ATTACHMENT E

Beaver Valley Power Station, Unit No. 2
License Amendment Request No. 07-007

Attached is SG-SGDA-05-048-NP, "WOG PA-MSC-0190, Revision 1: Test Results Related to TIG and Alloy 800 Sleeve Installation in 3/4 Inch and 7/8 Inch OD SG Tubing In-Service Inspection Requirements," dated January 2006 (Non-proprietary).

SG-SGDA-05-48-NP
Revision 1
(CEN-630-NP Revision 2 Addendum
WCAP-15918-NP Revision 2 Addendum
WCAP-15919-NP Revision 2 Addendum)

January 2006

WOG PA-MSC-0190, Revision 1: Test Results Related to TIG and Alloy 800 Sleeve Installation in 3/4 Inch and 7/8 Inch OD SG Tubing In-Service Inspection Requirements

Westinghouse

Westinghouse Non-Proprietary Class 3

SG-SGDA-05-48-NP
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SG-SGDA-05-48-NP

(CEN-630-NP Revision 2 Addendum, WCAP-15918-NP Revision 2 Addendum, WCAP-15919-NP Revision 2 Addendum)

WOG PA-MSC-0190, Revision 1: Test Results Related to TIG and Alloy 800 Sleeve Installation in 3/4 Inch and 7/8 Inch OD SG Tubing In-Service Inspection Requirements

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January 2006

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This work was performed under WOG Project Number PA-MSC-0190, Revision 1.

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* This is a list of participants in this project as of the date the final deliverable was completed. On occasion, additional members will join a project. Please contact the WOG Program Management Office to verify participation before sending documents to participants not listed above.

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Electrabel (Belgian Utilities)	Doel 1, 2 & 4, Tihange 1 & 3		X
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Spanish Utilities	Asco 1 & 2, Vandellos 2, Almaraz 1 & 2		X
Taiwan Power Co.	Maanshan 1 & 2		X
Electricite de France	54 Units		X

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Repair (for continued operation) of steam generator tubes with sleeves has been used since the early 1980's. Starting with these early designs, it was accepted that the application of a mechanical roll expanded joint between the tube and sleeve within the tubesheet would provide for a sufficiently robust joint such that postulated degradation of the parent tube within this region would not detrimentally affect the integrity of this joint. Additionally, it was believed that such degradation would be detectable using standard eddy current testing methods. As such, the design documentation, and NRC safety evaluation reports (SERs) addressing sleeving have not included an inservice inspection of the parent tube behind the sleeve.

With the advent of the ABB-CE TIG sleeve, enhancements to the design of the mechanical roll joint included application of a pure nickel band to the outside diameter (OD) of the sleeve. This band was intended to act as an additional barrier to primary fluid leakage between the sleeve and tube. However, the nickel band complicated eddy current data analysis for the parent tube in this region. This design was carried to the Alloy 800 sleeve design.

Inspection results from some plants have indicated a potential for primary water stress corrosion cracking (PWSCC) degradation in the parent tube throughout the expanded tubesheet length, including elevations consistent with the sleeve hardroll joint location. Thus, a potential exists for PWSCC degradation of the parent tube to have been present at the time of sleeve installation.

The industry has acknowledged the issues with flaw detection capabilities behind the nickel band and had previously concluded that degradation of the parent tube in this region would not prevent the sleeve from providing axial load bearing capability consistent with the design bases; i.e., greater than three times the normal operating pressure differential end cap load associated with sleeved tube geometries (Reference 1). The industry has undertaken a test program to verify the conclusions developed in Reference 1. This addendum serves to document the results of this testing program and formulate a basis establishing that axial and circumferential degradation of the parent tube adjacent to the nickel band, at any depth, will not prevent the sleeve from satisfying the design requirements. Thus, flaw detection capabilities within the parent tube adjacent to the sleeve nickel band are not necessary in order to evaluate continued operation of the sleeved tube. Current inspection methods can identify degradation of the parent tube beginning at depths that approach a through wall condition. Thus, sleeved tubes with identified degradation of the parent tube in this region will be removed from service by plugging prior to the degradation of the parent tube achieving the depths considered in this report. This report supplements the design documents that address each of the sleeve designs considered, TIG and Alloy 800, for installation in C-E, Westinghouse D series, and Westinghouse 51 series steam generators. The data presented herein does not alter any conclusion developed within the design documents.

Revision 1 of this document only corrects classification of proprietary information. No changes to text are associated with Revision 1. Revision 0 of this document was not issued or released.

1 INTRODUCTION

The TIG and Alloy 800 sleeve designs are currently installed in several US and European plants with recirculating steam generators. TIG sleeves have been installed in US plants since 1986, with the rolled lower joint replacing the welded lower joint in 1995. The original evaluation of the TIG sleeve design did not include a requirement for in service inspection of the parent tube behind the tube to sleeve hardroll joint, located at the bottom of the sleeve assembly. The TIG and Alloy 800 sleeve designs include two deposit bands applied to the sleeve OD in the hardroll joint region. The upper band, called the microlok band, is comprised of a nickel based alloy that acts to increase the coefficient of friction between the tube and sleeve, thus increasing the axial load capability of the joint. A pure nickel band is located immediately below the microlok band. The nickel band is intended to act as a barrier to leakage past the tube to sleeve hardroll joint. Each of these bands is ½ inch wide, with the interface between the microlok and nickel bands located at the center of the hardroll joint region. For the TIG sleeve the hardroll flat length, defined by the geometry of the roll pin, is 1.25 inch while the flat length for the Alloy 800 sleeve design is 1.10 inch.

Report CEN-630-P, Revision 2 documents the design and analysis of the TIG sleeve for installation in 3/4 inch OD steam generator tubing. The pressure boundary definition of the parent tube behind the sleeve provided by CEN-630-P is not specific. Further discussion contained in 96-OSW-003-P, Revision 0 can be used to conclude that the parent tube behind the sleeve to tube hardroll joint was not intended to be included as part of the pressure boundary, and thus not subject to routine in service inspection. However, it is realized that the parent tube must be "present" in order for the sleeve to tube hardroll joint to function as intended. Up to this point, the Plus Point© rotating pancake coil has been used to perform in service inspection of the installed sleeve and parent tube behind the sleeve at the upper and lower sleeve joints.

With the introduction of the Alloy 800 sleeving system, the WCAP report that documents the design specifically identified regions of the tube and sleeve which constitute the pressure boundary. WCAP-15918 and WCAP-15919 specifically identify the parent tube adjacent to the sleeve to tube hardroll joint as part of the pressure boundary. The logic behind this specification was that a tube was required in order for the joint to perform as designed.

Inspection results from some plants have indicated a potential for primary water stress corrosion cracking (PWSCC) degradation in the parent tube throughout the expanded tubesheet length, including elevations consistent with the sleeve hardroll joint location. One unit which currently has TIG sleeves installed has exhibited this potential. Thus, a potential exists for PWSCC degradation of the parent tube to have been present at the time of sleeve installation. The design document addressing SG tube repair with TIG sleeves did not require a rotating pancake coil (RPC) inspection of the parent tube in the sleeve to tube hardroll joint elevation prior to installation. Inspection of the parent tube in this region was not performed for earlier TIG sleeve installations, however this practice was implemented for the most recent TIG (2004) and Alloy 800 (2003 and 2004) sleeve installations. The issuance of NRC Generic Letter 2004-01 and NRC questioning of the industry regarding flaw detection capabilities in the parent tube adjacent to the nickel band of the sleeve were contributing factors leading to the initiation of the test program herein discussed.

As the nickel band can act as a conductor of eddy currents, the influence of the nickel band upon eddy current probe response is to act as a large noise source. The amplitude of this noise response can prevent the detection of part throughwall degradation in the parent tube adjacent to the sleeve nickel band. Evaluation of signal responses from TIG sleeve calibration standards concludes that axial and circumferential degradation of about 70% TW and greater on the parent tube adjacent to the sleeve nickel band would be readily detectable with current Plus Point probes. Detection of degradation more consistent with a typical technical specification repair limit of 40% TW by NDE is judged more challenging. Note that the technical specification repair limit represents a tube degradation depth that includes NDE measurement uncertainty, and considering the bases for this limit, represents degradation depths greater than the repair limit.

The industry has acknowledged the issues with flaw detection capabilities behind the nickel band and has concluded that degradation of the parent tube in this region would not prevent the sleeve from providing axial load bearing capability consistent with the design bases; i.e., greater than three times the normal operating pressure differential end cap load associated with sleeved tube geometries (Reference 1). The industry has undertaken a test program to verify the conclusions developed in Reference 1. This addenda serves to document the results of this testing program and formulate a bases that establishes that axial and circumferential degradation of the parent tube adjacent to the nickel band, at any depth, will not prevent the sleeve from satisfying the design requirements. Thus, flaw detection capabilities within the parent tube adjacent to the sleeve nickel band are not necessary in order to evaluate continued operation of the sleeved tube. To date, degradation of the parent tube behind the sleeve in the sleeve to tube hardroll joint region has not been reported.

2 SUPPLEMENTAL TESTING PROGRAMS

A testing program was performed to establish that the conclusions developed in the position paper (Reference 1) were valid. The testing program was designed to show that severe forms of tube degradation within the parent tube adjacent to the sleeve nickel band do not detract from the sleeve anchorage characteristics (i.e., the design requirement that the hardroll joint maintain axial resistive load capability of greater than the three times normal end cap load condition). The program involved testing of sleeves in 0.75 inch OD x 0.043 inch wall thickness hardroll expanded tubes simulating the Westinghouse Model D steam generator configuration, 0.75 inch OD x 0.048 inch wall thickness hydraulically expanded tubes simulating the C-E steam generator configuration, and 0.875 inch OD x 0.050 inch wall thickness hydraulically expanded tubes simulating the Westinghouse Model 51 steam generator configuration. With regard to anchorage capabilities, hydraulically expanded tube represents a bounding condition compared to hardroll expanded tubes. For the hardroll expanded tube condition more energy is available to increase the wall thinning of the sleeve, thus increasing the radial contact pressure between the tube and sleeve resulting in a more robust joint. In the hydraulically expanded condition the tube experiences additional wall thinning prior to completion of the wall thinning operation of the sleeve. As explosive expansion of tubes was not available, this condition was simulated using hydraulic expansion. The selection of the hydraulic expansion pressure was designed to result in a tube to tubesheet joint with similar axial load capabilities as explosively expanded tubes (Westinghouse "WEXTEX" and C-E "explansion"). Additional discussion regarding this selection process is provided later. For all tensile tests, the length of the tubesheet simulant collar was 6 inches. The hydraulic expansion was applied over a 5.5 inch length with the lower edge of the expansion located just inside of the collar. In field installations, the center of the sleeve to tube hardroll joint is located at the approximate mid-plane elevation of the tubesheet or approximately 10.5 inches below the top of tubesheet. In the field this length of tube expansion, as well as the expanded tube length below the mid-plane elevation anchor the tube to the tubesheet.

2.1 MODEL D SIMULATION TESTING

The first of these programs involved tensile testing of Alloy 800 sleeves installed in full depth mechanical roll expanded joints using 3/4" OD x 0.043" wall thickness tubing. These specimens simulate the condition at Comanche Peak Unit 1 and Watts Bar Unit 1. These specimens were configured to simulate a complete separation of the tube adjacent to the intersection of the microlok and nickel band regions. Figure 2-1 presents a schematic of the test configuration.

The specimens were prepared by rolling a mill annealed Alloy 600 tube section into a 1018 carbon steel tubesheet simulant collar with one end of the tube inserted from the secondary side of the collar to 0.75 inch from the primary face of the collar. A second tube section was inserted into the collar to contact with the first section and rolled in place. The roller and roll torque used are consistent with the original SG manufacture. This configuration simulates a complete circumferential separation of the parent tube.

A total of 5 specimens in this configuration were tensile tested. Specimens 1 and 2 were rolled using a sleeve torque of 110 in-lb which bounds the applied torque for the actual Comanche Peak installations. Specimens 3, 4, and 5 were rolled at the nominal installation torque of 130 in-lb. The sleeves were positioned such that the microlok to nickel band interface was adjacent to the tube separation.

The sleeves were internally pressurized to 1500 psi during tensile testing. During plant operation or accident conditions, the internal pressurization and thermal expansion characteristics of the materials used increases the normal contact force between the sleeve and tube thus increasing the axial load bearing capability. Testing at operating temperature was not performed due to complexity of the test configuration.

2.2 C-E SIMULATION TESTING

The second test program included both tensile and leakage testing. This program used 3/4" OD x 0.048" wall thickness mill annealed Alloy 600 tubing and 1018 carbon steel tubesheet simulant collars. The sample configuration used hydraulic expansion to simulate the explosive tube expansion process applied at SONGS 2 and 3. The hydraulic expansion parameters were selected by iterative testing. The test intent was to define an expansion process that resulted in a tube to tubesheet joint configuration that equaled the tensile test results of expansion specimens utilized in the C* program development (Reference 2). By using a hydraulic expansion process that gave similar tensile test results as the C* program, the hydraulic expansion is judged to have resulted in similar radial contact forces as expansion. As the axial load capabilities of the expanded tube are a function of the contact forces and coefficient of friction between the tube and sleeve, for equivalent coefficient of friction conditions the contact forces must then be equal if the axial load capabilities are equal. The eventual process included an [

]a,c,e. The pre expansion and post expansion outside diameters of the tubesheet simulant collars were compared to determine if the expansion resulted in yielding of the collars. For all collars, the pre and post expansion diameters were equal, thus yielding of the collar did not occur.

In this program, the tubes were modified to simulate axial degradation in the parent tube adjacent to the nickel band region. Six, 0.48 inch long, 85% deep OD axial EDM notches were equally spaced around the tube circumference with the upper edge of the EDM notches located at approximately 0.75 inch into the collar. The EDM notches were applied to the tube OD to prevent the rolled sleeve from embedding within the notches, which could artificially elevate axial load capabilities. The axial notches were designed to limit the ability of the tube to transmit radial loads resultant from the tube expansion process. The expansion process is expected to result in a compressive residual stress condition where the tube is restrained from additional diametrical expansion by the tubesheet. For the case of postulated axial degradation of the parent tube adjacent to the nickel band region of the sleeve the presence of axial degradation could result in some reduction of radial preload forces but would not result in a condition where the tube comes out of contact with the tubesheet in the radial direction. The subsequent sleeve installation will result in a normal force component in this area even for the case of a complete loss of radial preload forces in the tube.

Eight tensile specimens were configured in this manner. Four included TIG sleeves installed at nominal torque values of [

]a,c,e. The sleeves were positioned such that the interface between the microlok and nickel bands was adjacent to the top of the EDM notches in the parent tube. The sleeve installation torque for field applications is [

]a,c,e. While the nominal installation torque used for the lower end of the specimen preparation for TIG is slightly greater than the field acceptance limit actual field installation values are targeted towards the center of the range and field installation at 100 in-lb is unlikely. The installation tooling uses an electronic torque trip that shuts air supply to the motor when a resistive torque equal to the trip set point is achieved. For field installations, this setting is iteratively determined to produce a value of [ ]^{a,c,e}. The specified variance about the set point is +/- 10 in-lb with the typical true torque applied to the sleeve of slightly greater than the nominal set point. For all specimens, the applied torque was greater than the trip set point. Thus while some of the specimens were installed at lower torque values this torque is not likely to have been applied in the field.

Separated tube simulations were also prepared with the elevation of the separation approximately 0.75 inch into the collar. Two specimens were configured in this manner; the tubes did not include the axial EDM notches. In order to maintain the radial stiffness characteristics of the hydraulically expanded tube, once the tube was expanded in the collar, counterbored and threaded holes were installed axially (parallel with the tube axis) into the collar walls to a specified depth. The collar was then saw cut perpendicular to the tube axis and each saw cut face then milled to a smooth condition. The two collar sections were then bolted together using screws modified to maintain a tight tolerance fit with the counterbored holes in order to maintain tube axis alignment. The sleeves were installed such that the interface between the microlok and nickel bands was adjacent to the tube separation. Alloy 800 sleeves were installed at 110 in-lb so that a direct comparison with the Model D separated tube samples could be performed.

The average collar ID for all tensile specimens averaged 0.7580 inch, which represents the largest permissible tubesheet hole ID per the manufacturing drawing. The range of tubesheet hole diameters used was 0.755 to 0.760 inch.

Tensile specimens used in this program did not utilize internal pressurization, thus the benefits of internal pressurization and thermal expansion were not included.

2.3 MODEL 51 SIMULATION TESTS

The third test program involved use of 7/8 inch OD tubing. Mill annealed Alloy 600 tubes and 1018 carbons steel collars were used. The tubes used the configuration of six, 0.48 inch long, 85% TW axial OD EDM notches equally spaced around the tube OD. As it was judged that sleeve installation in an explosively expanded tube condition would represent a bounding case (compared to hardroll tube installation), the samples prepared used primarily hydraulic expansion with selection of the expansion pressures following the same process used for the C-E samples. Two samples were configured with tube expansion by rolling. For the 7/8 inch OD tube specimens, only Alloy 800 sleeves were used. The sleeves were installed such that the interface between the microlok and nickel bands were consistent with the upper edge of the axial EDM notches.

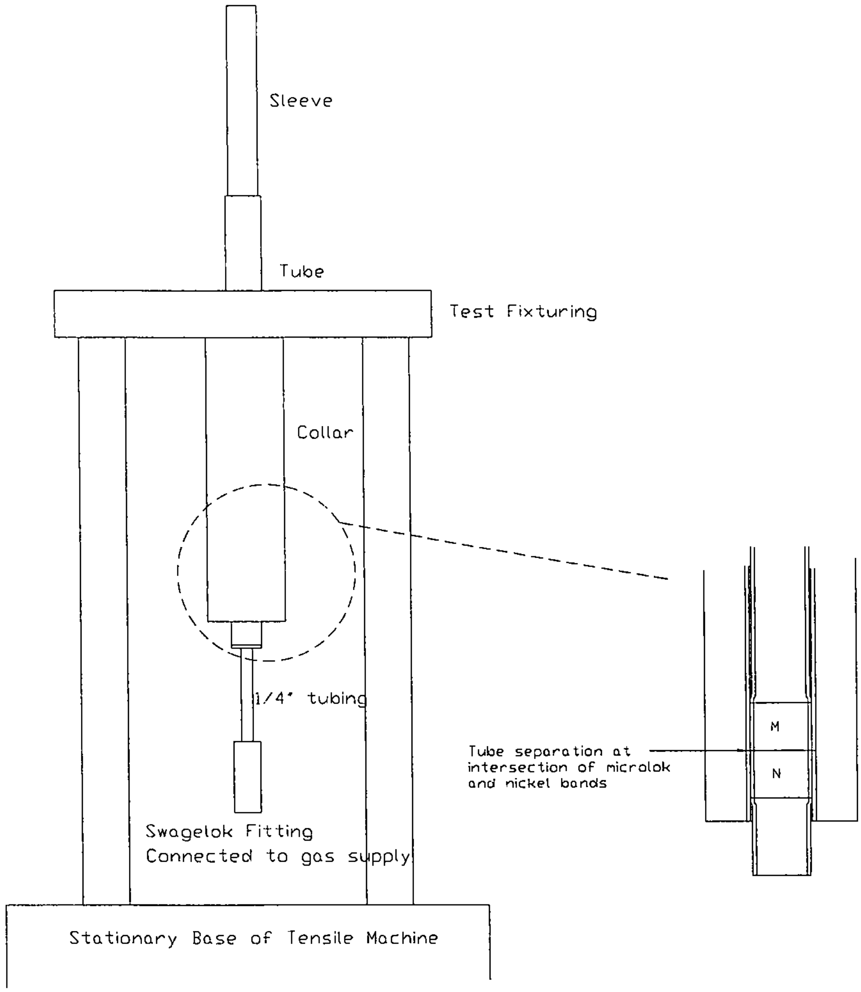

Figure 2-1 Schematic of Tensile Test Setup

3 LEAK SPECIMEN CONFIGURATION

The leak specimen configuration is shown in Figures 3-1, 3-2, and 3-3. The specimens were configured such that the primary fluid communicated with both the tube to collar and tube to sleeve joint regions. Two 1/16 inch diameter holes were milled through the collar to the point where the full mill diameter affected the sleeve OD surface. A 1/8 inch diameter hole was milled to a depth where the full mill diameter affected the tube OD surface. The sleeve was then deformed by staking to introduce a 0.001 to 0.003 inch separation from the tube ensuring that the primary fluid had a direct path to the sleeve to tube joint interface. The hole locations were such that the edge of the hole was consistent with the microlok to nickel band interface. Leak test primary to secondary pressure differentials used were 1500 psi and 2560 psi. Figure 3-3 presents a schematic of the leak test sample modification to permit primary fluid communication with both the tube to tubesheet and tube to sleeve interfaces. In addition, the end of the sleeve inside of the end cap was plugged, thus there was no pressure inside of the sleeve. Any pressure expansion benefit upon the sleeve to tube interface was not included. Also, due to the manner in which the primary fluid was delivered to the sleeve to tube interface, the direction of the pressure developed forces act to keep the sleeve to tube interface open to the primary fluid.

The specimens were first leak tested at room temperature at pressure differentials of 1500 and 2560 psi. The primary fluid used was deaerated to prevent oxidation of the carbon steel collars in the tube to tubesheet crevice region and included additional additives to simulate reactor coolant fluid. Previous testing has shown that the thermal expansion characteristics of the sleeve in tube and tube in collar configuration will result in increased contact pressures at elevated temperature, thus resulting is a lesser leak rate at elevated temperatures. Any specimen that leaked at room temperature was also leak tested at 600°F in a high pressure autoclave.

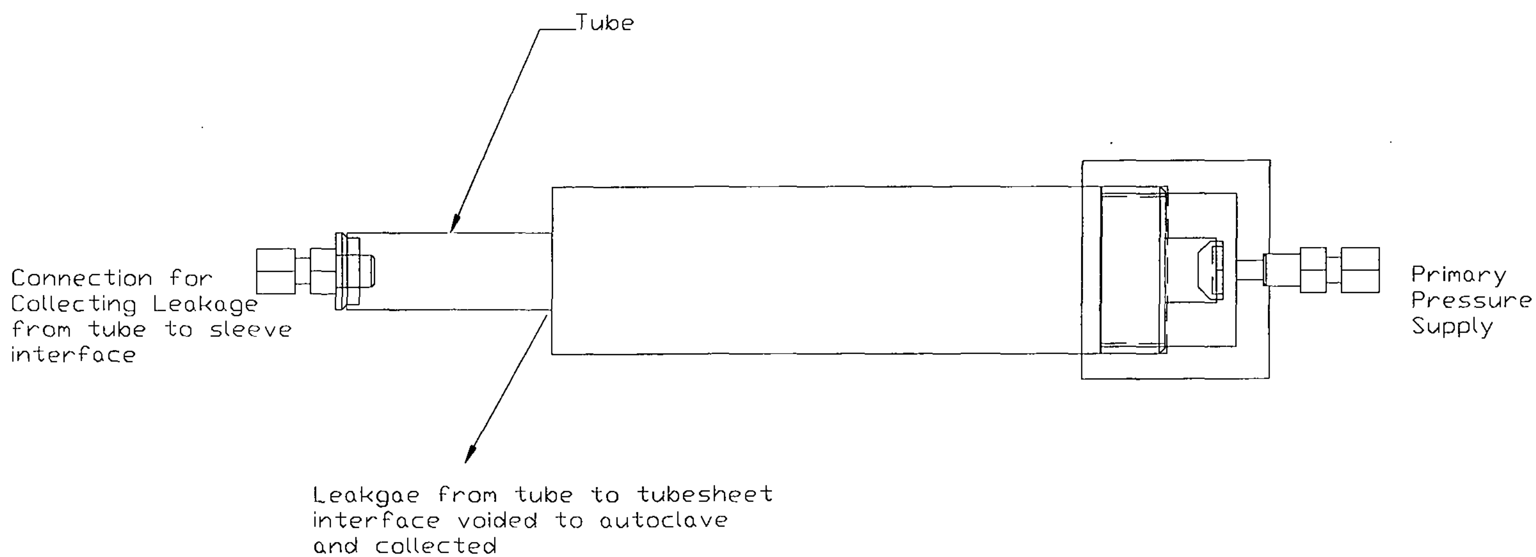

Figure 3-1 Leak Specimen Configuration

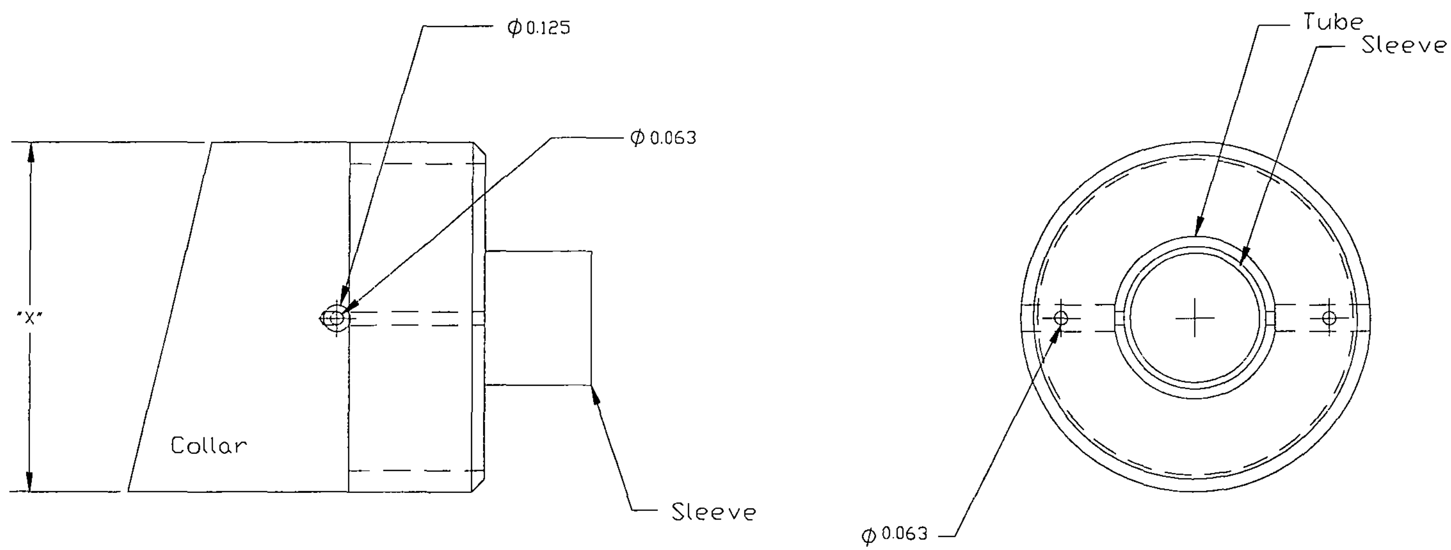

Figure 3-2 Modification to Leak Specimen

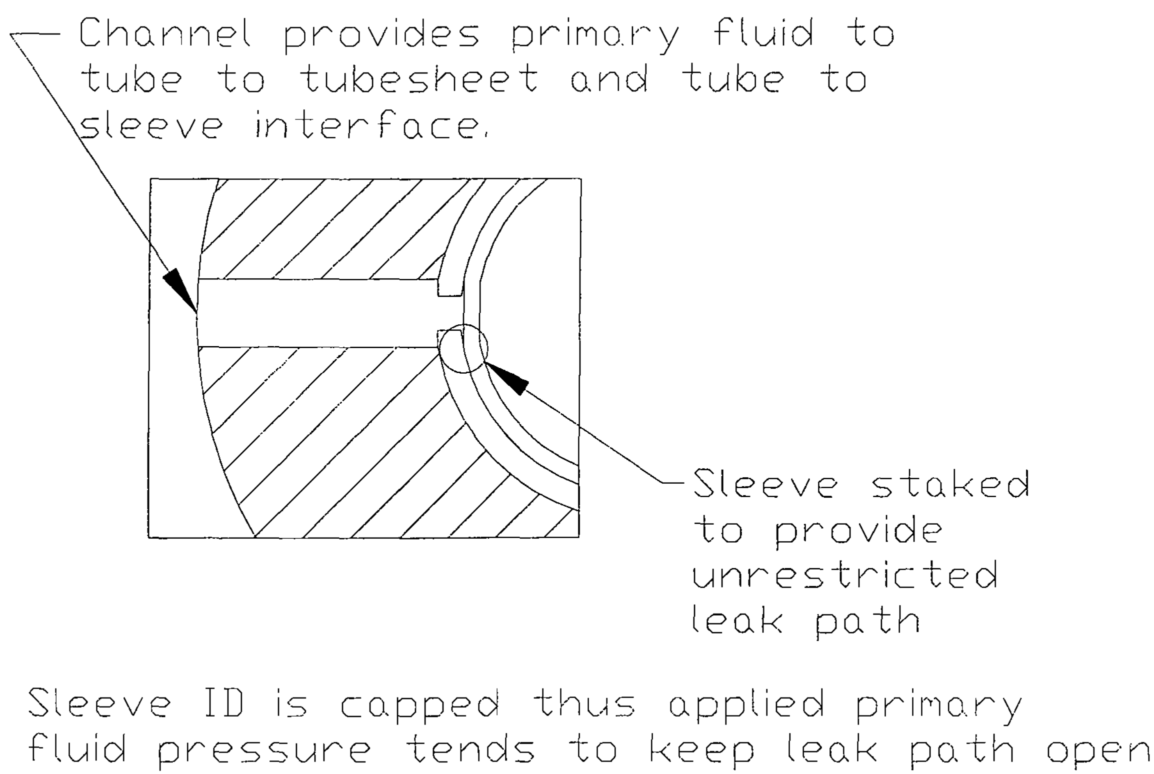

Figure 3-3 Details of Leak Path Configuration

4 DISCUSSION OF TENSILE TEST RESULTS

4.1 MODEL D SIMULATION TESTS

Table 4-1 presents the first slip and peak load data for these tests.

As seen from Table 4-1, all first slip and peak loads exceeded the Comanche Peak three times normal operating pressure differential end cap loading of 1486 lbf. The end cap loading was developed using the largest permissible tubesheet hole diameter and wall thickness of 0.041 inch which accounts for wall thinning due to expansion, and three times normal operating pressure differential of 4000 psi. First slip loads for the 110 in-lb sleeve installations averaged [ ]a,c,e, while the first slip load for the 130 in-lb installations averaged [ ]a,c,e . Peak loads were approximately 10% higher than first slip loads and peak loads occurred at about 2 inches of sleeve displacement. For specimen #3, the sleeve failed in tension at [ ]a,c,e prior to slippage of the sleeve to tube hardroll joint. The position paper argues that a circumferentially separated tube would not affect load characteristics. The first slip and peak load capabilities appear to be unaffected by a separated tube condition, thus validating the position paper (Reference 1).

A dummy specimen was prepared whose objective was to gather characteristic data regarding the test setup so that the testing of the official qualification specimens provided appropriate data. Internal pressurization was not included. This specimen used a fully intact tube, hardrolled at a nominal torque of [ ]a,c,e. The first slip load was approximately [ ]a,c,e, thus indicating that the internal pressurization added only about 400 lbf to the overall axial load capability. The impact of internal pressurization on axial load capability was calculated in a manner consistent with the methods developed for the F* alternate repair criteria. For 1500 psi internal pressurization of the sleeve, the increase in contact pressure is approximately 1050 psi. For an assumed coefficient of friction of 0.4 between the microlok region and tube, this equates to an additive axial load resistance capability of 420 lbf.

Comparison of the dummy and qualification specimen first slip loads indicates that the tube degradation (complete circumferential separation at the microlok to nickel band interface) had no effect on first slip loads.

Figure 4-1 presents the load-displacement curve for Specimen 1. The displacement measured is the total displacement of the tensile machine crosshead, and includes slippage of the gripper jaws on the tube OD (about 1/16 to 1/8 inch of total displacement), elongation of the sleeve due to general yielding in tension, and slippage of the sleeve within the tube. The total measured displacement for Specimen 1 is 5 inches. Measurement after completion of the test indicates that the sleeve displaced a total of 2.5 inches within the tube, thus the difference is attributed to elongation of the sleeve. Witnessing of the test verified that the indicated first slip at about [ ]a,c,e coincided with the first visual evidence of sleeve displacement. After first slip of the sleeve, no evidence of galling was observed. The expected performance was that after first slip the effects of galling would result in an irregular loading pattern as the material galled, broke free, galled, broke free, etc. This observation may be related to the hardness of the tube ID due to the mechanical roll expansion process or the sliding friction characteristics of the microlok region. The change in slope of the load-displacement curve at about 2400 lbf is consistent with the load to develop stresses in the sleeve equal to the indicated yield stress of the tube material.

4.2 C-E SIMULATION TESTS

Table 4-2 presents the first slip and peak load data for these tests.

As seen from Table 4-2, all first slip and peak loads exceeded the SONGS three times normal operating pressure differential end cap loading of 1515 lbf for a normal operating primary to secondary pressure differential of 1450 psi. The largest permissible tubesheet hole of 0.758 inch and wall thickness of 0.046 inch were used for calculation of the end cap loading. For all specimens the first slip loads exceeded [ ]a,c,e which shows no discernable difference from the Model D separated tube sample results. Unlike the Model D simulations the first slip loads for most of the C-E specimens were also the peak load achieved for the test. No discernable difference in first slip or peak load capabilities was observed for sleeve installations at [ ]a,c,e. A similar observation regarding first slip load and applied torque was made for hybrid expansion joint (HEJ) sleeves during development of this sleeve design. Figure 4-2 presents the load-displacement curve for Specimen Tensile-6.

Examination of tubes after testing indicates that none of the tubes slipped within the tubesheet collar during the tensile test. The axial load capability testing performed as part of the C* program indicates an axial load capability of approximately 6000 lbf for a 4 inch explosively expanded length. Thus for the 5.5 inch length utilized for the tube to collar installation the expected axial load capability is greater than 8000 lbf, which is significantly greater than the peak load achieved during tensile testing.

One specimen (Tensile-11) was configured using an EDM notched tube and an Alloy 800 sleeve installed at 100 in-lb. The intent of the test was to compare the first slip load capabilities for sleeves with and without the microlok band. The first slip load for this test was approximately [

]a,c,e. This load pattern is similar to the HEJ test data which shows peak loads greater than first slip loads.

4.3 MODEL 51 SIMULATION TESTS

Table 4-3 presents the first slip and peak load data for these tests.

As seen from Table 4-3, all first slip and peak loads exceeded the Diablo Canyon and Beaver Valley three times normal operating pressure differential end cap loading of 2219 lbf and 2172 lbf. These end cap loads were developed using an expanded tube diameter of 0.795 inch.

For three of the four hydraulically expanded samples, slippage of the tube within the collar occurred after the first slip load of the sleeve to tube hardroll joint was achieved. The load corresponding to this condition was less than the first slip load and occurred during load recovery. In one case (Tensile-2), slippage between the sleeve and tube did not occur; the tube slipped within the collar without displacement of the sleeve within the tube. The first slip load for this specimen was [ ]a,c,e. Examination of the OD dimensions for this sample indicate that the tube OD at the middle of the microlok band and at the middle of the axial EDM notched area is 0.001 to 0.0015 inch greater than the tube OD above the sleeve to tube roll region (in the hydraulically expanded tube length) indicating that the sleeve to tube roll provides additional axial load capability for the entire tube. The difference in diameters could have occurred upon sleeve rolling if a small gap existed between the tube and tubesheet collar, or the diameter change could have occurred due to equalizing of radial stresses in the roll region once the tube was completely pulled out of the collar. It should be noted that the hydraulically expanded joint length used for these specimens is roughly half of the expanded tube length above the sleeve to tube hardroll joint in field installations, thus such an observation (tube slippage) would not be expected in the field. The tube length below the joint would also add to the overall axial load capabilities of the tube. For the WEXTEX joint, the axial load capability at a 5.0 inch length is approximately 5800 lbf. The total expanded length was 5.5 inches, however, the lower 0.5 inch of tube length would not be expected to provide any additional resistive load capacity due to the axial EDM notches. At 6887 lbf first slip load, the first slip load is 1000 lbf greater than the integrity characteristics of the tube to tubesheet joint, thus, it can be concluded that the impact of sleeve rolling increases the tube to tubesheet joint axial load capabilities, and the results of this test are valid, with the first slip load for the tube to sleeve joint of greater than 6887 lbf. Specimen Tensile-1 experienced tube slippage at approximately 6125 lbf; the tube slippage occurred shortly after the sleeve to tube joint began to slip. Specimen Tensile-3 had no slippage of the tube; the peak load after first slip was 6553 lbf. Specimen Tensile-4 experienced tube slippage at approximately 5800 lbf, which is consistent with the WEXTEX joint. The sleeve had slipped several inches when the tube began to slip.

Specimen Tensile-5 had a first slip load of 6904 lbf; the sleeve joint did not slip, the tube slipped in the collar. Through the loading cycle the sleeve joint never slipped. Peak load after first slip was 6169 lbf. Specimen Tensile-6 had a sleeve first slip load of 6852 lbf. Slippage of the tube in the collar occurred at 6312 lbf. These specimens were produced by rolling the tube at 45 in-lb; hydraulic expansion was not used. The 45 in-lb value represents the lower end of the acceptable tube installation torque specification. The tube roll joint length for these tests was only 3 inches. It is suspected that for specimen Tensile-6 the expanded sleeve diameter began to interact with the unexpanded tube thus causing the tube to begin to slip. The total deflection at this point was about 4 inches. Still, first slip loads for these two specimens exceeded the limiting 3 times normal operating pressure differential end cap load based on the tubesheet hole diameter.

The first slip loads for Tensile-1 and Tensile-2 were on average about 10% lower than Tensile-5 and Tensile-6. The position paper stated that the simulated explosively expanded tube condition would represent a bounding condition between explosive and roll expanded tubes.

The axial load capabilities of the 7/8 inch OD tube specimens were so large that the validity of the specimens was questioned. The positioning of the sleeves for these samples was such that the centerline of the roll region was 0.55 inch into the test collar thus placing the bottom of the sleeve hardroll flat coincident with the tube end. It was theorized that the sleeve rolling operation had caused sleeve material to flow below the hardroll flat, thus creating a bulge of sleeve material just below the tube end. This bulge of material could have acted to artificially increase the axial load capabilities.

In response, four additional 7/8 inch OD tube specimens were prepared. These specimens used hardroll expanded tubes at 45 to 50 in-lb. The location of the EDM notches and thus the relative positioning of the sleeve were further into the collar to eliminate this potential. Specimen Tensile-7 was configured to simulate a separated tube at 1 inch into the collar. Specimens Tensile-8, Tensile-9, and Tensile-10 used EDM notched tubes. The top of the EDM notches, and thus interface between the microlok and nickel bands was located at 0.88 inch into the collar. These specimens used existing EDM notched tubes that located the top of the EDM notch at 0.54 inch above the tube end. This resulted in the lower end of the EDM notched tubes existing approximately 0.4 inch inside the collar. The actual bottom end of the EDM notched tubes were measured relative to the end of the collar before the second tube section was installed. The dimensions for specimens 8, 9, and 10 were 0.34 inch, 0.44 inch, and 0.30 inch, respectively. To provide for tube geometry below the EDM notched tubes a separate tube section was rolled into the collar below the EDM notched tubes. The two tube sections were abutted so no gap existed between the tube sections. Thus, specimens Tensile-8, Tensile-9, and Tensile-10 included both EDM notches in the parent tube adjacent to the sleeve nickel band and a simulated tube separation at the bottom of the sleeve to hardroll length. All sleeves were installed such that the interface between the microlok and nickel bands was 0.88 inch inside the collar. Based on the tube modifications applied, for specimen 7 the circumferential separation was located approximately 0.12 inch above the band interface, or within the microlok region. For specimen 8, the interface between the bands was located approximately 0.10 inch above the top of the EDM notches, for specimen 9 the interface between the bands was consistent with the top of the EDM notches, and for specimen 10 the interface between the bands was located approximately 0.14 inch above the top of the EDM notches. Sleeve installation torque for specimen 7 was 110 in-lb so that a direct comparison between the other separated tube samples can be made. For specimens 8 and 9 the nominal installation torque was 100 in-lb, and for specimen 10 the nominal installation torque was 130 in-lb.

Axial load capabilities for these specimens were found to be [ ]^{a,c,e} to the previous results. For specimen 7, the circumferentially separated tube specimen, the first slip load was approximately [

]^{a,c,e} but still more than twice the three times normal end cap load. The first slip load of [ ]^{a,c,e} for specimen 7 is about 800 lbf or about 16% greater than the 3/4 inch OD separated tube specimens. For an installed sleeve in a 7/8 inch OD tube, the sleeve to tube hardroll surface area is about 16% greater than for a sleeve installed in a 3/4 inch OD tube, thus the results are reasonable as the first slip load is a function of the coefficient of friction, contact pressure, and contact area. The load-displacement curve shape for specimens 7, 8, 9, and 10 was consistent with the previous specimens. Figure 4-3 presents the load displacement curve for 7/8 inch OD specimen 9, which had the lowest applied sleeve torque of 99 in-lb. The load cycle was manually halted at approximately 4 inches of total machine travel to avoid interaction of the expanded sleeve with the tube roll expansion transition. Comparing the first slip loads for the ¾ inch and 7/8 inch OD tube specimens, the first slip loads for the specimens installed using a nominal sleeve torque of 100 in-lb, the first slip loads for the 7/8 inch OD tube specimens is only about 100 lbf greater than the ¾ inch OD tube specimens. For the single 7/8 inch OD tube specimen installed at 130 in-lb the first slip load is about 12% greater than the average of the ¾ inch OD tube first slip loads.

To bolster the tensile test data base for 7/8 inch OD tubes, leak specimens 1 and 2 were tensile tested after completion of the leakage test. For the preparation of the sample for the leak test note that two, 1/8 inch leakage channels were machined through the collar wall to a full diameter engagement of the cutting tool diameter with the tube OD. A 1/16 inch diameter cutting tool was used to machine a hole through the tube wall resulting in a full diameter engagement of the cutting tool with the sleeve OD. The sleeve ID was then staked to produce a 1 to 3 mil permanent inward displacement of the sleeve wall. Thus for this test, the modification to the tube was limited, however the staking of the sleeve wall effectively resulted in separation of the sleeve from the tube for approximately 1/16 to 1/8 inch. The location of these modifications was at the micorok to nickel band interface. Sleeve installation torque for both samples was 100 in-lb. First slip loads for these samples are approximately [ ]^{a,c,e}. Thus the axial load capabilities of these specimens are well above the 3 times normal operating pressure differential for Beaver Valley Unit 2 or Diablo Canyon Units 1 and 2. The first slip loads for these specimens are about 14% greater than the 7/8 inch OD tube specimens that used axial EDM notches as the tube modification (for equal sleeve installation torque). Thus, the influence of axial degradation of the parent tube adjacent to the sleeve nickel band has a limited effect upon the first slip load capability of the sleeved tube joint.

Table 4-1 Alloy 800 Sleeve Tensile Test Results 3/4 Inch OD Hardrolled Tubes 3/4" OD x 0.043" Wall Thickness Hardroll Expanded Tube Circumferentially Separated at Microlok-Nickel Band Interface

Specimen	Sleeve Torque	First Slip Load (lbf)	Peak Load (lbf)		Comments
Dummy				a,c,e	Intact tube, no internal pressurization
1					Sleeve internal pressurization
2					Sleeve internal pressurization
3					Sleeve internal pressurization; sleeve failed in tension at mid span
4					Sleeve internal pressurization
5					Sleeve internal pressurization

*Sleeve installation torque was not recorded. This sample was used to set trip point to deliver 110 in-lb applied torque, thus the actual installation torque can be taken as 110 in-lb.

Table 4-2 TIG and Alloy 800 Sleeve Tensile Test Results 3/4 Inch Hydraulically Expanded Tubes

Specimen	Sleeve Type	Sleeve Torque	First Slip Load (lbf)	Peak Load (lbf)		Comments
Dummy	TIG				a,c,e	No tube modification
Tensile-01	TIG					EDM notched tube
Tensile-02	TIG					EDM notched tube
Tensile-03	TIG					EDM notched tube
Tensile-04	TIG					EDM notched tube
Tensile-05	A-800					EDM notched tube
Tensile-06	A-800					EDM notched tube
Tensile-07	A-800					EDM notched tube
Tensile-08	A-800					EDM notched tube
Tensile-09	A-800					Tube circumferentially separated at top of nickel band
Tensile-10	A-800					Tube circumferentially separated at top of nickel band
Tensile-11	A-800					Sleeve with no microlok or nickel bands

Table 4-3 Alloy 800 Sleeve Tensile Test Results 7/8 Inch Tubes

a,c,e

Specimen	Sleeve Type	Sleeve Torque	First Slip Load (lbf)	Peak Load (lbf)	Comments
Tensile-01	A-800				EDM notched tube, hydraulically expanded
Tensile-02	A-800				EDM notched tube, hydraulically expanded, tube slipped in collar, sleeve joint never slipped
Tensile-03	A-800				EDM notched tube, hydraulically expanded
Tensile-04	A-800				EDM notched tube, hydraulically expanded
Tensile-05	A-800				EDM notched tube, roll expanded
Tensile-06	A-800				EDM notched tube, roll expanded
Tensile-07	A-800				Circumferentially separated tube, roll expanded
Tensile-08	A-800				EDM notched tube, roll expanded
Tensile-09	A-800				EDM notched tube, roll expanded
Tensile-10	A-800				EDM notched tube, roll expanded
Leak-01	A-800				Tensile tested post leak test
Leak-02	A-800				Tensile tested post leak test

(1): Tensile results could be invalid based on sleeve positioning within collar.

a,c,e

Figure 4-1 Model D Load Displacement Curve for Specimen 1

a,c,e

Figure 4-2 Load Displacement Curve for Specimen C-E Tensile 6

a,c,e

Figure 4-3 Load Displacement Curve for Specimen 51-9

5 TENSILE TESTING RESULTS CONCLUSION

The results of the tensile testing program show that for a postulated circumferential separation of the parent tube adjacent to the microlok to nickel band interface, which represents the bounding elevation for this degradation mechanism, that a complete circumferential separation of the parent tube does not prevent the tube to sleeve joint from meeting its' design requirement. A postulated circumferential separation of the parent tube above the microlok to nickel band interface is expected to be detected through normal +Pt coil analysis. A postulated circumferential separation of the parent tube below the microlok to nickel band interface is expected to result in a condition bounded by the test. For the postulated case of severe axial degradation in the parent tube, the tube to sleeve hardroll joint continues to satisfy the design requirement. Therefore, the conclusions of the position paper are validated, and the inability to detect degradation in the parent tube adjacent to the nickel band of the sleeve at depths consistent with the technical specification does not result in a significant reduction in joint capability. The position paper also states that the presence of degradation in the parent tube adjacent to the nickel band would represent a condition where an additional resistive load component would be present due to normal force loading of the sleeve against the tube against the tubesheet. The tensile testing results support this judgment as the measured tensile load capabilities are substantially greater than the predicted values of the position paper.

Figure 5-1 presents a plot of the first slip loads for all 3/4 inch OD tube specimens and includes data for the axial EDM notched tubes and circumferentially separated tubes. [

]a,c,e The Comanche Peak and SONGS three times normal pressure differential end cap load calculated using the tubesheet hole diameter are provided on Figure 5-1 for comparison. As seen from Figure 5-1, the data shows large margins against the design requirement. While these data are developed at room temperature conditions the elevated temperature first slip loads are expected to be equal to or greater than the room temperature data. At operating or accident conditions the thermal expansion coefficient differences between the tubesheet, tube, and sleeve result in a larger contact force. Internal pressurization effects would also increase the contact force between the tubesheet, tube, and sleeve. These increases are judged to overcome any load reduction due to flow stress reduction at temperature. This statement is in agreement with the HEJ sleeve joint test data which shows essentially equal tensile load capabilities for room temperature and 600°F testing.

The Model 51 test results also show large margins against the design requirement, and the same conclusions applied to the ¾ inch OD tube test results are extended to the 7/8 inch OD tube condition. While the Model 51 data set is smaller in number than the ¾ inch data set, no evidence is apparent that suggests that a different conclusion would be drawn.

Following tensile testing several specimens were sectioned to examine the condition of the microlok and nickel bands after displacement within the tube. A photograph of the sleeve from C-E Tensile-03 is included as Figure 5-2. The microlok band appears to be relatively unaffected by the displacement. This helps to establish the integrity characteristics of the microlok region. A 7/8 inch OD tube specimen was also sectioned; the appearance of the microlok region is similar as shown in Figure 5-2.

a,c,e

Figure 5-1 First Slip Loads

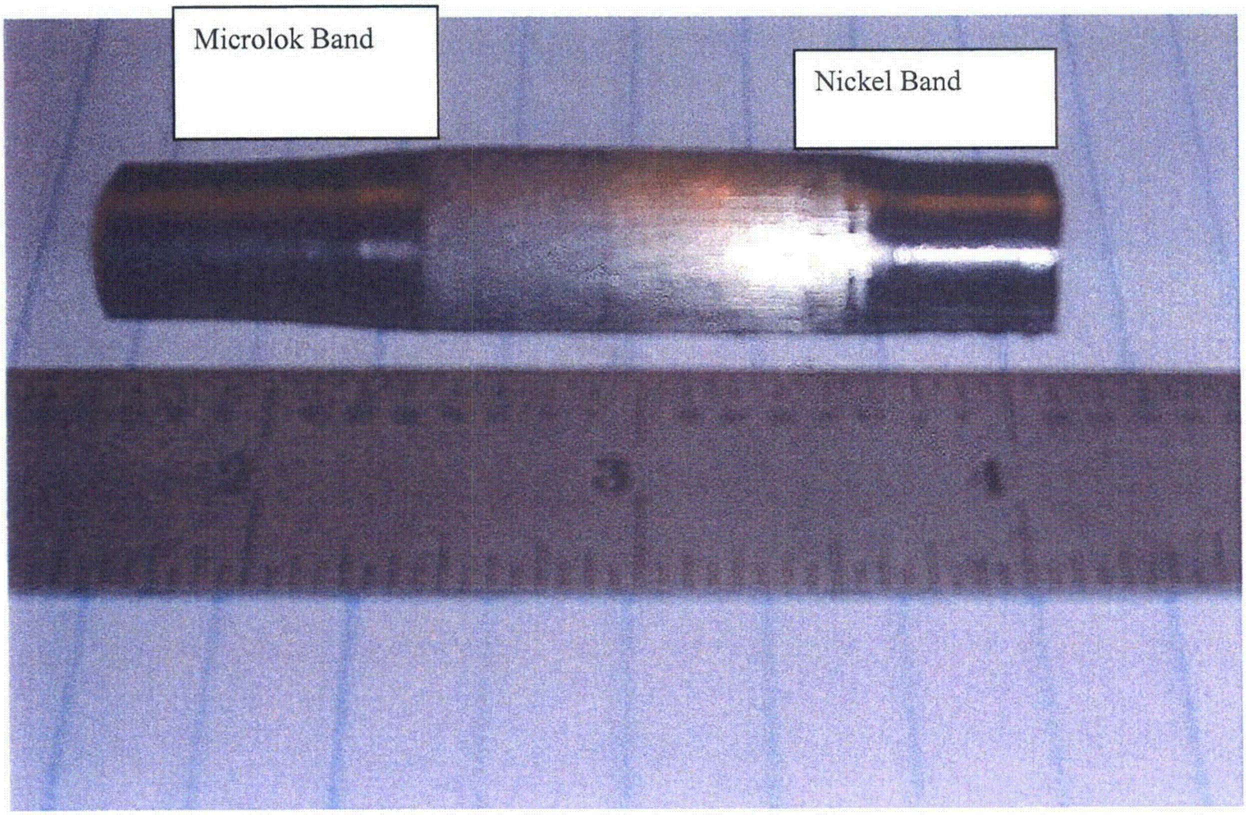

Figure 5-2 Specimen CE Tensile-03 Post Pull Sectioning

6 LEAKAGE TESTING RESULTS CONCLUSION

The leakage testing program has no corresponding acceptance criteria as does the tensile testing program. The capabilities of the eddy current inspection method are fully capable of detecting 100% TW degradation within the parent tube adjacent to the nickel band, thus, any results of the leakage testing program should only be applied to tubes with such observed degradation. Application of the specified leak rates for 100% TW degradation should be applied to the evaluation of operational leakage during a postulated steam line break event contained within the operational assessment.

As stated previously, leak testing was first performed at room temperature conditions and only those specimens that leaked at room temperature at SLB pressure differential were leak tested at 600°F. References 7 and 8 provide leak test data for HEJ and laser weld sleeve specimens. These hardroll joints do not include a nickel band. The results contained within these references indicate that a number of specimens leaked at room temperature conditions but no leakage was observed at 600°F thus supporting the position that the thermal expansion characteristics of the materials utilized result in a tighter joint with regard to leakage at elevated temperature. For the data contained in References 7 and 8 no specimens leaked at elevated temperature conditions. Note that a no leak report can be dependent upon the duration of the leak test.

Room temperature leak specimens were held at 1500 psi and 2560 psi pressure differentials for 20 minutes. Room temperature leakage testing of the samples identified in Table 6-1 indicates that 3/4 inch OD tube samples 1, 2, 6 and 8 and all 7/8 inch OD tube samples were essentially no leak conditions between the tube to sleeve joint. Any leakage from these specimens was extracted from the discharge line. The leak rate for those specimens that leaked is extremely small, and bounded by 2.72×10^{-6} gpm. As these values are so small, any sample with leakage over this period is assigned a leak rate of 2.7×10^{-6} gpm. The SLB pressure differential leak rate test for sample 4 was constant at 9×10^{-5} gpm while the leak rate for sample 5 varied between 4.4×10^{-6} and 1.8×10^{-5} gpm. For all specimens, leakage from the tube to tubesheet joint was collected as residual from the crevice or adhered to the tube wall. Leakage for the tube to tubesheet joint is bounded by 2.7×10^{-6} gpm. As these values are so small, any sample with leakage over this period is assigned a leak rate of 2.7×10^{-6} gpm. Table 6-1 presents the results of the room temperature and high temperature autoclave leak tests.

The results of the room temperature leak test show that the postulated condition of a degraded parent tube has essentially no impact to leakage performance of the sleeve to tube joint. Results of the high temperature autoclave testing show that for three of the four tests performed, the high temperature leak rate was 4 to 10 times less than the room temperature leak rate. One of the high temperature tests had a larger leak rate than the room temperature (3/4 OD, sample #5). However, when the rates are examined, the high temperature rate of 8.2×10^{-6} gpm is so small that judgments between leak and no leak condition are difficult. The high temperature tests were held at pressure for 70 minutes for sample #4, and overnight (about 15 hours) for sample #5. Figures 6-1 and 6-2 present a plot of the integrated leak rate over the test period for these samples. The integrated leak rate was essentially constant over these periods. Note that the leak rate is measured in grams per minute due to the low level of leakage observed. After completion of the leak test, 3/4 inch OD specimen number 4 was sectioned to determine the exact placement of the leak path holes with reference to the microlok to nickel band interface. The lower edge of the 1/16 inch diameter holes that intersected the sleeve were located at the microlok to nickel band interface, thus the placement of the holes was within the microlok band.

For all room temperature leak rate tests at a pressure differential of 2560 psi, the maximum observed value of 9×10^{-5} gpm is so small that any postulated leakage from sleeved tubes will have no meaningful impact upon allowable leakage comparison of the operational assessment. The high temperature leak rate for this sample was reduced to 2×10^{-5} gpm. Note also that this specimen utilized EDM notched tubing.

With regard to leakage contribution during a postulated steam line break (SLB) event, it is recommended that the maximum observed elevated temperature SLB leakage of 2×10^{-5} gpm be applied to all sleeved tubes in which observed degradation of the parent tube behind the sleeve to tube hardroll joint. This allowance is applied to only those sleeved tubes with degradation. For sleeved tubes with no observed degradation behind the sleeve to tube hardroll joint no leakage allowance is to be applied. Note that leakage specimen 75-4 included an axial EDM notched tube configuration in addition to the applied leakage channels and that the configuration of the specimen included primary fluid communication with both the tube to sleeve interface and the leakage channels.

Table 6-1 Sleeve Leakage Test Results

Specimen	Sleeve Type	Sleeve Torque	Room Temp Leak Rate 1500 psid (gpm)	Room Temp Leak Rate 2560 psid (gpm)	Comments
Leak-01-3/4	TIG	103 in-lb	2.72E-06	2.72E-06	EDM notched tube used, Note 1
Leak-02-3/4	TIG	104 in-lb	0	0	Note 1
Leak-04-3/4	TIG	127 in-lb	5.44E-05	9E-05	EDM notched tube used, Note 1
Leak-05-3/4	A-800	101 in-lb	0	1.8E-05	
Leak-06-3/4	A-800	115 in-lb	0	2.72E-06	
Leak-08-3/4	A-800	82 in-lb	2.72E-06	2.72E-06	
Leak-01-7/8	A-800	100 in-lb	2.72E-06	2.72E-06	
Leak-02-7/8	A-800	100 in-lb	0	2.72E-06	
Leak-03-7/8	A-800	103 in-lb	2.72E-06	0	
Specimen	**Sleeve Type**	**Sleeve Torque**	**Elevated Temp Leak Rate 1500 psid (gpm)**	**Elevated Temp Leak Rate 2560 psid (gpm)**	**Comments**
Leak-01-3/4	TIG	103 in-lb	Not Tested	Not Tested	EDM notched tube used, Note 1
Leak-02-3/4	TIG	104 in-lb	Not Tested	Not Tested	Note 1
Leak-04-3/4	TIG	127 in-lb	1.4E-05	2E-05	EDM notched tube used, Note 1
Leak-05-3/4	A-800	101 in-lb	8.2E-06	1E-06	
Leak-06-3/4	A-800	115 in-lb	Not Tested	Not Tested	
Leak-07-3/4	A-800	131 in-lb	Not Tested	Not Tested	
Leak-08-3/4	A-800	82 in-lb	Not Tested	Not Tested	
Leak-01-7/8	A-800	100 in-lb	Not Tested	Not Tested	
Leak-02-7/8	A-800	100 in-lb	Not Tested	Not Tested	
Leak-03-7/8	A-800	103 in-lb	Not Tested	Not Tested	

Note 1: Sleeve displaced downward during rolling approximately 0.1 inch, thus effective sleeve roll length above milled leak path was approximately 0.53 inch.

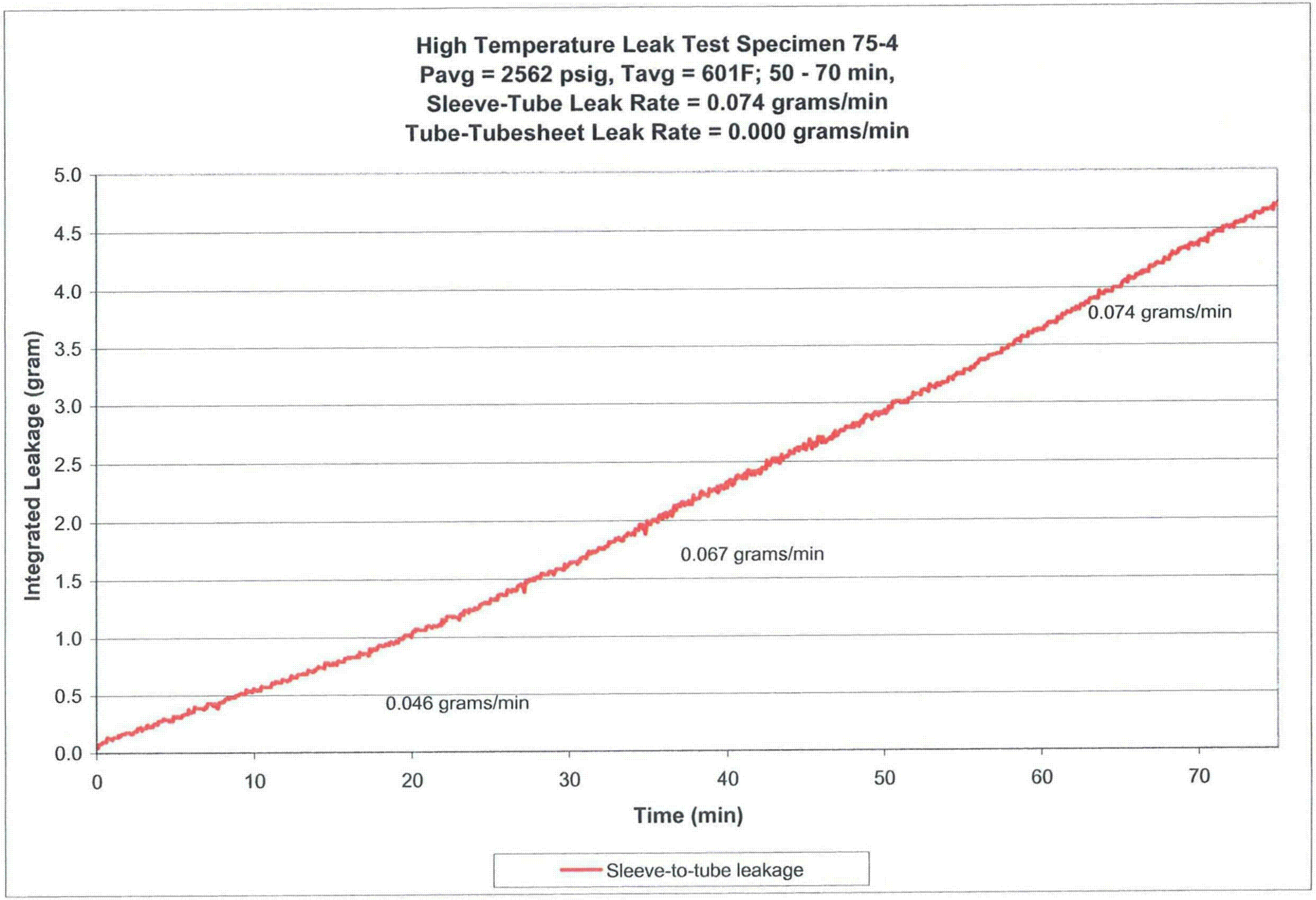

Figure 6-1 Integrated Leak Rate History of Specimen 75 Leak-4: 2560 psi Differential Pressure

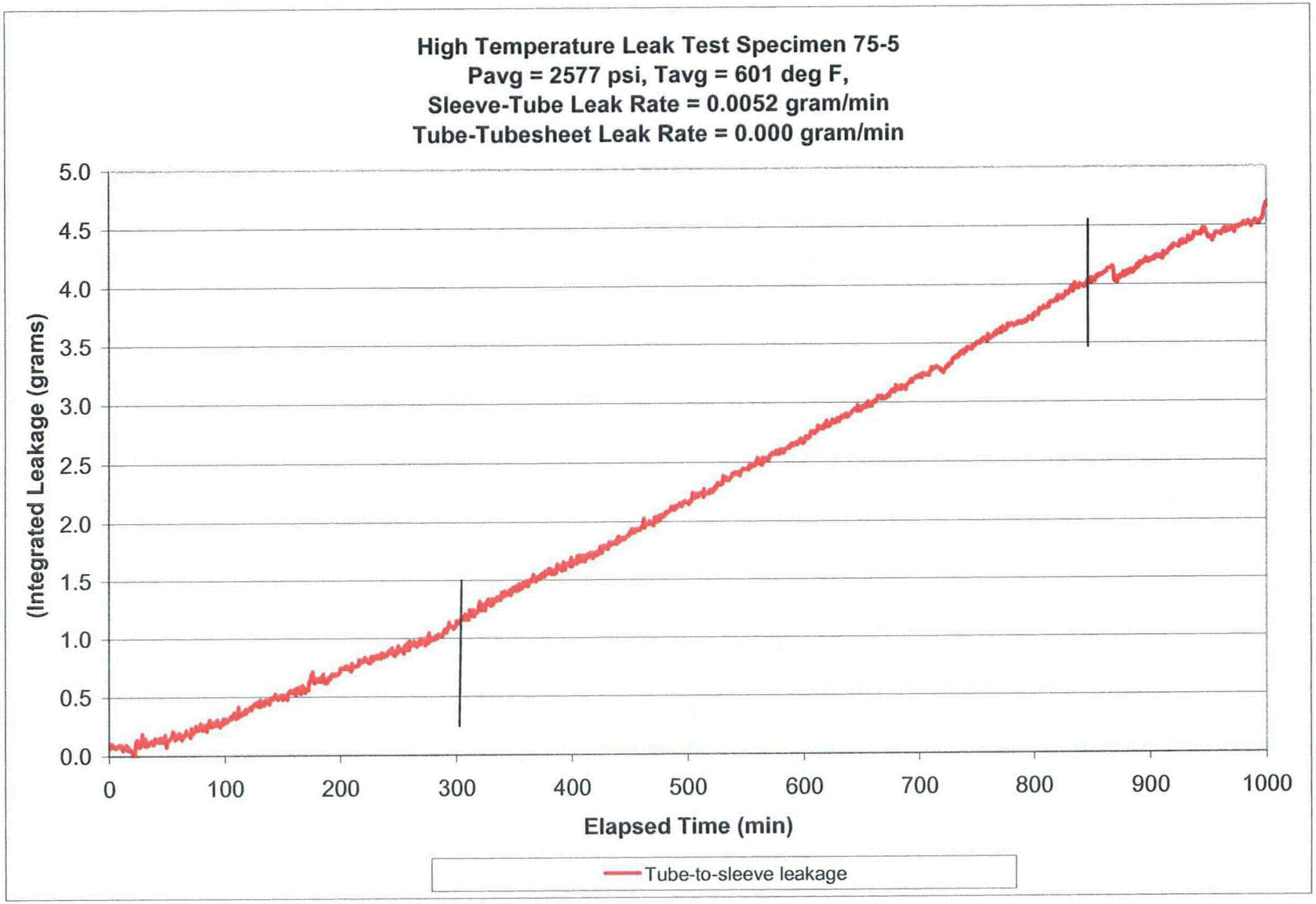

Figure 6-2 Integrated Leak Rate History of Specimen 75 Leak-5: 2560 psi Differential Pressure

7 IMPACT OF TESTING PROGRAM UPON PARENT TUBE ISI REQUIREMENTS

Per Reference 3, the eddy current test (ET) method is used to inspect the entire (TIG) sleeve region pressure boundary which has four distinct regions:

1. the sleeve between the upper weld and lower joint

2. the pressure boundary region of the steam generator tube behind the sleeve

3. the steam generator tube below the lower rolled joint for an expansion transition zone (ETZ) sleeve

4. the unsleeved portion of the steam generator tube

where item 4 is controlled by the prevailing methods as part of the normal tube inspection. Reference 3 however does not define the specific portions of the tube defined as part of the pressure boundary and therefore subject to routine in service inspection (ISI). Reference 4 documents the ET qualification of the sleeved tube assembly. The qualification process did not include simulated flaws within the parent tube adjacent to the lower hardroll. Reference 4 further defines the pressure boundary specification of the parent tube as the length adjacent to and above the upper weld; no portion of the parent tube below the weld is defined as pressure boundary. However, this addendum has recognized that in order for the hardroll joint to function as designed, that the parent tube must be "present."

References 5 and 6 document the design and analysis of the Alloy 800 leak limiting sleeve for 3/4 inch OD and 7/8 inch OD tube installations. References 5 and 6 define the pressure boundary specification of the parent tube to include the tube length above and adjacent to the upper hydraulic expansions and adjacent to the lower hardroll joint. Thus, References 5 and 6 differ from Reference 3 in that the parent tube adjacent to the lower hardroll is defined as pressure boundary and subject to routine in service inspection. All Alloy 800 sleeve installations at Comanche Peak Unit 1 and Watts Bar Unit 1 have included a Plus Point coil inspection of the parent tube adjacent to the sleeve lower hardroll joint prior to sleeve installation to verify that the parent tube is defect free. As the installation of the sleeve should effectively isolate the parent tube from the primary fluid, subsequent degradation of the parent tube adjacent to the sleeve nickel band is not expected to occur.

The results of the test program documented in this addenda show that severe cases of parent tube degradation adjacent to the nickel band region of the sleeve do not prevent the sleeve from satisfying the design requirement. The design requirement is that the sleeve to tube hardroll joint shall maintain anchorage capabilities that exceed the three times normal operating pressure differential. Reference 1 has established that axial and circumferential degradation of 70% TW and greater on the parent tube adjacent to the nickel band region would be readily detectable, thus, the degradation modeled by the testing program, which shows satisfactory results, would be readily detectable. The overall impact is that the ability to detect parent tube degradation consistent with the NRC interpretation of the technical specification does not represent a substantial safety issue. Therefore, this program can be used to develop a safety assessment consistent with NRC Generic Letter 2004-01 that states that non-detectable degradation within the parent tube adjacent to the sleeve nickel band region will not prevent the sleeve from meeting its design function. The specification of pressure boundary portion of the parent tube is to remain as defined by the corresponding design reports. The results of this test program are used to establish a position that degradation either of a sufficient depth supporting detection with current techniques or degradation of lesser depth within the parent tube adjacent to the lower hardroll joint of either the TIG or Alloy 800 sleeve will not prevent the sleeved tube from satisfying the design requirement for anchorage within the tubesheet. In spite of this conclusion, degradation detected by NDE methods within the parent tube adjacent to the sleeve lower hardroll joint is recommended to be removed from service by plugging.

To date, degradation of the parent tube adjacent to the sleeve to tube hardroll joint has no been reported at any of the plants' which have installed TIG or Alloy 800 sleeves. Until such time that degradation is reported, a sampling program consistent with the EPRI PWR Steam Generator Examination Guideline, Revision 6 is recommended for this region.

8 REFERENCES

1. WOG-05-338, "Engineering Position Paper on NDE Issues Related to TIG and Alloy 800 Sleeves with Regard to Sleeve Nickel Band NRC Discussion, Revision 1," July 2005

2. WCAP-16208-P, Revision 1 "NDE Inspection Length for CE Steam Generator Tubesheet Region Explosive Expansions," May 2005

3. CEN-630-P, Revision 2, "Repair of 3/4 Inch OD Steam Generator Tubes Using Leak Tight Sleeves," June 1997

4. 96-OSW-003-P, Revision 0, "EPRI Steam Generator Examination Guidelines Appendix H Qualification for Eddy Current Plus-Point Probe Examination of ABB CE Welded Sleeves," April 1996

5. WCAP-15918-P, Revision 2, "Steam Generator Tube Repair for Combustion-Engineering and Westinghouse Designed Plants with 3/4 Inch OD Tubes Using Leak Limiting Sleeves," July 2004

6. WCAP-15919-P, Revision 0, "Steam Generator Tube Repair for Westinghouse Designed Plants with 7/8 Inch OD Tubes Using Leak Limiting Sleeves," August 2003

7. WCAP-13088, Revision 4, "Westinghouse Series 44 and 51 Steam Generator Generic Sleeving Report, Laser Welded Sleeves," January 1997

8. WCAP-13698, Revision 1, "Laser Welded Sleeves for 3/4 Inch Diameter Tube Feedring Type and Westinghouse Preheater Steam Generators," May 1993

9. STD Letter Report STD-MCE-05-71, "Tensile Test Results of Sleeved Tube Specimens," November 2005