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Your ref: Docket No. 52-006
Our ref: DCP/NRC2410

March 25, 2009

Subject: AP1000 Response to Request for Additional Information (SRP 3)

Westinghouse is submitting a response to the NRC request for additional information (RAI) on SRP Section 3. This RAI response is submitted in support of the AP1000 Design Certification Amendment Application (Docket No. 52-006). The information included in this response is generic and is expected to apply to all COL applications referencing the AP1000 Design Certification and the AP1000 Design Certification Amendment Application.

Enclosure 1 provides the response for the following RAI:

RAI-SRP3.9.3-EMB2-07 R1

Questions or requests for additional information related to the content and preparation of this response should be directed to Westinghouse. Please send copies of such questions or requests to the prospective applicants for combined licenses referencing the AP1000 Design Certification. A representative for each applicant is included on the cc: list of this letter.

Very truly yours,

D. A. Lindgren /FOR

Robert Sisk, Manager
Licensing and Customer Interface
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/Enclosure

1. Response to Request for Additional Information on SRP Section 3

D063
NRO

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ENCLOSURE 1

Response to Request for Additional Information on SRP Section 3

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-SRP3.9.3-EMB2-07
Revision: 1

Revision 0 Question:

The staff conducted an on-site review of AP1000 component design on October 13 to October 17, 2008. The staff reviewed how Westinghouse translated DCD information into the design specifications for all components audited. The staff also reviewed the way in which Westinghouse documented the design analysis methodologies, criteria, and functional requirements in its design report for each major component in accordance with ASME Code, Section III. The staff requires response to the following Open Item in order to conclude its review of the proposed removal of the COL information item, currently addressed in the DCA.

Steam Generator - The transient resulting from primary system depressurization leading to external pressurization of the steam generator tubes leads to a calculated stress to allowable stress ratio of 0.96, and a fatigue limit ratio of 0.99. Since these ratios are close to their limiting values, the NRC audit team asked to examine the assumptions regarding the modeling of tube wall thinning.

The calculated stress on the tube wall depends on the wall thickness which depends on the integrated effects of erosion, corrosion, tube wear and chemical cleaning thinning. The rates of these phenomena are computed using correlations obtained from experimental simulations. Westinghouse is requested to provide confirmation that the margins to maximum stress and fatigue limits are adequate, considering the rates of erosion, corrosion, chemical cleaning and tube wear. Confirm that the experiments used to support evaluation of the erosion rate were performed under prototypic conditions, including flow velocity, and that the erosion rate used in the wall thickness calculations is conservatively derived from the experimental data.

Revision 1 Question:

Westinghouse reduced the CUF from 0.99 to 0.90 by redefining definition of transients that are used and number of fatigue cycles used for each transient and the tube collapse pressure limit ratio from 0.96 to 0.90 by redefining transient and use of an ASME Code Case in calculation. However, the response needs additional clarifications as discussed below:

1. Provide basis for the redefinition of the umbrella transient and explain how it relates to the historical data.

2. Explain the ASME Code Case N579-1 and its use in the tube collapse pressure limit calculation. Confirm if this Code Case is acceptable to the staff in RG 1.84.

3. Clarify how the design basis tube wall thinning allowance is applied to individual tubes and what ASME Code criteria ensure the functional performance and integrity of the tubes.

4. Discuss the reasons for the conservatism when 3 mils allowance is used for loss of material due to corrosion/erosion in SG tubes. Include a discussion of the prototypicality of the experiments and the conservatisms in the interpretation of the results.

5. Discuss how the analyses performed provide an adequate wall thinning tube allowance due to flow induced vibration wear and the details for scaling measured workrate trends from "prototypic" test conditions.

Westinghouse Revision 1 Response:

1. The purpose of defining umbrella design transients is to be able to analyze one limiting transient which envelopes several less severe transients of a similar type. This minimizes the analysis work required and provides a conservative result as long as the fatigue usage factor can be shown to be less than 1.0. As equipment analysis for the AP1000 has progressed, the differences in the AP1000 response to certain transient conditions compared to current operating plants has resulted in the calculated usage factors very close to or exceeding 1.0 for some components of the equipment. When this situation occurs, the umbrella transient that is driving the high usage factor and the individual transients that have been considered under that umbrella transient are reviewed to remove some of the large conservatism which results from the use of an enveloping transient.

   In the case of the steam generator tube fatigue evaluation, the inadvertent reactor coolant system (RCS) depressurization transient causes the majority of the fatigue usage based on the use of a stuck open pressurizer safety valve event as an umbrella transient to represent all 20 inadvertent RCS depressurization transients. Historically, very few RCS depressurization scenarios have been the umbrella stuck open pressurizer safety valve transient. We are aware of only two stuck open pressurizer safety valve events that have occurred in the entire Westinghouse operating fleet, and one of those was actually a cracked disk of less significance. The majority of the Level B RCS depressurization events used as design transients have been pressurizer PORV opening(s) [not applicable to the AP1000], and inadvertent main and auxiliary pressurizer spray. With these bases (very low frequency of stuck open pressurizer safety valve and no AP1000 PORVs that could stick open), the less conservative, but still bounding transients were redefined for the steam generator tubes. Five depressurization events are still considered to be a stuck open safety valve, but the remaining 15 RCS depressurizations are caused by inadvertent pressurizer spray events. Based on the historical frequency of RCS depressurization events, this transient grouping still results in a conservative fatigue analysis for the steam generator tubes.

2. Code Case N-759-1 provides alternative rules for determining allowable external pressure for cylinders in lieu of the rules provided by ASME Section III, Division 1, NB-3133. The Code Case is included in the DCD Rev. 17 Table 5.2-3. This code case is currently not included in Reg. Guide 1.84, however the ASME approved Code Case is more recent than the last revision of Reg. Guide 1.84. Acceptance by the NRC staff for the Code Case is currently being pursued.

3. The design basis tube wall thinning allowance is derived in the following manner from the nominal thickness of 40 mils. First the maximum specified diameter is used for the OD, which maximizes the end cap loads and bending stresses. From this value, the minimum specified tube thickness is subtracted from the outer radius r_o (1/2 OD) in order to calculate the maximum inner radius r_i. This assures that the hoop and axial stresses due to pressure are maximized. Erosion/corrosion is accounted for by subtracting 1 mil (secondary side erosion/corrosion allowance) from r_o and adding 2 mils (primary side erosion/corrosion allowance) to r_i. Further, in order to account for wear caused by Flow Induced Vibration (FIV), the maximum calculated wear of 4 mils is subtracted from the outer radius r_o at the applicable sections of the tube. Once the erosion/corrosion and the wear due to FIV are accounted for, the minimum thicknesses are calculated. From this, the tubes are evaluated at 27.5 % degradation with FIV wear and at 17.5% degradation without FIV wear. Figure 1 shows the design basis tube thickness at each evaluated section in the tube.

   Each tube section is evaluated to the dimension described above and shown to pass Section III of the ASME Code for Service Levels A, B, C and D along with test Conditions for Primary stresses and Primary plus Secondary stresses. ASME external pressure requirements are also evaluated with the dimensions described above and are shown to pass assuming the use of Code Case N-759-1.

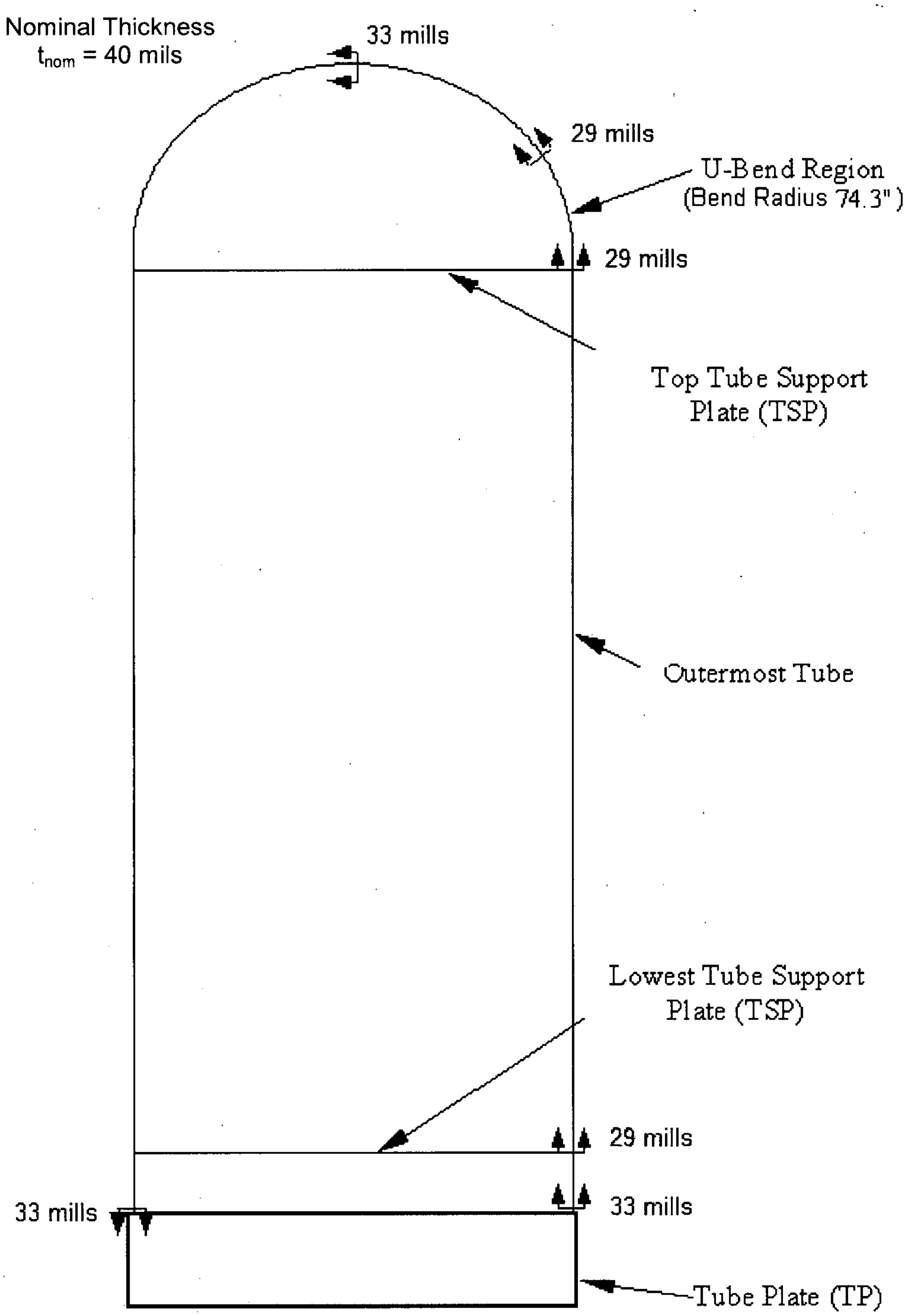

Figure 1: SG Design Basis Tube Thickness at each Evaluated Section

4. The use of 3 mils for corrosion/erosion was initially developed based on prototypical tests done with Inconel 600 material. Since that time, the tubing material has changed to Inconel 690. The Inconel 690 material has better corrosion/erosion resistance properties than Inconel 600. Therefore, the use of the 3 mils allowance is conservative.

   The tests performed to determine the corrosion/erosion properties of Inconel 600 material are documented in WCAP-7505 (Reference 2) for the secondary side environmental conditions and in WCAP-7504 (Reference 1) for the primary side environment conditions. These tests were designed to establish the long-term, steady-state corrosion rate for Inconel 600 tubes. These studies used multiple prototypical conditions to study the corrosive behaviors of Inconel 600. The environmental conditions used for the secondary side (Reference 2) included temperatures at 600°F and multiple variations of design chemistry that included both blowdown sludge and lead oxide particulates. The environmental conditions for the primary side (Reference 1) water included multiple pH levels of boric acid concentrations at 600°F. The specimens used for both tests included multiple variations of pre-stressed geometries at prototypical flow velocities. In conclusion, the tests performed to determine the erosion/corrosion rates are prototypical since they were performed at design conditions for the primary and secondary side that included such factors as flowrates, pre-stress, geometry, temperature, and chemistry.

5. The wear due to flow induced vibration is included in the wall thinning allowance as described in Item number 3. The potential for flow induced vibration wear is limited to locations at structures, such as the tube support plates and Anti-Vibration Bars (AVBs). Vibration induced wall thinning at other locations is not a possible degradation mechanism.

   Shaker tests have been performed on full-size U-tubes (documented in Reference 3) to characterize the wear producing impact/sliding forces and motions caused from fluidelastic excitations within clearances allowed by fabrication. The objective of the shaker tests is to simulate various flow excitation levels in terms of workrates for various tube/AVB fitup conditions. The results from the tests are used to develop semi-empirical workrate trends that are used to calculate tube wear depth as a function of time and fluid elastic excitation, with different levels of background turbulence. The semi-empirical workrate trends that are calculated from the shaker test data are scaled to operating conditions of interest using conventional instability ratios, modal effective lengths, and tube/AVB fitup characteristics using equations 3 through 6 from Reference 3. These tests addressed potential tube/AVB misalignment parameters that take into account local contact variations, such as gap eccentricity, local AVB twist, and manufacturing tolerances by using appropriate depth/volume geometric relationships.

   Based on the Flow Induced Vibration analysis, which employ the semi-empirical shaker test results, it is concluded that for the operating conditions expected in the AP1000 SG, the 10% (4 mils) allowance for vibration induced wear is conservative.

References:

1. Whyte, D.D., "Investigation of Long Term Corrosion Properties of Inconel-600 in Partially Neutralized Boric Acid," Westinghouse Electric Corporation, WCAP-7504, 1970.

2. Whyte, D.D., "Corrosion Behavior of Inconel-600 in Steam Generator Steam-Side Environment," Westinghouse Electric Corporation, WCAP-7505, 1970.

3. Langford, P.J. and Connors, H. J., "Calculation of tube-AVB wear from U-bend Shaker Test Data," Fifth Internal Conference on Flow-Induced Vibrations, Paper C416/040, *IMechE*, Brighton, U.K., May 1991, pp.45-55.

Westinghouse Revision 0 Response:

The high fatigue ratio (0.99) in the tubes originates extensively from the 20 cycles of Inadvertent Reactor Coolant System (RCS) Depressurization umbrella transient, which is a stuck open pressurizer safety valve (PSV) starting from 100% power. Subsequent to this fatigue calculation, new inadvertent RCS depressurization transients were defined in which the 20 umbrella cycles were broken down into 5 cycles of a stuck open PSV and 15 cycles of inadvertent pressurizer spray. This division of the required 20 cycles is based on historical data which shows the majority of Level B RCS depressurization transients are events other than a stuck open PSV. The resulting fatigue usage in the tube analysis is expected to be below 0.90.

The calculation of the 0.96 tube collapse pressure limit ratio was also revised. The limiting inadvertent automatic depressurization system (ADS) transient was revised and the use of ASME Code Case N-759-1 was invoked in the calculation. The resulting tube collapse pressure limit ratio will be reduced to less than 0.90.

The margins for the calculated collapse limit and the fatigue usage are adequate, because the design basis tube wall thinning allowance is applied to the individual tubes. Satisfaction of the ASME Code criteria for these allowances assures the functional performance and integrity of the AP1000 tubes.

The tube wall thinning allowance for the Steam Generator (SG) tubes is derived from two sources. First, the Corrosion/Erosion allowance for the tubes inside and outside surface is based on data generated in WNEP-8661 Rev 1, "Corrosion /Erosion /Wear Allowances for the Steam Generator and Pressurizer Materials". This data was generated for the Inconel 600 tubes by reviewing available plant data and experimental results. From this report, it is concluded that 3 mils (0.003") total is a conservative value to represent the loss of material due to Corrosion/Erosion. A letter, NPD/E/PEN-99-097 "Stainless Steel and Inconel Material Loss", was issued stating that Inconel 690 (the material currently used) is more corrosion resistant than Inconel 600 and therefore, Corrosion/Erosion allowance calculated for Inconel 600 can be used for Inconel 690 conservatively. The use of 3 mils is also specified in Section 5.4.2.3.4 of the AP1000 Design Control Document.

Secondly, local tube wear due to Flow Induced Vibration (FIV) is calculated for local regions adjacent to the Anti-Vibration Bars (AVBs) and the Tube Support Plates (TSPs). This calculation is based on scaling measured workrate trends from full-sized U-bend tubes documented in CN-NCE-07-19 Rev 2, “Flow Induced Vibration and Tube Wear Evaluation for AP1000 Steam Generators”. The analytical model developed to calculate limiting tube/AVB wear in the U-bend region uses empirical workrate trends obtained from prototypic test conditions that include nonlinear effects of the interactions at loose supports. The documented analyses cover the range of possible fit-up conditions determined by design and inspection of previous tube assemblies during and after fabrication. Workrates for both fluidelastic and turbulent excitation measured from tests are scaled to different steam generator operating conditions using appropriate fluid properties and vibration analysis parameters from qualified ATHOS models. Iterative calculations cover the 60-year operating period and account for increasing excitation with increasing wear in the case of fluidelastic excitation. These analysis methods provide a comprehensive review of the AP1000 tubes and demonstrate that the AP1000 SG has an adequate tube wall thinning allowance.

Design Control Document (DCD) Revision:

None

PRA Revision:

None

Technical Report (TR) Revision:

None