponds to one-half of the hot leg, such that the total number of expansions for the bundle is twice the number shown.

Load cases 102 and 103 served to provide a reference condition, providing displacement results for the plates as well as the resulting stresses for the plates and stayrods for the case without tube expansion. Load case 112 corresponds to the final set of tube expansions with pressure load applied only to only Plate C. The final load case, Case 111, shows the effects of applying the bounding load to Plates C, F, and J simultaneously. Load case 113 is a sensitivity evaluation to determine the effect on maximum TSP displacements of removing the highest loaded stayrod from the analysis case 112.

4.1.4 Expanded Tube Locations

As mentioned above, a number of cases were run varying the number and location of the expanded tubes. A summary of the final set of expanded tubes is provided in Table 4.2. The table provides a summary of the tube locations as well as the corresponding node in the finite element model. Note that the node locations do not match the tube positions exactly, but are generally within half an inch of the tube position. This should not have a significant effect of the plate displacements. Figure 4.2 shows the location on the expanded tubes superimposed on the finite element model grid for the tube support plate.

4.1.5 Maximum Plate Displacements

A summary of the resulting plate displacements for the cases considered is provided in Table 4.3. Results for Cases 102 and 103 show that the limiting condition is for load in the upward direction, thus subsequent cases only considered the upward loading condition. Based on the results for the Plate C, it was judged that eight tube expansions (16 for the full bundle) provided substantial stiffening of the tube support plate and provided significant margin relative to the bounding pressure load of 3.56 psid in order to limit the maximum plate displacement to less than 0.3". As expected, due to the plate interaction effects, applying load to Plates F and J also affects the response for

Plate C since the loads are transmitted through the expanded tubes. As the upper plates (above plate J) are loaded, there will also be an effect on the lower plates, however, the effect will not be as large, as the upper plates are coupled to the lower plates only at the stayrod locations and not at the expanded tube locations. The stayrod design cannot transmit tensile loads from a higher TSP to a lower TSP, but extension of the stayrods can relieve the constraint against upward deflection on the lower TSPs.

4.1.6 Component Stresses

The validity of the elastic static analysis is contingent on the component structures remaining elastic under the applied load. The limiting components under the applied loads are the tube support plates. Table 4.4 provides a summary of the maximum tube support plate stresses. These stresses represent the average stress across a plate ligament between holes. These stresses are calculated by applying a concentration factor to the equivalent plate stresses obtained from the finite element model.

The stress concentration factors are obtained from separate finite element model analyses of representative tube support plate sections. Two models are evaluated, one in the pitch direction of the square hole pattern and a second in the pitch direction. Moments are applied to the edges of the models, varying the biaxiality ratio of the applied moments from −1.0 to 1.0. The average stress across the ligament calculated using the finite element model are then compared to the equivalent solid plate stress and a stress concentration factor developed. The corresponding concentration factors are then applied to the stresses from the finite element model as a function of biaxiality of the stresses.

The maximum plate stresses summarized in Table 4.4 occur at very localized locations in the plate, with the stresses in the majority of the plate well below yield. These stresses also represent the bending stress at the surface of the plate, and not the development of a plastic hinge in any given ligament. The yield stress in the analysis is based on the minimum acceptable yield stress as defined in the material specification for the plates scaled to high temperature conditions using the ASME Code temperature dependent strength properties.

Stresses in the stayrods and spacers are summarized in Table 4.5. Although the stresses in these components will increase when pressure loads are applied to the remaining plates, significant margin exists relative to yield for the load conditions analyzed.

4.1.7 Expanded Tube Extensions / Stresses

The expansion zone stiffness used in the above calculations are based on pull tests of prototypic expansions. The test results show the expansion zone stiffness to be linear for differential displacements in the expansion zone of 100 mils or less. After 100 mils of displacement, the stiffness of the joints declines, although the restraint force remains constant for a significantly larger deflection. (The stiffness response is comparable to elastic / plastic material response.) A summary of the expansion joint extensions due to the applied loads is provided in Table 4.6. Calculations are also performed to determine the pressure load that would result in an expansion zone extension of 100 mils in the tube expansion joint based on the limiting location.

The stresses in the expanded tubes are also of interest. In order for the elastic analysis to remain valid, these stresses must also be less than yield. A summary of the stresses in the expanded tube elements is provided in Table 4.7

4.1.8 Plate Displacement Distribution

Table 4-3 provides a summary of the maximum plate displacements. Also of interest is the distribution of plate displacements by tube location. Tables 4.8 through 4.13 provide a summary of the plate displacements by tube location. In order to determine the plate displacement at any given tube location, the following process was followed.

1. Overlay the finite element grid on top of the tube array and determine what element overlays each tube location.
2. Extract the displacement for each of the nodes comprising the element that surrounds any given tube location.
3. Interpolate the nodal displacements based on the location of the tube inside the element.
4. Group the plate displacements at the tube locations into one on 10 groupings based on the maximum displacement anywhere on the plate.

4.2 Summary

The unit (1 psid) loading analysis provides the basis for determining the factors of safety that apply for the bounding loads developed in Section 3.

The principal criterion for evaluating the factors of safety is the maximum TSP displacement. Although the maximum displacement is localized on the TSP, a displacement limit of 0.3" was established because this value, when applied at every HL intersection at every TSP (Plates C through R) provides a probability of burst less than 10^{-5}, compared to the limit of 10^{-2} specified in GL 95-05.

Other potentially limiting criteria derive from the application of the elastic model. To preserve the validity of the deflection predictions, the elements of the model must remain elastic. Thus, the following criteria were also examined in the analysis:

- TSP ligament stress must be less than the TSP yield strength at operating temperature
- Stayrod and spacer stress must be less than the stayrod and spacer yield strengths at operating temperature
- The axial deflection in the TSP expansions must be less than 0.10"
- The stresses in the expanded tubes must remain within the elastic limit

Table 4.14 summarizes the factors of safety above he peak bounding load for each of these criteria for the key cases considered in the analysis. Cases 102 and 103 provide a baseline for "up" and "down" loading of the TSPs without expanded tubes. These two cases also show that the bounding deflection is due to "up" loads; therefore, "down" loads were not analyzed for the subsequent model variations. It is noted that the TSP without tube expansions meets all deflection and stress criteria noted above.

Case 112 provides the best representation of the margins to the peak bounding load for the TSP with 16 tube expansions. The minimum factor of safety is 3.74, based on the expanded tube yield criterion. For the pressure drop associated with this factor of safety (i.e., 3.74 x 3.56 = 13.33 psid), the predicted maximum local TSP deflection is 0.18".

Case 113 is a single plate model that considers the extremely unlikely case of one stayrod (the highest loaded from Case 112) inactive, but with 16 expanded tubes at TSPs C,F and J. The minimum factor of safety for this case is 2.37 (8.42 psid), determined by the stresses in a local area of the TSP The predicted maximum local displacement is 0.26".

Case 111 provides results for the simultaneous loading of 3 TSPs with the bounding load. This case is considered unnecessarily conservative, since the actual peak loading on the plates C, F and J is much less than the peak bounding load (3.56 psid) applicable at Plate R, and the bounding "up" load for plates C and F are much less than the predicted bounding load at Plate J (see Table 3.2). The minimum factor of safety for Case 111 (TSPs C , F and J loaded simultaneously with the peak bounding load) is 1.29, defined by the stress in the expanded tubes.

Table 4.1
Summary of Load Cases Considered

Static Load Application
Fully Elastic Response

Case	Applied Load (psi)	Plates Active	Number of Tube Expansions(1)	Expansion Stiffness (lb/in)
102	1.0	C	---	
103	-1.0	C	---	a, c
112	1.0	C	8	
113(2)	1.0	C	8	
111	1.0 (All Plates)	C, F, J	8	

(1) - Corresponds to one-half of hot leg. Total number of expansions is twice the number shown.

(2) - Stayrod support removed at element 8672

Table 4.2
Summary of Expanded Tube Locations

a,c

Note: If selected tubes are plugged, nearest adjacent tube will be selected

Table 4.3
Summary of Maximum Plate Displacements

Static Load Application
Fully Elastic Response

Case	Applied Load (psi)	Plates Active	Numer of Tube Expansions*	Expansion Stiffness (lb/in)	Maximum Vertical Displacement (inch)		Pressure Load to Cause 0.30" Displacement (psi)
102	1.0	C	—		Plate C	0.0808	3.7
103	-1.0	C	—	a, c	Plate C	-0.0565	-5.3
112	1.0	C	8		Plate C	0.0135	22.2
113	1.0	C	8		Plate C	0.0305	9.8
111	1.0 (All Plates)	C, F, J	8		Plate C	0.0240	12.5
					Plate F	0.0254	11.8
					Plate J	0.0282	10.6

* - Corresponds to one-half of hot leg. Total number of expansions is twice the number shown.

Table 4.4
Summary of Maximum Plate Stresses

Static Load Application
Fully Elastic Response

Case	Applied Load (psi)	Plates Active	Numer of Tube Expansions*	Expansion Stiffness (lb/in)	Stress (psi)		Pressure Load to Cause Support Plate to Yield (psi)
102	1.0	C	—		Plate C	9554.0	3.5
103	-1.0	C	—	a, c	Plate C	9866.0	3.4
112	1.0	C	8		Plate C	2379.0	14.2
113	1.0	C	8		Plate C	4026.0	8.4
111	1.0 (All Plates)	C, F, J	8		Plate C	2800.0	12.1
					Plate F	2500.0	13.6
					Plate J	3150.0	10.8

* - Corresponds to one-half of hot leg. Total number of expansions is twice the number shown.

Support Plate Yield Stress = 33,900 psi

Table 4.5
Summary of Stayrod / Spacer Stresses

Static Load Application
Fully Elastic Response

Case	Applied Load (psi)	Plates Active	Numer of Tube Expansions*	Expansion Stiffness (lb/in)	Element	Stress (psi)	Pressure Load to Cause Stayrod / Spacer to Yield (psi)
102	1.0	C	—		8650	682.0	49.9
					8661	679.0	50.1
					8672	1064.0	32.0
					8683	788.0	43.1
103	-1.0	C	—		8651,2	-603.0	-44.6
					8662,3	-700.0	-38.4
					8673,4	-1006.0	-26.7
				a, c	8684,5	-677.0	-39.7
112	1.0	C	8		8650	257.0	132.3
					8661	299.0	113.7
					8672	361.0	94.2
					8683	131.0	259.5
113	1.0	C	8		8650	250.0	136.0
					8661	294.0	115.6
					8672	Removed	
					8683	119.0	285.7
111	1.0 (All Plates)	C, F, J	8		8650	651.0	52.2
					8661	732.0	46.4
					8672	909.0	37.4
					8683	411.0	82.7

Stayrod Yield Stress = 34,000 psi   Spacer Yield Stress = 26,900 psi

* Corresponds to half of the Hot Leg; total number of exapnded tubes is twice the number indicated

Table 4.6
Summary of Tube Expansion Zone Extensions

Case	Tube Support Plate C		Tube Support Plate F		Tube Support Plate J		Pressure Load to Cause 0.10 inch Expansion Extension (psi)
	Element	Element Extension (inch)	Element	Element Extension (inch)	Element	Element Extension (inch)	
102							
103							
112	8748	0.0056	8749	N.A.	8750	N.A.	17.86
	8755	0.0060	8756	N.A.	8757	N.A.	16.67
	8762	0.0041	8763	N.A.	8764	N.A.	24.39
	8769	0.0063	8770	N.A.	8771	N.A.	15.87
	8776	0.0055	8777	N.A.	8778	N.A.	18.18
	8783	0.0027	8784	N.A.	8785	N.A.	37.04
	8790	0.0048	8791	N.A.	8792	N.A.	20.83
	8797	0.0037	8798	N.A.	8799	N.A.	27.03
113	8748	0.0069	8749	N.A.	8750	N.A.	14.49
	8755	0.0059	8756	N.A.	8757	N.A.	16.95
	8762	0.0054	8763	N.A.	8764	N.A.	18.52
	8769	0.0091	8770	N.A.	8771	N.A.	10.99
	8776	0.0071	8777	N.A.	8778	N.A.	14.08
	8783	0.0025	8784	N.A.	8785	N.A.	40.00
	8790	0.0045	8791	N.A.	8792	N.A.	22.22
	8797	0.0038	8798	N.A.	8799	N.A.	26.32
111	8748	0.0068	8749	0.0059	8750	0.0055	14.71
	8755	0.0065	8756	0.0055	8757	0.0049	15.38
	8762	0.0047	8763	0.0044	8764	0.0046	21.28
	8769	0.0070	8770	0.0060	8771	0.0053	14.29
	8776	0.0059	8777	0.0053	8778	0.0046	16.95
	8783	0.0034	8784	0.0025	8785	0.0019	29.41
	8790	0.0062	8791	0.0048	8792	0.0041	16.13
	8797	0.0051	8798	0.0038	8799	0.0032	19.61

Table 4.7
Summary of Expanded Tube Stresses

Case	Tubesheet - TSP C		TSP C - TSP F		TSP F - TSP J		Pressure Load to Cause Expanded Tube to Yield (psi)
	Element	Tube Stress (psi)	Element	Tube Stress (psi)	Element	Tube Stress (psi)	
102	Not Applicable						
103	Not Applicable						
112	8745	2325.0	8746	N.A.	8747	N.A.	15.18
	8752	2518.0	8753	N.A.	8754	N.A.	14.02
	8759	1697.0	8760	N.A.	8761	N.A.	20.80
	8766	2649.0	8767	N.A.	8768	N.A.	13.33
	8773	2320.0	8774	N.A.	8775	N.A.	15.22
	8780	1114.0	8781	N.A.	8782	N.A.	31.69
	8787	1990.0	8788	N.A.	8789	N.A.	17.74
	8794	1534.0	8795	N.A.	8796	N.A.	23.01
113	8745	2899.0	8746	N.A.	8747	N.A.	12.18
	8752	2459.0	8753	N.A.	8754	N.A.	14.36
	8759	2270.0	8760	N.A.	8761	N.A.	15.55
	8766	3828.0	8767	N.A.	8768	N.A.	9.22
	8773	2982.0	8774	N.A.	8775	N.A.	11.84
	8780	1063.0	8781	N.A.	8782	N.A.	33.21
	8787	1901.0	8788	N.A.	8789	N.A.	18.57
	8794	1607.0	8795	N.A.	8796	N.A.	21.97
111	8745	7569.0	8746	4742.0	8747	2285.0	4.66
	8752	7075.0	8753	4337.0	8754	2046.0	4.99
	8759	5746.0	8760	5771.0	8761	1916.0	6.12
	8766	7696.0	8767	4750.0	8768	2229.0	4.59
	8773	6631.0	8774	4162.0	8775	1942.0	5.32
	8780	3292.0	8781	1862.0	8782	814.0	10.72
	8787	6316.0	8788	3711.0	8789	1697.0	5.59
	8794	5052.0	8795	2921.0	8796	1327.0	6.99

Tube Yield Stress = 35,300 psi

-

Table 4.8
Summary of Plate Displacements

Case 102
Plate C Active
Upward Applied Load
Without Tube Expansions

	Displacement Range (inch)									
	0.000 0.008	0.008 0.016	0.016 0.024	0.024 0.032	0.032 0.040	0.040 0.048	0.048 0.056	0.056 0.064	0.064 0.072	0.072 0.081
Number of Tubes	**208**	**478**	**342**	**302**	**250**	**222**	**304**	**171**	**79**	**69**

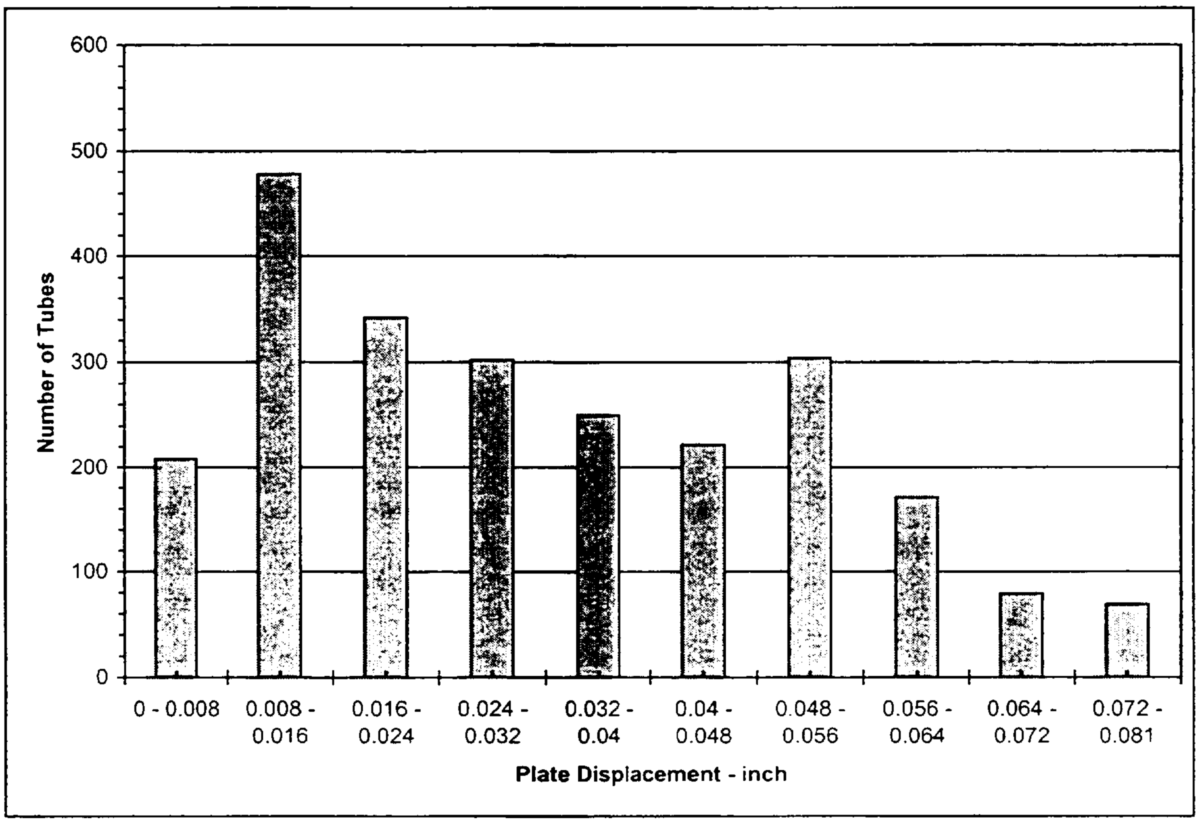


Table 4.9
Summary of Plate Displacements
Case 103

Plate C Active
Downward Applied Load
Without Tube Expansions

	Displacement Range (inch)									
	0.000 0.006	0.006 0.011	0.011 0.017	0.017 0.022	0.022 0.028	0.028 0.034	0.034 0.039	0.039 0.045	0.045 0.050	0.050 0.057
Number of Tubes	**556**	**409**	**371**	**226**	**274**	**245**	**198**	**48**	**50**	**44**

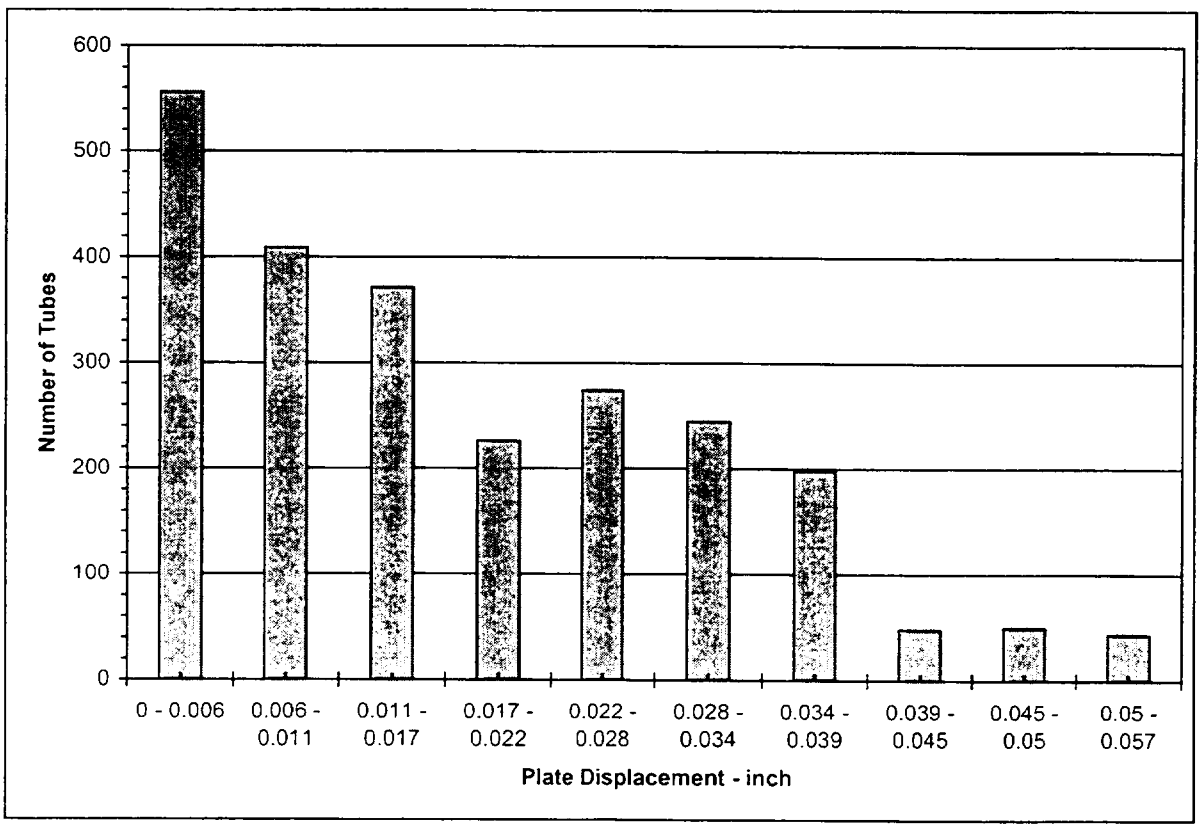


Table 4.10
Summary of Plate Displacements
Case 112

Plate C Active
Upward Applied Load
Eight Tube Expansions (Hot Leg – Half Bundle)

	Displacement Range (inch)									
	0.000 0.001	0.001 0.003	0.003 0.004	0.004 0.006	0.006 0.007	0.007 0.008	0.008 0.010	0.010 0.011	0.011 0.013	0.013 0.014
Number of Tubes	**0**	**30**	**122**	**217**	**216**	**450**	**404**	**556**	**368**	**62**

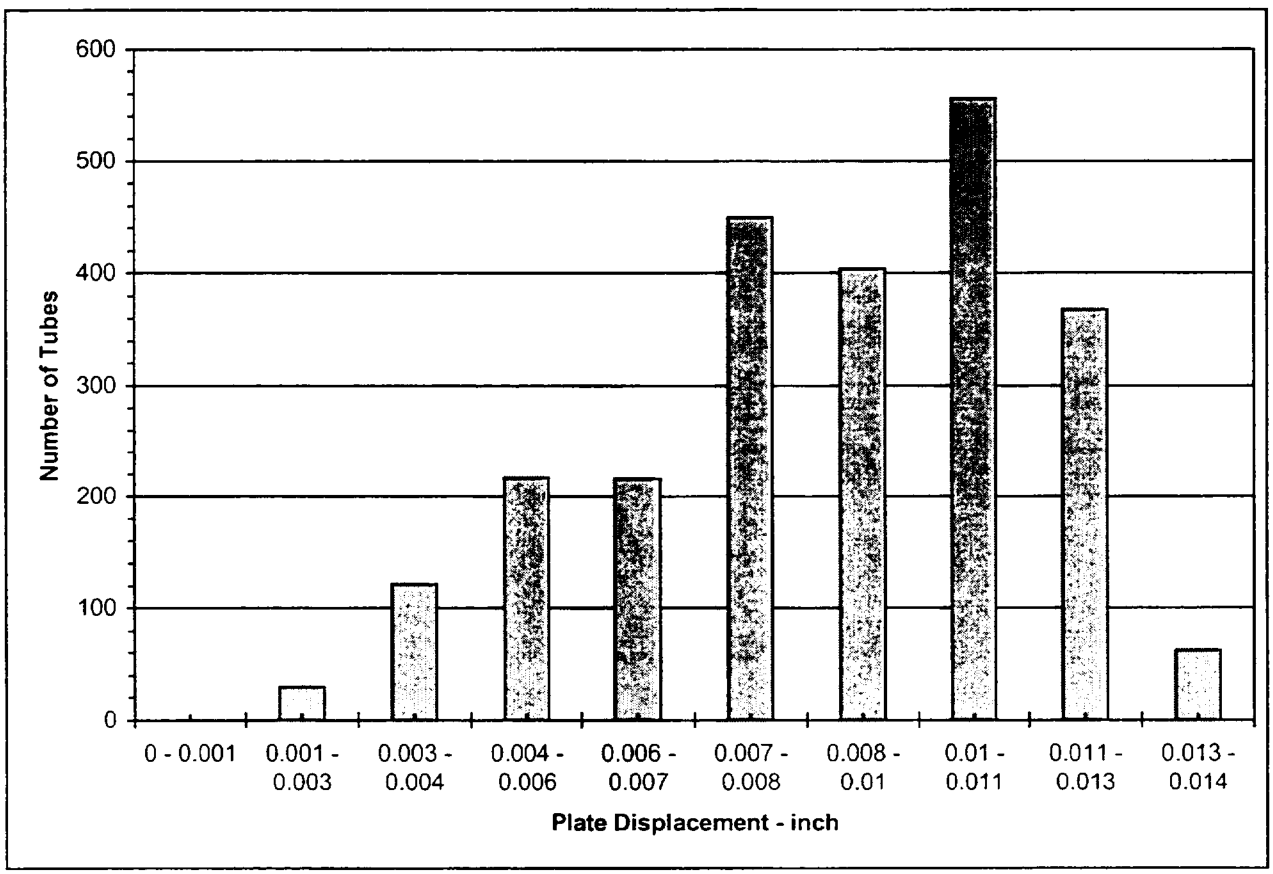


Table 4.11
Summary of Plate Displacements
Case 111

Plates C, F, and J Active
Upward Applied Load
Eight Tube Expansions (Hot Leg – Half Bundle)

Plate C

	Displacement Range (inch)									
	0.000 0.002	0.002 0.005	0.005 0.007	0.007 0.010	0.010 0.012	0.012 0.014	0.014 0.017	0.017 0.019	0.019 0.022	0.022 0.024
Number of Tubes	**2**	**66**	**144**	**185**	**247**	**276**	**437**	**625**	**250**	**193**

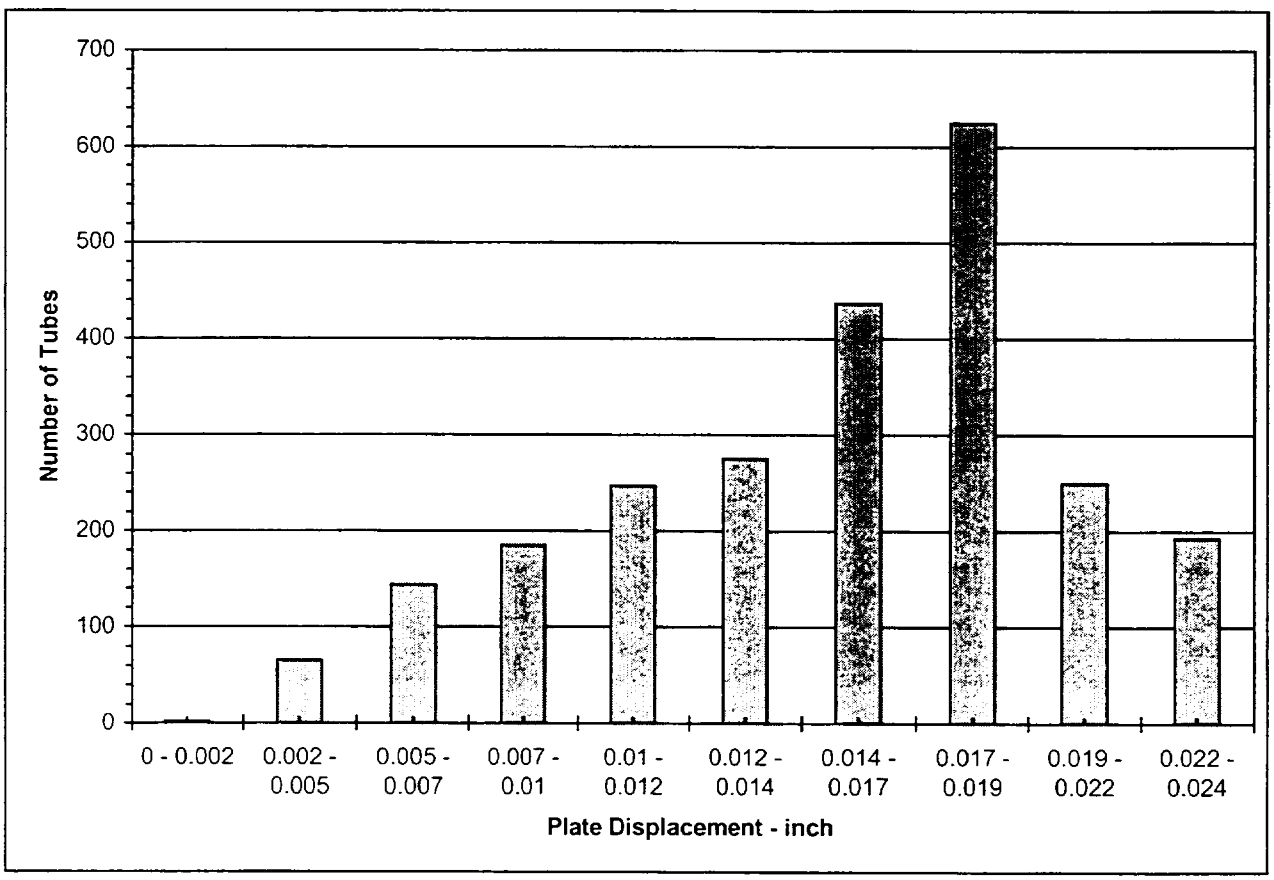


Table 4.12
Summary of Plate Displacements
Case 111

Plates C, F, and J Active
Upward Applied Load
Eight Tube Expansions (Hot Leg – Half Bundle)

Plate F

	Displacement Range (inch)									
	0.000 0.003	0.003 0.005	0.005 0.008	0.008 0.010	0.010 0.013	0.013 0.015	0.015 0.018	0.018 0.020	0.020 0.023	0.023 0.025
Number of Tubes	**2**	**62**	**141**	**193**	**209**	**243**	**299**	**351**	**395**	**530**

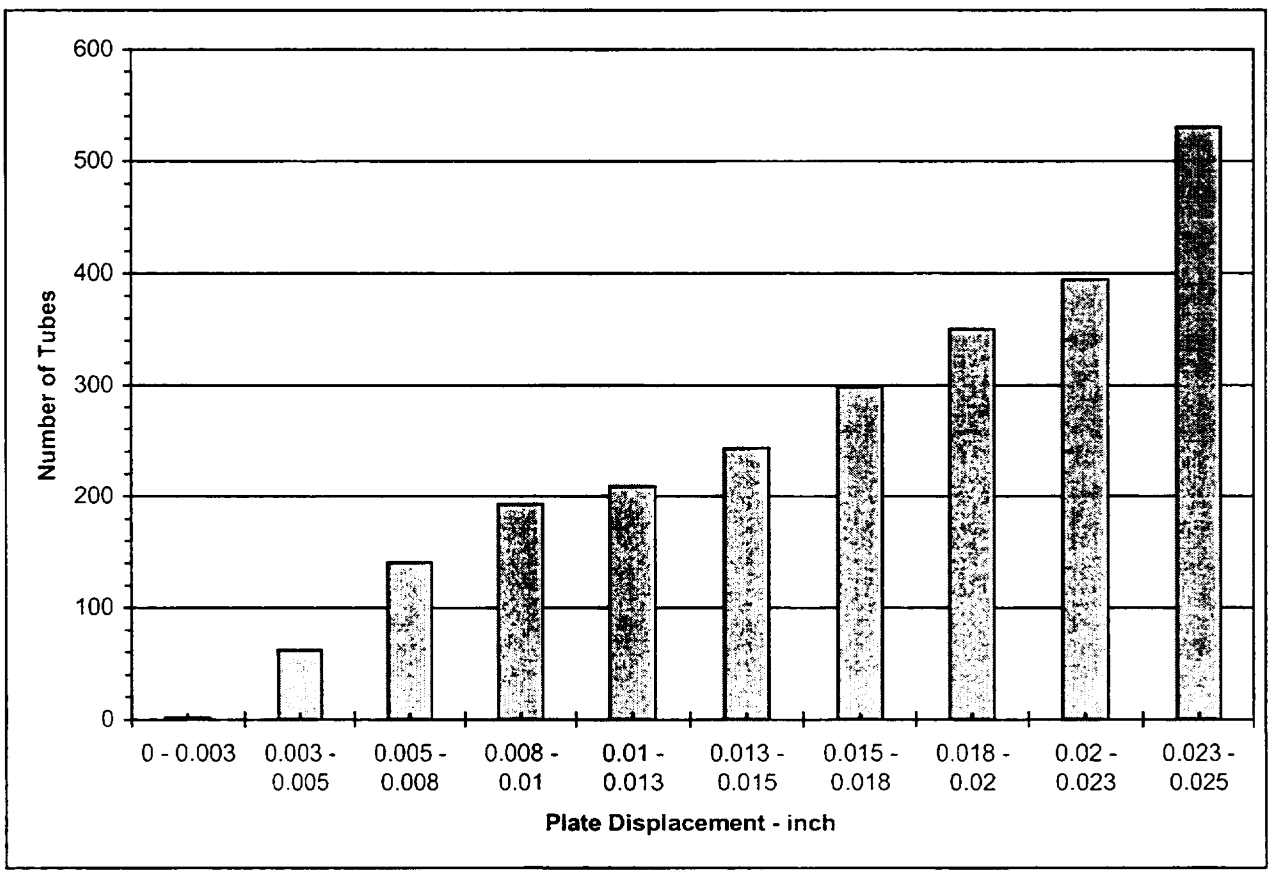


Table 4.13
Summary of Plate Displacements
Case 111

Plates C, F, and J Active
Upward Applied Load
Eight Tube Expansions (Hot Leg – Half Bundle)

Plate J

	Displacement Range (inch)									
	0.000 0.003	0.003 0.006	0.006 0.008	0.008 0.011	0.011 0.014	0.014 0.017	0.017 0.020	0.020 0.022	0.022 0.025	0.025 0.028
Number of Tubes	**4**	**94**	**186**	**225**	**252**	**283**	**330**	**336**	**382**	**333**

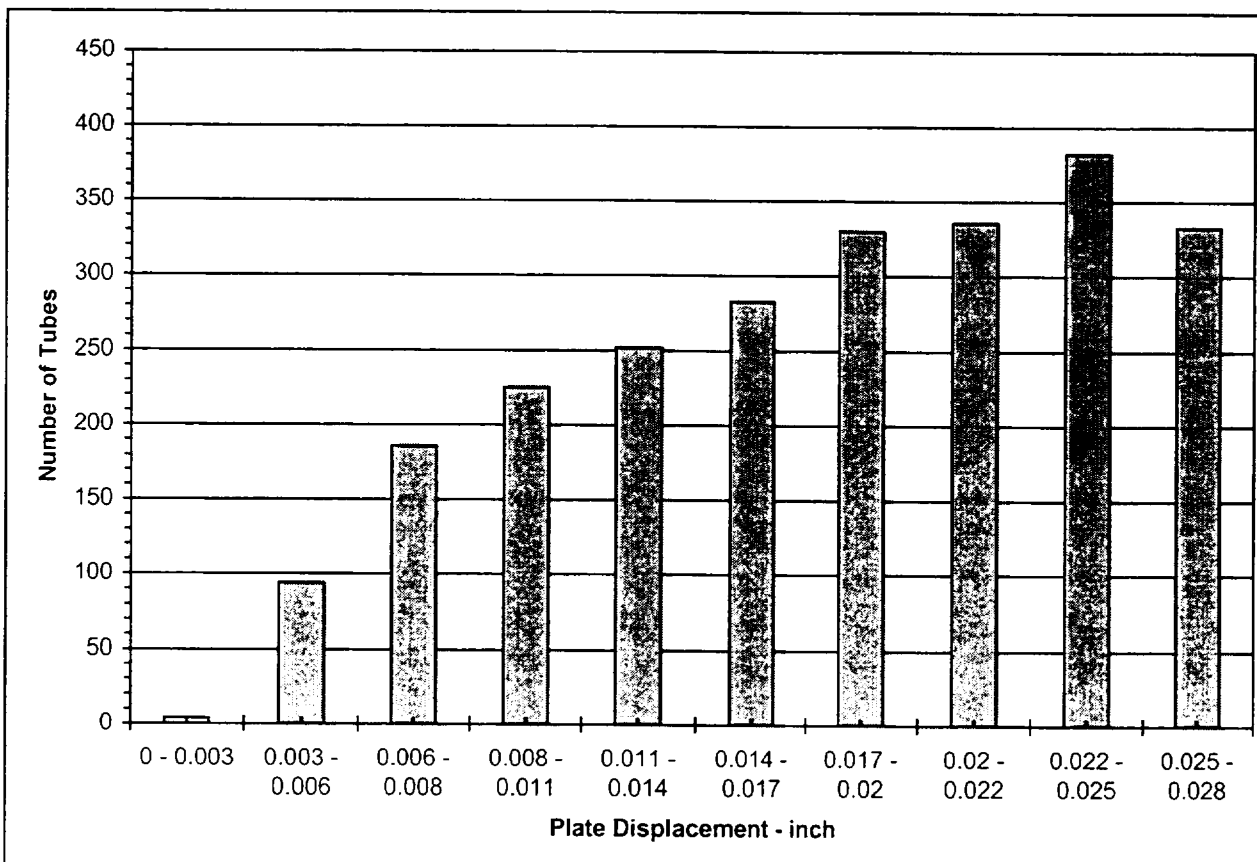


Table 4. 14
Summary of Factors of Safety for Applicable Criteria

Case	Applied Load (psi)	Noumber of Tube Expansions	Unit Load Max Displacement (inch)	ΔP to Reach 0.30" Displacement		ΔP to Reach TSP Yield		ΔP to Reach Stayrod/Spacer Yield		ΔP to Reach 0.1" Expansion Extension		ΔP to Reach Expanded Tube Yield	
				ΔP (psi)	Factor of Safety (1)	ΔP (psi)	Factor of Safety (1)	ΔP (psi)	Factor of Safety (1)	ΔP (psi)	Factor of Safety (1)	ΔP (psi)	Factor of Safety (1)
102	1.0	0	0.0808	3.71	1.04	3.55	1.00	31.95	8.98	NA	NA	NA	NA
103	-1.0	0	-0.0565	-5.31	2.27	-3.44	1.46	-26.74	-7.51	NA	NA	NA	NA
112	1.0	16	0.0135	22.17	6.23	14.25	4.00	94.18	26.46	15.87	4.46	13.33	3.74
113(3)	1.0	16	0.0305	9.84	2.76	8.42	2.37	115.65	32.48	10.99	3.09	9.22	2.59
111 (2)	1.0 (C)	16	0.0240	12.52	3.52	12.11	3.40	37.40	10.51	14.29	4.01	4.59	1.29
	1.0 (F)		0.0254	11.80	3.31	13.56	3.81						
	1.0 (J)		0.0282	10.64	2.99	10.76	3.02						

(1) - Maximum upward pressure drop = 3.56 psid; maximum downward load = -2.346 psid

(2) - Plates C, F, and J loaded simultaneously

(3) - Stayrod support removed at element 8672

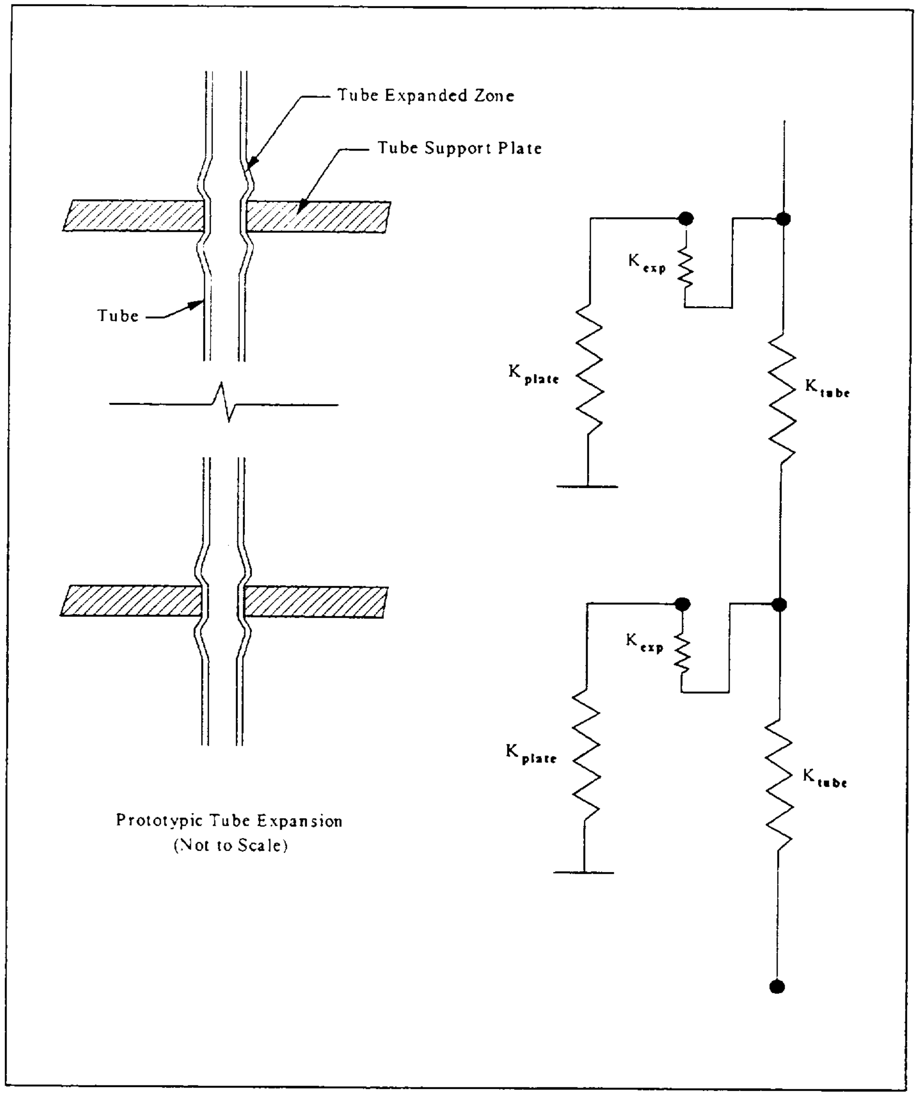


Figure 4.1
Model Representation of
Expanded Tube / Sleeve Interface

a,c

Figure 4.2
Expanded Tube Location

5.0 TUBE EXPANSION PROCESS AND TEST/ANALYSIS SUPPORT

5.1 Overview

Since the TSPs do not undergo any displacement relative to indications developed within the TSPs during normal operation, tube burst at these locations is prevented by the TSP. Thus, the burst capability requirement of 3 times the normal operating differential pressure is obviated by the presence of the TSP, and the RG 1.121 requirement relative to $3\Delta P_{NO}$ is inherently met. If the TSPs did not undergo displacements during a postulated SLB event, the same would be true of the RG 1.121 requirement relative to $1.43\Delta P_{SLB}$. However, the TSPs are subjected to out-of-plane loads during a SLB, and TSP displacements are predicted to occur at local areas on the TSPs thus exposing cracks presumed to exist in the tube within the span of the TSP.

The principal requirement of the tube expansions is to restrict TSP deflection to a value such that the probability of burst (POB) during a postulated SLB event is essentially negligible. It can be shown that the burst probability for the STP- 2 SGs under peak bounding SLB loading is negligible even without tube expansion; however, 16 hot leg tubes will be expanded at plates C, F and J (see Figure 3.2 of WCAP 15163, Rev 1) to provide added margin for the probability of burst. The modification design to accomplish this consists of expanding the tube, with an internal sleeve installed, into an hourglass shape at the elevation of the TSPs, such that the TSP is captured by the tube/sleeve combination (Figure 5-1). Expanded tubes will be plugged.

Interaction of the expanded tube region with the TSP will effectively cause the expanded tube assembly to act similar to a stayrod, to significantly restrict the potential out-of-plane motion of the TSPs. To increase the load capacity of the expanded joint and to prevent the potential for tube-to-tube interaction in the unlikely event that an expanded tube experiences a circumferential separation in the expanded region, a surrogate sleeve is used. The expanded tube OD will be larger than the nominal tube OD by approximately [ ] a,b,c and larger than the TSP tube hole diameter by approximately [ ]. a,c A description of the design and testing of the expansion process is provided in this section.

An implicit requirement of the tube expansion modification is that the integrity of the expansions must be such that they perform their intended function for long periods of exposure to the secondary side environment. For South Texas Unit 2, the period of performance is one cycle, approximately 18 months operation, since the SGs are scheduled to be replaced during the 2002 outage.

5.2 Review of Prior Applications

The tube expansion process has been previously applied at the Byron 1 and Braidwood 1 plants. The process to be applied at South Texas 2 differs from the Byron/Braidwood processes only in that the expansion diameter is slightly smaller than used at Byron/Braidwood and that standard thickness laser welded sleeves will be used instead of thinned sleeves at the TSP expansions.

5.3 Tube Expansion Process Requirements

The overall requirements for the application of tube expansion are summarized in Section 6 of this report. If TSP motion is restricted to less than or equal to 0.30" during a postulated SLB, the probability of burst will be less than 10^{-5} under the assumption that all tubes have throughwall indications at all of the hot leg intersections (Plates C through R included). If TSP displacement during a SLB is restricted to less than or equal to 0.20", the probability of burst is estimated to be much less than 10^{-5}. For TSP displacement <0.20", the leakage from cracked tubes is bounded by the leak rates for Indications Restricted from Burst (IRB) (see WCAP – 15163, Rev 1, section 8)

The following design requirements were established for the tube expansions. The actual performance of the tube expansions exceeds the design requirements as discussed below.

1) The tube expansion at the TSP shall provide resistance to TSP motion of at least [ ]. a,b,c The associated stiffness of the expansion relative to plate motion shall be [ ] a,b,c when averaged over the initial 0.05 inch of TSP displacement as determined by TSP pull force versus displacement test on expanded joints.

2) The expansion shall be performed above and below the TSP by a hydraulic expansion process. A sleeve stabilizer shall be installed to extend above and below the parent tube expansion.

3) The expansion process shall be designed to achieve a maximum expanded tube diameter increase of approximately [ ] a,b,c when applied over the range of material properties (tubes and TSPs) and over the range of tube/TSP intersection dimensions. The limit on the expansion diameter is a design goal to limit residual stresses in the expanded tube; larger expansions are acceptable to meet the expanded tube stiffness and load requirements.

5.4 Tube Support Plate Expansion Process Description

Figure 5-1 illustrates the TSP expansion configuration. The tube expansion is performed using hydraulic expansion equipment for Westinghouse ¾" diameter tube sleeving and a modified sleeve delivery mandrel. The expansion is generated by supplying high-pressure water to an expansion mandrel/bladder system. The same length bladder [ ] a,c used for sleeve expansion in the laser welded sleeving system is used for the tube expansion process.

For development purposes, the tubes, sleeves, and TSP simulants were manually positioned. The sleeve sections used for the TSP expansions were actual TSP laser welded sleeves cut to an overall length of [ ]. a,c Although the field applications of this process at Byron 1 and Braidwood 1 used sleeves thinned in the expansion region to accommodate tooling limitations, these limitations have been eliminated, and non-thinned sleeves are used for the South Texas 2 application. The test samples used to determine the resistive load characteristics of the expanded assembly were configured with the sleeve centered at the axial center of the TSP simulant, and with varying levels of axial misposition.

Field application is performed using the ROSA based sleeving system, which includes the Search and Locate End Effector (SALEE), SALEE expansion mandrel, ROSA control computer, and standard sleeving system hydraulic expansion pressure unit. The mandrel has an integral eddy current coil that senses the center of the TSP and enables the tool to automatically stroke into the install/expansion position. The sleeve delivery mandrel has been modified to properly position the center of the sleeve, and consequently the center of the expansion bladder, adjacent to the center of the TSP. The expansion process is computer controlled for consistency and repeatability.

During the expansion process, the sleeve initially yields and contacts the tube. After the yielded sleeve contacts the tube, the computer compares the applied pressure to deflection slope between successive data collection points (100 points/second minimum sample rate). When tube/sleeve yielding occurs, evidenced by a change in the slope of the pressure-time trace, the computer continues to supply a constant volumetric rate of fluid injection for a specified time period. When the prescribed time period has been achieved, the pressure input is terminated and the system is depressurized.

5.5 Tube Expansion Process Test and Analysis Results

5.5.1 Tube Support Plate Expansion Testing

Test specimens were prepared at various expansion pressures to establish a relationship between expansion pressure and projected tube OD and also to establish a relationship between tube OD and resistive load capability at varying TSP deflection levels.

Test specimens were made using [

] a,c,e nominal wall thickness sleeve sections. TSP simulants, Figure 5-2, were made from 405 SS plate material to ASME specification SA-240, which is the same as the South Texas 2 TSP material specification. The TSP simulants were ¾" thick, approximately 2.4" square sections with a center tube hole surrounded by 4 tube holes and 4 flow holes, with hole diameters, hole-to-hole pitches, and chamfers consistent with the SG manufacturing drawings. The ligament thickness at the edges of the TSP simulant was designed to be approximately half of the nominal ligament thickness. These simulants conservatively represented the in-plane stiffness of the TSPs since only a small portion of the plate pattern was used. It is expected that the use of a TSP simulant that represented a larger portion of the plate would yield higher resistive load capabilities. The tube yield strength, 48 ksi and sleeve yield strength, 45 ksi, used for the test samples represent lower bound limits. The manufacturing records for the South Texas 2 SGs indicate the actual minimum yield strength of the TSPs was 54.9 ksi. For test purposes, 405 SS plate with yield strength of 43 ksi was used. Sleeves were centered axially at the center of the TSP simulant, which was centered over the 12" tube length.

Samples were produced with a nominal fitup condition, that is, with the sleeve axially centered on the TSP, and with varying levels of sleeve/expansion mandrel axial misposition relative to the center of the TSP. Samples were tested at room temperature by tensile loading in a Satec® 120,000 lb capacity tensile loading machine. The load testing setup is shown in Figure 5-3. One end of the sample was attached to the movable crosshead using self-adjusting tube OD gripper jaws. A fixture was bolted to the stationary base of the machine. This fixture is a stiff, box-like structure that restrains the TSP simulant while the movable crosshead essentially extrudes the expanded tube/sleeve assembly through the TSP simulant hole. Plate bending effects encountered during an actual SLB event, which would act to pinch the tube and further increase the resistive load capacity of the expansion, were not modeled into the test setup. Machine speed was set at 0.25 ips. Previous testing, discussed in Reference 1, indicated that, at these speeds, the load response is independent of pull rate. The motion of the tube relative to the TSP simulant was accurately isolated by use of a deflectometer, a precision testing device designed for such purposes, attached to the tube and the TSP simulant. Use of the deflectometer eliminated the effects of potential gripper jaw slip and specimen elastic stretch during loading from influencing the load vs. displacement curve.

Resistive load vs. TSP displacement curves were produced for each specimen. A sample of these curves is given in Figure 5-4. At normal operating temperatures, the material properties of the tubes, sleeves, and TSPs would be reduced by approximately 8% compared to room temperature conditions, and therefore, would be expected to result in a slight reduction in the resistive load capacity compared to the room temperature results. However, further evaluation of the operating performance characteristics of the expanded joint indicates that the room temperature data are conservative for application at operating conditions for the following reasons:

1) Out-of-plane bending of the plate during a postulated SLB would cause a bending lockup (cam-lock) condition between the tube/sleeve and TSP, and would act to significantly increase resistive loads, compared to the room temperature tests that utilized flat plates to simulate the TSPs.

2) Interaction between the TSP and the tube OD results in a more severe galling condition at operating temperature than at room temperature. Previous testing related to structural integrity of hybrid expansion joint (HEJ) sleeve assemblies indicates that the extent of galling of Alloy 600 tubing and therefore, the galling forces, significantly increase at 600° F compared to room temperature. Because the geometry of an HEJ assembly and the TSP expansion assembly are similar; this result applies to the TSP expansions as well.

3) Crevice packing would limit the expanded diameter of the tube/sleeve assembly within the TSP, increasing the diameter difference between the expanded tube/sleeve assembly immediately above/below the TSP, and thereby increasing resistive load. The interaction angle between the tube OD and TSP hole diameter would become rotated towards the horizontal (plane of TSP), and this interaction angle would act to load the tube in shear as well as create resistive load by the extrusion action. Preliminary testing using ["] a,b,c long bladder assemblies indicates that the resistive load capability is dramatically increased over equal sized (Δd) expansion using the ["] a,b,c bladder, due primarily to the interaction angle between the tube OD and TSP. In this testing, the ["] a,b,c expansion was located so that 1/8" of the bladder overlapped the edge of the TSP. At the tube to TSP interface, a more shallow tube angle with reference to the horizontal is created, and a portion of the tube inside the TSP is not expanded. The expansion profile is symmetric about the axial center of the expansion. Using the ["] a,b,c bladder, the tube and sleeve are expanded to contact with the TSP, and a steeper angle with reference to the horizontal is created at the tube to TSP interface compared to the [ ] a,b,c bladder expansion profile. Open crevices were used in the tests performed. The interaction angle of the tube OD with the TSP is more shallow with reference to the horizontal compared to the interaction angle developed when a packed crevice limits the tube/sleeve expansion diameter.

4) Thermal expansion effects would act to create a tighter joint at operating temperatures since the sleeve expands more than the tube due to the differences in thermal expansion coefficients between the tube and sleeve materials. The tube/sleeve assembly would also act to create a tighter fitup condition with the TSP assembly, as the thermal expansion coefficients of both Alloy 600 and Alloy 690 are greater than the expansion coefficient of the 405 SS TSP material. This would result in higher radial preloading between the tube/sleeve and TSP at operating and faulted conditions. This thermal expansion effect was not provided by the room temperature testing, and therefore, will add to the resistive load capacity of the expanded TSP joint at operating conditions.

5) Material properties of the TSP simulant dramatically affect the resistive load capabilities of the expanded assemblies. The yield strength of the test TSP simulants was 43 ksi at room temperature, whereas the actual material test reports for the South Texas 2 TSPs indicate a minimum yield of 54.9 ksi at room temperature. The higher actual material properties of the South Texas 2 TSPs will more than compensate for any decreases in resistive load capability based on tube material property reduction at operating temperature.

6) The combined data sets of 2/17/98 and 1/30/98 (see Figure 5-5) are used to develop the minimum acceptable bulge size. In the 1/30/98 testing, the testing fixture was determined to have been set up in a manner that resulted in deflection of the test fixture being included in the overall measured TSP displacement value, which artificially reduced the apparent joint stiffness. In the 2/17/98 testing the test fixture was installed so that the fixture deflection was limited, with the result that the observed joint stiffness was considerably larger than that from the 1/30/98 data set for equal sized expansions (see Figure 5-5). For conservatism, the entire TSP data set including the 1/30/98 data was used for establishing the minimum acceptable bulge size.

It is concluded that it is reasonable and conservative to apply the room temperature joint stiffness values to SLB event conditions without adjustment for decreased material properties at elevated temperatures.

The expansion assembly stiffness was determined by calculating the stiffness coefficient over the first 50 mils of TSP displacement. A lower bound on the test population of joint stiffness was then used as input to the TSP dynamic analysis for determination of TSP displacements during a postulated SLB event. Figure 5-6 plots the resistive loads of the samples vs. bulge size at 50 mils of TSP displacement. The stiffness of the samples is obtained by dividing the load at 50 mils of displacement by the displacement (0.05") to obtain the stiffness in lb/in. The average stiffness of all samples (including axially mispositioned samples) was [

] a,b,c lb/in, which significantly exceeds the minimum stiffness of [ ] a,b,c lb/in assumed in the preliminary displacement analysis.

Only one data point exhibited a stiffness of less than [ ] a,b,c lb/in. This sample, which had a [ ] a,b,c" diametral expansion, exhibited a load at [ ] a,b,c, resulting in a stiffness of [ ] a,b,c lb/in, significantly less than those of the remainder of the test population. The low measured force at [ ] a,b,c mils of TSP displacement was due to an improperly installed test fixture, which resulted in indicated displacement with no resultant resistive load increase. At 100, 150, 200, and 250 mils of TSP displacement, the resistive load values of this specimen fit much better with the remainder of the population. In addition, the peak load fit well with the total population.

Several other samples from the 1/30/98 data set exhibited similar displacements with no load increase at the start of the loading. The distortion of the load curve for these samples is most likely attributable to free travel in the fixture and not to the sample, as all samples were observed to be axially locked prior to the load testing. All samples were checked for axial and rotational fixity prior to tensile loading. In all cases, the TSP simulant could not be rotated or axially displaced (by hand check) prior to testing. As the sample was axially (and rotationally) locked, it is not reasonable to believe that the TSP simulant could be displaced with no resistive load increase during the load tests. The source of the errors was attributed to the manner of attachment of the specimen to the test fixture, which resulted in excessive flexibility and free travel of the test fixture.

A second set of samples was tested with bulge sizes the same as for the first set, with the same tube and sleeve material heats, and with the same TSP simulant dimensions. This set is labeled "2/17/98 Data" in Figure 5-6. In these tests, the flexibility issues related to the test fixture were corrected. As seen in Figure 5-6, the second set of data results in significantly higher resistive loads, and comparison of the linear regression lines for each set of data indicates that the lines are parallel. For conservatism, the data sets of 1/30/98 and 2/17/98 were combined to form one data set. From this data set, the average stiffness over the first [ ] a,b,c. This data set can be further divided into nominal fitup samples, offset samples, samples with bulges [ ] a,b,c and samples with bulges [] a,b,c. In all cases, the stiffness over the first [ ] a,b,c mils never varied by more than 10% from the average value for the entire data set. If only the 2/17/98 data are used, the error about the regression is dramatically reduced, and the minimum acceptable bulge size is reduced by 10 mils compared to the minimum value indicated by the combined data.

The load vs. displacement testing indicates that the [TSP material properties have a significant effect upon the resistive load developed as the TSP is pulled over the bulge. Comparison of data from thinned sleeve assemblies, with bulge sizes comparable to the Reference 1 Addendum 1 data, indicates that use of the 42.76 ksi

TSP simulants increases resistive load by greater than a factor of 2. A linear regression line for the 1995 data indicates an expected load of [ ] a,b,c of TSP displacement. In those tests, SA-285 Grade C hot rolled plate with a yield of 33 to 36 ksi was used. The geometry of the TSP simulants was the same for both the 1995 data (Reference 1) and the current data. For the 1998 data, using 42.76 ksi yield 405 SS TSP simulants, a linear regression fit of the data indicates that the expected resistive load at [ ] a,c,e , more than twice the value for comparable sized specimens in the prior (1995) tests. Since the actual South Texas 2 TSPs are manufactured from SA-240 (405 SS) plate with a minimum yield of 54.9 ksi, use of the 1998 data will provide a substantial level of conservatism relative to the actual expected pull-out forces.

5.5.2 Considerations for Re-expansion of Undersized Expansions

The expanded tubes will be inspected following application of the process to verify that the expansion (proper bulge size) has been achieved. If the minimum acceptable bulge size has not been achieved, an additional tube must be selected for expansion. Due to the design of the expansion bladder, re-expansion of under-expanded joints is not feasible, since the increased sleeve to bladder gaps may cause bladder failure prior to complete expansion. Re-expansion should be attempted only if both expansions (above and below the TSP) are below the minimum acceptable value. This would be the case if a premature bladder failure occurred during the expansion process. The under-expanded tube will provide added margin against TSP deflection during a postulated SLB event.

5.6 TSP Stresses Produced By the Expansion

A finite element analysis of the expansion effects for application of the process at Byron/Braidwood was performed and documented in Reference 1. This evaluation concluded that the TSP ligaments would not be yielded by the expansion process, even for an off-nominal ligament thickness of 0.075", which is substantially less than the nominal ligament of 0.11". The assumed TSP material yield strength used in the Reference 1 analysis was the ASME Code minimum value of 30 ksi for SA-285 Grade C hot rolled plate. Material records for South Texas 2 indicate the TSPs have a minimum yield strength of 54.9 ksi. Therefore, the greater than 80% increase in TSP yield strength, compared to the Reference 1 results, is more than adequate to accommodate the approximately 5% higher expansion pressure required for use of a non-thinned sleeve to achieve the same bulge size. Due primarily to TSP material properties, smaller bulges are required for South Texas 2 than for Byron/Braidwood for equivalent expansion assembly stiffness. The smaller bulge requirement therefore results in reduced peak expansion pressures and reduced stresses in the TSP due to the expansion process.

5.7 NDE Support for Tube Expansion

5.7.1 Determination of Expansion OD from ID Measurement

Post-expansion diameter verification of the expansions is required to ensure that the minimum stiffness requirements are met. Field measurements are made by NDE to define the ID of the actual bulge. The expansion joint load test basis is in terms of tube OD bulge. Due to the required IDs and non-expanded sleeve ID, mechanical measurement devices could not be inserted into the samples to determine the ID corresponding to the test OD. Therefore, a set of calculations was developed to predict IDs based on measured ODs, and ODs based on measured IDs. The fitup drawings, References 2, will be included in the field procedure and design change specification, which define the range of acceptable tube IDs, based on these calculations.

To verify the adequacy of the OD to ID transfer calculation, several specimens were sectioned after expansion. The tube and sleeve pre-expansion dimensions were recorded, the specimens were assembled as TSP expansion samples, the expanded ODs were measured, and the specimens were sectioned at the maximum OD diameter of the bulges. The bulge IDs were measured with "Intrimiks" (special micrometers used for inspection of inside diameters) at the location of the maximum OD bulge diameter. Table 5-1 provides a summary of the calculated ID values and mechanically measured ID values for the sectioned samples. Although the sectioned samples used 7/8" tubes and sleeves, the calculation method is based on the measured sleeve wall thickness, assumed tube ID and wall thickness, and eddy current measured ID, which is used to calculate applied strains, and therefore, the amount of wall thinning due to the expansion process. The calculation method is independent of tube/sleeve size and can be applied equally to 7/8" and ¾" diameter tubes. The predicted IDs were nominally within 1 mil of the measured values. Similar results are obtained when the OD is predicted based on an ID measurement.

As part of the justification of eddy current ID measurement in the expansion region provided in Reference 1, 7 samples using ¾" tubes and sleeves were prepared for verification of efficacy of the process. Following assembly of the test samples, the maximum OD bulge sizes were measured. The IDs in the expansion region were then calculated and compared to the values determined using eddy current methods.. The average variance for the 7 samples (14 expansions) was -0.0008", with a standard deviation of 0.0018". The variance is defined as the eddy current measured diameter minus the calculated value. To verify these results, one of these samples was sectioned. The physically measured IDs were ["] a,b,c. The eddy current measured IDs were [ ] a,b,c, respectively, while the calculated IDs were [ ] a,b,c.

The required expansion ID dimensions will be established for each field expansion. Based on the excellent correlation between calculated and mechanically measured expansion IDs, a similar calculation can be performed to establish the resultant tube OD. Comparison of calculated and mechanically measured specimen IDs showed that in most cases the difference between the two values was less than 0.001". An accurate calculation of the expansion OD achieved can be performed, based on the known dimensions of the sleeve being used to calculate the sleeve hoop strain and the measured tube ID from the eddy current trace and an assumed tube wall thickness of 0.043".

5.7.2 Bobbin Profilometry for Expansion Diameter Measurements

In the field, a standard bobbin profilometry probe will be used to determine the mean diameter of the expansion maxima (above and below the TSP). If the minimum bulge diameter requirements are not achieved, additional tubes must be expanded. A detailed discussion of bobbin coil profilometry was presented in Reference 1. A summary is provided below.

The technique involves the use of a bobbin coil probe excited in differential and absolute modes at multiple frequencies, typically ranging form 10 kHz to 630 kHz. The lowest frequency penetrates outside of the sleeved tube and is used for steam generator landmark detection. The highest frequency has a very shallow depth of penetration and is used for the measurement of the diameter of the expansion. The bobbin probe integrates the signal response about the circumference of the tube and yields a mean diameter measurement at a given axial location.

A standard, with expansions of known diameter, is used to construct a calibration table that relates the diameter of the tube to the voltage of the eddy current response. The calibration standard for the process will include expansions bulge diameters that are close to the expected range of expansion process result in order to achieve the most accurate measurement possible.

Section 10.4 of Reference 1 shows the results of the evaluation of the expansions for both 7/8 and ¾ inch diameter tubing along with the calculated bulge I.D.s based on the O.D. measurements and the expansion strain. These tables show that the eddy current measurement of the inner diameter, on the average, meets the expected value within ±0.002" [ ] a,b,c. This uncertainty on the bobbin profilometry results is acceptable and no adjustments are necessary to the bobbin data for field process applications. This shows that the tube I.D. can be reliably measured using eddy current methods. This measurement coupled with the knowledge of the strain experienced during the expansion process can be used to verify that the O.D. of the bulge falls within the desired process range.

5.8 Tube Stabilization with an Expanded Sleeve

Adequate restraint is provided by the sleeve if circumferential cracking is postulated to occur in the original tube. For a crack that is postulated to form at the top edge of the TSP, the interaction between the tube and sleeve in the expanded area provides for a rigid link between the tube sections. Expanded specimens cut apart in the expansion region indicate intimate contact between the tube and sleeve. The expanded sleeve provides a relatively rigid structure with the tube even if it is assumed that the tube is separated at the upper edge of the bulge. The tube at this point still acts as though it were fixed due to the stiffness of the sleeve and the interaction of the tube and sleeve with the TSP.

The potential for fluidelastic vibration of the tube is negligible. If the tube is postulated to separate at the upper edge of the expansion, the tube end is effectively restrained by the sleeve expansion above the bulged region. At the intersection between the tube and sleeve, the gap is zero and progresses to a maximum of [ ] a,b,c inch in the unexpanded area. Lateral motion of the tube end is limited to the size of the gap, and the stiffness of the sleeve is sufficient to restrain further lateral motion of the tube, such that contact with adjacent tubes is precluded. The bending stiffness of the sleeve is sufficiently large that any operational loading due to flow effects is negated by the sleeve stiffness, and tube-to-tube contact will not occur. With the limited range of motion of the tube end, the end conditions are similar to a pinned connection when contact with the sleeve occurs. As long as some boundary condition fixity is provided, the potential for fluidelastic excitation is minimal.

In summary, the sleeve provides effective tube stabilization under the assumption that the parent tube is separated in the region of the expansion. The sleeve functions to essentially eliminate the likelihood of fluidelastic vibration of a separated parent tube and provides lateral restraint to prevent the assumed separated tube end from contacting adjacent tubes.

5.9 Potential for Circumferential Cracking In Expanded and Plugged Tubes

5.9.1 TSP Region

5.9.1.1 Operating Experience for Circumferential Cracking

After one cycle of operation, all TSP expansions at Braidwood were inspected using the +Point coil. No indications were detected. The OD bulge diameters inspected at Braidwood included a maximum of 0.108", and 31 bulges greater than 90 mils, of which 5 were greater than 0.100". Since the target expansion for South Texas 2 is [ ] a,c, compared to the target for Braidwood of [ ] a,c, and process improvements have been made to reduce the potential of axial misposition which, in turn, determines bulge variance and the potential for large bulges , the potential for having bulges greater than [ ] a,b,c is greatly reduced. Therefore, the likelihood of experiencing a circumferential crack in the parent tube at the TSP expansions is reduced for South Texas 2 compared to Braidwood. Since no circumferential indications were detected in the TSP expansions at Braidwood after one cycle, and smaller bulges will be made at South Texas 2, circumferential cracking is not considered an issue for the single cycle of operation planned for South Texas.

No cracking has been found in the hydraulic expansions at TSP intersections in the preheater region of South Texas Units 1 and 2. Similarly, no cracking at the expansions has been identified in the Model D4 SGs that include these expansions, which include expansions up to about 41 mils Δd in more than 10 years of plant operation.

5.9.1.2 Potential for Circumferential Cracking

The potential for circumferential cracking in the hydraulically expanded and plugged tubes was evaluated in Reference 1. The operating temperature of the expansions in the plugged tube condition is between 522° F and 540° F, as determined by the secondary coolant temperature. Operating and laboratory experience for hydraulic expansions are reviewed in Reference 1. It was concluded that the low temperatures in plugged tubes with hydraulic expansions having [ ] a,c lead to a low likelihood of circumferential cracking. The South Texas 2 TSP tube expansions will have bulge [ ] a,b,c; thus the likelihood of circumferential cracking is even further reduced.

5.9.2 Tubesheet Expansion Region

5.9.2.1 Operating Experience

After one operating cycle, circumferential indications were detected at the top of tubesheet region at Braidwood. The tube to tubesheet expansion process at Braidwood 1 was hard rolling. The EOC 6 inspection (first inspection after implementation of the 3V ARC) was the first use of the +Point probe at Braidwood 1; prior TTS inspections were performed with the RPC probe. The results of the Braidwood-1 1997 inspection were discussed in a meeting between Commonwealth Edison (ComEd) and the NRC on 4/29/1997 (Reference 3).

ComEd concluded that the top of tubesheet circumferential indications were likely undetected indications from the prior inspection that had grown to +Point detectable levels at EOC6. The signals of the circumferential indications were the same as circumferential indication signals in non-expanded tubes; thus, the indications in the expanded tubes did not represent a new degradation mechanism, but were, in fact, ODSCC at the roll transition.

Subsequent evaluation indicated that the incidence of circumferential indications among the population of expanded tubes was independent of the number of expansions performed in a single tube.

5.9.2.2 Potential for Circumferential Cracking

South Texas Unit 2 Manufacturing and Operating Experience

The South Texas Unit 2 SG tubes were hydraulically expanded in the tubesheet. The industry operating experience with hydraulically expanded tubes has suggested that hydraulic expansions are significantly less susceptible to circumferential cracking than are the hardrolled expansions.

During the prior +Point inspections at STP-2, no circumferential (or axial) cracking has been detected at the tube expansions. Consequently, compared to Braidwood 1, circumferential cracking at the transitions of the expanded tubes at STP-2 would be unlikely since:

1) No evidence of cracking at the top of tubesheet expansion transition has been observed to date during multiple cycles of inspections, nor during destructive examination of tube pulls from STP Unit 2 in support of the licensed 1-Volt ARC, whereas circumferential cracking had been previously observed at Braidwood
2) The detection capability of the +Point probe is significantly better than that of the RPC probe utilized at Braidwood EOC5. The potential undetected indications at STP are insignificant compared to those at Braidwood where the +Point probe had not been used prior to tube expansions. .

Expansion Joint Design

The design of the TSP locking expansion was modified for STP-2 based on the Braidwood operating experience. The objective was to reduce the residual stress in the tube due to expansion by reducing the required bulge diameter by 0.010-0.020". To compensate the expected loss of load carrying capability, a full wall thickness sleeve was utilized for the STP-2 process instead of the undercut sleeve utilized at Braidwood. The reduced expansion diameter reduces the residual stress in the tubes; thus the potential for circumferential cracking is reduced.

Summary

Circumferential cracking at the TTS tube expansions in the locked tubes at South Texas Unit 2 is not considered a significant issue for the following reasons:

1. Operation of the STP-2 SGs with locked tubes will be limited to one cycle, followed by replacement of the SGs.
2. The STP-2 SGs utilize hydraulic tube expansions. +Point inspections have been performed at the TTS transition region at STP-2 in prior cycles (at least 3 inspections). No circumferential (or axial) cracking has been observed in the transition region of the STP-2 SGs.

3. The design of the locking expansion was modified for STP 2 application to reduce the residual axial stress in the expanded tube. Compared to Braidwood 1, the potential for circumferential cracking at the TTS transitions in the locked tubes is essentially negligible because of the use of hydraulic tube expansions and because of the prior absence of observed TTS degradation.

5.10 Requirements on Limiting Tube Denting for TSP Integrity

No requirements related to denting are required for STP-2. The STP- 2 SGs utilize stainless steel TSPs; consequently, denting due to TSP corrosion is not possible. Although dents have been reported at STP-2, the reported indications are an artifact of the NDE definitions, and are, in fact, mechanically induced tube dings that coincidentally occur at the TSPs. Tube deformation at a structure such as the TSP is reported as a dent. The dents reported at STP-2 have been tracked back to the baseline inspection and have not changed since the baseline inspection. In the event a ding (dent) is large enough to prevent insertion of the stabilizing sleeve, an acceptable alternate tube that does not affect the structural analysis results tube will be selected for expansion.

5.11 Conclusions

The process for tube expansion at the TSPs for South Texas Unit 2 is essentially the same process that was applied for the prior implementation of 3V ARC at Byron and Braidwood.

A target expansion size of [ ] a,b,c was selected for the TSP expansion. The computer controlled expansion program will produce expansions of [ ] a,b,c in low yield strength tubing and expansions of [ ] a,b,c in high yield strength tubing. Expansions of this size will result in axial stiffness exceeding the minimum required stiffness of [ ] a,b,c at the TSPs. Based upon the load displacement data developed for the TSP expansions, a regression curve (Figure 5-6a) plotted through the data indicates that for low yield tubing (48 ksi yield), expansions produced at the target value of [ ] a,b,c would provide approximately [ ] a,b,c resistive load, resulting in an axial stiffness of approximately [ ] a,b,c of TSP displacement.

At the lower 90% prediction interval, a minimum expansion of [ ] a,b,c (Figure 5-6a) in low yield strength tubing would provide a resistive load of [ ] a,b,c lb, resulting in the minimum stiffness requirement of [ ] a,b,c lb/in. It is important to note that this minimum acceptable value was conservatively developed using the entire TSP resistive load data set, which includes the 1/31/98 data set in which the test fixture was installed such that the indicated deflection included fixture deflection. If only the 2/17/98 data set is used (Figure 5-6b), at the 90% prediction interval a minimum acceptable bulge size of [ ] a,b,c is supported. An artificial data point at 20 mils tube OD bulge and 0 lb resistive load was added to the data set, because for an open crevice, the tube OD bulge must exceed the crevice gap ([ ] a,b,c diametral) for the expansion to create a resistive load. The 90% prediction interval curve, when evaluated for engineering principle, shows its conservatism. The lower 90% prediction interval curve for all data (Figure 5-6a) indicates a minimum [ ] a,b,c diametral bulge in order to develop a resistive load greater than 0 lb. This is physically illogical, since any bulge greater than the crevice gap will create a resistive load greater than 0.

As the tube to TSP interaction angle (with reference to the vertical axis) gets larger - for example, if the crevices are packed- the resistive loads increase. In the testing program the crevices were all open, resulting in smaller tube to TSP interaction angles. This causes the tube to more easily pulled through the TSP as the angle decreases. Figures 5-6a and 5-6b provide the indicated regression curves, along with the 90% confidence intervals, and 90% prediction intervals for the combined data set and the corrected data set. The regressions were selected based on the compatibility of the data set with the physical phenomena in the Δd range tested (up to about 0.100") in these, and prior tests. A strictly mathematical "best fit" may not logically represent the physical interaction of the expansion. For example, the best fit solution for the combined TSP data set results in large predicted loads at small expansions. Therefore, the chosen fit was selected based on the expected dynamic interaction between the expanded tube and TSP.

A minimum bulge size of [ ] a,b,c would not be expected to result in the TSP being "locked" to the tube with a high degree of confidence. That is, the springback of the material would permit a small amount of axial play between the tube and TSP in the expanded condition. The TSP displacement analysis (Section 4) assumes the TSP is locked to the tube. If axial play were present, the stiffness assumptions applied to the dynamic analysis would not remain valid. Therefore, an additional requirement was imposed which requires the minimum bulge size to support axial locking of the tube to the TSP. All samples were checked for axial and rotational locking, and it was found that expansions greater than or equal to [ ] a,b,c resulted in the TSP being both axially and rotationally locked to the tube. Therefore, a minimum bulge size of [ ] a,b,c is defined for both high and low yield tubing. It should be further noted that the amount of axial play in samples with approximately ["] a,b,c of diametral bulge is approximately [ ] a,b,c. Previous testing indicates that the load difference between low (50 ksi) and high yield tubing (73 ksi) in the range of [ ] a,b,c expansion bulges ranges from [ ] a,b,c lb, respectively. Therefore, equal sized expansions in high yield tubing will result in greater stiffnesses. The determination of high yield strength can be based upon the tube heat records for South Texas 2, which identify the yield strength values for individual tubes. The expansion process therefore can be adjusted for the individual tube being expanded to optimize the expansion production.

In summary, the expansion process will be targeted toward obtaining approximately [ ] a,b,c bulges in low yield strength tubing and approximately [ ] a,b,c bulges in high yield strength tubing. For TSP expansions, minimum bulge diametral increase is [ ] a,b,c independent of material yield strength.

5.12 References

1. WCAP-14273; Technical Support for Alternate Plugging Criteria with Tube Expansion at Tube Support Plate Intersections for Braidwood-1 and Byron-1 Model D4 Steam Generators; W-NSD, February 1995.

2. W-NSD Drawing 1B80238 , "South Texas Unit #2 (THX) Support Plate Expansion Sleeve Installation Fitup".

3. Westinghouse Internal Memo NSD-RFK-97-017; "Com-Ed NRC Meeting on Braidwood 1 Inspection Results", 5/2/1997.

Table 5-1
Comparison of Calculated vs. Mechanically Measured IDs of Sectioned Samples
Calculated ID is based on Mechanical Measurement of Maximum Expansion Bulge Size

Sample	Mech. Meas. ID 1	Mech. Meas. ID 2	Calc. ID 1	Calc. ID 2	ID 1 Var. (Meas - Calc.)	ID 2 Var. (Meas. - Calc.)
D	0.7680	0.7646	0.7684	0.7659	-0.0004	-0.0013
E	0.7796	0.7802	0.7796	0.7822	0.0000	-0.0020
F	0.7776	0.7826	0.7793	0.7837	-0.0003	-0.0011
G	0.7776	0.7792	0.7781	0.7792	-0.0005	0.0000
H	0.8058	N/A	0.8060	N/A	0.0002	N/A
I	0.7862	N/A	0.7870	N/A	-0.0008	N/A

Figure 5-1
Tube Support Plate Expansion

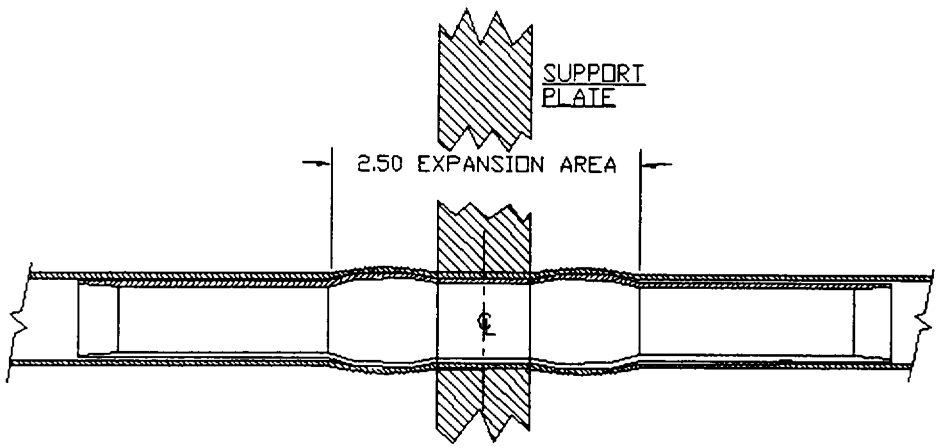
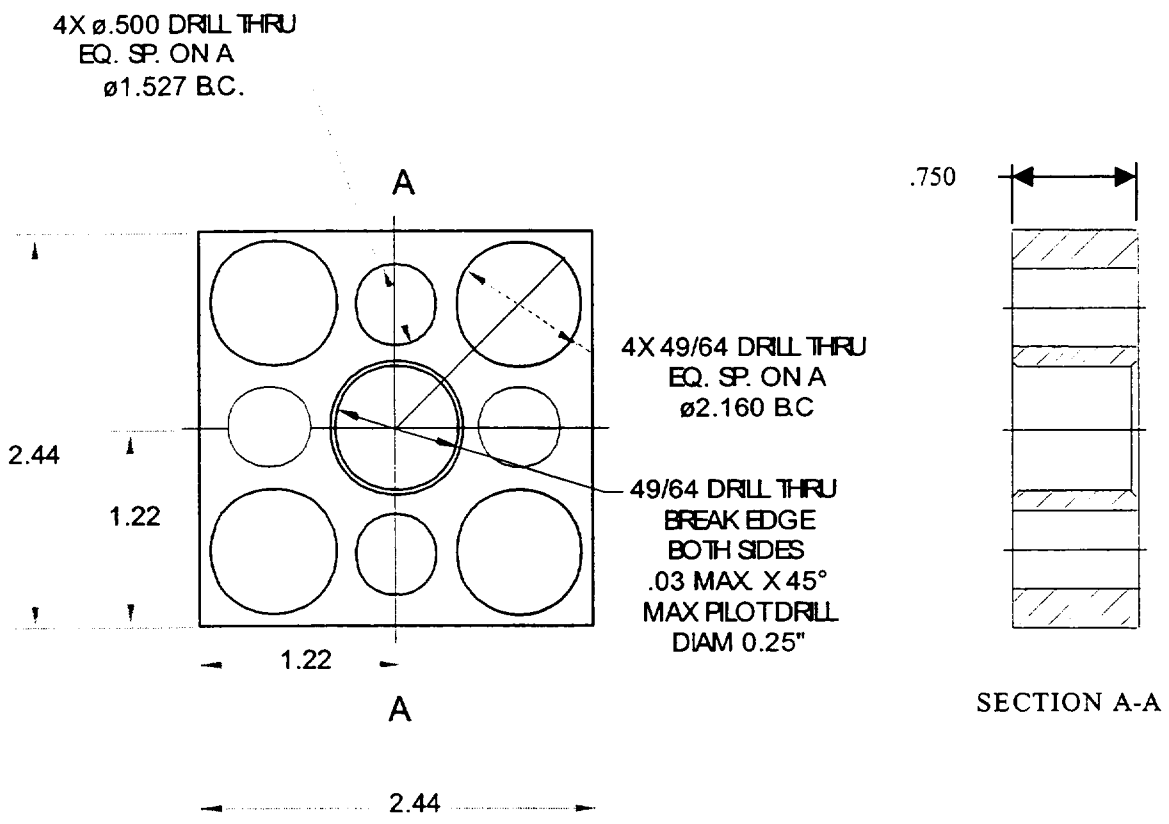


Figure 5-2
Tube Support Plate Simulant for Expansion Load Testing



Material: ASME SA-240 405 Stainless Steel Plate

Figure 5-3
Expansion Joint Load Test Setup

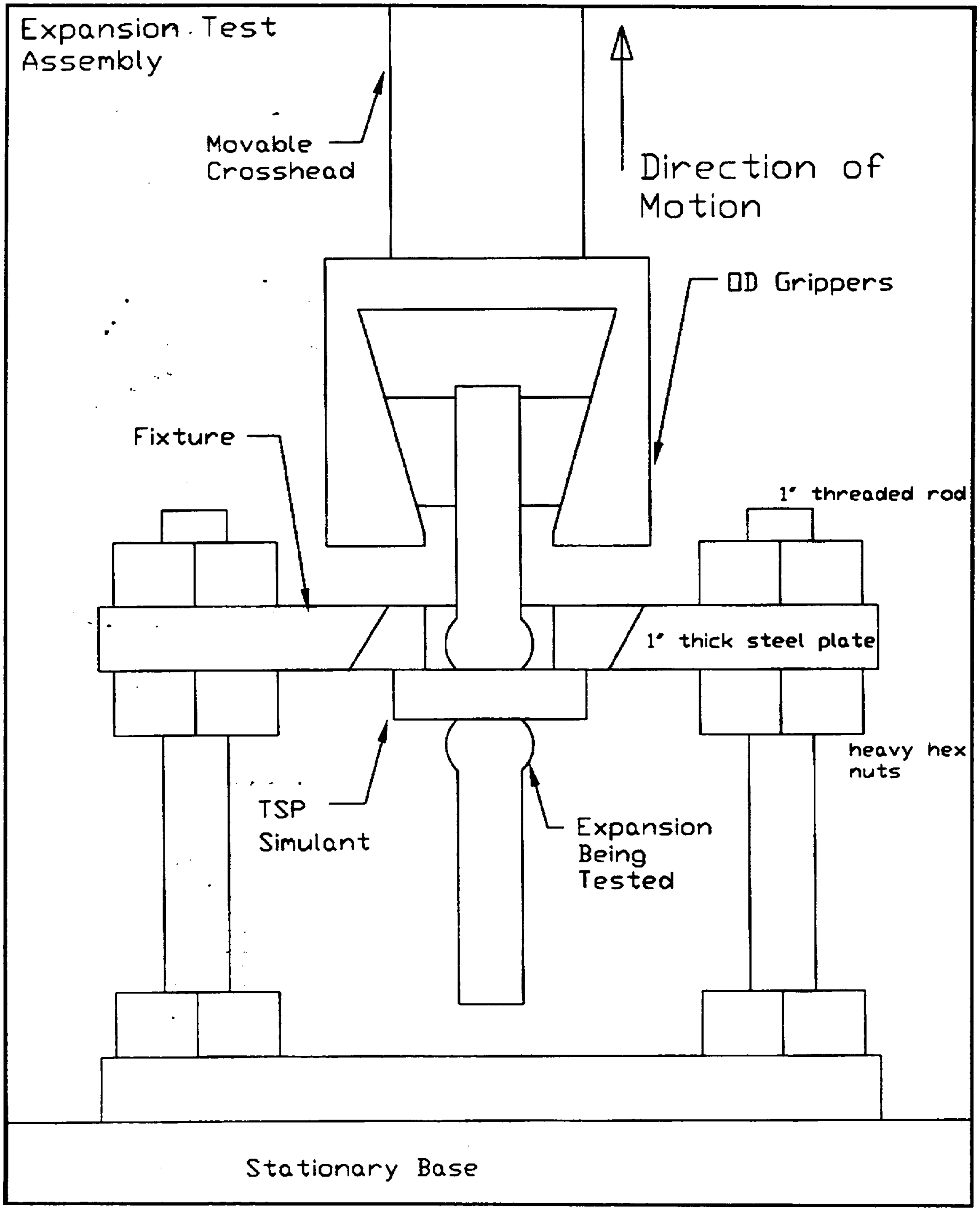


Figure 5-4
Typical Resistive Load vs. Bulge Size Tensile Loading Curve: TSP Specimen

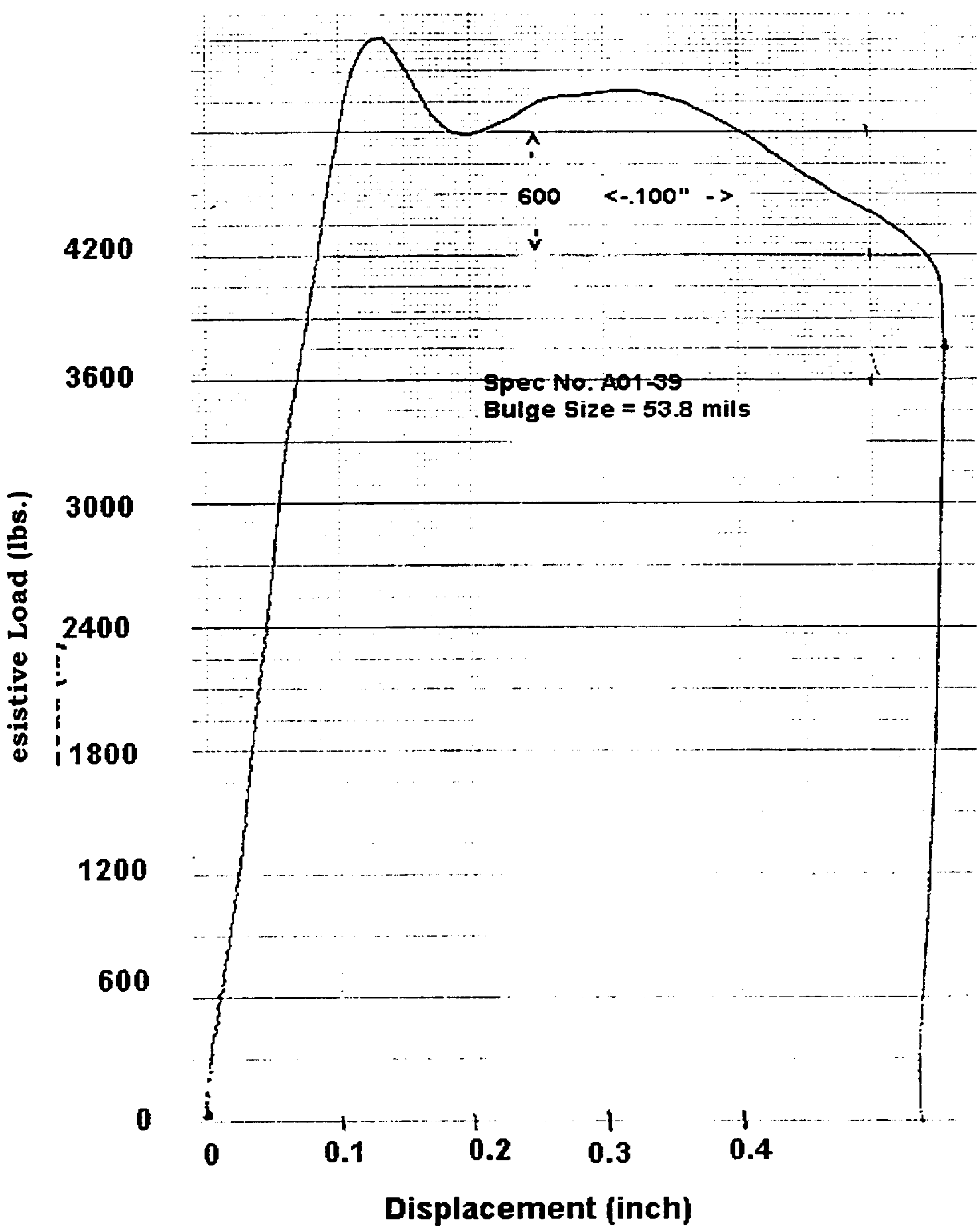


Figure 5-5
Comparison of Resistive Loads at 50 mils TSP Displacement:
1/30/98 Data Set, 2/17/98 Data Set, and Combined Data Set

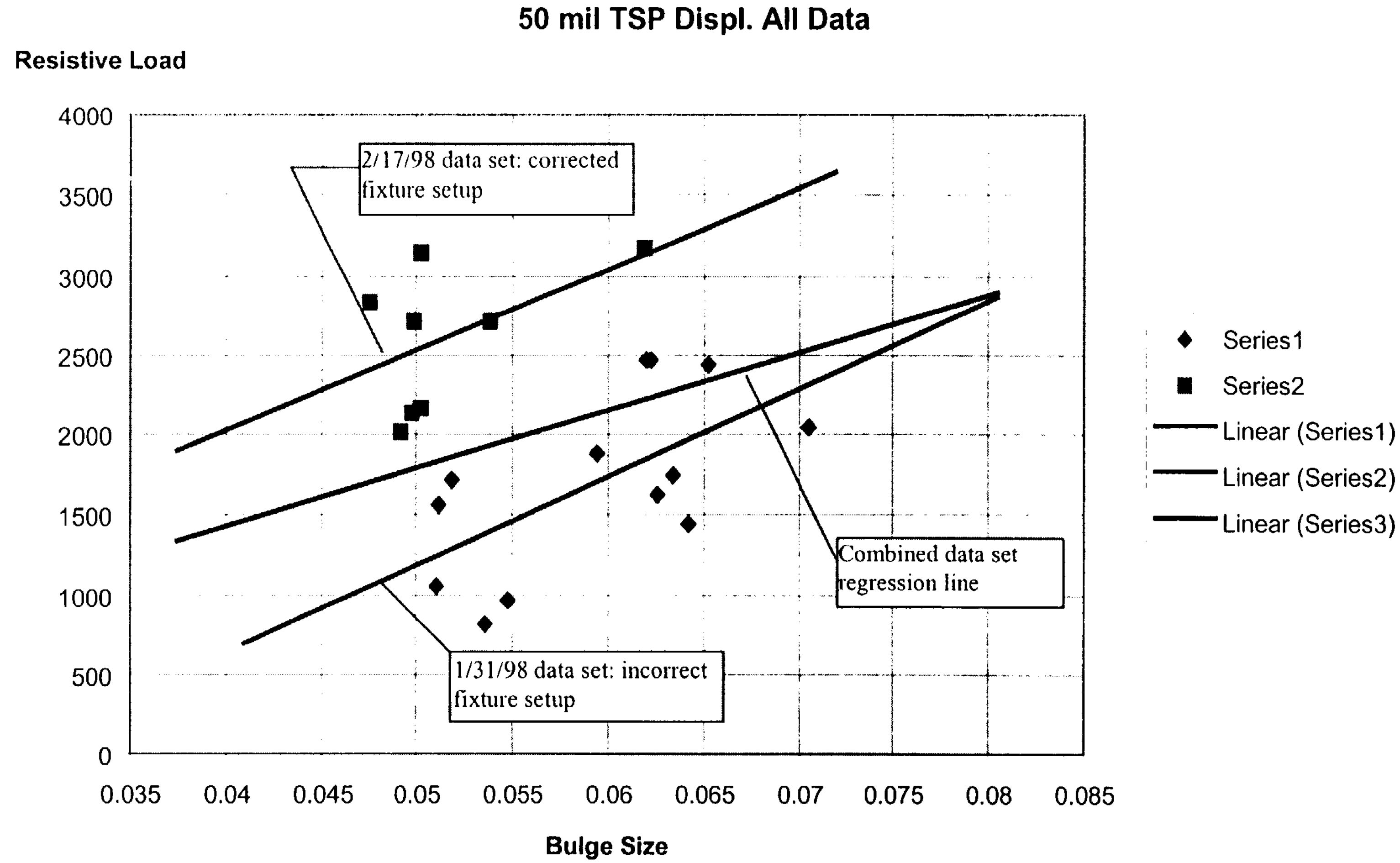


Figure 5-6a
Resistive Loads at 50 mils TSP Displacement: TSP Sample Combined Data Set
Determination of Minimum Bulge Size
Normal Regression, 90% Confidence and Prediction Intervals

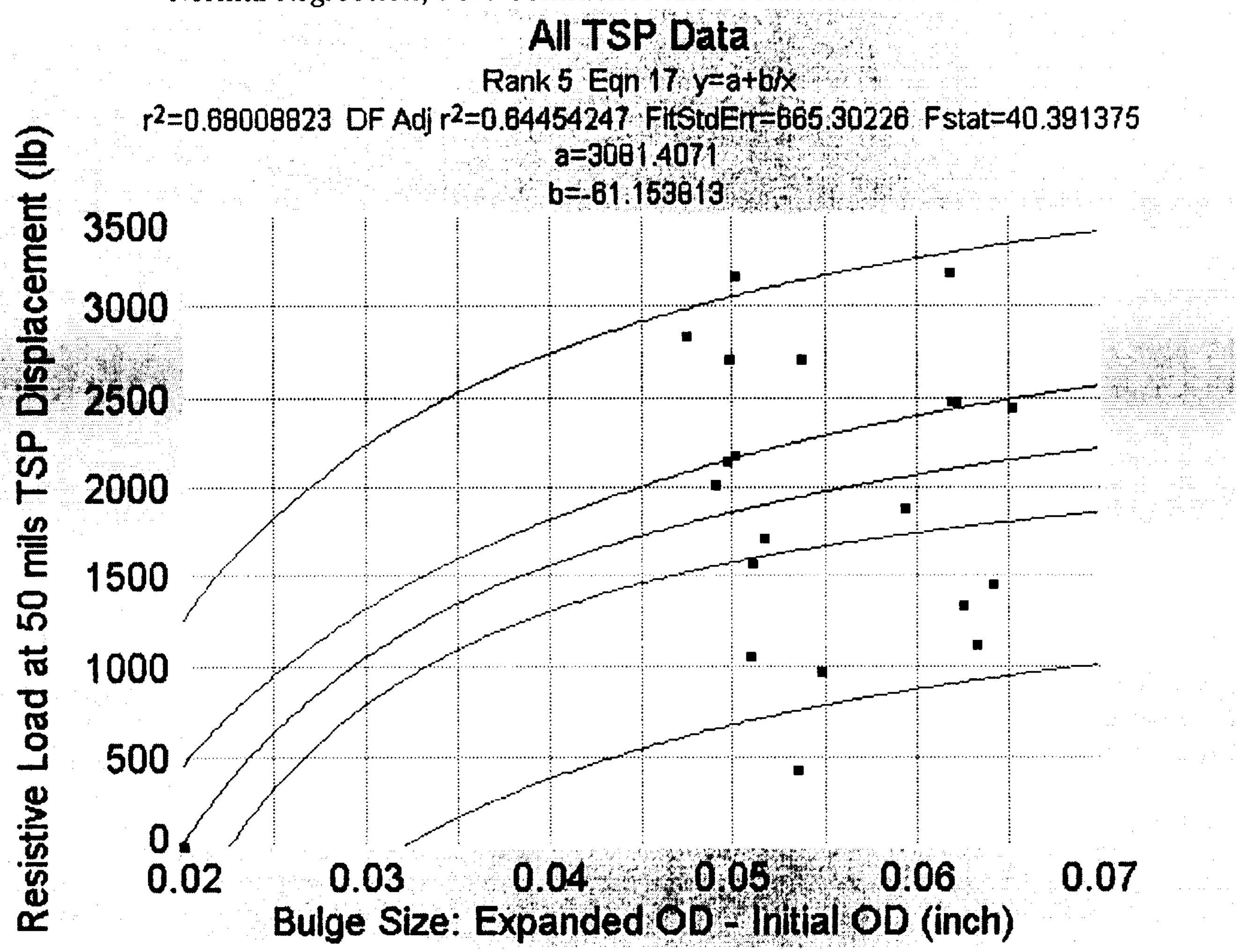
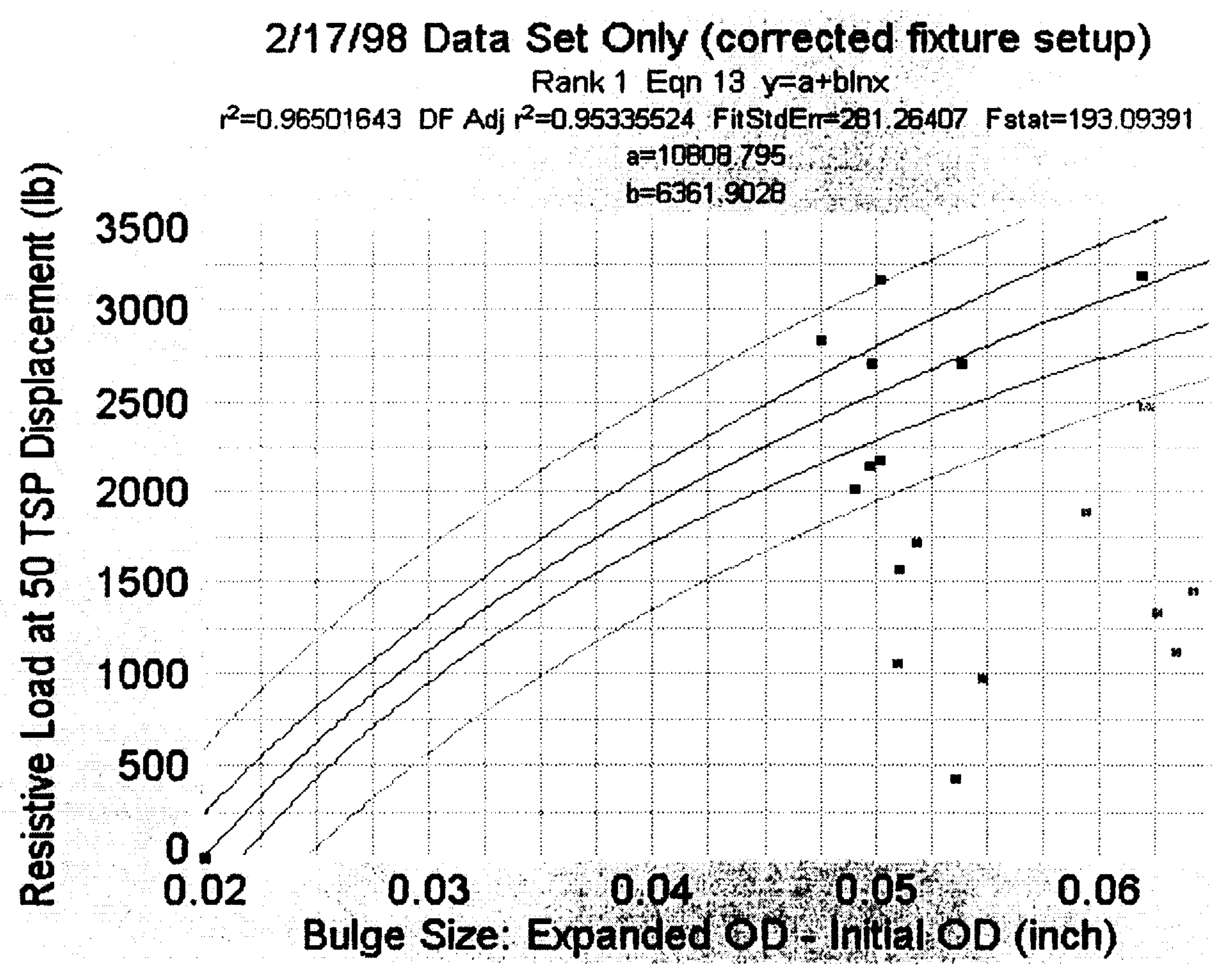


Figure 5-6b
Resistive Loads at 50 mils TSP Displacement: 2/17/98 TSP Sample Data Set
Determination of Minimum Bulge Size: Normal Regression, 90% Confidence and Prediction Intervals



6.0 HIGH VOLTAGE ALTERNATE REPAIR CRITERIA AT TUBE SUPPORT PLATES FOR SOUTH TEXAS UNIT 2

This section integrates the results of the prior sections of this report to develop the alternate repair criteria at the three lowest hot leg TSP intersections (TSPs C, F and J) above the FDB (Plate A). The general approach, design requirements, performance summary and recommended alternate repair criteria are provided in this section for the South Texas-2 SGs. Tube repair limits for the FDB, hot leg TSPs above TSP J and all cold leg TSP intersections are based on NRC Generic Letter 95-05 (Reference 1) and the South Texas Unit 2 1-volt ARC submittal (Reference 2).

6.1 General Approach to Tube Repair Criteria

In Reference 3, a 3-volt ARC was developed for TSPs C to M based on applying RELAP5 hydraulic TSP loads to demonstrate limited TSP displacements of ≤ 0.15" without tube expansion. The approach for the ARC of this report is to very conservatively define a 3-volt ARC independent of RELAP5 hydraulic loads and to provide large margins against even bounding hydraulic loads.

The elements of the approach to the tube repair criteria are:

- Limit the 3-volt ARC to the lowest 3 TSPs (plates C, F and J) above the FDB.
- Apply bounding hydraulic loads as developed in Section 3 of this report.
- Expand tubes at the TSP intersections to "lock" TSPs C, F and J to demonstrate acceptable SLB tube burst probabilities and leak rates for large hydraulic load margins even relative to the bounding hydraulic loads.

Limiting the 3-volt ARC to TSPs C, F and J restricts the ARC application to TSPs for which the SG flow would be one-dimensional even under SLB conditions. Consequently, the one-dimensional assumption used to develop the hydraulic loads (limiting and RELAP5 loads) is more clearly applicable since potential uncertainties due to mixing of the hot and cold leg flow above TSP L are eliminated. The partition plate separating the hot leg from the cold leg between plates B and L prevents hot and cold leg mixing over this span. Limiting the 3-volt ARC to 3 plates also limits the tube expansions to "lock" the TSPs to three plates. The maximum of 3 expansions in any tube limits the tube axial tensile stress at the top of the tubesheet that results from expanding the tubes, and minimizes the potential for circumferential cracking at the TTS expansion transition compared to a larger number of expansions per tube. In addition, the limitation of expansions to the 3 TSPs reduces the interaction of displacements between TSPs, and excludes effects of upwards displacements at the higher TSPs, which tend to have the largest hydraulic loads, on the lower TSPs.

The bounding hydraulic loads are developed in Section 3, Table 3.2, under the assumptions of up-flow only and split flow (half of flow up and half down). The up-flow only assumption maximizes the loads at the upper TSPs and the split flow assumption maximizes the loads at the lower TSPs. The 50/50 split flow assumption to maximize the lower TSP loads is an overestimate of the expected down direction flow since the upward direction has lower flow resistance than the down direction path requiring flow up through the downcomer of the SG. The stagnation point for the split flow would be lower than the assumed plates L to M span (such as J to L span for RELAP5 results), and the lower TSP loads would be smaller than obtained from the bounding analysis assumptions. The bounding up direction loads on TSPs L to R, with a maximum pressure drop of 3.56 psid across TSP R, are about a factor of two higher than obtained from the RELAP5 results. The 2.33 psid load across TSP C bounds the down direction loads on TSPs C, F and J, and is about a factor of three higher than the RELAP5 loads. The maximum loads on the 3-volt ARC TSPs are -2.35 psid for TSP C, -1.37 psid for TSP F and +1.76 psid for TSP J, and the maximum load on any TSP is the +3.56 psid load at the top TSP (plate R).

Although the TSPs C, F and J displacements would be acceptable without TSP expansions even for the bounding TSP loads (See Section 6.2), 16 tubes are being expanded on the hot leg to “lock” the TSPs at plates C, F and J. The principal objective for the tube expansions is to provide additional hydraulic load margins above the bounding loads even though the bounding loads represent the limiting TSP pressure drops. The tube expansions maintain limited TSP displacements with increasing assumed loading conditions. At some point in the assumed increased loading conditions, the prediction of TSP displacements becomes unreliable because stresses in a structural member can be predicted to exceed yield and permit plastic deformation. The point of plastic deformation of a structural member defines the allowable loading condition and maximum TSP displacements as described in Section 6.2.

Allowable TSP Displacements for Acceptable SLB Tube Burst Probability

The overall objective is to have limited TSP displacements such that the tube burst probability is negligible for indications at TSPs C, F and J under the 3-volt ARC. Tube burst probabilities as functions of the throughwall crack length extending outside a TSP were developed in

Section 9.3 of WCAP 15163, Revision 1. The calculated burst probabilities per indication are very small (< 10^{-8}) for exposed throughwall lengths up to about 0.35".

To support application of a 3V ARC for ODSCC indications at TSPs, a deterministic estimate of the probability of burst of exposed indications was made based on the use of postulated bounding assumptions. These assumptions were:

1. that every hot-leg intersection was cracked (a total of 43,659),
2. that the tube-to-TSP clearance was a large value (28 mils),
3. that each tube had a 0.75" long throughwall crack at the TSP intersection, and,
4. that each crack would be exposed by 0.31" during a postulated SLB event.

The probability of burst was simply calculated based on the assumption that the distribution of burst pressures was normally distributed about a regression line relating the burst pressure to the length of the throughwall crack. The actual regression process consisted of non-dimensionalizing the burst pressures by dividing by the sum of the yield and ultimate tensile strengths. Once a regression equation was found, and the distribution of the residuals verified to be normal, the actual burst pressure is found for any crack length by multiplying the non-dimensionalized value by the material strength. The distribution of material strengths of SG tubing has also been verified to follow a normal distribution. Hence, the distribution of the actual burst pressures is formed as the product of two normal distributions, one of the regression errors and the other of the material strength. The distribution of the product of two normal distributions is skewed right. This means the distribution is not symmetric and the longer tail of the distribution encompasses the larger values of the distribution. Likewise, the shorter tail of the distribution describes the variation of the smaller values. This means that conservative estimates of the probability of burst ensue if the joint distribution is treated as a symmetric distribution with normal properties for calculation purposes.

For the calculation of the probability of burst, the normal statistic,

$$Z = \frac{P_{SLB} - P_B}{s_B}$$

is calculated from the estimated burst pressure, P_B, and the standard deviation, s_B, of the above described burst pressure distribution. Here, P_{SLB} is the differential pressure associated with the postulated steam line break event. For example, the expected burst pressure corresponding to an exposed length of 0.18" (the maximum local TSP displacement under upper bound loading) is 7294 psi. This is 4734 psi greater than the postulated SLB pressure of 2560 psi. The standard deviation of the burst pressure for an exposed length of 0.18" is 405 psi; thus, Z is 11.7. The probability of burst of a single such indication would be calculated to be on the order of 10^{-16} to 10^{-17}. This simply means that the expectation of burst for such an indication is incredibly small.

Assuming every hot leg TSP intersection (all hot leg plates except FDB included; 43,659 intersections) had an exposed throughwall crack length of 0.308", the steam generator burst probability would be negligibly small at about 10^{-5}. Therefore, for the 3 TSPs under the 3-volt ARC, a maximum TSP displacement of 0.30" results in a total tube burst probability of $< 10^{-5}$. Clearly, maximum TSP displacements up to 0.30" are acceptable to obtain a negligible burst probability for TSPs C, F and J. Since this is a lower bound burst probability even if every TSP intersection has a throughwall crack exposed at 0.30", a total burst probability of 10^{-5} can be assigned to all 3-volt ARC indications in developing the total SG burst probability for the operational assessment.

There could be a maximum of 14,553 active tube-to-TSP intersections in the three TSPs (C, F and J) for which a 3V ARC is being considered. If it is postulated that all such intersections have a throughwall axial crack that becomes exposed by 0.18" as a consequence of a postulated SLB event, the combined probability that none of the tubes experiences a burst is still very nearly unity, and the probability that one or more of the tubes does experience a burst is still very nearly zero. Note that the assumption is a practical impossibility because the deformation of the TSPs during such and event is not uniform, the tube-to-TSP clearance would be expected to be much smaller than the maximum postulated, and the existence of such throughwall cracks would be very unlikely.

However, owing to the possibility that some indications have been observed outside of the tube-to-TSP interface (see Appendix C.2 of Reference 5), another estimate of the probability of burst is in order. There have been in excess of 210 tube-to-TSP intersections (from pulled tubes) destructively examined since the beginning of the ARC program. Seven indications have been found with crack indications extending outside of the TSP. The exposed lengths have ranged from 0.025 to 0.27" with average depths up to 25% (for a crack with an exposed length of 0.11") and maximum depths up to 50% at the edge of the TSP (for the same crack with an exposed length of 0.11"). If the likelihood of existence of each of such cracks is taken to be 7 in 200 and the above calculation is repeated, the number of intersections of each of the seven types of crack would be approximately 73, i.e., 1 in 200 times 14,553 total intersections in the hot legs of the three plates. The total of all such intersections would be 7 in 200 times 14,553 or 509. If it is very conservatively assumed that each of these 509 cracks is throughwall for half of the maximum extension observed (i.e., approximately 0.15") and this length is added to the maximum displacement of the TSP (0.18"), the resulting calculated probability of burst is 1.2×10^{-6}. This analysis is very conservative since all 509 cracks are assumed to be longer than the maximum length observed outside the TSP (actual range is 0.025" to 0.27"), and all of the cracks are assumed to be throughwall for half of their length when none of the observed cracks were throughwall or even nearly throughwall.

For reference, even more conservatively, if the depths of the total length of the cracks outside the TSP are very assumed to be 100% TW and the lengths are added to the maximum predicted TSP displacement, the cumulative probability of at least one burst during a postulated SLB event is 6×10^{-3}. For even this unrealistically conservative case, the burst probability is still significantly less than 10^{-2}; thus, conservatively assumed crack growth outside the TSP meets the GL 95-05 probability of burst limits.

An incremental value of 10^{-5} will be used for the 3V ARC at plates C, F and J for the total burst probability calculation for the SG.

Allowable TSP Displacements for SLB Leakage Considerations

Although an indication inside the TSP cannot burst, the flanks of a crack that could burst at SLB conditions can open up within the confines of the TSP. This condition has been labeled as an indication restricted from burst, or an IRB. Conceptually, the IRB leak rate can vary with TSP displacement that exposes part of the throughwall crack. A leak test program was performed to determine a leak rate that would conservatively envelop the leak rate from an IRB. This test program and results are described in Section 8 of WCAP 15163, Rev. 1.

For South Texas-2, the applicable SLB pressure differential is 2405 psid, based on the pressurizer PORVs for pressure relief. At this pressure differential, the bounding IRB leak rate is 5.0 gpm (Section 8 of WCAP 15163, Rev. 1). The IRB leak rate, as compared to the much larger leak rate from a freespan burst, is dependent upon the ID of the TSP hole limiting the crack opening at or near the center of the crack. This crack opening constraint leads to a limit on TSP displacement. It is shown in WCAP 15163, Rev. 1 that tests were performed up to a maximum TSP displacement of 0.21" in developing the bounding IRB leak rate of 5.0 gpm. Since the throughwall crack lengths that led to the 5.0 gpm IRB leak rate were on the order of 0.6" or longer, the center of the crack limiting the crack opening would be inside the TSP for displacements up to about 0.3". For assessing conservative design margins, displacements up to about 0.3" are reasonable for application of the IRB leak rate. For the predicted bounding TSP loads, the maximum TSP displacements should be ≤ 0.21" to maintain the displacements within the database used to develop the 5.0 gpm IRB leak rate.

6.2 TSP Load Margins and Bounding Displacements

To estimate the limiting load margins and bounding TSP displacements, the results of Table 4.14 for single plate loading are applied. The intent is to estimate the margins on the pressure drops for any single plate since it would be unrealistic to apply the large load margins to all the plates. Without tube expansion, the maximum TSP displacements per unit load (per psid across the TSP) are given by Cases 102 and 103 of Table 4.14. The maximum load for the 3-volt ARC plates would be the down direction load on TSP C, which has a displacement of 0.0565" per psi load. The bounding downward load on this plate is –2.35 psid so that the bounding displacement would be –0.133". The maximum local TSP displacement in the upward direction is 0.0808" per psi load. As noted in Section 6.1, the maximum up direction load for TSPs C, F and J is +1.76 psid for TSP J, and the maximum up direction displacement for the bounding loads at these plates would be +0.142". These maximum displacements of –0.133" and 0.142" for the bounding hydraulic loads are well within acceptable values to limit burst probabilities to negligible levels and to remain within the test range of 0.21" displacement for the IRB leakage database. The maximum acceptable load is that at which a structural member becomes plastic such that the associated TSP displacements are no longer predictable. From Table 4.14, the limiting components for maintaining stresses in the elastic range are the TSPs. The pressure drops to reach yield in the TSPs with no tube expansion are +3.5 and –3.4 psid. These pressure drops provide a factor of 2 margin against yield on the maximum upward load of 1.75 psid at TSP J and a factor of 1.5 margin on the bounding downward load of 2.35 psid at TSP C.

The most conservative assumption to assess load margins would be to assume that the bounding top TSP R pressure drop of 3.56 psid applies for the lower TSPs C, F and J. This is twice the predicted bounding up direction load for TSP J and TSPs C and F would be expected to have downward loads under any realistic assumption for the flow stagnation point in a SLB event. For the upward direction 0.0808" displacement per psi load, the maximum TSP displacement for a 3.56 psid load would be 0.288". Even under this very conservative assumption, the displacements result in negligible burst probabilities even if it is assumed that all TSPs have this displacement. Although the displacement exceeds the 0.21" displacement test range for the IRB leakage data, the result is sufficiently close that the bounding IRB leak rate of 5.0 gpm can be considered applicable. From Table 4.14, the upward pressure drop to reach yield in the TSPs is 3.5 psid so that the maximum upward displacement of about 0.288" is also the maximum allowable displacement to maintain TSP stresses in the elastic range.

The above assessments show that TSP displacements are acceptable under the bounding load conditions even if no expansions are performed to "lock" the TSPs.

At South Texas-2, 16 hot leg TSP expansions will be performed to increase the design margins against the TSP hydraulic loads. The TSP displacement results of Case 112 from Table 4.14 can be used to estimate the expected TSP displacements and the acceptable load margins that result in TSP displacements maintaining the structural members within elastic limits. For the 16 tube expansions, the TSP displacement in the up direction is 0.0135" per psi so that applying the bounding up direction load of 3.56 psid (top TSP R) would result in TSP displacements of only about 0.048". The limiting TSP load to maintain the TSPs within elastic limits is 14.3 psid. This load for maintaining elastic limits would result in a TSP displacement of about 0.19". Thus, even for TSP loads as high as 14.3 psid, the TSP displacements would be less than the 0.3" acceptance guideline discussed in Sections 6.1.1 and 6.1.2 and the TSPs would remain elastic. The 14.3 psid load provides safety factors of 8.1 against the bounding up direction load of 1.756 psid at plate J for the 3-volt ARC TSPs, 6.1 against the bounding down direction load of 2.35 psid at TSP C and 4.02 against the maximum up direction load of 3.56 psid for the top TSP R. It can be concluded that the TSP expansions provide acceptable TSP displacement margins for loads well beyond the credible load conditions indicated by the bounding load of 3.56 psid at the top TSP R.

In summary, the maximum expected displacement for TSPs C, F and J with 16 tubes expanded is about 0.048" for the maximum bounding load of 3.56 psid, which envelopes the limiting case of 2.35 psid on TSPs C, F and J. TSP loads as high as 14.3 psid result in an acceptable maximum TSP displacement of about 0.19" based on the maximum load that maintains TSP stresses within elastic limits. Since the tube expansions are not required to limit TSP displacements to acceptable values for the bounding loads, the addition of the 16 hot leg tube expansions to "lock" the TSPs leads to the very conservative margins on hydraulic loads. Table 6-2 summarizes the conservatism and load margins incorporated in the design for implementation of the 3-volt ARC.

6.3 Tube Repair Limits for South Texas Unit 2

Tube repair limits are required for ODSCC indications at the hot leg TSPs, at the FDB and at the cold leg TSPs. At the time of this report, few indications in Model E SGs have been reported at the FDB intersections or at cold leg TSP intersections. The largest voltage indications and the largest number of indications occur at the lower TSPs C, F and J. Therefore, for indications at TSPs above TSP J including the cold leg TSPs and for the FDB, it is adequate and conservative to apply the GL 95-05 ARC for ODSCC at TSPs, which are based on the assumption of free span indications at SLB conditions. The GL 95-05 criteria are the recommended repair criteria for ODSCC indications at the FDB and intersections above TSP J including the cold leg TSP intersections (i.e., all intersections except TSPs C, F and J). The repair limit for these indications is 1.0 volt. For these TSP indications, the appropriate structural limit would be $1.43\Delta P_{SLB}$ since the R.G. 1.121 margin of $3\Delta P_{NO}$ is satisfied at normal operating conditions due to the constraint provided by the TSPs. Due to the large tube to FDB clearances, constraint against burst cannot be confidently assured and the $3\Delta P_{NO}$ structural margin requirement is appropriate for indications at the FDB intersections. GL 95-05 requires the upper voltage repair limit to be updated on an outage-by-outage basis to the latest database, correlations and growth information. Separate upper voltage repair limits will be provided for the TSP and FDB intersections as described in the South Texas-2 1-volt ARC submittal of Reference 2. Bobbin indications >1.0 volt and below the upper voltage repair limit that are not confirmed by RPC inspection may be left in service.

For free span indications, tube repair limits are based on the R.G. 1.121 guidelines for structural margins against tube burst as discussed above for indications at TSPs and at FDBs. Since the small maximum TSP displacement during a postulated SLB event reduces the tube burst probability at TSPs C, F and J to negligible levels ($< 10^{-5}$), independent of the degree of ODSCC at the hot leg TSP intersections (i.e., all hot leg TSP intersections are assumed to have throughwall indications), tube repair limits for axial tube burst are not required for these TSPs. Tube repair is primarily required only as necessary to maintain SLB leakage within acceptable limits. The structural limit for the hot leg TSP intersections and the full ARC repair limit for limited displacement of the TSPs is addressed below.

As developed in Section 9.8 of WCAP 15163, Rev. 1, a structural limit for axial tensile tearing of cellular and IGA indications applies at very high voltages with limited TSP displacements. This structural limit appears to be in excess of [35]^{a,c} volts. Even if a factor of two reduction is applied for growth and NDE allowances (factor of about 1.5 to 1.75 is typical), the full ARC repair limit would be about [17]^{a,c} volts. For conservatism in defining the ARC repair limit for limited TSP displacement, a tube repair limit of > 3.0 volts is conservatively applied for indications at hot leg TSPs C, F and J for the South Texas-2 SGs. Bobbin indications > 3.0 volts are repaired at these TSPs independent of RPC (or equivalent probe) confirmation.

6.4 Inspection Requirements

6.4.1 Expanded Tubes

The GL 95-05 requirements applied for the 1-volt ARC eddy current inspections also apply for implementation of the limited displacement ARC. However, the inspection threshold for RPC confirmation of bobbin indications should be adjusted for the increased repair limits. RPC inspection of bobbin indications greater than the 3.0 volt repair limit with a sample inspection of a minimum of 100 intersections below the 3.0 volt repair limit will be applied at hot leg TSPs C, F and J intersections. The GL 95-05 1.0-volt RPC threshold is applied for the 1.0 volt repair limit at hot leg intersections at plates L through R, at the FDB and at cold leg TSP intersections.

The addition of the expanded tubes, as described in Section 5, leads to additional inspection requirements. Prior to the tube expansion, tubes selected for expansion will be bobbin inspected, potential indications at TSPs C, F and J found by the bobbin inspection will be +Point inspected, and a +Point inspection will be performed for the tube sheet expansion transition. The tubes to be expanded must have no circumferential indication at the expansion transition, no indications within one inch above or below the TSP and no +Point confirmed bobbin indications greater than one bobbin volt within the confines of the TSP. Following implementation of the tube expansion process, the tube expansions are inspected to confirm that the expansion process resulted in the minimum acceptable bulge size as described in Section 5.11.

6.4.2 Steam Generator Internals

As noted in Section 6.2, the tube expansions at TSPs C, F and J are not required to limit TSP displacements to acceptable levels for the bounding hydraulic loads. The TSP expansions provide for large margins on the

TSP hydraulic loads while maintaining acceptable TSP displacement and structural component stresses within elastic limits. Given the expansions to "lock" TSPs C, F and J and limit displacements, the dependence of TSP displacements on the stayrods and peripheral supports is reduced significantly.

As a consequence, visual inspection of the stayrods and peripheral TSP supports is not considered necessary for the application of the 3V ARC to the hot leg intersections at TSPs C, F and J. Over the operating history of all models of Westinghouse SGs, no loss of structural integrity of the stayrods or peripheral supports of the TSPs is known to have been reported. Moreover, no degradation mechanism has been identified that would lead to loss of function of these components (stayrods, backup bars, wedges).

The stayrod nuts are welded to the top TSP at one of the flats of the nut using a 0.25" x 1-inch long fillet weld. There are no known torsion loads on the nuts whose rotation is restricted by preload friction loads between the nuts and the TSP as well as by the welds. In the absence of significant loading, there is no known degradation mechanism that would lead to cracking of the welds. The stayrod and the nut are made from carbon steel, and the TSP is made from stainless steel.

The wedges and the backup bars are welded to the wrapper using fillet welds along both sides and the top edge (bottom edge for the bottom backup bars). All tack welds between the TSPs and nuts, spacers, etc. were performed using the same qualified weld procedure.

For a similar implementation of 3V ARC at Braidwood 1, visual inspections were performed. Table 6-1 summarizes the inspections performed. It was concluded from the inspections that the load carrying components were undegraded.

STP has performed multiple inspections of secondary side components. These inspections are documented in Reference 6. Tables 1 and 2 of attachment 2 to this letter identify the inspections performed and the results of these inspections. No degradation of any of the SG internals was identified in the secondary side inspections performed. While these inspections did not include specific examination of the stayrods, the examinations did address backing bars and wedges, which were confirmed to be in place with no visible cracks. Tack welds between the stayrods and lower baffle plates (i.e., B and C) were found intact. These tack welds are located in the preheater of the SG where the environment is more conducive to the onset of potential degradation. Therefore, by inference, since these welds were found to be intact, it can be expected that the stayrod tack welds are also intact.

At STP Unit 1, approximately 60% of the TSP intersections have been examined for TSP cracking and missing ligaments using an eddy current technique. No evidence of TSP cracking has been detected in the carbon steel support plates of Unit 1. Since the Unit 2 TSPs are made of stainless steel, the potential for TSP cracking is essentially negligible. The corrosion/ cracking performance of the carbon steel TSPs in unit 1 is considered an enveloping precursor to similar degradation in Unit 2. Since no TSP degradation has been reported in Unit 1, it is judged that the TSPs are undegraded in Unit 2.

The STP-2 SGs are scheduled to be replaced in 2002 after a final operating cycle of approximately 18 months following tube expansion at the TSPs. No degradation of the SG internals has been observed over the operating time since these SGs were put into service in 1989; thus, no degradation is expected during the next operating cycle of 18 months.

For application of the 3V ARC to STP-2 hot leg TSPs C, F and J, 16 tubes will be expanded at each TSP to lock the TSP in place. Sixteen expansions on each plate is significantly larger than the number of expansions performed at Byron-1 and Braidwood-1. The number of tube expansions at the corresponding TSPs at Byron and Braidwood was 8 or fewer. As demonstrated by the bounding loads analysis, a substantial margin on TSP displacement exists with this number of tube expansions. Based on the upper bound analysis for TSP loads, the peak bounding Δp is 3.56 psid at the top TSP, which is a factor of more than 2 greater than the highest bounding load applicable to plates C, F or J (1.76 psid). The peak Δp that satisfies all structural and displacement criteria is 13.3 psid. At the 13.3 psid loading for a single plate model, the maximum local deflection of the TSP is 0.18", well within the conservatively acceptable displacement of 0.31" for burst probability and 0.21" for application of the IRB leak rates. These substantial margins, the absence of prior industry history of steam generator weld failure, and insignificant loading conditions that do not challenge the welds justify not performing visual inspections of the stayrod nuts, spacer, backup bars and wedges.

If it is assumed that the highest loaded stayrod does not perform its function due to postulated stayrod nut loosening, the resulting factor of safety on loads relative to the bounding load is 2.36 compared to 3.74 with the stayrod active. The limiting condition is due to the stress in the TSP. At the corresponding Δp of 8.42 psid (2.36 x 3.56), the maximum local displacement is 0.26", well within the 0.308" displacement limit to achieve a burst probability of 10^{-5}. Thus, it is concluded for the extremely unlikely condition of one (the highest loaded) stayrod inactive, significant margin to the limiting TSP displacement under upper bound loading exists. Therefore, inspecting the stayrod nuts is unnecessary.

Finally, the limited benefits that inspection of the secondary side components would provide, as noted above, do not justify the personnel exposure and costs of performing the inspections. The costs have been estimated both in expenditure of real resources and in accumulation of personnel dose. Assuming a 2 shift per day work schedule, the actual costs to perform the inspections have been estimated at $440,000. The attendant incremental personnel dose is estimated at 12 Rem.

In summary, visual inspection of the SG internals (the stayrod nuts, spacer, backup bars and wedges) is considered unnecessary for the following reasons:

1. No loss of structural integrity of these components has been observed in prior visual inspection of similar components during application of 3V ARC at Byron 1 and Braidwood 1.
2. No SG internals loss of structural integrity has been observed in several inspections at STP Units 1 and 2 since the SGs were placed in service in 1989.
3. Backup bars and wedges have been confirmed to be in place for the lower TSPs, including plate C, during inspections at STP 1 and 2.
4. The loading on the stayrods and the individual backup bars is low, even during a postulated SLB.
5. No mechanism has been identified for degradation of these components during operation.
6. No mechanism has been identified to unthread the stayrod nuts, particularly working against the force of gravity.
7. There is substantial margin for TSP displacement under bounding loads as demonstrated in this Addendum to WCAP 15163.
8. There is significant margin for TSP displacement under bounding load conditions for the postulated condition of the highest loaded stayrod being inactive.
9. The proposed operating time for application of the 3V ARC is limited to one 18 months operating cycle.
10. The real cost, $440,000, and the personnel dose, 12Rem, required to perform these inspections are not justified by the added information that could be obtained by performing the inspections.

6.5 SLB Analysis Requirements

Per GL 95-05, SLB leak rate and tube burst probability analyses for condition monitoring are required prior to returning to power and the results are to be included in a report to the NRC within 90 days of restart. SLB leak rates and burst probabilities obtained for the actual voltage distribution measured at the inspection (condition monitoring) are required prior to restart and the projected next EOC values (operational assessment) are required in the 90 day report. If allowable limits on leak rates and burst probability are exceeded for either the condition monitoring or operational assessment, the results are to be reported to the NRC and an assessment of the significance of the results is to be performed. For the limited displacement ARC, SLB leak rates must be calculated for the hot leg TSP indications at plates C through J, and both leak rates and tube burst probability are to be calculated for the FDB, cold leg TSP indications and hot leg indications at plates L through R. The contribution to the tube burst probability for TSPs C, F and J would be $< 10^{-5}$ and will be included as an increment to the tube burst probability analyses performed for the remainder of the bundle according to GL 95-05. The required SLB analyses are discussed below.

The SLB leak rates for hot leg TSP indications at plates C, F and J are to be calculated as free span leakage using the GL 95-05 leak rate methods, if the sampled indication is not found to be a potentially overpressurized indication. Potentially overpressurized indications in the Monte Carlo analyses are indications for which the sample is predicted to burst as a freespan indication. For indications that are found to be potentially overpressurized indications, the bounding leak rate of 5.0 gpm for indications restricted from burst (IRB) is applied. Free span leak rate methods must be applied for the FDB and cold leg TSP indications and hot leg indications at plates L through R. The free span leak rates are based on the EPRI methodology for correlating probability of leakage and SLB leak rates with bobbin voltage. Acceptable methods are described in WCAP-14277, Revision 1 (Reference 4).

As noted above, in addition to the free span leak rates, the leak rate analyses for hot leg TSP indications at plates C, F and J (TSPs with 3-volt ARC) are to include the potential leakage from overpressurized indications within the TSP. There is a finite probability that a crack might open up significantly more than the crack opening that occurred in the SLB leak rate measurements. The probability that a crack will open up to the limits of the tube to TSP gap is equivalent to the probability of free span burst. The analysis methods for the overpressurized condition are given in Section 9.5 of WCAP 15163, Rev. 1. The overpressurized condition leak rates are obtained from the probability of free span burst and the bounding leak rate of 5.0 gpm (IRB bounding leak rate) for the overpressurized condition.

The SLB leak rate analysis can be symbolically represented as:

$$LRSLB = [(1\text{-}POB)*POL*LR_c + POB*LR_b]\text{Hot Leg TSPs C, F and J} + [POL*LR_c]\text{FDB+Cold Leg TSPs+Hot Leg TSPs L to R}$$

where:

LRSLB= Total SLB leak rate
POL = Probability of leakage based on POL versus voltage correlation
LR_c = Leak rate based on leak rate versus voltage correlation
POB = Probability of burst at SLB conditions for hot leg TSP indications based on free span burst pressure versus voltage correlation (zero or one)
LR_b = Bounding leak rate for overpressurized indications as developed in Section 9.6 of Reference 3

The free span tube burst probability must be calculated for the FDB, hot leg TSPs L to R and cold leg TSP indications per the requirements of the GL 95-05. The contribution to the burst probability for TSPs C, F and J can be assumed to be $< 10^{-5}$. The free span analysis methods are described in Reference 4. Per NRC GL 95-05, the burst probability limit for reporting results to the NRC is $>10^{-2}$.

6.6 Summary of South Texas-2 ARC at TSPs

This section provides a summary of the alternate tube repair criteria (ARC), as developed above, to be applied at South Texas-2 tube support plates, including plates C, F and J with limited SLB displacement. This summary includes the tube repair limits, general inspection requirements, SLB leak rate and tube burst probability analysis requirements. SLB analysis methodology is summarized in Section 6.5 and described in detail in Section 9 of WCAP 15163, Rev. 1. Tube expansions at 16 locations on TSPs C, F and J are required to support these ARC. A summary of the conservatism and load margins for the ARC design is provided in Table 6-2.

South Texas-2 Tube Repair Limits

- For hot leg TSP indications at plates C, F and J, bobbin flaw indications >3.0 volts shall be repaired independent of RPC confirmation.

- For indications at hot leg plates L through R, at the FDB and at cold leg TSP intersections, bobbin flaw indications >1.0 volt and confirmed by RPC inspection shall be repaired. Bobbin flaw indications greater than the upper voltage repair limits for South Texas-2 indications at these intersections shall be repaired independent of RPC confirmation. The upper voltage repair limits for hot leg plates L through R, for the FDB and for cold leg TSP intersections shall be updated at each inspection based on the latest database, correlations and plant specific growth rate information. Growth rates as required by GL 95-05, 2.a.2 shall be used to develop the upper voltage repair limits.

- All indications found to extend outside of the TSP and all circumferential crack indications shall be repaired and the NRC shall be notified of these indications prior to returning the SGs to service.

- All flaw indications found in the RPC sampling plan for mechanically induced dents (corrosion denting is not present with stainless steel TSPs at South Texas-2) at TSP intersections and bobbin mixed residuals potentially masking flaw indications shall be repaired.

- For the South Texas-2 Model E SGs, no intersections near TSP wedge supports are excluded from application of ARC repair limits due to potential deformation of these tube locations under combined LOCA + SSE loads.[1]

Inspection Requirements

- The bobbin coil inspection shall include 100% of all hot leg FDB and TSP intersections and cold leg TSP intersections down to the lowest cold leg TSP with ODSCC indications. The lowest cold leg TSP with ODSCC indications shall be determined from an inspection of at least 20% of the cold leg TSP intersections.

- All bobbin flaw indications exceeding 3.0 volts for hot leg TSP intersections at plates C to J, and 1.0 volt for hot leg intersections at plates L through R, for all FDB intersections and for all cold leg TSP intersections shall be RPC (or equivalent probe) inspected. In addition, a minimum of 100 hot leg TSP intersections at plates C through J with bobbin voltages less than or equal to 3.0 volts shall be RPC inspected. The RPC data shall be evaluated to confirm responses typical of ODSCC within the confines of the TSP.

- A RPC inspection shall be performed for intersections with mechanically induced dent signals >5.0 volts and with bobbin mixed

[1] Fifteen tubes in SG D that are thermally treated Alloy 600 tubes are excluded 9 see Section 2 WCAP 15163, Rev 1)

residual signals that could potentially mask flaw responses near or above the voltage repair limits.

- Prior to the tube expansion, tubes selected for expansion will be bobbin inspected, potential indications at TSPs C, F and J found by the bobbin inspection will be +Point inspected, and a +Point inspection will be performed at the tube sheet expansion transition. The tubes to be expanded must have no circumferential indication at the expansion transition, no indications within one inch above or below the TSP and no +Point confirmed bobbin indications greater than one bobbin volt within the confines of the TSP.

- Following implementation of the tube expansion process, the tube expansions are inspected to confirm that the expansion process resulted in the minimum acceptable bulge size as described in Section 5.11.

- Visual inspections of the stayrods or peripheral supports are not required to adequately limit TSP displacements and maintain structural integrity. The TSP expansions at TSPs C, F and J provide for large margins on the TSP hydraulic loads while obtaining acceptable TSP displacements and maintaining structural component stresses within elastic limits. The tube expansions more than compensate for an assumed loss of one stayrod or one peripheral support, both of which are very low likelihood events over the planned one operating cycle with the 3-volt ARC at South Texas-2.

SLB Leak Rate and Tube Burst Probability Analyses

- SLB leak rates and tube burst probabilities shall be evaluated for the actual voltage distribution found by inspection and for the projected next EOC distribution. The burst probability for hot leg TSPs C, F and J is assigned a burst probability of 10^{-5} and added to the burst probability calculated per GL95-05 for the other hot leg and cold leg indications at TSP intersections.

- Based on the voltage distribution obtained at the inspection, the SLB leak rate shall be compared to the South Texas-2 allowable. The SLB tube burst probability for FDB and cold leg TSP intersections and the hot leg intersections at plates L through R shall be compared to the reporting value of 10^{-2} and the NRC shall be notified prior to returning the SGs to service if the allowable limits are exceeded. If the allowable limits are exceeded for the projected EOC distribution, the NRC shall be notified and an assessment of the significance of the results shall be performed. A report shall be prepared that includes inspection results and the SLB analyses within 90 days following return to power.

6.7 References

1. NRC GL 95-05; "Voltage Based Repair Criteria for Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking"; August 1995.

2. SG-98-01-004; "South Texas Project Unit 2 Technical Justification for License Amendment to Implement NRC Generic Letter GL 95-05 Voltage Based Repair Criteria for Steam Generator Tube ODSCC"; January 1998.

3. WCAP-15163, Revision 1, "Technical Support for Implementing High Voltage Alternate Repair Criteria at Hot Leg Limited Displacement TSP Intersections for South Texas Plan Unit 2, Model E Steam Generator," March 1999.

4. WCAP 14277; SLB Leak Rate and Tube Burst Probability Analysis Methods for ODSCC at TSP Intersections (Revision 1); December 1996.

5. EPRI NP-7480-L, V1, Rev 2; "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates – Database for Alternate Repair Limits, V1: 7/8" Diameter Tubing"; August 1996.

6. STP Letter NOC-AE-000117; "South Texas Project Units 1 and 2; Docket Nos. STN 50-498, STN 50-499; 90-Day Response to Generic Letter 97-06, "Degradation of Steam Generator Internals"; dated March 30, 1998.

Table 6-1
Inspections Performed at Braidwood-1
for Implementation of 3V ARC

Feature	Inspection
TSP Integrity	Bobbin probe at reduced speed (12 ips). No indications of TSP damage found.
	Visual inspection of the periphery of the top TSP was performed, five rows deep into the bundle, near the anti-rotation keys and along the patch plate seam. No degradation of any kind was found.
157 welds on 89 vertical support Bars (Backup Bars) ;	Visual inspection after bundle flush (24 locations were also mechanically cleaned); no corrosion, cracking or distortion was found in any weld inspected.
Stayrod nuts	In one SG, nine of eleven stayrod nuts and their tack welds were visually inspected. No damage was found and it was verified that all nuts were in contact with the TSP and could not un-screw from the TSP.
Stayrod Spacers	Seven of 11 TSP spacers were visually inspected between the 8^{th} and 9^{th} TSP in the bundle. No degradation was found.
Wedges	Five TSP wedges at the top TSP were inspected visually. No damage to the welds was found. The presence of the wedges at the FDB was verified by an inspection from below the FDB. The presence of the wedges implies that the welds are intact and that the wedges are tight in the annulus.

Table 6-2
Summary of Conservatism and Load Margins for Application of the Limited TSP Displacement ARC

Issue	Conservatism Identified
Hydraulic Loads for TSP Displacements	Bounding loads developed to envelop potential TSP pressure drops. Loads bound prior RELAP5 loads at all TSPs.
Tube Expansions to "Lock" TSPs	16 tubes expanded in hot leg at TSPs C, F and J even though expansions not required to obtain acceptable TSP displacements for bounding loads.
TSP Displacements	TSP displacements with expanded tubes are limited to maximum of about 0.048" for bounding loads
Hydraulic Load Margins for Acceptable TSP Displacements	• TSP displacements < 0.21" for TSP loads as high as 14.3 psid, which provides design margin safety factor of about 3.74 against bounding TSP loads. • Acceptable load margins to 14.3 psid limited by value at which TSP ligament stresses exceed elastic limits. • TSP displacements < 0.3" required to obtain tube burst probability < 10^{-5}, and < 0.21" desirable for application of the IRB bounding leak rate.
Burst Probability Estimate of < 10^{-5} for Contribution from TSPs C, F and J	Conservatively, all hot leg TSPs are assumed to have exposed throughwall indications of 0.3" under SLB conditions. Cracks that have potentially grown outside the TSP also included.
SLB Leakage	SLB leakage based on applying a bounding IRB leak rate for all indications predicted to burst under free span conditions and free span leakage for indications not predicted to burst under free span conditions. All leak rates very conservatively assume open crevice conditions with maximum tube to TSP hole clearance
Tube Repair Limit	Although axial tensile rupture data support a much higher repair limit, the tube repair limit is very conservatively set at 3 volts.