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VERIFICATION OF THE INSTALLATION PROCESS AND OPERATING PERFORMANCE OF THE ABB CENO STEAM GENERATOR TUBE SLEEVE FOR USE AT COMMONWEALTH EDISON BYRON AND BRAIDWOOD UNITS 1 & 2

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1.0 PURPOSE

The purpose of this report is to provide information in support of technical specification changes allowing installation of Combustion Engineering repair sleeves in recirculating steam generators. This report supplements data that ABB Combustion Engineering has provided in the topical report (Reference 6.1) on repair of steam generator tubes using leak tight sleeves for Byron and Braidwood Units 1 & 2, demonstrating both the Sleeve Installation Verification and the Sleeve Performance Verification.

2.0 SUMMARY

Actual sleeve operating history, as well as the qualification test program described herein indicate that the ABB-CENO steam generator tube sleeve is capable of performing as well as, if not longer than the original tube in which it has been installed. The expected life of any particular installation depends a great deal on the specific physical condition of the steam generator, metallurgical condition of its tubing, the degradation mechanism originally experienced, and the environmental conditions expected to exist after sleeve installation.

It is reasonably clear, however, that the use of a post weld heat treatment, particularly on a limited number of applications within a given tube, increases the margin for sleeve joint life. In selecting the installation processes, specifically whether to utilize post weld heat treatment, all of these factors must be considered in an attempt to provide a cost effective repair consistent with the long term operational plans for that particular steam generator.

3.0 SLEEVE INSTALLATION PROCESS

3.1 SLEEVE DESIGN DESCRIPTION

There are three (3) types of sleeves which may be installed in various combinations within a steam generator tube. Only two types, the roll transition and tube support plate, are being considered for installation in Byron and Braidwood. Each sleeve type has a nominal outside diameter of [ ] and a nominal wall thickness of [ ]. The sleeve material is thermally treated Inconel 690. Each of the sleeve types includes a chamfer at both ends to prevent hang-up of equipment used to install the sleeve and to inspect the steam generator tube and sleeve.

The first type of sleeve spans the roll transition zone (RTZ) at the top of the tubesheet to a minimum height of 3.5 inches above the flow distribution baffle. This sleeve is up to [ ] long and includes [

]. A shorter sleeve (approximately [ ]) of the same design is used to span defective areas of a steam generator tube which exist just above the tubesheet.

The second type of sleeve spans the tubesheet (TS) and a portion of the tube to a maximum height of [ ] above the tubesheet. This sleeve is designed for use only in steam generators with partial depth rolled tubes. The sleeve is chamfered at the upper end to prevent hang-up with equipment which is used to install or inspect the sleeve (or steam generator tube). [

].

The third type of sleeve spans a tube support plate (TSP). The sleeve is up to [ ] in length, although a shorter sleeve (approximately [ ]) may be used. The tube support plate sleeve is used at the first and/or second tube support plate elevation or on any free span section of the tube between the top of the tubesheet and the second support plate. One or two tube support plate sleeves may be used in a tube containing an roll transition or tubesheet sleeve.

3.2 SLEEVE-TUBE ASSEMBLY

3.2.1 Roll Transition Zone Sleeve

The RTZ sleeve is up to [ ] in length. The upper end of the sleeve is located above the secondary face of the tubesheet, while the sleeve lower end is located near the neutral axis of the tubesheet. [

]

[ ]

[ ]

The lower end of the RTZ sleeve is rolled into the tube within the tubesheet. The roll is torque controlled to provide a leak tight structural joint. A roll which does not meet the criteria can be repaired by rerolling at the same location.

3.2.2 Tubesheet Sleeve

The tubesheet sleeve (not for use at Byron or Braidwood) is up to [ ] inches long, with the bottom of the sleeve positioned flush with the bottom of the steam generator tube. The sleeve is expanded in the steam generator tube at the upper end in preparation for welding. The steam generator tube is expanded slightly because of steam generator tube springback after expansion so that the gap between the sleeve and tube is minimized.

The lower end of the sleeve is tapered to an outside diameter that is larger than the inside diameter of the steam generator tube. The taper serves three purposes: The taper limits the insertion of the tube to the proper elevation during installation, temporarily holds the sleeve in place and provides tight contact with the tube for welding.

[ ]

3.2.3 Tube Support Plate

The TSP sleeve is up to [ ] inches in length. It is approximately centered at either the first and/or second support plate. [.]

[ ]

[ ]

For all sleeve welds except for the lower edge weld of the TS sleeve, the weld joint may be given a post weld heat treatment in the range of [.] This time and temperature combination is sufficient to reduce the level of residual stress in Alloy 600 without resulting in detrimental effects such as grain growth or sensitization. This treatment is similar to that utilized in some operating units to heat treat the tight radius U-bends.

3.3 SLEEVE INSTALLATION SEQUENCE - RTZ SLEEVE

RTZ sleeves are installed in the following sequence of operations:

3.3.1 Tube I.D. Cleaning

Prior to sleeve installation, the tube I.D. is mechanically cleaned with an abrasive wire brush. A motor rotates the tool head as it is inserted in the end of the tube. [ ]

[ ]

3.3.2 Sleeve Installation/Expansion

The sleeve expansion equipment is used to deliver and to provide the required sleeve/tube fit-up prior to welding or rolling.

The sleeve is located on the sleeve expansion tool for positioning within the steam generator tube. The expansion tool functions to guide the sleeve into the tube and install the sleeve to the selected elevation within the tube. A tool hardstop is provided for proper sleeve vertical positioning. Once the sleeve is at the proper elevation within the steam generator tube, it is hydraulically expanded.

The expansion tool consists of a mandrel and two bladders which contain the demineralized water which is used as the pressurization fluid. The sleeve is located over the two bladders prior to insertion in the steam generator tube. When the hydraulic expansion tool is pressurized, the bladders act directly against the inside diameter of the sleeve causing expansion of the sleeve.

[ ]

3.3.3 Structural Weld Near Sleeve Upper End

The welding equipment used for the sleeve to tube welds is comprised of two major components; the weld head assembly and the weld power supply. The welding head contains a copper wand which is used to hold and conduct the power to the tungsten electrode. The weld head includes a stainless steel sheath to prevent damage during insertion of the weld head into the steam generator tube and sleeve. Passages within the weld wand are provided for the shield gas to reach the weld torch area.

The weld head is rotated inside the sleeve when it is positioned at the proper elevation. The current and shielding gas are provided to the weld tool tungsten electrode by connections at the bottom end of the weld tool shaft. A maximum of [ ] welds can be made with each tungsten electrode.

The Gas Tungsten Arc welding power source is pre-programmed to supply argon shielding gas and pulsating D.C. current in four distinct power output levels. Current output from level one is set to initiate the arc and form the weld "puddle". As weld heat build-up increases, current output from each subsequent level is decreased in order to maintain consistent weld penetration and height. Weld essential variables, such as; current, voltage, head speed and gas flow are outlined in the applicable Weld Procedure Specification (WPS).

3.3.4 Ultrasonic Examination Of Sleeve Upper Weld

Ultrasonic testing using an immersion technique with demineralized water as a couplant is used to inspect the tube to sleeve weld. A one-quarter inch diameter focusing transducer is positioned in the weld area and rotated by the probe pusher or motor at the tool base to scan the weld. The pulse echo tester has the ability to interface with an on line data reduction computer to produce a display/hardcopy during radial and axial scanning.

3.3.5 Visual Examination Of Sleeve Upper Weld

Visual inspection of the sleeve upper weld is accomplished with the use of a micro camera system.

3.3.6 Post-Weld Heat Treatment Of Sleeve Upper Weld

The post weld heat treatment is performed with a resistance heater designed to heat the weld, the weld heat affected zone, and the pressure boundary portion of the tube expanded, including the outboard transition, during sleeve installation. The temperature control is accomplished by thermocouple measurement of the temperature of the resistance heater. The thermocouple readings are input to a controller which initiates the heat treatment process and maintains the heater at a pre-set temperature. [

]

3.3.7 Sleeve End Torque Rolling

The sleeve rolling equipment is used to expand the RTZ sleeve into contact with the steam generator tube within the tubesheet, forming a strong leak tight joint.

The rolling equipment consists of the air motor, tube expander, torque read-out, strip chart recorder and a torque calibration unit. The torque read-out and settings of the rolling tool are verified on the torque calibration unit prior to rolling of the sleeves. The rolling tool is located within the portion of the sleeve which was hydraulically expanded during sleeve installation. The approximately 1-1/4 inch long roll is located at the nickel and chromium oxide bands on the lower end of the RTZ sleeve. The sleeve is expanded to a torque which has been demonstrated by testing to provide a leak tight joint. A strip chart record of the rolling tool torque is taken for further evaluation of the rolling process on the individual sleeves. A rolled joint which fails to meet the acceptance criteria may be re-rolled.

3.3.8 Sleeve Baseline Examination With ECT

A multi-frequency eddy current method will be used to perform a base line examination of the installed sleeve for future reference. The ET fixture, with conduit, is used on the manipulator arm to position the probe.

3.4 SLEEVE INSTALLATION SEQUENCE - TS SLEEVE

TS sleeves (not to be installed in Byron or Braidwood) are installed in the following sequence of operations performed as described in Section 3.3.

3.4.1 Tube I.D. Cleaning

3.4.2 Sleeve Installation/Expansion

3.4.3 Structural Weld Near Sleeve Upper End

3.4.4 Ultrasonic Examination Of Sleeve Upper Weld

3.4.5 Visual Examination Of Sleeve Upper Weld

3.4.6 Post-Weld Heat Treatment Of Sleeve Upper Weld

3.4.7 Structural Weld Near Sleeve Lower End

3.4.8 Visual Examination Of Sleeve Lower Weld

3.4.9 Sleeve Baseline Examination With ECT

3.5 SLEEVE INSTALLATION SEQUENCE - TSP SLEEVE

TSP sleeves are installed in the following sequence of operations performed as described in Section 3.3.

3.5.1 Tube I.D. Cleaning

3.5.2 Sleeve Installation/Expansion

3.5.3 Structural Weld Near Sleeve Upper End

3.5.4 Structural Weld Near Sleeve Lower End

3.5.5 Ultrasonic Examination Of Sleeve Upper And Lower Welds

3.5.6 Visual Examination Of Sleeve Upper And Lower Welds

3.5.7 Post-Weld Heat Treatment Of Sleeve Upper And Lower Welds

3.5.8 Sleeve Baseline Examination With ECT

4.0 SLEEVE INSTALLATION VERIFICATION

4.1 WELD INTEGRITY

Initiated in 1983, Combustion Engineering has conducted a comprehensive development program to ensure the sleeve to tube weld joint integrity. Tube I.D. brushing tests, sleeve/tube expansion tests and weld parameter evaluation tests were all completed as part of the process verification. During this development, hundreds of welds have been made, examined, and/or tested to establish the essential variables associated with these processes.

4.1.1 Tube Cleaning Qualification

In preparation for welding, any oxide layer must be removed from the tube I.D. surface. Extensive tests were performed to develop, qualify and improve the cleaning process and tool. The cleaning program that was completed resulted in the qualification of an air powered, expandable wire brush.

4.1.2 Sleeve/Tube Expansion Qualification

An extensive test program was performed to qualify the bladder expansion tool and process. A particular effort has been made to minimize the diametral expansion of the tube while providing a tight sleeve/tube fit up to ensure a sound sleeve to tube weld. This program considered tubing with thick, thin and nominal walls as well as tubing with different yield strengths.

4.1.3 Weld Qualification

4.1.4 Ultrasonic Testing Qualification

Ultrasonic (U.T.) techniques are employed to confirm the presence of weld fusion into the tube. A test program was completed by C-E to qualify the ultrasonic examination of sleeve/tube upper welds. Fourteen sleeve/tube weld specimens were prepared for this qualification program. Each weld was ultrasonically inspected and then hydrostatically tested to confirm U.T. results. Test results indicate complete correlation between ultrasonic and hydrostatic testing. Further verification of the U.T. technique under field conditions was provided by the comparison of two unacceptable and six acceptable welds removed from the Ringhals 2 steam generators.

4.1.5 Post Weld Heat Treatment Qualification

The tubing used in some steam generators has been shown to be highly susceptible to Primary Water Stress Corrosion Cracking (PWSCC). As a result, the residual stress induced in the steam generator tubing associated with any repair process must be minimized. In these cases, a post weld heat treatment (PWHT) applied to the sleeve to tube weld joint as well as the weld heat affected zone and primary pressure boundary portion of the tube expansion may be performed. The Electrical Power Research Institute (EPRI) has documented evidence in support of the benefits of this process. Combustion Engineering has followed EPRI guidelines (Ref. 6.6) to determine the tube temperature and hold time required to maximize tube life.

intended to measure the long range, macro stresses imparted to the tube primarily when the tubes were locked at support plate or egg crate locations.

Accelerated Corrosion Tests

The accelerated corrosion tests were used to verify the temperature/time parameters for the process by determining the level of stress relief obtained. Initial tests were performed on a mockup consisting of a four by four array of .750 inch O.D. x 0.042 inch wall tubes arranged in a square pitch array. In all mockup installations sleeves were installed using the standard procedures and sequences described above. Additionally, the tubes were locked by welding to the support location.

After installation these mockups were cut to remove the tube sections for testing. No provisions were made to simulate the long range residual stresses due to tube locking. The resultant tube/sleeve assemblies were then fabricated into individual capsule corrosion specimens. The I.D. surface of the samples were exposed to a 10% solution of dearerated sodium hydroxide at 660°F. At the same time, C-ring samples of the Alloy 600 tube material were stressed to various levels and exposed to the same environment. In other tests, representative roll transition samples were also exposed. These control samples provided a measure of the stress levels at which the sleeve/tube joints would fail. Some of this work was performed by ABB-CENO and some by independent organizations. The results of the two most prominent tests are shown in Tables 4-1 and 4-2.

The conclusion of these tests was that the as-welded tube/sleeve joint[

].

Instrumented Analysis of Locked Tubes

[

]

A plot of the temperature profile and the axial load measured are shown in Figure 4-2.

The results of this test are shown in Table 4-3. Although no measurements were taken, no abrupt changes in the tube diameter were observed along the length of the tube. It was concluded that the deformation experienced by the tube would not be detrimental either to the installation process, i.e.. in preventing the tool from being removed, or to the long term performance of the sleeve/tube joint as described in Section 5.

A similar test was performed on a two by four array of .750 inch O.D. x .042 inch wall tubes arranged in a square pitch and supported as shown in Figure 4-3. This configuration replicates the first three hot leg supports of a typical Westinghouse D3 Series generator while conservatively simulating aspects of a CE unit. Four of the tubes were locked at their support (but not the FDB) location by tack welding in four locations. The other four were free from the tubesheet to Support Plate No. 8. Two Tube Support Plate (TSP) sleeves and a Roll Transition (RTZ) sleeve were installed in each tube as shown in the figure. The tubes were instrumented with strain gages to determine the strain in the outer fibers. During the heat treatment of each sleeve the strain in the tube was recorded. A load cell was used to determine the total load in the upper most section of tube. In the case of this mockup, the heat treatment commenced at the upper most weld and proceeded toward the tubesheet. Both sleeve welds (where applicable) were treated prior to any strain gage measurements. A typical temperature/time plot is shown in Figure 4-4. The results of the test are shown in Table 4-4. As would be expected, the more times the tube segments experiences the heat treat cycle the greater the residual stress. Examination of the tube surfaces in the vicinity of the welds indicated [

].

4.1.6 Summary

In summary, C-E has conducted a comprehensive development and verification program to ensure weld integrity of its leak tight sleeves. Experience has shown that oxide layers as visually confirmed to exist on the steam generator secondary side do not affect weld parameters and the abrasive cleaning method described in Section 3.3 is effective in preparing the tube for welding. Further, a method has been developed to stress relieve the welded sleeve to tube joint to provide increased resistance to PWSCC.

4.2 ROLLED JOINT INTEGRITY

A development program was conducted to ensure the rolled joint of the RTZ sleeve was leak tight and capable of withstanding the design loads. The sleeves were rolled into mock-ups consisting of steam generator tubes which had been rolled into blocks simulating the tubesheet. The sleeves were then tested to confirm the rolled joint was leak tight both before and after cyclic load testing. Tests of the rolled joint were also conducted where process parameters such as torque, tube diameter and roll location were varied. A test matrix was used to verify the sleeve installation with sleeve rolling process parameter tolerances. The test program confirmed that the rolled joint integrity is acceptable within the allowable rolling process tolerances.

In some cases, tubes have been installed into steam generator tubesheets by hydraulic expansion instead of rolling. In this case, a slightly greater gap may exist between the tube and the tubesheet hole. The torque applied by the sleeve rolling tool would close that gap and cause the tube to contact the tubesheet hole. Upon removal of the tool, either the tube would stay in place or spring back. In the first case the tube would act as a rolled tube and in the second the spring back would provide some additional holding force to the sleeve joint. For this reason the joint is considered qualified for application in this configuration as well as in a rolled tube.

Further verification of the acceptability of the rolled joint are the more than 15,000 rolled steam generator tube plugs in service for up to ten (10) years.

TABLE 4-1
ABB-CENO ACCELERATED PRIMARY SIDE SCC TESTS

TABLE 4-2
ENSA ACCELERATED PRIMARY SIDE SCC TEST
(Reference 6.7)

TABLE 4-3
0.875 O.D. SLEEVED TUBE PWHT DATA

TABLE 4-4
0.750 O.D. SLEEVED TUBE PWHT DATA
TUBES LOCKED AT ALL SUPPORTS

FIGURE 4-1
0.875 O.D. LOCKED TUBE TEST

FIGURE 4-2
0.875 O.D. LOCKED TUBE TEST
TEMPERATURE AND AXIAL LOAD PROFILE

[ ]

FIGURE 4-3
0.750 O.D. LOCKED TUBE MOCKUP

FIGURE 4-4
0.750 O.D. TYPICAL TEMPERATURE PROFILES

Key

5.0 SLEEVE PERFORMANCE VERIFICATION

5.1 COMMERCIAL SLEEVE INSTALLATION

C-E's commercial sleeving experience is shown in Table 5-1.

This data is also compiled in Table 5-2 to indicate the number of EFPY of exposure sleeves in each of the specific plants have experienced. The steam generators in which sleeves have been installed have experienced various tube degradation mechanisms, primarily caustic secondary side attack and primary water stress corrosion cracking. In one of these units, Ringhals 2, six (6) sleeved tubes which had seen up to three (3) EFPY were removed when the steam generators were replaced in 1989 (Reference 6.4). Examination of these sleeved tubes indicated weld heights consistent with ultrasonic inspection, acceptable weld penetration, and no evidence of any form of attack to the tube, sleeve, or the weld.

Recently over 1100 of these sleeved tubes at five plants have been inspected with one of two advanced eddy current probes (I-coil or Plus Point), which have been demonstrated highly effective in detecting cracks in sleeved tubes. Of these tubes, 162 (62 with PWHT) have seen from 4 to 6.5 EFPY and the remaining 953 (523 with PWHT) from 1 to 2.5 EFPY (Table 4-2). These inspections revealed no service related defects.

TABLE 5-1
INSTALLATIONS OF C-E'S WELDED SLEEVE

PLANT	DATE	SLEEVE QUANTITY INSTALLED *
ANO 2	10/95	662
Zion 1	10/95	911
Zion 2	01/95	162
Prairie Island 1	05/94	117
Zion 1	11/93	61
KRSKO 1	06/93	160 RTZ 14 TSP
Ginna	04/93	51
Zion 2	12/92	172
Prairie Island 1	11/92	158
ASCO 1	06/92	5 RTZ 49 TSP
Ginna	04/92	175 63 curved
Zion 1	04/92	124
Kewaunee	03/92	16 curved
Ringhals 3	07/91	46 RTZ 22 TSP
Ginna	04/90	192 48 curved

TABLE 5-1

INSTALLATIONS OF C-E'S WELDED SLEEVE
(continued)

PLANT	DATE	SLEEVE QUANTITY INSTALLED *
Zion 2	04/90	83
Prairie Island 1	01/90	63
Zion 1	09/89	445
Ginna	04/89	395 107 curved
Prairie Island 1	09/88	74
Ringhals 2	05/87	571
Ginna	02/87	105
Zion 1	10/86	128
Ringhals 2	05/86	599
Ginna	02/86	36
Ringhals 2	05/85	59
Ringhals 2	05/84	18

* Straight sleeves unless otherwise noted

RTZ - Roll Transition Sleeve
TSP - Tube Support Plate Sleeve

TABLE 5-2

ABB-CENO S/G Sleeve Operating History (to July 1995)

Plant	Hot Leg Temp (F)	Sleeve Type (1)	<1	1	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	Total
			Estimated EFPY of Sleeve Operation (2)														
Ringhals 2	610	STAW		16													
	600	STAW			571	599		59	16								1245
Ginna	601	STAW			51	178		183	198		408			104		36	1158
		PTAW				63		29	48		107						247
Prairie Island (4)	590	STAW												73		27	100
		STHT		117		158					62						337
Kewaunee (4)	590	PTAW				16											16
Zion 1	594	STAW		61	124			445				128					758
Zion 2 (4)	594	STAW	162	170				82									414
Ringhals 3[(4)]	610	RTHT						46									46
		SPHT						22									22
KRSKO (4)	619	RTHT		164													164
		SPHT		16													16
Total			162	528	746	1014	0	866	262	0	577	128	0	177	0	63	4523
Cumulative Total			4523	4361 (3)	3833	3087	2073	2073	1207	845	845	368	240	240	63	63	

Notes:

(1) Sleeve Type designations and their totals are as follows:

		Totals
STAW	StandardTubesheet sleeves where the welds are in the As Welded condition	3737
PTAW	Peripheral (Initially Curved) Tubesheet sleeves where the welds are in the As Welded condition	263
STHT	StandardTubesheet sleeves where the upper weld has been Post Weld Heat Treated	275
RTHT	Roll Transition sleeves where the weld has been Post Weld Heat Treated	210
SPHT	Support Plate sleeves where the welds have been Post Weld Heat Treated	38

(2) EFPY of operation is based either on data received from the plant or calculated from the load factor published in Nuclear Engineering International for the period during which the sleeves have been in place. Operating time is rounded to the neares 0.1 EFPY as of 1 July 1995

(3) 16 Sleeves which ran for a year at Ringhals 2 before T hot was reduced are included in totals for 600 F

(4) Plants inspected with I-coil or Plus Point ECT probe

5.2 SLEEVE-TUBE CORROSION TEST PROGRAM

In addition to the mechanical design described in Reference 6.1, the most significant aspect of a sleeved tube's performance is its resistance to the various corrosion mechanisms encountered in the steam generator. As described in Reference 6.1, C-E has conducted a number of bench and autoclave tests to evaluate the corrosion resistance of the welded sleeve joint. Of particular interest is the effect of the mechanical expansion/weld residual stresses and the condition of the weld and weld heat affected zone. Various tests have been conducted under accelerated conditions to assess the sleeve-tube joint performance under nominal and potential fault environmental conditions. Tests have been performed on welded joints with and without a post-weld heat treatment from which the relative margin afforded the sleeve life by applying such a process step can be estimated.

5.2.1 Primary Side

The life of the sleeved tube is mostly likely a function of the resistance of the parent tube area adjacent to the sleeve/tube joint to primary water stress corrosion cracking (PWSCC). As is well documented elsewhere, this resistance will depend on three issues; the initial metallurgical condition of the tube, the stresses in the tube and the temperature of the joint. Barring operational changes, the temperature of the joint will not differ from that of the parent tube nor in general will the metallurgical condition (in some cases, the grain growth and solution annealing that occurs in the weld heat affected zone may actually improve the resistance). Therefore, the single most important difference in assessing the life of the sleeve/tube joint from the primary side is the state of stress associated with the installed sleeve.

ABB-CENO has performed analyses and tests, described above to evaluate the total stress state at the critical location of the tube I.D. surface immediately adjacent to the weld. Preliminary tests confirmed that this location, as would be expected, contained the highest residual stress and therefore the life determining area. The total stress state associated with this area can be defined by its three components; the applied stress, short range or micro residual stress, and long range or reaction stress.

Once the stress state for the specific plant conditions has been established, the following Arrhenius relation described by EPRI in Reference 6.5 can be used to make a relative assessment of the increased margin afforded by post weld heat treatment:

$$L_{PWHT} / L_{AW} = (S_{PWHT} / S_{AW})^{-n}$$

where:

L_{PWHT} = Life of the Post Weld Heat Treated sleeved joint
L_{AW} = Life of the As Welded original tube
S_{PWHT} = Stress in a Post Weld Heat Treated joint
S_{AW} = Stress in an As Welded Tube/Sleeve joint
n = Empirically determined exponent
(conservative value = 4)

a) Sleeve Stress State

Applied Stresses - The applied stresses were calculated using the finite element analysis of the tube/sleeve joint described in Reference 6.1 for the region immediately adjacent to the tube/sleeve joint. The combination of pressure and thermal stresses results in a low stress on the tube I.D. surface. The compressive thermal stress is a result of the greater expansion of the sleeve relative to the tube due to its higher thermal expansion coefficient and higher temperature. This produces a bending moment on the I.D. surface and the corresponding compressive stress.

TABLE 5-3
APPLIED STRESSES IN BYRON/BRAIDWOOD TUBE SLEEVE JOINT

[ ]

Micro Residual Stresses in the Weld HAZ - The HAZ stresses due to the localized weld shrinkage have been determined from the accelerated corrosion tests, as described above. Under these conditions, stresses for the post weld heat treated joint were found to be on the order of [.].

Reaction Stresses in Locked Tubes - When the tubes are locked at support locations due to denting or other mechanisms, the tube undergoes a compressive load during heating (whether by welding or PWHT) which shortens the tube and causes some column buckling. During cooling the tube is put into tension. The magnitude of the resulting stresses depends on the amount of deformation which is a function of the temperature, length of the heated zone, and the time the tube is heated. In the case of the as-welded sleeve/tube joint, the stresses are on the order of a few ksi. For the heat treated sleeve/tube joint the level of stress in any particular tube ranged considerably depending on the length of the locked tube span, the number of sleeves, and the location of the sleeves with respect to the tube section being measured. Although the worst case involves the installation of multiple sleeves in a single tube, the more common practice is to install only a roll transition zone sleeve for which the stresses would be significantly less.

These stresses represent a worst case scenario and may not necessarily be present in all units. The locked condition described is less likely to be the case in a steam generator that has an open support structure design such as eggcrates and/or where denting has not been experienced. However, inasmuch as it is difficult to determine whether tubes are locked, the assumption is that they are locked.

TABLE 5-4
TOTAL AXIAL STRESS ASSOCIATED TUBE/SLEEVE JOINT

Using the above relationship and the stresses given in Table 5-4, the relative improvement in sleeve joint life for a post weld heat treated sleeve as compared to one in the as-welded condition is expected to range from [ ] depending on the number of sleeves installed in a particular tube.

[ ]

5.2.2 Secondary Side

The life of the sleeved tube from the steam generator secondary side environment depends on interactions at two locations on the sleeved tube. First with respect to the tube at the location immediately above the weld on the O.D. surface. Second, if the original mode of tube failure was from the secondary side, in the annulus between the tube and the sleeve.

By the very nature of the weld joint in both an RTZ, TS and TSP sleeve, it must be located outside a region where fault species are capable of concentrating, i.e.. tube/support intersections or sludge pile. Therefore the principle environment experienced by the tube O.D. in the vicinity of the weld is the volatile secondary side chemistry. This environment is similar to that of the primary side in that it consists of very pure water without the aggravating factors of hydrogen and the higher primary side temperature. Therefore, stress corrosion cracking from the tube O.D. due to secondary side environments is not considered likely at the weld location.

In the annulus between the tube and the sleeve, it may be possible to concentrate whatever fault species had caused the initial failure of the tube. In this case the failure of the sleeve/tube combination would be dependent on the sleeve and sleeve weld's resistance to the concentrated species as well as the time it took for the environment in the annulus to develop. Corrosion testing performed on tube/sleeve assemblies as well as that performed on thermally treated Alloy 690 itself (Reference 6.1) shows that the sleeve and weld offer superior resistance to the typical fault environments which may form in this region. Any detrimental effect of the sleeve installation on the tube would result in only further degradation of the tube in that area where the sleeve has established the fluid boundary. Inasmuch as no credit is taken for the original tube in this region, the structural integrity of the assembly would not be degraded.

5.3 SLEEVE-TUBE INSPECTION

As described in Reference 6.1, the inspection of new sleeves is performed using both ultrasonic (UT) and eddy current (ECT) examination methods. Ultrasonic inspection is used only upon the initial installation of the sleeve. Subsequent to installation a multi frequency eddy current testing is performed on the sleeve and sleeve joint as a baseline for future in service examinations. At present, the ECT method being employed utilizes the Plus Point probe considered to be among the current state of the art.

5.4 SUMMARY

The operating performance of the welded tube sleeve has been shown to provide acceptable service life in a variety of steam generators both in the as-welded and post weld heat treated condition. Corrosion testing and evaluation of sleeved tubes, even under conditions of considerable tube restraint, have demonstrated the beneficial effects in stress corrosion cracking resistance associated with post weld heat treated joints. Further, inspection methods have been developed and qualified that are sufficiently sensitive to detect tube and/or sleeve defects in accordance with present industry standards. As such, periodic inspection and leakage monitoring will ensure that any premature degradation that may occur in the sleeved joint will be identified.

6.0 REFERENCES

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