FENOC®
FirstEnergy Nuclear Operating Company

Beaver Valley Power Station
P.O. Box 4
Shippingport, PA 15077

Richard D. Bologna
Site Vice President

724-682-5234
Fax: 724-643-8069

March 28, 2018
L-18-081

10 CFR 50.90

ATTN: Document Control Desk
U. S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT:
Beaver Valley Power Station, Unit No. 2
BV-2 Docket No. 50-412, License No. NPF-73
Steam Generator Technical Specification Amendment Request

Pursuant to 10 CFR 50.90, FirstEnergy Nuclear Operating Company (FENOC) hereby requests an amendment to the facility operating license for Beaver Valley Power Station, Unit No. 2. The proposed amendment would revise Technical Specification (TS) 5.5.5.2.d, "Provisions for SG [Steam Generator] Tube Inspection," and TS 5.5.5.2.f, "Provisions for SG Tube Repair Methods." More specifically, Specifications 5.5.5.2.d.5 and 5.5.5.2.f.3 would be simplified and clarified, respectively, without changing the intent of the specifications. Specification 5.5.5.2.f.3 would also be amended by changing the number of fuel cycles that Westinghouse Electric Company LLC leak-limiting Alloy 800 sleeves may remain in operation.

FENOC's evaluation of the proposed change is provided in Enclosure A. An application for withholding proprietary information from public disclosure, accompanying affidavit, proprietary information notice, and copyright notice are provided in Enclosure B. Nonproprietary and proprietary versions of the technical basis for the proposed change to the number of fuel cycles that Alloy 800 sleeves may remain in service are provided in enclosures C and D, respectively.

Approval of the proposed amendment is requested by March 29, 2019. The amendment shall be implemented within 60 days of approval.

There are no regulatory commitments contained in this submittal. If there are any questions or if additional information is required, please contact Mr. Thomas A. Lentz, Manager – Fleet Licensing, at 330-315-6810.

I declare under penalty of perjury that the foregoing is true and correct. Executed on March 28, 2018.

Sincerely,

Richard D. Bologna

Enclosures:

A. Evaluation of the Proposed Change
B. Application for Withholding Proprietary Information from Public Disclosure
C. Steam Generator Alloy 800 Nickel Band Tubesheet Sleeve Operating Cycle Length Extension License Amendment Request: Technical Bases (Nonproprietary Version)
D. Steam Generator Alloy 800 Nickel Band Tubesheet Sleeve Operating Cycle Length Extension License Amendment Request: Technical Bases (Proprietary Version)

cc: NRC Region I Administrator
NRC Resident Inspector
NRC Project Manager
Director BRP/DEP
Site BRP/DEP Representative

Enclosure A
L-18-081

Evaluation of the Proposed Change

(18 pages follow)

Subject: Proposed Revision of Technical Specification (TS) 5.5.5, "Steam Generator (SG) Program" for the Beaver Valley Power Station, Unit No. 2

1.0 SUMMARY DESCRIPTION

This evaluation supports a request to amend Renewed Facility Operating License No. NPF-73 for Beaver Valley Power Station, Unit No. 2 (BVPS-2). The proposed amendment would revise Technical Specification (TS) 5.5.5.2.d, "Provisions for SG [Steam Generator] Tube Inspection," and TS 5.5.5.2.f, "Provisions for SG Tube Repair Methods." Specifications 5.5.5.2.d.5 and 5.5.5.2.f.3 would be simplified and clarified, respectively, without changing the intent of the specifications. Specification 5.5.5.2.f.3 would also be amended by changing the number of fuel cycles that Westinghouse Electric Company LLC (Westinghouse) leak-limiting Alloy 800 sleeves may remain in operation.

Affected pages of the current TSs, annotated to show the proposed changes, are provided in the Attachment.

2.0 DETAILED DESCRIPTION

2.1 System Design and Operation

The SGs in pressurized water reactor designs remove heat from the reactor coolant system (RCS) and produce steam to operate the main generator and other balance-of-plant equipment. SG tubes constitute the heat transfer surface area between the primary (reactor coolant) and secondary (main steam) systems and, as such, are relied on to maintain the primary system's pressure and inventory. As an integral part of the reactor coolant pressure boundary (RCPB), the SG tubes isolate the radioactive fission products in the primary coolant from the secondary system. Maintaining tube integrity ensures that the tubes are capable of performing their intended safety functions consistent with the plant licensing basis and applicable regulatory requirements.

2.2 Current Technical Specification Requirements

TS 5.5.5.2.d.5 - For Alloy 800 sleeves: The parent tube, in the area where the sleeve-to-tube hard roll joint (lower joint) and the sleeve-to-tube hydraulic expansion joint (upper joint) will be established, shall be inspected prior to installation of the sleeve. Sleeve installation may proceed only if the inspection finds these regions free from service induced indications.

TS 5.5.5.2.f.3 - Westinghouse leak-limiting Alloy 800 sleeves, WCAP-15919-P, Revision 2. An Alloy 800 sleeve shall remain in service for no more than five fuel cycles of operation starting from the outage when the sleeve was installed.

2.3 Reason for Proposed Change

A proposed change to delete the parenthetical words (upper joint) and (lower joint) in the first sentence of TS 5.5.5.2.d.5 would simplify the description of the required inspection region without changing the intent. The proposed amendment would make it clear that the SG parent tube (parent tube) is to be inspected in the areas where the

joints will be established prior to installation of the sleeve, regardless of the sleeve location.

A proposed change to TS 5.5.5.2.f.3 would add the words "installed in the hot-leg or cold-leg tubesheet region" after the words "An Alloy 800 sleeve" to make it clear that the specification only applies to Alloy 800 tube sleeves installed in the SG tubesheet. This proposed change does not change the intent of the specification.

The current TS 5.5.5.2.f.3 wording does not differentiate between an Alloy 800 sleeve installed in the tubesheet and an Alloy 800 sleeve installed at a tube support plate. Therefore, the operational life limitation of TS 5.5.5.2.f.3 applies to both sleeve designs, but it should only apply to the Alloy 800 tubesheet sleeve design.

Technical Specification 5.5.5.2.f.3 also limits the operational life of Alloy 800 tube sleeves to five fuel cycles of operation. Changing the operating life of the sleeves is needed as some currently-installed sleeves will reach the end of their five fuel-cycle operating life in the spring of 2020. Removing the sleeves from service at the end of five fuel cycles would require plugging of the associated SG tubes and is expected to limit the unit to reduced (less than 100 percent) power output. Alloy 800 sleeves were first used in the fall of 2012 refueling outage (2R16) when 94 tubesheet sleeves were installed. An additional 171 tubesheet sleeves were installed in the spring of 2017 refueling outage (2R19). This proposed license amendment would allow an Alloy 800 tubesheet sleeve to remain in service for no more than eight fuel cycles of operation. This would avoid having to remove tubesheet sleeves from service during the spring 2020 refueling outage (2R21), that were installed in the fall 2012 refueling outage (2R16). Also, this would avoid having to remove sleeves from service during the fall 2024 refueling outage (2R24), that were installed in the spring 2017 refueling outage (2R19).

2.4 Description of the Proposed Change

The proposed amendment would change the first sentence of TS 5.5.5.2.d.5 to read:

> For Alloy 800 sleeves: The parent tube, in the area where the sleeve-to-tube hard roll joint and the sleeve-to-tube hydraulic expansion joint will be established, shall be inspected prior to installation of the sleeve.

The proposed amendment would change the second sentence of TS 5.5.5.2.f.3 to read:

> An Alloy 800 sleeve installed in the hot-leg or cold-leg tubesheet region shall remain in service for no more than eight fuel cycles of operation starting from the outage when the sleeve was installed.

3.0 TECHNICAL EVALUATION

The following technical evaluation is based largely on the information provided in the technical bases document entitled "Steam Generator Alloy 800 Nickel Band Tubesheet Sleeve Operating Cycle Length Extension License Amendment Request; Technical

Bases" (Enclosure D of Letter L-18-081), and addresses Alloy 800 sleeves installed within the tubesheet.

3.1 Background

The leak-limiting Alloy 800 sleeves are designed using the applicable American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code and, therefore, meet the design objectives of the original steam generator tubing. The applied stresses and fatigue usage for the sleeves are bounded by the limits established in the ASME Code. Mechanical testing has shown that the structural strength of sleeves under normal, upset, emergency, and faulted conditions provides margin to the acceptance limits. These acceptance limits bound the most limiting (three times normal operating pressure differential) burst margin in Nuclear Regulatory Commission (NRC) Regulatory Guide 1.121, "Bases for Plugging Degraded PWR [Pressurized Water Reactor] Steam Generator Tubes," Revision 0. The design requirement is that each joint of the sleeve must independently provide for axial load bearing capability greater than the hydraulic end cap load applied to the tube during normal operating conditions, with a safety factor of three. The design requirement for BVPS-2 is 2,271 pounds.

Steam Generators installed at BVPS-2 employ Alloy 600 tubes. Alloy 600 is susceptible to primary water stress corrosion cracking (PWSCC). Alloy 800 SG tube sleeve material is not susceptible to PWSCC. The three conditions that must be present for initiation of stress corrosion cracking are a corrosive environment, a susceptible material, and tensile residual stress. If any one of these three necessary conditions is absent or reduced below a threshold value, SCC cannot occur. BVPS-2 SG tubes in the hot and cold leg tubesheet regions were shot-peened prior to commercial operation, to apply compressive residual stresses at the SG tube inside diameter (ID) and improve performance of the tubing with regard to PWSCC initiation.

For sleeves installed in the tubesheet, the upper tube-sleeve joint is formed by six equally-spaced, approximately 3/8-inch wide hydraulic expansions. The lower tube-sleeve joint is a mechanical roll expansion, and the elevation of the centerline of the roll expansion is approximately located at the mid-plane elevation of the tubesheet.

The Westinghouse Alloy 800 sleeve design includes a nickel band applied to the sleeve outside diameter (OD) in the lower mechanical roll expansion joint region for sleeves installed in the tubesheet. The nickel band was added as an additional barrier to leakage through the tube-sleeve joint. The nickel band has a nominal thickness of 0.002 inch, extends for an axial length of 0.5 inch, and is located on the lower half of the roll expansion length. A "microlok" band, 0.5 inch in axial length, is applied to the sleeve at the upper half of the roll expansion length. The microlok band is a thermally applied material that acts to increase the coefficient of friction between the tube and sleeve, thus increasing axial load bearing capability of the sleeve joint.

The design of Alloy 800 sleeves installed in SG tube locations other than the tubesheet does not include a nickel band. For these sleeves, nondestructive examination

methods have been demonstrated to be effective and limits on sleeve operating life are not necessary.

3.2 Worldwide Installation Summary

The majority of Alloy 800 sleeve installations have occurred in Europe and Asia using the PLUSS sleeve. The PLUSS design is essentially identical to the Alloy 800 sleeve installed in the US except the PLUSS sleeve does not include nickel banding at the lower joint region. Westinghouse is not aware of, and has no knowledge of any reports of parent-tube stress corrosion cracking (SCC) in the sleeve roll joint region for any Westinghouse sleeve design.

Of the greater than 14,000 Alloy 800 tubesheet sleeve installations, nearly all were installed at plants using Alloy 600 mill annealed SG tubing. The only tubesheet sleeve installations in non-mill annealed tubing were two Korean plants that used Alloy 600 thermally treated tubing.

Another approximate 12,000 tube support plate sleeves were installed by Westinghouse in Korea starting approximately 2013. These were installed in plants using both mill annealed and thermally treated Alloy 600 tubing. The Alloy 800 tube support plate sleeve design does not contain a nickel band.

An extensive history of Westinghouse hybrid expansion joint (HEJ) and laser welded sleeve (LWS) installations also supports the conclusion that degradation of the parent tube adjacent to the roll expansion at the lower sleeve joint is not anticipated. Neither of these designs include nickel application to the sleeve OD. The sleeve material is Alloy 690, or in the case of one plant, Alloy 690 with an Alloy 625 cladding on the entire length of the sleeve OD. There are no known reports of parent tube stress corrosion cracking (SCC) adjacent to the sleeve roll expansion.

3.3 Steam Generator Parent Tube SCC Potential

Previous analyses have indicated that the hydraulic tube expansion results in compressive residual stresses at the SG tube inside diameter (ID) surface in the uniform expansion region. A similar condition would be expected for mechanical roll expansion in the lower SG tube-sleeve joint.

The nominal top-of-tubesheet +POINT™ probe inspection distance for BVPS-2 is from 6 inches above to 3 inches below the top-of-tubesheet. The 3 inch dimension is a requirement of the F Star (F*) alternate repair criteria (ARC). Tubes with indications identified in this region are plugged or sleeved. Prior to sleeve installation, the parent tube is inspected in the sleeve joint regions using a +POINT™ probe. At the lower joint, the +POINT™ probe inspection distance is from 8 to 14 inches above the hot leg tube end. The centerline of the sleeve roll joint is located at 12.5 inches above the tube end. The added +POINT™ inspection distance below the sleeve satisfies requirements of the F* ARC. In addition, the inspection data for the tube is re-evaluated prior to sleeve installation to ensure that there are no geometric discontinuities in the tubesheet that

could influence sleeve insertion. Although not a required inspection for satisfaction of the F* ARC, it is standard practice at BVPS-2 to perform +POINT™ probe inspection of previously identified bulge and over-expansion signals in the hot leg tubesheet region below the F* distance on a sampling basis. To date, (through the 2R19 outage), no indications have been reported at bulges or over-expansions within the tubesheet at BVPS-2.

Steam generator tubes in the BVPS-2 hot and cold leg tubesheet regions were shot peened from 3 inches above the top-of-tubesheet to approximately 1 inch above the tube end to apply compressive residual stresses at the tube ID. Peening has dramatically improved performance of the tubing with regard to PWSCC initiation. To date, six tubes have been affected by PWSCC in the tubesheet at BVPS-2, and the PWSCC in each tube was located at the top-of-tubesheet expansion transition. Axial PWSCC indications were reported at refueling outages 2R09, 2R13, 2R17, and 2R18, while circumferential PWSCC indications were reported at refueling outages 2R11 and 2R16. This performance is dramatically improved compared to other units that used full depth mechanical roll expansion. Based on information contained within the Electric Power Research Institute (EPRI) Steam Generator Degradation Database (SGDD) for domestic plants, at Plant A with original Model 51 SGs, which also used full depth roll expansion, no less than 833 tubes were affected by PWSCC in the tubesheet region up to the final eddy current inspection in 1999 (14.9 Effective Full Power Years or EFPY). Westinghouse inspection records estimate the total number of tubes affected by PWSCC is approximately 1,200. Information contained in the SGDD for Plant B with original Model D3 SGs, which used full depth roll expansion, no less than 2,313 tubes were affected by PWSCC in the tubesheet region up to the final eddy current inspection in 1993 (7.4 EFPY). Therefore, peening of the SG tubes in the tubesheet region helps to preclude PWSCC initiation in the BVPS-2 SGs.

Barring localized influences such as bulges, over-expansions, and roll overlaps, the process of tube expansions produces compressive ID residual stresses due to hysteresis of the tube after the radial force from the expansion process is removed. In the case of mechanical roll expansion, the tubesheet is believed to remain elastic. Thus, as the rolling force is removed, the tubesheet would act to elastically spring-back, producing compressive residual stresses on the tube ID. This sequence is expected to be present whether the rolling process involves the original tube expansion or sleeve expansion.

Finite element modeling of the tubesheet-tube-sleeve roll expansion was performed. This analysis concludes that adjacent to the nickel band (and within the expanded length resulting from contact by the flat length of the roller pin), the residual stresses on the tube ID surface remain compressive following sleeve installation. Thus, as one of the necessary fundamental parameters, tensile residual stress, is absent, SCC of the parent tube cannot occur.

Additionally, the flat dimension of the sleeve roller pins is 1.1 inches. The deflection of the sleeve material around the roller pin will effectively extend the length that the tube and sleeve are in contact. By design, the nickel band extent stops short of the lower extent of the roll flat length, thus, the area of the parent tube adjacent to the nickel band is physically isolated from the corrosive environment, the primary coolant fluid. Any communication between the parent tube ID surface adjacent to the nickel band and the primary coolant fluid would be limited to postulated leakage through the tube-sleeve interface. Therefore, one of the essential fundamental parameters, a corrosive environment, is absent or reduced, as a minimum. Leakage is addressed further in Section 3.6.

Finally, the susceptibility of the material to PWSCC initiation is inherently reduced by the application of shot peening of the SG tubes through the tubesheet region prior to operation.

In conclusion, of the three fundamental parameters necessary for PWSCC initiation of the parent tube adjacent to the nickel band, one is absent (tensile stress), one is absent or reduced (corrosive environment), and one is reduced (susceptible material). Thus, it can be concluded that PWSCC of the parent tube adjacent to the nickel band of the sleeve is not a potential degradation mechanism.

3.4 Similarity with Other Sleeve Designs

The Alloy 800 tubesheet sleeve with a nickel band is similar to many other sleeve designs. This similarity is in the lower joint roll expansion.

The other industry designs which use a roll expansion to form the lower joint are the ABB C-E TIG tungsten inert gas welded (TIG) sleeve, the ABB C-E PLUSS (PLUSS) sleeve, and the Westinghouse HEJ and LWS designs. Sleeve material is thermally treated Alloy 690 except for of the PLUSS sleeve, which uses Alloy 800 material. The PLUSS sleeve does not include the additional nickel band.

The Alloy 800, TIG, and PLUSS sleeves include a thermal spray applied microlok band on the sleeve OD in the lower joint roll expansion region. The microlok band is adjacent to the nickel band and the intersection between the two bands is located at the axial center of the roll expansion region. The microlok material is similar to the base metal of the sleeve and acts to increase the coefficient of friction between the sleeve and tube, thus increasing the axial load bearing capability of the joint.

Given the inherent similarities of the roll expansion joint used in these other sleeves, mechanical testing results for these other sleeve designs will be used to help form the technical bases for the condition of postulated parent tube degradation adjacent to the nickel band of the Alloy 800 sleeve design.

3.5 Roll Expansion Joint Integrity Characteristics

This section will address the load bearing capability of the TIG and Alloy 800 sleeve joints utilizing limited effective joint lengths, consistency of TIG and Alloy 800 sleeve joint design and performance with existing HEJ sleeve test data, and overall axial load bearing capability of the tube in the tubesheet.

Load bearing capability was investigated as described in Section 6.1 of letter L-18-081, Enclosure D. Testing was based primarily on "abnormal" HEJ test data where key rolling parameters, such as the effective roll length and applied torque were varied. The nominal HEJ sleeve applied torque is 135 inch-pounds (in-lb) and the nominal roll flat length is 2.16 inches. The abnormal joint length test conditions varied applied torque from 80 to 135 in-lb with joint lengths ranging from 0.75 to 2.16 inches. It was concluded that for an assumed effective TIG or Alloy 800 joint length of 0.55 inch, which represents the axial length of the roll joint above the intersection between the microlok and nickel bands, that the sleeve joint would continue to provide axial load bearing capability in excess of the design requirement.

As the HEJ and TIG and Alloy 800 designs use slightly different roll joint lengths and applied torque values, these data were normalized using a torque per unit length basis. The relevant observations from this data are that:

- The HEJ abnormal joint length test data bounds the range of torque per unit area values for the TIG and Alloy 800 sleeve, and thus any torque per unit area between these bounds is described by the existing abnormal joint length HEJ test data.
- Results of room temperature (68 to 72 degrees Fahrenheit [°F]) and elevated temperature (600°F) testing show no apparent difference in the outcome of the two tests. The reduction in material properties at elevated temperature are balanced by the increase in contact force created by the thermal expansion coefficient difference between the sleeve and tube.

The axial load bearing capability of the sleeve joint would not be reduced to less than the design requirement by an undetected flaw in the nickel band region.

As described in Section 6.1 of letter L-18-081, Enclosure D, it is concluded that roll joints are inherently robust and that variations in applied torque and effective joint length have a minimal impact upon the ultimate axial load bearing capability. The conclusion that effective sleeve roll joint lengths of 0.55 inch would satisfy the design requirement, are supported by test data which forms the basis of the F* ARC.

Mechanical testing of Alloy 800 sleeves installed into modified parent tubes was performed. The tubes used in this test program contained the two following types of specimens.

- Simulated circumferentially separated tubes at the intersection of the microlok and nickel band region

- Axially slotted tubes (which eliminated the potential for the tube to transmit load in the radial direction).

Five circumferentially separated specimens were prepared and tested at room temperature. The sleeve was internally pressurized using a nitrogen source at 1,500 pounds per square inch (psi). The internal pressurization added approximately 400 pounds to the axial load capability. An additional contact pressure of 1,050 psi due to internal pressurization was calculated. The circumferentially separated tube specimens retained axial load bearing capability well in excess of the design requirement.

Hydraulically expanded specimens included eight specimens with axial slots in the parent tube, two circumferentially separated specimens, and one axially slotted specimen with no microlok or nickel band. The axially slotted specimens exhibited slightly reduced peak loads compared to the roll expanded tube, circumferentially separated tube specimens. The hydraulically expanded tube specimens also showed a greater propensity for first slip and peak load to be consistent. Observed loads were well in excess of the design requirement.

The axially slotted tube tests showed that the ability of the tube to transmit load in the radial direction has little impact on the axial load bearing capability of the sleeve roll joint. Whether an axial through wall (TW) crack is present in the tube or not, the work done to the sleeve will be transmitted normally through the tube to the tubesheet. Additionally, the presence of an TW axial crack has essentially no impact upon the ability of the parent tube to transmit axial loads. For up to 15, 0.5-inch long axially oriented, 100 percent TW electro discharge machining (EDM) notches, the axial load bearing capability of the tube is consistent with non-flawed tubes. Thus, whether the axial load is applied to the cross section of the tube along its axis or across the axial slots, the ultimate load capability is unaffected.

The axially slotted specimen (that did not include a microlok or nickel band) exhibited lower first slip and peak load. This showed the benefit of the microlok band, which is designed to increase coefficient of friction between the tube and sleeve thus increasing axial load bearing capability.

The results of the parent tube testing program showed that expected operating temperature axial load bearing capability for both circumferentially separated tubes, separated at the microlok to nickel band region, and for axially slotted tubes that prevent the tube from transmitting resistive loads in the radial direction, will provide for a minimum margin of 1.31 times the design requirement (2,271 pounds for BVPS-2) when considering first slip loads and a minimum margin of 1.92 times the design requirement when considering peak loads.

3.6 Nickel Band Sleeve Leakage Integrity

Section 7 of letter L-18-081, Enclosure D, describes a leakage testing program that demonstrated the leakage integrity of nickel banded sleeves. Nine room temperature

leakage specimens were used; three TIG sleeve specimens in 3/4 inch OD tubing, three Alloy 800 sleeve specimens in 3/4 inch OD tubing, and three Alloy 800 sleeve specimens in 7/8 inch OD tubing. Applied rolling torques ranged from 82 to 127 in-lb, which are all less than the nominal installation torque value of 130 in-lb. Room temperature leak rate data shows that of the nine specimens, only two had reliable, measurable leak rates for limited length sleeve roll expansions of approximately one half of the roll expanded length. Elevated temperature testing shows that the Alloy 800 sleeve material will effectively act to reduce leak rates through thermal expansion with subsequent increase in tube-sleeve contact forces. Thus, the limited sleeve roll length leakage testing shows that postulated parent tube TW degradation that would be detectable by normal eddy current inspection, will not lead to excessive leakage or leakage beyond that currently allotted per sleeve for BVPS-2.

3.7 Nondestructive Examination (NDE) Capabilities

Standard eddy current techniques have demonstrated detection of parent tube degradation in tubes adjacent to the nickel band region of Alloy 800 and TIG sleeves. However, no formal eddy current technique qualification exists for this configuration.

Eddy current standards for TIG sleeve installations at one plant included 50, 70, and 100 percent through wall axial ID EDM notches in the parent tube adjacent to the sleeve nickel band region. These notches are readily detectable with the +POINT™ probe using both 75 and 150 kilohertz (kHz). However, the ability to detect true SCC flaws and EDM notches can be different, due primarily to the signal amplitude response. As the TIG (Alloy 690) and Alloy 800 sleeve materials are similar with similar eddy current characteristics, the observations from the standards using TIG sleeves are applicable to Alloy 800 sleeves.

Eddy current examination of installed Alloy 800 sleeves with parent tube OD flaws adjacent to the sleeve nickel band shows that flaws, ranging in depth from 40 percent to 100 percent TW from the OD were detectable in the 75 kHz channel. As these flaws are initiated from the OD the unanimous detection supports high detection capability of deep ID initiated flaws. Comparison of responses for a flaw which spanned the interface of the microlok and nickel band shows the flaw response was larger adjacent to the nickel band. This demonstrates that the nickel band represents an elevated null condition and that the nickel band does not completely impede flaw detection. The readily detectable condition for the OD-initiated SCC suggests that 100 percent TW ID initiated degradation will be readily detected. Part through-wall PWSCC degradation will be detectable at probabilities increasing with increasing flaw depth using existing eddy current examination techniques.

The mechanical and leakage tests described in Sections 3.5 and 3.6 have confirmed that degradation of the parent tube adjacent to the nickel band will not prevent the sleeve from satisfying its design function. The results of eddy current testing have established that both part TW and 100 percent TW degradation of the parent tube will

be detectable using standard eddy current techniques and thus the standard eddy current techniques provide a defense in depth approach.

3.8 Conclusions

PWSCC of the parent tube adjacent to the nickel band of the Alloy 800 tubesheet sleeve is not credible based on the compressive residual stress condition at the tube ID surface, reduced corrosive environment, and the shot peened SG tubes that are less susceptible. In the event that ID initiated degradation of the parent tube at the nickel band interface were to occur, including 100 percent TW degradation either axially or circumferentially oriented, the degradation would not reduce the axial load bearing capability of the sleeve lower roll joint to less than the design requirement. The limited sleeve roll length leakage testing shows that postulated parent tube TW degradation that would be detectable by normal eddy current inspection, will not lead to excessive leakage or leakage beyond that currently allotted per sleeve for BVPS-2. Thus, the lack of an NDE technique qualified according to the Appendix H requirements will not increase the risk of the plant experiencing an unanalyzed accident. The proposed amendment has no significant effect on either the configuration of the plant, the manner in which it is operated, or ability of the sleeve to perform its design function.

4.0 REGULATORY EVALUATION

4.1 Applicable Regulatory Requirements / Criteria

10 CFR 50.55a, Codes and Standards - (c) Reactor coolant pressure boundary

Specifies that components which are part of the reactor coolant pressure boundary must meet the requirements for Class 1 components in Section III of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (Code). 10 CFR 50.55a further requires, in part, that throughout the service life of a pressurized water reactor facility, ASME Code Class 1 components meet the requirements, except design and access provisions and pre-service examination requirements, in Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components," of the ASME Code, to the extent practical. This requirement includes the inspection and repair criteria of Section XI of the ASME Code. The design criteria of the Westinghouse leak-limiting sleeves were established to meet the loading condition and stress requirements of Section III of the ASME Code (1995 edition, no addenda), which is consistent with the section of the ASME Code that applies to the original SG tubes.

10 CFR 50.67, Accident Source Term

Specifies requirements for holders of operating licenses who seek to revise the current accident source term used in their design basis radiological analyses. As part of the plant licensing basis, applicants for pressurized water reactor licenses are required to analyze the consequences of postulated design-basis accidents, such as an SG tube rupture and main steam line break. These analyses consider the primary-to-secondary leakage through the tubing that may occur during these events.

10 CFR 50, Appendix A. General Design Criteria for Nuclear Power Plants

General Design Criteria 14, 15, 19, 30, 31, and 32 of 10 CFR Part 50, Appendix A, define requirements for the reactor coolant pressure boundary with respect to structural and leakage integrity, and adequate radiation protection to permit access and occupancy of the control room under accident conditions. Steam generator tubing and tube repairs constitute a major fraction of the reactor coolant pressure boundary surface area. Steam generator tubing and associated repair techniques and components, such as plugs and sleeves, must be capable of maintaining reactor coolant inventory and pressure. Steam generator tube leakage must be less than or equal to that assumed in the accident analysis to ensure criteria for control room operator doses is met.

The Steam Generator Program required by the BVPS-2 Technical Specifications establishes performance criteria, repair criteria, repair methods, inspection periods and the methods necessary to meet them. These requirements provide reasonable assurance that tube integrity will be met in the interval between SG inspections.

There are no proposed changes in this request that impact these regulatory requirements.

4.2 Significant Hazards Consideration

FirstEnergy Nuclear Operating Company has evaluated whether or not a significant hazards consideration is involved with the proposed amendment by focusing on the three standards set forth in 10 CFR 50.92, "Issuance of amendment," as discussed below:

1. Does the proposed amendment involve a significant increase in the probability or consequences of an accident previously evaluated?

   Response: No

   Proposed amendment of Technical Specification 5.5.5.2.d.5 to simplify the description of the required inspection region, and Technical Specification 5.5.5.2.f.3 to clarify that this specification is only applicable to sleeves installed in the steam generator tubesheet and to change the number of fuel cycles that an Alloy 800 steam generator tubesheet sleeve may remain in service from five to eight fuel cycles of operation, does not affect structures, systems or components of the plant, plant operations, design functions or analyses that verify the capability of structures, systems or components to perform a design function. The proposed amendment does not increase the likelihood of steam generator tube sleeve leakage.

   The proposed amendment of Technical Specification 5.5.5.2.d.5 to simplify the description of the required inspection region, makes it clear that the steam generator parent tube is to be inspected in the areas where the joints will be established prior to installation of the sleeve, regardless of the sleeve location. This proposed amendment does not change the intent of the specification.

The proposed amendment of TS 5.5.5.2.f.3 includes two changes. The first change would add the words "installed in the hot-leg or cold-leg tubesheet region" after the words "An Alloy 800 sleeve" to make it clear that the specification only applies to Alloy 800 tube sleeves installed in the steam generator tubesheet. The design of Alloy 800 sleeves installed in steam generator tube locations other than the tubesheet does not include a nickel band. For these sleeves, nondestructive examination methods have been demonstrated to be effective and limits on sleeve operating life are not necessary. This proposed amendment does not change the intent of the specification.

The second change to Technical Specification 5.5.5.2.f.3, increases the number of fuel cycles Alloy 800 tube sleeves installed in the tubesheet may remain in service. The leak-limiting Alloy 800 sleeves are designed using the applicable American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code and, therefore, meet the design objectives of the original steam generator tubing. The applied stresses and fatigue usage for the sleeves are bounded by the limits established in the ASME Code. Mechanical testing has shown that the structural strength of sleeves under normal, upset, emergency, and faulted conditions provides margin to the acceptance limits. These acceptance limits bound the most limiting (three times normal operating pressure differential) burst margin of NRC Regulatory Guide 1.121, "Bases for Plugging Degraded PWR Steam Generator Tubes."

The leak-limiting Alloy 800 sleeve depth-based structural limit is determined using NRC guidance and the pressure stress equation of ASME Code, Section III with margin added to account for the configuration of long axial cracks. Calculations show that a depth-based limit of 45 percent through-wall degradation is acceptable. However, Technical Specifications 5.5.5.2.c.2 and 5.5.5.2.c.3 provide additional margin by requiring an Alloy 800 sleeved tube to be plugged on detection of any flaw in the sleeve or in the pressure boundary portion of the original tube wall in the sleeve to tube joint. Degradation of the original tube adjacent to the nickel band of an Alloy 800 sleeve installed in the tubesheet, regardless of depth, would not prevent the sleeve from satisfying design requirements. Thus, flaw detection capabilities within the original tube adjacent to the sleeve nickel band are a defense in-depth measure, and are not necessary in order to justify continued operation of the sleeved tube.

Evaluation of repaired steam generator tube testing and analysis indicates that there are no detrimental effects on the leak-limiting Alloy 800 sleeve or sleeved tube assembly from reactor coolant system flow, primary or secondary coolant chemistries, thermal conditions or transients, or pressure conditions that may be experienced at Beaver Valley Power Station, Unit No. 2. Westinghouse is not aware of, and has no knowledge of any reports of parent-tube stress corrosion cracking (SCC) in the sleeve roll joint region for any Westinghouse sleeve design.

The proposed increase in the number of fuel cycles Alloy 800 tube sleeves installed in the tubesheet may remain in service has no effect on sleeve operation or capability of the sleeve to perform its design function. The mechanical and leakage tests have confirmed that degradation of the parent tube adjacent to the nickel band will not prevent the sleeve from satisfying its design function.

Consequences of a hypothetical failure of the leak-limiting Alloy 800 sleeve and tube assembly are bounded by the current main steam line break and steam generator tube rupture accident analyses described in the Beaver Valley Power Station, Unit No. 2 Updated Final Safety Analysis Report. The total number of plugged steam generator tubes (including equivalency associated with installed sleeves) is required to be consistent with accident analysis assumptions. The sleeve and tube assembly leakage during plant operation is required to be within the allowable Technical Specification leakage limits and accident analysis assumptions.

Therefore, the proposed amendment does not involve a significant increase in the probability or consequences of an accident previously evaluated.

2. Does the proposed amendment create the possibility of a new or different kind of accident from any accident previously evaluated?

   Response: No

   Proposed amendment of Technical Specification 5.5.5.2.d.5 to simplify the description of the required inspection region, and Technical Specification 5.5.5.2.f.3 to clarify that this specification is only applicable to sleeves installed in the steam generator tubesheet do not change the intent of these specifications, and do not affect the design function or operation of the tube sleeves. The proposed amendment of Technical Specification 5.5.5.2.f.3 to change the number of fuel cycles that an Alloy 800 steam generator tubesheet sleeve may remain in service from five to eight fuel cycles of operation, does not affect the design function or operation of the tube sleeves. Since these changes do not create any credible new failure mechanisms, malfunctions, or accident initiators not considered in the design or licensing bases, the changes do not create the possibility of a new or different kind of accident from any previously evaluated.

   The leak-limiting Alloy 800 sleeves are designed using the applicable ASME Code, and therefore meet the objectives of the original steam generator tubing. As a result, the functions of the steam generator will not be significantly affected by the installation of the proposed sleeve. Therefore, the only credible failure modes for the sleeve and tube are to leak or rupture, which has already been evaluated. The continued integrity of the installed sleeve and tube assembly is periodically verified as required by the Technical Specifications, and a sleeved tube will be plugged on detection of a flaw in the sleeve or in the pressure boundary portion of the original tube wall in the sleeve to tube joint.

The proposed amendment to Technical Specification 5.5.5.2.f.3 increases the number of fuel cycles Alloy 800 tube sleeves installed in the tubesheet may remain in service to eight fuel cycles of operation. Implementation of this proposed amendment has no significant effect on either the configuration of the plant, the manner in which it is operated, or ability of the sleeve to perform its design function.

Therefore, the proposed amendment does not create the possibility of a new or different kind of accident from any previously evaluated.

3. Does the proposed amendment involve a significant reduction in a margin of safety?

   Response: No

   Proposed amendment of Technical Specification 5.5.5.2.d.5 to simplify the description of the required inspection region, and Technical Specification 5.5.5.2.f.3 to clarify that this specification is only applicable to sleeves installed in the steam generator tubesheet, do not change the intent of these requirements or reduce the margin of safety. The proposed amendment to Technical Specification 5.5.5.2.f.3 to change the number of fuel cycles that an Alloy 800 steam generator tubesheet sleeve may remain in service from five to eight fuel cycles of operation, does not affect a design basis or safety limit (that is, the controlling numerical value for a parameter established in the Updated Final Safety Analysis Report or the license) or reduce the margin of safety.

   The proposed amendment to Technical Specification 5.5.5.2.f.3 increases the number of fuel cycles Alloy 800 tube sleeves installed in the tubesheet may remain in service to eight fuel cycles of operation. Implementation of this proposed amendment would not affect a design basis or safety limit or reduce the margin of safety. The repair of degraded steam generator tubes with leak-limiting Alloy 800 sleeves restores the structural integrity of the degraded tube under normal operating and postulated accident conditions. Minimum reactor coolant system flow rate from the cumulative effect of repaired (sleeved) and plugged tubes will be greater than the flow rate limit established in the Technical Specification limiting condition for operation 3.4.1. The design safety factors utilized for the sleeves are consistent with the safety factors in the American Society of Mechanical Engineers Boiler and Pressure Vessel Code used in the original steam generator design. Tubes with sleeves are subject to the same safety factors as the original tubes, which are described in the performance criteria for steam generator tube integrity in the existing Technical Specifications. The sleeve and portions of the installed sleeve and tube assembly that represent the reactor coolant pressure boundary will be monitored, and a sleeved tube will be plugged if a flaw is detected in the sleeve or in the pressure boundary portion of the original tube wall in the leak-limiting sleeve and tube assembly. Use of the previously-identified design criteria and design verification testing ensures that the margin of safety is not significantly different from the original steam generator tubes.

Therefore, the proposed amendment does not involve a significant reduction in a margin of safety.

Based on the above, FENOC concludes that the proposed amendment involves no significant hazards consideration under the criteria set forth in 10 CFR 50.92 and, accordingly, a finding of "no significant hazards consideration" is justified.

4.3 Conclusions

In conclusion, based on the considerations discussed above, (1) there is reasonable assurance that the health and safety of the public will not be endangered by operation in the proposed manner, (2) such activities will be conducted in compliance with the Commission's regulations, and (3) the issuance of the amendment will not be inimical to the common defense and security or to the health and safety of the public.

5.0 ENVIRONMENTAL CONSIDERATIONS

A review has determined that the proposed amendment would change a requirement with respect to installation or use of a facility component located within the restricted area, as defined in 10 CFR 20, or would change an inspection or surveillance requirement. However, the proposed amendment does not involve (i) a significant hazards consideration, (ii) a significant change in the types or significant increase in the amounts of any effluents that may be released offsite, or (iii) a significant increase in individual or cumulative occupational radiation exposure. Accordingly, the proposed amendment meets the eligibility criterion for categorical exclusion set forth in 10 CFR 51.22(c)(9). Therefore, pursuant to 10 CFR 51.22(b), no environmental impact statement or environmental assessment need be prepared in connection with the proposed amendment.

Attachment

Technical Specification Page Markups
(1 page follows)

5.5 Programs and Manuals

5.5.5.2 Unit 2 SG Program (continued)

3. Indications left in service as a result of application of the tube support plate voltage-based plugging or repair criteria (Specification 5.5.5.2.c.4) shall be inspected by bobbin coil probe during all future refueling outages.

   Implementation of the steam generator tube-to-tube support plate plugging or repair criteria requires a 100-percent bobbin coil inspection for hot-leg and cold-leg tube support plate intersections down to the lowest cold-leg tube support plate with known outside diameter stress corrosion cracking (ODSCC) indications. The determination of the lowest cold-leg tube support plate intersections having ODSCC indications shall be based on the performance of at least a 20-percent random sampling of tubes inspected over their full length.

4. When the F* methodology has been implemented, inspect 100% of the inservice tubes in the hot-leg tubesheet region with the objective of detecting flaws that may satisfy the applicable tube plugging or repair criteria of Specification 5.5.5.2.c.5 every 24 effective full power months or one interval between refueling outages (whichever is less).

5. For Alloy 800 sleeves: The parent tube, in the area where the sleeve-to-tube hard roll joint ~~(lower joint)~~ and the sleeve-to-tube hydraulic expansion joint ~~(upper joint)~~ will be established, shall be inspected prior to installation of the sleeve. Sleeve installation may proceed only if the inspection finds these regions free from service induced indications.

e. Provisions for monitoring operational primary to secondary LEAKAGE

f. Provisions for SG Tube Repair Methods

   Steam generator tube repair methods shall provide the means to reestablish the RCS pressure boundary integrity of SG tubes without removing the tube from service. For the purposes of these Specifications, tube plugging is not a repair. All acceptable tube repair methods are listed below.

   1. ABB Combustion Engineering TIG welded sleeves, CEN-629-P, Revision 02 and CEN-629-P Addendum 1.
   2. Westinghouse laser welded sleeves, WCAP-13483, Revision 2.
   3. Westinghouse leak-limiting Alloy 800 sleeves, WCAP-15919-P, Revision 2. An Alloy 800 sleeve [installed in the hot-leg or cold-leg tubesheet region] shall remain in service for no more than ~~five~~ [eight] fuel cycles of operation starting from the outage when the sleeve was installed.

Enclosure B
L-18-081

Application for Withholding Proprietary Information from Public Disclosure

(7 Pages Follow)

Westinghouse

Westinghouse Electric Company
1000 Westinghouse Drive
Cranberry Township, Pennsylvania 16066
USA

U.S. Nuclear Regulatory Commission
Document Control Desk
11555 Rockville Pike
Rockville, MD 20852

Direct tel: (412) 374-4643
Direct fax: (724) 940-8542
e-mail: greshaja@westinghouse.com

CAW-18-4719

March 9, 2018

APPLICATION FOR WITHHOLDING PROPRIETARY INFORMATION FROM PUBLIC DISCLOSURE

Subject: Steam Generator Alloy 800 Nickel Band Sleeve Operating Cycle Length Extension License Amendment Request: Technical Bases (Proprietary)

The Application for Withholding Proprietary Information from Public Disclosure is submitted by Westinghouse Electric Company LLC ("Westinghouse"), pursuant to the provisions of paragraph (b)(1) of Section 2.390 of the Nuclear Regulatory Commission's ("Commission's") regulations. It contains commercial strategic information proprietary to Westinghouse and customarily held in confidence.

The proprietary information for which withholding is being requested in the above-referenced report is further identified in Affidavit CAW-18-4719 signed by the owner of the proprietary information, Westinghouse. The Affidavit, which accompanies this letter, sets forth the basis on which the information may be withheld from public disclosure by the Commission and addresses with specificity the considerations listed in paragraph (b)(4) of 10 CFR Section 2.390 of the Commission's regulations.

Accordingly, this letter authorizes the utilization of the accompanying Affidavit by FirstEnergy Nuclear Operating Company.

Correspondence with respect to the proprietary aspects of the Application for Withholding or the Westinghouse Affidavit should reference CAW-18-4719, and should be addressed to James A. Gresham, Manager, Regulatory Compliance, Westinghouse Electric Company, 1000 Westinghouse Drive, Building 2 Suite 259, Cranberry Township, Pennsylvania 16066.

James A. Gresham, Manager
Regulatory Compliance

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF BUTLER:

I, James A. Gresham, am authorized to execute this Affidavit on behalf of Westinghouse Electric Company LLC ("Westinghouse") and declare that the averments of fact set forth in this Affidavit are true and correct to the best of my knowledge, information, and belief.

Executed on: 3/9/18

James A. Gresham, Manager
Regulatory Compliance

(1) I am Manager, Regulatory Compliance, Westinghouse Electric Company LLC ("Westinghouse"), and as such, I have been specifically delegated the function of reviewing the proprietary information sought to be withheld from public disclosure in connection with nuclear power plant licensing and rule making proceedings, and am authorized to apply for its withholding on behalf of Westinghouse.

(2) I am making this Affidavit in conformance with the provisions of 10 CFR Section 2.390 of the Nuclear Regulatory Commission's ("Commission's") regulations and in conjunction with the Westinghouse Application for Withholding Proprietary Information from Public Disclosure accompanying this Affidavit.

(3) I have personal knowledge of the criteria and procedures utilized by Westinghouse in designating information as a trade secret, privileged or as confidential commercial or financial information.

(4) Pursuant to the provisions of paragraph (b)(4) of Section 2.390 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld.

(i) The information sought to be withheld from public disclosure is owned and has been held in confidence by Westinghouse.

(ii) The information is of a type customarily held in confidence by Westinghouse and not customarily disclosed to the public. Westinghouse has a rational basis for determining the types of information customarily held in confidence by it and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The application of that system and the substance of that system constitute Westinghouse policy and provide the rational basis required.

Under that system, information is held in confidence if it falls in one or more of several types, the release of which might result in the loss of an existing or potential competitive advantage, as follows:

(a) The information reveals the distinguishing aspects of a process (or component, structure, tool, method, etc.) where prevention of its use by any of

Westinghouse's competitors without license from Westinghouse constitutes a competitive economic advantage over other companies.

(b) It consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), the application of which data secures a competitive economic advantage, (e.g., by optimization or improved marketability).

(c) Its use by a competitor would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing a similar product.

(d) It reveals cost or price information, production capacities, budget levels, or commercial strategies of Westinghouse, its customers or suppliers.

(e) It reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

(f) It contains patentable ideas, for which patent protection may be desirable.

(iii) There are sound policy reasons behind the Westinghouse system which include the following:

(a) The use of such information by Westinghouse gives Westinghouse a competitive advantage over its competitors. It is, therefore, withheld from disclosure to protect the Westinghouse competitive position.

(b) It is information that is marketable in many ways. The extent to which such information is available to competitors diminishes the Westinghouse ability to sell products and services involving the use of the information.

(c) Use by our competitor would put Westinghouse at a competitive disadvantage by reducing his expenditure of resources at our expense.

(d) Each component of proprietary information pertinent to a particular competitive advantage is potentially as valuable as the total competitive advantage. If competitors acquire components of proprietary information, any one component may be the key to the entire puzzle, thereby depriving Westinghouse of a competitive advantage.

(e) Unrestricted disclosure would jeopardize the position of prominence of Westinghouse in the world market, and thereby give a market advantage to the competition of those countries.

(f) The Westinghouse capacity to invest corporate assets in research and development depends upon the success in obtaining and maintaining a competitive advantage.

(iv) The information is being transmitted to the Commission in confidence and, under the provisions of 10 CFR Section 2.390, is to be received in confidence by the Commission.

(v) The information sought to be protected is not available in public sources or available information has not been previously employed in the same original manner or method to the best of our knowledge and belief.

(vi) The proprietary information sought to be withheld in this submittal is that which is appropriately marked in LTR-SGMP-18-3 P-Attachment, "Steam Generator Alloy 800 Nickel Band Sleeve Operating Cycle Length Extension License Amendment Request: Technical Bases" (Proprietary), for submittal to the Commission, being transmitted by FirstEnergy Nuclear Operating Company (FENOC) letter. The proprietary information as submitted by Westinghouse for use by FENOC for Beaver Valley Unit 2 is applicable to other licensee submittals in response to certain NRC requirements for the use of Alloy 800 sleeves for the repair of degraded steam generator tubes.

(a) This information is part of that which will enable Westinghouse to demonstrate the acceptability of extending the life of Alloy 800 sleeves that are already installed or planned to be installed in the Beaver Valley Unit 2 steam generators from five operating cycles to eight operating cycles.

(b) Further, this information has substantial commercial value as follows:

(i) Westinghouse can sell the use of similar information to its customers for the purpose of meeting NRC requirements for licensing documentation supporting the use of Alloy 800 or other types of sleeves.

(ii) Westinghouse can sell support and defense of this information on Alloy 800 sleeves or other types of sleeves to customers in the licensing process.

(iii) The information requested to be withheld reveals the distinguishing aspects of a methodology which was developed by Westinghouse.

Public disclosure of this proprietary information is likely to cause substantial harm to the competitive position of Westinghouse because it would enhance the ability of competitors to provide similar technical evaluation justifications and licensing defense services for commercial power reactors without commensurate expenses. Also, public disclosure of the information would enable others to use the information to meet NRC requirements for licensing documentation without purchasing the right to use the information.

The development of the technology described in part by the information is the result of applying the results of many years of experience in an intensive Westinghouse effort and the expenditure of a considerable sum of money.

In order for competitors of Westinghouse to duplicate this information, similar technical programs would have to be performed and a significant manpower effort, having the requisite talent and experience, would have to be expended.

Further the deponent sayeth not.

PROPRIETARY INFORMATION NOTICE

Transmitted herewith are proprietary and non-proprietary versions of a document, furnished to the NRC in support of a license amendment to extend the life from five operating cycles to eight operating cycles of Alloy 800 sleeves used to repair degraded steam generator tubes in the Beaver Valley Unit 2 steam generators, and may be used only for that purpose.

In order to conform to the requirements of 10 CFR 2.390 of the Commission's regulations concerning the protection of proprietary information so submitted to the NRC, the information which is proprietary in the proprietary versions is contained within brackets, and where the proprietary information has been deleted in the non-proprietary versions, only the brackets remain (the information that was contained within the brackets in the proprietary versions having been deleted). The justification for claiming the information so designated as proprietary is indicated in both versions by means of lower case letters (a) through (f) located as a superscript immediately following the brackets enclosing each item of information being identified as proprietary or in the margin opposite such information. These lower case letters refer to the types of information Westinghouse customarily holds in confidence identified in Sections (4)(ii)(a) through (4)(ii)(f) of the Affidavit accompanying this transmittal pursuant to 10 CFR 2.390(b)(1).

COPYRIGHT NOTICE

Enclosure C
L-18-081

Steam Generator Alloy 800 Nickel Band Tubesheet Sleeve
Operating Cycle Length Extension License Amendment Request: Technical Bases
(Nonproprietary Version)

(52 Pages Follow)

Westinghouse Electric Company

Steam Generator Alloy 800 Nickel Band Tubesheet Sleeve

Operating Cycle Length Extension License Amendment Request: Technical Bases

March 10, 2018

Author:
Electronically Approved*
Jesse S. Baron*
Steam Generator Management Programs

Verifier:
Electronically Approved*
Jay R. Smith*
Steam Generator Management Programs

Reviewer:
Electronically Approved*
Gary W. Whiteman*
Plant Licensing and Engineering

Reviewer:
Electronically Approved*
Ronald J. Pocratsky*
Steam Generator Management Programs

Approved:
Electronically Approved*
David P. Lytle*, Manager
Steam Generator Management Programs

Electronically approved records are authenticated in the Electronic Document Management System.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

In October of 2008, FirstEnergy Nuclear Operating Company (FENOC) submitted a license amendment request (LAR) to permit the installation of Westinghouse Alloy 800 steam generator (SG) tube sleeves. By Nuclear Regulatory Commission (NRC) letter dated September 30, 2009, Amendment 170 to Facility Operating License No. NPF-73 was issued which permitted installation of Alloy 800 sleeves. The amendment required Alloy 800 sleeves be removed from service by the spring 2017 refueling outage (2R19), which was the originally planned SG replacement date. The amendment assumed Alloy 800 sleeves would be installed at the fall 2009 (2R14) outage, thus imposing an effective Alloy 800 sleeve lifetime of five (5) operating cycles. This imposition was related to perceived limitations of the non-destructive examination (NDE) methods available at the time, introduced by the nickel band applied to the outer diameter (OD) of the sleeve in the sleeve lower joint mechanical roll expansion region. By NRC letter dated September 30, 2009, Amendment 184 to Facility Operating License No. NPF-73 was issued. This amendment clarified the Alloy 800 sleeve lifetime as five cycles following sleeve installation.

The technical bases supporting the original license amendment related to mechanical and leakage testing are unchanged. The results of this testing show that modifications performed to the parent tube adjacent to the sleeve nickel band would not reduce the axial load bearing capability of the sleeve-tube joint to less than the design requirement. Similarly, leakage integrity testing shows that a testing condition which simulated a complete inability of the sleeve-tube joint to transmit installation loads would not result in unacceptable primary-to-secondary leakage during all plant conditions. Thus, the original technical bases established that postulated degradation of the parent tube adjacent to the nickel band of the sleeve would not affect structural or leakage integrity.

With regard to NDE capabilities, the original bases established that 100% through-wall (TW) stress corrosion cracking (SCC) degradation of the parent tube adjacent to (at the same axial elevation as, e.g., behind) the sleeve OD nickel band would be readily detectable and the partial depth SCC degradation would be detectable at probabilities related to the actual degradation depth. Recently, advancements in probability of detection (POD) simulation methodology developed since preparation of the original license amendment request were applied to the sleeved tube condition. These analyses conclude that SCC degradation of the parent tube adjacent to the nickel band will be detectable using eddy current testing methods at probability levels consistent with existing non-sleeved tube examination technique specification sheets (ETSS).

Also, finite element analysis (FEA) of the tube-sleeve joint indicates that residual stresses at the surface of the parent tube, where the tube is contacting the sleeve at the lower roll joint will remain compressive following sleeve installation. Compressive residual stresses are not subject to SCC initiation. Thus, SCC of the parent tube is not postulated based on existing SCC initiation theory.

This document summarizes the prior mechanical and leakage testing discussed in References 1, 2, and 3 and introduces new or updated analyses. The NRC Staff has stated within the two license amendments identified above that it finds the mechanical testing program acceptable. The new or updated analyses address NDE capabilities that show the NDE limitation is not as restrictive as initially perceived and

evaluation of parent tube residual stress conditions which conclude that SCC of the parent tube adjacent to the sleeve nickel band is not postulated. As such, the initial issues related to NDE capabilities are no longer considered relevant and a basis exists for removal of the five cycle limitation on sleeve operating lifetime. However, FENOC has elected to request an extension of the sleeve operating period from five to eight operating cycles. This extension is requested to provide additional time to qualify an NDE technique for detection of SCC in the parent tube adjacent to the nickel band commensurate with NDE technique qualification requirements outlined in the Electric Power Research Institute (EPRI) Pressurized Water Reactor Steam Generator Examination Guidelines (Reference 5).

1.0 BACKGROUND

The Westinghouse Alloy 800 sleeve design is an evolution of the Asea Brown Boveri (ABB) Combustion Engineering (C-E) PLUSS sleeve design. The two designs are essentially identical; the only difference being the addition of the nickel band applied to the sleeve OD in the lower roll expansion joint region. The nickel band was added as an additional barrier to leakage through the tube-sleeve joint. The nominal nickel band thickness is 0.002 inch and extends for an axial length of 0.5 inch; the nickel band is located on the lower half of the roll expansion length. A 0.5 inch wide "microlok" band is applied to the tube at the upper half of the roll joint. The microlok band is a thermally applied material similar to the sleeve material which acts to increase the coefficient of friction between the tube and sleeve, thus increasing axial load bearing capability of the sleeve joint. Figure 1 presents a schematic of the Alloy 800 tubesheet region sleeve. The sleeve is a maximum of 25 inches long. The upper tube-sleeve joint is formed by six equally spaced, approximately 3/8 inch wide hydraulic expansions. The lower tube-sleeve joint is a mechanical roll expansion and the elevation of the centerline of the roll expansion is approximately located at the mid-plane elevation of the tubesheet. An additional detail schematic of the lower joint region is included to help identify the various elements of the design and the post-installed condition.

The Alloy 800 tube support plate sleeve does not include a nickel band. To date, there are no Alloy 800 tube support plate sleeves installed at the Beaver Valley Power Station Unit 2 (BVPS-2). The first PLUSS sleeve installation occurred in Europe in 1995; the first US Alloy 800 sleeve installation occurred in 2000.

NRC Generic Letter (GL) 2004-01, "Requirements for Steam Generator Tube Inspections," issued August 3, 2004, presented the NRC position regarding expectations for SG tube inspections. All utilities were required to submit responses regarding eddy current inspections performed at licensed units. As a result of these responses, the NRC issued requests for additional information (RAI) related to inspection capabilities of currently available eddy current methods of those utilities with installed tungsten inert gas (TIG) welded sleeves. The TIG sleeve includes a tube-to-sleeve weld at the upper (freespan) joint and a mechanical roll expansion for the lower attachment joint. The TIG sleeve includes a microlok and nickel band identical to the Alloy 800 tubesheet sleeve. At the lower roll expansion joint, both the parent tube and the sleeve constitute the pressure boundary.

The industry responded with a "white paper," (Reference 1) which concluded that any deficiencies in the NDE methods at the nickel band were not relevant as, 1) each joint of the sleeve must satisfy the axial load bearing capability requirement, thus a failure of any one joint would keep the sleeve located within the tube, and 2) the inherent structural integrity characteristics of a tube-sleeve roll joint with postulated degradation of the parent tube would retain sufficient axial load bearing capability to satisfy the design requirement of the joint. The design requirement is that each joint of the sleeve must independently provide for axial load bearing capability greater than the hydraulic end cap load applied to the tube during normal operating conditions, with a safety factor of three.

The investigation was continued with the issuance of an update to the white paper (Reference 2) which described test results of mechanical and leakage testing of similar (hybrid expansion joint (HEJ), and laser welded sleeve (LWS)) designs. Each of these designs uses a mechanical roll joint for the lower

attachment joint. This testing includes cases where the roll length, applied torque, and surface conditions of the tube-sleeve installation were modified to represent abnormal or atypical installations used to support the judgment that postulated non-detected degradation of the parent tube adjacent to the nickel band region does not degrade the axial load bearing capability of the sleeve joint to less than the requirement. As these designs use different rolling torques and roller lengths, the data was normalized using a torque per unit area of contact concept in order to extend the HEJ and LWS results to the TIG and Alloy 800 sleeve designs. Again, the results support the judgment that postulated degradation of the parent tube would not degrade the axial load bearing capability of the tube-sleeve joint to less than the design requirement.

The final update to the white paper (Reference 3) described results of mechanical and leakage testing of tube-sleeve assemblies where the parent tube was modified to simulate postulated degradation. In one case, the modification to the parent tube simulated a circumferential separation of the parent tube at the intersection of the microlok and nickel bands. In the other case, the parent tube was modified with axial OD electro discharge machining (EDM) notches designed to reduce the ability of the tube to transmit loads in the radial direction. In both cases the results show the axial load bearing capability of the tube-sleeve joint remains well above the design requirement. In fact, the axial load bearing capability at room temperature conditions is more than twice the design requirement. Reference 3 documents the results of the modified parent tube mechanical testing and the results of leakage testing.

Finally, as part of the BVPS-2 original license amendment request, NDE capabilities using the **+POINT™**[1] probe were investigated (Reference 4). This effort showed that degradation of the type simulated in the Reference 3 effort, as well as shallower degradation, would be readily detectable using current eddy current methods. The conclusion of this effort is that since the mechanical and leakage integrity testing showed the postulated parent tube degradation would not reduce the joint load bearing capabilities to less than the design requirement, and that current NDE methods could readily detect such degradation, that the risk of experiencing an unanalyzed event was not increased. Only tubesheet region Alloy 800 sleeves are installed at BVPS-2. All Alloy 800 sleeves are inspected each outage over their full length using a +POINT probe.

Despite this technical basis, the BVPS-2 license amendments previously identified approved a five operating cycle lifetime for the Alloy 800 nickel band sleeves. This requires that the sleeves installed in fall 2012 outage (2R16) be removed from service in the spring 2020 outage (2R21) and sleeves installed in the spring 2017 outage (2R19) be removed from service in the fall 2024 outage (2R24). Currently 94 sleeves installed at 2R16 remain in service and 171 sleeves installed at 2R19 remain in service. Removing these sleeves from service would result in steam pressure loss that would jeopardize the ability of the unit to achieve 100% electrical output. Additionally, the unnecessary removal from service of these sleeves would cause the plant control system to operate in a control valves wide open (VWO) position, limiting the ability of the plant to respond to minor load changes. Thus, FENOC is requesting an extension of the Alloy 800 sleeve service life to eight (8) operating cycles after installation. This additional operating period is requested to permit development and qualification of an NDE technique that satisfies the requirements of Appendix H of Reference 5.

---

[1] *+POINT is a trademark or registered trademark of Zetec, Inc., in the United States and/or other countries. Other names may be trademarks of their respective owners.*

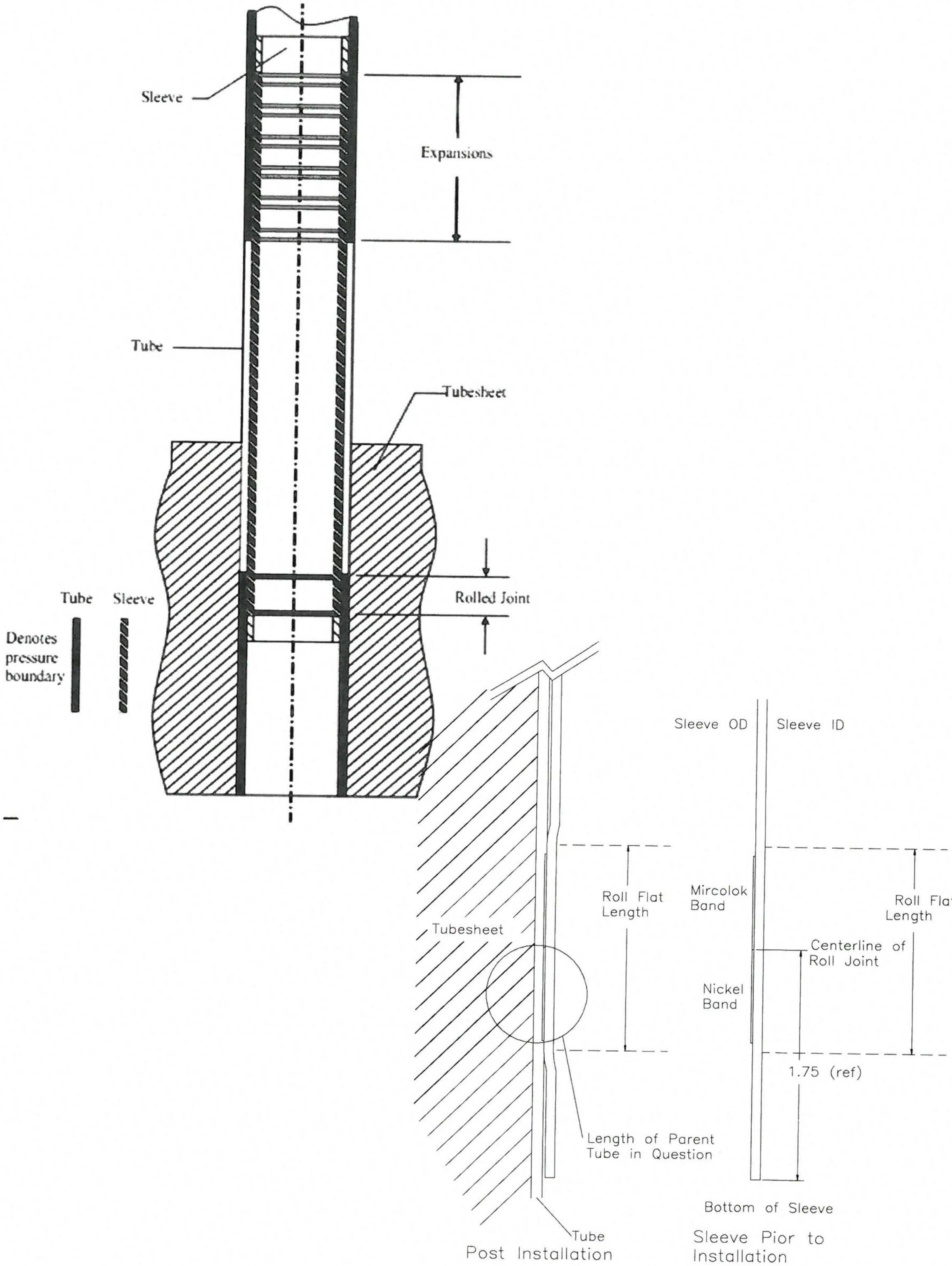

Figure 1: Alloy 800 Tubesheet Sleeve

2.0 WORLDWIDE INSTALLATION SUMMARY

The majority of Alloy 800 sleeve installations have occurred in Europe and Asia using the PLUSS sleeve. The PLUSS design is essentially identical to the Alloy 800 sleeve installed in the US except the PLUSS sleeve does not include nickel banding at the lower joint region. To date, Westinghouse is not aware of any reports of parent tube degradation in the lower joint roll region for any Westinghouse sleeve design.

Figure 2 presents a running summary of the number of Alloy 800 tubesheet sleeves in service over the past 20 years based on information contained in Reference 13. As many as 8,750 Alloy 800 tubesheet sleeves were in-service at one time with no reports of parent tube degradation. In some cases, the installation of sleeves was used to extend the SG operating period to the point in time when SG replacement occurred; thus, on Figure 2 the cumulative number of in-service sleeves is reduced. In 2017 approximately 1,800 tubesheet sleeves were installed in France due to large numbers of tubes affected with primary water stress corrosion cracking (PWSCC) at the top-of-tubesheet expansion transition. Another 1,800 sleeves (approximately) are anticipated to be installed at another French plant in 2018.

Of the greater than 14,000 Alloy 800 tubesheet sleeve installations, nearly all are/were installed at plants using Alloy 600 mill annealed tubing. The only tubesheet sleeve installations in non-mill annealed tubing were two Korean plants that used Alloy 600 thermally treated tubing.

Another approximately 12,000 tube support plate sleeves were installed by Westinghouse in Korea starting in approximately 2013. These are/were installed in plants using both mill annealed and thermally treated Alloy 600 tubing.

An extensive history of Westinghouse HEJ and LWS installations also supports the conclusion that degradation of the parent tube adjacent to the roll expansion at the lower sleeve joint is not anticipated. Neither of these designs includes nickel application to the sleeve OD. The sleeve material is Alloy 690 or in the case of one plant, Alloy 690 with an Alloy 625 cladding on the entire length of the sleeve OD. Westinghouse is not aware of, and has no knowledge of, any reports of parent tube SCC in the sleeve roll joint region for any Westinghouse sleeve design.

The majority of these installations (with subsequent SG replacement) occurred prior to 1995, which is when the +POINT probe gained widespread acceptance and application. The installations for which post-installation sleeved tube inspection likely included the +POINT probe are summarized on the next page.

Plant	Sleeve Installation Date	Number Sleeves Installed	EFPY to SG Replacement	Type of Sleeve
Beaver Valley 1	3/2000	380	5.3	LWS
Braidwood 1	10/1996	897	1.5	LWS
Braidwood 1	4/1997	270	1.2	LWS
Byron 1	10/1995	2046	1.5	LWS
Byron 1	4/1996	3527	1.2	TIG
Farley 1	9/1992	44	6.3	LWS
Farley 1	3/1994	77	5.1	LWS
Farley 1	3/1997	919	2.4	LWS
Farley 1	12/1998	243	1.1	LWS
Farley 2	3/1992	21	7.6	LWS
Farley 2	9/1993	216	6.3	LWS
Farley 2	10/1996	826	3.8	LWS
Farley 2	4/1998	108	2.5	LWS

Of these, only Farley Unit 2 would have been anticipated to experience degradation of the parent tube prior to SG replacement using a Weibull initiation model based on the observed non-sleeved tube flaw initiations. As no sleeve parent tube flaw indications were detected in Farley Unit 2 prior to SG replacement, there is one, two, or both possible assumptions applicable to SCC flaw initiation. These assumptions are that the residual stresses at the parent tube inside diameter (ID) surface do not support SCC initiation or that the installation of the sleeve results in a reduced tube temperature resulting in a reduced SCC initiation function.

2.1 BVPS-2 Sleeve Plugging Experience

To date, three sleeved tubes have been removed from service through plugging of the parent tube. Note that due to the elevation of the installed sleeve, any sleeved tube which requires plugging involves installation of a standard sized tube plug; the plug is not installed into the sleeve.

During the spring 2014 outage (2R17), two sleeved tubes, R42 C43 and R15 C85, both in SGA, were plugged due to volumetric indications on the parent tube ID surface at approximately 2 inches above the top-of-tubesheet. Both tubes included two volumetric indications in close axial and circumferential proximity. The measurable geometry of these indications were very similar; approximately 0.3 inch axially and 70 degrees arc circumferentially. The installation records of both sleeves were reviewed; no apparent abnormalities were observed. The other commonality between the two locations is that both are beyond the normal sleeve installation boundary. This boundary is computer generated and is based on the tooling and channelhead bowl dimensions. The intent of this boundary is to prevent a failed sleeve installation attempt which could result in sleeve damage or the sleeve wedged into the tube prior to complete insertion and is not related to the ability to successfully create the upper and lower joints. Sleeves have been successfully installed in locations that are slightly (up to two tube pitches) beyond the computer generated boundary, however, this practice is attempted only by the most experienced operators. Whether or not installation beyond the installation boundary resulted in some damage to the tube during installation of the sleeve which then manifested into an eddy current signal after one cycle of operation cannot be determined. However, the similarity of location of the indications, geometry of the indications, and lack of future observations on any other sleeved tubes within the sleevable boundary suggests that this experience is not generic.

Also during the 2R17 outage, one sleeved tube, R3 C48 in SGB was plugged due to a reported distorted support indication (DSI) at the 05H TSP. For Row 3 and Row 4 sleeved tubes the hot leg vertical straight section of tubing above the sleeve is inspected using a 0.630 inch diameter wide groove bobbin probe as a standard 0.720 inch diameter bobbin probe cannot reliably pass through Row 4 and smaller U-bends. Amplitude sizing of DSI signals using the 0.630 inch wide groove probe is not part of the BVPS-2 alternate repair criterion for axial ODSCC at TSP intersections, thus, any detected indications are plugged upon detection. A 0.720 inch diameter bobbin coil distorted support indication was reported at this location at the time of sleeve installation.

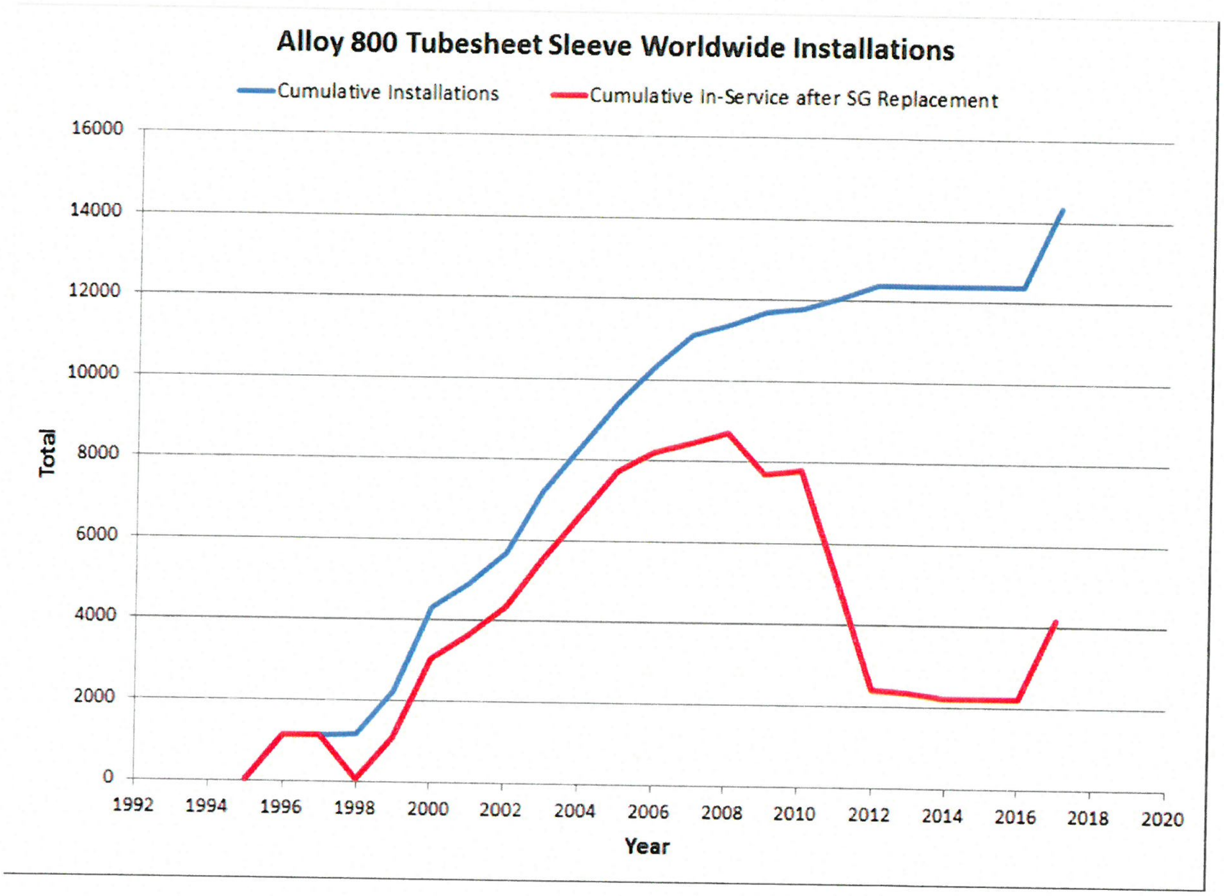

Figure 2: Alloy 800 Sleeve Worldwide Installations

3.0 SIMILARITY WITH OTHER SLEEVE DESIGNS

The Alloy 800 tubesheet sleeve with nickel band shares similarity with many other sleeve designs. This similarity is in the lower joint roll expansion.

The other industry designs which use a roll expansion to form the lower joint are the ABB C-E TIG welded sleeve, the ABB C-E PLUSS sleeve, and the Westinghouse HEJ and LWS designs. Sleeve material is Alloy 690 thermally treated with the exception of the PLUSS sleeve, which uses Alloy 800 material. The PLUSS sleeve does not include the additional nickel band.

The Alloy 800, TIG, and PLUSS sleeves include a thermal spray applied microlok band on the sleeve OD in the lower joint roll expansion region. The microlok band is adjacent to the nickel band and the intersection between the two bands is located at the axial center of the roll expansion region. The microlok material is similar to the base metal of the sleeve and acts to increase the coefficient of friction between the sleeve and tube, thus increasing the axial load bearing capability of the joint.

Given the inherent similarities of the roll expansion joint used in these other sleeves, mechanical testing results for these other sleeve designs will be used to help form the technical bases for the condition of postulated parent tube degradation adjacent to the nickel band of the Alloy 800 sleeve design.

4.0 ANALYSIS LOGIC OF THIS EVALUATION

This document uses a multi-tiered approach to establish that each question of a significant hazards consideration consistent with 10 CFR 50.92 addressing extension of the sleeve operational life restriction from five to eight cycles can be answered in the negative. First, the document will establish that PWSCC degradation of the parent tube adjacent to the nickel band region of the sleeve is not a credible event. Section 5 presents the discussion regarding PWSCC non-susceptibility. In the event that PWSCC degradation of the parent tube were to occur, this document will establish that the presence of PWSCC degradation will not reduce the axial load bearing capability of the lower sleeve joint to less than the design requirement of three times the normal operating pressure differential applied to the tube cross-sectional flow area. This load is often referred to as the "end cap load." Section 6 presents the discussion of assumed degraded joint integrity characteristics. Finally, this document will establish that current NDE capabilities will reliably detect degradation of depths less than used in the mechanical testing program described in Section 6. Section 8 presents the discussion of NDE capabilities. Thus:

1. Residual stresses at the parent tube ID surface are shown by analysis to remain compressive, thus SCC degradation of the parent tube is not a credible event.
2. Even if PWSCC degradation of the parent tube does occur, mechanical testing of modified parent tube specimens with installed Alloy 800 sleeves shows that SCC degradation of the parent tube adjacent to the nickel band of the sleeve does not reduce the axial load bearing capability of the sleeve lower joint to less than the design requirement. Therefore, the lack of formal certification of the applied NDE technique for detection of PWSCC degradation in the parent tube adjacent to the nickel band of the sleeve will not increase the risk of the plant experiencing an unanalyzed accident or result in a significant reduction in safety margin. Additionally, conservatively configured leakage tests described in Reference 3 have quantified leakage characteristics of postulated degraded parent tubes. This contribution will be considered when performing the SG Operational Assessment following each outage to ensure that current radiological analyses remain valid.
3. Investigation of current NDE capabilities shows that 100% through-wall (TW) degradation of the parent tube will be readily detectable and parent tube degradation consistent with part through-wall depths of the parent tube modifications (implemented as part of the mechanical testing program) will be readily detectable using current inspection methods.

As such, each question of a significant hazards consideration evaluation consistent with 10 CFR 50.92 addressing extension of the sleeve operational life restriction from five to eight cycles can be answered in the negative.

This document establishes that SCC degradation of the parent tube adjacent to the sleeve nickel band is not a credible event (not a potential degradation mechanism). As such, consistent with GL 2004-01, the Degradation Assessment prepared for the BVPS-2, fall 2018 outage (2R20) and all subsequent outages will identify that SCC of the parent tube adjacent to the nickel band is not a potential degradation mechanism. Per Reference 5, NDE techniques qualified for detection according to Appendix H of Reference 5 are required for the inspection of regions susceptible to existing or potential degradation mechanisms. Since a potential degradation mechanism is not present, NDE techniques qualified

according to Appendix H of Reference 5 are not required for the parent tube adjacent to the nickel band of the sleeve and inspection of this region is considered a diagnostic test. Per Reference 5, diagnostic techniques should be mocked-up to demonstrate the techniques' capabilities prior to use. The results of a diagnostic test can be used in integrity assessments provided the limitations are understood. Section 8 includes discussion of the NDE specimens used, which include doped steam generated SCC, thus, the condition has been mocked-up. Section 8 also establishes that the probability of detection (POD) of parent tube degradation depths consistent with the modifications used in the mechanical testing program is approximately 0.95. Thus it can be established that the current +POINT probe inspection techniques and capability limitations would not represent a challenge to the structural or leakage integrity characteristics of the sleeve joint. The current inspection techniques are judged to be consistent with the expectations and intent of Reference 5.

FENOC intends to continue to proactively perform such diagnostic tests on all sleeves each outage to monitor the condition of the tube-to-sleeve roll joint using the +POINT probe, as well as the upper joint region and the sleeve length between.

5.0 PARENT TUBE SCC POTENTIAL

Previous analyses (Reference 11) have indicated that hydraulic expansion of tubes in tubesheets results in compressive ID residual hoop stresses below the top-of-tubesheet with a potential for tensile residual axial stresses within the first 0.3 to 0.4 inch below the top-of-tubesheet which transition to compressive at greater than 0.4 inch below the top-of-tubesheet. A similar condition would be expected for explosive expansions. Upon dissipation of the expansion force, hysteresis would reverse the direction of the tube ID surface stresses to compressive. A similar logic can be applied to mechanical roll expansions. Reference 12 presents the technical basis for the F* alternate repair criterion (ARC) which includes tube ID measurement data for tubes roll expanded into tubesheet collars. Upon removal of the collar, the tube ID dimension was increased, thus supporting a compressive residual stress condition at the tube ID, post-roll expansion.

Varying levels of, and directionality of, residual stresses in the expansion transition region (from expanded to non-expanded) exist for the different expansion methods. Based on these analyses, crack initiation at greater than about 0.4 inch below the expansion transition is therefore likely associated with a tubesheet hole geometric discontinuity, i.e., bulges, over-expansions, or dents.

The nominal top-of-tubesheet +POINT probe inspection distance for BVPS-2 is from 6 inches above to 3 inches below the top-of-tubesheet; the 3-inch dimension is a requirement of the F-star (F*) tubesheet region alternate repair criterion (ARC). Indications identified within this 3 inch inspection distance are plugged or sleeved. Prior to sleeve installation, the parent tube is inspected using a +POINT probe at the location of the sleeve joint regions. At the lower joint the +POINT probe inspection distance is from 8 to 14 inches above the hot leg tube end. The centerline of the sleeve roll joint is located at 12.5 inches above the tube end. The added +POINT inspection distance below the sleeve satisfies requirements of the F* ARC. In addition, the bobbin data for the tube is re-evaluated prior to sleeve installation to ensure that there are no geometric discontinuities in the tubesheet which could influence sleeve insertion or installation. Although not a required inspection for satisfaction of the F* ARC, it is standard practice at BVPS-2 to perform +POINT probe inspection of previously identified bulge and over-expansion signals in the hot leg tubesheet region below the F* distance, on a sampling basis. To date (through the 2R19 outage), no indications have been reported at bulges or over-expansions within the tubesheet at BVPS-2.

5.1 SCC Elevation Trending

Operating experience has shown that PWSCC indications can be observed in the uniformly expanded region below the expansion transition. However, the following discussions present data which will show that for the parent tube, the observation of indications below the bottom of the expansion transition are strongly associated with bulges, over-expansions, or other geometric discontinuities. This supports the posit that the expansion process will result in compressive residual stresses below the expansion transition thus no SCC initiation potential exists in the absence of bulges or over-expansions. Additional information is provided which examines the elevation trending of indications below the expansion transition and concludes that at the elevation in the tubesheet of the sleeve roll joint, the probability of SCC observation is negligible. The following discussion will examine the three forms of tube expansion used in the industry; hydraulic, explosive, and mechanical roll.

In Alloy 600 thermally treated tubing using hydraulic expansion the first observations of PWSCC degradation were reported in 2004 at bulges or over-expansions in the expanded tube length below the top-of-tubesheet expansion transition. Bulges or over-expansions are localized areas where the tube hole diameter is enlarged resulting in tensile stresses where the tube material is formed over the edge of the bulge or overexpansion. The first observation of PWSCC at the top-of-tubesheet expansion transition in Alloy 600 thermally treated tubing was reported in 2015. Only a few US plants used a combination of Alloy 600 mill annealed with Alloy 600 thermally treated hydraulically expanded tubing. One of these plants had Westinghouse Model E2 and the other had Westinghouse Model F original SGs. Both plants have since replaced their SGs.

Based on information contained in the EPRI Steam Generator Degradation Database (SGDD), SCC degradation (either ID or OD initiated) at the tubesheet region was not reported in the plant with Model E2 SGs up to the time of SG replacement. The hot leg tubes in the Model E2 SGs were shotpeened prior to operation. Accumulated EFPYs at the time of SG replacement was 10.3 EFPY. The plant with Model F original SGs included thermally treated Alloy 600 tubing in Rows 1 through 10 and mill annealed Alloy 600 tubing in all remaining rows. Based on information contained in the EPRI SGDD, ODSCC was reported at the top-of-tubesheet at the plant with Model F SGs beginning with the 1992 inspection. ID initiated SCC was first reported at the 1995 inspection; of the 21 PWSCC indications reported 19 were located at the expansion transition, one was located at approximately 1 inch below the top-of-tubesheet, and one was located at approximately 2.5 inches below the top-of-tubesheet. At the 1996 inspection, 111 PWSCC indications were reported. Figure 3 presents a distribution plot of the 1996 PWSCC elevations. This figure shows a strong predominance for initiation at the top-of-tubesheet with dramatically reduced initiation frequency below the top-of-tubesheet. The available information from the 1998 outage includes data for 57 ID initiated circumferential indications. Six of these are located at greater than 1 inch below the top-of-tubesheet. After the first observation of PWSCC in the tubesheet region in hydraulically expanded Alloy 600 thermally treated tubing, which was associated with a bulge, the available 1998 data was reviewed to determine if the indications below the top-of-tubesheet could be associated with bulges or over-expansions. Four of these 6 are associated with 4 to 5 mil bulges based on bobbin profilometry analysis and one is associated with an incomplete (not full depth) tube expansion. No information is available for the final indication thus no association can be made for this indication if or if not it is associated with a bulge, over-expansion, or other anomaly. Of the 20 ID axial indications reported in 1999, all were associated with the expansion transition. Thus, the hydraulically expanded tubing experience strongly supports the association of indications below the top-of-tubesheet with localized bulges or over-expansions.

In Alloy 600 mill annealed tubing using explosive expansion a higher incidence rate of PWSCC compared to hydraulic expansions was observed with the majority of the indications reported at the top-of-tubesheet expansion transition. As with hydraulic expansions, indications below the top-of-tubesheet are believed to be associated with bugles or other drilling anomalies. Figure 4 is taken from Reference 8. This plot shows the elevation dependence of ID initiated indications at the Sequoyah Unit 2, BVPS1, and Diablo Canyon original SGs, which used mill annealed Alloy 600 tubing with explosive tube expansion, and shows that as the depth below the top-of-tubesheet is increased, the probability of identifying a SCC indication is reduced. As the root cause of the initiation of the PWSCC below the top-of-tubesheet was not considered critical given the timeframes these original SGs were in operation, no detailed review of

bobbin data to isolate a root cause was considered. This plot shows that at the elevation of the sleeve lower roll joint, approximately 10 inches below the top-of-tubesheet, the probability of observation is essentially zero. Note that the cumulative probability distribution for the Sequoyah Unit 2 SGs is elevated for the Cycle 11 and Cycle 12 inspections due to an increase in the +POINT probe inspection depth into the tubesheet at the Cycle 11 inspection, required by application of the W* ARC.

Mechanical roll expansion has only been applied in plants using Alloy 600 mill annealed tubing and have experienced a much higher incidence rate of PWSCC compared to explosive expansions at the top-of-tubesheet. Note that only a few original SGs with mill annealed Alloy 600 tubing utilized hydraulic expansion; all others used explosive or mechanical roll expansion. The incidents of PWSCC indications below the top-of-tubesheet expansion transition in mechanical roll expansions have occurred at the roll overlap areas. The mechanical roll process begins at the bottom of the tubesheet progressing upwards. The flat length (length of the roll pin with a uniform diameter) of the roll pin is typically 1.25 inches for original Westinghouse SGs. The roller is "stepped" into the tube using a mechanically controlled device which indexes the roller in 1 inch increments, thus creating a roll overlap length of approximately ¼ inch for each successive roll application. During the rolling process the upper portion of the roller creates a transition, just as the top-of-tubesheet when the final roll is created. This temporary transition region is then reworked to a flat condition by application of the next successive roll.

The Farley Unit 2 original SGs were essentially identical to the BVPS-2 Model 51M SGs. The Farley Unit 2 SGs experienced an aggressive PWSCC initiation function. Due to the large quantity of data available for the Farley Unit 2 SGs, only PWSCC flaw data from SGA during the 1996 inspection was interrogated. Figure 5 presents the PWSCC elevation dependence for SGA from the Farley Unit 2, 1996 inspection. This plot shows that the probability of initiation below the expansion transition is negligible. The bins were populated using the uppermost flaw elevation thus explaining the large number of indications in the +1 bin, which captures indication elevations from 0.01 to 1.0 inch above the top-of-tubesheet.

Thus this data related to indication elevation trending supports the argument that in general:

- Tube ID residual stresses below the expansion transition are not a likely initiation condition
- ID initiated SCC below the expansion transition is likely associated with localized tube geometry discontinuities (bulges, over-expansions, dents, etc.
- The probability of ID SCC initiation below the expansion transition is decreased with increasing depth below the expansion transition, and,
- The probability that the parent tube would experience ID SCC at an elevation consistent with the sleeve roll joint is extremely low.

5.2 PWSCC Remediation Methods

Peening, both roto-peening and shot peening, have been used to apply compressive residual stresses at the tube ID. The BVPS-2 hot and cold leg tube regions were shot peened from 3 inches above the top-of-tubesheet to approximately 1 inch above the tube end. Peening has dramatically improved performance of the tubing with regard to PWSCC initiation. To date, six (6) tubes have been affected by PWSCC in the tubesheet at BVPS-2; all have been located at the top-of-tubesheet expansion transition. Axial

indications were reported at 2R09, 2R13, 2R17, and 2R18 while circumferential PWSCC indications were reported at 2R11 and 2R16. This performance is dramatically improved compared to other units which used full depth mechanical roll expansion. Based on information contained within the EPRI SGDD, a plant with original Model 51 SGs, which also used full depth tubesheet roll expansion, no less than 833 tubes were affected by PWSCC in the tubesheet region up to the final eddy current inspection in 1999 (14.9 EFPY). Westinghouse inspection records suggest the total number of tubes affected by PWSCC is approximately 1,200. Information contained in SGDD for a plant with original Model D3 SGs, which used full depth roll expansion, no less than 2,313 tubes were affected by PWSCC in the tubesheet region up to the final eddy current inspection in 1993 (7.4 EFPY). Therefore, the application of peening to the entire tube length in the tubesheet region also helps to preclude PWSCC initiation in the BVPS-2 SGs.

5.3 Parent Tube ID Residual Stresses Post-Sleeve Roll

Numerous industry documents have included forms of the Venn diagram shown on Figure 6. This figure, taken from Reference 6, describes the three elements necessary for SCC initiation; a corrosive environment, a susceptible material, and tensile residual stress. If any one of these three necessary fundamental parameters is absent or reduced below some threshold value, SCC cannot occur. Reference 6 is one of a series of training modules prepared for the NRC staff by Structural Integrity Associates.

Barring localized influences such as bulges, over-expansions, and roll overlaps, the process of tube expansions produces compressive ID residual stresses due to hysteresis of the tube after the radial force from the expansion process is removed. In the case of mechanical roll expansion the tubesheet is believed to remain elastic. Thus as the rolling force is removed, the tubesheet would act to elastically spring-back thus producing a compressive residual stress on the tube ID. This sequence is expected to be present whether the rolling process involves the original tube expansion or sleeve expansion.

A finite element modeling of the tubesheet-tube-sleeve roll expansion was performed (Reference 7). This analysis concludes that adjacent to the nickel band (and within the length contacting the flat length of the roller pin) that the residual stresses on the tube ID surface remain compressive. This is an expected result as the tubesheet is expected to remain elastic during the tube rolling process. Springback of the tubesheet, and the overwhelming thickness of the tubesheet compared to the tube/sleeve would be expected to impart a compressive residual stress on the tube ID surface after the normal force due to roll expansion is removed. The same logic can be extended to the sleeve which is rolled into the tube which is rolled into the tubesheet. The results of the finite element modeling show that for the normal (to the tubesheet) and radial directions, parent tube residual stresses remain compressive in the uniformly expanded length (length contacted by the roll flat). As the roll flat length bounds (axially) the width of the nickel band, the parent tube residual stresses at the tube ID surface adjacent to the nickel band remain compressive. This analysis also shows that [

]a,c,e. Thus, as one of the necessary fundamental parameters, tensile residual stresses, is absent, SCC of the parent tube cannot occur.

Additionally, the flat dimension of the sleeve roller pins is 1.1 inches. The deflection of the sleeve material around the roller pin will effectively extend the length that the tube and sleeve are in contact. By design, the nickel band extent stops short of the lower extent of the roll flat length, thus, the area of the parent tube adjacent to the nickel band is physically isolated from the corrosive environment, the primary coolant fluid. Any communication between the parent tube ID surface adjacent to the nickel band and the primary coolant fluid would be limited to postulated leakage through the tube-sleeve interface. Therefore, one of the essential fundamental parameters, a corrosive environment, is absent or reduced, as a minimum.

Finally, the susceptibility of the material to PWSCC initiation is inherently reduced by the application of shot peening of the SG tubes through the tubesheet region prior to operation.

In conclusion, of the three necessary fundamental parameters necessary for PWSCC initiation of the parent tube adjacent to the nickel band, one is absent (tensile stress), one is absent or reduced (corrosive environment), and one is reduced (susceptible material). Thus it can be concluded that PWSCC of the parent tube adjacent to the nickel band of the sleeve is not a credible event and thus PWSCC of the parent tube adjacent to the nickel band of the sleeve is not a potential degradation mechanism.

5.4 Parent Tube ID Temperature Behind Sleeve Roll Joint

An ANSYS modeling of the tubesheet, tube, and sleeve was performed to determine the tube ID temperature where the tube is in intimate contact with the sleeve (Reference 9). The sleeve will effectively reduce the temperature of the tube at the roll joint. Above the roll joint and below the upper hydraulic expansions an air gap is inherently created between the tube and sleeve thus acting as an insulating layer which then reduces the tube temperature further. As the heat input to the tube between the joints is reduced the tubesheet heat sink effect is enhanced. This analysis determines that the temperature of the parent tube where the tube and sleeve are in contact is [ ][a,c,e]. Figure 7 presents a Weibull initiation function analysis for the parent tube PWSCC reported at BVPS-2. Parent tube PWSCC indications at BVPS-2 have only been reported in the expansion transition region at the top-of-tubesheet. The Weibull slope is 2.76 and the characteristic life is 336.5 EFPY. The characteristic life is the projected point in time when 63.2% of the population is affected. The accepted methodology for adjustment of the initiation function for varying temperatures is to shift the characteristic life by the temperature adjustment factor determined using an Arrhenius equation. Typical activation energies for PWSCC used by the industry range from 33 kcal/mole for propagation (growth) rate effects to 50 kcal/mole for initiation rate effects. Using the 50 kcal/mole activation energy with an original temperature of 609 F and the adjusted temperature of [ ][a,c,e], the propagation adjustment factor is 1.082 and the initiation adjustment factor is 1.127.

By adjusting the characteristic life by the adjustment factor of 1.127, a new characteristic life of 379 EFPY is established. The new characteristic life, original Weibull slope, and the Weibull probability of failure equation can be used to define the point in time when the first tube from the 2012 sleeve installations is predicted to experience initiation assuming the Weibull initiation function for the top-of-tubesheet is applicable to the roll joint region. There are 94 sleeves in-service from the 2012 sleeving campaign. Using the above parameters with the Weibull probability of failure equation, the first tube

failure (a "whole" tube, or predicted number of failures of 1.0 or greater) is predicted at 73 EFPY after sleeve installation. Note that the time to achieve one "whole" predicted failure is a function of the susceptible population count. If it is assumed that 500 sleeves were installed in 2012, the time to achieve one whole failure is reduced to 40 EFPY from 73 EFPY. Note that +POINT probe inspection of the parent tube in the roll joint region and a review of the bobbin coil data for geometry discontinuities are performed prior to sleeve installation. Continued +POINT probe sampling of bulge and over-expansion signals in the hot leg tubesheet below the F* distance have not identified PWSCC degradation to date thus it is reasonable to assume that no degradation of the parent tube was present at the time of sleeve installation and the new Weibull initiation function is controlling. Note that the time to achieve one failed tube is slightly reduced for the 2017 sleeve installations since a larger population (171 sleeved tubes) is included.

5.5 Conclusions Related to PWSCC Initiation Potential:

The above discussion supports the conclusion that PWSCC initiation of the parent tube adjacent to the nickel band region of the sleeve is not a credible event based on the calculation of parent tube ID surface residual stresses via finite element methods. Additionally, the discussion supports the conclusion that barring any tube hole geometry discontinuities, the residual stresses of the parent tube are expected to be compressive, thus PWSCC initiation is not supported. As the (to be sleeved) tube bobbin coil data for BVPS-2 is reviewed for the presence of tube ID geometry discontinuities prior to sleeve installation the portion of the BVPS-2 parent tube length adjacent to the nickel band of the sleeve does not represent a PWSCC initiation potential. However, FENOC plans to conservatively inspect this region of tube with a technique that will identify postulated parent tube PWSCC prior to this degradation affecting the structural or leakage integrity characteristics of the sleeve roll joint.

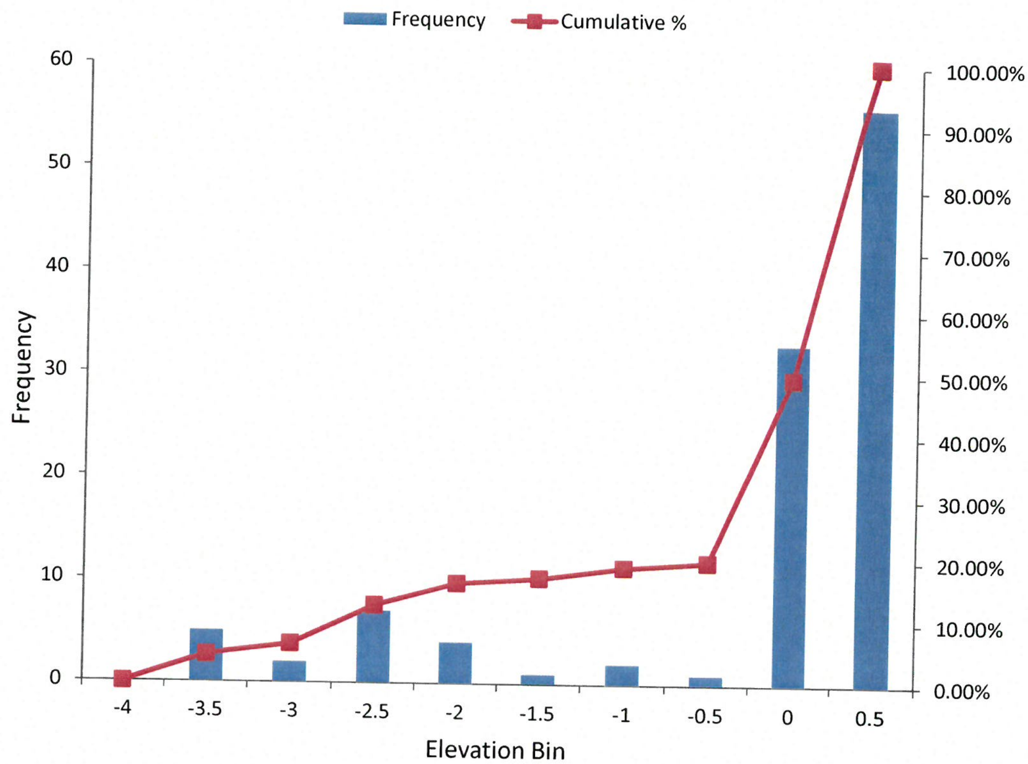

Figure 3: Model F Alloy 600 Mill Annealed Hydraulically Expanded Tube PWSCC Elevation Trending Within the Tubesheet

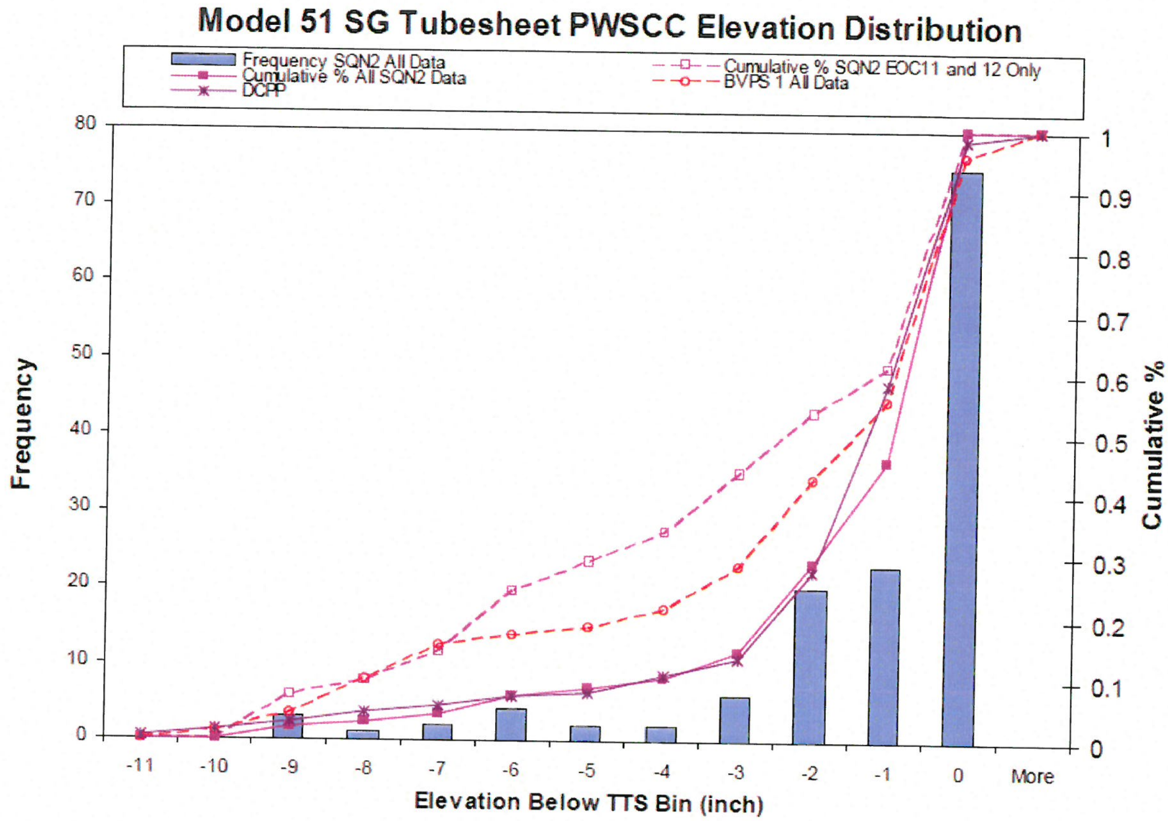

Figure 4: Model 51 Alloy 600 Mill Annealed Explosively Expanded Tube PWSCC Elevation Trending Within the Tubesheet

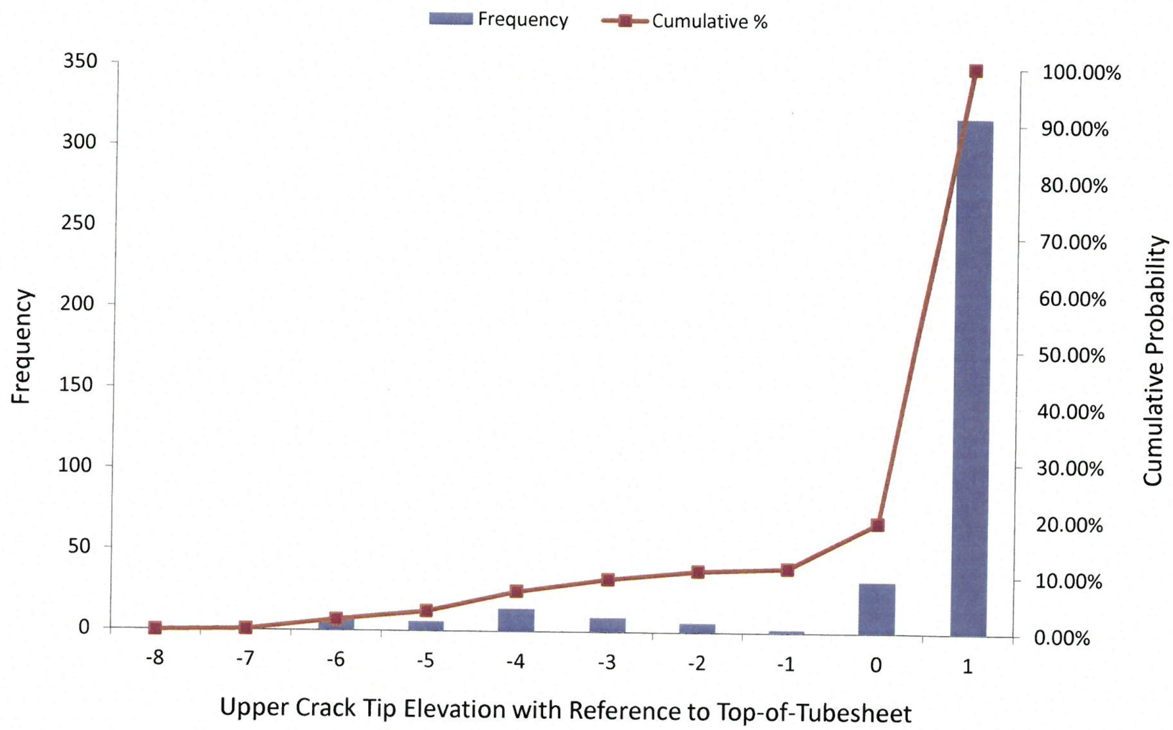

Figure 5: Model 51 Alloy 600 Mill Annealed Mechanical Roll Expanded Tube PWSCC Elevation Trending Within the Tubesheet

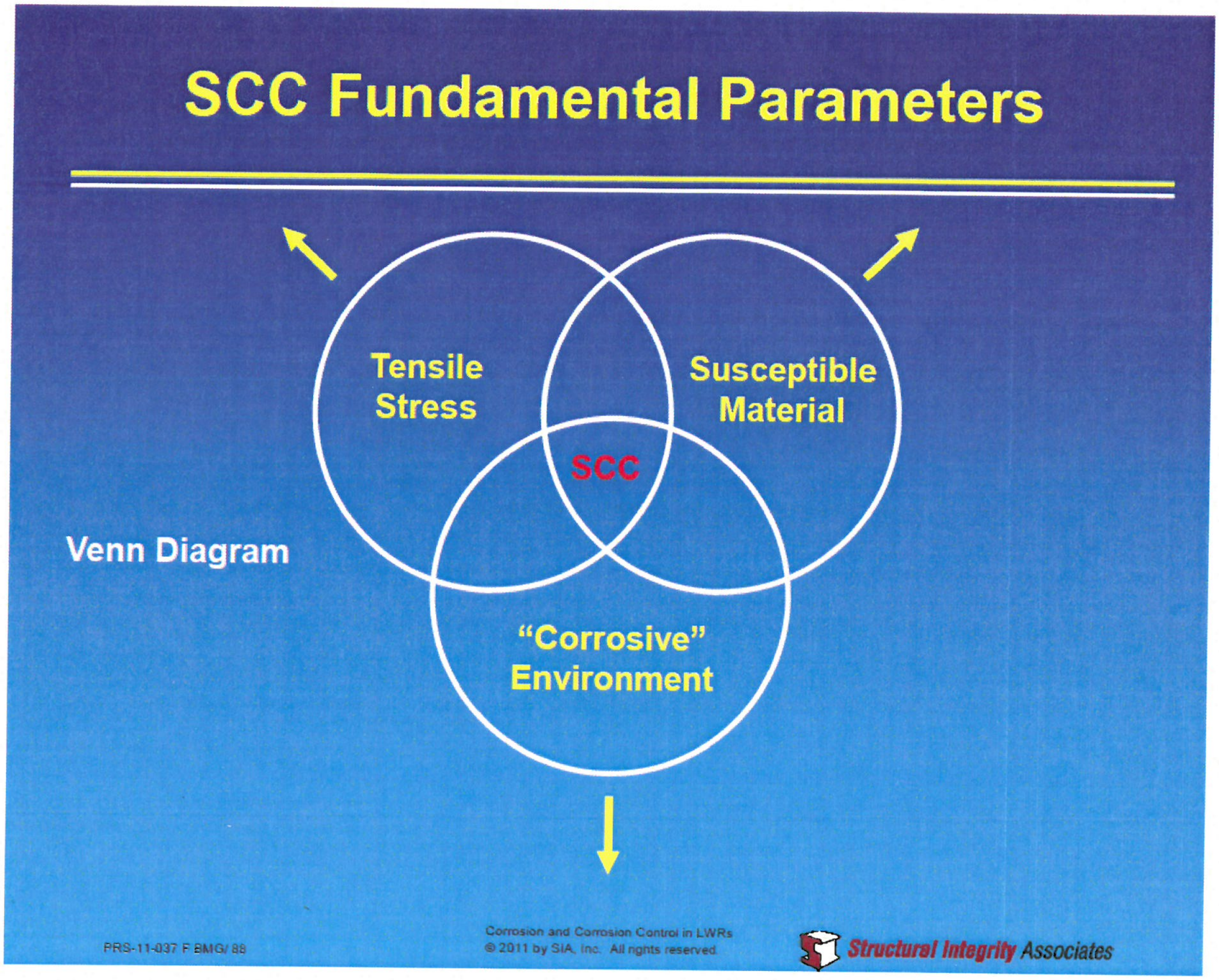

Figure 6: Necessary Fundamental Elements of SCC Initiation

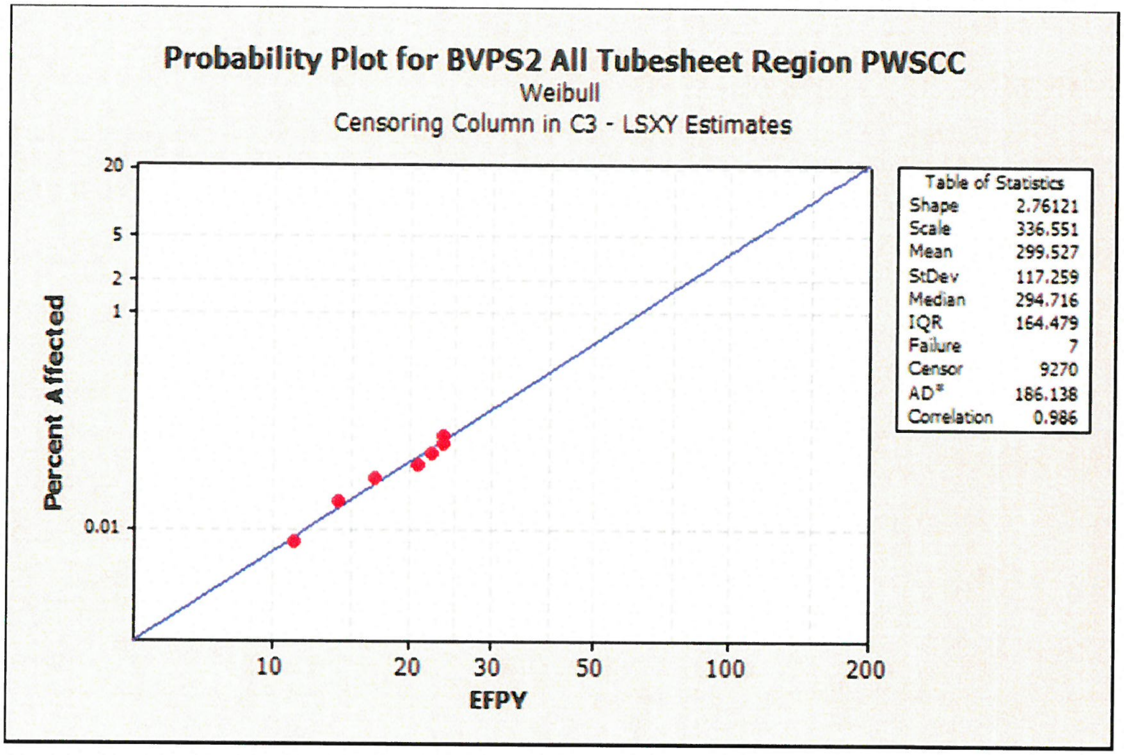

Figure 7: BVPS-2 Tubesheet Region Parent Tube PWSCC Initiation Function

6.0 ROLL EXPANSION JOINT INTEGRITY CHARACTERISTICS

The information in this section reintroduces the previous mechanical testing results contained in References 2 and 3.

A teleconference between the NRC Staff and the industry was conducted on August 3, 2004 in which a generalized (industry) position (related to implication of issuance of GL 2004-01 upon TIG and Alloy 800 sleeve installations) was discussed. In response to this teleconference, the NRC staff issued several questions by email on August 9, 2004. The NRC questions outlined in the email were:

- Load bearing capability of the TIG and Alloy 800 sleeve joints for limited effective joint lengths
- Consistency of TIG and Alloy 800 sleeve joint design and performance with existing HEJ sleeve test data
- Overall tube anchorage in the tubesheet
- Leakage integrity of postulated limited effective joint length TIG and Alloy 800 sleeve joints.

Load bearing capabilities and anchorage of the sleeve for postulated degraded parent tube conditions will be addressed in this section. This section presents discussion of roll expanded joint characteristics and describes testing of modified parent tube conditions that will show that regardless of the parent tube degradation adjacent to the nickel band of the sleeve, the sleeve joint will retain axial load bearing capability in excess of the design requirement. Leakage characteristics are discussed in Section 7.

6.1 Industry Responses to Original NRC Questions

Reference 1 was prepared to present responses to these questions. The responses are based primarily on "abnormal" HEJ test data where key rolling parameters, such as the effective roll length and applied torque were varied. The nominal HEJ sleeve applied torque is 135 in-lb and the nominal roll flat length is 2.16 inches. The abnormal joint length test conditions varied applied torque from 80 to 135 in-lb with joint lengths ranging from 0.75 to 2.16 inches. Reference 1 concluded that for an assumed effective TIG or Alloy 800 joint length of 0.55 inch, which represents the axial length of the roll joint above the intersection between the microlok and nickel band that the sleeve joint would continue to provide axial load bearing capability in excess of the design requirement.

Continued investigation was performed in 2005. Reference 2 presents a more thorough assessment of the joint integrity characteristics. As the HEJ and TIG and Alloy 800 designs use slightly different roll joint lengths and applied torque values, these data were normalized using a torque per unit length basis. The compilation of HEJ test data were plotted to show that variation in the applied torque or effective joint length had little impact upon the axial load bearing capability. Figure 8 is taken from Reference 2 and presents the plotting of peak resistance load versus torque per unit area for the HEJ test data. The relevant observations from this data are that:

- The HEJ abnormal joint length test data bounds the range of torque per unit area values for the TIG and Alloy 800 sleeve thus any torque per unit area between these bounds is described by the existing abnormal joint length HEJ test data
- Results of room temperature and elevated temperature testing show no apparent difference in result. The reduction in material properties at elevated temperature are balanced by the increase in contact force created by the thermal expansion coefficient difference between the sleeve and tube.

Figure 8 shows that the range of torque per unit area values for the HEJ test data are clustered in the 20 to 25 in-lb/in^2 range and at 59 in-lb/in^2. The applied torque per unit area of an Alloy 800 sleeve ranges approximately from 34 to 56 in-lb/in^2 based on the allowable range of acceptable sleeve applied torques. Thus, the axial load bearing capability of the sleeve joint would not be reduced to less than the design requirement by an undetected flaw in the nickel band region.

These analyses support the conclusion that roll joints are inherently robust and that variations in applied torque and effective joint length have a minimal impact upon the ultimate axial load bearing capability. A practical comparison of these results with required effective roll joint length associated with the F* ARC can be made. The F* ARC has been applied at numerous plants including BVPS-2. The original tubes were roll expanded into the tubesheet using maximum torque of 50 in-lb and a stepping roller with an effective roll flat length of 1.25 inches producing a torque per unit area of approximately 16 in-lb/in2 (50 in-lb divided by area of a 0.775 inch diameter, 1.25-inch long cylinder). The F* analyses are based on applied contact pressures and the F* length is required to satisfy the design requirements. F* mechanical test data indicates that for a joint length of 0.5 inch with 5% wall thinning, that the axial pullout loads range from [ ]^{a,c,e} lb. Hydraulic proof testing shows that joint lengths of 0.5 inch with wall thinning of 2 to 5% had failure pressures (failure defined as excessive leakage or tube expulsion from the collar) of [ ]^{a,c,e} lb (Reference 14). Thus, the conclusions of References 1 and 2 that effective sleeve roll joints lengths of 0.55 inch would satisfy the design requirement are supported by test data which forms the basis of the F* ARC.

6.2 Modified Parent Tube Test Results

A final industry position was transmitted by Reference 3. Under this program, mechanical and leakage testing of Alloy 800 sleeves installed into modified parent tubes were performed. The tubes used in this program contained two types of specimens:

- Simulated circumferentially separated tube at the intersection of the microlok and nickel band region
- Axially slotted tubes which eliminated the potential for the tube to transmit load in the radial direction.

The circumferentially separated tubes were simulated by roll expanding one section of tube into a collar with the end of the tube inside located at a specified elevation. A second tube was abutted to the first and

roll expanded. The sleeve was then rolled into the tube, locating the intersection of the microlok and nickel band at the intersection of the two tubes.

The axially slotted tubes were formed by applying six, 0.48-inch long axial OD EDM notches, equally spaced around the circumference of the tube. The depth of these notches was 80%TW. The notches were applied to the tube OD to preclude the potential for the sleeve to become embedded into the notch, thus resulting in a potentially non-conservative test condition. The axially slotted tubes were hydraulically expanded into the collar to limit deformation of the notches. Figure 9 presents a schematic of the assembly of the modified parent tube test specimens. The circumferentially separated tube setup is the upper schematic and the axially slotted tube setup is the lower schematic.

Five circumferentially separated specimens were prepared and tested at room temperature. The sleeve was internally pressurized using a nitrogen source at 1,500 psi. Reference 3 indicates that the internal pressurization adds approximately 400 lb to the axial load capability. Reference 3 calculates additional contact pressure of 1,050 psi due to internal pressurization and which then equates to an effective coefficient of friction of [ ][a,c,e]. Sleeve installation torques ranged from 110 to 135 in-lb while first slip loads ranged from [ ][a,c,e] lb and peak loads ranged from [ ][a,c,e] lb. Thus the circumferentially separated tube specimens retain axial load bearing capability well in excess of the design requirement.

The hydraulically expanded specimens include eight specimens with axial slots in the parent tube, two circumferentially separated specimens, and one axially slotted specimen with no microlok or nickel band. Sleeve installation torques ranged from 103 to 142 in-lb. First slip loads ranged from [ ][a,c,e] and peak loads ranged from [ ][a,c,e] lb for the axially slotted specimens. For the two circumferentially separated specimens, first slip load and peak load were consistent, at [ ][a,c,e] lb for the other. Thus, the axially slotted specimens exhibited slightly reduced peak loads compared to the roll expanded tube, circumferentially separated tube specimens. The hydraulically expanded tube specimens also showed a greater propensity for first slip and peak load to be consistent. Still, the observed loads are well in excess of the design requirement.

The axially slotted tube tests show that the ability of the tube to transmit load in the radial direction has little impact on the axial load bearing capability of the sleeve roll joint. Whether an axial crack is present in the tube or not the work done to the sleeve will be transmitted normally through the tube to the tubesheet. Additionally, the presence of an axial crack has essentially no impact upon the ability of the parent tub to transmit axial loads. Reference 10 presents the technical basis of the W* ARC. This ARC addresses degradation of the tube in the tubesheet region for explosively expanded tubing. Axial cracks observed within the expanded region of tubing are assumed to not provide contact pressure and therefore are not considered in the pullout load analysis. The observed crack lengths must be summed with the original W* distance in order to satisfy the license requirements. However, Reference 10 provides test data which shows that the presence of axially oriented degradation does not detract from the axial load bearing capability of the tube itself. For up to 15, 0.5-inch long axially oriented, 100%TW EDM notches, the axial load bearing capability of the tube is consistent with non-flawed tubes. Thus, whether the axial load is applied to the cross section of the tube along its axis or across the axial slots, the ultimate load capability is unaffected.

Of most interest is the specimen which did not include a microlok or nickel band. This specimen had a first slip load of [ ]a,c,e lb with a peak load of [ ]a,c,e lb. Thus this specimen shows the benefit of the microlok band, which is designed to increase coefficient of friction between the tube and sleeve thus increasing axial load bearing capability.

6.3 Axial Load Bearing Capability at Operating Temperature:

The mechanical tests of modified parent tubes described in Reference 3 were performed at room temperature. A methodology has been developed to estimate the axial load bearing capability at operating temperature.

It is theorized that the first slip loads would be controlled by the sleeve material yield strength whereas peak loads would be controlled by the sleeve material ultimate strength. The Alloy 800 sleeve test has shown that the microlok band dramatically increases load bearing capability thus the Alloy 800 sleeve test data cannot be used to validate this theory. Instead the HEJ test data will be used.

The average room temperature first slip load for the HEJ abnormal joint length test data is [ ]a,c,e lb. The average elevated temperature first slip load is [ ]a,c,e lb. Thus the average elevated to room temperature first slip load ratio is [ ]a,c,e or 0.80. The ratio of elevated (600°F) to room temperature yield strength for Alloy 690 from the 2013 American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code is 0.79.

The average room temperature peak load for the HEJ abnormal joint length test data is [ ]a,c,e lb. The average elevated temperature peak load is [ ]a,c,e lb. Thus the average elevated to room temperature peak load ratio is [ ]a,c,e or 0.93. The ratio of elevated (600°F) to room temperature ultimate strength for Alloy 690 from the 2013 ASME Boiler and Pressure Vessel Code is 0.94.

Thus, excellent agreement between the ratio of measured loads at elevated and room temperature and the ratio of ASME Code yield and ultimate strength ratios for elevated and room temperature conditions and the ASME Code ratios can therefore be applied to the modified parent tube room temperature test data for estimation of the operating temperature conditions axial load bearing capability.

The design requirement for each joint of the sleeve is that the joint must provide for axial load bearing capability equal to the normal operating conditions primary-to-secondary pressure differential with factor of safety of three. For the case of axially oriented SCC at the top-of-tubesheet or circumferential SCC of 100%TW and less than 270 degrees arc at the top-of tubesheet, the end cap load is transmitted through the tube to the tubesheet and the sleeve joints see minimal load transference. For the case of a postulated circumferentially separated tube at the top-of-tubesheet, the developed tube ID cross-sectional area (above the assumed tube separation point) available to the primary-to-secondary pressure differential is based on the nominal tube ID and is 0.4717 in^2. The hydraulic end cap load is assumed to be reacted across the upper sleeve joint and thus transferred to the lower roll joint. For a bounding normal operating primary-to-secondary pressure differential of 1,525 psi the design requirement is 2,158 lb (0.4717 in^2 x

1,525 psi x safety factor of 3). As primary pressure would act on both the upper and lower cross sections of the sleeve any pressure effects are balanced and would not add to the end cap load value. However, References 1, 2, and 3 applied the end cap for this condition to the parent tube ID surface, with a nominal diameter of a tube expanded within the tubesheet of 0.795 inch, which would result in an end cap load of 2,271 lb. For consistency with the previous analyses, the end cap load of 2,271 lb (based on the nominal expanded tube diameter of 0.795 inch) will be applied and is conservative for this geometry and assumed loading condition.

The ratio of elevated to room temperature yield is 0.62 and the ratio of elevated temperature to room temperature ultimate strength is 0.84 for Alloy 800. The minimum first slip load for the circumferentially separated test specimens is [ ]a,c,e lb. The product of this result and the ASME Code elevated to room temperature yield strength ratio is [ ]a,c,e, or 1.39 times the design requirement [ ]a,c,e. The minimum peak load for the circumferentially separated test specimens is [ ]a,c,e lb. The product of this result and the ASME Code elevated to room temperature ultimate strength ratio is[ ]a,c,e, or 2.06 times the design requirement [ ]a,c,e.

The minimum first slip load for the axially slotted test specimens is [ ]a,c,e lb. The product of this result and the ASME Code elevated to room temperature yield strength ratio is [ ]a,c,e, or 1.31 times the design requirement [ ]a,c,e. The minimum peak load for the axially slotted test specimens is [ ]a,c,e lb. The product of this result and the ASME Code elevated to room temperature ultimate strength ratio is [ ]a,c,e, or 1.92 times the design requirement [ ]a,c,e.

6.4 Conclusions Related to Axial Load Bearing Capability:

The results of the modified parent tube testing program show that expected operating temperature axial load bearing capability for both circumferentially separated tubes, separated at the microlok to nickel band region and for axially slotted tubes which prevent the tube from transmitting resistive loads in the radial direction will provide for a minimum margin of 1.31 times the design requirement of 2,271 lb when considering first slip loads and a minimum margin of 1.92 times the design requirement of 2,271 lb when considering peak loads, for BVPS-2.

a,c,e

Figure 8: HEJ Sleeve Abnormal Joint Length Peak Load versus Torque per Unit Area Data

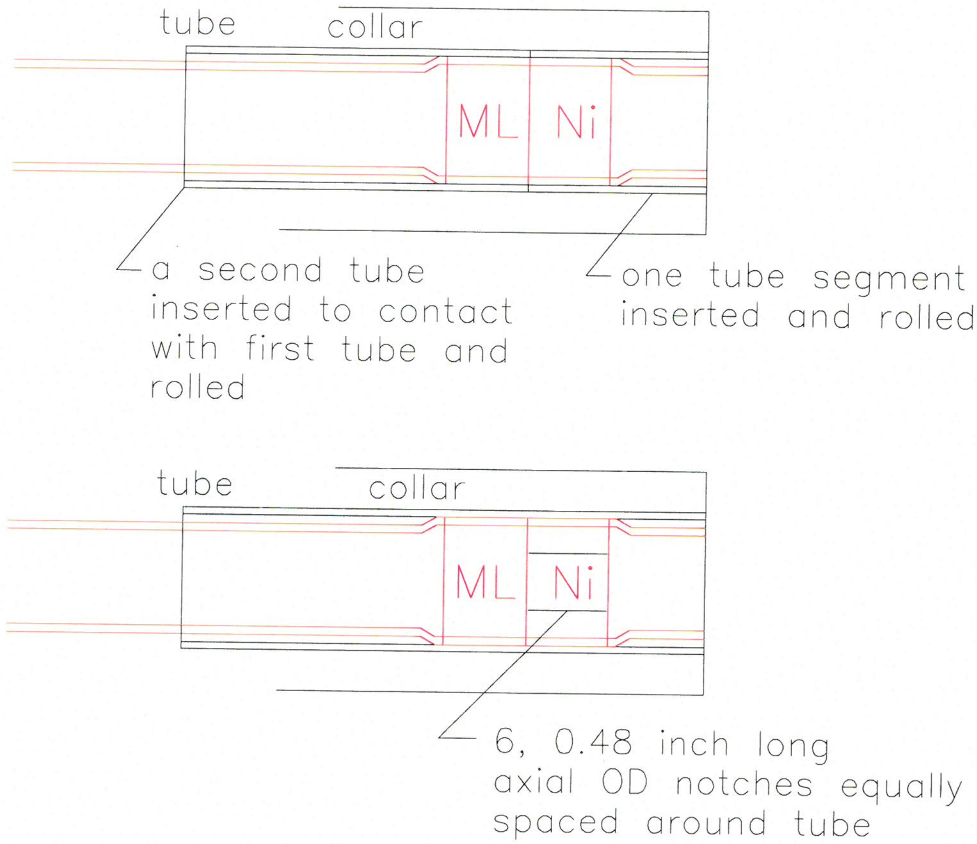

Figure 9: Schematic of Modified Parent Tube Test Specimens

7.0 NICKEL BAND SLEEVE LEAKAGE INTEGRITY

The information in this section reintroduces the previous leakage testing results contained in Reference 3.

Leakage testing was performed in response to the NRC questions presented in the email of August 9, 2004. Unlike the mechanical testing program which had a defined acceptance criteria that the modified parent tube testing shows axial load bearing capability of greater than the design requirement, the leakage testing program had no defined acceptance criteria.

The leakage test specimen configuration is shown on Figures 10 and 11. The specimens were configured such that primary fluid was delivered directly to the tube-sleeve interface at the microlok to nickel band interface. Two 1/16 inch diameter holes were milled through the collar to the point where the full mill diameter affected the sleeve OD. Two 1/8 inch diameter holes were milled through the collar to the point where the full mill diameter affected the tube OD. 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 tube to sleeve interface. In addition, the end of the sleeve inside of the end cap was plugged by welding thus there was no pressure delivered to the inside of the sleeve. Any pressure expansion benefit upon the sleeve to tube interface was not included. A welded end cap was located over the collar thus closing off the leak path from the pressure source to the autoclave environment Pressurized fluid was then delivered to the end cap via a high pressure fitting and supply line. Also, due to the manner in which the primary fluid was delivered to the tube to sleeve interface, the direction of the pressure developed forces act to keep the tube to sleeve interface open to the primary fluid. Leak test pressures were 1,500 and 2,560 psi. Specimens were held at pressure for a minimum of 20 minutes. For elevated temperature testing, the 20 minute hold was after achieving thermal equilibrium.

Nine room temperature leakage specimens were used; three TIG sleeve specimens in ¾ inch OD tubing, three Alloy 800 sleeve specimens in ¾ inch OD tubing, and three Alloy 800 sleeve specimens in 7/8 inch OD tubing. Applied rolling torques ranged from 82 to 127 in-lb, which are all less than the nominal installation torque value of 130 in-lb. Table 1 presents the room temperature leak rate data and is a recreation of Table 6-1 of Reference 3. Several specimens were suspected to have experienced some small amount of leakage but the quantity of fluid collected was too small to be reliably measured. These specimens have an indicated leak rate of [ ]^{a,c,e} gpm.

The two specimens which had reliable, measurable leakage at room temperature (Leak 04-3/4 and Leak 05-3/4) were retested at 600°F. The leak rate for Leak 04-3/4 was slightly reduced at a pressure differential of 2,560 psi for the 600°F condition compared to room temperature ([ ]^{a,c,e} gpm at room temperature versus [ ]^{a,c,e} gpm at 600°F). A slight reduction is expected due to the thermal expansion characteristics of the Alloy 690 sleeve and Alloy 600 tube and carbon steel collar. However, the leak rate for Leak 05-3/4 was almost an order of magnitude lower at 600°F ([ ]^{a,c,e} gpm at room temperature versus [ ]^{a,c,e} gpm at 600°F). As the Alloy 800 sleeve material has a larger thermal expansion coefficient than Alloy 690 it is expected the Alloy 800 sleeve at 600°F would have a larger reduction in leak rate for a repeat of the room temperature test.

7.1 Conclusions Regarding Leakage Testing

Room temperature leak rate data shows that of the nine specimens, only two had reliable, measurable leak rates for limited length sleeve roll expansions of approximately one-half of the roll expanded length. Elevated temperature testing shows that the Alloy 800 sleeve material will effectively act to reduce leak rates through thermal expansion with subsequent increase in tube-sleeve contact forces. Thus, the limited sleeve roll length leakage testing shows that postulated parent tube degradation beyond what is hypothesized for the parent tube material and for degradation which would certainly be readily detectable by normal eddy current inspection will not lead to a potential for excessive leakage or leakage beyond the 2×10^{-5} gpm at operating temperature currently allotted per sleeve (Reference 4).

Table 1: TIG and Alloy 800 Sleeve Room Temperature Leakage Results for Limited Roll Engagement Length

Specimen	Sleeve Type	Sleeve Torque (in-lb)	Room Temperature Leak Rate at 1500 psid (gpm)	Room Temperature Leak Rate at 2560 psid (gpm)	Comments
Leak 01-3/4	TIG	103	[ ]a,c,e	[ ]a,c,e	Note 1, 2
Leak 02-3/4	TIG	104	[ ]a,c,e	[ ]a,c,e	Note 2
Leak 04-3/4	TIG	127	[ ]a,c,e	[ ]a,c,e	Note 1, 2
Leak 05-3/4	A800	101	[ ]a,c,e	[ ]a,c,e	-
Leak 06-3/4	A800	115	[ ]a,c,e	[ ]a,c,e	-
Leak 08-3/4	A800	82	[ ]a,c,e	[ ]a,c,e	-
Leak 01-7/8	A800	100	[ ]a,c,e	[ ]a,c,e	-
Leak 02-7/8	A800	100	[ ]a,c,e	[ ]a,c,e	-
Leak 03-7/8	A800	103	[ ]a,c,e	[ ]a,c,e	-

Note 1: EDM notched tube

Note 2: Sleeve displaced downward approximately 0.1 inch during rolling, thus sleeve effective roll length above milled leak path was approximately 0.53 inch.

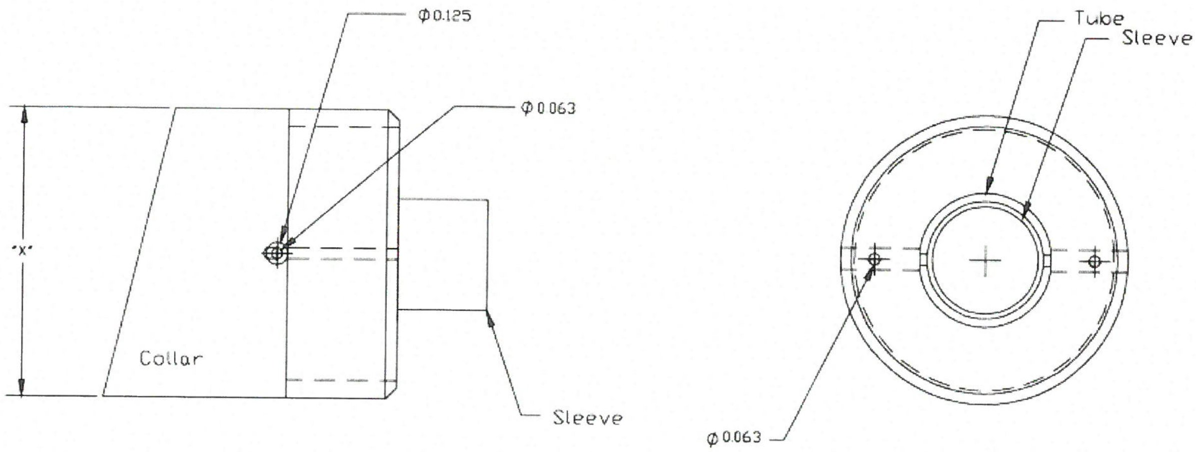

Figure 10: Leak Test Specimen Modification and Configuration

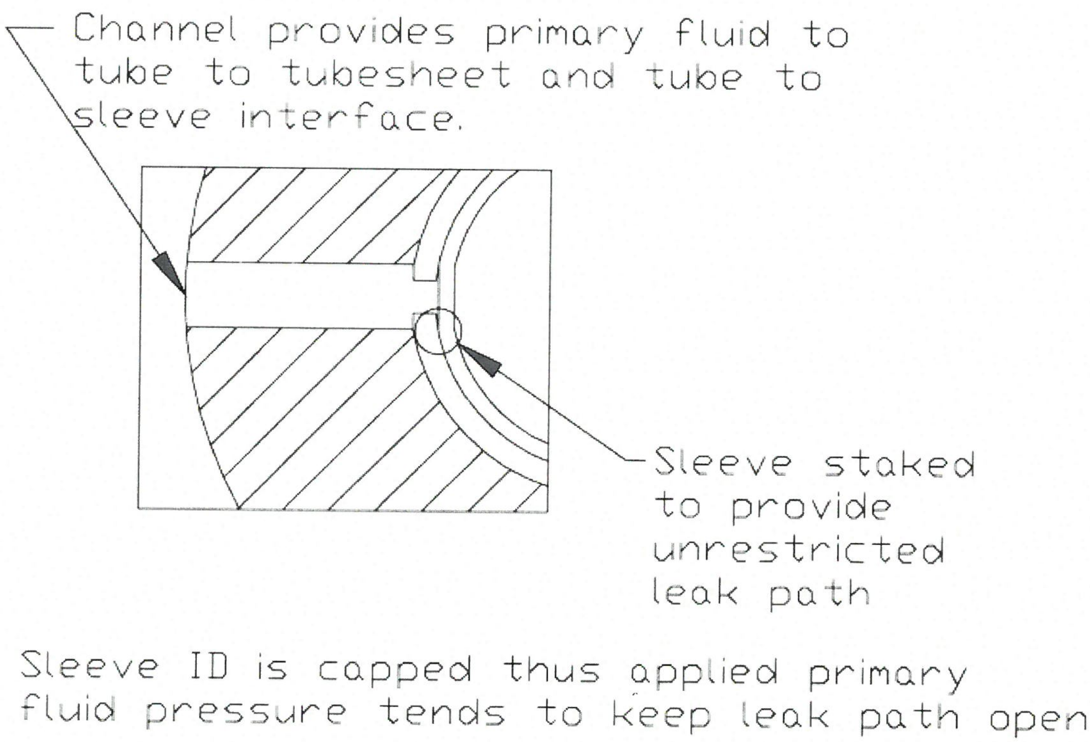

Figure 11: Detail of Leak Test Specimen Primary-to-Secondary Leak Path

8.0 CURRENT NDE CAPABILITIES

The industry has long advocated that standard eddy current techniques would adequately detect parent tube degradation in tubes adjacent to the nickel band region of Alloy 800 and TIG sleeves. However, no formal eddy current technique qualification exists for this configuration. This position was discussed in Reference 1. Eddy current standards for TIG sleeve installations at one plant included 50%, 70%, and 100% through-wall axial ID EDM notches in the parent tube adjacent to the sleeve nickel band region. These notches are readily detectable with the +POINT probe using both 75 and 150 kHz, however, the ability to detect true SCC flaws and EDM notches can be different, due primarily to the signal amplitude response. As the TIG (Alloy 690) and Alloy 800 sleeve materials are similar with similar eddy current characteristics, the observations from the standards using TIG sleeves are applicable to Alloy 800 sleeves.

8.1 Eddy Current Test Results for Axial ODSCC Specimen

To assess detection capabilities for true SCC flaws, a section of 0.75 inch OD x 0.043 inch wall thickness mill annealed Alloy 600 tubing with laboratory (doped steam) generated flaws was used. This specimen contained four, axially oriented, OD initiated flaws all at the same approximate elevation. The four flaws are equally spaced around the tube circumference. Due to the generation of 100%TW flaws, this specimen was not used in the original program (a bobbin coil based detection program) under which it was developed.

The tube was hydraulically expanded into a close fitting carbon steel collar simulating the tubesheet. Hydraulic expansion was used to limit the deformation of the flaws during expansion. +POINT probe eddy current data was collected for the parent tube prior to and after expansion into the collar. The +POINT coil data prior to expansion suggests that based on flaw amplitude, two of the four flaws had 100%TW penetration for a limited axial length (less than the total flaw length), one possibly had 100%TW penetration, and one had less than 100%TW penetration. The flaw amplitudes ranged from 4.65 to 0.86 volt in 300 kHz

For PWSCC, 100%TW flaw penetration has 300 kHz +POINT coil amplitude of approximately 4 volts. As the 100%TW length is increased the flaw amplitude will also increase within the field of the eddy currents. Only the 4.65 volt signal exceeds this value. The slip-fit condition between the collar and tube included [

][a,c,e] can result in overestimation of flaw depth using amplitude based sizing methods. After expansion of the tube into the collar, the 4.65 volt was increased to 7.25 volts while the other flaws experienced much smaller increases and remained below 4 volts. The 0.86 volt signal was increased to only 1.25 volts.

An Alloy 800 sleeve was then roll expanded (within procedure specifications) into this assembly with the sleeve nickel band placed adjacent to the parent tube flaws. +POINT probe eddy current data was collected after sleeve installation.

The main sleeve analysis frequency is 75 kHz for 0.75 inch OD tubing (70 kHz for 0.875 inch OD tubing). This frequency is selected to provide for detection of flaws in both the parent tube and sleeve. The result of this analysis showed that all four parent tube flaws were readily detectable. The responses produced both visual response (from the terrain plot) and signal response (measurable amplitude and phase angle in the flaw plane). The amplitude responses for all flaws in the respective frequencies are essentially equal (5 to 6 volts in 75 kHz, 4 to 5 volts in 150 kHz), suggesting that the eddy current penetration into the parent tube extends well into the tube wall. This observation also suggests that the direction of flaw initiation will not significantly affect detection. That is, whether the flaws are initiated from the OD or ID, as long as the crack face extends through the depth of the eddy current field penetration, the flaw should be detectable. The observation that the EDM notches of the standard discussed above were detectable in both 75 and 150 kHz suggests that for the nickel band configuration, that the influence of the nickel band on these frequencies is not as limiting as initially thought, and that flaw penetration beyond this influence would result in a high probability of detection.

Eddy current theory supports these 75 and 150 kHz amplitude responses; reduced amplitude in a higher frequency is expected for this geometry. For the range of +POINT coil frequencies used in this test, 50, 75, 150, and 300 kHz, the phase responses follow eddy current theory. That is, as inspection frequency is increased, the phase response of the flaw rotates towards larger phase angles. Figures 12, 13, 14, and 15 present the Flaw 1 +POINT coil analysis responses for the analysis frequencies (50, 75, 150, and 300 kHz). With increasing frequency the depth of penetration of the eddy currents into the tube is reduced. In 300 kHz, no flaws produced eddy current signals which would be judged as readily detectable. However, a slightly rotated signal response is observed consistent with azimuthal locations of Flaws 1, 2, and 3. Being that Flaw 4 (86%TW maximum penetration from the OD) was not detectable in 300 kHz suggests that for this frequency the eddy current penetration into the tube is limited. The observation of signals associated with Flaws 1, 2, and 3 at 50, 75 and 150 kHz shows that the nickel band presents a minimal interference at lower frequencies. Figure 13 is particularly important as it shows that SCC at the tube ID is observable through the nickel band in a lower frequency (75 kHz) channel with minimal influence from the nickel band. Thus, with reduced frequency increased eddy current depth of penetration is achieved resulting in improved flaw detection.

The pre-sleeve installation and post-sleeve installation flaw length values were compared. The total flaw length values were similar for three of the four flaws. PWSCC typically exhibits minimal taper due to the highly stress dependent nature of the mechanism. Thus flaw length at the tube ID and OD (for 100%TW degradation), or at the crack front for part through-wall flaws should be similar. As such, any influence upon detection capability at the tube-sleeve interface due to the nickel band will not adversely affect detection as sufficient flaw length at the crack front would permit detection.

Destructive examination (DE) of the parent tube was performed to compare NDE reported flaw length against true flaw length. Prior to disassembly of the specimen, a notch was placed on the parent tube at a location judged to be in-line with one of the suspected eddy current flaw signals. Upon destructive examination this notch was confirmed to be in-line with a flaw, confirming that the observed eddy current signals were in fact generated by the ODSCC. The prior to expansion flaw lengths were compared against the DE data. For Flaws 1, 2, and 3, the NDE length exceeded the DE length. For Flaw 4, the NDE length underestimated the DE length by 0.05 inch. Destructive examination showed that Flaw 4 had

a local maximum depth of approximately 85%TW with an average depth of 54%TW over the length of the flaw (0.36 inch). Flaw 4 also had the shortest overall flaw length by DE and by NDE.

Previous and future Alloy 800 sleeve installations will include +POINT probe (or equivalent) inspection of the parent tube in the tube-sleeve hardroll joint region prior to sleeve installation. The +POINT probe used for this (parent tube) inspection is qualified for detection according to Appendix H of the EPRI PWR Steam Generator Examination Guidelines Revision 8 (Reference 5). Thus, PWSCC in the parent tube would be identified prior to sleeve installation. If degradation of the parent tube in this region is observed, the tube is not a candidate for repair by sleeving. Once the sleeve is installed, one element required for flaw initiation, a corrosive environment, would be absent or minimized after sleeve installation.

8.2 Eddy Current Test Results for OD EDM Notch Specimen

An additional specimen was prepared using a tube from the structural and leakage integrity testing program described by Reference 3. The tube contained six axial OD EDM notches, equally spaced around the tube circumference, each with a nominal depth of 80%TW. The EDM notch length was 0.48 inch. An axially oriented, 40%TW OD milled slot, using a 1/16th inch diameter end mill cutter was applied to the tube. The milled slot total length was 0.43 inch, and was located such that the axial center of the milled slot was adjacent to the upper edge of the EDM notches. Thus, approximately one-half of the milled slot length extended inside and outside of the EDM notches. The slot was radially located between two of the axial EDM notches. Figure 16 presents a schematic of the tube flaws. This tube was lightly rolled into a carbon steel split collar. The tube hole diameter in the split collar is 0.756 inch, thus the amount of radial expansion applied to the tube was minimal. +POINT probe eddy current data was collected prior to and after rolling. As expected, the prior to rolling signal amplitudes for the EDM notches were similar; about 2.5 volts in 300 kHz. However, the 300 kHz flaw responses for the expanded tube in collar condition shows the flaw amplitudes were actually reduced to about 1.0 to 2.0 volts. This is likely due to compression of the EDM width nearer to the tube ID surface due to roll expansion. An Alloy 800 sleeve was installed such that the microlok to nickel band interface was adjacent to the axial center of the milled slot.

Results of the eddy current analysis of the installed sleeve-tube combination indicate that all of the tube 80%TW axial OD EDM notches and the 40%TW axial milled slot are detectable through the nickel band in 75 kHz. Note that the post-roll expansion notch 300 kHz signal amplitudes were as small as 1 volt and still produced a flaw-like signal in 75 kHz after sleeve installation.

As the 1/16th inch diameter milled slot extends above the EDM notches into the microlok band, detection was readily apparent in this area. In the nickel band area the proximity of the EDM notches and milled slot make distinguishing of the signals difficult, but still, the milled slot is judged detectable in the nickel band region and at the microlok to nickel band interface. Starting in the microlok area, each scan line at the axial slot was interrogated; the axial slot produced a signal response for each scan line well into the nickel band region. Additional interrogation of this data performed in 2017 shows that the 75 kHz signal amplitude of the slot was actually <u>larger</u> in the nickel band region than in the microlok region. This is a critical observation when considering the true influence of the nickel band upon detection. At the edge of

the nickel band there could be a transitioning noise effect similar to expansion transitions at the top-of-tubesheet, however, at the center of the nickel band, the relative noise influence is minimal due to the design of the +POINT coil. This "nulling" effect of the +POINT coil is observed in other conditions where the external influencing parameter exists in both the axial and circumferential directions. This observation suggests that the nickel band represents an elevated mean null condition and explains why the signal amplitudes of flaws in the nickel band can be larger than outside of the nickel band. Table 2 presents the amplitude responses of the four ODSCC flaws and six EDM notches in 300 kHz prior to sleeve installation and 75 kHz after sleeve installation.

Detection of the axial slot and all EDM notches is evident in the 75 kHz channel. In 300 kHz, only three of the six axial EDM notches produce a flaw-like signal response, however, this signal response is judged not reliably detectable. The 0.052 inch diameter, 100%TW hole in the parent tube located approximately 3 inches above the axial slot is also not detectable through the sleeve in the 300 kHz channel. This is expected as the higher frequencies will project the eddy currents to a lesser depth of penetration compared to lower frequencies. The presence of an air gap between the sleeve and tube at the elevation of the 0.052 inch parent tube drill hole will also negatively affect detection. One interesting artifact of the inspection was that the axial seam between the two halves of the carbon steel split collar can be observed in both 75 kHz and 150 kHz through the microlok band also possibly through the nickel band indicating that in these frequencies, the eddy currents are penetrating through the combined tube-sleeve wall thickness.

An artifact of the test configuration was that a simulated circumferential separation of the parent tube was inherently developed. From Figure 16, the distance from the center of the 0.052 inch diameter drill hole to the end of the tube is 3.00 inches. Once the tube with EDM notches was rolled into the tubesheet collar, a second tube was then abutted against the first and rolled in place. This was performed to permit sleeve installation such that the end of the sleeve was located at the end of the collar. To assess how well this fit was created, the axial length involvement of the tube-to-tube fit up was compared with the circumferential EDM notch of the calibration standard. Prior to sleeve installation the axial length involvement of the 100%TW circumferential notch of the calibration standard was 0.38 inch, while the axial length involvement of the tube-to-tube fit up was measured at 0.31 inch. The amplitude in 300 kHz was [ ][a,c,e] of the normalization amplitude of 20 volts on the 100%TW circumferential EDM notch. The length of the sleeve hardroll flat is 1.1 inches. Figure 17 presents a terrain plot of the sleeve-tube assembly. The top of the hardroll flat was defined as the 0.00 elevation point. The cursor is located at 1.1 inches below the reference elevation, or the bottom of the sleeve hardroll flat and shows the bottom of the roll position. Immediately below this point, a large differential signal is noted, and is located at 3 inches below the parent tube drill hole, coinciding with Figure 16. Thus, the tube-to-tube fit up condition is detected through the sleeve, and it can be judged that a postulated circumferentially separated tube condition located at the heel of the tube-to-sleeve roll would be readily detectable. Figure 17 shows the vertical amplitude of the response representing the intersection of the two tube segments is several times larger than the amplitude response represented by the transitions from nickel to non-nickel locations, thus, any similar condition would be readily detectable regardless of its location in the roll expansion region. Still, the relevance of the detection capabilities of such a condition are moot as mechanical testing of a simulated separated tube at the microlok to nickel band region provides for axial load bearing capability in excess of the design requirement.

8.3 Conclusions Regarding SCC and EDM Notch Detection Capability

Eddy current examination of installed Alloy 800 sleeves with parent tube OD flaws adjacent to the sleeve nickel band shows that all flaws, ranging in depth from 40% to 100%TW from the OD were detectable in the 75 kHz channel. As these flaws are initiated from the OD, the unanimous detection supports high detection capability of deep ID initiated flaws. Comparison of flaw responses for a flaw which spanned the interface of the microlok and nickel band shows the flaw response was larger adjacent to the nickel band showing that nickel band represents an elevated null condition and the nickel band did not completely impede flaw detection. The readily detectable condition for the OD initiated SCC suggests that 100% TW ID initiated degradation will be readily detected and part through-wall PWSCC degradation will be detectable at probabilities increasing with increasing flaw depth using existing eddy current examination techniques.

The mechanical and leakage testing program described by Reference 3 has established that degradation of the parent tube adjacent to the nickel band will not prevent the sleeve from satisfying its design function. Reference 3 concludes that NDE of the parent tube adjacent to the nickel band region is not required to satisfy the tube-sleeve system integrity requirements. The results of this eddy current testing program have established that both part through-wall and 100%TW degradation of the parent tube will be readily detectable using standard eddy current techniques, and thus provides a defense in depth approach to the position established by Reference 3 that postulated degradation of the parent tube adjacent to the nickel band of the sleeve will not reduce the axial load bearing capability to less than the design requirement.

8.4 POD Simulation

At the time of the original BVPS-2 Alloy 800 sleeve license amendment request, probability of detection (POD) simulation tools were in the final stages of development. EPRI has developed a tool for performing such simulations called model assisted probability of detection (MAPOD). MAPOD is a simplistic POD simulation tool which bases detection solely on eddy current signal-to-noise (S/N) comparison. Other resultant signal characteristics that create a difference between the current and historical eddy current data such as change in signal shape or phase rotation above baseline but not in the reportable phase angle window which are indicative of flaw presence are not capable of modeling in MAPOD. MAPOD is a Monte Carlo based methodology which randomly samples from an eddy current noise distribution and from a flaw eddy current signal-to-depth relationship, called the A-hat function. For each Monte Carlo iteration, a unique S/N ratio is determined. For S/N ratios less than a lower bound value, the iteration is assumed to be a miss (non-detection), for S/N ratios greater than an upper bound value, the iteration is assumed to be a hit (detection), and for S/N ratios between the bounds, detection is randomly assigned. The hit-miss results are then processed through a log-logistic curve fitting process to develop a POD curve that relates indication depth to probability of detection. A form of this methodology has been used for many years primarily for aircraft wing inspections.

The major challenge to performance of a MAPOD simulation for the parent tube adjacent to the nickel band of the Alloy 800 sleeve was that the main analysis frequency of the tube/sleeve combination is 70 kHz (for 7/8 inch tubing) while non-sleeved parent tube flaw data is present using 300 kHz. Thus there is no direct amplitude correlation between parent tube flaws between the two frequencies. This deficiency was overcome by recognizing that [

]a,c,e.

Examination of the TIG sleeve calibration standard ID EDM flaw information for locations where the [

]a,c,e.

Thus, it was judged that existing A-hat function for axial PWSCC in non-sleeved tubes could be extended to the sleeve tube condition in 70 kHz. All that is then necessary to perform a MAPOD simulation is a noise distribution. This noise distribution was developed by performing noise measurements of the BVPS-2 installed sleeves in both 70 kHz and 130 kHz at the center of the nickel band. Since an axial PWSCC indication would involve a very short affected arc length, the noise measurements were performed using a 60 and 90 degree wide analysis window. The noise distributions for both analysis window widths were approximately equal.

The Alloy 800 sleeve calibration standards include parent tube flaws, however, these flaws are located in areas where the sleeve is not expanded to contact with the tube. Evaluation of the signal amplitude

response of these flaws indicates the signal amplitude is roughly half of the TIG sleeve calibration standards. This is an expected result due to the air gap between the tube and sleeve.

Figure 18 presents the 70 kHz noise distribution developed from all installed nickel band sleeves in SGC at BVPS-2. One interesting artifact of the individual noise values for these tubes was that some tubes had approximately equal noise amplitudes for each of the 60 or 90 degree eddy current analysis windows while other tubes exhibited a more sinusoidal distribution of noise values. This sinusoidal distribution of noise values is believed to be an artifact of less than optimal probe translation (a "wobbly" probe). Thus it can be judged that improvements to the probe translation system could also improve detection capability. The A-hat function applied is based on data points that compared signal amplitude to destructive examination depth for both pulled tube and doped steam generated PWSCC indications. This data, based on 300 kHz responses, was determined to be consistent with the expected parent tube PWSCC response in 70 kHz.

Two A-hat functions were investigated. The nominal fit is based on the existing depth-amplitude response for axial PWSCC which implies a 100%TW amplitude of approximately 4 volts. The second, or "best estimate" function is based on a 100%TW amplitude of 5 volts, based on the SCC detection specimen. Note that the information in Table 2 shows that the amplitude response within the nickel band in 75 kHz compared to 300 kHz for equal depth flaws is increased compared to non-nickel band conditions. The average increase is 2.68 times, that is, a 1 volt, 300 kHz parent tube indication would on average, represent a 2.68 volt indication in 75 kHz in the nickel band region. Thus, application of the existing parent tube axial PWSCC depth-amplitude relationship would be expected to give a conservative POD approximation.

The results of the POD simulations are provided as two individual POD curves on Figure 19. These are a log-logistic fit and a logistic fit. The logistic fit is judged to provide a more accurate assessment of POD for deep depths. Table 3 presents a summary of the depths associated with various POD levels for the POD curves plotted on Figure 19 and for the best estimate fits.

From Figure 19, the log-logistic fit, based on the nominal A-hat function implies a POD of 0.80 at a depth of 66%TW and POD of 0.95 at a depth of 92%TW, while the logistic fit based on the nominal A-hat function implies a POD of 0.80 at a depth of 65%TW and POD of 0.95 at a depth of 80%TW. Note that the 80% depth is the depth of the axial EDM notches applied to the modified parent tube test specimens, thus the POD simulation implies that flaws of this depth, 80%TW, would be reported at a high probability level (0.95).

It should be noted that such curve fits have to be balanced about a centroid and are therefore influenced by the data at the opposite side of the centroid. To emphasize how this influences the developed curve, the individual simulation of detections and non-detections in various %TW depth ranges can be used. Table 4 presents the total number of simulations within various depth bins, the number of simulated detections, and the apparent POD, defined as the number of detections divided by the total number of simulations, within the bin range. Thus, while the log-logistic POD curve implies POD ranging from 0.94 to 0.96 for the depth range of 90 to 100%TW, the apparent POD for this range from the simulation results implies a POD of 0.999. Also included is a measure of compliance of the Appendix H binomial POD requirement per Reference 5 for each bin range and for the depth range of 60 to 100%TW, which is

the Appendix H depth range for evaluation. Thus, from this data based on the nominal A-hat function, the results of the POD simulation would imply compliance with the Appendix H requirements of Reference 5. Note that certification of an eddy current technique according to the requirements of Appendix H of Reference 5 has not been applied to a POD simulation, only to techniques with specific detection/non-detection specimens.

In addition, the POD curves provided by Figure 19 were compared with other qualified techniques. This comparison shows that the POD performance shown on Figure 19 is improved compared to other techniques currently utilized for inspection of other areas of the tube.

Table 2: 75 kHz and 300 kHz Responses of NDE Samples					
	+POINT 300 kHz Amplitude (volts)	+POINT 300 kHz Amplitude (volts)	+POINT 75 kHz Amplitude (volts)	+POINT 150 kHz Amplitude (volts)	75 kHz/300 kHz Amplitude Ratio
Flaw	**Unexpanded No Sleeve**	**Expanded in Collar No Sleeve**	**With A800 Sleeve**	**With A800 Sleeve**	**With A800 Sleeve**
Crack 1	4.65	7.25	5.34	4.20	0.74
Crack 2	2.54	3.41	5.61	3.89	1.65
Crack 3	1.95	2.34	5.99	4.68	2.56
Crack 4	0.86	1.25	5.28	4.44	4.22
Notch 1	2.65	1.98	8.68	6.03	4.38
Notch 2	2.40	1.82	1.71	NDD	0.94
Notch 3	2.51	1.03	4.86	3.77	4.72
Notch 4	2.32	1.48	6.16	4.21	4.16
Notch 5	2.14	1.57	2.12	1.01	1.35
Notch 6	2.61	1.78	3.66	2.04	2.06
Average					2.68

Table 3: Summary of MAPOD Based POD Curve Statistics				
	Log-Logistic 0.95	**Log-Logistic 0.50**	**Logistic 0.95**	**Logistic 0.50**
Nominal A-hat	92%TW	49%TW	80%TW	52%TW
Best Estimate A-hat	82%TW	43%TW	72%TW	46%TW

Table 4: POD Simulation Apparent POD and Appendix H Compliance for Various Depth Bins					
Depth Bin Upper Bound	**Depth Bin Lower Bound**	**Number of Simulations**	**Number of Simulated Detections**	**Apparent POD**	**Compliance with Appendix H Binomial POD Requirement**
100	90	926	925	0.999	Yes
90	80	920	907	0.986	Yes
80	70	1053	962	0.914	Yes
70	60	1008	797	0.791	No
60	50	1031	596	0.578	No
100	60	3907	3591	0.919	Yes

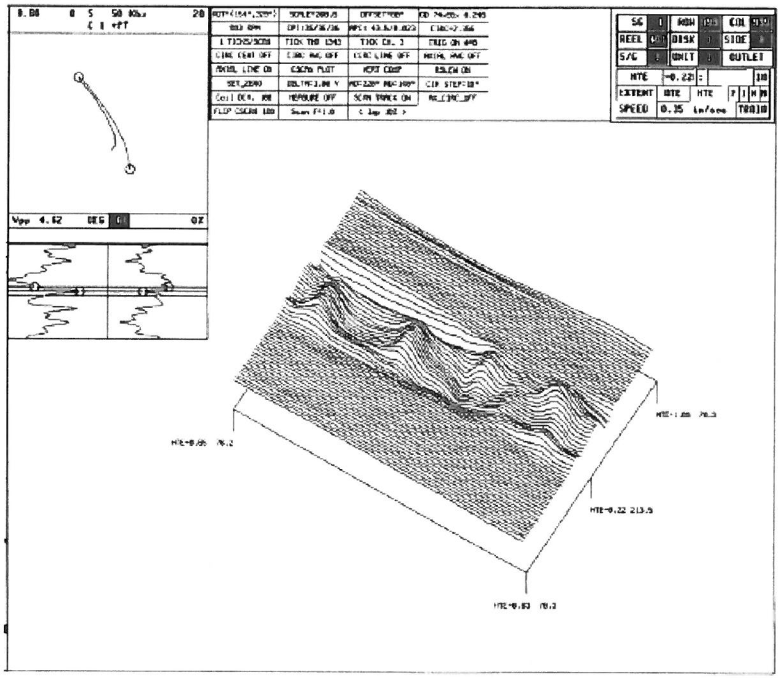

Figure 12: Flaw 1 +POINT Probe 50 kHz Response

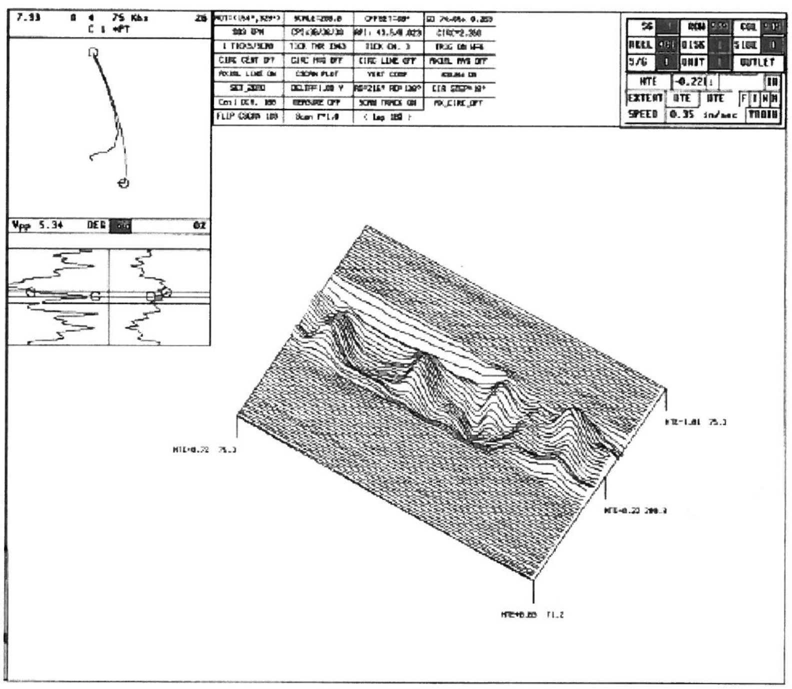

Figure 13: Flaw 1 +POINT Probe 75 kHz Response

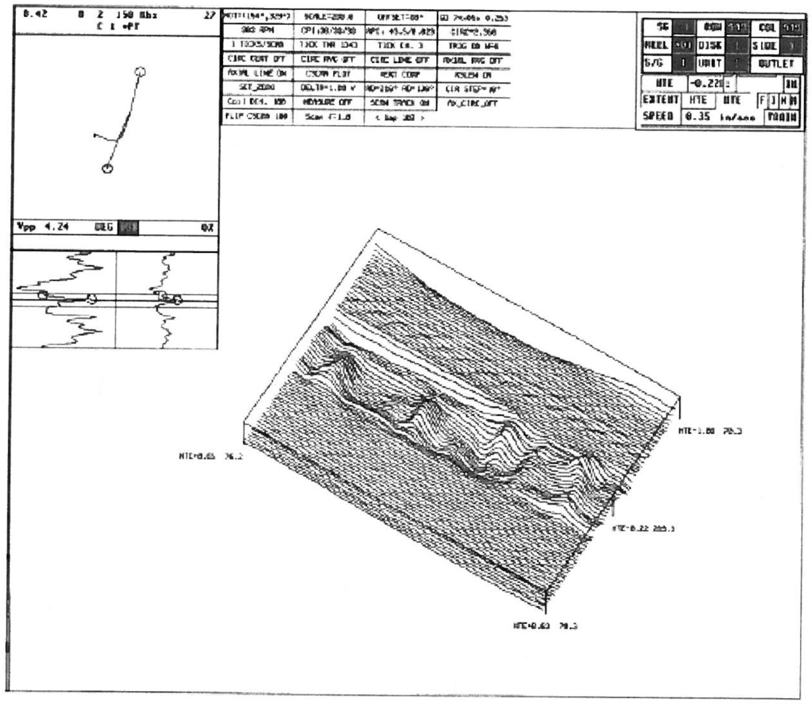

Figure 14: Flaw 1 +POINT Probe 150 kHz Response

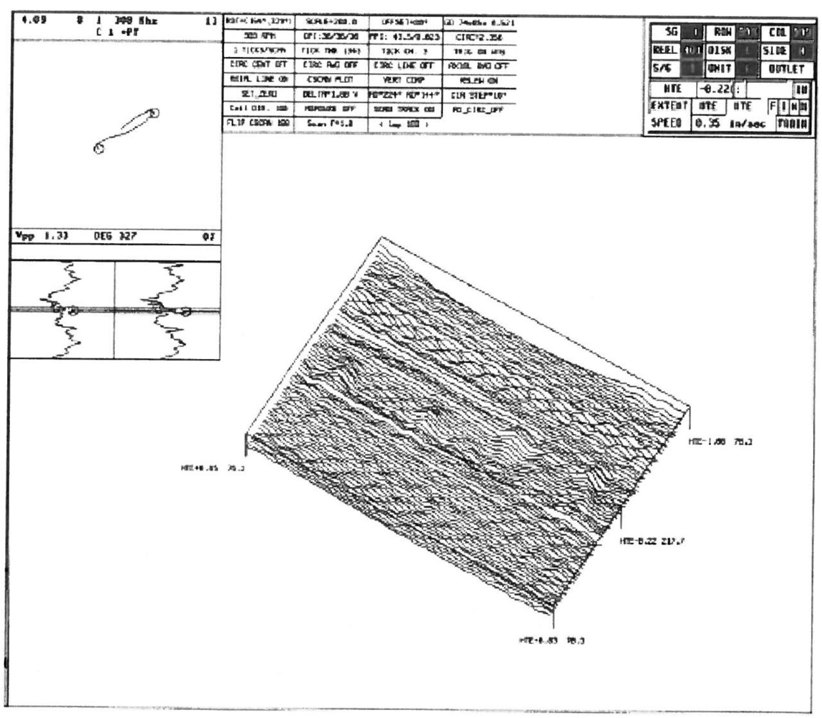

Figure 15: Flaw 1 +POINT Probe 300 kHz Response

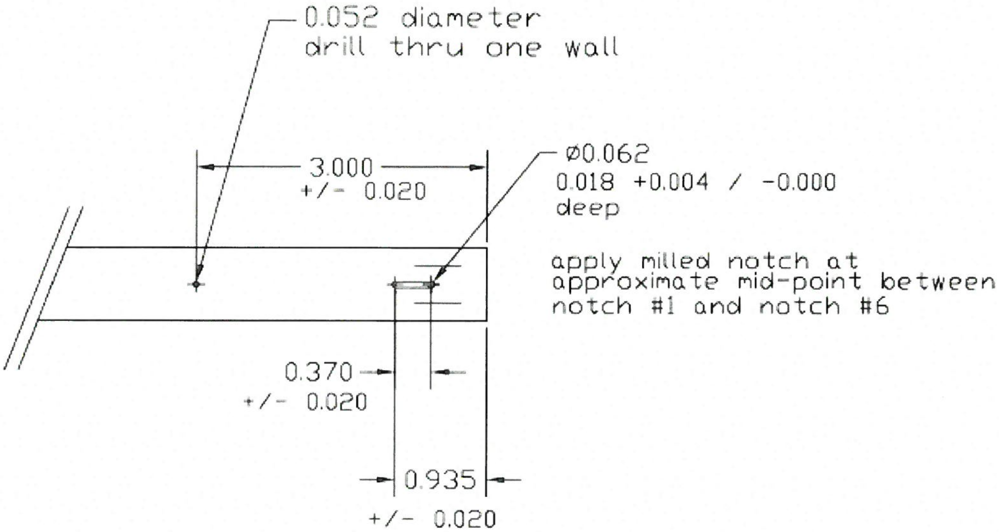

Figure 16: Location of Tube OD Flaws Used for NDE Investigation

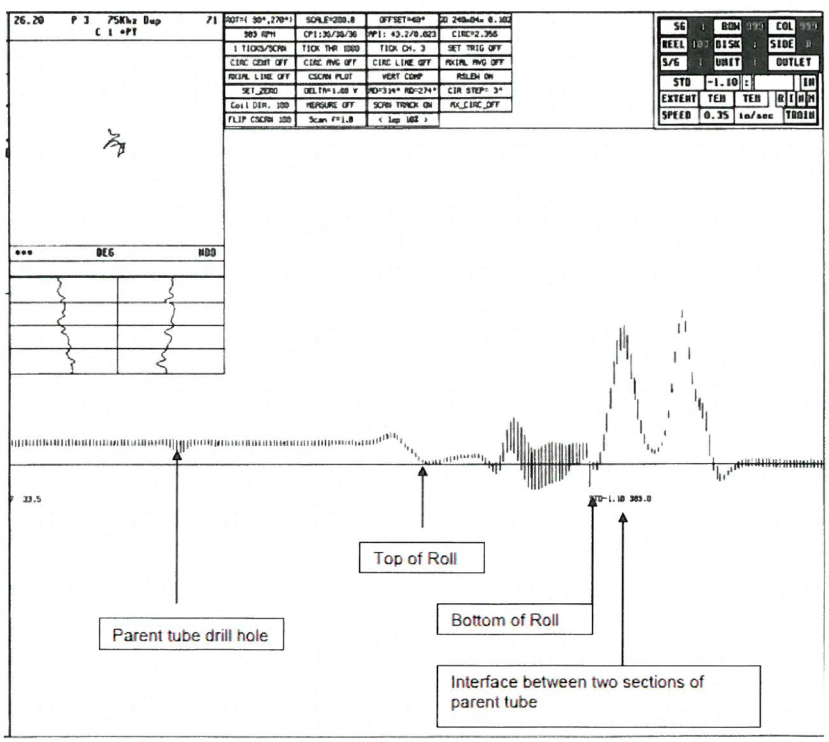

Figure 17: +POINT Probe Terrain Plot of Alloy 800 Sleeved Tube Showing Simulated Tube Circumferential Separation Near Bottom of Sleeve Roll Joint

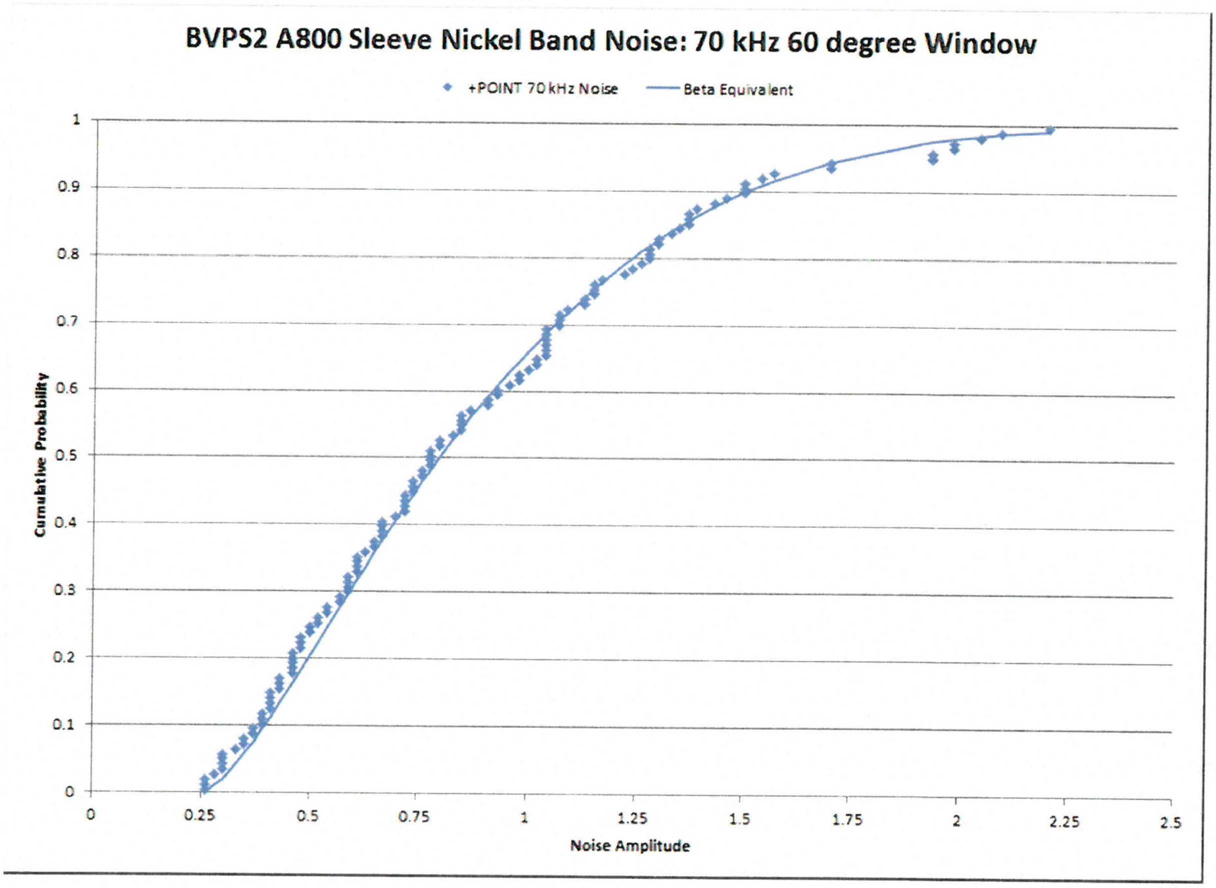

Figure 18: 70 kHz +POINT Probe Noise Distribution at Center of Nickel Band

a,c,e

[ ]

Figure 19: Developed POD Curves for Axial PWSCC in Parent Tube Adjacent to Sleeve Nickel Band

9.0 CONCLUSION

This document concludes that degradation of the parent tube adjacent to the nickel band of the Alloy 800 tubesheet sleeve is not credible based on the residual stress condition at the tube ID surface, isolation of the area in question (parent tube ID surface adjacent to the sleeve nickel band) since the sleeve roll joint length bounds this area, and modification of parent tube ID surface stresses due to application of shot peening prior to operation. In the event that ID initiated degradation of the parent tube at the nickel band interface were to occur, including 100%TW degradation either axially or circumferentially oriented, it will not reduce the axial load bearing capability of the sleeve lower roll joint to less than the design requirement or result in a significant reduction of safety margin. Thus the lack of formal qualification of the currently applied NDE technique and inspection probe according to the Appendix H requirements of Reference 5 will not increase the risk of the plant experiencing an unanalyzed accident and the results of existing radiologic analyses will remain valid. This document concludes that current NDE capabilities will readily detect 100%TW degradation of the parent tube and SCC degradation greater than or equal to the depth of part through-wall degradation included in the mechanical testing program. Therefore, in the event that PWSCC of the parent tube adjacent to the nickel band is experienced, this degradation will be detected prior to achieving equal depth as the part through-wall degradation included in the mechanical testing program. Since the mechanical testing program has established that degradation of the parent tube will not reduce the axial load bearing capability of the sleeve lower joint, the sleeve will continue to provide its' required safety function during all plant conditions.

10.0 REFERENCES

1. WOG-04-518, Revision 0, "Transmittal of 'Engineering Position Paper on NDE Issues Related to TIG and Alloy 800 Sleeves with Regard to Nickel Band NRC Discussion,' To Cafeteria Task PA-MSC-0190," Westinghouse Electric Company, October 2004.
2. WOG-05-338, Revision 0, "Transmittal of 'Final Engineering Position Paper on NDE Issues Related to TIG and Alloy 800 Sleeves with Regard to Nickel Band NRC Discussion, Revision 1' To Cafeteria Task (PA-MSC-0190)," Westinghouse Electric Company, July 2005.
3. WOG-06-23, Revision 0, "Transmittal of Final Report SG-SGDA-05-48-P/NP Revision 1 entitled 'Test Results Related to TIG and Alloy 800 Sleeve Installation in ¾ Inch and 7/8 Inch OD SG Tubing In-Service Inspection Requirements," Westinghouse Electric Company, January 2006, (PA-MSC-0190).
4. FENOC, L-08-307, "Beaver Valley Power Station, Unit No. 2 Docket No. 50-412, License No. NPF-73, License Amendment Request No. 07-007 Alloy 800 Steam Generator Tube Sleeving," October 2008.
5. Steam Generator Management Program: Pressurized Water Reactor Steam Generator Examination Guidelines: Revision 8. EPRI, Palo Alto, CA: 2016, 3002007572.
6. US NRC, "1009 - E116 - Corrosion and Corrosion Control in LWRs - Corrosion Fatigue and Introduction to SCC," ML11229A045/ML11229A051, August 17, 2011.
7. CN-SGMP-17-7, Revision 1, "Tube and Tube Sleeve Compression Study," Westinghouse Electric Company, March 2018.
8. LTR-SGMP-09-35, Revision 0, "Application of W* Alternate Repair Criteria to Sequoyah Unit 2 Cold Leg Tubes," Westinghouse Electric Company, March 2009.
9. LTR-SGMP-18-4, Revision 0, "Beaver Valley Unit 2 Tube Sleeve Lower Rolled Joint Temperature Determination," Westinghouse Electric Company, February 2018.
10. WCAP-14797-P, Revision 2, "Generic W* Tube Plugging Criteria for 51 Series Steam Generator Tubesheet Region WEXTEX Expansions," Westinghouse Electric Company, March 2003.
11. "Residual stresses associated with the hydraulic expansion of steam generator tubing into tubesheets," Nuclear Engineering and Design Volume 143, March 1993.
12. WCAP-11228, Revision 1, "Tubesheet Region Plugging Criterion for the South Carolina Electric and Gas Company V. C. Summer Nuclear Station Steam Generators," Westinghouse Electric Company, October 1986.
13. LTR-SGMP-15-13, Revision 0, "Transmittal of Alloy 800 Sleeve Installations Worldwide," Westinghouse Electric Company, March 2015.
14. STD-7.3.1-7089, Revision 0, "Rolled Tube Retention Test, Test Plan and Results, Duke Power," Westinghouse Electric Company, July 1986.