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General Comment

The specific Operational Difference between SONGS Units 2 & 3, which will provide the NRC the required basis for refusing any restart of Unit 2 at any power setting. This data shows why the SCE poorly designed replacement steam generators are dangerous and the technical reasons why!

The NRC must start providing technical information so that knowledgeable public experts can review all the claims that Utility operators are making for accuracy; until the present practice of only providing redacted information is eliminated, we will never be able to insure that our reactors are being designed and operated safely. Until then, we will have to depend solely upon TRUST, which SCE's handling of San Onofre proves is nothing but an industry fairytale!

Attachments

Operational Difference between SONGS Units

Reference: Nuclear Regulatory Commission [Docket No. 50-361; NRC-2013-00701, Application and Amendment to Facility Operating License Involving Proposed No Significant Hazards Consideration Determination; San Onofre Nuclear Generating Station, Unit 2]

Defects or Deviations:

The design of San Onofre Replacement Steam generators (RSGs) are identical (Neglecting the impact of Units 3 and Unit 2, Tube-to-AVB contact forces due to manufacturing errors – See Item C below). As shown below, SONGS Unit 2 potentially did not suffer in-plane fluid elastic instability due to operation at higher steam pressures and lower RCS flows. SONGS Unit 3 suffered in-plane fluid elastic instability due to operation at lower steam pressures and higher RCS flows. This conclusion is consistent with Westinghouse Operational Assessment, but challenges the SCE, NRC AIT, AREVA and MHI conclusions. NRC AIT Report, SCE, MHI and AREVA conclusions on Unit 3 and Unit 2 FEI are incomplete, inconsistent, confusing and inconclusive and based on faulty computer simulations and hideous testing data (Shielded under the false pretense of Proprietary information). The analysis in these reports does not meet the intent of NRC CAL ACTION 1, which states "Southern California Edison Company (SCE) will determine the causes of the tube-to-tube interactions that resulted in steam generator tube wear in Unit 3, and will implement actions to prevent loss of integrity due to these causes in the Unit 2 steam generator tubes. SCE will establish a protocol of inspections and/or operational limits for Unit 2, including plans for a mid-cycle shutdown for further inspections."

Repeated requests to NRC AIT Leader, NRC SONGS Special Panel and NRC Region IV Allegation Coordinator to examine carefully the operational difference between Units 2 & 3 and determine its impact on the tube-to-tube interactions that resulted in steam generator tube wear in Unit 3, and actions to prevent loss of integrity due to these causes in the Unit 2 steam generator tubes have not been addressed to date. NRR has not asked SCE in its RAI(s) the impact of operational differences between Units 2 and 3 on Unit 2 and Unit 3 tube-to-tube wear. Honorable NRC Commissioner Mr. Apostolakis was totally confused on Unit 2 FEI inconsistent statements by SCE, Westinghouse and AREVA.

Required Action: The NRC Chairman has publically stated that SCE is responsible for the work of MHI, Westinghouse, AREVA and Intertek. The NRC Chairman is formally requested to retain an Independent Thermal-Hydraulic Expert to examine the operational differences between Units 2 & 3 during Cycle 16 and determine its impact on NRC CAL Action 1 by examining the entire SONGS Cycle 16 operational data for Units 2 & 3. Unit 2 Restart Permission at 70% power should be contingent on completion of the corrective actions required by NRC CAL Action 1 and 10CFR 50 Appendix B.

A. Introduction: The SG functions as a heat exchanger, by means of which the high temperature pressurized radioactive primary water on the inside of the tubes heats up the non-radioactive secondary water on the outside of the tubes, in order to generate the steam that turns the turbine which in turn generates electricity. In addition to providing a barrier (Reactor Coolant Pressure Boundary) to radioactivity and producing steam, a steam generator has many other important functions. It is the major component in the plant that contributes to safety during transients and/or accidents. A steam generator provides the driving force for natural circulation and-facilitates heat removal from the reactor core during a wide range of loss of coolant accidents. Proper steam generator operation is of major safety significance and therefore any adverse changes to its design and operation may have significant safety consequences.

A review of operating history by AREVA and MHI Steam Generators shows that void fractions have to be ≤ 98.5% to prevent formation of areas of high dry steam (in-plane fluid elastic instability (FEI)) in nuclear steam generators. A review of published literature indicates that 1.5% percent of water in the U-tube bundle steam-water mixture is required for nucleate boiling to occur to prevent FEI. According to Dr. Pettigrew, the steam-mixture velocities in U-tube bundle have to be ≤ 20 feet/sec to prevent out-of-plane FEI and excessive flow-induced vibrations. The above parameters are achieved by operating steam generators with circulations ratios > 4 and steam pressures > 900 psi (e.g., Palo Verde Replacement Steam Generators (RSGs) are the largest steam generators in the world, had similar design changes (except AVB design and tube pitch to tube/diameter ratio) as San Onofre, but have not suffered FEI in 10 years due to very high steam flows because of steam generator operation at 1039 psi and circulations ratios > 4.

B. Operational Differences between SONGS Units 2 and 3: The undersigned would honestly and conservatively make an error on public safety side (Unless proven wrong by NRC Commission and NRC OIG). Therefore, the undersigned certifies that based on review of SONGS SGM Procedure (Attached) and discussions with the SONGS Unit 3 Root Cause Team Contractor, that due to higher Unit 2 SG pressure (Range 892 – 942 psi) compared with Unit 3 (833 psi), lower Unit 2 RCS flows (75.76 Million Lbs/hour) compared Unit 3 RCS flows (79.79 Million Lbs/hour), FEI did not occur in Unit 2.

SONGS SGM Procedure - Figure 8b: (U2) Steam Pressure - 942 psi – Blue Curve (Page 95)
SONGS SGM Procedure - Figure 8b: (U3) Steam Pressure – 833 psi – Blue Curve (Page 96)
SONGS SGM Procedure, Coolant flow rate, each: (U2) 75.76 x 106 lb/hr; (U3) 79.79 x 10^6 lb/hr (Page 8)
SONGS SGM Procedure, Steam pressure1: (U2) 892 psia; (U3) 833 psia (Page 9)

NRC AIT Report, SCE, Westinghouse, MHI and AREVA conclusions on Unit 2 FEI and operational differences between SONGS Units 2 and 3 are as follows:

B.1 - **NRC AIT Report Conclusions** (Pages 22 & 23): Operational Differences: The team performed a number of different thermal hydraulic analysis of Units 2 and 3 steam generators. The output of the various analyses runs where then compared and reviewed to determine if those differences could have contributed to the significant change in steam generator tube wear. It was noted that Unit 3 ran with slightly higher primary temperatures, about 4°F higher than Unit 2. Other differences were noted in steam and feedwater flow but none of the differences were considered sufficient to significantly affect thermal hydraulic characteristics inside the steam generators. The different analyses included:

• Lower bounding thermal hydraulic analysis using the steam generator base design condition, where primary inlet temperature was 598°F, and an upper bound case where primary inlet temperature was 611°F as identified in Mitsubishi Document L5-04GA021, Revision 3

• Varying steam generator pressures from 833 to 942 psia

• Steam mass flow rates from 7.59 to 7.62 Mlbm/hr

• Primary loop volumetric flow rate from 102,000 to 104,000 gpm, and

• Recirculation ratio from 3.2 to 3.5.

The result of the independent NRC thermal-hydraulic analysis indicated that differences in the actual operation between units and/or individual steam generators had an insignificant impact on the results and in fact, the team did not identify any changes in steam velocities or void fractions that could attribute to the differences in tube wear between the units or steam generators.

B.2 – **Westinghouse Operational Assessment** (Page 4, Attachment 6, Appendix D, SONGS Unit 2 Return to Service Report) : An evaluation of the tube-to-tube wear reported in two tubes in SG 2E089 showed that, most likely, the wear did not result from in-plane vibration of the tubes since all available eddy current data clearly support the analytical results that in-plane vibration could not have occurred in these tubes. There is evidence of proximity in these tubes from pre-service inspection results. Hence, the tube- to-tube wear is most likely a result of out-of-plane vibration of the two tubes in close proximity to the level of contact during operation.

- Westinghouse Operational Data for Units 2 & 3, Table 2-7. Summary of ATHOS Results (Page 37)
    - RCS Flow for Units 2 & 3 – 79.79 Mlbs/hr
    - SG Pressure for Units 2 & 3 – 837.6 psi
    - Void Fraction for Units 2 & 3 – 99.6%
    - Circulation Ratio for Units 2 & 3 – 3.26

B.3 – **AREVA Operational Assessment** (Page 15, Attachment 6, Appendix B, SONGS Unit 2 Return to Service Report): Given identical designs, Unit 2 must be judged, a priori, as susceptible to the same TTW degradation mechanism as Unit 3 where 8 tubes failed structural integrity requirements after 11 months of operation. Indeed, the location and orientation of the two shallow TTW indications in Unit 2 are consistent with the behavior observed in Unit 3 and indicates that in-plane fluid-elastic instability in Unit 2 began shortly before the end of cycle 16 operation after 22 months of operation. It should be noted that this statement is contested by a viewpoint that TTW in Unit 2 is simply a consequence of tubes being in very close proximity to one another with self-limiting wear produced by a combination of turbulence and out-of- plane fluid-elastic excitation. This viewpoint has been evaluated completely and is considered to be arguable but not definitive. The argument that incipient in-plane fluid-elastic has developed in Unit 2 is considered a more logical explanation for the observed TTW but again cannot be stated as definitive. It is ultimately a moot point since the observations in Unit 3 make TTW via in-plane fluid-elastic instability a potential degradation mechanism for Unit 2. Based on the extremely comprehensive evaluation of both Units, supplemented by thermal hydraulic and FIV analysis, assuming, a priori, that TTW via in-plane fluid-elastic instability cannot develop in Unit 2 would be inappropriate.

B.4 – **SCE Enclosure 2** (Page 30, Unit 2 Return to Service Report): Because of the similarities in design between the Unit 2 and 3 RSGs, it was concluded that FEI in the in-plane direction was also the cause of the TTW in Unit 2. After the RCE for TTW was prepared, WEC performed analysis of Unit 2 ECT data and concluded TTW was caused by the close proximity of these two tubes during initial operation of the RSGs. With close proximity, normal vibration of the tubes produced the wear at the point of contact. With proximity as the cause, during operation the tubes wear until they are no longer in contact, a condition known as 'wear arrest'.

- Root Cause Evaluation: Unit 3 Steam Generator Tube Leak and Tube-to-Tube Wear Condition Report: 201836127, Revision 0, 5/7/2012, San Onofre Nuclear Generating Station (SONGS), Page 37 (Attached)
    - Reactor Coolant Flow (at cold leg temperature), 209,880 gpm
    - Secondary Side Operating Pressure (@100% power), 833 psia

B.5 – **February 7, 2013 NRC Commission Meeting** (Attached – pages 70-75): Honorable NRC Commissioner Mr. Apostolakis was totally confused on Unit 2 FEI inconsistent statements by SCE, Westinghouse and AREVA.

C. **Contact Force Differences between SONGS Units 2 and 3:** NRC AIT, SCE and MHI state that supports were better in Unit 2, so no tube-to-tube wear occurred in Unit 2. Fabrication differences during manufacture of SONGS RSGs caused difference of contact forces in supports between Units 2 & 3. Let us now examine that whether insufficient contact tube-to AVB forces in the Unit 3 upper tube bundle caused "fluid-elastic instability" which was a significant contributor to the tube-to-tube wear resulting in the tube leak.

C.1 - **MHI states**, "By design, U-bend support in the in-plane direction was not provided for the SONGS SG's". In the design stage, MHI considered that the tube U-bend support in the out-of-plane direction designed for "zero" tube-to-AVB gap in hot condition was sufficient to prevent the tube from becoming fluid-elastic unstable during operation based on the MHI experiences and contemporary practice. MHI postulated that a "zero" gap in the hot condition does not necessarily ensure that the support is active and that contact force between the tube and the AVB is required for the support to be considered active. The most likely cause of the observed tube-to-tube wear is multiple consecutive AVB supports becoming inactive during operation. This is attributed to redistribution of the tube-to-AVB-gaps under the fluid hydrodynamic pressure exerted on the tubes during operation. This phenomenon is called by MHI, "tube bundle flowering" and is postulated to result in a spreading of the tube U-bends in the out-of-plane direction to varying degrees based on their location in the tube bundle (the hydrodynamic pressure varies within the U bend). This tube U-bend spreading causes an increase of the tube-to-AVB gap sizes and decrease of tube-to-AVB contact forces rendering the AVB supports inactive and potentially significantly contributing to tube FEI. Observations Common to BOTH Unit-2 and Unit-3: The AVBs, end caps, and retainer bars were manufactured according to the design. It was confirmed that there were no significant gaps between the AVBs and tubes, which might have contributed to excessive tube vibration because the AVBs appear to be virtually in contact with tubes. MHI states, "The higher than typical void fraction is a result of a very large and tightly packed tube bundle, particularly in the U-bend, with high heat flux in the hot leg side. Because this high void fraction is a potentially major cause of the tube FEI, and consequently unexpected tube wear (as it affects both the flow velocity and the damping factors)."

C.2. – **AREVA states** – "The primary source of tube-to-AVB contact forces is the restraint provided by the retaining bars and bridges, reacting against the component dimensional dispersion of the tubes and AVBs. Contact forces are available for both cold and hot conditions. Contact forces significantly increase at normal operating temperature and pressure due to diametric expansion of the tubes and thermal growth of the AVBs. After fluid elastic instability develops, the amplitude of in-plane motion continuously increases and the forces needed to prevent in-plane motion at any given AVB location become relatively large. Hence shortly after instability occurs, U-bends begin to swing in Mode 1 and overcome hindrance at any AVB location."

C.3 – **Westinghouse states**, "Test data shows that the onset of in-plane (IP) vibration requires much higher velocities than the onset of out-of-plane (OP) fluid-elastic excitation. Hence, a tube that may vibrate in-plane (IP) would definitely be unstable OP. A small AVB gap that would be considered active in the OP mode would also be active in the IP mode because the small gap will prevent significant in-plane motion due to lack of clearance (gap) for the combined OP and IP motions. Thus, a contact force is not required to prevent significant IP motion. Manufacturing Considerations: There are several potential manufacturing considerations associated with review of the design drawings based on Westinghouse experience. The first two are related to increased proximity potential that is likely associated with the ECT evidence for proximity. Two others are associated with the AVB configuration and the additional orthogonal support structure that can interact with the first two during manufacturing. Another relates to AVB fabrication tolerances. These potential issues include: (1) The smaller nominal in-plane spacing between large radius U-bend tubes than comparable Westinghouse experience, (2) The much larger relative shrinkage of two sides (cold leg and hot leg) of each tube that can occur within the tubesheet drilling tolerances. Differences in axial shrinkage of tube legs can change the shape of the U-bends and reduce in-plane clearances between tubes from what was installed prior to hydraulic expansion, (3) The potential for the ends of the lateral sets of AVBs (designated as side narrow and side wide on the Design Anti-Vibration Bar Assembly Drawing that are attached to the AVB support structure on the sides of the tube bundle to become displaced from their intended positions during lower shell assembly rotation, (4) The potential for the 13 orthogonal bridge structure segments that are welded to the ends of AVB end cap extensions to produce reactions inside the bundle due to weld shrinkage and added weight during bundle rotation, and (5) Control of AVB fabrication tolerances sufficient to avoid undesirable interactions within the bundle. If AVBs are not flat with no twist in the unrestrained state they can tend to spread tube columns and introduce unexpected gaps greater than nominal inside the bundle away from the fixed weld spacing. The weight of the additional support structure after installation could accentuate any of the above potential issues. There is insufficient evidence to conclude that any of the listed potential issues are directly responsible for the unexpected tube wear, but these issues could all lead to unexpected tube/AVB fit-up conditions that would support the amplitude limited fluid-elastic vibration mechanism. None were extensively treated in the SCE root cause evaluation."

C.4 – **John Large States**, "Causes of Tube and Restraint Component Motion and Wear: My study of the various OAs leads me to the following findings and opinion that; (i) degradation of the tube restraint localities (RBs, AVBs and TSPs) occurs in the absence of fluid elastic instability (FEI) activity; (ii) TTW, acknowledged to arise from in-plane FEI activity, generally occurs where the AVB restraint has deteriorated at one or more localities along the length of individual tubes; (iii) the number of tube wear sites or incidences for AVB/TSP locations outstrips the TTW wear site incidences in the tube free-span locations. I find that the 'zero-gap' AVB assembly, which features strongly in the onset of TTW, is clearly designed to cope only with out-of-plane tube motion since there is little designed-in resistance to movement in the in-plane direction – because of this, it is just chance (a combination of manufacturing variations, expansion and pressurization, etc) that determines the in-plane effectiveness of the AVB; (iv) Uniquely, the SONGS RSG fluid regimes are characterized by in-plane activity, which is quite contrary to experience of other SGs used in similar nuclear power plants in which out-of-plane fluid phenomena dominate. Moreover, from the remote probe inspections when the replacement steam generator (RSG) is cold and unpressurized, I consider it impossible to reliably predict the effectiveness of the many thousands of AVB contact points for when the tube bundle is in a hot, pressurized operational state., and (5) v) The combination of the omission of the in-plane AVB restraints, the unique in-plane activity levels of the SONGS RSGs, together the very demanding interpretation of the remote probe data from the cold and depressurized tube inspection, render forecasting the wear of the tubes and many thousands of restraint components when in hot and pressurized service very challenging indeed. John Large continues, "Phasing of AVB-TSP Wear -v- TTW: I reason that, overall, the tube wear process comprises two distinct phases: First, the AVB (and TSP) -to-tube contact points wear with the result that whatever level of effectiveness is in play declines. Then, with the U-bend free-span sections increased by loss of intermediate AVB restraint(s), the individual tubes in the U-bend region are rendered very susceptible to FEI induced motion and TTW. Whereas the OAs commissioned by SCE broadly agree that the wear mechanics comprises two phases, there are strong differences over the cause of the first phase comprising in-plane AVB wear: AREVA claim this is caused by in-plane FEI whereas, the contrary, Mitsubishi (and Westinghouse) favor random perturbations in the fluid flow regime to be the tube motion excitation cause. Put simply: (i) if AREVA is correct then reducing the reactor power to 70% will eliminate FEI, AVB effectiveness will cease to decline further and TTW will be arrested; however, to the contrary, (ii) if Mitsubishi is right then, even at the 70% power level, the AVB restraint effectiveness will continue to decline thereby freeing up longer free-span tube sections that are more susceptible to TTW; or that (iii) the assertion of neither party is wholly or partly correct. As I have previously stated, I consider that AVB-to-tube wear is not wholly dependent upon FEI activity.

C.5 - **Violette R., Pettigrew M. J. & Mureithi N. W. state** (Ref. 1 – See below), "In nuclear power plant steam generators, U-tubes are very susceptible to undergo fluid elastic instability because of the high velocity of the two-phase mixture flow in the U-tube region and also because of their low natural frequencies in their out of plane modes. In nuclear power plant steam generator design, flat bar supports have been introduced in order to restrain vibrations of the U-tubes in the out of plane direction. Since those supports are not as effective in restraining the in-plane vibrations of the tubes, there is a clear need to verify if fluid elastic instability can occur for a cluster of cylinders preferentially flexible in the flow direction. Almost all the available data about fluid elastic instability of heat exchanger tube bundles concerns tubes that are axisymmetrically flexible. In those cases, the instability is found to be mostly in the direction transverse to the flow. Thus, the direction parallel to the flow has raised less concern in terms of bundle stability." Reference 1: Fluid-elastic instability of an array of tubes preferentially flexible in the flow direction subjected to two-phase cross flow, Violette R., Pettigrew M. J. & Mureithi N. W., 2006, http://yakari.polytechnique.fr/people/revio/masters_research_subject.html

C.6 - **Dr. Pettigrew** (Presentation to NRC Commission, February 2013): So, you notice the U-bend — the plane of the U-bend is being installed, and on top of the U-bends are bars. They are anti-vibration bars. And so you can see here that from the point of view of out-of-plane motion, the tubes are really very well supported because you have a large number of bars all around; but from the point of view of in-plane motion, there's really no positive restraint here to prevent the tube to move in the in-plane direction. Essentially, it relies on friction forces to limit the vibration.

C.7 – **Contact Force Definition:** Contact force is the force in which an object comes in contact with another object. Some everyday examples where contact forces are at work are pushing a car up a hill, kicking a ball, or pushing a desk across a room. In the first and third cases the force is continuously applied, while in the second case the force is delivered in a short impulse. The most common instances of contact force include friction, normal force, and tension. Contact force may also be described as the push experienced when two objects are pressed together. The MHI-designed AVBs had zero contact forces in Unit 3 to prevent in-plane fluid elastic instability and subsequently, wear occurred under localized thermal-hydraulic conditions of high steam quality (void fraction) and high flow velocity. Large u-bends were moving with large amplitudes in the in-plane direction without any contact forces imposed by the out-of-plane restraints. The in-plane vibration associated with the wear observed in the Unit 3 RSGs occurred because all of the out-of-plane AVB supports were inactive by design in the in-plane direction. The Unit 3 tube-to-AVB contact force for the tubes with tube-to-tube wear (TTW) was zero. That is why they did not restrain the tubes in the in-plane direction.

C.8 – **Contact Force Conclusions:** SONGS Unit 3 RSG's were operating outside SONGS Technical Specification Limits for Reactor Thermal Power and Current Licensing Basis for Design Basis Accident Conditions. I agree with MHI that high steam *flows and cross-flow velocities combined with narrow tube pitch-to-diameter ratio* caused elastic deformation of the U-tube bundle from the beginning of the Unit 3 cycle, which initiated the process of tube-to-AVB wear and insufficient contact forces between tubes and AVBs. Tube bundle distortion is considered a major contributing cause to the mechanism of tube-to-tube/AVB/TSP wear seen in the Unit 3 SG's. After 11 months of wear, contact forces were virtually eliminated between the tube and AVBs in the areas of highest area of Unit 3 wear as confirmed by ECT and visual inspections. I conclude that FEI and MHI Flowering effect redistributed the tube-to-AVB gaps in Unit 3 RSG's. FEI did not occur in Unit 2, because of the absence of high steam dryness and NOT the better supports and/or differences in fabrication, which resulted in substantially increased contact forces (reduced looseness) between tubes and AVBs for Unit 2 and prevented FEI from occurring. My findings on Unit 2 FEI are consistent with the findings of AREVA, Westinghouse, John Large, SONGS RCE Anonymous Root Cause Team Member and latest research performed by Eminent Professor Michel Pettigrew and others in 2006. In-plane fluid elastic instability did not happen in Unit 2 because of operational differences, so therefore double contact forces and better supports is just conjecture in Unit 2 to justify the restart of an Unsafe Unit 2.