Westinghouse Non-Proprietary Class 3

WCAP-16385-NP
Revision 1

March 2005

F* Tube Plugging Criterion for Tubes with Degradation in the Tubesheet Roll Expansion Region of the Beaver Valley Unit 2 Steam Generators

Westinghouse

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March 2005

Official Record Electronically Approved in EDMS 2000

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TABLE OF CONTENTS

LIST OF TABLES v

LIST OF FIGURES vii

ABSTRACT ix

1 INTRODUCTION 1-1

2 EVALUATION 2-1
- 2.1 ELASTIC PRELOAD DUE TO HARDROLLING PROCESS 2-2
  - 2.1.1 Radial Preload Test Configuration Description 2-2
  - 2.1.2 Preload Test Results: Discussion and Analysis 2-3
  - 2.1.3 Residual Radial Preload During Plant Operation 2-4
  - 2.1.4 Calculations of F* Based on Limiting Operation Conditions 2-5
  - 2.1.5 Increase in Radial Preload Due to Thermal Expansion Tightening 2-5
  - 2.1.6 Increase in Radial Preload During N.O. and FLB Due to Differential Pressure 2-5
  - 2.1.7 Change in Radial Preload Due to Tubesheet Bow 2-6
  - 2.1.8 Net Preload in Roll Transition Region for N.O. and FLB Conditions 2-6
- 2.2 ENGAGEMENT LENGTH 2-7
  - 2.2.1 Applied Loads 2-7
  - 2.2.2 End Effects 2-7
  - 2.2.3 Calculation of Engagement Distance Required, F* 2-8
- 2.3 LIMITATION OF PRIMARY TO SECONDARY LEAKAGE 2-9
  - 2.3.1 Operating Plant Leakage Experience for Tube Cracks Within Tubesheet 2-9
- 2.4 TUBE INTEGRITY UNDER POSTULATED LIMITING CONDITIONS 2-10
- 2.5 EDDY CURRENT ELEVATION MEASUREMENT UNCERTAINTY 2-10

3 APPLIED INSPECTION LENGTH 3-1
- 3.1 SENSITIVITY OF CALCULATED F* VALUE TO STEAM PRESSURE CHANGES 3-2

4 REFERENCES 4-1

LIST OF TABLES

Table 2-1	Model 51 Steam Generator Tube Roll Preload Test Data	2-12
Table 2-2	Model 51 Steam Generator Tube Roll Preload Test Stress Analysis Results	2-15
Table 2-3	Preload Analysis Summary and Specification of Inputs	2-17
Table 2.4	Evaluation of Required Engagement Lengths Normal and Faulted Conditions	2-18

LIST OF FIGURES

Figure 1 Definition of Symbols, Terms, and Abbreviations viii

Figure 1 LIST OF TERMS and ABBREVIATIONS

Abbreviation	Description
AVB	Anti Vibration Bar
BRT	Bottom of the Roll Transition
BVPS	Beaver Valley Power Station
CE	Combustion Engineering
ECT	Eddy Current Testing
EPU	Extended Power Uprate conditions
FENOC	FirstEnergy Nuclear Operating Company
FLB	Feedwater Line Break
HEJ	Hybrid Expansion Joint
ID	Inside Diameter
LOCA	Loss-of-Coolant Accident
NDE	Non-Destructive Examination
NSSS	Nuclear Steam Supply System
OD	Outside Diameter
PWSCC	Primary Water Stress Corrosion Cracking
RE	Roll Expansion
RG	Regulatory Guide
RPC	Rotating Probe Coil
SG	Steam Generator
SGTP	Steam Generator Tube Plugging
SLB	Steam Line Break
T_{cold}	Steam Generator Vessel Outlet Temperature
T-cold	Steam Generator Vessel Outlet Temperature
T_{hot}	Reactor Coolant Temperature to Steam Generator
T-hot	Steam Generator Vessel Inlet Temperature
TIG	Tungsten Inert Gas
TTS	Top of Tubesheet
TW	Throughwall
USNRC	United States Nuclear Regulatory Commission
WEXTEX	Westinghouse Explosive Tube Expansion
"	Inch or inches
°F	Degrees Fahrenheit
gpd	Gallons per day
gpm	Gallons per minute
MWt	Megawatts thermal
psi	Pounds Per Square Inch
psia	Pounds Per Square Inch Atmospheric
+Pt	Plus Point™ probe (or equivalent EPRI Appendix H qualified probe)
+Point	Plus Point™ probe (or equivalent EPRI Appendix H qualified probe)

ABSTRACT

An evaluation was performed to develop a plugging criterion, known as the F* criterion, for determining whether or not repairing (by sleeving) or plugging of full depth (through the entire tubesheet thickness) hardroll expanded steam generator tubes is necessary for degradation that has been detected in the expanded region of the tubes located within the tubesheet. The evaluation consisted of analysis and testing programs aimed at quantifying the residual preload of Westinghouse 51M Series steam generator tubes hardrolled into the tubesheet. An analysis was performed to determine the length of hardroll engagement required to resist tube pullout forces during normal and faulted plant operation. It was postulated that the radial preload would be sufficient to significantly restrict leakage during normal operating and faulted conditions. On this basis, an F* criterion value of 1.97 inch was established for the Beaver Valley Unit 2 steam generators as sufficient for continued plant operation regardless of the extent of tube degradation below F*. The evaluation also demonstrates that application of the F* criterion for tube degradation within the tubesheet affords a level of plant protection commensurate with that provided by RG 1.121 for degradation located outside of the tubesheet region. This WCAP is also considered to be commensurate with the recommendations of Generic Letter GL 2004-01, "Requirements for Steam Generator Tube Inspection."

This evaluation was based on an F* Criterion evaluation that was performed for the original Farley Unit 2 Model 51 Steam Generators documented in WCAP-11306, Revision 2 (Reference 2), and subsequently repeated in similar evaluations performed for other Series 51 steam generators. WCAP-11306, Revision 2 forms the basis of the Farley 2 license amendment, subsequently approved by the USNRC for Farley Unit 2, implementing the F* criterion. The F* distance was developed from the limiting set of input parameters based on faulted conditions and is, therefore, independent of NSSS power level. The current BVPS Unit 2 normal operating conditions and normal operating conditions at an extended power uprate (EPU) NSSS power level of 2910 MWt with varying steam generator tube plugging levels were evaluated using a methodology consistent with Reference 2; it was determined that the faulted condition F* value of 1.97 inches bounds the normal operating conditions evaluated. The methodology applied to BVPS Unit 2 differs slightly from the reference analysis in that secondary side pressure was assumed to act in the tube to tubesheet crevice and tubesheet flexure was accounted for when calculating the pressure preload. These assumptions conservatively affect the F* calculation such that the F* distance for BVPS Unit 2 is about 0.5 inch longer than the Farley 2 F* distance.

The F* criterion will be functionally applied by performing Plus Point™ probe eddy current examination to a nominal depth of 3 inches below the top of the tubesheet for all hot leg tubes. This inspection depth encompasses the F* distance and includes allowance for consideration of NDE length measurement uncertainty and location of the bottom of roll transition. F* distances were also calculated using steam generator outlet temperature, which is conservative for degradation located on the hot leg side of the tube. To date, no cold leg SCC degradation has been reported at BVPS Unit 2.

In addition, application of the F* Criterion, with eventual revision to the BVPS Unit 2 technical specifications, results in a change to the definition of tube inspection by not requiring non destructive examination of the tube below the F* distance.

1 INTRODUCTION

The purpose of this WCAP is to document the development of a criterion to be used in determining whether or not repairing or plugging of full depth hardroll expanded steam generator tubes is necessary for degradation which has been detected in the expanded region of the tube within the tubesheet. Existing BVPS Unit 2 Technical Specification tube repairing/plugging criteria apply throughout the tube length, but do not take into account the reinforcing effect of the tubesheet on the external surface of the tube. The presence of the tubesheet will constrain the tube and will complement its integrity in that region by essentially precluding tube deformation beyond its expanded outside diameter. The resistance to both tube rupture and tube collapse is significantly strengthened by the tubesheet. In addition, the proximity of the tubesheet significantly affects the leak behavior of through wall tube cracks in this region, i.e., no significant leakage relative to plant technical specification allowances is to be expected.

This evaluation forms the basis for the development of a criterion which obviates the need to repair a tube (by sleeving) or to remove a tube from service (by plugging) due to detection of indications, e.g., by eddy current testing (ECT), in the roll expanded region of the tube within the tubesheet. This evaluation applies to the Beaver Valley Unit 2 Westinghouse Series 51M steam generators and assesses the integrity of the tube bundle, for tube ECT indications occurring in the roll expanded length of tubing within the tubesheet, relative to:

1) Maintenance of tube integrity for all loadings associated with normal plant conditions, including startup, operation in power range, hot standby and cooldown, as well as all anticipated transients.

2) Maintenance of tube integrity under postulated limiting conditions of primary to secondary (feedline break) and secondary to primary (LOCA) differential pressure,

3) Limitation of primary to secondary leakage consistent with accident analysis assumptions.

The Beaver Valley Unit 2 SGs are identical to the Farley Unit 2 original SGs with the exception that the Beaver Valley Unit 2 Model 51M SGs utilize a flow distribution baffle located between the top of tubesheet and the first tube support plate. The presence of the flow distribution baffle has been considered and has no negative impact upon this analysis. Friction forces existing between the tube and tube support plates during normal and faulted conditions would act to counter the end cap loading within the tube due to pressure differential. By neglecting these forces the determination of the F* distance is conservative. Also, the 51M SG design has 12 less tubes than a typical 51 SG, and 3 additional stayrods. These additional stayrods limit TSP deflection during a postulated steam line break event. However, this condition has no impact upon calculation of the F* distance.

The result of the evaluation is the identification of a distance, designated F* (and identified as the F* criterion), below the bottom of the roll transition or top of tubesheet, whichever is lower in elevation, for which tube degradation of any extent does not necessitate remedial action, e.g., plugging or sleeving. The F* criterion provides for sufficient engagement of the tube to tubesheet hardroll such that pullout forces that could be developed during normal operating or faulted conditions would be successfully resisted by the elastic preload between the tube and tubesheet. The necessary engagement length applicable to the Beaver Valley Unit 2 steam generators was found to be 1.97 inches based on preload analysis. Application of the F* criterion provides a level of protection for tube degradation in the tubesheet region commensurate with that afforded by Regulatory Guide (RG) 1.121, for degradation located outside the tubesheet region.

This evaluation forms the basis for the development of the required sound roll engagement length and subsequent Plus Point (+Pt) RPC inspection distance. Current (2697 MWt) and uprated (2910 MWt) conditions as well as faulted (feedline break) conditions were evaluated.

The F* alternate repair criterion has been approved for use by the USNRC at numerous nuclear power plants, including V. C. Summer (original SGs), Farley Unit 2 (original SGs), D. C. Cook Unit 1 (original SGs), Kewaunee (original SGs), Watts Bar, and Comanche Peak Unit 1.

2 EVALUATION

Tube rupture in the conventional sense, i.e., characterized by an axially oriented "fishmouth" opening in the side of the tube, is not possible within the tubesheet. The reason for this is that the tubesheet material prevents the wall of the tube from expanding outward in response to the internally acting pressure forces. The forces that would normally act to cause crack extension are transmitted into the walls of the tubesheet, the same as for a nondegraded tube, instead of acting on the tube material. Thus, axially oriented linear indications, e.g., cracks, cannot lead to tube failure within the tubesheet and may be considered on the basis of leakage effects only.

Likewise, a circumferentially oriented tube rupture is resisted because the tube is not free to deform in bending within the tubesheet. When degradation has occurred such that the remaining tube cross-sectional area does not present a uniform resistance to axial loading, bending stresses are developed which may significantly accelerate failure. When bending forces are resisted by lateral support loads provided by the tubesheet, the acceleration mechanism is mitigated and a tube separation mode similar to that which would occur in a simple tensile results. Such a separation mode, however, requires the application of significantly higher loads than for the unsupported case.

In order to evaluate the applicability of any developed criterion for indications within the tubesheet, some postulated type of degradation must be considered. For this evaluation, it was postulated that a circumferential severance of a tube could occur, contrary to existing plant operating experience with hardrolled tube-to-tubesheet joints. However, implicit in assuming a circumferential severance to occur is the consideration that degradation of any extent could be demonstrated to be tolerable below the location determined acceptable for the postulated condition. Thus, any observed degradation below the F* distance is acceptable for continued operation.

When the tubes have been hardrolled into the tubesheet, any axial loads developed by pressure and/or mechanical forces acting on the tubes are resisted by frictional forces developed by the elastic preload that exists between the tube and the tubesheet. For some specific length of engagement of the hardroll, i.e., F*, no significant axial forces will be transmitted further along the tube and that length of tubing will be sufficient to anchor the tube in the tubesheet. In order to determine the value of F* for application in Series 51 and 51M steam generators, a testing program was conducted to measure the elastic preload of the tubes in the tubesheet.

The presence of the elastic preload presents a significant resistance to flow of primary-to-secondary or secondary-to-primary water for degradation which has progressed fully through the thickness of the tube. In effect, no leakage would be expected if a sufficient length of hardroll is present. This has been demonstrated in high pressure fossil boilers where hardrolling of tube-to-tubesheet joints is the only mechanism resisting flow and also in steam generator sleeve-to-tube joints made by the Westinghouse hybrid expansion joint (HEJ) process.

The net operating preload within the tubes of a SG is comprised of the preload induced by the hardrolling process that the tubes undergo and the preload induced by the operating conditions of the SG. The following sections provide brief explanations of the two types of preloads.

2.1 ELASTIC PRELOAD DUE TO HARDROLLING PROCESS

Tubes are installed in the steam generator tubesheet by a hardrolling process which expands the tube to bring the outside surface into intimate contact with the tubesheet hole. The roll process and roll torque are specified to result in a metal-to-metal interference fit between the tube and the tubesheet.

A test program was conducted by Westinghouse to quantify the degree of interference fit between the tube and the tubesheet provided by the full depth hardrolling operation, also referred to as roll expansion (RE). The data generated in these tests was analyzed to determine the length of hardroll required to preclude axial tube forces from being transmitted farther along the tube, i.e., to establish the F* criterion.

The amount of interference was determined by installing tube specimens in collars specifically designed to simulate the tubesheet radial stiffness. A hardroll process representative of that used during steam generator manufacture was used in order to obtain specimens which would exhibit installed preload characteristics like the tubes in the tubesheet. Once the hardrolling was completed, the test collars were removed from the tube specimens and the springback of the tube was measured. The amount of springback was used in an analysis to determine the magnitude of the interference fit, which is a function of the residual tube-to-tubesheet radial load in the Westinghouse Model 51 and 51M SGs.

2.1.1 Radial Preload Test Configuration Description

The test program was designed to simulate the interface of a tube to tubesheet full depth hardroll for a Series 51 steam generator. The tube hardroll expansion process for the BVPS Unit 2 SGs is identical to the process used for the original Farley Unit 2 SGs. The test configuration consisted of six cylindrical collars, approximately [ ]^{a,c,e} inches in length, [ ]^{a,c,e} inches in outside diameter (OD), and [ ]^{a,c,e} inch in inside diameter (ID). A mill annealed, Alloy 600 (ASME-SB-163) tubing specimen approximately [ ]^{a,c,e} inches long with a nominal 0.875 inch OD before rolling, was hard rolled into each collar using a process which simulated actual tube installation conditions.

The design of the collars was based on the results of a finite element analysis of a section of the steam generator tubesheet to determine radial stiffness and flexibility. The inside diameter of the collar was chosen to match the size of holes drilled in the tubesheet. The outside diameter was selected to provide the same radial stiffness as the tubesheet.

The collars were fabricated from AISI 1018 carbon steel similar in mechanical properties to the actual tubesheet material. The collar assembly was clamped in a vise during the rolling process and for the post roll measurement of the tube ID. Following recording of all post roll measurements, the collars were saw cut to within a small distance from the tube wall. The collars were then split for removal from the tube and tube ID and OD measurements repeated.

Two end boundary conditions were imposed on the tube specimen during rolling. The end was restrained from axial motion in order to perform a tack roll at the bottom end, and was allowed to expand freely during the final roll.

2.1.2 Preload Test Results: Discussion and Analysis

All measurements taken during the test program are tabulated in Table 1. The data recorded were employed to determine the interfacial conditions of the tubes and collars. These consisted of the ID and OD of the tubes prior to and after rolling and removal from the collars as well as the inside and outside dimensions of each collar before and after tube rolling. Two orthogonal measurements were taken at six axial locations within the collars and tubes. All measured dimensions given in Table 1 are in inch units. The remainder of the data of particular interest was calculated from these specific dimensions. The calculated dimensions included wall thickness, change in wall thickness for both rolling and removal of the tubes from the collars, and percent of spring back.

Using the measured and calculated physical dimensions, an analysis of the tube deflections was performed to determine the amount of preload radial stress present following the hardrolling. The analysis consisted of application of conventional thick tube equations to account for variation of structural parameters through the wall thickness. However, traditional application of cylinder analysis considers the tube to be in a state of plane stress. For these tests the results implied that the tubes were in a state of plane strain elastically. This is in agreement with historical findings that theoretical values for radial residual preload are below those actually measured, and that axial frictional stress between the tube and the tubesheet increases the residual pressure. In a plane stress analysis such stress is taken to be zero (Reference 2). Based on this information the classical equations relating tube deformation and stress to applied pressure were modified to reflect plane strain assumptions. The standard analysis of thick walled cylinders results in an equation for the radial deflection of the tube as:

$$u = C_1 r + \frac{C_2}{r} \quad (1)$$

where, u = radial deflection
r = radial position within the tube wall,

and the constants, C_1 and C_2 are found from the boundary conditions to be a function of the elastic modulus of the material, Poisson's ratio for the material, the inside and outside radii, and the applied internal and external pressures. The difference between an analysis assuming plane stress and one assuming plane strain is manifested only in a change in the constant C_2. The first constant is the same for both conditions. For materials having a Poisson's ratio, ν, of 0.3, the following relation holds for the second constant:

$$C_2\,(\text{Plane Strain}) = 0.862\,C_2\,(\text{Plane Stress}) \quad (2)$$

The effect on the calculated residual pressure is that plane strain results are higher than plane stress results by slightly less than 10 percent. Comparing this effect with the results reported in Reference 2 indicated that better agreement with test values is achieved. It is to be noted that the residual radial pressure at the tube to tubesheet interface is the compressive radial stress at the OD of the tube.

By substituting the expression for the constants into Equation (1), the deflection at any radial location within the tube wall as a function of the internal and external pressure (radial stress at the ID and OD) is found. This expression was differentiated to obtain flexibility values for the tube deflection at the ID and OD respectively, e.g., dU_i/dP_o is the ratio of the radial deflection at the ID due to an OD pressure. Thus, dU_i/dP_o was used to find the interface pressure and radial stress between the tube and the tubesheet as:

$$S_{ro} = -P_o = -\text{ID Radial Springback} \times \left(\frac{dU_i}{dP_o} \right)^{-1} \quad (3)$$

The calculated radial residual stress for each specimen at each location is tabulated in Table 2. The mean residual stress and the standard deviation were found to be [ ] ^{a,c,e} psi and [ ] ^{a,c,e} psi, respectively. In order to determine a value to be used in the analysis, a tolerance factor for 95 percent confidence to contain 95 percent of the population was calculated, considering the 36 useable data points, to be 2.16. Thus, a 95/95 lower tolerance limit (LTL) for the radial residual preload at room temperature is [ ] ^{a,c,e} psi.

2.1.3 Residual Radial Preload During Plant Operation

During plant operation the amount of preload will change depending on the pressure and temperature conditions experienced by the tube. The room temperature preload stresses, i.e., radial, circumferential and axial, are such that the material is nearly in the yield state if a comparison is made to the ASME Code, Reference 4, minimum material properties. Since the coefficient of thermal expansion of the tube is greater than that of the tubesheet, heatup of the plant will result in an increase in the preload and could result in some yielding of the tube. In addition, the yield strength of the tube material decreases with temperature. Both of these effects may result in the preload being reduced upon return to ambient temperature conditions, i.e., in the cold condition. However, as documented in Reference 5, for a similar investigation, tube pullout tests which were preceded by a very high thermal relaxation soak showed the analysis to be conservative.

The plant operating pressure influences the preload directly based on the application of the pressure load to the ID of the tube, thus increasing the amount of interface loading. The primary to secondary pressure differential also affects the radial preload. This pressure differential causes an upward bowing of the tubesheet that decreases the interface loading above the tubesheet neutral axis by placing the tube hole surface in tension and increases the interface loading below the tubesheet neutral axis by placing the tube hole surface in compression for normal operating and faulted conditions. For the LOCA event, the tubesheet bows in the opposite direction, producing compression of the tube hole surface near the op of the tubesheet and dilation of the tube hole surface near the bottom of the tubesheet. Each of these effects were quantitatively integrated to develop the sound roll expansion distance, i.e., F*, required to prevent tube pullout.

The maximum amount of decrease in preload due to tubesheet bow for primary-to-secondary pressure differential will occur at the top of the tubesheet, near the center of the tube bundle. Since F* is measured from the bottom of the hardroll transition (BRT) or top of tubesheet, whichever is lower, and leakage is to be restricted by the F* region of the tube, the potential for the tube section within the F* region to experience a net tightening or loosening during operation is evaluated. The central location case is the most stringent case for normal operation and FLB; tubes located near the peripheral will experience little or no bowing effect for normal operation and FLB. The F* distance is determined using the most conservative tubesheet bowing effects for the central region. The effects of the three identified mechanisms affecting the preload, pressure tightening, thermal tightening, and tubesheet bow loss are considered in the following sections.

2.1.4 Calculations of F* Based on Limiting Operation Conditions

An evaluation was performed to determine the effect of variations in operating parameters on residual preload at the tube/tubesheet expansion zone, the axial pullout force on the tube, and the resulting value of F*. For Beaver Valley Unit 2, current normal operating and operation at the EPU NSSS level of 2910 MWt with varying steam generator tube plugging levels were evaluated. The residual preload in the roll expansion is affected by differential thermal expansion, internal pressure and tubesheet bowing, T_{hot}, T_{cold}, and the primary to secondary pressures are used to evaluate these effects. The primary to secondary ΔP affects the axial pullout load on the tube. These parameters are summarized in Tables 3 and 4 for each condition evaluated. Table 3 shows calculation of F* for the current operating conditions, Table 4 shows the calculation of F* for the EPU condition with 4% SGTP. For EPU conditions the replacement turbine is sized for optimal performance at a steam pressure at the SG outlet nozzle of 774 psia. As SGTP increases, so will T_{hot}. At 4% SGTP, T_{hot} is calculated to be 609.5°F while at 8% SGTP, T_{hot} is calculated to be 611.2°F. Steam pressure at the SG outlet nozzle will be maintained at 774 psia over this range of varying SGTP and T_{hot}. Therefore, as thermal expansion tightening is increased for increased T_{hot}, the limiting EPU F* analysis case considers minimum SGTP and minimum T_{hot}. For conservatism, the F* distance is calculated using T_{cold}. At 4% SGTP, T_{cold} is also minimized for the range of EPU operating parameters. The T_{cold} value for this condition is 538.9°F however a value of 538.5°F will be used for the analysis. Internal steam pressure losses due to moisture separation and flow through the SG outlet nozzle are approximately 15 psi. The F* calculation conservatively neglects these losses as doing so maximizes primary to secondary pressure differential across the SG tubes. In actuality, for a constant pressure differential, the change is thermal tightening between 538.9°F and 540.2°F is so small that the F* distance for EPU conditions for 4 to 8% SGTP that the F* distances are equal.

Calculations were also performed for faulted conditions. The feedline break event is used as the limiting faulted condition. Faulted condition calculation of F* is independent of power level and SGTP. While the steamline break (SLB) event provides the most stringent radiological conditions for postulated accidents involving a loss of pressure or fluid in the secondary system, the FLB pressure differential of 2650 psia maximizes the axial end cap loading on the tube for tube pullout considerations.

Based on the calculated values of F* for normal operation in Tables 3 and 4, and separate calculations for faulted conditions, the maximum value of F* is obtained for the faulted condition. The results for this limiting case are presented in the following sections.

2.1.5 Increase in Radial Preload Due to Thermal Expansion Tightening

For conservatism in determining the total residual preload for normal operating conditions, tightening of the tube/tubesheet joint due to differential thermal expansion is minimized by applying the SG outlet temperature to the tubing. For the limiting condition this corresponds to a cold leg temperature of 538.5°F. The mean coefficient of thermal expansion for the Alloy 600 tubing between ambient conditions and 538.5°F is approximately $7.75*10^{-6}$ in/in/°F, and $7.32*10^{-6}$ in/in/°F for the carbon steel tubesheet. Thus, there is a net difference of $0.43*10^{-6}$ in/in/°F between the two materials. Considering a temperature difference of (538.5 – 70) = 468.5°F between ambient and operating conditions, the increase in preload between the tube (T) and tubesheet (TS) was calculated as:

$$S_{rt} = 0.43 \cdot 10^{-6} \cdot 468.5 \frac{D_{i,collar}}{2\left(\left.\frac{dU_i}{dP_i}\right|_{TS} - \left.\frac{dU_o}{dP_o}\right|_{T} \right)} \quad (4)$$

The results indicate that the increase in preload radial stress due to thermal expansion is [ ]^{a,c,e} psi for normal operating conditions. A conservative lower bound steady state temperature of 530°F was assumed for Thot and Tcold for faulted conditions. The increase in preload radial stress due to thermal expansion for faulted conditions is [ ]^{a,c,e} psi.

2.1.6 Increase in Radial Preload During N.O. and FLB Due to Differential Pressure

The normal operating (N.O.) differential pressure from the primary-to-secondary side of the steam generator during the most limiting condition is 1476 psi while the limiting faulted condition pressure differential is 2650 psi. The internal pressure acting of the wall of the tube will result in an increase of the radial preload on the order of the pressure value. The increase was found as:

$$S_{rP} = -P_o = -P_i \frac{\left.\frac{dU_o}{dP_i}\right|_{T}}{\left.\frac{dU_i}{dP_i}\right|_{TS} - \left.\frac{dU_o}{dP_o}\right|_{T}} \quad (5)$$

In actuality, the increase in preload will be more dependent on the internal pressure of the tube since water at secondary side pressure would not be expected between the tube and the tubesheet. However, the primary-to-secondary ΔP is used for conservatism.

The increase in radial contact pressure due to differential pressure was evaluated for both normal operating (ΔP = 1476 psi) and faulted (ΔP = 2650 psi) conditions. The results indicate that the increase in preload radial stress is [ ]^{a,c,e} psi for normal operating conditions and [ ]^{a,c,e} psi for faulted (FLB) conditions.

2.1.7 Change in Radial Preload Due to Tubesheet Bow

An analysis of the Series 51 tubesheet was performed to evaluate the change in preload stress that would occur as a result of tubesheet bow for interior tubes. The analysis was based on performing finite element analysis of the tubesheet and SG shell using equivalent perforated plate properties for the tubesheet. Boundary conditions from the results were then applied to a smaller, but more detailed model, in order to obtain results for the tubesheet holes. Basically, the deflection of the tubesheet was used to find the stresses active on the top surface and then the presence of the holes was accounted for. For plants with full tubesheet depth expansion, tubesheet bowing during normal and faulted conditions results in a reduction of contact pressures near the top of tubesheet and an increase in contact pressures near the bottom of tubesheet when the primary (RCS) pressure exceeds secondary side (steam) pressure. For the location where the loss of preload is a maximum, the radial preload stress would be reduced by [ ] ^{a,c,e} psi during normal operation and [ ] ^{a,c,e} psi during faulted conditions.

However, the interior tubes are not the limiting case for primary-to-secondary pressure difference. The limiting case involves peripheral tubes where tubesheet bowing has a negligible effect on tube-to-tubesheet preload. Therefore, the N.O. and FLB analyses address only tubes in the peripheral region of the tubesheet. During LOCA, the differential operating pressure is from secondary to primary. Thus, the radial preload at the top of tubesheet will increase as the tubesheet bows downward. This tubesheet bowing direction has no negative effect upon calculation of the F* distance.

2.1.8 Net Preload in Roll Transition Region for N.O. and FLB Conditions

Combining the room temperature hardroll preload with the thermal and pressure effects and tubesheet bowing effects results in a net operating preload of [ ] ^{a,c,e} psi during normal operation and [ ] ^{a,c,e} psi for faulted conditions.

2.2 ENGAGEMENT LENGTH

The calculation of the F* value recommended for application to the BVPS Unit 2 SGs is based on determining the length of hardroll necessary to equilibrate the applied loads during the maximum normal operating or faulted conditions, whichever provides the largest value. Thus, the applied loads are equilibrated to the load carrying ability of the hardrolled tube for the above conditions. In performing the analysis, consideration is made of the potential for the ends of the hardroll at the hardroll transition and the assumed severed condition to have a reduced load carrying capability.

2.2.1 Applied Loads

The applied loads to the tubes that could result in pullout from the tubesheet during all normal and postulated accident conditions are predominantly axial and due to the primary-to-secondary pressure differences. For a tube which has not been degraded, the axial pressure load is given by the product of the pressure with the internal cross-sectional area. However, for a tube with internal degradation, e.g., cracks oriented at an angle to the axis of the tube, the internal pressure may also act on the flanks of the degradation. Thus, for a tube which is conservatively postulated to be severed at some location within the tubesheet, the total force acting to remove the tube from the tubesheet is given by the product of the pressure and the cross-sectional area of the tubesheet hole. The force resulting from the pressure and internal area acts to pull the tube from the tubesheet and the force acting on the end of the tube tends to push the tube from the tubesheet. For this analysis, the tubesheet hole diameter is used to determine the magnitude of the pressure forces acting on the tube. The forces acting to remove the tube from the tubesheet are 885 pounds and 1649 pounds respectively for current normal operating and faulted conditions. Other forces such as fluid drag in the U-bend region are negligible by comparison, and would likely be balanced by frictional forces at tube support plates and at AVBs.

2.2.2 End Effects

For a tube which is postulated to be severed within the tubesheet there is a material discontinuity at the location where the tube is severed. For a small distance from each assumed discontinuity the stiffness, and hence the radial preload, of the tube is reduced relative to that remote from the ends of the roll expansion. The analysis of end effects in thin cylinders is based on the analysis of a beam on an elastic foundation. For a tube with a given radial deflection at the end, the deflection of points away from the end relative to the end deflection is given by:

$$\frac{u_{rx}}{u_{ro}} = e^{-\lambda x}\cos(\lambda x) \text{ where } \lambda^4 = \frac{3(1-\nu^2)}{R_m^2 t^2} \quad (6)$$

that is, λ = [ ]a,c,e = end effect constant, and,
x = distance from the end of the tube.

For the radially preloaded tube, the distanced for the end effects to become negligible is the location where the cosine term becomes zero. Thus, for the roll expanded Series 51 tubes the distance corresponds to the product of λ times x being equal to (π/2) or 0.174 inch. For a distance of 0.174 inch above the severed end and below the bottom of the roll transition, the expanded joint has a reduced radial load carrying capability relative to the remainder of the F* length.

The above equation can be integrated to find the average deflection over the affected length to be 0.384 of the end deflection. This means that on the average the stiffness of the material over the affected length is 0.616 of the stiffness of the material remote from the ends. Therefore, the effective preload for the affected length is 61.6 percent of the preload at regions more than 0.174 inch from the ends. For example, for the current normal operating net preload of [ ]a,c,e psi, or [ ]a,c,e pound per inch of length, the effective preload for a distance of 0.174 inch from the end is [ ]a,c,e pound per inch or [ ]a,c,e pounds.

2.2.3 Calculation of Engagement Distance Required, F*

The calculation of the required engagement distance is based on determining the length for preload frictional forces to equilibrate the applied operating loads. The axial friction force was found as the product of the radial preload force and the coefficient of friction between the tube and tubesheet. The value assumed for the coefficient of friction was [ ]a,c,e, from Reference 2. For current normal operation the radial preload is [ ]a,c,e psi or [ ]a,c,e pounds per inch of engagement. Thus, the axial friction resistance force is [ ]a,c,e pounds per inch of engagement. It is to be noted that this value applies away from the ends of the tube. For any given engagement length, the total axial resistance is the sum of that provided by the two ends plus that provided by the length minus the two end lengths. From the preceding section the axial resistance of each end is [ ]a,c,e pounds. Considering both ends of the presumed severed tube, i.e., the hardroll transition is considered one end, the axial resistance is [ ]a,c,e pounds plus the resistance of the material between the ends, i.e., the total length of engagement minus 0.348 inch. This is a conservative assumption because there should be no end-effect at the roll transition where the geometry will actually increase the radial stiffness of the tube. For example, a one inch length has an axial resistance of,

[ ]a,c,e

Conversely, for the maximum current normal operating pressure applied load of 885 pounds, considered as 2655 pounds with a safety factor of 3, the length of hardroll engagement required is given by,

$$F^* = \frac{\text{Net Preload - End Effect Resistance}}{\text{Net Axial Resistance}} + 0.348 \text{ inch}$$

The F* values corresponding to the current normal operating, normal operating at 2910 MWt, and faulted conditions were found to be 1.74 inches, 1.77 inches, and 1.97 inches respectively.

The calculation of the above values is summarized in Table 4. The F* value thus determined for the required length of hardroll engagement for faulted conditions is sufficient to resist tube pullout during normal operation for all plant NSSS power levels up to 2910 MWt.

Based on the results of testing and analysis, it is concluded that following the installation of a tube by the standard hardrolling process, a residual radial preload stress exists due to the plastic deformation of the tube and tubesheet interface. This residual stress is expected to restrain the tube in the tubesheet while providing a leak limiting seal condition.

2.3 LIMITATION OF PRIMARY TO SECONDARY LEAKAGE

The allowable amount of primary-to-secondary leakage in a steam generator during normal plant operation is limited by plant technical specifications, and is 150 gpd. This limit based on plant radiological release considerations and implicitly enveloping the leak-before-break consideration for a throughwall crack in the free span of the tube, is also applicable to a leak source within the tubesheet. As no known existing degradation will be permitted to remain in service within the F* distance, no primary-to-secondary leakage contribution is postulated.

To date, only one axial PWSCC indication within the expansion transition has been reported in the BVPS Unit 2 steam generators. This indication was short, 0.3" reported by Plus Point, and well less than the 100%TW critical flaw length. The use for several cycles of the Plus Point coil and 100% inspection at the hot leg top of tubesheet region should preclude future development of 100%TW indications within the F* distance between inspections. Use of the Plus Point coil by the industry has effectively identified indications much earlier in their progression compared to pancake coils. Also, the BVPS Unit 2 hot leg tubes were shotpeened prior to operation. This is believed to be a key element in the limited PWSCC history at BVPS Unit 2.

For a crack within the F* region of the tubesheet, expected leakage would be insignificant for hardrolled joints. Leakage through cracks in tubes has been investigated experimentally for a number of tube wall thicknesses and thinning lengths, e.g., Reference 6. In general the amount of leakage through a crack for a particular tube size has been found to be approximately to the fourth power of the crack length. Analyses have also been performed which show, on an approximate basis for both elastic and elastic-plastic crack behavior, that the expected dependency of the crack opening area is on the order of the fourth power, e.g., see the axial crack equations in Reference 7. The amount of leakage through a crack will be proportional to the area of the opening, thus, the analytic results substantiate the test results. The presence of the tubesheet will preclude deformation of the tube wall adjacent to the crack, i.e., the crack flanks, and the crack opening area may be considered to be directly proportional to the length. The additional dependency discussed above, i.e., fourth power relative to first power, is due to the dilation of the unconstrained tube in the vicinity of the crack and the bending of the side faces or flanks of the crack. For a tube crack located within the tubesheet, the dilation of the tube and bending of the side faces of the crack is suppressed. Thus, a 0.5 inch crack located within the F* region up to the top of the roll transition would be expected to leak, without considering the flow path between the tube and tubesheet, at a rate less than similar crack in the freespan, i.e., less than the BVPS Unit 2 technical specification limit of 150 gpd (~0.1 gpm). Additional resistance provided by the tube-to-tubesheet interface would reduce this amount even further, and in the hardroll region the residual radial preload would be expected to eliminate it. This conclusion is supported by the results of the preload testing and analysis which demonstrates that a residual preload in excess of [ ] [a,c,e] psi exists between the tube and the tubesheet at normal operating conditions.

2.3.1 Operating Plant Leakage Experience for Tube Cracks Within the Tubesheet

A significant number of indications within the tubesheet have been reported for some non-domestic units, and to a lesser extent in domestic units. The only other domestic full depth roll expanded Model 51 SGs were the original Farley Unit 2 SGs. Despite over 600 tubes reported with PWSCC indications near the top of tubesheet, no primary to secondary leakage was reported due to these indications. The Diablo Canyon SGs use an explosive tube expansion process known as WEXTEX to close the tube to tubesheet gap, however this process results in substantially less residual preload compared to roll expansion. The W* alternate repair criteria has been applied in these units and includes a methodology for justification of continued operation of axial indications in the W* distance. Westinghouse knows of no primary-to secondary leakage being reported from these indications, many of which have been in service for multiple cycles. Extensive in situ pressure testing of axial PWSCC indications within a few inches of the top of tubesheet showed no leakage at the normal operating pressure difference for axial PWSCC indications with +Pt signal amplitudes up to 5.6 volts, and no leakage at three times the normal operating pressure difference for axial PWSCC indications with +Pt signal amplitudes up to 3.6 volts, Reference 8. At these amplitudes the indications likely contain segments which are 100%TW. Unlike the W* criterion, indications located within the F* distance are either removed from service by plugging or repaired by sleeving. That is, all hot leg tubes are inspected using a +Pt coil through the F* distance and any observed degradation is repaired using the F* criterion. Subsequently observed indications at future outages are either newly initiated or existing indications that contain depths less than the detection capability of the +Pt coil, about 40%TW. Crack growth rate data for similar units has shown a negligible potential for newly initiated or existing indications to experience growth such that a 100%TW progression is present at the time of discovery, Reference 9. Additionally, recent in situ pressure testing of a circumferential PWSCC indication with +Pt signal amplitude of 1.9 volts located within the expansion transition in a plant with CE SGs (explosively expanded tubing) showed no leakage at the normal operating condition pressure difference, Reference 10. Such experiences show that the leakage potential of PWSCC indications within the expanded portion of tubing is negligible for explosively expanded tubing, and by virtue of higher residual radial preload essentially zero for hardroll expanded tubing.

2.4 TUBE INTEGRITY UNDER POSTULATED LIMITING CONDITIONS

The final aspect of the evaluation is to determine tube integrity under the postulated loss of coolant accident (LOCA) conditions of secondary to primary pressure differential. A review of tube collapse strength characteristics indicates that the constraint provided to the tube by the tubesheet gives a significant margin between tube collapse strength and the limiting secondary to primary differential pressure condition, even in the presence of circumferential or axial indications, e.g., a discussion is provided in Reference 6.

The maximum secondary to primary differential pressure during a postulated LOCA is approximately 1000 psi. This value is significantly below the radial preload between the tubes and the tubesheet. Therefore, no significant secondary to primary leakage would be expected to occur. In addition, loading on the tubes is axially toward the tubesheet and could not contribute to pullout.

2.5 EDDY CURRENT ELEVATION MEASUREMENT UNCERTAINTY

In applying the F* alternate tube plugging criterion or similar methodologies, it is required that the distance from the BRT or the top of the tubesheet (whichever is lower in elevation) to the top of the degraded area of the tube be determined. This distance can be measured using conventional eddy current testing techniques. During the inspection of the steam generators, eddy current data is collected in both the differential and absolute modes. The tube degradation is typically measured employing the differential mode, while location measurements are normally taken from the absolute mode data. The absolute mode is used for length measurements because the top and the bottom of the roll transition being observed can be more easily determined. The sound roll engagement length, plus the measurement uncertainty distance, is directed downward from the BRT or the top of the tubesheet, whichever is lower in elevation. The physical phenomenon that is responsible for the requirement of assigning an uncertainty to any measured F* engagement length is the field spread of the eddy currents in front of and behind the eddy current coil. In other words, the eddy current coil reacts before the coil is actually positioned at the discontinuity. The effect is commonly referred to as "look-ahead" and "look-back." The eddy current uncertainty was demonstrated to be 0.25" in Reference 2. With the advent of the +Point coil and improved eddy current data collection procedures, this value is believed to be conservative.

Table 2-1 Model 51 Steam Generator Tube Roll Preload Test Data

a,c,e

Test No.	Location No.	Collar ID Pre-Roll	Collar OD Pre-Roll	Tube ID Before Roll	Tube OD Before Roll
1	1				
	2				
	3				
	4				
	5				
	6				
	Avg.				
2	1				
	2				
	3				
	4				
	5				
	6				
	Avg.				
3	1				
	2				
	3				
	4				
	5				
	6				
	Avg.				
6	1				
	2				
	3				
	4				
	5				
	6				
	Avg.				
7	1				
	2				
	3				
	4				
	5				
	6				
	Avg.				
8	1				
	2				
	3				
	4				
	5				
	6				
	Avg.				
Column Avg.					

Table 2-1 Model 51 Steam Generator Tube Roll Preload Test Data (cont'd)

a,c,e

Test No.	Location No.	Pre-Roll Thickness	Collar OD Post-Roll 0 Deg.	90 Deg.	Avg	Collar Delta	Tube ID Post-Roll 0 Deg.	90 Deg.	Avg.	Tube ID Growth	Tube ID Post-Roll Collar Removed 0 Deg.	90 deg.	Avg.
1	1												
	2												
	3												
	4												
	5												
	6												
	Avg.												
2	1												
	2												
	3												
	4												
	5												
	6												
	Avg.												
3	1												
	2												
	3												
	4												
	5												
	6												
	Avg.												
6	1												
	2												
	3												
	4												
	5												
	6												
	Avg.												
7	1												
	2												
	3												
	4												
	5												
	6												
	Avg.												
8	1												
	2												
	3												
	4												
	5												
	6												
	Avg.												
Column Avg.													

Table 2-1 Model 51 Steam Generator Tube Roll Preload Test Data (cont'd)

a,c,e

Test No.	Location No.	Tube OD Post-Roll Collar Removed 0 Deg.	90 Deg.	Avg	Post -Roll Thickness (%)	Thickness Reduction (%)	Collar Flex. dUi/dPi	Radii Ratio	Tube ID Springback
1	1								
	2								
	3								
	4								
	5								
	6								
	Avg.								
2	1								
	2								
	3								
	4								
	5								
	6								
	Avg.								
3	1								
	2								
	3								
	4								
	5								
	6								
	Avg.								
6	1								
	2								
	3								
	4								
	5								
	6								
	Avg.								
7	1								
	2								
	3								
	4								
	5								
	6								
	Avg.								
8	1								
	2								
	3								
	4								
	5								
	6								
	Avg.								
Column Avg.									

Notes:
1. All measured dimensions are in inches.
2. The OD stress is calculated using the measured ID springback.
3. The radii ratio is a term that appears frequently in the analysis and is found as (OD^2+ID^2)/(OD^2*ID^2).

Table 2-2 Model 51 Steam Generator Tube roll Preload Stress Analysis Results

a,c,e

Test No.	Location No.	Tube ID Spring-Back	Tube Flex. dUi/dPo	Tube Flex. dUo/dPo	OD Radial Stress	OD Hoop Stress	OD Axial Stress	Thermal Exp Radial Stress	Tube Flex. dUo/dPi	Operating Pressure Radial	Total Radial Stress	Total vonMises Stress
1	1											
	2											
	3											
	4											
	5											
	6											
	Avg.											
2	1											
	2											
	3											
	4											
	5											
	6											
	Avg.											
3	1											
	2											
	3											
	4											
	5											
	6											
	Avg.											
6	1											
	2											
	3											
	4											
	5											
	6											
	Avg.											

Table 2-2 Model 51 Steam Generator Tube roll Preload Stress Analysis Results (cont'd)

a,c,e

Test No.	Location No.	Tube ID Spring-Back	Tube Flex. dUi/dPo	Tube Flex. dUo/dPo	OD Radial Stress	OD Hoop Stress	OD Axial Stress	Thermal Exp Radial Stress	Tube Flex. dUo/dPi	Operating Pressure Radial	Total Radial Stress	Total vonMises Stress
7	1											
	2											
	3											
	4											
	5											
	6											
	avg.											
8	1											
	2											
	3											
	4											
	5											
	6											
	Avg.											
Column avg.												

Notes: 1) The OD stress is calculated using the measured ID springback.

Table 2-3 Preload Analysis Summary and Specification of Inputs

Material Properties:	
Tube Elastic Modulus (Normal Op Current)	2.89E+07 psi
Tube Elastic Modulus (Normal Op 2910 MWt)	2.89E+07 psi
Tube Elastic Modulus (Faulted)	2.89E+07 psi
Tubesheet Elastic Modulus (Normal Op Current)	2.67E+07 psi
Tubesheet Elastic Modulus (Normal Op 2910 MWt)	2.68E+07 psi
Tubesheet Elastic Modulus (Faulted)	2.68E+07 psi
Poisson's Ratio	0.3
Alloy 600 Expansion Coefficient (Normal Op Current)	7.75E-06 in/in/°F
Alloy 600 Expansion Coefficient (Normal Op 2910 MWt)	7.75E-06 in/in/°F
Alloy 600 Expansion Coefficient (Faulted)	7.75E-06 in/in/°F
Tubesheet Expansion Coefficient (Normal Op Current)	7.32E-06 in/in/°F
Tubesheet Expansion Coefficient (Normal Op 2910 MWt)	7.32E-06 in/in/°F
Tubesheet Expansion Coefficient (Faulted)	7.32E-06 in/in/°F
T-hot (Current)	608.5°F
T-cold (Current)	543.3°F
T-hot (2910 MWt)	609.5°F
T-cold (2910 MWt)	538.5°F
T-hot (Faulted)	530.0°F
T-cold (Faulted)	530.0°F
Operating ΔT (Current)	473.3°F
Operating ΔT (2910 MWt)	468.5°F
Operating ΔT (Faulted)	460.0°F
Steam Pressure (Current)	827 psia
Pressure Differential (Current)	1423 psi
Steam Pressure (2910 MWt, 4% SGTP)	774 psia
Steam Pressure (2910 MWt, 22% SGTP)	700 psia
Internal SG Pressure Losses	15 psi
Pressure Differential (2910 MWt, 4% SGTP)	1476 psi
Pressure Differential (2910 MWt, 22% SGTP)	1550 psia
Steam Pressure (Faulted)	15 psia
Pressure Differential (Faulted)	2650 psi
End Effect Length:	0.174 inch
End Effect Load Factor	0.6155
Current Tube Plugging	3.8%
2910 MWt Assumed Plugging Level	4 to 22%

Note: Tube and tubesheet material properties taken from 1995 ASME Code.

Table 2-4

Evaluation of Required Engagement Length: Current Normal, 2910 MWt Normal and Faulted Conditions

Elastic Analysis:	Current	2910 MWt	Faulted
			a,c,e
Roll Expansion Preload			
Thermal Expansion Preload			
Pressure Preload			
Tubesheet Bow Loss			
Net Preload			
Net Radial Force			
Net Axial Resistance			
Applied Load			
Analysis Load			
End Effect Resistance (x2)			
Net Analysis Load			
F* Length Required			
Total F* Length Required	1.74 inch	1.77 inch	1.97 inch

Notes:

(1): 95%/95% Lower Tolerance Limit Rolled Preload Used.

(2): For Normal Operation a factor of safety of 3 was used.

(3): For Faulted Conditions a factor of safety of 1.43 was used consistent with ASME Code use of 0.7 SF on ultimate strength.

(4): The Total F* Length Required does not include NDE uncertainty or allowance for bottom of WEXTEX transition location.

(5): Preload stresses used were for the most stringent location, i.e., cold leg, peripheral location. This minimizes the thermal expansion preload and eliminates the preload due to bowing.

(6): Faulted condition analysis assumes the tube and tubesheet are isothermal, with applied temperature equal to T-cold based on normal conditions.

3 APPLIED INSPECTION LENGTH

A nominal 3 inch below the top of the tubesheet Plus Point inspection length requirement will be applied to the tubes in the SGs at BVPS Unit 2. The NDE axial position uncertainty at 95% confidence was previously determined to be 0.25 inch. Bobbin coil inspection data from the BVPS 2R09 outage was used to define the bottom of roll expansion transition for all hot leg and cold leg tubes. The lower 95% confidence value hot leg bottom of roll expansion transition is 0.28 inch, while the lower 95% confidence cold leg bottom of roll expansion transition is 0.19 inch, see Reference 11. Therefore, strict application of the F* criterion would not require repair by plugging or sleeving of a hot leg tube with the upper tip of a detected axial PWSCC indication located at greater than (1.97 + 0.25 + 0.28) = 2.50 inches below the hot leg top of tubesheet.

The bobbin coil data evaluation used to identify the bottom of roll transitions for all tubes identified ten (10) tubes with bottom of roll transitions located at >1 inch below the hot leg top of tubesheet. The Plus Point data collection for these tubes will be adjusted to ensure that at least (1.97, F* + 0.25, NDE uncertainty) = 2.22 inches of sound roll expansion below the bottom of roll transition is collected and analyzed. If indications of degradation are detected within 2.22 inches of the bottom of roll transition for these tubes, they will be repaired by plugging or sleeving. For all but these 10 tubes, the nominal 3 inch below top of tubesheet inspection distance bounds the sum of the F* length (1.97 inch), the BRT location, and NDE uncertainty allowance (0.25 inch).

3.1 SENSITIVITY OF CALCULATED F* VALUE TO STEAM PRESSURE CHANGES

Reference 3 provides best estimate operating parameters for the BVPS Unit 2 SGs at an uprated normal operating condition of 2910 MWt and varying steam generator tube plugging (SGTP). FENOC has selected an upper bound operating T_{hot} value of 611.2°F for the BVPS Unit 2 SGs at a NSSS power level of 2910 MWt. The associated steam generator tube plugging that will provide sufficient steam mass flow for this condition is 4%, Reference 3. FENOC has also chosen to use sleeving as a method of controlling tube plugging at an upper bound of 8%. Both laser welded and TIG welded sleeving repair are licensed at BVPS Unit 2.

The current tube plugging level for BVPS Unit 2 is 3.8%, the current T_{hot} is 608.5°F, the current T_{cold} is 543.3°F, and the current steam pressure at the SG outlet is 827.3 psia, Reference 3, with a normal operating primary to secondary pressure differential of approximately 1423 psi, based on the steam pressure at the nozzle outlet. Internal pressure losses due to moisture separation and the outlet nozzle venturis are approximately 15 psi, however, the pressure differential based on steam pressure at the outlet nozzle will be applied. The required inspection length commensurate with current operating conditions is bounded by the inspection length for uprated (2910 MWt NSSS power level) normal operating conditions.

Calculation of the F* value for a NSSS power level of 2910 MWt with 4% steam generator tube plugging results in a value of 1.77 inches, which is bounded by the faulted condition value of 1.97 inches as shown in Table 4. Westinghouse has been informed by FENOC that FENOC has chosen to control steam generator tube plugging at 2910 MWt to a maximum of 8% by sleeving. This in turn will help to limit the T_{hot} temperature increase associated with the uprate. However, inspection transients or observation of a new degradation mechanism at a future outage could potentially result in a condition where the steam generator tube plugging prior the outage was well below 8%, but greater than 8% after the outage. In this case the time periods involved for mobilization of sleeving equipment, preparation of procedures, training of personnel, etc, could result in a significant extension to the outage length. Therefore, the F* distance was evaluated at a bounding primary to secondary pressure differential of 1550 psi (700 psia steam pressure) to address temporary conditions where steam generator tube plugging could exceed 8%. The normal operation F* distance for this condition was calculated to be 1.81 inches, which remains bounded by the faulted condition F* distance of 1.97 inches. Therefore, temporary conditions where steam generator tube plugging exceeds 8% do not invalidate the 1.97 inch F* value provided the primary to secondary pressure differential does not exceed 1550 psi. Per Reference 3, for a T_{avg} of 576.2°F with 22% steam generator tube plugging, the expected steam pressure at the SG outlet nozzle is 733 psia.

4 REFERENCES

1. Regulatory Guide 1.121, "Basis for Plugging Degraded PWR Steam Generator Tubes," United States Nuclear Regulatory Commission, August 1976.
2. WCAP-11306, Revision 2, "Tubesheet Region Plugging Criterion for the Alabama Power Company, Farley Nuclear Station, Unit 2 Steam Generators," April 1987, (Proprietary).
3. LTR-MPG-05-4, "Best Estimate NSSS Parameters for Beaver Valley Power Station Unit 2", January 2005
4. ASME Boiler and Pressure Vessel Code, Section III, "Rules for Construction of Nuclear Power Plant Components," The American Society of Mechanical Engineers, New York, New York, 1995.
5. WCAP-11241, "Tubesheet Region Plugging Criterion for the Central Nuclear de ASCO, ASCO Nuclear Station Unit 1 and 2 Steam Generators", October 1986 (Proprietary).
6. WCAP-9922, Part 3, Revision 1, "Reliability and Safety Evaluations of the Westinghouse Model F Steam Generator Part 3: Safety Evaluations of the Westinghouse Model F Steam Generator Tubing," Westinghouse Electric Company LLC, Pittsburgh, PA, August 1983 (Proprietary).
7. NUREG/CR-3464, "The Application of Fracture Proof Design Methods Using Tearing Instability Theory to Nuclear Piping Postulating Circumferential Through Wall Cracks," USNRC, Washington, DC, September 1983.
8. LTR-SGDA-04-192, "Application of W* to Beaver Valley Unit 1 Steam Generator Tubes", July 2004 (Proprietary)
9. SG-SGDA-04-47, "Beaver Valley 1R16 Condition Monitoring and Preliminary Operational Assessment", November 2004
10. LTR-SGDA-03-52 Revision 1, "Waterford 3 RF12 Condition Monitoring Report and Interim Operational Assessment", November 2003
11. LTR-SGDA-03-26, "Beaver Valley 1R15 Steam Generator Engineering Summary Report", December 2003

ATTACHMENT D

Beaver Valley Power Station, Unit No. 2
License Amendment Request No. 2A-183

Westinghouse WCAP-16385-P, March 2005
"F* Tube Plugging Criterion for Tubes with Degradation in the Tubesheet Roll Expansion Region of the Beaver Valley Unit 2 Steam Generators"

Note: The attached WCAP is Westinghouse proprietary per CAW-05-1946.

Westinghouse

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Our ref: CAW-05-1972

March 24, 2005

APPLICATION FOR WITHHOLDING PROPRIETARY
INFORMATION FROM PUBLIC DISCLOSURE

Subject: WCAP-16385-P, Rev. 1, "F* Tube Plugging Criterion for Tubes with Degradation in the Tubesheet Roll Expansion Region of the Beaver Valley Unit 2 Steam Generators," March 2005 (Proprietary)

The proprietary information for which withholding is being requested in the above-referenced report is further identified in Affidavit CAW-05-1972 signed by the owner of the proprietary information, Westinghouse Electric Company LLC. 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 this letter, CAW-05-1972, and should be addressed to J. A. Gresham, Manager, Regulatory Compliance and Plant Licensing, Westinghouse Electric Company LLC, P.O. Box 355, Pittsburgh, Pennsylvania 15230-0355.

Very truly yours,

J. A. Gresham, Manager
Regulatory Compliance and Plant Licensing

Enclosures

cc: B. Benney, NRC
L. Feizollahi, NRC

bcc: J. A. Gresham (ECE 4-7A) 1L
R. Bastien, 1L (Nivelles, Belgium)
C. Brinkman, 1L (Westinghouse Electric Co., 12300 Twinbrook Parkway, Suite 330, Rockville, MD 20852)
RCPL Administrative Aide (ECE 4-7A) 1L, 1A (letter and affidavit only)
E. P. Morgan, Waltz Mill
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G. W. Whiteman, Waltz Mill
R. F. Keating, Waltz Mill
W. K. Cullen, Waltz Mill

CAW-05-1972

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF ALLEGHENY:

Before me, the undersigned authority, personally appeared J. A. Gresham, who, being by me duly sworn according to law, deposes and says that he is authorized to execute this Affidavit on behalf of Westinghouse Electric Company LLC (Westinghouse), and that the averments of fact set forth in this Affidavit are true and correct to the best of his knowledge, information, and belief:

J. A. Gresham

J. A. Gresham, Manager
Regulatory Compliance and Plant Licensing

Sworn to and subscribed
before me this 24th day
of March, 2005

Sharon L. Fiori

Notary Public

Notarial Seal
Sharon L. Fiori, Notary Public
Monroeville Boro, Allegheny County
My Commission Expires January 29, 2007
Member, Pennsylvania Association Of Notaries

(1) I am Manager, Regulatory Compliance and Plant Licensing, in Nuclear Services, 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 Commission's regulations and in conjunction with the Westinghouse "Application for Withholding" 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 constitutes Westinghouse policy and provides 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.

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.

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

(iv) 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.

(v) The proprietary information sought to be withheld in this submittal is that which is appropriately marked in WCAP-16385-P, Rev. 1, "F* Tube Plugging Criterion for Tubes with Degradation in the Tubesheet Roll Expansion Region of the Beaver Valley Unit 2 Steam Generators," (Proprietary) dated March 2005. The information is provided in support of a submittal to the Commission, being transmitted by FirstEnergy Nuclear Operating Company and Application for Withholding Proprietary Information from Public Disclosure, to the Document Control Desk. The proprietary information as submitted for use by Westinghouse for Beaver Valley Unit 2 is expected to be applicable to other licensee submittals in support of implementing the F* tube plugging criterion which addresses service induced degradation in the tube joint region of steam generators.

This information is part of that which will enable Westinghouse to:

(a) Provide documentation of the analyses, methods, and testing for the implementation of the F* tube plugging criterion.

(b) Provide evaluation of the required F* engagement length for Beaver Valley Unit 2.

(c) Provide a primary-to-secondary leakage evaluation for Beaver Valley Unit 2 during all plant conditions.

(d) Define an eddy current elevation measurement uncertainty for the distance from the bottom of the roll transition or the top of the tubesheet (whichever is lower in elevation) to the top of the degraded area of a tube.

(e) Assist the customer to respond to NRC requests for information.

Further this information has substantial commercial value as follows:

(a) Westinghouse plans to sell the use of similar information to its customers for purposes of meeting NRC requirements for licensing documentation.

(b) Westinghouse can sell support and defense of this information to its customers in the licensing process.

(c) 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 licensing support documentation 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/or non-proprietary versions of documents furnished to the NRC in connection with requests for generic and/or plant-specific review and approval.

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).

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