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Westinghouse Non-Proprietary Class 3

WCAP-15091
Revision 1

SPECIFIC APPLICATION OF LASER WELDED SLEEVES FOR THE COMANCHE PEAK UNITS 1 AND 2 STEAM GENERATORS

Westinghouse Electric Company LLC

WESTINGHOUSE NON-PROPRIETARY CLASS 3

WCAP-15091
Revision 1

SG-99-03-006

SPECIFIC APPLICATION OF LASER WELDED SLEEVES FOR THE COMANCHE PEAK UNITS 1 AND 2 STEAM GENERATORS

March, 1999

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ABSTRACT

Under Plant Technical Specification requirements, steam generator tubes are periodically inspected for degradation using non-destructive examination techniques. If established inspection criteria for tube integrity are exceeded, the tube must be removed from service by plugging, or the tube must be brought back into compliance with the Technical Specification Criteria. Tube sleeving is one technique used to return the tube to an operable condition. The purpose of this evaluation is to establish the applicability of a generic laser welding sleeving analysis for 3/4 inch diameter tube feedring-type and Westinghouse preheater steam generators (WCAP-13698, Rev. 3) to the Comanche Peak steam generators. (Note: The terms "Comanche Peak", "Comanche Peak Project", TU, and Texas Utilities will be used interchangeably in this document.)

The sleeve design, mechanical testing, stress corrosion resistance testing and evaluations, installation processes and nondestructive examination discussed in the generic report apply directly to Comanche Peak.

This revision to the initial issue of this WCAP is provided to accommodate a minor change in the tubesheet sleeve lower joint which is caused by the primary-to-secondary side pressure differential resulting from uprating.

Based on the combined results of this evaluation and the generic evaluation (WCAP-13698, Rev. 3), the laser welded sleeves are concluded to meet applicable ASME Boiler and Pressure Vessel Code and regulatory requirements for Comanche Peak.

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1.0 INTRODUCTION

This report documents the results of an analysis to evaluate the applicability of the generic laser welded sleeving analysis for 3/4 inch diameter tube feedring-type and Westinghouse preheater steam generators (WCAP-13698, Rev. 3), Reference 1, to the Comanche Peak Units 1 and 2 steam generators. In performing the generic analysis, transient loads are used that umbrella the steam generators to be sleeved. Included in the generic analysis are calculations to determine minimum wall thickness requirements for the sleeves. These calculations are a function of plant operating parameters, which vary from plant to plant, and which can change with the implementation of operating or system modifications. The purpose of this evaluation then, is to compare the current set of transient and operating parameters for Comanche Peak to those used in the generic analysis, with the intent of confirming that the generic analysis provides a bounding analysis for Comanche Peak, and to also remove any conservatism in the generic analysis for minimum wall thickness, if possible. The results of this analysis are based on transient data supplied by the generic design specification, Reference 2, and supported by the Comanche Peak design specifications, References 3 through 6.

In establishing the structural adequacy of the laser welded sleeves in the generic analysis, criteria were evaluated for primary stress limits, maximum range of stress intensity and fatigue, and minimum wall thickness requirements. The load conditions applicable to each of these areas are reviewed in this analysis to establish the applicability of the generic analysis. In general, the discussions to follow provide only a brief overview of each area. More in-depth discussions are contained in Reference 1 for the generic analysis.

2.0 SLEEVE DESIGN AND DESCRIPTION

The laser welded sleeve and tube geometries for use in Comanche Peak Model D4 and D5 steam generators are the same as the sleeve and tube geometries considered in the generic LWS structural evaluation in Reference 1, namely, nominal [ ][a,c,e] sleeves installed in nominal 0.750 inch OD x 0.043 inch wall thickness tubes. The width (interfacial axial extent) of the laser weld joining the tube and sleeve for all joints is also the same as in the generic LWS structural evaluation in Reference 1. Thus, with respect to sleeve, tube, and weld geometry, the results and conclusions of Reference 1 apply directly to the Comanche Peak LWS installation.

The generic sleeve analysis in Reference 1 evaluates three sleeve designs, the full length tubesheet sleeve (FLTS), the elevated tubesheet sleeve (ETS), and the tube support sleeve (TSS). Each of the sleeve geometries has been evaluated and concluded to be applicable to Comanche Peak Units 1 and 2.

3.0 ANALYTICAL VERIFICATION

3.1 Structural Analysis

This section provides the structural analysis basis for installation of Alloy 690 laser welded sleeves (LWS) in 3/4 inch nominal outside diameter Alloy 600 tubes with [ ][a,c,e] nominal wall thickness in the Comanche Peak Model D4 and D5 steam generators. The generic structural evaluation of laser welded sleeves for 3/4 inch tubes with [ ][a,c,e] walls is documented in Reference 1 and essentially covers the Comanche Peak application, as stated above in Section 2. The major structural topics covered are the ASME Code evaluation, the sleeve/tube contact pressure evaluation (for the elevated tubesheet sleeve lower joint), and the minimum sleeve wall thickness requirements that define the associated plugging limits.

While the bulk of the verification is based on data in Reference 1, the sleeve/tube contact pressure assessment uses the finite element results from the evaluation performed for equivalent laser welded sleeves installed in the Byron Unit 1 Model D4 steam generators. The Comanche Peak Models D4 and D5 tubesheet, channel head, and cylinder are the same as the Byron 1 counterparts. However, the Comanche Peak steam generators have external support rings attached to the tubesheet, while the Byron 1 steam generator supports are part of the channel head castings. This difference in geometry is considered in Section 3.1.5.

3.1.1 Materials

Table 3-1 lists the materials considered in the generic structural evaluation of the laser welded sleeves in Reference 1. These same materials apply to the Comanche Peak installation. Note that the material of construction for the 3/4 inch tubes in the Comanche Peak Unit 1 Model D4 steam generators is nickel based Alloy 600 in the mill annealed (MA) condition with a 35 ksi minimum yield, while the material of construction for the 3/4 inch tubes in the Comanche Peak Unit 2 Model D5 steam generators is nickel based Alloy 600 in the thermally treated (TT) condition, also with a 35 ksi minimum yield. Thus, with respect to sleeve, tube, tubesheet, channel head, and cylinder materials, the results from Reference 1 are directly applicable to Comanche Peak.

3.1.2 Applicable Criteria

The criteria for assessing the structural integrity of the laser welded sleeves for the Comanche Peak Unit 1 and 2 steam generators is unchanged from the criteria defined in the generic structural analysis, Reference 1.

3.1.3 Applicable Loading Conditions and Structural Assessments

The umbrella loading conditions used in the generic analysis of Reference 1 are defined in Reference 2, and include transient loads from the applicable design specifications for ABB-CE feedring steam generators, and for Westinghouse Model D3, D4, D5 and E1/E2 steam generators. Thus, the transient loadings in References 1 and 2 are applicable to the installation of LWS in the Comanche Peak Model D4 and D5 steam generators. Note that in Reference 1, that a conservative bounding evaluation is performed for seismic loads, and it is shown that seismic loads result in negligible stress and fatigue usage in the tube and sleeve. The results in Reference 1 are concluded to bound the Comanche Peak plant specific seismic loads.

3.1.3.1 Pressure Loads

Table 3-2 lists the pressure loads, specified in Reference 2 for design, faulted, test, and emergency conditions, considered in the generic LWS structural analysis reported in Reference 1. Pressure stresses in the sleeve were evaluated for each load classification at the limiting ΔP values shown in Table 3-2. Table 3-3 shows a comparison of the pressure drop loads for the generic case, Reference 1, versus the values for Comanche Peak obtained from References 4 and 6. As shown in Table 3-3, none of the Comanche Peak values exceeds the existing limiting ΔP in each classification. Therefore, the results for the pressure stress evaluations in Reference 1 remain valid and are applicable for Comanche Peak, and it may be concluded that the ASME Code pressure stress limits are satisfied.

3.1.3.2 Normal, Upset, and Test Loads

The maximum range of primary plus secondary stresses and the cumulative fatigue usage are calculated and evaluated in Reference 1 for the normal, upset, and test loads specified in Reference 2. For many of the transients, the change in pressure and temperature conditions are defined as changes from the corresponding initial conditions. A number of the transients initiate from full power conditions. A comparison of the full power temperatures and pressures used in the Reference 1 generic analysis to the full power parameters for Comanche Peak Units 1 and 2 is shown in Table 3-4. Two sets of Comanche Peak parameters are considered. The first corresponds to current operating conditions, and the second to a potential plant uprating. The uprating conditions represent a bounding set of conditions and correspond to 10% tube plugging with low T_{avg}. This comparison shows that both the primary to secondary pressure drop, and the primary to secondary temperature gradient (t_{hot} - t_{sec}), are higher for the generic case. Thus, the corresponding transient conditions for the generic analysis also are bounding for Comanche Peak. Also of note is that the number of transients and the corresponding transient cycles included in the generic analysis will umbrella the Comanche Peak duty cycle of events. Therefore, the results for the maximum range of stress and fatigue evaluations in

Reference 1 remain valid, and are applicable for Comanche Peak, and it may be concluded that the applicable ASME Code limits are satisfied.

3.1.3.3 Accident Conditions

The dominant loading for LOCA and SSE loads occurs [

]a,c. From Tables 3-2 and 3-3, the maximum primary-to-secondary pressure differential of [
]a,c accident.

3.1.4 Minimum Required Sleeve Wall Thickness

In establishing the safe limiting condition of a sleeve in terms of its remaining wall thickness, the effects of loadings during both normal operation and postulated accident conditions must be evaluated. The applicable stress criteria are in terms of allowables for the primary membrane and membrane plus bending stress intensities. Hence, only the primary loads (those necessary for equilibrium) need be considered. Since primary bending stresses are negligible in the sleeve and tube, the pressure stress equation NB-3324.1 of the Code, Reference 7, is used to calculate t_{min}. That is,

$$t_{min} = \frac{\Delta P_i \, R_i}{P_m - 0.5\,(P_i + P_o)}$$

where: R_i = maximum inner radius of sleeve = [ ]a,c,e

P_i = internal pressure = P_P = primary pressure (psig),

P_o = external pressure = P_S = secondary pressure (psig).

$\Delta P_i = P_i - P_o = P_P - P_S$,

P_m = allowable value for primary membrane stress intensity (psi).

Using the above formulation, calculations are performed to determine the minimum acceptable wall thickness. A summary of the minimum required wall thicknesses for the generic analysis and for the two sets of Comanche Peak operating conditions is provided in Table 3-5.

3.1.4.4 Determination of Plugging Limits

The minimum acceptable wall thickness and other recommended practices in Regulatory Guide 1.121, Reference 8, are used to determine a plugging limit for the sleeve. The Regulatory Guide was written to provide guidance for the determination of a plugging limit for steam generator tubes undergoing localized tube wall loss and can be conservatively applied to sleeves. Tubes with sleeves which are determined to have indications of degradation of the sleeve in excess of the plugging limit, would have to be repaired or removed from service.

As recommended in paragraph C.2.b of the Regulatory Guide, an additional thickness degradation allowance must be added to the minimum acceptable tube wall thickness to establish the operational sleeve thickness acceptable for continued service. Paragraph C.3.f of the Regulatory Guide specifies that the basis used in setting the operational degradation allowance include the method and data used in predicting the continuing degradation and consideration of NDE measurement errors and other significant eddy current testing parameters. An NDE measurement uncertainty value of [ ]a,c,e, Reference 1, of the sleeve wall thickness is applied for use in the determination of the operational sleeve thickness acceptable for continued service and thus determination of the plugging limit.

Paragraph C.3.f of the Regulatory Guide specifies that the bases used in setting the operational degradation analysis include the method and data used in predicting the continuing degradation. To develop a value for continuing degradation, sleeve experience must be reviewed. To date, no degradation has been detected on Westinghouse designed mechanical joint sleeves and no sleeved tube has been removed from service due to degradation of any portion of the sleeve. This result can be attributed to the changes in the sleeve material relative to the tube and the lower heat flux due to the double wall in the sleeved region. Sleeves installed with the laser weld joint are expected to experience the same performance. As a conservative measure, the conventional practice of applying a value of [ ]a,c,e of the sleeve wall, Reference 1, applied as an allowance for continued degradation, is used in this evaluation.

A summary of the resulting plugging limits, as determined by Regulatory Guide 1.121 recommendations, is given in Table 3-6. Results are presented for both sets of Comanche Peak conditions, and for comparison purposes, the results for the Generic case are also provided.

3.1.5 Sleeve/Tube Contact Pressures

Inside the tubesheet, it is important to maintain adequate contact pressure at the hard rolled sleeve/tube interfaces to prevent pullout and leakage in the elevated tubesheet sleeve configuration. Some of the sleeves for Comanche Peak Units 1 and 2 are to be

installed in the upper half of the tubesheet, where tubesheet bow during operation tends to increase the diameter of the holes drilled in the tubesheet. This diameter increase could result in a decrease in the contact pressures between the sleeve/tube and tube/tubesheet produced by system pressures and differential thermal expansions among the sleeve, tube, and tubesheet. This section determines the effect of tubesheet bow on the sleeve/tube and tube/tubesheet contact pressures.

The primary side of the Byron 1 Model D4 steam generator geometry and materials (tubesheet, channel head, and shell) is essentially the same as the Comanche Peak Model D4 and D5 steam generator primary side geometry except for the addition of the external support rings to the OD of the tubesheets at Comanche Peak. These support rings provide some additional stiffness to the tubesheet, resulting in smaller displacements for a given pressure load. Therefore, the displacements obtained during the Byron 1 analysis are conservative when applied to the Comanche Peak steam generators.

Loads are imposed on the sleeve as a result of tubesheet bow under pressure and temperature conditions. A 2-D axisymmetric finite element analysis of a Model D4 tubesheet, channel head, and lower shell, which is conservative when applied to the Comanche Peak Units 1 and 2 steam generators, is shown in Figure 3-1. Displacements are calculated throughout the tubesheet for five reference load cases, two pressure and three thermal unit loads. The three temperature loadings consist of applying a uniform thermal expansion to each of the three component members, one at a time, while the other two remain at ambient conditions.

Previous calculations performed with a 3-D finite element model of this region of a Model D4 steam generator showed that the displacements at the center of the tubesheet when the divider plate is included are [

]^{a,c,e}.

The radial deflection at any point within the tubesheet is found by scaling and combining the unit load radial deflections at that location according to:

a,c,e

[ ]

This expression is used to determine the radial deflections along a line of nodes at a constant axial elevation (e.g. neutral axis) within the perforated area of the tubesheet.

The expansion of a hole of diameter D in the tubesheet at a radius R is given by:

Radial: $\Delta D = D \{dU_R(R)/dR\}$

Circumferential: $\Delta D = D \{U_R(R)/R\}$

U_R is available directly from the finite element results. dU_R/dR may be obtained by numerical differentiation.

The maximum expansion of a hole in the tubesheet is in either the radial or circumferential direction. Typically, these two values are within [ ]a,c of each other. Since the analysis for calculating contact pressures is based on the assumption of axisymmetric deformations with respect to the centerline of the hole, a representative value for the hole expansion must be used that is consistent with the assumption of axisymmetric behavior. A study was performed to determine the effect of hole out-of-roundness on the contact pressures between the sleeve and tube, and between the tube and tubesheet. The equation used for the hole ΔD is:

$$\Delta D = (SF)(\Delta D_{max}) + (1 - SF)(\Delta D_{min})$$

where SF is a scale factor between zero and one. For the eccentricities typically encountered during tubesheet rotations, SF is usually between [ ]a,c.

The hole expansion includes the effects of tubesheet rotations and deformations caused by the system pressures and temperatures. It does not include local effects produced by interactions between the sleeve, tube, and tubesheet hole. Thick shell equations from Reference 10 in combination with the hole expansions from the finite element model

displacements are used to calculate the contact pressures between the sleeve and tube, and between the tube and tubesheet.

For a given set of primary and secondary side pressures and temperatures, the contact pressure equations are solved for selected elevations in the tubesheet to obtain the contact pressures between the sleeve and tube and the tube and tubesheet as a function of tubesheet radius. The elevations selected were the neutral axis of the tubesheet and three elevations spanning the section from the bottom of the ETS to two inches from the top surface of the tubesheet.

3.1.5.1 Normal Operation

The temperatures and pressures for normal operating conditions at Comanche Peak Units 1 and 2 are summarized below.

a,c,e

For the above set of primary and secondary side pressures and temperatures, contact pressures between the sleeve and tube and the tube and tubesheet are obtained as functions of radius for selected elevations in the tubesheet for both intact tubes and tubes separated above the tubesheet. The primary pressure acts on the inside of the tube and, for conservatism, the secondary pressure is assumed to act on the outside of the tube and the inside of the tubesheet hole. With separated tubes, the secondary pressure is assumed to act on the outside of the sleeve and inside of the tube as well as between the tube and tubesheet.

3.1.5.2 Faulted Condition

The temperatures and pressures for the limiting faulted condition are (References 4 and 6):

a,c,e

[ ]

The above conditions occur late in the feed line break transient. The ΔP early in the transient is higher [ ][a,c,e] but the primary and secondary side temperatures are much higher. That case was considered, but the contact pressures based on the above parameters are lower than those calculated with the higher ΔP.

For this set of primary and secondary side pressures and temperatures, the contact pressures between the sleeve and tube and the tube and tubesheet are obtained as functions of radius for selected elevations in the tubesheet for both intact tubes and tubes separated above the tubesheet.

3.1.5.3 Summary of Results

The contact pressures between the sleeve and tube, and between the tube and tubesheet are plotted versus radius in Figures 3-2 through 3-4. For normal operation, only the case for current operation is shown plotted. Similar distributions exist for the uprating case. Results from the analysis are summarized in Table 3-7 for the elevation [ ][a,c,e] below the top of the tubesheet, which corresponds to the top of the hard roll of the ETS. The interface pressures at this elevation are conservative for any lower elevation in the tubesheet.

Note that, in all cases, the net effect of the [ ][a.c.e]. This contact pressure is [ ][a,c,e]

3.2 Hydraulic Equivalency

The hydraulic equivalency number (N_{hyd}) for a sleeved tube configuration is defined as the number of tubes with this configuration which will be equivalent to one plugged tube in terms of primary flow resistance. The generic sleeving report for 3/4" tubes (Reference 1) calculated bounding values for the hydraulic equivalency number for various tube sleeve configurations (tubesheet plus tube support plate sleeves). These values could be used for all possible sleeve configurations in 3/4" tubes. The bounding hydraulic equivalency value for a sleeved tube configuration was calculated by assuming the longest tubesheet sleeve, 36 inches, in combination with tube support plate sleeves, was part of each sleeved tube configuration. Conservative assumptions were also made with respect to the location of the sleeves (cold leg / hot leg) and plant operating conditions. Since the sleeves planned for Comanche Peak are much shorter, the generic value is overly conservative. Also, after the generic report was issued, measurements of sleeve hydraulic equivalency have shown that the calculation of hydraulic equivalency contains significant conservatism. The inherent conservatism in the calculation eliminates the need to impose additional conservatism in the analysis by assuming the most conservative sleeve configurations and plant operating conditions.

3.2.1 Test Measurement of Hydraulic Equivalency

While the SLEEVE Code, used to calculate the hydraulic equivalency, is designed to be conservative, the degree of conservatism was only established through testing in 1997. The test results showed that hot leg tubesheet sleeves had measured equivalency values a factor of two to four bigger, i.e., more conservative, than the SLEEVE Code calculation. Though cold leg sleeves are rarely used, tests of these sleeves were used to confirm the conservatism of the SLEEVE code. Measured cold leg sleeve hydraulic equivalencies were 25 to 60% larger than those calculated by the SLEEVE code. Although these results are not used to adjust values calculated by SLEEVE, they justify the use of best estimate sleeve configurations and operating conditions.

3.2.2 Steam Generator Total Equivalent Plugging

The primary application of hydraulic equivalency numbers is to estimate where a plant stands with respect to its analyzed plugging limit. When the total equivalent plugging due to sleeving is added to the number of plugged tubes, the total can be compared to the plugging limit to confirm adequate primary flow will be measured. For moderate numbers of sleeved tubes (<1000 per steam generator) use of the conservative equivalency values in the generic report will not add significantly to the total equivalent plugging.

For very large sleeving programs the best estimate values of hydraulic equivalency can be used to calculate total equivalent plugging due to the sleeving. These best estimate calculations use the actual hydraulic equivalency values for the installed sleeves. Because

of the noted conservatism in the SLEEVE code calculation, these calculations continue to have adequate conservatism. To illustrate the conservatism in using the longest tube sheet sleeves, Table 3-8 lists the hydraulic equivalency values for various tubesheet sleeves installed in a 3/4 inch tube with operating conditions similar to Comanche Peak. Hydraulic equivalency values range from [

]^{a,c} elevated hot leg sleeve. Multiple sleeves result in lower equivalence values, but also vary significantly with respect to hydraulic equivalence. Thirty-inch sleeves in both the hot leg and cold leg have an equivalency number of [

]^{a,c}.

For moderate sleeving programs, the generic report equivalency values can be used without significantly affecting the steam generator total equivalent plugging. When large scale sleeving programs are anticipated, the expected sleeve configurations should be calculated on a best estimate basis to determine the total equivalent plugging which will result.

3.3 Sleeved Tube Relative Flow Induced Vibration Assessment

In the generic laser welded sleeving evaluation for 3/4 inch tubes (Reference 1), the vibration characteristics of a [

]^{a,c,e}

Table 3-1
Materials Used in Reference 1 for the Structural Evaluation of Laser Welded Sleeves

Component(s)	ASME Designation Appendix I of Reference 7
Tube & Weld	SB-163 - Mill Annealed Alloy 600 (35 ksi min yield)
Sleeve	SB-163 - Thermally Treated Alloy 690 (40 ksi min yield)
Tubesheet & External Support Ring	SA-508 Class 2a
Channel Head	SA-216 Grade WCC
Cylinder Shell	SA-533 Grade A Class 2

Table 3-2
Pressure Loads for Design, Faulted, Test, and Emergency Conditions Considered in Reference 1

a,c,e

[ ]

Table 3-3
Pressure Drop Loads for Design, Faulted, Test, and Emergency Conditions Considered in Generic Evaluation of Reference 1 versus Comanche Peak Values

a,c,e

Table 3-4
Comparison of Normal Operation Parameters
Generic Versus Comanche Peak

a,c

[ ]

Table 3-5
Summary of Minimum Wall Thickness Calculations for Laser Welded Tubesheet Sleeves For Use in 3/4 inch OD Tubes for Comanche Peak S/G's

a,c,e

Table 3-6
Summary of Recommended Plugging Limit
for Laser Welded Tubesheet Sleeves For
Use in 3/4 inch OD Tubes in Comanche Peak Model S/G's

a,c,e

Table 3-7
Minimum Contact Pressures Between Sleeve and Tube

a,c,e

(1) Similar distribution as case for Current Operating Parameters

Table 3-8
Hydraulic Equivalency Values for Tubesheet Sleeves

a,c

a,c

Figure 3-1
Finite Element Model of Model D4 Channel Head/Tubesheet/Shell

a,c

Figure 3-2
Contact Pressures for Normal Conditions with an Intact Tube

a,c

Figure 3-3
Contact Pressures for Normal Conditions with a Separated Tube

a,c

Figure 3-4
Contact Pressures for Faulted Conditions with Intact or Separated Tube

4.0 MECHANICAL TESTS

Mechanical test results provided in Reference 1 are, in general, directly applicable to the laser welded sleeves to be used for Comanche Peak Units 1 and 2. However, due to a change in the installation procedure for the elevated tubesheet sleeves (ETS), discussed more fully below, additional test results are provided in discussions to follow to demonstrate the acceptability of the ETS lower joint. The lower joint of the full length tubesheet sleeve (FLTS), developed for the Model E1 LWS (Doel 4) program, is directly applicable to the full-depth roll expanded tube joints of TU Unit 1. The FLTS lower joint for the hydraulic expanded joints of TU Unit 2, and for the explosive expanded (WEXTEX) joints of the several thousand WEXTEX tubes in Unit 1, are similar to that of the roll expanded TU Unit 1. A minor confirmatory test program will be performed to verify this application at an appropriate point in a Unit 2 or Unit 1, respectively, sleeving program.

Although the FLTS lower joints for 3/4 inch tube sleeves shown in Reference 1 have been completely satisfactory for the respective applications, the ETS lower joints for 3/4 inch tube sleeves have been developed separately. Both types of joints must meet the same pullout and leakage resistance requirements for the respective applications. One of the reasons for the separate developments is that [

]a,c,e

The longest ETS which has been generically evaluated in Reference 1 is [ ]a,c,e. The maximum length is bounding in terms of stress in the sleeve/tube structure; i.e., sleeves of shorter lengths involve lower stresses in the sleeve/tube joint. The basis for the ETS lower joint in the roll expanded tubes of TU Unit 1, designated as TU1RT is provided below. The basis for the TU Unit 1 WEXTEX tube (TU1WT) ETS lower joint and the TU Unit 2 ETS lower joint is provided below, plus a minor program to be performed for confirmatory strength and leakage resistance testing during the outage preparation.

(Note: In the discussions to follow, where Unit 1 is to be differentiated from Unit 2, the terms TU1 or TU2, respectively, are used.)

4.1 Establishment of TU ETS Lower Joint Processes Based on Previous Qualifications

The standard TU1, Model D4 ETS lower joint consists of a [

]a,c,e

One of the previous ETS lower joints is the Westinghouse Model E1 SG configuration at Doel 4. It was used in the 100 percent sleeving program at that site. Consisting of the same sleeve, as well as the factory roll expanded tube as the rolled tube TU1 joint, it was developed for the [ ]a,c,e inch wall, Alloy 600 tube, in 1994. The tubesheet unit cells, the quantity of tubesheet material that is considered part of the tube joint surrounding a single tube, are the same for the Doel and TU SGs. The pressure boundary materials, including the sleeve material, are also the same. The sleeve lower joint fabrication, including the roll expansion and hydraulic expansion processes, roll expander type and torque are the same for sleeves for the two SG models. However, the Doel 4 sleeve installation sequence was slightly different from the planned TU sequence; [

]a,c,e

The [

]a,c,e

The Maine Yankee ETS results are used herein to show that the qualification results for the [ ]a,c,e

[

]a,c,e

The TU1WT tubes and the TU2 tubes have the same dimensions as the TU1RT tubes and are also fabricated of Alloy 600. However, the TU1WT tubes are explosively expanded in the tubesheet holes and the TU2 tubes are [

]a,c,e

A comparison of the Main Yankee lower joint process with the TU1 and TU2 processes is provided in Tables 4-1 and 4-2, respectively.

4.2 Tube / Sleeve Interface Pressures

Mechanical testing is primarily concerned with leak resistance and joint strength. Sleeve pullout and leakage resistance for the MIF joint are directly related to the interference fit radial contact pressure between the tube inside surface, or "diameter" (ID), and the sleeve outside surface or diameter (OD). The interface pressures for a given set of operating parameters (temperatures and pressures) is a function of the interface pressure following sleeve installation, and changes in the contact pressure resulting from the system parameters.

Leak tests have been performed to establish the tube / sleeve contact pressure following installation. The pressure at which the leakage becomes significant is a conservative measure of the contact pressure; the actual contact pressure is higher than the leakage initiation pressure. The resulting test pressures were [

]a,c,e

[

][a,c,e]. An evaluation for Maine Yankee, that considered both [ ][a,c,e] sequences shows that contact pressure [ ][a,c,e]. Based on the joint similarities presented above, the TU interface pressure following sleeve installation is concluded to be the same as or greater than the Maine Yankee value, or [ ][a,c,e] psi.

The change in contact pressure due to system temperatures and pressures is calculated using the methodology discussed in Section 3.1.5. Changes to the as-installed contact pressure of the sleeve result from four types of loading conditions, normal operation, faulted, upset and test conditions. The change in contact pressure for TU was evaluated for the most stringent conditions, a tube located in the tubesheet at a radius of approximately [

][a,c,e]

Applied Load Effects on Sleeve-to-Tube Lower Joint Roll Expansion – Normal Operation

a,c,e

[ ]

An evaluation for the faulted load conditions, similar to that for the normal operation conditions above, was made and also indicates a [

][a,c,e]

Applied Load Effects on Sleeve-to-Tube Lower Joint Roll Expansion - SLB

a,c,e

[

]

A comparison of the tube / sleeve interface pressures for the Doel 4, Maine Yankee, and TU lower joints is provided in Table 4-3 for normal operating conditions, and in Table 4-4 for faulted conditions. The results show the TU joints to have contact pressures under normal operation that are comparable to the Doel 4 joint, but about 12% less than the Maine Yankee joints. Similar comparisons result for the three joints under faulted conditions. The variations in contact pressure are accounted for in the evaluation of joint leakage and pullout resistance to follow.

4.3 Joint Process Qualifications

Mechanical tests are used to provide information related to sleeve joint performance. Unit test cells are used for mechanical testing. A unit test cell or specimen consists of a single sleeve joint and sufficient tube and sleeve length to bound transition effects. For tubesheet specimens, a collar is used to simulate the effect of the tubesheet. The wall thickness of the collar is selected to simulate the radial stiffness of the steam generator tubesheet.

Mechanical testing was previously applied to both HEJ and laser welded lower joint sleeving. A consistent characteristic observed in testing the mechanical interference fit (MIF) lower joints for sleeves, is that [

]a,c,e

Previous mechanical tests for 3/4 inch tube sleeves show the roll expanded portion of the MIF lower joint provides the required strength, based on optimal roll thinning of the sleeve. This same "roll procedure" is used to achieve the required strength of the roll expanded portion of the MIF for the TU sleeves. Due to the explosive expansion of the applicable TU1WT tubes, and the hydraulic expansion of the TU2 tubes (versus full depth

roll expansion), minor confirmatory room temperature leakage resistance tests (to be performed during outage preparation prior to a sleeving program) are needed to provide final confirmation of the TU2 and TU1WT sleeve MIF joints.

In previous testing documentation, Reference 1, some of the 3/4 inch tube sleeve lower joint specimens were also subjected to cyclic thermal and mechanical loads, simulating plant transients. The magnitude of the forces and temperatures were determined from plant normal operating and postulated accident conditions. The force loadings assumed locking of the tube to the support plate structure and accounted for differential thermal expansion between the steam generator shell and the tube bundle. Other specimens were subjected to tensile and compressive loads to the point of mechanical failure. These tests demonstrate that the required joint strength (fatigue capability) exceeded the loading the sleeve joint would receive during normal plant operations or accident conditions.

Note: (In the following test portions of this report, the units of primary-to-secondary side differential pressures are listed simply as "psi", rather than "psid", as the secondary side pressures were at zero psig.)

4.3.1 Acceptance Criteria

4.3.1.1 Primary to Secondary Leakage

Bounding criteria for permissible primary-to-secondary side leakage during normal operation were established for Maine Yankee by allocating one-half of the 150 gpd limit, i.e., 75 gpd, to the lower joints of laser weld sleeves, and by conservatively assuming that all sleeved tubes develop throughwall degradation in the sleeve-spanned portion. This allocation permits the other 75 gpd to be assigned to other potential primary-to-secondary leakage. This flow, averaged over all of the hot leg (Maine Yankee) tube joints, for the 100 percent sleeving case, resulted in a per-sleeve average leakage of approximately 0.81 drops per minute (dpm) per sleeved tube. Similar assumptions for faulted conditions, i.e., allocation of one-half of the permissible flow, for 100 percent sleeving, for the usual 1 gpm (1440 gpd) primary-to-secondary leakage for the plant, results in an average permissible flow of approximately 3.9 dpm per sleeve. Corresponding criteria for TU are not available at present, and the Maine Yankee criterion will be used as a guide in evaluating the estimated TU primary to secondary leakage.

4.3.1.2 Pullout Resistance

For normal operation, a pullout resistance of three times the maximum primary-to-secondary pressure differential, times the tube cross sectional area, i.e., the "end cap" load, has been used as the requirement for sleeve MIF lower joints, which is consistent with the ASME B&PV Code. For the limiting faulted condition, a pullout resistance of 1.43 times the "end cap" load for the corresponding primary-to-secondary pressure differential is used

as the requirement for sleeve MIF lower joints, also consistent with the ASME Code. Evaluations of pullout loads on the sleeves for normal upset and test conditions in prior evaluations have been bounded by normal conditions, and it is judgeed that the same is true for this case. Thus, the limiting axial load for the joint design is the greater of the "3 ΔP" end cap load for the normal operation condition, and the "1.43"times the largest faulted end cap load.

4.3.2 Primary to Secondary Leakage

The objective of leak tests is to determine potential primary-to-secondary side leakage for the rare case where the tube becomes completely degraded within the sleeve length. The upper, laser welded joint, the laser weld, is taken as leak tight. As discussed earlier, previous tests have shown that if a MIF joint passes the room temperature leak test at prototypical pressure differentials, it will pass the elevated temperature leak test. Accordingly, leak tests were performed at room temperature for ΔPs of [

]a,c,e

Leak tests have been performed for both the Doel 4 and Maine Yankee lower sleeve joints. Because the tests were performed at room temperature, the [

]a,c,e A summary of the test results are summarized in Tables 4-3 and 4-4 for normal operation and faulted conditions, respectively.

The change from the [

]a,c,e

Assuming a linear relationship between contact pressure and leakage, and since leakage will be inversely proportional to interface pressure, the projected leakage for TU1RT joints is estimated by ratioing the leakage results from the Maine Yankee tests. For normal operation, the estimated leakage for TU is 0.115 dpm {(6535 / 6402) 0.113}. Similarly for faulted conditions, estimated leakage for TU is 0.189 dpm {(7633/ 5985) 0.148}. Both of

these values are well below the 0.81 dpm and 3.9 dpm limits set above for normal operation and faulted conditions, respectively. A summary of the resulting leakage is provided in Tables 4-3 and 4-4 for normal operation and faulted conditions, respectively.

It is estimated that, for a TU1 SG with 500 ETSs installed in rolled tubes, [

]a,c,e

Based on the test results, the projected ETS average leakage for TU1RT sleeves is [

]a,c,e The average per-tube, projected, ETS leakage source during accident conditions, [

]a,c,e gpd, also an insignificant value.

4.3.3 Pullout Resistance Results

In pullout resistance tests, the sleeve-to-tube as-installed interference fit contact pressure is first determined by a secondary-to-primary side pressure test. The test is based on the fact that the interface between the sleeve and tube without axial or helical scratches will leak only when the fluid pressure in the sleeve-to-tube annulus exceeds the sleeve-to-tube contact pressure. The contact pressures for given, i.e., normal operation and FLB conditions, are then determined by adding or subtracting the respective contact pressure change to the as-installed contact pressure. This contact pressure for normal operation, FLB or any other condition, acting over the effective area of contact between the sleeve and tube, along with an appropriate coefficient of friction determine the pullout resistance at that condition.

A summary of the resulting calculations for pullout resistance are summarized in Tables 4-3 and 4-4 for normal operation and faulted conditions, respectively.

4.4 Analysis Conclusions

Based on the results of this evaluation, the ETS joints for the sleeves at TU are concluded to result in insignificant primary-to-secondary leakage, and to meet applicable criteria for leakage and pullout resistance.

Table 4-1
Maine Yankee Roll-Last ETS Lower Joint
as Basis for TU1RT Roll-Last ETS Lower Joint

a,c,e

*TU1RT lower joint rolling process will be Doel 4 process; installation sequence for Doel 4 was roll-first; for TU1RT it will be roll-last. TU1WT ETS lower joint process will be qualified in minor program during outage preparation.

Table 4-2
Maine Yankee Roll-Last ETS Lower Joint as Basis for TU1WT & TU2 Roll-Last ETS Lower Joint

a,c,e

*Confirmatory qualification needed.

Table 4-3 (part 1 of 2)
Applicability of Doel 4 (Model E1) Elevated Tubesheet Sleeve *Lower Joint Process to TU1 & 2 - Normal Operation

a,c,e

Table 4-3 (Part 2 of 2)
Applicability of Doel 4 (Model E1) Elevated Tubesheet Sleeve * Lower Joint Process to TU1 & 2 - Normal Operation

a,c,e

[ ]

* As conservatively modified by Maine Yankee Lower Joint results

** Discard 4500 psi "outlier" value - 6 of 6 were 6000 psi, the limit of the test.

*** Note: Roll-first $CP_{As\text{-}installed}$ was 6,000 psi.

**** Confirmatory testing to be performed for TU1WT/TU2.

Nomenclature: m: leak rate; ~: Approximately; #: Lbs.; P (psi): Pressure; dpm: drops per minute

Notes: (1) CP - Contact Pressure
(2) N.Op. - Normal Operation

Table 4-4 (Part 1 of 2)
Applicability of Doel 4 (Model E1) Elevated Tubesheet Sleeve
***Lower Joint Process to TU1 & TU2 - Faulted Condition**

a,c,e

Table 4-4 (Part 2 of 2)
Applicability of Doel 4 (Model E1) Elevated Tubesheet Sleeve
*Lower Joint Process to TU1 & TU2 - Faulted Condition

a,c,e

*   As conservatively modified by Maine Yankee Lower Joint results

**   Discard 4500 psi "outlier" value - 6 of 6 were 6000 psi, the limit of the test.

***   Note: Roll-first $CP_{As\text{-}installed}$ was 6,000 psi.

****   Confirmatory testing to be performed for TU1WT & TU2 during outage preparation.

Nomenclature: m: leak rate; ~: Approximately; #: Lbs.; P (psi): Pressure; dpm: drops per minute

Notes: (1) CP - Contact Pressure
(2) N.Op. - Normal Operation

5.0 STRESS CORROSION TESTING OF LASER WELDED SLEEVE JOINTS

Section 5.0 of Reference 1 discusses stress corrosion testing of laser welded sleeve joints. It applies directly to Comanche Peak Units 1 and 2. An estimate of sleeve performance is presented in Section 5.7 of Reference 1 for two tube support conditions. The first corresponds to the condition where the tube is free to expand axially, and the second assumes the tube to be locked in place at the first tube support plate. For the second case, where the tube is assumed locked at the first tube support plate, the locking can result in residual far-field stresses being introduced in the tube during the stress relief process.

The magnitude of far field stresses is a function of the distance from the tubesheet to the first tube support plate and of the stress relief temperature. The magnitude of the far-field stress in turn affects the corrosion performance of the sleeved tubes. In the Comanche Peak Model D4 and D5 steam generators, the first TSP is at an elevation approximately 37 inches above the top of the tubesheet, compared to 29 and 47 inches used in the generic analysis. For fixed conditions at these span lengths, the far-field stresses after thermal stress relief of the weld of [

]a,c,e

Corrosion testing of mockups under this condition of stress, again from comparison with roll transition mockups exposed at the same time, indicates degradation-free sleeve performance for periods approximately twenty times those required to initiate PWSCC in roll transitions. Adjusting these results to the case of Comanche Peak provides a best estimate of [ ]a,c,e years of service for the laser welded sleeves. Note that this best estimate could be made lower if conservative adjustments to some of the test data or stress dependency assumptions were incorporated. Furthermore, while the thermal stress relief target temperature is [ ]a,c,e, temperatures of [ ]a,c,e are considered acceptable. Stress relief temperatures above [ ]a,c,e will increase far field stresses to the point that the service life estimate would need to be reduced.

6.0 INSTALLATION PROCESS DESCRIPTION

The outline of the installation process in Reference 1 applies directly to Comanche Peak Units 1 and 2. The detailed installation process steps are specified in the applicable field service procedures that will be provided by Westinghouse as part of the job.

7.0 NONDESTRUCTIVE EXAMINATION (NDE) INSPECTABILITY

Section 7.0 of Reference 1 specifies the installation NDE plan logic and defines the principles of the NDE processes to be used. It applies directly to Comanche Peak Units 1 and 2.

8.0 REFERENCES

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3. Design Specification 952332, Rev. 7, "Texas Utilities Comanche Peak Unit 1 Model D Steam Generator", August 26, 1981.

4. General Design Specification G-952124, Rev. 4, "Reactor Coolant System Model D Steam Generator",

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12. WCAP-14107, Rev. 0, "Specific Application of Laser Welded Sleeves For Doel Unit 4 Steam Generators", Westinghouse NSD, Pittsburgh, PA, April 1994.

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