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STAFF ASSESSMENT BY THE OFFICE OF NUCLEAR REACTOR REGULATION RELATED TO WCAP-14707/14708, REVISION 1, "MODEL 51 STEAM GENERATOR LIMITED TUBE SUPPORT PLATE DISPLACEMENT ANALYSIS FOR DENTED OR PACKED TUBE-TO-TUBE SUPPORT PLATE CREVICES"

PACIFIC GAS & ELECTRIC COMPANY

DIABLO CANYON POWER PLANT, UNIT NOS. 1 AND 2

DOCKET NOS. 50-275 AND 323

1.0 INTRODUCTION

In a letter dated October 4, 1996, and supplemented by letters dated May 30, 1997, February 23, 1998, November 24, 1998, April 13, 1999, and June 8, 1999, and telephone conversation held on October 21, 1997, Pacific Gas and Electric Company (PG&E), the licensee for Diablo Canyon Units 1 and 2, submitted for staff review and approval Westinghouse technical reports WCAP-14707 (proprietary) and WCAP-14708 (nonproprietary), Revision 1, "Model 51 Steam Generator Limited Tube Support Plate Displacement Analysis for Dented or Packed Tube-to-Tube Support Plate Crevices." The report assesses the potential for tube support plate (TSP) displacement during a postulated steam line break (SLB) event and concludes that the TSPs in Model 51 steam generators (SGs) are essentially "locked" in place due to corrosion product buildup in the tube-to-TSP crevices. If the TSPs do not move under accident conditions, the probability of tube burst resulting from tube degradation located within the TSP intersections drops significantly because of the TSP constraint. The report also concludes that the presence of corrosion product in the tube-to-TSP crevice significantly reduces accident-induced leakage through tube degradation located within the TSP intersections. The licensee plans to apply the conclusions of WCAP-14707/14708 as part of an alternate repair criteria (ARC) for primary water stress corrosion cracking (PWSCC) located in the TSP intersections of the SG tubes. PG&E currently expects to submit the ARC late in 1999 and plans to implement the ARC, upon staff approval, in the fall of 2000 or 2001.

2.0 BACKGROUND

When licensees changed the secondary side water treatment from a phosphate treatment to an all volatile treatment, and the secondary side water became less alkaline, accelerated corrosion of the carbon steel TSPs and tubesheet resulted. The buildup of the corrosion product (iron oxide) between the tube and the TSP "squeezed" the tube enough to cause permanent, plastic deformation of the tube. The tube deformation (or denting) raised local stresses; thus, dented tubes become prime candidates for PWSCC. Most plants have eliminated denting as an active mechanism through careful control of secondary water chemistry to mitigate corrosion of the TSPs and the tubesheet. However, PWSCC at these dented intersections continues to occur.

The SGs at Diablo Canyon Power Plant, Units 1 and 2 (DCPP) are Westinghouse Model 51s with tubes fabricated from mill annealed Alloy 600. The carbon steel TSPs are 3/4-inch thick. The licensee has thousands of dented SG tubes and PWSCC at the dented intersections is an active degradation mechanism at DCPP. PG&E has reported PWSCC in both large and small dents and has provided information that indicates the cracking is strongly temperature dependent. For example, at DCPP, approximately 60 percent of the PWSCC is located at the lowest hotleg TSP, 25 percent at second lowest hotleg TSP, 9 percent at the third lowest TSP, and so on. With thousands of dented intersections, the population of tubes at risk for PWSCC is very large at this plant. The licensee currently applies a qualified depth-sizing technique for PWSCC and repairs tubes in accordance with its technical specifications.

3.0 OVERVIEW OF WCAP-14707/14708

The WCAP describes a generic Model 51 SG assessment for limited TSP displacements in a postulated SLB event. A SLB event results in blowdown of steam and water which in turn leads to the depressurization of the SG secondary side. The resulting pressure drops develop and exert hydraulic loads on the TSPs. Westinghouse chose the SLB event because the load conditions that could potentially displace the TSPs vertically relative to the SG tubes are the most limiting for this event. Westinghouse performed analyses for a guillotine break of the steam line located both downstream of the flow limiter (small break) and upstream of the flow limiter (large break) because the location of the flow limiter in the steam line may differ between plants with Model 51 SGs.

The WCAP presents tube pull force test results used to determine the force required to displace a tube relative to the TSP when the tube-to-TSP intersection is packed with corrosion product. Westinghouse then compares this force with the calculated SLB force per tube acting to displace the TSP relative to the tube. To obtain this calculated force, Westinghouse used both the RELAP5 and TRANFLO codes to obtain and/or verify the pressure drop loads acting on the TSP in a SLB event. Westinghouse also applied a 1.5 factor on the TSP pressure drops to account for uncertainties. After obtaining the hydraulic loads, Westinghouse performed a dynamic finite element analysis of the TSPs and supporting SG structures to determine TSP motion and the forces per tube-to-TSP intersection acting to displace the TSPs across the TSP and for all TSP elevations. The maximum axial force acting to displace a TSP relative to the tube is 31 lbs per intersection for the SLB located downstream of the flow limiter and 60 lbs per intersection for a SLB located upstream of the flow limiter. These forces are, in general, much smaller than the measured forces required to displace a tube relative to the TSP when the tube-to-TSP intersection is packed with corrosion product and/or dented. Thus, given enough such intersections, Westinghouse concludes that the TSPs are essentially "locked" in place.

Westinghouse also evaluated the maximum axial loads acting per TSP intersection during the change between full power and cold shutdown, assuming "locked" TSPs. The maximum loads acting to displace the TSPs are actually higher during this evolution than during a SLB event due to the large temperature change between full power and cold shutdown. These maximum loads occur near the wedge and tierod locations on the TSP. Some number of tubes at certain

TSP elevations are predicted to move relative to the TSP in the vicinity immediately adjacent to the wedge regions. Because the number of such tubes at a particular wedge location is small, Westinghouse believes there should not be an effect on the dynamic response of the TSPs to SLB loads; that is, the TSPs remain "locked."

The staff's review of the hydraulic analyses is not complete. What follows is the staff's review of Sections 4.0, 8.0, 9.0 and 10.0 of the WCAP, as supplemented by additional information provided by PG&E, related to tube pull force testing, leak rate testing and structural modeling.

4.0 TUBE PULL FORCE AND LEAK RATE TESTING

Section 4.0 of the WCAP presents data obtained from laboratory pull force and leak rate testing, domestic plant tube pull force measurements, and foreign plant tube pull force measurements and leak rate testing. Based on this information, Westinghouse drew conclusions regarding (1) the force required to move a tube relative to the TSP at a packed and dented intersection, and (2) the leakage through cracks located at packed and dented TSP intersections under both normal operating and accident conditions.

Laboratory Test Results

Fatigue precracked tubes and tubes with laboratory-grown stress corrosion cracks (SCC) were used to simulate cracked tubes in dented TSPs. Lengths of the throughwall fatigue cracks ranged from 0.3 to 0.7 inches. For the tubes with SCC, throughwall lengths ranged from approximately 0.33 to 0.85 inches. The cracked tubes were inserted into carbon steel collars packed with magnetite to simulate a packed tube-to-TSP intersection. After inserting the tube, the ends of the specimens were sealed and exposed to a corrosive solution at a relatively high temperature. The additional corrosion of the collars caused a small amount of denting in the tubes. The average radial dent size ranged from 0.0 to 0.00087 inches, with corresponding voltages ranging from 0.0 to 17.4 volts.

The axial force needed to displace the cracked tubes relative to the dented tube-to-TSP intersection was measured based on two pull and five push tests performed at room temperature. The specimens with relatively large dent voltages (6.1 and 12.1 volts) were subjected to a pull test with 4200 and 3220 lbs force, respectively, recorded to move the tube relative to the TSP. The five remaining specimens had smaller dent voltages (0.0, 2.5, 2.7, 3.4, and 4.55 volts). Push forces for these specimens ranged from 80 to 700 lbs. There was no apparent correlation between dent size and force. For example, the force required to move the tube past the nondented intersection was significantly larger than the force required to move the tube past the 3.4 volt dent. The force required to move the tube past the 6.1 volt dent was larger than the force required to move the tube past the 12.1 volt dent. The WCAP did not discuss the tube-to-TSP displacement measurements corresponding to these push/pull force measurements.

Leak rate tests on six of the fatigue precracked specimens and two of the laboratory SCC specimens were performed at pressure differentials and temperatures typical of both normal operating and SLB accident conditions. One fatigue precracked specimen leaked. Leak rates for this specimen were measured at both normal operating (0.00011 gpm) and SLB (0.0002 gpm) conditions. This specimen had the smallest dent size of those tested (at 2.75 volts). The remaining specimens did not leak. The licensee commented that the largest of the specimens tested, a fatigue precracked specimen with a throughwall length of 0.7 inches, had it been located in the freespan, would have been expected to leak over 10 gpm under accident conditions.

Staff Comments on Laboratory Test Results

In a request for additional information (RAI) dated June 23, 1998, the staff commented that given the small sample size and the highly variable test results, the laboratory specimens tested in the pull/push force tests described in the WCAP did not support the conclusion that corrosion products in the tube-to-TSP intersection provide significant resistance to tube-to-TSP relative displacement. The staff suggested that additional pull force testing, performed at temperature, appeared warranted to develop a more robust database. In its November 24, 1998 response to the RAI, the licensee commented that the denting process used for these specimens resulted in dents that are larger at the edges of the TSP than in the center of the TSP, and the dents have a relatively large dent voltage response for the size of the dents. Field dents have larger dent sizes for the same voltage level, and they are more commonly centered within the TSP. Thus, the licensee claims that the dented laboratory specimens described in the WCAP (and hereafter referred to as the "first set of laboratory specimens") are not representative of field conditions. In addition, the short exposure times for these specimens did not permit high temperature baking of the crevice material to form a hardened deposit which is also not representative of field conditions. The licensee believes a hardened deposit would provide a larger resistive force against tube-to-TSP displacement. PG&E stated that Westinghouse has prepared additional dented laboratory specimens (hereafter referred to as the "second set of laboratory specimens") for testing using a denting process to induce cracking (as opposed to using specimens that are dented after they are cracked, as were the first set of laboratory specimens). The process caused TSP corrosion to grow such as to ovalize and locally deform the tube. The licensee believes the new denting process results in laboratory specimens that are more representative of field conditions. As described in its April 13, 1999 submittal, the second set of laboratory specimens have been subjected to pull force tests. Table 1 shows the results from four tests performed at room temperature and four tests performed at operating conditions of 550°F. The results demonstrate that tube-to-TSP crevice deposits generate large resistance to tube-to-TSP relative displacement for dents that range from 1.8 volts to 8.6 volts in size. The data from the second set of laboratory specimens does not display a strong correlation between dent size and pull force. Nor does the data exhibit an obvious difference between tests performed at room temperature versus those performed at operating temperatures.

The licensee stated in their November 24, 1998 letter that they plan to disregard the push/pull force test results obtained from the first set of laboratory specimens because the specimens are not representative of field conditions, as discussed in the preceding paragraph. The staff is not similarly prepared to disregard this data without additional information from the licensee. Specifically, the licensee should provide in its future ARC submittal eddy current information to support the assertion that the first set of laboratory specimens are not representative of field conditions. If the licensee later determines that the data from the first laboratory specimens should be considered, the staff also requests the licensee provide a discussion of the tube-to-TSP relative displacements associated with the tube push/pull force tests. The staff also requests the licensee provide eddy current information that demonstrates that the second set of laboratory specimens are representative of field conditions at Diablo Canyon Units 1 and 2.

With respect to leakage, the first set of laboratory specimens demonstrated that packed crevices appear to significantly reduce leakage. For example, the specimen with the longest fatigue precrack (0.7 inches) would be expected to leak approximately 10 gpm under freespan accident conditions, and the licensee reported no or very low leakage for that or any other specimen. Also, the fatigue precracked specimens conservatively represent SCC of the same length because of the expected tortuous crack morphology of SCC compared with fatigue cracks. In the June 23, 1998 RAI, the staff commented that the leak rate tests may have been compromised by the specimen preparation process (i.e., denting after cracking). The staff also considered the database to be too limited for the broad application suggested by the WCAP. In its November 24, 1998 response to the RAI, the licensee responded that they plan additional leak rate tests on specimens prepared using the "new" denting process described above to further support the conclusion that crevice deposits limit leakage. The licensee also stated that they believe the denting process described in the WCAP would be expected to open the cracks rather than close the cracks, such that the tests should be expected to yield conservative results. The staff notes that this position contradicts a statement on page 4-2 of the WCAP and requests the licensee provide the basis for its position in its future ARC submittal. Regardless of the specific test procedure applied, the results support the principle that leakage through degradation is significantly reduced in packed and dented TSP intersections, as long as the TSP remains in place. The licensee plans additional leak rate testing of specimens with PWSCC cracks developed in corrosion-dented laboratory specimens as discussed above to support the crevice restriction element of the leakage model that will be applied in a future ARC amendment. As discussed in the preceding paragraph, the licensee plans to disregard the push/pull test data obtained from the first set of laboratory specimens because the licensee does not consider the specimens representative of field conditions. The staff assumes then that the leakage measurements obtained from these same specimens should also be disregarded. However, the licensee did not discuss this aspect in their submittal. The staff requests the licensee clarify its position with respect to using the leakage measurement data obtained from the first set of laboratory specimens.

<u>Domestic Plant Pulled Tube Force Measurements</u>

Most licensees perform tube pulls by first relaxing the tube from the tubesheet, then cutting the tube at the desired upper elevation and finally pulling the tube through the tubesheet. This type of tube pull includes drag on the tube due to friction within the tubesheet, and it is not possible to discern the TSP breakaway force from the tubesheet friction force. For direct measurements of the pull force required to move a tube relative to the TSP, one must first remove the tubesheet portion of the tube and bore the tubesheet hole. The force required to initiate tube movement after these operations is then the force required to break away the tube from the TSPs. To obtain an average breakaway force per TSP intersection, PG&E divided the total breakaway force measured by the number of TSP intersections spanned by the tube section removed. The licensee provided information obtained from six tube pulls from three domestic plants, including Diablo Canyon Unit 2. The TSP intersections were nondented except for the fifth hotleg TSP from plant Z-2 which had a 2.0 volt dent. Table 2 summarizes the pulled tube force measurements. The results appear to demonstrate large resistance to tube motion past the TSP, even in tubes with nondented intersections. Tube-to-TSP displacement as a function of pull force was not discussed by the licensee.

PG&E recently removed a tube from Diablo Canyon Unit 1 that had a 5.1 volt dent at the first hotleg TSP. The breakaway force was measured at 2566 lbs. This is consistent with results obtained from tubes with nondented intersections, as well as the laboratory test results discussed in the preceding section. The licensee provided information relative to the displacement of the tube relative to the TSP. The pull force as a function of displacement increased rapidly to 1434 lbs at 0.042 inch displacement and was about 1927 and 2282 lbs at displacements of 0.108 and 0.157 inches, respectively. The pull force increased continuously until a breakaway force of 2566 lbs was reached at a displacement of 0.285 inch, after which the load decreased.

Staff Comments on Domestic Plant Pulled Tube Force Measurements

The pull force measurements appear to support the licensee's contention that intersections packed with corrosion product (even nondented intersections) offer significant resistance to tube displacement relative to the TSPs. Additional information not provided by the licensee but available to the staff include tube pull force measurements taken during the removal of tubes from the retired McGuire Unit 1 SGs. During one tube pull, the tube completely severed at the top of the tubesheet immediately upon pulling. After removing the tubesheet portion of the tube, the staff measured a breakaway force for this tube at 8000 lbs total over four TSP intersections, with a resulting average per TSP of 2000 lbs. This data supports the pulled tube data provided by the licensee. There remains the issue of the validity of averaging tube pull force measurements over the number of TSPs. The breakaway force may be due to one TSP or many and how it was distributed among the TSPs appears impossible to determine. However, data from single TSP tube pulls (e.g., from the laboratory and foreign data discussed in Section 3.0 of this review) appear to support that approach at least as a best estimate. The staff requests the licensee provide a discussion of the tube-to-TSP displacements associated with the measured pull force obtained from the domestic plant tube pulls in its upcoming ARC submittal.

Foreign Plant Pulled Tube Force and Leakage Measurements

The WCAP presented pull force and leak rate test results obtained from tube/TSP sections removed from retired Dampierre-1 and Ringhals-3 SGs. Tubes were harvested from the retired SGs with the TSP section left intact around the tubes to retain the tube-to-TSP crevice deposits. Electricite' de France (EdF) removed 17 tube/TSP sections that included the first TSP as well as the seventh and eighth TSPs. None of the TSP intersections were dented. The SGs at Dampierre-1 were Westinghouse design Model 51s while those at Ringhals-3 were Westinghouse Model D3s (which also have carbon steel drilled hole TSPs like the Model 51s).

EdF measured the force required to displace a tube relative to the TSP. The tests were performed at both room temperature and at operating temperature. The values shown in Table 3 are the forces required for an initial tube-to-TSP displacement of 0.08 inches. Relatively large forces were required to move the tubes relative to the TSPs, consistent with domestic tube pull force measurements discussed in the preceding section.

For the leak rate tests, EdF drilled a 20 mil hole through the middle of the TSP, through the deposits and through the wall of the tube. The hole in the TSP was then plugged such that the leak path was from the 20 mil hole in the tube through the crevice deposits. EdF measured leak rates as a function of incremental tube-to-TSP displacement, from 0.0 inches to 0.20 inches. Leak rate testing was performed at room temperature at pressures representative of both normal operating and SLB accident conditions. Table 4 summarizes the test results. With tube-to-TSP displacements less than or equal to 0.08 inches, leak rates at normal operating conditions ranged from 0.0 to 0.00018 gpm. Leak rates at accident conditions ranged from 0.0 to 0.0029 gpm. The expected leak rate from a 20 mil hole located in the freespan at a pressure differential of 2500 psi would be about 0.4 gpm. Even at larger tube-to-TSP displacements of 0.12 inches, leakage under both normal and accident conditions was less than 0.005 gpm. Large leak rates were obtained when the tube-to-TSPs displacement was 0.16 inches or more.

EdF also performed two additional tests using a 47 mil drilled hole through the deposits and tube. The first tube leaked approximately 0.00029 gpm at normal operating pressure differentials and 0.00013 gpm at accident conditions. The second tube leaked approximately 0.00007 gpm at normal operating pressure differentials and negligible at accident conditions. The tube was not displaced relative to the TSP for these tests.

Staff Comments on Foreign Plant Pulled Tube Force and Leakage Measurements

The pull force data based on the Dampierre-1 and Ringhals-3 tests support the assertion that packed tube-to-TSP intersections provide significant resistance to movement of the tube relative to the TSP, even at nondented intersections. The foreign data may not be representative of the U.S. field conditions given the possibility of large differences in secondary side water chemistry, operating temperature and other plant-specific attributes that may affect the physical and mechanical properties of the crevice deposits that, in turn, affect the ability of the crevice deposits to limit TSP motion and accident-induced leakage. However, the staff does believe the data supports and in no way contradicts the licensee's conclusions. The foreign data also provides information relative to the condition of the tube-to-TSP intersections higher in the SGs, at the seventh and eighth TSPs, which is not available from the U.S. plant data. The pull forces for the foreign data are higher than those from the U.S. plants. The licensee doesn't know if this is due to test conditions, plant differences, or some combination of both.

The Dampierre-1 pull force tests were performed at both room temperature and at operating temperature. The data suggest a decrease in pull force with an increase in temperature. This seems counter intuitive because at the higher temperatures, the tubes would be expected to expand more than the TSPs and thus tighten the crevice conditions further and require more force to move the tube relative to the TSP. This may be more a matter of data variability than of test conditions. The licensee plans to provide additional margin in its upcoming ARC submittal to account for this difference between room temperature pull force measurements and operating conditions.

With respect to leakage, the Dampierre-1 specimens described in the WCAP demonstrated that packed crevices appear to significantly reduce leakage. The specimens had 20 mil throughwall holes that would be expected to leak approximately 0.4 gpm under freespan accident conditions, and the licensee reported no or very low leakage for any specimen, as long as the tube-to-TSP displacement was less than 0.12 inches. The staff provided comments earlier in an RAI dated June 23, 1998, that the Dampierre-1 leak rate tests were performed at room temperature and thus may not be representative of operating or accident conditions. The licensee responded that this test condition may be more conservative than performing them at higher temperatures because the tube expansion against the TSP should compress the deposits further. The staff notes that this argument is not supported by the pull force tests described above and reiterates that leak rate tests to support an ARC should be performed under representative conditions. The staff also commented that the leak rate test results were sometimes inconsistent. For example, for some specimens the leak rates at normal operating conditions are higher than those measured at accident conditions. Also, it would make sense that leak rates would increase with increasing tube-to-TSP displacement, but this also doesn't always happen. These inconsistencies, which are generally small, may be the result of normal testing variability. Despite the relatively minor inconsistencies, the data presented support the assertion that crevice deposits significantly reduce leakage under both normal operating and accident conditions, as long as the TSP remains in place.

5.0 STRUCTURAL MODELING FOR TSP DISPLACEMENTS

In Section 8.0 of the WCAP, Westinghouse presents the structural modeling for TSP displacements. Westinghouse developed a finite element structural model of the tube bundle to analyze TSP displacements. The WECAN computer code, a general purpose finite element code, was used to develop the model for the overall tube bundle and to provide mass and stiffness matrices for prescribed dynamic degrees of freedom. The dynamic responses of the TSPs were then calculated using a special purpose computer program, *pltdym*.

The tube bundle model consisted of the seven TSPs plus the tierods, channel head, lower shell, wrapper, tube groups and tubesheet. With the exception of the tierods and tube groupings, which were modeled using three-dimensional beam elements, all of the structural components were modeled using three dimensional shell elements. The dynamics code incorporated the spacers through stiffnesses that were coupled to the various TSP elements when the corresponding gaps were closed. In modeling the TSPs, the flow slots along the tube lane were modeled explicitly. For the tubed regions, Westinghouse specified modified material properties to account for the tube holes in the tubesheet and the tube and flow holes in the TSPs. The properties that were modified included Young's modulus, Poisson's ratio, and the material density. For the TSPs, the density was also modified to account for the "added mass" effect resulting from the TSP moving through the secondary fluid. The resulting added mass is a direct function of the fluid density. Because the dynamic analysis could not account for the change in fluid density with time, the analysis used an average density value during a transient. Actual TSP properties were used along the tube lane.

Staff Comments on Structural Modeling

In setting up the overall tube bundle model, it was necessary to define dynamic degrees of freedom. In prior analyses to determine the TSP response under SLB loads, which did not consider dented or packed tube-to-TSP crevices, the dynamic response of the TSPs was a combination of various TSP frequencies. In the present analysis, which assumes packed tube-to-TSP crevices, Westinghouse selected the dynamic degrees of freedom to coincide with the locations where the tube/TSP interaction occur. On the assumption that all of the tube intersections are dented or packed, the TSPs then displace with the tubes, which have a significantly higher axial stiffness than the out-of-plane stiffness of the TSPs. Thus, the response of the system has been reduced to the fundamental mode of the tube bundle. The analysis based on the fundamental mode response of the tube bundle is valid only if all the tube-to-TSP intersections are considered fully packed and rigid. Once the tubes disengage from the TSP upon exceeding the breakaway forces, a separate analysis involving consideration of other model frequencies and degrees of freedom would be necessary. The WCAP does not discuss such an analysis. The staff requests the licensee verify if such an analysis was performed and discuss the effects of considering other modal frequencies on the analysis results.

Staff Comments on Structural Damping

The analysis in WCAP-14707/14708 is based on a structural damping of 4 percent. Westinghouse considers this value appropriate for the type of dynamic loading and response presented for the generic analysis in the topical report. The staff has reviewed a separate Diablo Canyon submittal in which the licensee provided sensitivity analyses which indicated essentially no difference in response for damping levels ranging from 1 percent to 4 percent for single degree of freedom systems.

Lower damping values may be appropriate in an analysis of individual tubes within a simple supporting structure of infinite rigidity, where damping is mainly a function of the microscopic characteristics of the individual materials involved. However, more complex structures exhibit damping characteristics significantly larger than the hysteretic damping values of the materials involved. The additional damping comes from frictional damping created by nonlinearities and other local conditions, and viscous damping due to vibration in a fluid and two-phase environment. Thus, the lower damping factors used in previous analyses related specifically to the Diablo Canyon SGs may not be appropriate for calculations involving evaluations of the SG tube structure as a whole, which need to recognize the complexity of the SG structure.

Generally, SGs are supported vertically by pinned columns and plates, with the plates attached to the containment basemat via anchorages. The SGs are laterally supported at their lower end by the reactor coolant piping and shimmed structural members that are attached to the building structure. They are also laterally supported near the feedwater nozzles by snubbers and shimmed structural members. The snubbers contribute viscous damping, while the shimmed structural members contribute frictional damping to the system. The anti-vibration bars in the U-tube region and the gaps between the wrapper plate structural channel sections and the SG shelf also contribute significant damping; each of these contributions are in addition to the inherent hysteretic damping characteristics of the materials used in the fabrication of the SGs. Westinghouse Topical Report WCAP-7921 contains some limited data which supports the use of the higher damping factors for a complex SG structural system. This data forms part of the basis for the recommendations in Regulatory Guide 1.61 for welded steel structures.

In summary, the staff finds the use of 4 percent structural damping in WCAP-14707/14708 appropriate for general applications. The use of 2 percent structural damping for an operating basis earthquake and 4 percent structural damping for a safe shutdown earthquake is considered acceptable instead of the 1 percent damping value used at Diablo Canyon in its original analyses. The considerations discussed above justify the use of these higher values.

Staff Comments on the Computer Program "pltdym"

The special purpose computer program *pltdym* calculates the dynamic response of the TSPs. Westinghouse developed, verified and validated *pltdym* specifically for evaluating the tube bundle response to a time history pressure loading. The staff has reviewed sample problems used for verifying this special purpose code and the basic algorithm for solving the differential equation for displacements. This algorithm has been used extensively in other codes related to dynamic response that have been previously approved by the staff (Braidwood Unit 1, License Amendment No. 69, issued November 9, 1995).

In addition to the basic equation solving capability of the code, non-linearities in TSP vertical motion can be taken into account. In some SG models, wedges are welded to TSP at the edges to provide resistance to vertical TSP motion. The primary function of the wedges is to provide in-plane alignment of the support TSPs. The non-linear support interaction can be analyzed in such a manner that it can act in either the up or down direction. This feature would be used in cases where the wrapper is not incorporated directly in the finite element model. Because the wrapper is included in this analysis, it was not necessary to invoke this feature of the code. The code can also take into account non-linearity due to interaction between the TSPs and the spacers between the TSPs. The support system for the tube support TSPs is composed of several types. One type of support is a tierod/spacer combination. The tierods are solid bars that are threaded into the tubesheet at the bottom of the tube bundle, run the full height of the bundle passing through each of the TSPs, with a nut on the top surface of the top TSP. On the outside of the tierods are cylindrical spacers that are situated between the TSPs and serve to align the TSPs vertically. The TSP/spacer interface is non-linear in nature. The staff finds these code features, including the capability for non-linear TSP/spacer interaction, acceptable for the present application.

If sufficient TSP displacement and bending occurs under the applied loads, it is possible that interaction between the TSPs and tubes may occur. If the TSP bends locally such that the top surface of the TSP contacts the tube on one side while the bottom surface of the TSP contacts the tube on the other side, then the tube will bind up in the TSP and restrict further deflection of the TSP just as it is locked when the crevices are packed. However, the locked condition due to TSP bending is temporary. Once the TSP bending is relieved, the tube will move independently from the TSP. In the case of a packed crevice, the tube always moves rigidly with the TSP. Apparently, the code would not be able to distinguish between the two cases. Because such a distinction may affect the results, the staff requests the licensee discuss how this inability to distinguish between the two cases affects the analysis results.

In order to account for tube/TSP interaction under dented or packed crevices, the code is able to check interaction forces in dynamic elements to determine if "breakaway" (loss of tube/TSP interaction) has occurred. If the prescribed interaction forces are exceeded, then the corresponding degrees of freedom are uncoupled for the remainder of the transient. In addition to the capability to solve the time history response of the structure, the code can also solve an initial set of statically applied forces.

In summary, the staff finds the structural modeling of the SG tube bundle sufficiently detailed but requests the licensee discuss the effects of considering other modal frequencies on the analysis results, as discussed above. The methodology related to the modification of the material properties and added mass effects, as discussed above, is also considered reasonable and acceptable. The special purpose code "*pltdym*" has adequate capabilities and features incorporated in the code to enable the determination of the dynamic response of the TSPs.

6.0 TSP DISPLACEMENT ANALYSIS RESULTS

Section 9 of the WCAP provides a summary of the TSP displacements and the tube/TSP interface forces for the SLB analysis. Results were provided for both the small and the large break sets of loads. The objective of the time history analysis is to define the magnitude and distribution of the tube/TSP interface loads.

The analytical results are dependent on the pressure drop loads acting on the TSP during a postulated SLB event. These loads were obtained using the RELAP 5 and TRANSFLO codes discussed in Sections 5.0 and 6.0 of WCAP-14707. These sections of the report are currently under review. While the staff accepts the structural modeling and dynamic analysis methodology, as discussed in the previous section of this safety evaluation, acceptance of the TSP displacement and analytical results are subject to acceptance of the pressure drop loads acting on the TSP.

As part of the dynamic analysis, calculations were also performed to demonstrate the applicability of the elastic analysis approach in determining the resulting displacements and interface forces. These calculations consist of demonstrating that the tubes, which are loaded through the tube/TSP interface forces, remain elastic throughout the transient. Calculations were also performed to determine the loads and corresponding stresses in the welds joining the wedges and support blocks to the TSP. Because the objective of this analysis is to define the magnitude and distribution of the tube/TSP interface loads, it was necessary to have the tube/TSP interaction remain intact for the duration of the transient. Thus, for this analysis, an arbitrarily high breakaway force (the force necessary to overcome the tube/TSP interaction) of 200.0 pounds/tube intersection was specified.

Overall, these results demonstrate that, assuming all tubes can develop a 200 pound/intersection force, the supporting structures such as the TSPs, tierods and wedges remain elastic during the SLB event and thus justify the use of elastic analysis to calculate the TSP response to the SLB loading. The staff concurs with this assessment.

7.0 TSP STRESSES UNDER DENTED CONDITIONS

Section 10 of the WCAP provides a summary of the TSP stresses assuming "locked" TSPs. With dented or packed tube-to-TSP crevices, the TSPs will experience bending stresses near the wedge and tierod locations when cycling between full power and cold shutdown conditions. If it is assumed that the tube-to-TSP crevices become packed while at full-power conditions, then the tubes will impose a downward load on the TSPs due to differential thermal expansion effects when cycling between different operating regimes. The most significant temperature swings occur when cycling between full power and cold shutdown. Because the TSP displacement analysis relies on the integrity of the TSPs and on a tight tube/TSP interface, calculations were performed to determine the degree to which the TSPs are loaded as a result of the thermal cycling.

The finite element model used for the dynamic analysis of the TSPs (discussed in the previous section) is the starting point for the detailed evaluation. However, in the regions adjacent to the wedges and the central tierod, Westinghouse used a finer mesh for this analysis. In order to define equivalent TSP properties in these regions, a separate model was developed for each area, and corresponding properties are determined. Westinghouse then applied the thermal gradient to the model to calculate the tube/TSP interaction forces. For any location where the tube/TSP breakaway force was exceeded, the tube/TSP interface was de-coupled, and the thermal analysis was repeated. This process was continued until a converged solution was reached; i.e., all the remaining tube/TSP interface forces were less than the breakaway value.

Staff Comments on TSP Stresses Under Dented Conditions

It was assumed in the calculation of TSP stresses under dented conditions that full-power operation effectively represents the stress-free condition for this case. The structure was then assumed to contract as a result of the transition from the full-power temperature condition to cold condition. For purposes of calculations, negative coefficients of thermal expansion were defined for the materials, which effectively caused a contraction in going from cold shutdown to full power conditions. This allowed the proper reference temperature (70°F) to be maintained, and the proper thermal gradient to be calculated for determining the differential thermal expansions. The staff finds this methodology acceptable provided it can be established that thermal cycling between full power and cold shutdown represents the bounding thermal cyclic loading. The topical report does not provide any assessment of the loading during other possible thermal transients to establish the validity of this assumption. In addition, the SLB analysis assumes that there are no pre-existing loads on the TSPs. This does not take into consideration the effect of thermal cycling on tubes which become partially disengaged. The licensee should consider the effect of the net compressive forces that may exist in disengaged or partially disengaged tubes that occurred during previous cooldown/heatup cycles.

The models include the TSPs and the interfacing tubes, appropriate flow holes, and in the case of the central tierod model, the TSP cutout along the tube lane. The models also include a row of elements around each tube corresponding to the corrosion products that cause the TSPs to be held in place. These elements were included in the model development so as to permit possible future evaluation of the radial tube/TSP interface but were not included as part of this evaluation. Instead, for this evaluation, the tube vertical displacements were coupled to the hole boundaries at each interfacing node. Material properties were varied until the axial stresses in the tubes in the equivalent TSP model closely matched the results for the detailed model. The results indicate that the peak strains are concentrated near the TSP/wrapper interfaces and then drop off rapidly with distance away from the support locations. The staff concurs with this assessment.

The analysis indicated that for some tubes in the uppermost and bottom TSP, the tube/TSP force exceeds the breakaway force. Westinghouse indicated that the combined tube/TSP stiffness in the interior region can be increased by defining a new set of equivalent TSP properties in this region to more closely approximate the combined bending stiffness of the tube and TSP. This change may affect the specific locations and numbers of tubes predicted to exceed the breakaway force. However, the central TSP region is removed from the areas of concern, and the interface forces have been reduced to relatively low values at the edge of the detailed regions; thus, the reduced stiffness of the interior region is not expected to have a significant effect on the wedge regions, and an analysis to improve on the combined tube and TSP stiffness in the interior region was not considered necessary. The staff concurs with this assessment.

The concern relative to the TSP stresses is one of fatigue and the potential to develop cracks in the vicinity of the wedges or tierods. The functional requirement of the TSPs is to provide lateral support for the tubes. Westinghouse contends that the TSPs can satisfy the structural requirement, even with cracks present, so long as the cracks do not form in such a way as to lose a piece of the TSP. The formation of cracks in the vicinity of the wedges could also potentially affect the deformation characteristics of the TSPs under in-plane loading conditions, such as LOCA + SSE, where the loads are reacted through the wedges to the shell. The topical report does not address how the in-plane strength of the TSPs is affected by the presence of cracks in the vicinity of the wedges. Rather, the scope of this report is limited to an assessment of the potential to develop fatigue cracks as a result of the cyclic loading.

The fatigue analyses provided in Sections 10.8 and 10.9 of the WCAP should consider a pre-existing flaw in the TSPs as well as in the welds joining the TSP to the wedges. Westinghouse used ASME Code, Section III, Class 1, "Fatigue Usage Factor" evaluation procedures to determine cumulative fatigue usage at the end of the evaluation period for the TSPs and the welds joining the wedges to the TSPs. The staff believes such an evaluation is not applicable when the TSPs and welded joints may be cracked. Flaw tolerance evaluation and crack growth procedures in accordance with ASME Code Section XI, IWB-3740, Article L-3000 are more appropriate to assess the structural integrity of the TSPs and welded joints.

Based on the preliminary work to establish equivalent material properties for the TSPs, Westinghouse determined the stresses in the top TSP at certain wedges were the most limiting. Thus, TSP stresses were calculated for the top TSP at these wedge regions only. Given that the differential expansion between the tubes and wrapper is also highest for this TSP, the stresses for the top TSP are expected to bound the lower TSPs. Except for the central tierod region, significant stresses are determined to occur in the TSP. The most limiting region is in the vicinity of the wedges. In the course of this analysis, the local stiffness of the TSP was found to vary relative to the orientation of the hole pattern with the loading introduced through interaction between the TSP and the wrapper. The staff concurs with this assessment.

A limited number of tubes are predicted to exceed the breakaway force in the vicinity immediately adjacent to the wedge regions in the uppermost and bottom TSPs. Should any localized cracks develop in the TSPs, Westinghouse contends that the safety function of the TSPs would not be impaired unless there is a loss of a piece of the TSP. The number of tubes exceeding the breakaway force at particular wedge locations is small, and according to Westinghouse, should not effect the dynamic response of the TSPs to SLB loading. The staff believes that, while a TSP with limited cracks may be able to transmit lateral loads and remain functional, its integrity would be questionable as a result of vertical loads and corresponding bending moments such as those imposed during an SLB event.

As a result of the thermal cycling load with dented or packed intersections, locally high stresses are predicted to occur in the TSPs. Given the potential for high fatigue usage predicted by this analysis, Westinghouse recommends that plants with high levels of dented or packed crevices include a sampling of tubes in and around the wedge regions for eddy current inspection in order to check for any ligament cracking that might develop. Visual examination of the wedge regions is also recommended to look for the presence of cracks. Relative to in-plane loadings, and potential TSP deformation under LOCA+ SSE, should TSP cracking be observed, an evaluation is recommended to establish any tubes that might be at risk due to the presence of the cracks. However, Westinghouse did not provide the details or methodology of an analysis which would be needed for this purpose. In the staff's view, an analysis to predict crack propagation in accordance with ASME Code Section XI, IWB-3600, would be appropriate.

As with the TSPs, thermal cycling with dented or packed intersections results in potentially high fatigue usage in the welds joining the wedges and the TSP, and the welds between the vertical bar supports and the TSPs. If cracks are formed at these locations, Westinghouse contends that cracking of the welds between the wedges and TSPs, or between the vertical support bar and the TSPs would not impact the ability of the TSPs to provide lateral support to the tubes. With the assumption of dented or packed intersections, the dynamic response of the TSPs under SLB loads should also not be significantly affected by the presence of cracks in these welds. The tubes provide significant restraint to the TSPs under SLB loads, and would continue to hold TSPs in place. Thus, according to Westinghouse, cracking of these welds is deemed to be of no consequence relative to the conditions considered as part of the limited displacement analysis. In the staff's view, because the loading through these welds affects the loading on the TSPs, the above conclusion should be validated.

It is assumed that the SGs evaluated have TSP corrosion as demonstrated by the presence of some denting of the SG tubes at TSP intersections. TSP corrosion, but not denting, is the basis for the pull force tests used to determine the axial forces required on the TSP to cause displacement. The results are applied to develop a basis for performing structural integrity assessments even at intersections with cracked TSPs. It is unclear how the pull force test data can be used to assess the acceptability of cracked TSPs on a generic basis. The extent of cracking present should be assessed on a plant-specific basis before developing integrity assessments and/or alternate repair criteria for indications at TSP intersections.

The analysis results provided in the topical report are based on the assumption that load conditions that could potentially displace the TSPs vertically relative to the tubes are steam line break, feed line break and seismic; but the analytical results provided in the topical report are based on steam line break loads alone. These loads, according to Westinghouse, represent the bounding loads, and thus satisfy the requirement to consider the combined effect of pipe break loads plus seismic. No quantitative data has been provided to support this conclusion. All transients and potential combination of events should be evaluated before SLB can be accepted as a bounding event for such evaluations on a generic basis.

8.0 STAFF SUMMARY

Tube-to-TSP Pull Force Requirements

The licensee provided data from laboratory tests, domestic plant tube pulls and foreign plant tube pulls that demonstrates crevice deposits in the tube-to-TSP intersection provide significant resistance to tube-to-TSP movement. To reiterate staff comments made above regarding this data, the staff requests the licensee provide the following information in the upcoming ARC submittal:

- The licensee stated that they plan to disregard the push/pull force test results obtained from the first set of laboratory reported in the WCAP report because the specimens are not representative of field conditions. The staff requests the licensee provide eddy current information to support the assertion that the first set of laboratory specimens are not representative of field conditions. The licensee should also provide eddy current information to demonstrate that the second set of laboratory specimens are representative of field conditions at Diablo Canyon Units 1 and 2.

- If the licensee determines that the tube push/pull force test results from the first set of laboratory specimens should be considered, the staff requests the licensee provide a discussion of the tube-to-TSP displacements associated with the measured tube pull force.

- The licensee should provide a discussion of the tube displacement associated with the measured pull forces obtained from the plant tube pulls.

In addition, the pull force test results presented in the WCAP and in supplemental letters appear to be the result of quasi-static pull force testing. The staff requests the licensee discuss why it is appropriate to use quasi-static pull force testing to simulate the dynamic loading conditions in a SLB event.

The staff notes that the majority of data available for the measured tube pull forces is from measurements taken at nondented TSP intersections. In other words, denting is not required to obtain high pull forces. However, the available laboratory data is not consistent, and the available domestic tube pull data has been taken from a small number of plants with Model 51 SGs. This data is not sufficiently robust to apply to all radial and circumferential locations, including both hot leg and cold leg, high and low flow rate regions, differing proximities to wedge and stay rod supports, etc. in all Model 51 SGs. Differences in secondary water chemistry performance, operating temperature, and other plant-specific attributes may affect the physical and mechanical properties of the crevice deposits that, in turn, affect the ability of the crevice deposits to limit TSP motion and accident-induced leakage. Accordingly, plant-specific pull force data must be acquired to support plant-specific application of ARC methodologies which take credit for such resistance. In addition, unless additional U.S. plant data is obtained from higher TSPs to supplement the current database, the application of an ARC that relies on crevice deposits to limit TSP motion will be limited to the tubes with dented intersections and located at the first one or two TSPs on the hotleg side of the SG. The staff also has a concern with the general strategy suggested in the topical report. The WCAP attempts to establish a minimum breakaway force that can be relied upon to exist at each intersection based on industry data and to confirm that this number is valid for a specific plant on the basis of a limited number of tube pull specimens. The staff believes such a small sample does not provide a rigorous statistical basis for assuring that all intersections at the subject plant can develop this minimum breakaway force. However, the results from such a sample can be used to establish a plant-specific estimate (or lower bound estimate) of the percentage of the TSP intersection population expected to exhibit a given breakaway force when evaluated at some appropriate confidence level (e.g., 95 percent). The number of tubes assumed capable of developing this breakaway force in the TSP displacement analysis should be consistent with aforementioned calculated percentage value.

Because the staff has not completed its review of the thermal-hydraulics analyses portion of the WCAP report, the staff has not yet verified the loads on the TSPs. The staff needs to verify the maximum loads acting to displace the TSPs relative to the tubes before it can conclude whether or not packed and dented TSP intersections effectively "lock" the TSPs into position. The staff can state at this time that the licensee has demonstrated the concept that large forces are required to move a tube past a packed and dented TSP intersection.

Accident Leakage

The licensee provided data from laboratory leak rate tests and foreign plant leak rate tests to demonstrate that tightly packed crevice deposits significantly reduce leakage through tube degradation located within the TSP, as long as the TSP remains in place. To reiterate staff comments made earlier in this assessment regarding this data, the staff requests the licensee provide the following information in the upcoming ARC submittal:

- The licensee stated that they plan additional leak rate tests on specimens prepared using the "new" denting process to further support the conclusion that crevice deposits limit leakage. The licensee also stated that they believe the denting process described in the WCAP for the first set of laboratory specimens would be expected to open the cracks rather than close the cracks, such that the data obtained from the first set of laboratory tests should be expected to yield conservative results. The staff notes that this position appears to contradict a statement on page 4-2 of the WCAP and requests the licensee provide the basis for its position in its future ARC submittal. In addition, the licensee plans to disregard the tube push/pull force test results from the first set of laboratory specimens because the licensee does not consider the specimens representative of field conditions. The staff assumes then that the leakage measurements obtained from these same specimens should also be disregarded. However, the licensee did not discuss this aspect in their submittal. The staff requests the licensee clarify its position with respect to using the leakage measurement data obtained from the first set of laboratory specimens.

The staff notes that the majority of data available for leakage measurements is from measurements taken at nondented TSP intersections. In other words, denting is not required to obtain a significant restriction in leakage. The staff remains concerned with the limited database and various testing inconsistencies (e.g., testing at room temperature) which were discussed above. However, the staff does not believe they impact the overall conclusion that crevice deposits significantly reduce leakage. The licensee is preparing additional laboratory specimens to support its future ARC submittal. Although the licensee provided some discussion of how leakage will be treated in the WCAP report and supplemental letters, the staff defers its discussion pending receipt of the ARC which will presumably contain the details of the leakage model, how it will be applied, and how it will be validated.

Integrity of Secondary Side Components

Consistent with previous staff approval of ARCs that rely, in part, on the integrity of the TSPs, the staff requested the licensee provide its plans for secondary side inspections to ascertain the integrity of the SG internals (e.g., TSPs, tierods, vertical support bars, and tube bundle wrapper). With respect to the integrity of the tube bundle wrapper, the licensee stated that if sludge lancing equipment cannot be inserted due to interference, or there is evidence of wrapper misposition, or tube damage in the periphery of the first TSP, then the lower wrapper support blocks will be visually inspected. With regard to the integrity of the TSPs, PG&E currently performs inspections for ligament cracking. This inspection consists of screening all bobbin data to identify potentially new ligament cracks each refueling outage and performing a 20 percent plus point inspection sample of the baseline ligament crack indications each refueling outage to verify no changes. The licensee claims that reliance on corrosion product buildup to limit TSP motion and accident-induced leakage apply even to those TSPs with cracked ligaments, as long as there is not a loss of section of the TSP surrounding the indication. In the second set of laboratory specimens described in the April 13, 1999 letter, there were two specimens that had broken collars that resulted in low resistance to TSP displacement. This appears to contradict the assertion that intersections with cracked TSPs may be relied upon to limit TSP motion. The staff requests the licensee demonstrate that cracked ligaments do not compromise the ability of the deposits to limit TSP motion or accident-induced leakage through testing. The licensee stated that, upon approval of an ARC for PWSCC at TSP intersections, PG&E will review the status of completed secondary side inspections and conduct a supplementary inspection consistent with previous staff approvals of ARCs dependent on the integrity of SG internals. The licensee should define and commit to secondary side inspections as part of its upcoming ARC submittal.

Chemical Cleaning

WCAP-14707/14708 does not provide enough data to reach a conclusion relative to the effects of chemical cleaning. The staff believes that plant response to chemical cleaning may vary widely. In addition, the chemical cleaning process is continually evolving to become more effective. The effects of chemical cleaning need to be addressed on a process- and plant-specific basis. Any licensee who plans to rely on tube-to-TSP crevice deposits to limit TSP motion and accident-induced leakage as part of an ARC and has performed or plans to continue to perform chemical cleaning will need to provide plant- and process-specific information supporting such an application. Such evaluations must demonstrate that after cleaning, the TSP breakaway forces would continue to be bounded by the pull force measurement database and that leakage assumptions remain valid. The staff believes such demonstrations will require additional tube pulls and leakage testing.

Structural Modeling

The staff finds the structural modeling of the overall tube bundle with the finite element computer code WECAN and the general methodology for calculation of the dynamic response of the TSPs with packed crevices based on the computer code "*pltdym*" acceptable. The acceptability of calculational results and assessments relative to TSP displacements provided in Sections 9.0 and 10.0 of this report are subject to resolution of the following concerns identified in the staff's evaluation and the acceptance of the pressure loads acting on the TSPs during postulated accidents. To reiterate staff comments made earlier regarding structural modeling, the staff requests the licensee provide the following information in the upcoming ARC submittal:

- Westinghouse assumed that all the TSPs were "locked" and thus, the response of the system was reduced to the fundamental mode of the tube bundle. If enough tubes disengage from the TSP upon exceeding the breakaway forces, a separate analysis involving consideration of other model frequencies and degrees of freedom would be necessary. The WCAP does not discuss such an analysis. The staff requests the licensee verify if such an analysis was performed and discuss the effects of considering other modal frequencies on the analysis results.

- The staff requests the licensee discuss how the inability to distinguish between a tube and TSP "locked" due to bending and a tube and TSP "locked" due to packed and dented intersections affects the analysis results.

- Westinghouse assumed that thermal cycling between full power and cold shutdown represents the bounding thermal cyclic loading. The staff requests the licensee provide an explicit discussion of other thermal transients to establish the validity of this assumption. In addition, the SLB analysis assumes that there are no pre-existing loads on the TSPs. This does not take into consideration the effect of thermal cycling on tubes which become partially disengaged. The licensee should consider the effect of the net compressive forces that may exist in disengaged or partially disengaged tubes that occurred during previous cooldown/heat up cycles.

- The fatigue analysis in Sections 10.8 and 10.9 of the WCAP did not consider a pre-existing flaw in the TSPs and in the welds. The staff requests the licensee consider a pre-existing flaw in the TSPs as well as in the welds joining the TSP to the wedges and assess the structural integrity of the TSPs and welded joints using flaw tolerance evaluation and crack growth procedures in accordance with ASME Code Section XI, IWB-3740, Article L-3000 and IWB-3600.

- The staff requests the licensee provide the basis that supports SLB as the bounding event, including seismic loadings, on a generic basis for the subject evaluation.

In addition to those comments above that were discussed in the body of this review, the staff provides the following two comments:

- In Section 10.10 of the WCAP, under item 1, the following conclusion is made: "The number of tubes exceeding the breakaway force at particular wedge location is small...and should not effect the dynamic response of the tube support plates to the Steam Line Break loading." The staff requests the licensee clarify this statement. The staff is unclear how the dynamic response of the TSPs to a SLB is affected by the number of tubes that exceed the breakaway force during plant cooldown cycles.

- Section 10 of WCAP-14707/14708 reported that some locked SG tubes in the vicinity of wedges and tierods would experience high axial loads due to thermal expansion differences between the tube and secondary support structures. The staff notes that these loads are greater than those that would occur due to nominal endcap pressure loads acting on the tube under normal operating and design basis accident conditions. Depending on the magnitude of the axial forces that develop in locked tubes and the plant operating conditions that exist during thermal transients, the licensee should provide the staff its assessment of the effects of locked tube loads on the structural limit for circumferentially-oriented degradation and/or alternate tube repair criteria applied elsewhere in the steam generator (e.g., F*, W*).

General Considerations

The following additional comments stem from the staff's review of the WCAP report as well as from experience with past ARC submittals. Additional questions may arise when the staff reviews an actual ARC amendment that relies on tube-to-TSP crevice deposits to restrict TSP motion and leakage under accident conditions. The licensee should address these comments in its upcoming ARC submittal.

- Provide a demonstration of how corrosion-induced versus mechanically-induced dented intersections may be identified such that the latter intersections are not relied upon to restrict tube-to-TSP relative movement.

- Our current policy requires the staff to consider potential risk implications (including severe accident risk) as part of its evaluation of an ARC proposal. For example, the staff may question the validity of the assumption that the deposits will retain their properties under severe accident conditions such that the deposits will continue to severely restrict TSP motion and accident-induced leakage. The licensee should provide the staff with any information it would like the staff to consider as part of its evaluation.

- Provide information discussing how the pull force and leakage model databases will be managed. Clarify what data presented in the WCAP will be included in these databases, what data will be excluded, and the basis for both, including supporting statistical analyses.

- Discuss the appropriate margins to be maintained between applied loadings transmitted to the tube at each TSP intersection and the breakaway forces, considering the corrosion product in the tube-to-TSP intersections is a non-Code material whose physical and mechanical properties may vary widely.

- Discuss the appropriateness of requiring an on-going tube pull program to verify, over time, that the nature of the deposits is not changing. Denting is no longer an active degradation mechanism, and the constant flow of water may, over time, lower the ability of the deposits to limit TSP motion and accident-induced leakage.

Attachments: Tables 1 through 4

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Date: January 10, 2000

Table 1: Additional Laboratory Specimen Pull Force Test Results

Specimen ID	Test Temperature (°F)	Dent Size (volts)	Load (lbs) at 0.005" TSP Displacement	Load (lbs) at 0.010" TSP Displacement	Breakaway Load (lbs) at room temperature
TSP-28	70	5.4	280	280	320
TSP-29	70	1.9	1600	--	3000
TSP-31	70	1.8	100	200	750
TSP-32	70	8.6	1000	2000	2560
TSP-22	550	6.9	1750	3000	4790
TSP-24	550	4.5	1500	1800	2184
TSP-26	550	5.5	500	1125	2737
TSP-27	550	2.6	650	1125	4537

- Samples TSP-28 and TSP-31 had broken collars (the collars simulate the TSP); the licensee does not credit these specimens with being representative of field conditions.
- Breakaway load was experienced at TSP displacement values of 0.02 to 0.04 inches.
- Sample TSP-29 does not have data at 0.010 inches of TSP displacement because the test exceeded the full scale plotter setting. Peak load (the breakaway load) was tracked by the tensile machine and not the plotter; thus, peak load was recorded.

Table 2: Domestic Plant Data on Tube Pull Force for Nondented TSP Intersections

Plant	Tube	TSPs Included	Total Breakaway Force (lbs)	Average Breakaway Force per TSP (lbs) at Room Temperature
Diablo Canyon - 2	R2C66	TSPS 1-2	1000	500
L	R29C70	TSPs 1-3	7955	2652
L	R30C64	TSPs 1-3	2775	925
L	R18C70	TSPs 1-3	4955	1652
Z-2	R11C27	TSPs 1-2	4600	2300
Z-2	R21C71	TSPs 1-5	9000	1800
Average				1638
Std. Dev.				812

Note: Tube R21C71 from Plant Z-2 had a 2.0 volt dent at the 5th TSP.

Table 3: Dampierre and Ringhals Data on Tube Pull Force at 0.08" of Displacement

Tube/TSP	Displacement Force (lbs) at Room Temperature (RT)	Displacement Force (lbs) at 547°F
Dampierre-1 R10C90/TSP 8	2644	
Dampierre-1 R10C91/TSP 8	3471	
Dampierre-1 R9C91/TSP 8	2464	
Dampierre-1 R9C93/TSP 8	1313	
Dampierre-1 R42C59/TSP 7	3103	
Dampierre-1 R42C60/TSP 7	4496	
Dampierre-1 R42C61/TSP 7	4339	
Dampierre-1 R5C94/TSP 8	3192	
Dampierre-1 R6C93/TSP 8	1686	
Dampierre-1 R12C92/TSP 8		3260
Dampierre-1 R12C93/TSP 8		3664
Dampierre-1 R11C91/TSP 8		1798
Dampierre-1 R11C92/TSP 8		2068
Ringhals-3 tube not identified	1790	
Average	**2850**	**2698**
Std. Dev.	**1081**	**905**

Table 4: Leak Rate Test Results from Dampierre-1
Leak Rates Through 20 mil Throughwall Hole

Specimen ID/TSP	TSP Displacement (inches)	NOPS Leak Rate (gpm)	SLB Leak Rate (gpm)
R40C60/TSP 7	--	0	0
R40C59/TSP 7	--	0.00003	0.00003
R41C60/TSP 7	--	0	0
R39C59/TSP 7	0.08	0	0
R41C61/TSP 7	0.08	0	0
R41C59/TSP 7	0.08	0	0
R42C59/TSP 7	0.08	0.00018	0.0029
	0.12	0.0022	0.0042
	0.16	0.0021	0.0015
	0.20	0.00057	0.0015
R42C60/TSP 7	--	0.00011	--
	0.12	0	0
	0.16	0	0
	0.20	0	0.00046
R42C61/TSP 7	--	0.00007	--
	0.16	0.00031	0.00008
	0.20	0	0
R5C94/TSP 8	0.20	0.198	HIGH
R6C93/TSP 8	0.16	HIGH	HIGH