DRAFT

## 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 operating cycle (18 months), 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 bounding 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 ($\Delta p$) 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 $\Delta p$ 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 $\Delta p$ across plates C, F and J is 1.76 psid at plate J. The maximum $\Delta p$ 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 $\Delta p$ 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 $\Delta p$ across the TSPs is <1 psid. The maximum $\Delta p$ 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 will 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.

## 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 $\Delta p$, 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 $\Delta p$. 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 $\Delta p$ 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.

## 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.

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 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.

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.

*General 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 for bobbin mixed residual signals that could potentially mask flaw responses near or above the voltage repair limits.

- Visual inspections of the stayrods or peripheral supports are not required to adequately limit TSP displacements and maintain structural integrity. The stayrods are very lightly loaded; a factor of safety of 26.5 on the peak bounding $\Delta p$ is predicted for the stayrod and spacer stresses for the single plate loading case. 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 10.2 of WCAP 15163, Rev. 1)

*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 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.

- 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.