Appendix-10
SG Tube Wear Analysis for Unit-2/3

1. Purpose

The purpose of this analysis is to evaluate the tube wear depth at the U-bend region due to fluid elastic instability in order to verify the estimated mechanism of the tube wear observed in both of Unit-2 and Unit-3 as mentioned in Section 6.1 and 6.2 of the main report.

A single tube, R106C78 (that leaked in Unit-3) was selected for analysis. Only the tube support boundary conditions were varied to produce a set of wear depths along the tube that was similar to what was measured by ECT from Unit-2 and Unit-3. The R106C78 tube wear indications (i.e. wear depths reported by ECT at TSPs and AVBs) are replicated analytically.

2. Conclusion

The analysis results indicate followings, which are consistent with the mechanistic causes described in Section 6 of the main report;

- When consecutive AVB support points are inactive and in-plane FEI occurs, the tube vibrates to be in contact with the adjacent tube. The calculated wear depths at the contact point with the adjacent tube, AVBs and the top tube support plates are equivalent to the wear depths measured in Unit-3 SGs.

- When consecutive 6 or 8 AVB support points are inactive and in-plane FEI does not occur, the calculated tube wears at AVB support points due to only the turbulent flow force are equivalent to the wear depths measured in Unit-2 SGs.

3. Assumption

Following assumptions are applied for this analysis.

1) Flow characteristics

The U-bend fluid velocity, density, void fraction, and hydrodynamic pressure distributions are supplied by the ATHOS / SGAP thermal hydraulic analysis program for the normal operating conditions with T-hot =[ ] as shown in Appendix-12.

2) Damping ratio

The structural damping ratio is assumed to be 0.2%, which is a minimum value based on MHI test results. The relationship between the two-phase damping and void fraction is based on Pettigrew's test results and is described in Section 6.1, paragraph (5).

3) Boundary conditions at tube supports

The support condition at TSPs #1 through #6 is assumed to be pinned. "Pinned" means free to displace parallel to the hole and free to rotate, but prevented from lateral movement by the TSP. The support conditions at TSP #7 and the AVBs are variables in the parametric evaluation.

4) Number of support points

All AVB supports for the Unit-3 free-span simulation are assumed to be inactive with tube support only provided by the TSPs. Number of AVB support points is a parameter for case study of the Unit-2 simulation. All TSP supports are assumed to be active.

5) Contact force at TSP #7 and the gap between TSP and tubes

The tube support condition at TSP #7 (hot and cold sides) is assumed to be a [ ]compressive contact force based on thermal expansion at operating conditions. The tube-to-TSP diametral clearance is assumed to be [ ], based on the maximum manufacturing tolerances.

6) Length of tube-to-tube wear

The measured length of the tube-to-tube wear on a typical tube was about [ ]. Since the wear depth is not uniform, the length of tube-to-tube wear (assuming to be uniform over the length) is assumed to be[ ] to simulate the actual wear depth.

7) Modeling of the adjacent tube for Unit-3 simulation.

The gap elements are used at the impact locations in order to consider sliding and impact vibration of the adjacent tube. Tube to tube gap is assumed to be [ ][ ], since the displacement of the tube which has free span wear indication is assumed to be more than the half of the nominal tube-to-tube gap in-plane (25.4mm – 19.05mm = 6.35 mm). This is considered as a parameter of case study and assumed to be[ ].

4. Acceptance criteria

Acceptance criterion is to simulate the trend of the wear of both of Unit-2 and Unit-3. The tube of Row 106 Column 78 of Unit-3 #B SG and the tube of the same address of Unit-2 #A SG are selected as a representative tubes for this analysis since R106 C78 of 3B SG is the leakage tube and R106 C78 of 2A SG has some wear at AVB locations and since the support condition can be compared without considering the flow characteristics.

Table 4-1 Wear depth of R106 C78 of 2A SG and 3B SG

Location	Wear depth of 2A SG, %	Wear depth of 3B SG, %
#1 to 6 TSP (hot & cold)		
#7TSP at Hot side		
B01		
B02		
B03		
B04		
tube to tube		
B05		
B06		
B07		
B08		
B09		
tube to tube		
B10		
B11		
B12		
#7TSP at Cold side		

5. Design Inputs

5.1 Geometry of tube bundle region

The tube bundle consists of ¾-inch diameter, thermally treated Alloy 690 U-tubes that are arranged in a 1.0-inch equilateral triangular pitch and are supported by the tubesheet, seven tube support plates, and six sets of anti-vibration bars (AVBs). Tube support plates (TSPs) have broached trifoil tube holes. All the contacting support structures above the tubesheet are made of [ ]. The nominal dimension of tube, TSPs and AVBs are listed in Table 5-1.

5.2 Thermal and hydraulic flow of steam generator secondary side

The ATHOS thermal hydraulic analysis program was used to determine the distributions of fluid velocity, fluid density, void fraction, and hydrodynamic pressure (see Appendix 12). Fig 5-1 shows the normal operating, full power, loading conditions that were applied to the tube for the wear analysis.

Table 5-1 Nominal dimensions of tubes, TSPs, and AVBs

Part	Item	Value
Tubes	Material	Thermally treated SB-163 UNS N06690
	Outside diameter	0.75 in
	Thickness	0.043 in
	Number of tubes	9727
	Tube pitch	1.0 in
	Tube arrangement	Triangular
TSPs	Material	
	Thickness	
	Number of TSPs	
	Tube support span (between TSP centers)	
	Tube support span (from tubesheet to TSP-1)	
AVBs	Material	
	Type	
	Thickness	
	Width	

[ ]

Fig.5-1 Flow distribution of Row 106 Column 78

5.3 Vibration calculation input

The calculation inputs are derived as follows by using the values obtained from the flow analysis code (ATHOS).
Modulus of elasticity of tube E and shear modulus of tube G are interpolated for the tube average temperature of $\frac{T_{av}+T_s}{2}$ from table of ASME Boiler and Pressure Vessel Code, Sec II, Materials, 1998 Edition, 2000 addenda.

T_{av} : Primary side average temperature (°F)

T_s : Secondary side temperature (°F)

Tube mass distribution per unit length m is calculated according to the following equation.

$$m=\frac{1}{144}\left(A_i\rho_i+A_t\rho_t+A_e\rho_o\right) \quad \cdots\cdots(3)$$

where,

$$A_i=\frac{\pi}{4}D_i^2 \text{ (in}^2\text{)} \quad \cdots\cdots(4)$$

$$A_t=\frac{\pi}{4}(D_0^2-D_i^2) \text{ (in}^2\text{)} \quad \cdots\cdots(5)$$

$$A_e=\frac{\pi D_o^2}{4} \text{ (in}^2\text{)} \quad \cdots\cdots(6)$$

$$D_e/D_o=\left(1+\frac{1}{2}P/D_o\right)P/D_o \quad \cdots\cdots(7)$$

D_i : tube inside diameter (in)

D_o : tube outside diameter (in)

ρ_i : Density of water inside the tube (lbm/ft^3)

ρ_t : Density of tube material (lbm/ft^3)

ρ_o : Density of water outside the tube (lbm/ft^3)

P : Tube pitch (in)

5.4 Wear coefficient

Wear coefficient of AECL data (Alloy800/SS410, which is similar combination to TT690 tube /SS405) at[ ]F is used for this analysis in order to evaluate the effect of the temperature is assumed to be[ ].

Wear coefficient of tube to tube is 35 times as large as that of 690/SUS405 based on MHI test results (Fig.5-2).

[ ]

Fig.5-2 Impact Wear Coefficients (MHI internal data)

5.5 Operating duration

Unit 2 completed a cycle of 628 effective full power days (EFPD). Unit 3 shut down after operating 338 EFPD.

6. Methodology

6.1 Evaluation Flow Chart

The leaking tube assuming all inactive AVB supports is evaluated. Wear analysis methodology is described in Figure 6.1

Collect information on geometry

↓

Calculate flow data (ATHOS)
- Cross flow velocity
- Void fraction
- Fluid density

↓

Identify critical tubes
- Fluid-elastic vibration analysis for the leakage tube with all inactive AVB supports

↓

Generate time history of flow induced forces
- Turbulence induced forces using CPSD
- Fluid-elastic forces based on experimental data

↓

System damping
- Structural damping, Two-phase damping and Friction coefficients
- Squeeze film damping is not considered because of high void fraction.

↓

Time history response (FEM)
- Tube displacement
- Tube-to-support reaction force
- Sliding distance

↓

Wear Calculation
- Tube metal volume reduction from work rate
- Tube thickness reduction

Fig. 6-1 Wear Evaluation Flow Chart

(1) Collect Information on Geometry

Refer to Section 5.1. The gaps between tube and AVBs are a parameter to be evaluated.

(2) Calculate Flow Data

Refer to Section 5.2. The distribution of flow through the steam-generator tube bundle has an influence on the turbulence-induced loads and fluid-elastic instability. The ATHOS thermal and hydraulic analysis code provides the distribution of local cross-flow velocity, fluid density and void fraction. The turbulence-induced loads, fluid-elastic forces, added mass are obtained by analysis.

(3) Identify Critical Tubes

A linear screening analysis is usually used to identify the potential for fluid-elastic instability of the tubes at different locations in the tube bundle and to choose the most unstable tube for wear analysis. However the Unit-3 leaking tube R106C78 is selected for this wear analysis.

(4) Generate Time History of Flow Induced Forces

Turbulence induced forces are obtained by considering spatial correlations of the turbulence forces using the cross-correlated power spectral density (CPSD) functions. The turbulence induced forces in the U-bend portion are determined from the CPSD function from test data. The CPSD (cross power spectral density) is taken from a reference by Axisa, et al (Ref.5).

$$\Phi_{CPSD}\left(Z_p, Z_p\right) = \left(\rho U^2 D/2\right)^2 \times \left(U/D\right) 5 \times 10^{-5} \left(fD/U\right)^{-2.7} \left(U_p U_q\right)^2 e^{\left(-\left|Z_p - Z_q\right|/\lambda_c\right)} C_f$$

Where,

Φ_{CPSD}	:Cross power spectral density function between elements p and q
U_p	:Ratio between tube gap velocity at elements p to U
U_q	:Ratio between tube gap velocity at elements q to U
Z_p, Z_p	:Separation distance along tube length between centroids of elements p & q
λ_c	:Correlation length of turbulence (assumed to be 4D)
C_f	:Correlation factor for finite-element approximation

Fluid-elastic forces are those induced on the tubes by a coupling between the tube vibratory motion and the flowing fluid. The fluid-elastic forces are defined by a feedback loop in which the tube forces are calculated from the tube vibratory amplitude through an analytical model based on experimental correlations of fluid-elastic forces in tube bundles.

Fluids-force components were measured as functions of imposed harmonic displacements of a cylinder. These experimental data were reduced by Chen into fluid-damping and fluid stiffness coefficients which were functions of the reduced-flow velocity (U/fD) (Ref.6).

$$\hat{f}_i = -\sum_{j=1}^{M}\left[\left(\rho RU\overline{\alpha'_{ij}}\right)\frac{\partial u_j}{\partial t} + \left(\rho RU\overline{\sigma'_{ij}}\right)\frac{\partial v_i}{\partial t}\right] + \rho U^2\sum_{j=1}^{M}\left(\alpha''_{ij}u_j + \sigma''_{ij}v_j\right)$$

$$\hat{g}_i = -\sum_{j=1}^{M}\left[\left(\rho RU\overline{\tau'_{ij}}\right)\frac{\partial u_j}{\partial t} + \left(\rho RU\overline{\beta'_{ij}}\right)\frac{\partial v_i}{\partial t}\right] + \rho U^2\sum_{j=1}^{M}\left(\tau''_{ij}u_j + \beta''_{ij}v_j\right)$$

These data can be used directly to accurately predict the fluidelastic response in linear cases where the response frequency usually coincides with one of the fundamental frequencies. However, in nonlinear cases where the tube supports have clearances, the tube response can be at a number of frequencies. Such cases require a fluidelasitc modeling procedure that accounts for the presence of different frequencies. Transfer function method is used for this purpose.

This approach recognizes that fluidelastic stiffness and fluid damping coefficients are functions of reduced flow velocity and, therefore, functions of frequency. The transfer function method converts these frequency dependent functions into time dependent differential equations.

$$\overline{\alpha'_{ii}}u_i \approx a_1 u_i + a_3\frac{d^2 u_i}{dt_2}\theta^2$$

$$\overline{\alpha''_{ii}}u_i \approx a_0 u_i + a_2 u_i\theta^2$$

$$\overline{\beta'_{ii}}v_i \approx b_1 v_i + b_3\frac{d^2 v_i}{dt_2}\theta^2$$

$$\overline{\beta''_{ii}}v_i \approx b_0 v_i + b_2 v_i\theta^2$$

Where,

$\theta = D/2\pi U$

$a_0, a_1, a_2, a_3, b_0, b_1, b_2, b_3$ = Constants

f_i, g_i	: Forces acting upon the cylinders in the X and Y directions, respectively
ρ	: Fluid density
U	: Tube gap velocity
R	: Radius of tubing
M	: Number of tubing
u_j	: Displacement in x-direction
v_j	: Displacement in y-direction
$\alpha_{ij}, \sigma_{ij}, \tau_{ij}, \beta_{ij}$	:Added-mass coefficient
$\alpha'_{ij}, \sigma'_{ij}, \tau'_{ij}, \beta'_{ij}$	:Fluid-damping coefficient
$\alpha''_{ij}, \sigma''_{ij}, \tau''_{ij}, \beta''_{ij}$	:Fluid-stiffness coefficient
$\overline{\alpha}_{ij}, \overline{\sigma}_{ij}, \overline{\tau}_{ij}, \overline{\beta}_{ij}$	:Viscous damping coefficient

The fluid damping and fluid stiffness coefficients are derived for the single flexible tube surrounded by rigid tubes as constraint conditions. Fluid damping and fluid stiffness coefficients measured by MHI experiment are used for this evaluation.

(5) System Damping

Damping ratio consists of structural damping, two-phase damping, viscous damping and squeeze film damping in the crevices between the tube and its support. Although ASME Sec. III Appendix N-1330 suggests that the damping ratio 1.5% as a sum of structural and two-phase damping, more reliable values based on experimental data is used in this evaluation.

For structural damping, MHI test results show 1.0% average (0.2% in minimum) as shown in Figure 6-2 (from Ref.2), therefore 0.2% is assumed for the conservative evaluation.

For two-phase damping, Pettigrew's test result of Figure 6-3, which is the function of superficial void fraction, is used as the effective two-phase damping along the tube length by considering vibration mode (Ref.4).

Since the viscous damping is negligible in high void fraction (Ref.3), it is neglected in this analysis.

Since the void fraction is high and the support condition at AVB is considered to be dry, the squeeze film damping is assumed to be zero.

(6) Time History Response

A finite element model of the tube with support clearances is formulated. The tube vibratory response consists of tube displacements and tube support interaction characteristic of impact and sliding is calculated.

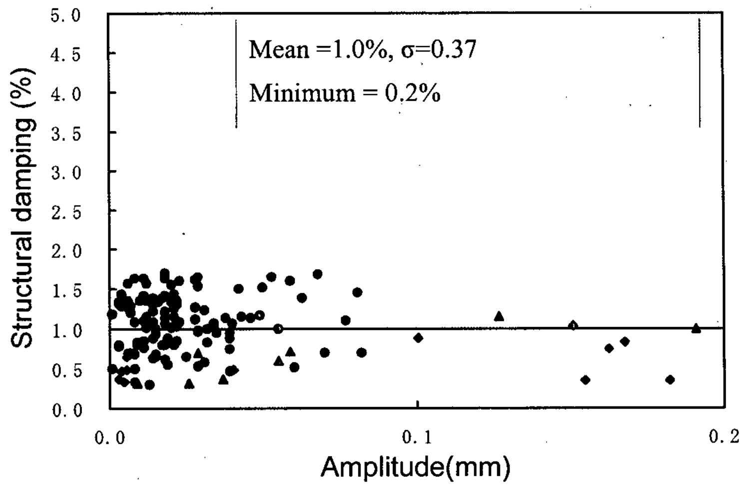
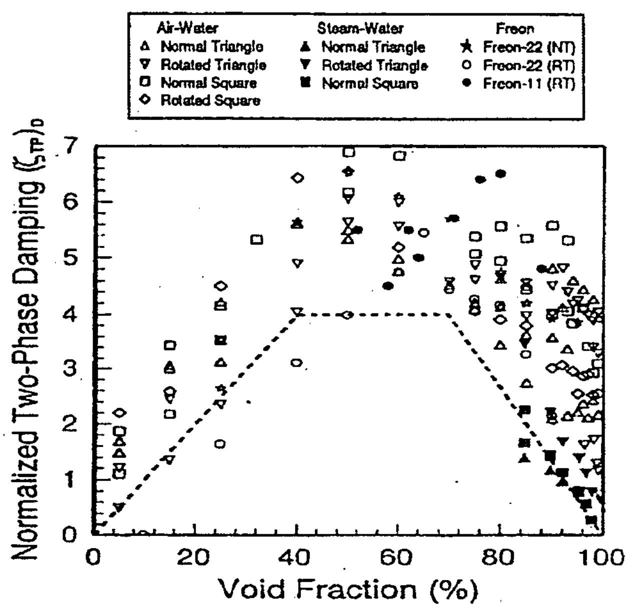


Fig.6-2 Structural damping test data by MHI



$$(\zeta_{TP})_D = \zeta_{TP}(\rho_\ell D^2/m)^{-1}\{[1+(D/D_e)^3]/[1-(D/D_e)^2]^2\}^{-1}$$

Fig.6-3 Two phase damping and superficial void fraction

(7) Wear Calculation

Using the time history response of the tube displacements and tube support interactions, a set of wear parameters (work rate parameter, sliding distance, impact forces and contact time) is calculated. The work rate parameter is calculated by integrating the incremental work (the product of support reaction and incremental sliding).

The metal loss is calculated using Archard's wear law.

$$dV/dt = K'W$$

Where,

dV/dt : Volume wear rate

W : Work rate parameter

K' : Specific wear coefficient for tube/AVB material combination

Experimental correlations between the metal loss and the work rate are used to calculate tube metal volume reduction. The relation between wear volume (V) and wear depth (h) is represented as follows.

(a) Tube to AVB wear and Tube-to-Tube wear

The tube thickness reduction is then calculated using the wear properties and work rate parameter as assuming the wear configuration as shown in Fig.6-4.

The wear width of tube to AVB wear is assumed to be the same as the width of AVB.

The measured length of the tube-to-tube wear was about [ ]. Since the wear depth is not uniform, the length of tube to tube wear is assumed to be[ ] in this calculation to simulate the actual wear depth.

$$V = \frac{1}{2}R^2(\phi - \sin\phi)\cdot L$$

$$\phi = \cos^{-1}\left(1 - \frac{h}{R}\right)\times 2$$

V: Wear volume

R: Tube radius

h: Wear depth

L: Wear width

ϕ: Wear angle

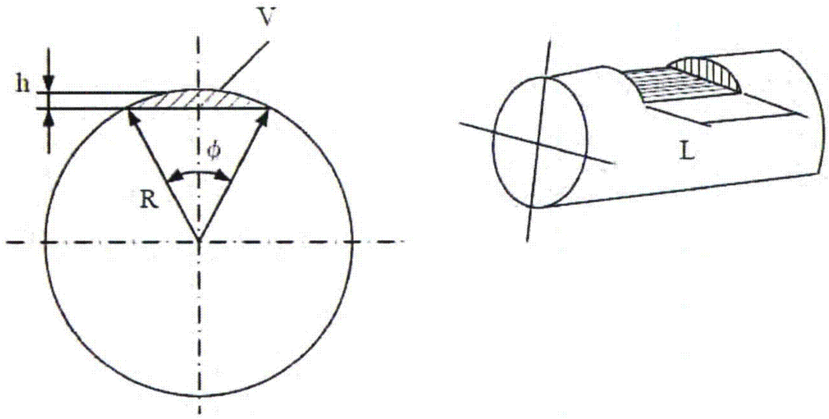


Fig. 6-4 Wear shape of tube at the contact point with AVB

(b) Tube to TSPL contact wear

We use the following equation which shows the relation between wear volume and wear depth. This equation is obtained by 3 dimensional geometry model.

V =[ ]

V : Wear volume (mm^3)

h : Wear depth (mm)

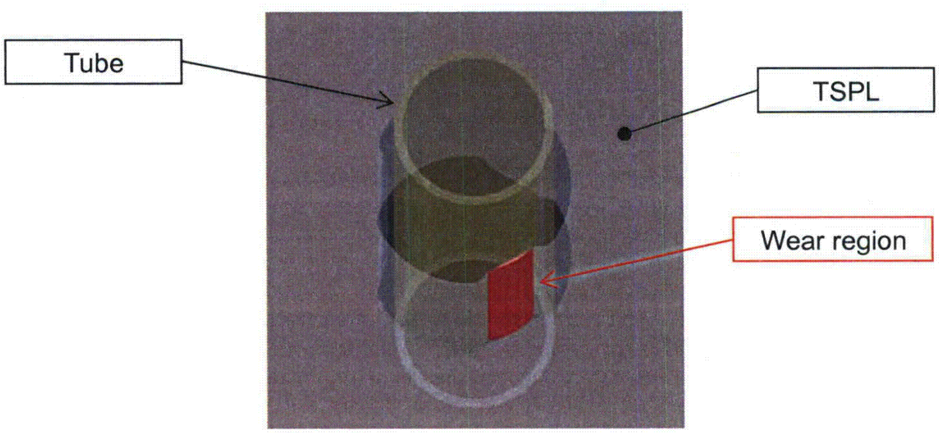


Fig. 6-5 Wear volume evaluation (Wear depth 1.0mm)

The relation between the work rate and wear depth of each unit is calculated based on the equations above, the wear coefficients and the effective full power operating days as shown in Fig.6-6 and Fig.6-7.

[ ]

Fig.6-6 Relation between Work Rate and Wear Depth of Unit-2 (628 EFPD)

[ ]

Fig.6-7 Relation between Work Rate and Wear Depth of Unit-3 (338 EFPD)

6.2 Analysis Model

Analysis model is shown in Figure 6-8.

(1) Support Condition with AVB

All AVB support points for Unit-3 are assumed to be inactive (to offer no support of the tube). The 2 - 12 central AVB support points for Unit-2 are assumed to be inactive (For example, the 2 central AVB support points are B06 and B07). Gap elements are used at the inactive support locations in order to produce sliding distance and impact loading information for the wear analysis. The tube-to-AVB clearance is an analysis variable.

(2) Support Condition with TSP

Gap elements are used at the support locations to determine the sliding and impact values at the support locations. The intersection with the top TSP (TSP #7) hot and cold sides is represented by a gap element based on the tube-to-TSP drawing clearance. The initial position of the tube is assumed to be in contact with an assumed contact force against one side of the broached hole.

(3) Impact location with adjacent tube

For the simplicity of the calculation, the wear volume is calculated by using single leaking tube model. The gap elements are used at the impact locations in order to consider sliding and impact vibration adjacent tube. The tube to tube gap is assumed to be[ ]. This means that the tube must travel across that distance before wear can occur.

Fig. 6-8 Analysis Model for Tube Wear Evaluation

6.3 Evaluation cases

6.3.1 Simulation of Unit-3 tube wear

To simulate the tube-to-tube wear, tube-to-TSP wear, and tube-to-AVB wear of Unit-3, following cases are evaluated.

(1) Evaluation of gap effect

To evaluate the effect of the tube-to-AVB gap, 3 cases shown in Table 6-1 are analyzed. All AVB supports are assumed to have small gaps as described in Section 4.5 of the main report.

(2) Evaluation of contact force

To confirm the contact force between tube and AVB can prevent the in-plane fluid elastic instability of tube, the case studies shown in Table 6-2 are performed.

(3) Evaluation of distance to the adjacent tube

To evaluate the effect of the distance to the adjacent tube on tube-to-tube wear, the case study with changing the location of the gap element is performed.

In Case 1-3-2, the location of the gap element is changed to[ ]to evaluate the effect of the distance by comparing Case 1-3-1 in which the distance is[ ].

(4) Evaluation of random vibration effect

In order to confirm that the energy and frequencies associated with turbulence are not sufficient to produce large displacements necessary for tube-to-tube wear, the case study without fluid elastic instability force is performed.

In Case 1-3-3, the fluid elastic force is not taken into account to evaluate the vibration due to the turbulent flow force by comparing Case 1-3-1 in which both of the fluid elastic force and turbulent flow force are considered.

6.3.2 Simulation of Unit-2 tube wear

(1) Number of active support points

To simulate the Tube-to-AVB wear Unit-2, the case studies shown in Table 6-3 are performed when only the turbulent flow forces are taken into account. The fluid elastic force is not taken into account because MHI concludes the cause of AVB wear is random vibration as described in Section 6.2 of the main report. The number of inactive support points is changed from 2 to 12. [ ]of contact load that is sufficient to restrain the tube at these supports are used to simulate the active supports. And the number of active supports is reduced until in-plane instability occurs. The tube is assumed to be the center between the AVBs in order to evaluate the effect of the active support number.

(2) Evaluation of gap effect and contact force

To evaluate the effect of the contact between tube and AVB in one side and contact force, the case studies shown in Table 6-4 are performed.

Table 6-1 Unit-3 Gap Effect Wear Evaluation Cases 1-1 to 1-3

Case		#1-6 TSPs	#7 TSP at hot	B01	B02	B03	B04	B05	B06	B07	B08	B09	B10	B11	B12	#7 TSP at cold
1-1 ***	Gap A**	Pined														
	Gap B**	Pined														
1-2 ***	Gap A**	Pined														
	Gap B**	Pined														
1-3-1 *** 1-3-2 *** 1-3-3 ***	Gap A**	Pined														
	Gap B**	Pined														

*: Contact force

**: The gap is the distance between AVB and tube in each side as shown in the figure below

***: Tube is in contact with the AVBs on one side.

In Case 1-3-2, the location of the gap element is changed from [ ] to [ ] to evaluate the effect of the distance.

In Case 1-3-3, only turbulence flow force is taken into account.

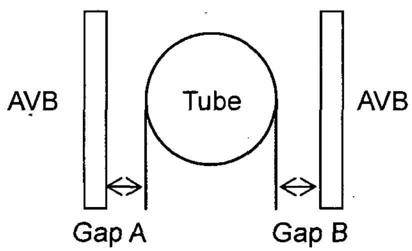


Table 6-2 Unit-3 Contact Force Wear Evaluation Cases 2-1 to 2-3

Case		#1-6 TSPs	#7 TSP at hot	B01	B02	B03	B04	B05	B06	B07	B08	B09	B10	B11	B12	#7 TSP at cold
2-1***	Gap A**	Pined														
	Gap B**	Pined														
2-2***	Gap A**	Pined														
	Gap B**	Pined														
2-3***	Gap A**	Pined														
	Gap B**	Pined														

*: Contact force

**: The gap is the distance between AVB and tube in each side as shown in the figure below

***: Tube is in contact with the AVBs on one side.

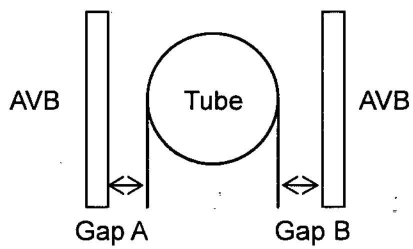


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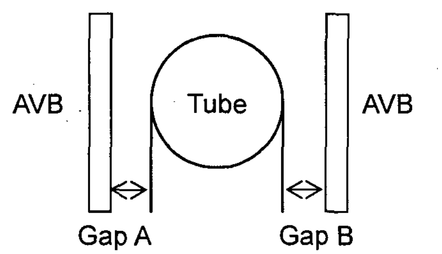
Table 6-3 Unit-2 Wear Evaluation Cases 3-1 to 3-6

Case		#1-6 TSPs	#7 TSP at hot	B01	B02	B03	B04	B05	B06	B07	B08	B09	B10	B11	B12	#7 TSP at cold
3-1	Gap A**	Pined														
	Gap B**	Pined														
3-2	Gap A**	Pined														
	Gap B**	Pined														
3-3	Gap A**	Pined														
	Gap B**	Pined														
3-4	Gap A**	Pined														
	Gap B**	Pined														
3-5	Gap A**	Pined														
	Gap B**	Pined														
3-6	Gap A**	Pined														
	Gap B**	Pined														

*: Contact force

**: The gap is the distance between AVB and tube in each side as shown in the figure below

***: Tube is in contact with the AVBs on one side.



7. Results

The following results supersede the tube wear evaluation performed at the design stage (Ref.8).

7.1 Simulation of tube wear in Unit-3

The analysis model and the natural frequency are shown in Fig.7-1. The analysis results are shown in Fig 7-2, 7-3, Tables 7-1, 7-2 and 7-3. It can be seen from Fig 7-1, that the effect of the tube-to-AVB gap is small when the all support points are inactive in-plane direction. It is consistent with the actual phenomenon of the tube wear at Unit-3. As shown in Fig 7-3, when the tube-to-AVB contact force is large[ ], the in-plane vibration can be prevented.

Under a condition where small gaps are present in all AVB support points, small contact forces are loaded on each of the inactive support points and all tubes are supported on one side by the top TSP #7 (Case 1-3-1), a free span fluid elastic instability is simulated. The wear depth obtained from the simulation has a consistent trend with the actual measurement results of tube wear in Unit-3.

Case 1-3-2 simulates tube-to-tube wear does not occur when the distance between the tubes in columns is larger than the in-plane amplitude.

The result of Case 1-3-3 indicates the energy and frequencies associated with turbulence are not sufficient to produce large displacements necessary for tube-to-tube wear.

[ ]

Fig7-1 Verification analysis for Unit-3 free span wear

[ ]

Fig.7-2 Wear analysis results of Case 1-1 to 1-3-3

[ ]

Fig.7-3 Wear analysis results of Case 1-3-1 to 2-3

Table 7-1 Wear analysis results of Case 1-1 to 1-2

Case		#1-6 TSPs	#7 TSP at hot	B01	B02	B03	B04	Tube To Tube	B05	B06	B07	B08	B09	Tube To Tube	B10	B11	B12	#7 TSP at cold
Unit-3 wear																		
1-1	Gap A																	
	Gap B																	
WR	mW																	
Wear depth*	%																	
1-2	Gap A																	
	Gap B																	
WR	mW																	
Wear depth	%																	

*: Contact force

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Table 7-2 Wear analysis results of Case 1-3-1 to 1-3-3

Case		#1-6 TSPs	#7 TSP at hot	B01	B02	B03	B04	Tube To Tube	B05	B06	B07	B08	B09	Tube To Tube	B10	B11	B12	#7 TSP at cold
Unit-3 wear																		
1-3-1	Gap A																	
	Gap B																	
WR	mW																	
Wear depth	%																	
1-3-2	Gap A																	
	Gap B																	
WR	mW																	
Wear depth	%																	
1-3-3	Gap A																	
	Gap B																	
WR	mW																	
Wear depth	%																	

*: Contact force

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Table 7-3 Wear analysis results of Case 1-3-1 to 2-3

Case		#1-6 TSPs	#7 TSP at hot	B01	B02	B03	B04	Tube To Tube	B05	B06	B07	B08	B09	Tube To Tube	B10	B11	B12	#7 TSP at cold
Unit-3 wear																		
1-3-1	Gap A																	
	Gap B																	
WR	mW																	
Wear depth*	%																	
2-1	Gap A																	
	Gap B																	
WR	mW																	
Wear depth	%																	
2-2	Gap A																	
	Gap B																	
WR	mW																	
Wear depth	%																	
2-3	Gap A																	
	Gap B																	
WR	mW																	
Wear depth	%																	

7.2 Simulation of tube wear in Unit-2

The analysis model and the natural frequency are shown in Fig.7-5.The analysis results are shown in Fig 7-6, Tables 7-4 and 7-5. The analysis results of the wear depth due to random vibration, when 6 or 8 consecutive AVB support points are inactive (Case 3-3 and 3-4), show consistent trends with the actual measurement results of tube wear in Unit-2.

Fig 7-5 Verification analysis for Unit-2 AVB wear

Fig. 7-6 Wear analysis results of Case 3-1 to 3-6

Table 7-4 Wear analysis results of Case 3-1 to 3-3

Case		#1-6 TSPs	#7 TSP at hot	B01	B02	B03	B04	B05	B06	B07	B08	B09	B10	B11	B12	#7 TSP at cold
Unit-2 wear																
3-1	Gap A															
	Gap B															
WR	mW															
Wear depth	%															
3-2	Gap A															
	Gap B															
WR	mW															
Wear depth	%															
3-3	Gap A															
	Gap B															
WR	mW															
Wear depth	%															

*: Contact force

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Table 7-5 Wear analysis results of Case 3-4 and 3-6

Case		#1-6 TSPs	#7 TSP at hot	B01	B02	B03	B04	B05	B06	B07	B08	B09	B10	B11	B12	#7 TSP at cold
Unit-2 wear																
3-4	Gap A															
	Gap B															
WR	mW															
Wear depth	%															
3-5	Gap A															
	Gap B															
WR	mW															
Wear depth	%															
3-6	Gap A															
	Gap B															
WR	mW															
Wear depth	%															

*: Contact force

8. References

1) (Deleted)
2) T. Nakamura, et al., “An advanced method to estimate fluid elastic instability of steam generator U-bend tube bundle.”, ASME PVP 2001
3) S. M. Fluit and M. J. Pettigrew, “Simplified method for predicting vibration and fretting-wear in nuclear steam generator U-bend tube bundle”, ASME PVP 2001
4) M.J. Pettigrew.,et.al.,2003,"Vibration analysis of shell-and-tube heat exchangers” Journal of Fluids and Structures 18 (2003) 469-483
5) F. Axisa, J. Antunes and B. Villard, "Random excitation of heat exchanger tubes by cross-flows", Journal of Fluids and Structures (1990) 4, 321-341
6) S. S. Chen, Instability Mechanisms and Stability Criteria of a Group of Circular Cylinders Subjected to Cross-Flow, Part 2: Numerical Results and Discussions, J. of Vibration, Acoustics, Stress, and Reliability in Design, April 1983, Vol. 105, pp. 253-260
7) Design of AVB, L5-04GA428 Rev.5

Appendix-11
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Appendix-12
Thermal Hydraulic Evaluation of Area Plugging

1. Purpose

This appendix provides evaluation of flow characteristics of tubes in U-bend region of San Onofre Units 3 Replacement Steam Generators (RSGs) after area plugging. The results of this evaluation are also applicable to the smaller plugging area in the Unit 2 SGs

2. Conclusion

It has been confirmed that the maximum quality and void fraction during reduced power operation are lower than during 100% power operation in Cycle 16. Additionally, the location of the area with high T/H parameters does not change. The results are summarized in Table 2-1 and the contour is shown in Fig. 7-1 and 7-2.

Table 2-1 Summary of quality and void fraction distribution in U-bend region
(3-D contours are shown in Fig. 7-1 and 7-2.)

T/H parameters in U-bend region	Cycle 16	RTS at 70% power
Max. quality		
Max. void fraction		

3. Assumption

(1) As shown in Table 6-1, the operating condition for Cycle 16 is assumed to be the design condition (Ref.22) and the operating condition for RTS is assumed to be identical to 70% thermal power condition of Unit-3 (Ref.21).

(2) The void fraction is analyzed utilizing the "ATHOS/SGAP" code (Ref. 1). Therefore, the assumptions used in the ATHOS/SGAP code apply to this document. Two-phase flow is represented by using a drift flux model which is the standard model of two-phase flow analysis. The mathematical models in the ATHOS/SGAP are constituted under the following assumptions: (Ref. 1)

(3) All dimensions in analysis are assumed in the cold metal condition because the effect of heat expansion of metals on the calculation results is negligible.

4. Acceptance criteria

Void fraction and flow velocity will be lowered by operating the plant upon return to service (RTS) at reduced power.

5. Design Inputs

The nominal dimensions are obtained from the design drawings (Ref.2 to 19) and the manufacturing tolerances are not considered. The geometrical inputs are identical to those used in reference 20 and 21.

6. Methodology

Based on the design input of the operating conditions, the calculation of the circulation ratio is performed by evaluating the pressure loss and the recirculation head with SSPC, which is a 1 dimensional Thermal and Hydraulic parameter calculation code (Ref.22). Using ATHOS/SGAP (Ref.1), the thermal hydraulic analysis is performed to obtain the 3 dimension flow distribution which includes the void fraction.

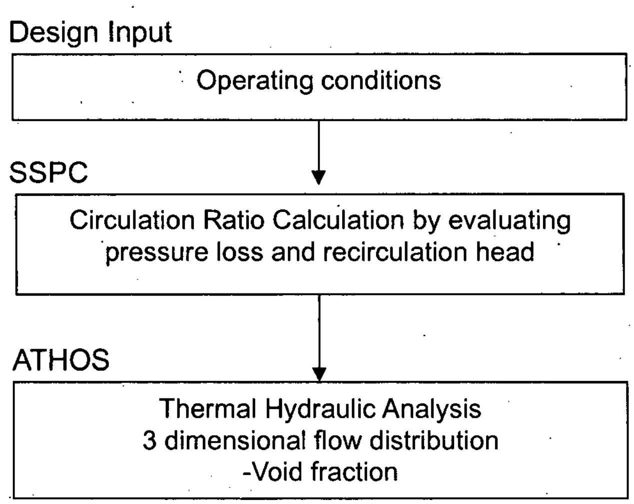

Fig.6-1 Flow of the evaluation

6.1 Thermal and Hydraulic Conditions

The operating parameters used for the calculation are shown in Table 6-1. the primary flow rate when 420 tubes are plugged is calculated by interpolating the flow rate specified in Ref.20 and the operating parameters shown in Table 6-1 are calculated by the steady-state performance calculation code. The overlapping plugged tubes as described in Sec. 6.4 are not taken into account for the calculation of the boundary conditions mentioned above.

Table 6-1 Operating parameters for calculation

	Cycle 16	RTS at 70% power
Thermal power (MWt/SG)		
Plugging		
RCS flow rate(gpm)		
T_{cold} (°F)		
$T_{sg\text{-}out}$ (°F)		
T_{hot} (Tsg-in) (°F)		
$T_{feedwater}$ (°F)		
Saturation Steam Pressure (psia)		
Steam Mass Flow (lb/hr)		
Circulation ratio		

6.2 Modeling

The cell structure model is [ ] [ ] cells in vertical and horizontal directions as shown in Fig.6-2(a) and Fig.6-2(b), respectively. The model simulates from the top of tubesheet to the bottom deck plate and this model is symmetrical to the center of tube columns. AVBs are modeled to take into account of the flow resistance. However, the pressure loss due to the resistance of AVB is negligibly smaller than that of the tube bundle. The horizontal tube pitch refers to the average spacing of the sections of tubes that lie horizontally in the U-bend region. Since U-bends of SONGS RSGs start at different elevations for each tube row (U-bend has index), the horizontal pitch is set to a representative average value in the U-bend.

6.3 Boundary conditions

The boundary conditions are shown in Fig. 6-3. 5 Pa of the maximum pressure correction and [ ] of the under relaxation factor are used for the convergence of the solution, which is the same as "Run-5" of L5-04GA565 (Ref.20).

6.4 Tube plugging

Fig.6-4 shows the the address of tubes to be plugged of 3B SGs. Since ATHOS can only created a symmetrical half model of the tube bundle in referece to the center column of the SG, the asymmetrical plugged tubes can not be modeled. Therefore the pluggged tubes are assumed to be overlapped as shown in Fig.6-5.(see Ref.22)

Fig. 6-2 (a) Vertical sectional calculation mesh at center of column

Fig. 6-2 (b) Cross-sectional calculation mesh

Fig. 6-3 Boundary conditions of ATHOS/SGAP

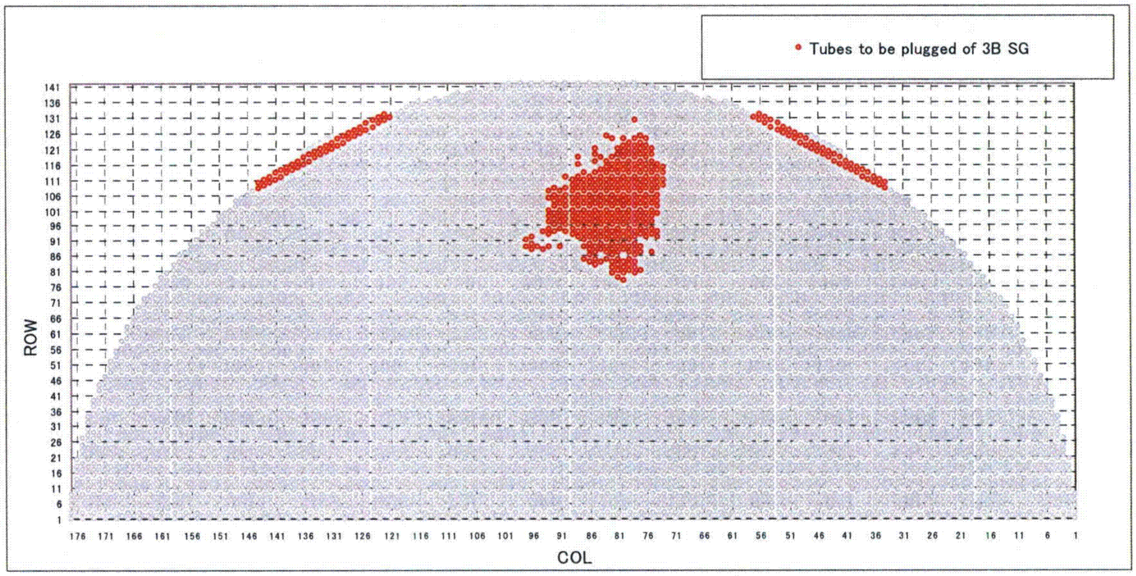

Fig.6-4 Tubes to be plugged of 3B SG

Fig.6-5 Tube plugging model of ATHOS for RTS at 70% power

7. Results

The flow characteristics of U-bend region obtained from the analysis are shown in Fig.7-1 to 7-2. The region where the void fraction is high is concentrated on the region of center columns and the outer rows. Although the trend of 100% power operation is similar to 70% power operation, the maximum void fraction of 70% power operation is lower than that of 100% power operation and the concentrated area is almost identical.

The difference of void fraction between 100% power operation and 70% power operation is described as follows:

The higher saturation steam pressure causes the lower void fraction. Since the thermal power of 70% power operation is lower than that of 100% power operation, the saturation pressure of 70% power operation is higher than that of 100% power operation despite tube plugging condition. For this reason in addition to the lower heat flux, the maximum void fraction of 70% power operation is lower than that of 100% power operation.

Fig. 7.-1 (a) Contour of vertical sectional quality distribution of Cycle 16

[ ]

Fig. 7-1 (b) Contour of vertical sectional quality distribution of RTS at 70% power

Fig. 7-2 (a) Contour of cross-sectional quality and void fraction distribution at the height of the maximum quality in U-bend region of Cycle 16

Fig. 7-2 (b) Contour of cross-sectional quality and void fraction distribution at the height of the maximum quality in U-bend region of RTS at 70% power

References

1) Analysis of Thermal Hydraulics of Steam Generators/Steam Generator Analysis Package, Ver.3.1, 1016564, EPRI
2) L5-04FU001 the latest revision, Component and Outline Drawing 1/3
3) L5-04FU002 the latest revision, Component and Outline Drawing 2/3
4) L5-04FU003 the latest revision, Component and Outline Drawing 3/3
5) L5-04FU021 the latest revision, Tube Sheet and Extension Ring 1/3
6) L5-04FU022 the latest revision, Tube Sheet and Extension Ring 2/3
7) L5-04FU023 the latest revision, Tube Sheet and Extension Ring 3/3
8) L5-04FU051 the latest revision, Tube Bundle 1/3
9) L5-04FU052 the latest revision, Tube Bundle 2/3
10) L5-04FU053 the latest revision, Tube Bundle 3/3
11) L5-04FU111 the latest revision, AVB assembly 1/9
12) L5-04FU112 the latest revision, AVB assembly 2/9
13) L5-04FU113 the latest revision, AVB assembly 3/9
14) L5-04FU114 the latest revision, AVB assembly 4/9
15) L5-04FU115 the latest revision, AVB assembly 5/9
16) L5-04FU116 the latest revision, AVB assembly 6/9
17) L5-04FU117 the latest revision, AVB assembly 7/9
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20) L5-04GA565 the latest revision, Selection of Thermal Hydraulic Analysis (ATHOS) Model
21) L5-04GA566 the latest revision, Case study of the input parameters and tube plugging impact on internal SG thermal - hydraulics parameters
22) L5-04GA510 the latest revision, Thermal and Hydraulic Parametric Calculations

Appendix-13
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Appendix-14
Analytical evaluation of the impact on the Tube Support Plate and Tube Bundle due to Tubesheet deflection during Divider Plate detachment

1 Purpose

This document demonstrates that even with the SONGS Divider Plate detachment condition at Hydrostatic test, the heat exchanger tube deformation due to tube sheet deformation would not be the cause of the tube wear and thickness reduction since there is no change in the adjacent tubes' gap.

2 Conclusions

For the U-bend portion, the displacements in the X and Y directions are negligible small. As for the Z direction displacement, it is about the same as the Tubesheet towards the upper direction.

As for the neighboring tubes, in comparing the displacement results in all three directions (X, Y & Z), it was found that they are approximately the same and that the gap on the adjacent tubes have no effect.

3 Assumptions and Open Items

Deformation of tubesheet on the secondary side is equivalent to deformation of tubes at the secondary side surface of the tubesheet.

4 Acceptance Criteria

Deformation due to detachment of the divider plate during the hydrostatic test does not have impact on the U-bend portion.

Tube Support Plate (TSP) and Stay Rod do not plastically deform.

5 Design Input

5.1 Geometry

9

The dimensions are obtained from the design drawings. Major dimensions are shown in Fig 5.1-1 through 5.1-6.

Divider Plate detachment condition: Detachment between Divider Plate and Flat Bottom of Channel Head.

5.2 Loading Conditions

9

5.2.1 Test Condition

Primary side Hydrostatic test

Pressure: [ ]

Temperature: [ ]

Fig. 5.1-1 Major dimensions of Tubesheet model (1/5)

Fig. 5.1-2 Major dimensions of Tubesheet model (2/5)

Fig. 5.1-3 Major dimensions of Tubesheet model (3/5)

Fig. 5.1-4 Major dimensions of Tubesheet model (4/5)

Fig. 5.1-5 Major dimensions of Tubesheet model (5/5)

Fig. 5.1-6 Major dimensions of TSP and Stay Rod

5.3 Material Properties

9

Material properties used in the analysis for each part are shown in Table 5.3-1 through 5.3-6.

Table 5.3-1 Material Properties for [ ]

E (ksi)	ν (-)
[	]

Table 5.3-2 Material Properties for [ ](Tubesheet perforated area)

$E_1^{*1)}$ (ksi)	$\nu_1^{*1)}$ (-)	$E_2^{*1)}$ (ksi)	$\nu_2^{*1)}$ (-)
[			]

Note 1) E_1^* and ν_1^* are equivalent properties in radial and hoop directions of the tubesheet, and E_2^* and ν_2^* are equivalent properties in thickness direction.

Table 5.3-3 Material Properties for [ ] (Divider Plate)

E (ksi)	ν (-)
[	]

Table 5.3-4 Material Properties for [ ](TSP)

E (ksi)	ν (-)	$E^{*1)}$ (ksi)	$\nu^{*1)}$ (-)	Sy (ksi)
[				]

Note 1) E^* and ν^* are equivalent properties in perforated region.

Table 5.3-5 Material Properties for [ ] (Stay Rod)

E (ksi)	ν (-)	Sy (ksi)
[		]

Table 5.3-6 Material Properties for [ ] (Tube)

E (ksi)	ν (-)	Sy (ksi)
[		]

6 Methodology

6.1 Analytical Model

The following three models used in each analysis are shown in Fig.6.1-1, 6.1-2, and 6.1-3.

(i) Tubesheet, Channel Head, and Lower Shell

(ii) Tube Support Plate and Stay Rod

(iii) Tube

Fig. 6.1-1 Tubesheet model (Tubesheet, Channel Head, and Lower Shell)

(i) Bird's-eye view

(ii) Top view

Fig. 6.1-2 TSP model (Tube Support Plate and Stay Rod)

Row104 Column78(Neighboring tubes with the leaked tube)
Row106 Column78(Leaked tube)
Row140 Column89(Tubes adjacent to the outermost tube)
Row140 Column89(Outermost tube)

Fig. 6.1-3 Tube model

6.2 Mechanical Boundary Condition

9

Mechanical boundary condition for each model is shown in Fig.6.2-1 through 6.2-4.

6.3 Method

9

To simulate the tube deformation due to tubesheet deformation as a result of the hydrostatic test, the following three models are used:

(i) Tubesheet, Channel Head, and Lower Shell

(ii) Tube support plate and Stay Rod

(iii) Tube

At first, the primary side internal pressure is applied on model No. (i) to get the tubesheet deformation. Then the tube sheet deformation results from model No. (i) are input to model No. (ii) to cause the tube support plate deformation. At last, the deformation results from both models No. (i) and (ii) are input to model No. (iii) to analyze the deformation of tubes. The tubes to be analyzed are the following tubes which include the leaked tube and one outermost tube together with the neighboring ones.

Fig. 6.2-1 Boundary condition for Tubesheet model (1/2)

Fig. 6.2-2 Boundary condition for Tubesheet model (2/2)

Fig. 6.2-3 Boundary condition for TSP model

Fig. 6.2-4 Boundary condition for Tube model

7 Computation Results

7.1 FE Analysis Results

The tube displacement analysis results for the hydrostatic test effects with divider plate detachment are as follows.

(1) The tubesheet is swelled out upward with minimal deformation in horizontal direction. Displacements of the stay rod and the tube at the tubesheet on the secondary side surface are shown in Table 7.1-1 and 7.1-2 respectively and related Node No. is shown in Fig. 7.1-1. Displacement of TSP is shown in Table 7.1-3 and 7.1-4.

(2) Due to this tubesheet deformation, the tubes are displaced a little in horizontal direction at the vicinity of the tubesheet and displaced towards the upper direction over its entire length.

The deformation figures for the tube sheet by the primary side pressure, and the ones for the tube support plate and the tube deformation due to the tubesheet deformation are shown in Figures 7.1-2 though 7.1-7.

From these figures, the following is concluded.

(1) Displacement of the leaked tube

For Row 106 Column78 tube, the maximum displacement along the whole-tube is;

- [ ] inch in the X direction
- [ ] inch in the Y direction
- [ ] inch in the Z direction

Regarding the U-bend portion of this tube, the displacement in the X and Y direction is negligible small. As for the neighboring tubes, in comparing the displacement result in all three directions (X, Y & Z), it was found that they are approximately the same and that the gaps on the adjacent tubes have no effect towards the upper direction. (See Fig. 7.1-8)

(2) Comparing two sets of neighboring tubes

To look at the tube gap change due to the tube deformation, the following two sets of neighboring tubes are checked.

I. Leaked tube and the neighboring tube

II. One outermost tube and the neighboring tube

Fig. 7.1-8 shows that their displacement in all three directions (X, Y & Z) is approximately the same among the sets. Therefore it was found that the gap between the adjacent tubes would not be affected by the hydrostatic test with the divider plate detachment.

Contour plots of Tresca stresses for the TSP model are shown in Fig. 7.1-9 and 7.1-10, and calculated stress results of TSP and Stay Rod are shown in Table 7.1-4

Table 7.1-1 Displacement of Stay Rod at Tubesheet on the secondary side surface

Node *1)	Displacement				
	Transition (inch)			Rotation (rad)	
	X	Y	Z	X	Y

Note 1) See Fig. 7.1-1.

Fig. 7.1-1 Node No. of the Stay Rod at the Tubesheet on the secondary side surface

Table 7.1-2 Displacement of Tubes at Tubesheet on the secondary side surface

Side	Tube		Displacement				
			Transition (inch)			Rotation (rad)	
	Row	Col.	X	Y	Z	X	Y
Hot	106	78					
	104	78					
	140	89					
	142	89					
Cold	106	78					
	104	78					
	140	89					
	142	89					

Table 7.1-3 Displacement of TSP (Hot side)

Side	Tube Row	Tube Col.	Displacement Transition (inch) X	Displacement Transition (inch) Y	Displacement Transition (inch) Z	Displacement Rotation (rad) X	Displacement Rotation (rad) Y
#1	104	78					
#2							
#3							
#4							
#5							
#6							
#7							
#1	106	78					
#2							
#3							
#4							
#5							
#6							
#7							
#1	140	89					
#2							
#3							
#4							
#5							
#6							
#7							
#1	142	89					
#2							
#3							
#4							
#5							
#6							
#7							

Note: only transitions in X and Y directions are used as input to Tube analysis.

Table 7.1-4 Displacement of TSP (Cold side)

Side	Tube		Displacement				
			Transition (inch)			Rotation (rad)	
	Row	Col.	X	Y	Z	X	Y
#1	104	78					
#2							
#3							
#4							
#5							
#6							
#7							
#1	106	78					
#2							
#3							
#4							
#5							
#6							
#7							
#1	140	89					
#2							
#3							
#4							
#5							
#6							
#7							
#1	142	89					
#2							
#3							
#4							
#5							
#6							
#7							

Note: only transitions in X and Y directions are used as input to Tube analysis.

Fig. 7.1-2 Tubesheet deformation (primary side: 1ksi, secondary side 0ksi) (x300)

Fig. 7.1-3 TSP Deformation (x10)

Fig. 7.1-4 Tube Deformation Row104(x10)

Fig. 7.1-5 Tube Deformation Row106(x10)

Fig.7.1-6 Tube Deformation Row140(x10)

Fig.7.1-7 Tube Deformation Row142(x10)

Fig.7.1-8 Tube displacement

Figure 7.1-9 Contour plots of Tresca stresses for TSP model (1/2)

Note) Stress results in regions 1 through 3 in the figure is shown in Table 7.1-5.

Fig.7.1-10 Contour plots of Tresca stresses for TSP model (2/2)

Table 7.1-5 Stress results of TSP and Stay Rod

Region(*1)	Parts	P/h2)	K2)	Membrane + bending stress (ksi)	Sy (ksi)
1	TSP				
2	TSP(perforated)2)				
3	Stay Rod				

Note 1) See Fig.7.1-8 and 7.1-9.

Note 2) Calculated in accordance with ASME Sec. III App. A-8142.1 using the stress value derived from the FEA results. K=2 is the max value shown in A-8142.1 conservatively.

7.2 Evaluation

As long as the tube gaps are uniformly (regularly) spaced, there is no direct relation to the observed thickness reduction wear. In relation to the divider plate's detachment condition at hydrostatic test, the tubes' deformation analysis shows that although there is a slight deformation of the tubes close to the tubesheet in the horizontal direction as a result of the tubesheet deformation and some displacement towards the upper direction due to tubesheet deformation, adjacent tubes displacement value is approximately the same and the gaps remain uniform. Also the U-bend tube displacements in the horizontal directions are minimal and are negligible

The calculated stresses of the Tube Support Plates and the Stay Rods at the hydrostatic test are lower than the yield strength Sy as shown in Table 7.2-1. Therefore plastic deformation does not remain after hydrostatic test and there is no impact on the U-bend portion.
Therefore, the divider plate's detachment at hydrostatic test is considered not related to the observed tube wear phenomenon.

Table 7.2-1 Stress results of TSP and Stay Rod

Parts	Membrane + bending Stress (ksi)	Sy(ksi)
TSP		
TSP(perforated)		
Stay Rod		

8 Reference

9

[1] MHI document, L5-04GA401 Rev.7, Design Report of the Tubesheet Region (Tubesheet, Extension Ring, Lower Shell, Divider Plate).
[2] MHI document, L5-04GA411 Rev.7, Design Report of the Tubes Support Plate and Stay Rod.
[3] MHI document, L5-04GA418 Rev.5, Design Report of the Tube.

Appendix-15
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Appendix-16
Fatigue Evaluation of the Tube due to In-Plane Vibration

9

1. Purpose

The purpose of this document is to show that the stress of the tube in SONGS RSG due to in-plane vibration is under the fatigue limit.

2. Conclusions

The stress on the tube due to in-plane vibration is 4.2ksi and is under fatigue limit (13.6ksi). The tube has structural integrity for the stress due to in-plane vibration from the view point of fatigue evaluation.

3. Assumptions and Open Items

The tube deforms in-plane until contacting with the outer next tube in Row direction due to in-plane vibration.

The stress due to in-plane vibration is high cycle fatigue 9

4. Acceptance Criteria

The fatigue limit is 13.6ksi according to the following design fatigue curve.

Fig. I-9.2.2 1998 SECTION III, DIVISION 1 — APPENDICES

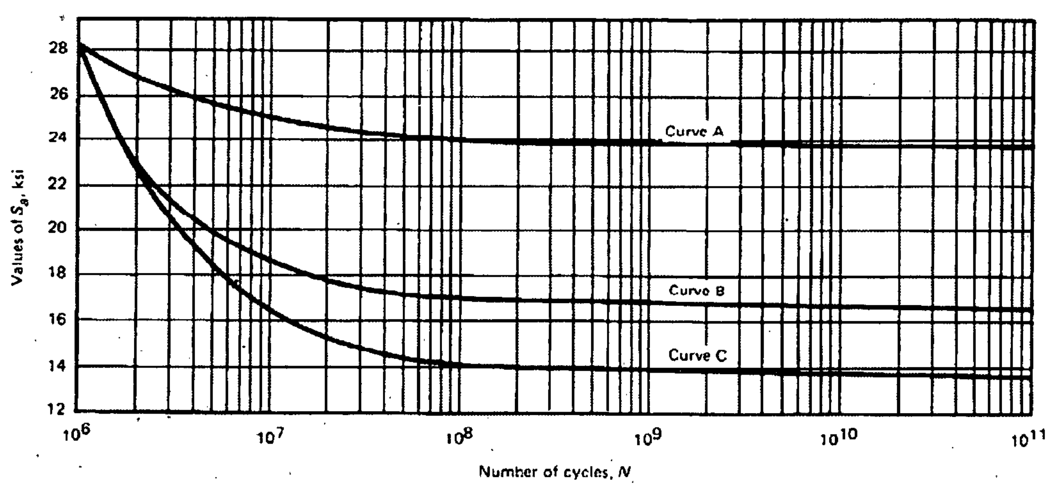

Figure 4-1 Design Fatigue Curve for Tube

5. Design Input

5.1 Geometry

The leaked tube (Row106 Column78) dimensions are used.

5.2 Loading Conditions

5.2.1 Normal Operating Condition

The temperature is as follows.

Thot:[ ]
Tcold:[ ]
Tsteam:[ ]

5.3 Material Properties

Tube temperature:[ ] (=((Thot+Tcold)/2+Ts)/2)
Young's modulus:[ ]

6. Methodology

6.1 Analytical Model

The tube of Row106 Column78 is modeled (Figure 6-1).

[ ]

Figure 6-1 Analysis Model

6.2 Mechanical Boundary Condition

The tube is fixed on secondary side of the tube sheet and pin supported at each TSP (Figure 6-2).

Figure 6-2 Analysis Model

6.3 Method

The stress to contact next tube is calculated and fatigue evaluation is performed with the stress in the following steps.

(1) A unit force due to gravity 1G is applied on the U-bend tube (Figure 6-3) and the tube deformation ($\delta 1$) (Figure 6-4) and the tube stress ($\sigma 1$) at #7TSP are calculated by FE analysis.

(2) The tube deformation to contact the next tube ($\delta 2$) is calculated using the drawing (Figure 6-4).

(3) The tube stress to contact next tube is calculated by multiplying $\sigma 1$ by the ratio of $\delta 2/\delta 1$.

(4) The stress obtained in (3) is compared to the fatigue limit and is confirmed under the fatigue limit.

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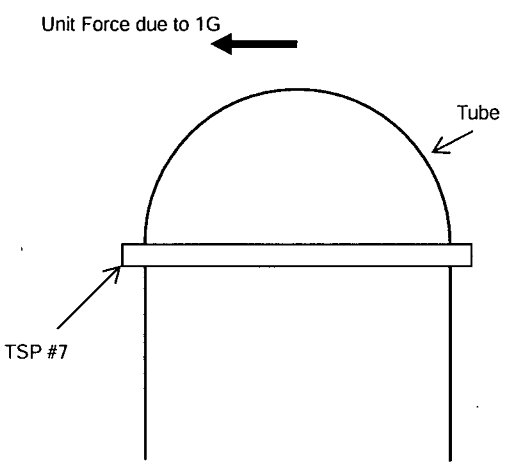

Figure 6-3 Loading Condition

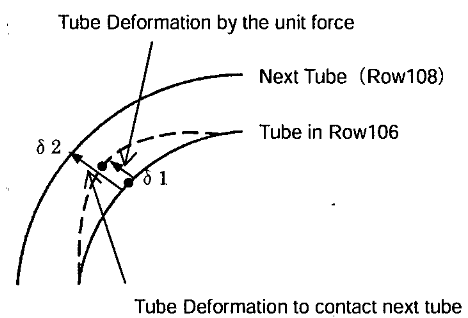

Figure 6-4 Deformation

7. Computation Results

7.1 FE Analysis Results

The deformation of the tube when unit force is applied is shown in Figure 7-1. The deformation by the unit force (δ1), and the deformation required for the tube to contact the next tube (δ2), is shown in Table 7-1.

Table 7-1 Location and Deformation of the Tube Contact

Location of the Contact (θ*1)	
Deformation by Unit Force (δ1)	
Deformation required for Tube Contact (δ2)	
Ratio of δ2 / δ1	

Note *1 The definition of θ is shown below

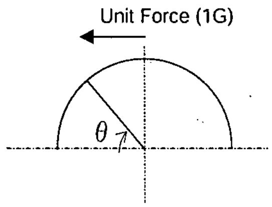

Figure 7-1 Tube Deformation when Unit Force is applied (x100)

The tube stress to contact next tube ($\sigma 2$) at TSP #7, which is calculated based on $\sigma 1$ and the ratio of $\delta 1$ and $\delta 2$, is shown in Table 7-2. The tube stress due to in-plane vibration is [ ] and is under the fatigue limit of 13.6ksi.

Table 7-2 Tube stress at TSP #7 due to in-plane vibration

Stress by Unit Force ($\sigma 1$)	
Stress to contact next tube	
Fatigue Limit	

Note*1 Calculated as follows

$\sigma 2 = \sigma 1 \times \delta 2 / \delta 1$

Where,

$\sigma 1$: Tube Stress at TSP #7 by Unit Force

$\sigma 2$: Tube Stress at TSP #7 during In-plane Vibration

$\delta 1$: Deformation by the Unit Force

$\delta 2$: Deformation Required for Tube Contact

7.2 Evaluation

The stress on the tube due to in-plane vibration is [ ] and is under fatigue limit (13.6ksi). The structural integrity of the tube is confirmed from the view point of fatigue due to in-plane vibration.

Attachment 1: Fatigue Evaluation of the Wear Tube due to In-Plane Vibration

1. Purpose

The purpose of this attachment is to show that the stress of the wear tube in SONGS RSG due to in-plane vibration is under the fatigue limit.

2. Conclusions

The stress on the tube due to in-plane vibration is[ ]and is under fatigue limit (13.6ksi). The structural integrity of the tube is confirmed from the view point of fatigue due to in-plane vibration.

3. Assumptions

The tube deforms in-plane until contacting with the outer next tube in Row direction due to in-plane vibration.

The stress due to in-plane vibration is high cycle fatigue.

Thickness of the tube is reduced conservatively with flat surface, which makes the smaller sectional area, at the contact location with the land area of TSP tube hole.

4. Acceptance Criteria

The fatigue limit is 13.6ksi according to the following design fatigue curve.

5. Design Input

5.1 Geometry

Nominal tube dimensions are considered and tube is worn[ ]in thickness

5.2 Loading Conditions

The member forces from the result of the beam model analysis shown in Figure 7-1 are used.

6. Methodology

6.1 Analytical Model

Part of the tube Row106 Column78 worn [ ] in thickness at #7TSP is to be evaluated. Modeling methodology of cross section of the tube is shown in Figure A6.1-1. Analysis model is a half sector model considering symmetric configuration and is generated using quadratic solid element as shown in Figure A6.1-2. The thickness of the tube is 0.0429inch for the general part, and the outer diameter is 0.75inch. The height of the model is 1inch.

6.2 Mechanical Boundary Condition

Displacement of the bottom surface of the tube model is constrained in all directions. Boundary condition of the model is shown in Figure A6.2-1. 9

6.3 Method

Stress of the worn tube is calculated and fatigue evaluation is performed with the stress in the following steps.

(1) Member forces of the tube at #7TSP due to unit force are derived from the analysis result of the beam model shown in Figure 7-1.

(2) The member forces are loaded on the top of the model as shown in Figure A6.3-1. The member forces have to be loaded on the node at the center of the tube coupled with the tubes on the same cross section. Tube stresses are influenced locally by this coupling. To avoid the influence, the loading point must be put far away from the evaluated point, therefore tube stresses evaluated on a section at the middle elevation of the model and the member forces are loaded on the top. To evaluate tube stresses on a section at the middle elevation, a counter moment is added to the loading point to cancel the cantilever effect by the shear force, which is loaded above the evaluated point. Pressure stresses are not considered because pressure does not contribute the stresses for the high cycle fatigue due to in-plane vibration.

(3) Peak stress is calculated by multiplying membrane plus bending stresses derived from FE analysis by a stress concentration factor.

(4) In addition, the peak stress calculated in (3) is multiplied by the ratio of $\delta 2/\delta 1$ (Table 7-1).

(5) The stress obtained in (4) is compared to the fatigue limit and is confirmed under the fatigue limit.

[ ]

Figure A6.1-1 Modeling Methodology of Tube Cross Section

[ ]

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Figure A6.1-2 Analysis model

[ ]

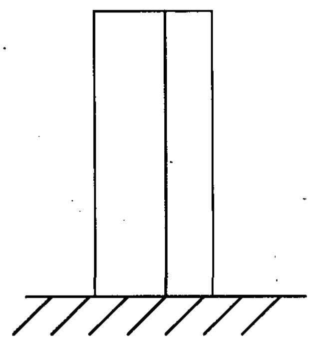

Figure A6.2-1 Mechanical Boundary Condition

[ ]

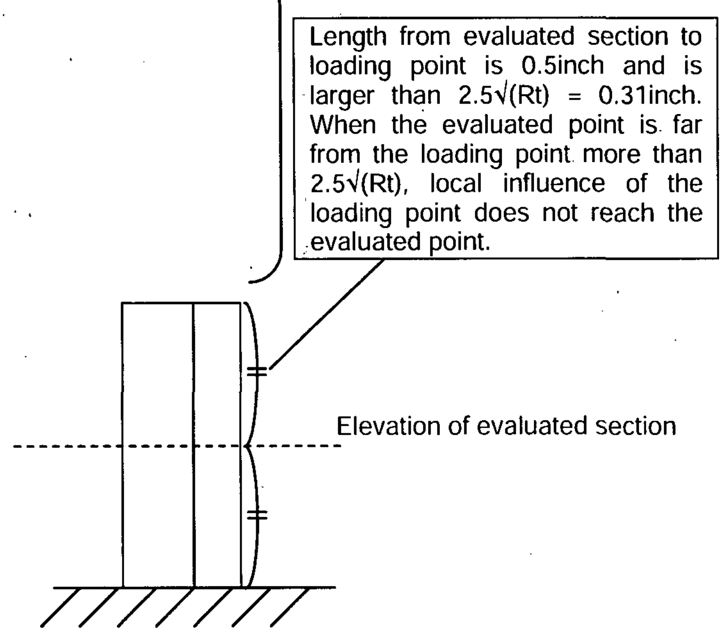

Figure A6.3-1 Loading Condition

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7. Computation Results

7.1 FE Analysis Results

Member forces at #7TSP derived from the analysis result of the beam model due to the unit force are provided in Table A7.1-1. Half of each force is loaded on the top of the half model of the worm tube shown in Figure A6.3-1. Deformation of the model is shown in Figure A7.1-1, and contour plot of tresca stress on the evaluated section, which is at middle elevation of the tube model, is shown in Figure A7.1-2. The maximum stress occurred at the worn thickness on the asymmetric boundary.

Stresses on the inner surface resulting from FE analysis is dealt with as membrane plus bending plus peak stress by unit force since there is no discontinuity on the inner surface of the tube. On the outer surface, stress concentration factor shall be applied considering discontinuity of the shape due to the wear. The stresses resulting from FE analysis through the thickness are classified to membrane plus bending stresses, then membrane plus bending plus peak stresses are obtained by multiplying membrane plus bending stresses by a stress concentration factor. Calculated results of the tube stresses at the severest point are provided in Table A7.1-2. The tube stress due to in-plane vibration is[ ]and is under the fatigue limit of 13.6ksi.

7.2 Evaluation

The stress on the tube due to in-plane vibration is[ ]and is under fatigue limit (13.6ksi). The structural integrity of the tube is confirmed from the view point of fatigue due to in-plane vibration.

Table A7.1-1 Member forces derived from the beam model analysis at #7TSP

Element	Node	Axial force Fz (kips)	In-plane force Fy (kips)	Bending moment Mx (kips-in.)

Table A7.1-2 Worn tube stress at TSP #7 due to in-plane vibration

Items	Inner surface	Outer surface
Membrane plus bending stresses by unit force		
Stress concentration factor		
Membrane plus bending plus peak stresses by unit force		
Ratio of δ2 / δ1		
Membrane plus bending plus peak stresses		
Fatigue limit		

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(*1)The stress concentration factor is derived from Chart 3.5 of Ref. [3], which is a chart for a thin tube with fillet. Value t/h (t: thinner thickness, h: thicker thickness) for the tube model is [ ] Although a curve for t/h = [ ] is not drawn in the chart, it is obvious that a curve for t/h = [ ] become lower than the t/h = [ ] curve in the chart, therefore the t/h = [ ] curve is used conservatively for evaluation. Parameter t/r is 1.33, where r is fillet radius assuming equal to be t-h = [ ] therefore stress concentration factor is less than 1.5.

Figure A7.1-1 Deformation of the worn tube due to the member forces (×500)

[ ]

9

Figure A7.1-2 Contour plot of tresca stress on the evaluated section

8. Reference

[1] MHI drawing, L5-04FU051 Rev.1, Tube Bundle 1/3.

[2] MHI drawing, L5-04FU108 Rev.3, Tube Support Plate Assembly 3/3.

[3] Walter D. Pilkey, Peterson's Stress Concentration Factors Second Edition, John Wiley & Sons, Inc., 1997.

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ATTACHMENT 5

MHI Document L5-04GA571, Screening Criteria for Susceptibility to In-Plane Tube Motion

[Proprietary Information Redacted]

Non-proprietary Version

[ ](1/62)

San Onofre Nuclear Generating Station, Units 2 & 3
REPLACEMENT STEAM GENERATORS

Screening Criteria for Susceptibility to In-Plane Tube Motion

Supplier Status Stamp

VPL No: SO23-617-1-M1540	Rev No: 0	QC: N/A

☐DESIGN DOCUMENT ORDER NO. 800873488

☒REFERENCE DOCUMENT--INFORMATION ONLY ☐VIRP IOM MANUAL

MFG MAY PROCEED: ☐YES ☐NO ☒N/A

STATUS - A status is required for design documents and is optional for reference documents. Drawings are reviewed and approved for arrangements and conformance to specification only. Approval does not relieve the submitter from the responsibility of adequacy and suitability of design, materials, and/or equipment represented.

☐1. APPROVED

☐2. APPROVED EXCEPT AS NOTED - Make changes and resubmit.

☐3. NOT APPROVED - Correct and resubmit for review. NOT for field use.

APPROVAL: (PRINT / SIGN / DATE)

RE: D. Calhoun / [signature] 10/1/12

FLS:

Other:

SCE DE(123) 5 REV. 3 07/11 REFERENCE: SO123-XXIV-37.8.26

[ ]

Purchase Order No.	4500024051
Specification No.	SO23-617-01R3

CONTENT		REMARKS	PURCHASER	ORDER No.	DATE	Nuclear Plant Component Designing Department Steam Generator Designing Section	
DESCRIPTION	- PAGE			ITEM No.	REFERENCE		
FIGURE	- SHEET		Edison (MNES)	2591012	[ ]	APPROVED BY	[ ]
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TOTAL	62 PAGE			1002		DESIGNED BY	
						DRAWN BY	——
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Revision History

No.	Revision	Date	Approved	Checked	Prepared
0	Initial issue	See cover sheet			
1	-Revised in accordance with SCE comment to L5-04GA571 Rev. 0 (RSG-SCE/MHI-12-5690)				
2	-Revised in accordance with SCE comment to L5-04GA571 Rev. 1 (RSG-SCE/MHI-12-5691)				
3	-Revised in accordance with SCE comment to L5-04GA571 Rev. 2 (RSG-SCE/MHI-12-5693)				
4	-Revised in accordance with SCE comment to L5-04GA571 Rev. 3 (RSG-SCE/MHI-12-5702)				
5	-Revised in accordance with SCE comment to L5-04GA571 Rev. 4 (RSG-SCE/MHI-12-5746)				
6	-Revised in accordance with SCE comment to L5-04GA571 Rev. 5 (RSG-SCE/MHI-12-5755)				

Table of Contents

1 Purpose

This document describes steam generator tube screening criteria that can be used as the basis for a return to service strategy. The criteria are designed to identify tubes that are susceptible to in-plane tube motion and freespan wear. Applying the screening criteria to the Unit 2 steam generators will enable Southern California Edison (SCE) to identify tubes that should be preventatively plugged before the steam generators are returned to service.

2 Background

Recent inspections of the San Onofre Nuclear Generating Station (SONGS) Unit 2 steam generators during the first refueling outage following steam generator replacement (SGR) identified the following number of tubes with wear indications (Ref.1):

2A-SG (Steam Generator 2E089): 861 tubes (See Note 1)

2B-SG (Steam Generator 2E088): 734 tubes (See Note 1) 6

Tubes adjacent to the retainer bars (94 tubes / SG) were plugged in both steam generators. In addition, four tubes in 2B-SG were plugged: two tubes that had wear indications with depths at or above 35% and two tubes that had wear indications with depths at or above 30% and less than 35%.

Inspections of the SONGS Unit 3 steam generators after approximately eleven months of operation following SGR identified more numerous and more severe tube wear indications than Unit 2. In particular, Unit 3 steam generators both experienced tube wear in the U-bend caused by contact with adjacent tubes. This free span tube-to-tube wear (FSW) occurred in 326 tubes (165 tubes in 3A-SG and 161 tubes in 3B-SG) (Ref.1). The consensus from industry experts is that the tube-to-tube contact was caused by in-plane fluid-elastic instability. This caused the tubes to move parallel to the anti-vibration bars (AVBs) and contact one another on the intrados and extrados of the tubes. The conclusion of in-plane tube motion was also confirmed by evidence of wear scars at AVB intersections that are longer than the width of the AVB. 6

The inspections of SONGS Unit 2 steam generators have identified a single pair of tubes with indications of FSW motions in 2A-SG: Column 81, Rows 111 and 113. The region of Unit 2 tubes affected by AVB wear is similar to the region in the Unit 3 steam generators that experienced AVB wear. MHI has developed empirically-based criteria based on Unit 3 results to identify tubes that are susceptible to in-plane motion. Since the criteria are developed from Unit 3 wear data, the criteria are directly applicable to Unit 3; however, they may also be conservatively applied to Unit 2 to preventatively plug tubes as a defense-in-depth measure against tube-to-tube wear. This document describes the basis for these screening criteria.

(Note 1)

These values for number of tubes with wear indications are according to the SONGS Unit 2 In-Service Inspection (ISI) records. For the analysis performed in this report, two additional tubes in 2B-SG are included based on MHI's review of the eddy current examination. In addition, tubes that had been previously plugged (6 tubes in 2A-SG and 16 tubes in 2B-SG) are removed from consideration because they are unrelated to FSW and therefore not relevant to the screening criteria. The analysis that follows considers 855 tubes in 2A-SG and 720 tubes in 2B-SG, as shown in Table 13 and 14. For additional detail, see appendix-3. 6

3 Proposed screening criteria based on Unit 3 results

FSW tubes identified in the Unit 3 steam generators are shown in Figures 1 and 2. The FSW tubes are located in a well-defined, contiguous region of the tube bundle from row "X" through row "Y" consecutively for each column. In addition, FSW tubes exhibit specific characteristics in terms of the wear indications in affected tubes. Criteria proposed to select tubes for plugging that are potentially susceptible to FSW (in-plane motion tubes) are based on identifying the specific characteristics in the eddy current inspection data and the steam flow characteristics that could lead to potential susceptibility to the FSW phenomenon.

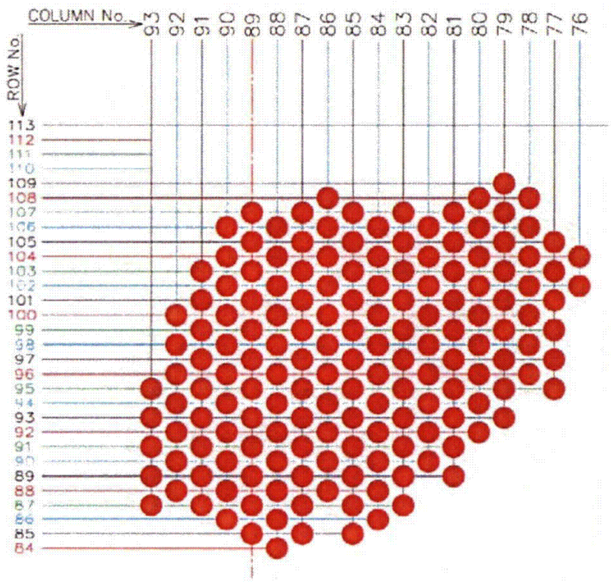


Figure 1 FSW tubes in Unit-3A

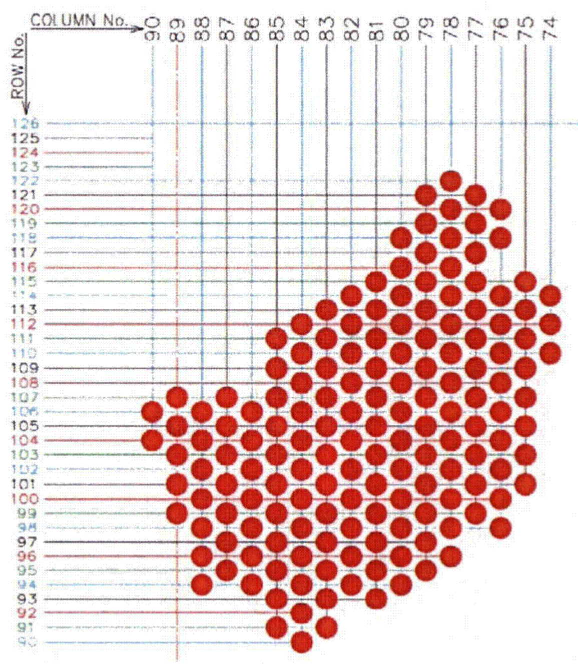


Figure 2 FSW tubes in Unit-3B

MHI developed preventive plugging screening criteria by evaluating the condition necessary to cause the FSW observed in Unit 3. Although the specific causes that resulted in tubes being susceptible to fluid-elastic excitation are not yet completely known, MHI's understanding of fluid-elastic instability and motion of the tubes is sufficient to correlate the observations from the inspections of FSW tubes with the conditions necessary to produce the vibration mechanism. The following conditions are required for, or indicative of, in-plane tube motion in the U-bend of a steam generator:

- Low friction with AVBs – Low friction allows the tube to move freely in the fundamental mode. Lower contact force between a tube and AVB will minimize friction causing high AVB wear rates to develop at these locations.
- Low vibration frequency – The critical velocity determined using Conner's equation is proportional to the vibration frequency of the tube. A low frequency of vibration decreases the velocity threshold for the onset of fluid-elastic instability.
- Low fluid damping – Loss of fluid damping contributes to instability. High steam void fraction reduces squeeze film damping between tubes and the AVBs and increases the potential for fluid-elastic excitation.
- High fluid velocities – The onset of fluid-elastic instability occurs when the steam velocity exceeds the critical velocity. Reducing the steam velocity decreases the potential for fluid-elastic instability and tube in-plane motion.

MHI created nine criteria to identify tubes that have potential for fluid-elastic instability and in-plane tube motion. Each of the nine criteria relates to one of the following characteristics of in-plane fluid-elastic vibration: (1) tube-to-AVB friction, (2) vibration frequency, (3) in-plane tube motion, (4) high void fraction, (5) regional effect, and (6) coupling effect. A screening approach was developed based on assigning a score using steam generator tube inspection data and analytically derived flow conditions. The scoring criteria are based on the FSW probability among all tubes exhibiting wear. A description of each is given below:

Tube-to-AVB friction

Tubes that experience in-plane motion must have low friction with the AVBs, otherwise tubes could not move parallel to the AVBs. Low contact force between tubes and AVBs contributes to in-plane motion leading to FSW. Tubes with wear indications at multiple AVB intersections may have reduced friction. Two criteria are proposed for identifying tubes with low tube-to-AVB friction. The name of each criterion and a description of how they are calculated are given in Table 1.

Vibration Frequency

Steam generators are designed with multiple AVBs to minimize the span length between successive AVBs. This raises the fundamental frequency of the span between the two support locations, assuming displacements are restrained at the AVBs. The presence of AVB wear indications at the first two AVB intersections above the straight-leg portion and the presence of AVB wear indications at several successive AVB intersections suggests that the tube has limited support over the top of the tube U-bend region. Table 1 provides two criteria used to quantify susceptibility due to low tube vibration frequency.

In-Plane Tube Motion

Inspection data from the Unit 3 steam generators show a strong correlation between tubes with tube-to-tube wear indications and either TSP wear or extended AVB wear length. In FSW tubes, the largest TSP indications occur at the 7th TSP intersections; however, wear depths are similar on the hot and cold leg sides of the steam generator. Extended AVB wear length occurs as a result of differential movement between the tube and AVB. Both of these effects are associated with post-instability behavior, in that the TSP or extended AVB wear develops after the tubes have already experienced in-plane motion. Table 1 provides two criteria proposed to identify tubes that have experienced in-plane tube motion. 6

Void Fraction

The void fraction is equal to the volume of steam in the fluid normalized by the total volume of the steam/water mixture. The tubes in Unit 3 that exhibited FSW pass through a region of the U-bend where the void fraction is relatively high. High void fraction reduces vibration damping and increases a tube's susceptibility to fluid elastic instability. MHI calculated the fluid void fraction in the U-bend during power operation. The results of the analysis are included in Appendix 2. A criterion is proposed to identify tubes that are located where steam void fractions are high in the U-bend thus increasing the potential for in-plane vibration. Table 1 describes this screening factor.

Regional Effect

The majority of tubes with AVB wear indications exist in tubes that are located within a defined region in the center of the steam generator tube bundle. The boundaries of this AVB wear region vary slightly for each steam generator, which may reflect slight differences in the mechanical configuration of the tube bundle or thermal hydraulic conditions. The FSW tubes exist in an area that is near the center of the AVB wear regions of each steam generator. MHI developed a screening criterion to more heavily weight tubes in the center of the AVB wear region as being more susceptible to in-plane motion and FSW. Table 1 describes the regional effect screening factor.

Coupling Effect

According to laboratory test results, in-plane vibration tends to occur in groups of tubes simultaneously. The Unit 3 FSW phenomenon is also strongly regionalized, to the extent that all FSW tubes are within a contiguous, bounded region. An additional screening criterion is applied to take this coupling effect between adjacent tubes into account when screening FSW tubes. Table 1 describes this screening factor. 6

Tables 2 through 9 include a column that calculates the ratio of FSW tubes with the screening criterion attribute (that is, the number of true positive results) to the total number of tubes in 3A/3B with the attribute. A point value is assigned, approximately equal to 1 point for each 10 percent of the calculated ratio. Additional tubes are selected by a final weighting factor, COUPLING, added to the point total after summation of the points from the first eight criteria. The point value for COUPLING is assigned based on the number of tubes previously screened in by the point system that are adjacent to the tube in question.

Table 1 Summary of Steam Generator Tube Screening Criteria

Technical Basis	Criterion	Screening Factor
Tube-to-AVB friction	COUNT	AVB wear trends in the Unit 3 steam generators indicate that FSW tubes tend to have many AVB wear indications (See Figure 3), which indicates low contact forces at these intersections. The value assigned to COUNT is equal to the number of AVB intersections in each tube with a wear indication (See Table 2).
	HOT COUNT	AVB wear trends in the Unit 3 steam generators indicate that FSW tubes tend to have many AVB wear indications on the hot side (See Figure 4). This criterion is calculated similarly to the COUNT criterion described above; only the number of AVBs with wear indications at B01 to B06 are considered (See Table 3).
Vibration frequency	HIGH/LOW	AVB wear trends in the Unit 3 steam generators indicate that many tubes have wear indications at the low (B01/B02) and high (B11/B12) AVB intersections (See Figure 5 and Table 4.).
	CONTINUOUS	AVB wear trends in the Unit 3 steam generators indicate that FSW tubes tend to have a large number of consecutive AVB wear indications (See Figure 6 and Table 5).
In-plane tube motion	TSP	TSP wear trends in the Unit 3 steam generators indicate that most FSW tubes have wear indications at the 5th through 7th TSPs (See Figure 7 and Table 6).
	LENGTH	A review of AVB wear trends in the Unit 3 steam generators indicates that FSW tubes tend to have longer wear indications (See Figure 8 and Table 7).
Void fraction	VOID	The tubes with FSW indications in the Unit 3 steam generators are located where the secondary side fluid void fraction is relatively high. Void fraction and fluid damping significantly influence the vibration behavior of steam generator tubes during operation. The value assigned to VOID is theaverage void fraction in the U-bend (See Figure 9 and Table 8).
Regional effect	REGION	Tubes located close to the center of the AVB wear region in each steam generator tend to be more susceptible to FSW wear. The value assigned to REGION is the distance to the center of the AVB wear region (See Figure 10 and Table 9).
Coupling effect	COUPLING	As shown in Figures 1 and 2, FSW tubes exist in groups (both in row and column directions). Tubes adjacent to a group of susceptible FSW tubes have increased potential for fluid-elastic instability due to fluid coupling with susceptible tubes (See Table 10).

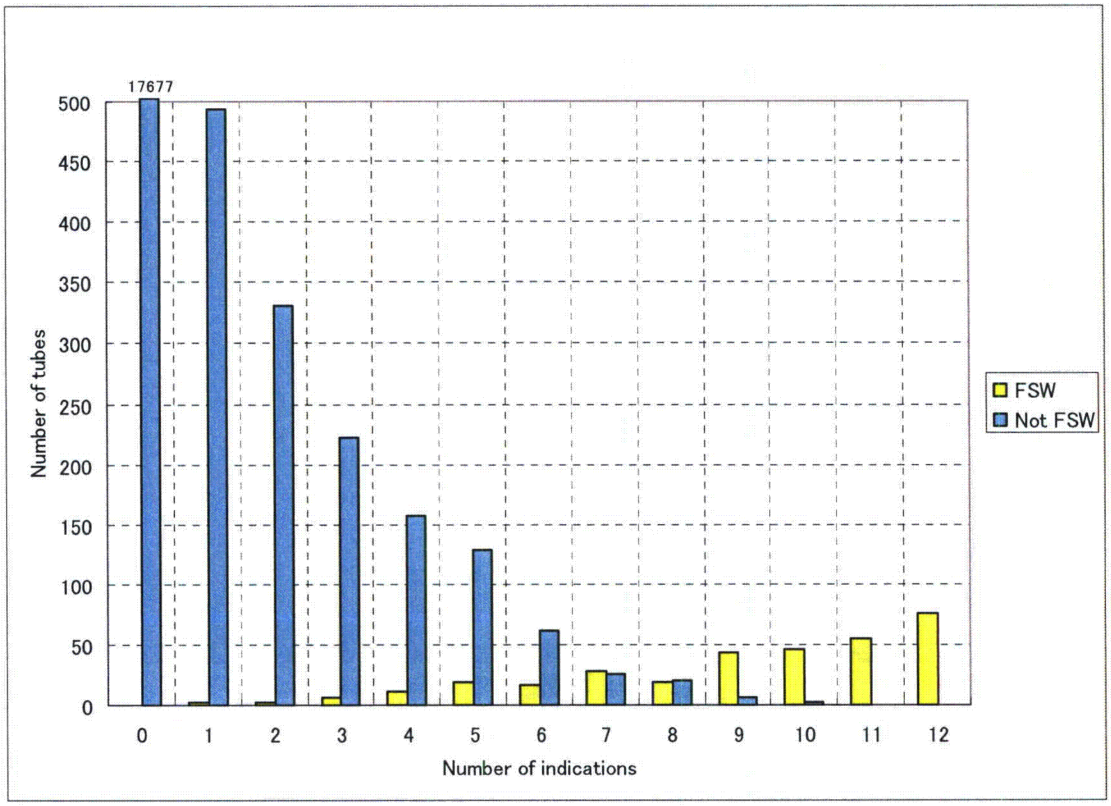


Figure 3 AVB wear indications (COUNT)

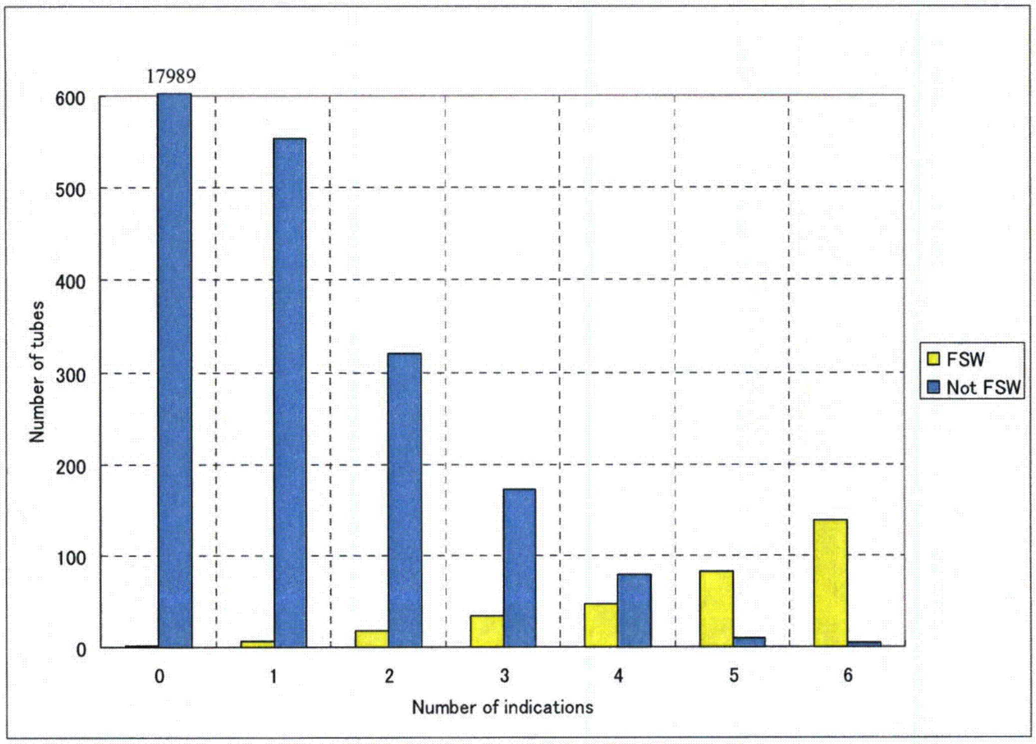


Figure 4 AVB wear indications at hot side (HOT COUNT)

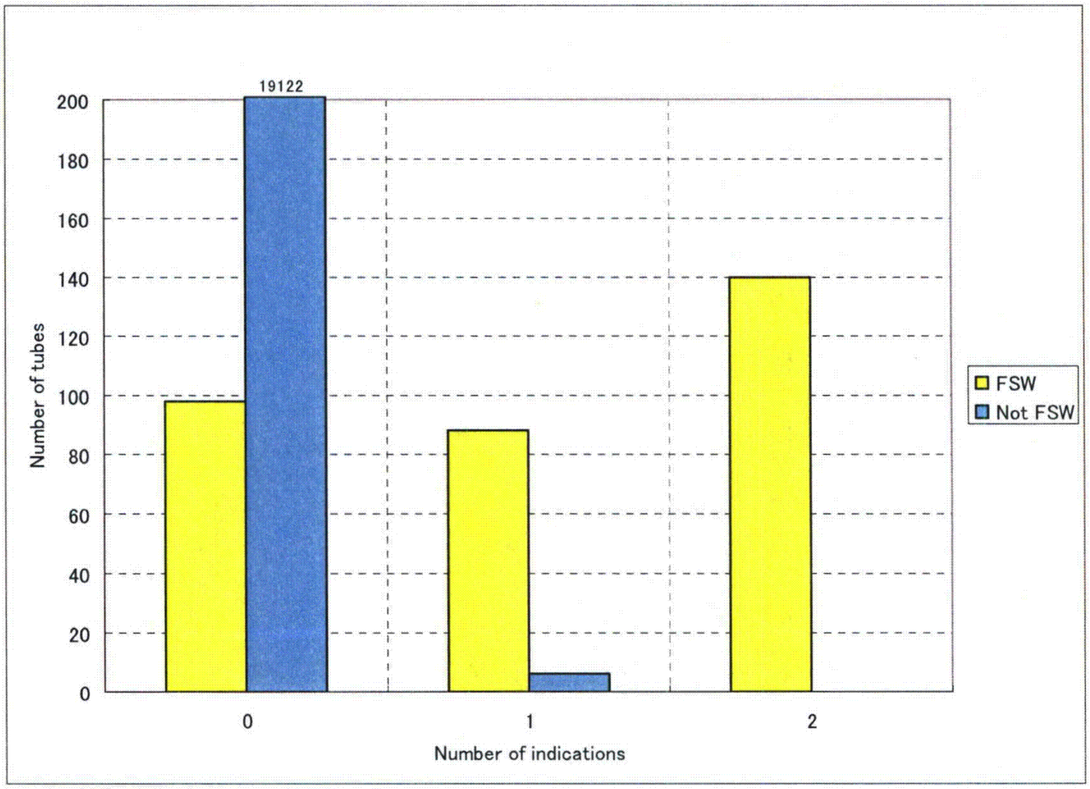


Figure 5 AVB wear indications at B01/B02 or B11/B12 positions (HIGH/LOW)

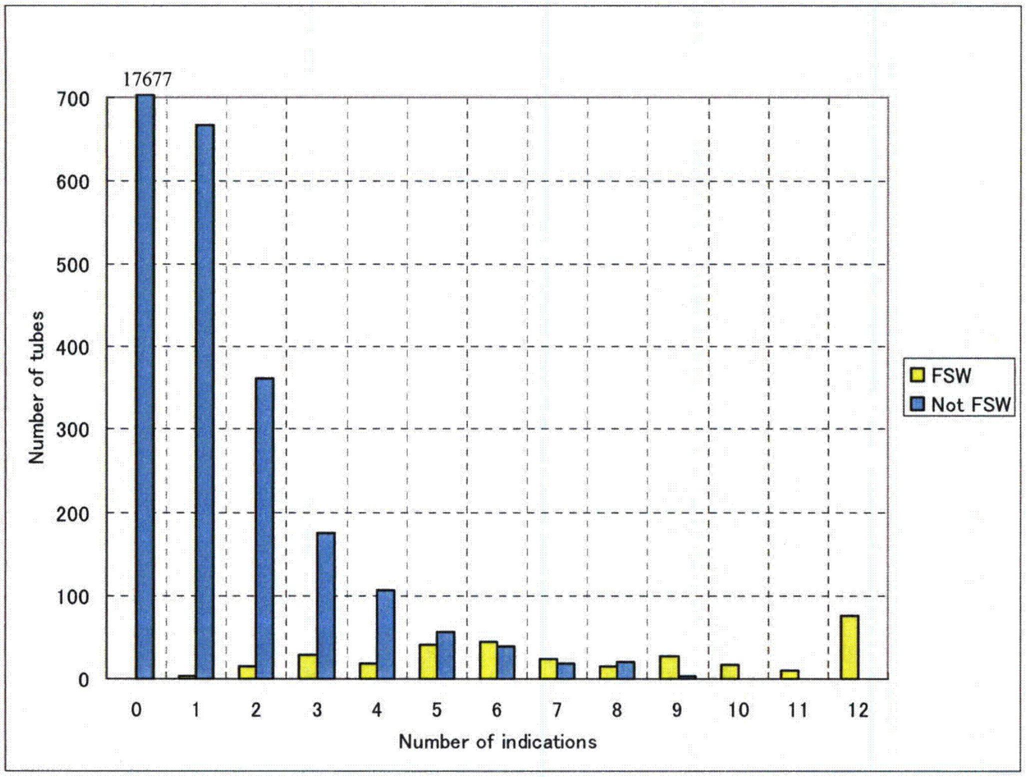


Figure 6 AVB continuous wear indications (CONTINUOUS)

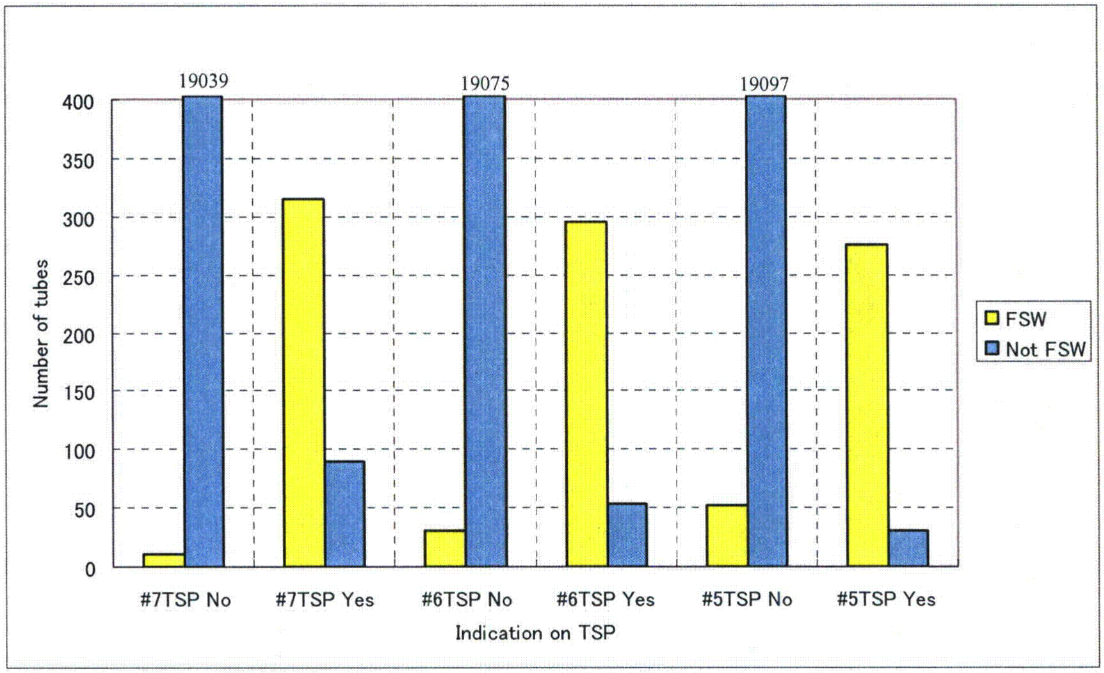


Figure 7 TSP wear (TSP)

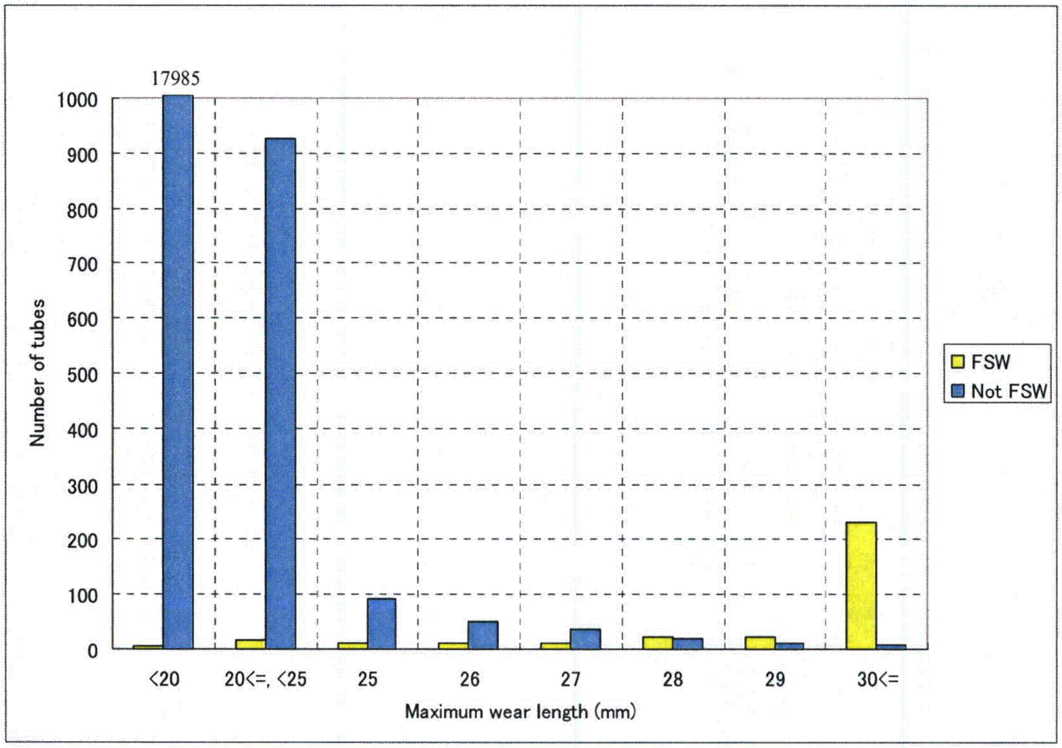


Figure 8 AVB Wear length (LENGTH)

Figure 9 Void fraction (VOID)

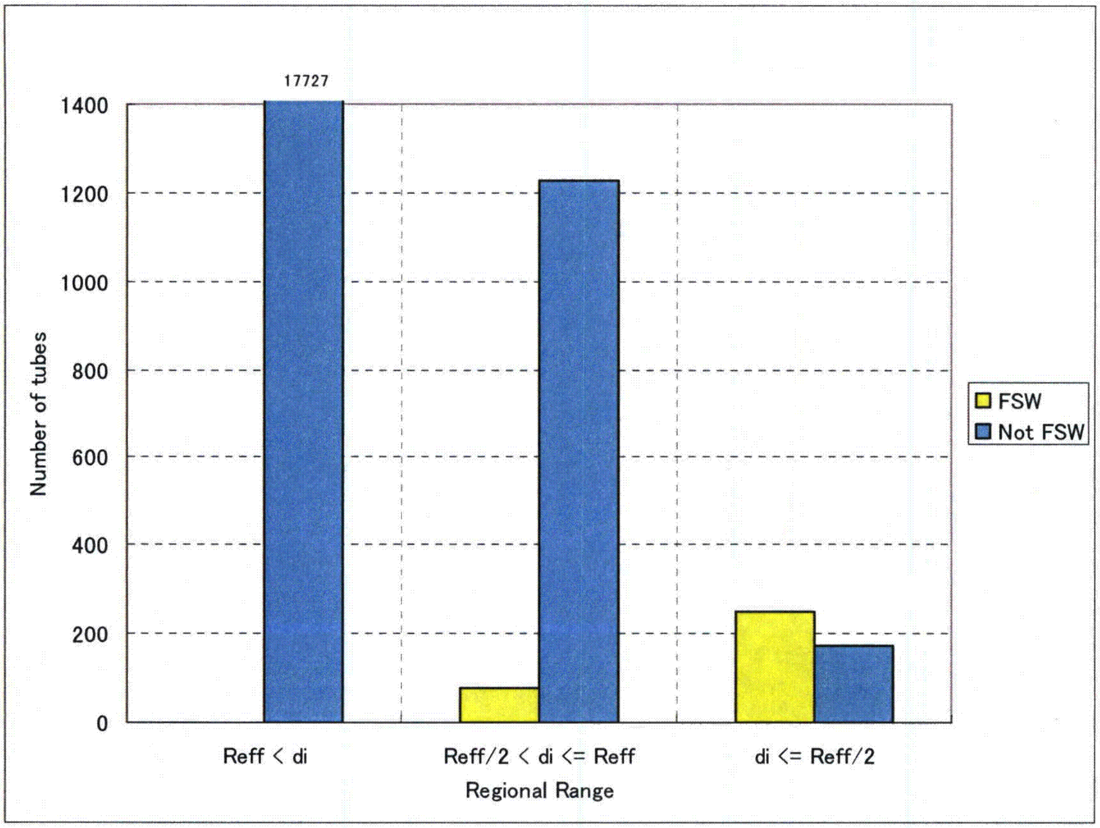


Figure 10 Regional effect (REGION)

Table 2 Number of AVB indications (COUNT)

Number of AVB Indications	Unit 3A/3B Total Tubes [A]	Unit 3A/3B FSW Tubes [B]	[B]/[A] [%]	Points Awarded
0 – 3	18736	11	0	0
4 – 6	395	47	12	1
7 – 9	144	91	63	6
10 – 12	179	177	99	10
Total	19454	326		

Table 3 Number of hot side AVB indications (HOT COUNT)

Number of AVB Indications	Unit 3A/3B Total Tubes [A]	Unit 3A/3B FSW Tubes [B]	[B]/[A] [%]	Points Awarded
0 – 2	18887	25	0	0
3 – 4	331	80	24	3
5 – 6	236	221	94	9
Total	19454	326		

Table 4 AVB wear indications at B01/B02 or B11/B12 positions (HIGH/LOW)

Number of AVB Indications	Unit 3A/3B Total Tubes [A]	Unit 3A/3B FSW Tubes [B]	[B]/[A] [%]	Points Awarded
0	19220	98	1	0
1	94	88	94	9
2	140	140	100	10
Total	19454	326		

Table 5 Number of continuous AVB indications (CONTINUOUS)

Number of AVB Indications	Unit 3A/3B Total Tubes [A]	Unit 3A/3B FSW Tubes [B]	[B]/[A] [%]	Points Awarded
0 – 2	18725	19	0	0
3 – 5	431	91	21	2
6 – 8	163	85	52	5
9 – 12	135	131	97	10
Total	19454	326		

Table 6 TSP wear (TSP)

Indication at #7TSP	Unit 3A/3B Total Tubes [A]	Unit 3A/3B FSW Tubes [B]	[B]/[A] [%]	Points Awarded
No	19050	11	0	0
Yes	404	315	78	8*1
Total	19454	326		
Indication at #6TSP	**Unit 3A/3B Total Tubes [A]**	**Unit 3A/3B FSW Tubes [B]**	**[B]/[A] [%]**	**Points Awarded**
No	19106	31	0	0
Yes	348	295	85	8*1
Total	19454	326		
Indication at #5TSP	**Unit 3A/3B Total Tubes [A]**	**Unit 3A/3B FSW Tubes [B]**	**[B]/[A] [%]**	**Points Awarded**
No	19148	51	0	0
Yes	306	275	90	9*1
Total	19454	326		

*1: These points are allocated for "TSP." Only the maximum value of these points is used for screening.

Table 7 Wear length (LENGTH)

Max. AVB Wear Length for Each Tube [mm]	Unit 3A/3B Total Tubes [A]	Unit 3A/3B FSW Tubes [B]	[B]/[A] [%]	Points Awarded
<20	17990	5	0	0
20<=, <25	942	16	2	0
25	103	11	11	1
26	62	11	18	2
27	45	10	22	3
28	41	21	51	5
29	31	21	68	7
30<=	240	231	96	10
Total	19454	326		

Table 8 Void fraction (VOID)

Void Fraction Range [-]	Unit 3A/3B Total Tubes [A]	Unit 3A/3B FSW Tubes [B]	[B]/[A] [%]	Points Awarded

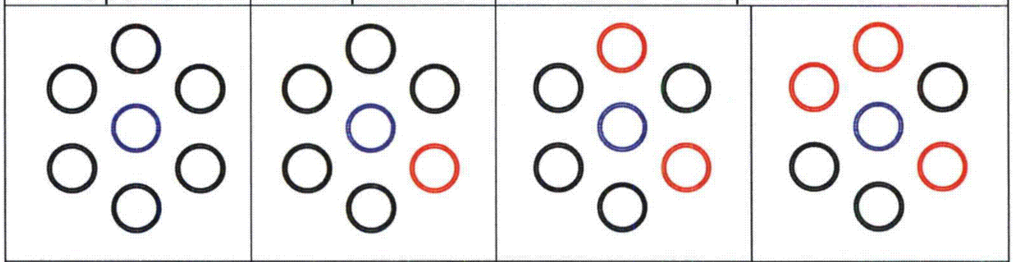
Table 9 Regional effect (REGION)

Regional Range [-]	Unit 3A/3B Total Tubes [A]	Unit 3A/3B FSW Tubes [B]	[B]/[A] [%]	Points Awarded
di <= Reff/2	422	250	59	6
Reff/2 < di <= Reff	1305	76	6	1
Reff < di	17727	0	0	0
Total	19454	326		

UNIT	Reff [inch]
3A-SG	15.46
3B-SG	15.57

Table 10 Coupling effect (COUPLING)

After selection of screening level from the first eight criteria, additional points are added by the following process which accounts for "coupling effect." See Section 4 for details of this process.

0 points	5 points	10 points
		
No adjacent tube	One adjacent tube	Two or more adjacent tubes

: Tube under consideration for coupling effect

: Screened tubes with more than 16 points

4 Screening Level Selection

The screening effectiveness using the point system for Unit 3 ECT data is checked in the following manner:

(1) The points for each of the first eight criteria are summed for each tube. Then, the number of tubes and FSW tubes for each point category are counted to give the number of tubes falling in each point range. Table 11 shows the number of tubes with wear, the number of FSW tubes, and the number of tubes without FSW in each point range.
(2) A screening level is selected, based on the results shown in Table 11, such that a high percentage of tubes exhibiting FSW is above the screening level.
(3) Additional tubes are selected considering coupling effect.
(4) A false negative check on the screening level is performed by ensuring that the point total, including coupling effect, for all tubes exhibiting FSW is above the screening level. This conservatively assures that the false negative rate for the final screening level is zero.

A listing of all tubes in the Unit 3 steam generators with tube scores greater than 16 and added tubes for the coupling effect is included in Appendix-1 with the point breakdown. Table 12 shows the non-FSW tubes in 3A-SG and 3B-SG that were screened in. Figure 12 shows that the final screening, including the coupling effect, covers all FSW tubes; that is, the false negative rate for the final screening level is zero.

Table 11 (1/2) False negative / positive check unit 3A

without coupling effect	Total Tubes	Tubes with FSW	Tubes without FSW
25 points +	158	150	8
24 points	2	1	1
23 points	3	1	2
22 points	4	0	4
21 points	4	2	2
20 points	6	1	5
19 points	2	0	2
18 points	4	1	3
17 points	14	2	12
16 points	10	1	9
15 points	9	1	8
14 points	24	2	22
13 points	10	1	9
12 points	9	1	8
11 points	13	1	12
10 points	4	0	4
9 points	43	0	43
8 points	19	0	19
7 points	8	0	8
6 points	39	0	39
5 points	39	0	39
4 points	28	0	28
3 points	215	0	215
2 points	37	0	37
1 points	47	0	47
0 points	143	0	143
Total	894	165	729

Note 1: Tubes with FSW with fewer than 16 points are False Negatives

Total False Negatives = 6

Note 2: Tubes without FSW with 16 points + are False Postivies

Total False Positives = 48

Note 3: Previously plugged tubes related to retainer bar wear (1 tube in 3A-SG) are not included in total tubes.

Table 11 (2/2) False negative / positive check unit 3B

without coupling effect	Total Tubes	Tubes with FSW	Tubes without FSW
25 points +	155	136	19
24 points	7	3	4
23 points	3	2	1
22 points	7	2	5
21 points	4	1	3
20 points	4	0	4
19 points	10	3	7
18 points	12	2	10
17 points	16	4	12
16 points	7	2	5
15 points	9	1	8
14 points	20	1	19
13 points	3	1	2
12 points	17	1	16
11 points	32	2	30
10 points	15	0	15
9 points	45	0	45
8 points	35	0	35
7 points	24	0	24
6 points	19	0	19
5 points	21	0	21
4 points	27	0	27
3 points	192	0	192
2 points	38	0	38
1 points	47	0	47
0 points	149	0	149
Total	918	161	757

Note 1: Tubes with FSW with fewer than 16 points are False Negatives

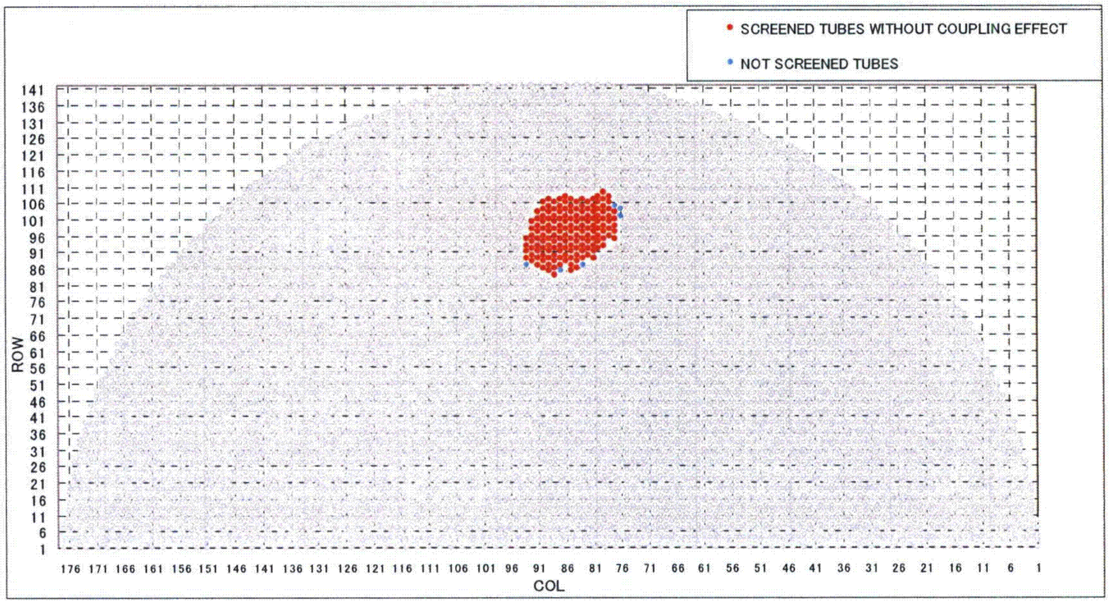
Total False Negatives = 6

Note 2: Tubes without FSW with 16 points + are False Postivies

Total False Positives = 70

Note 3: Previously plugged tubes related to retainer bar wear (3 tubes in 3B-SG) are not included in total tubes.

Unit 3A



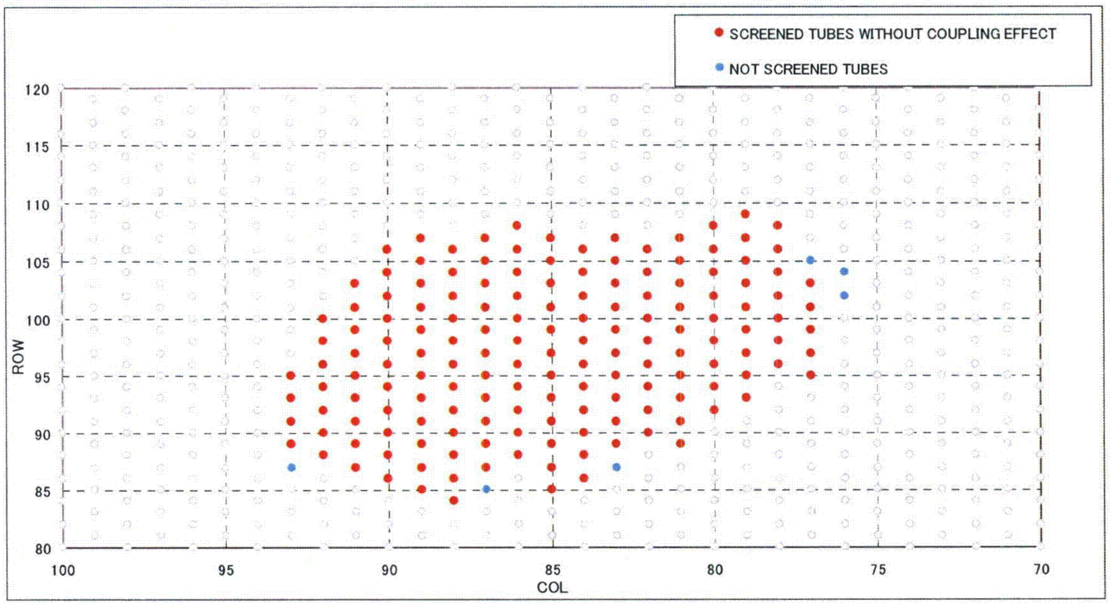
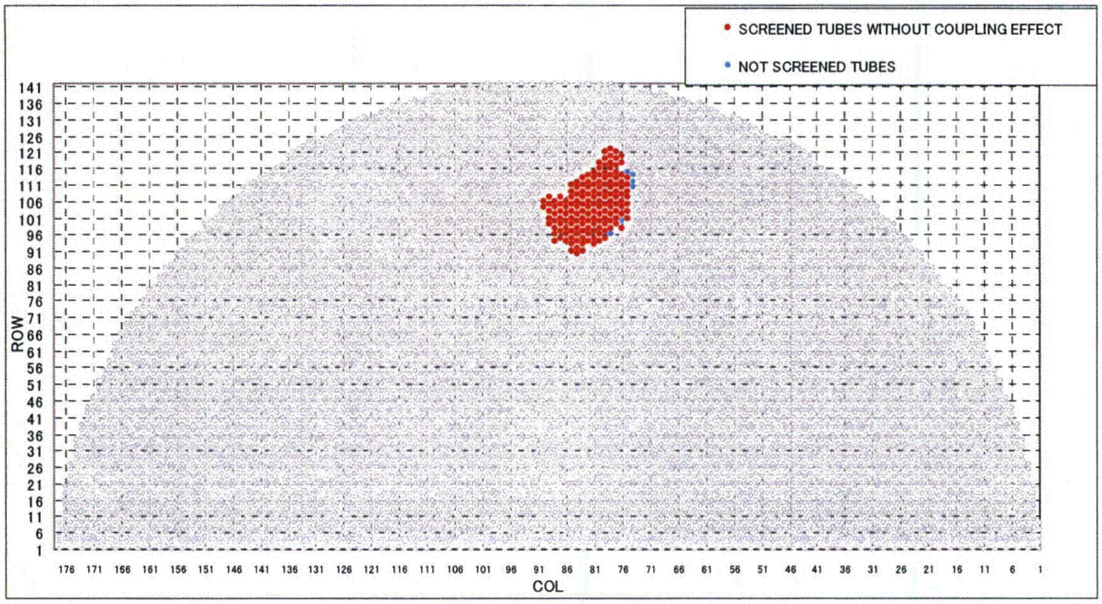


Figure 11 (1/2) False negative check (Unit 3A)

Unit 3B



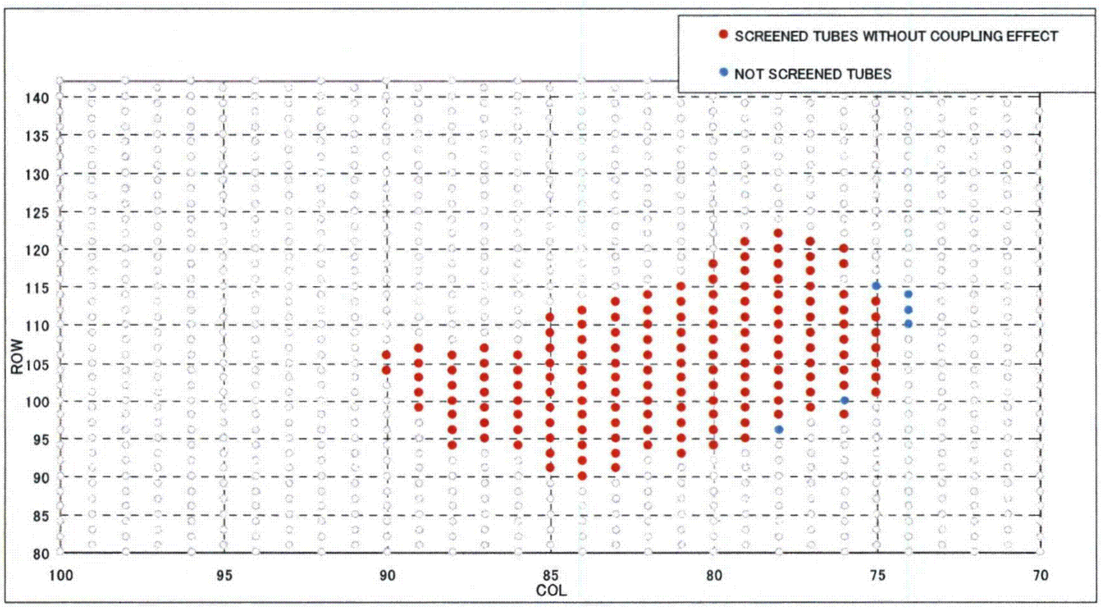
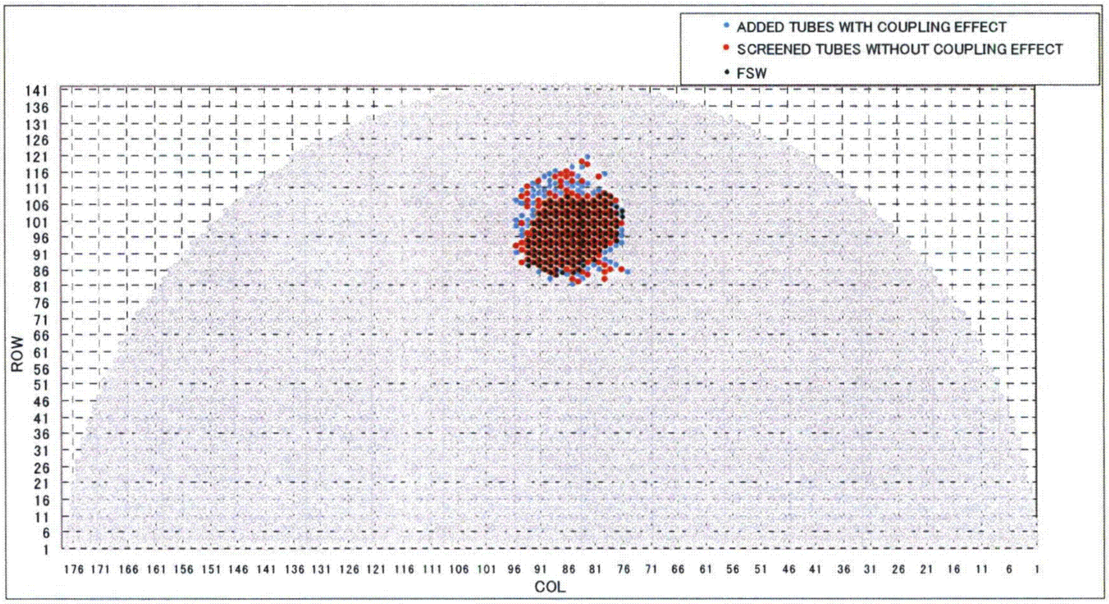


Figure 11 (2/2) False negative check (Unit 3B)

Unit 3A



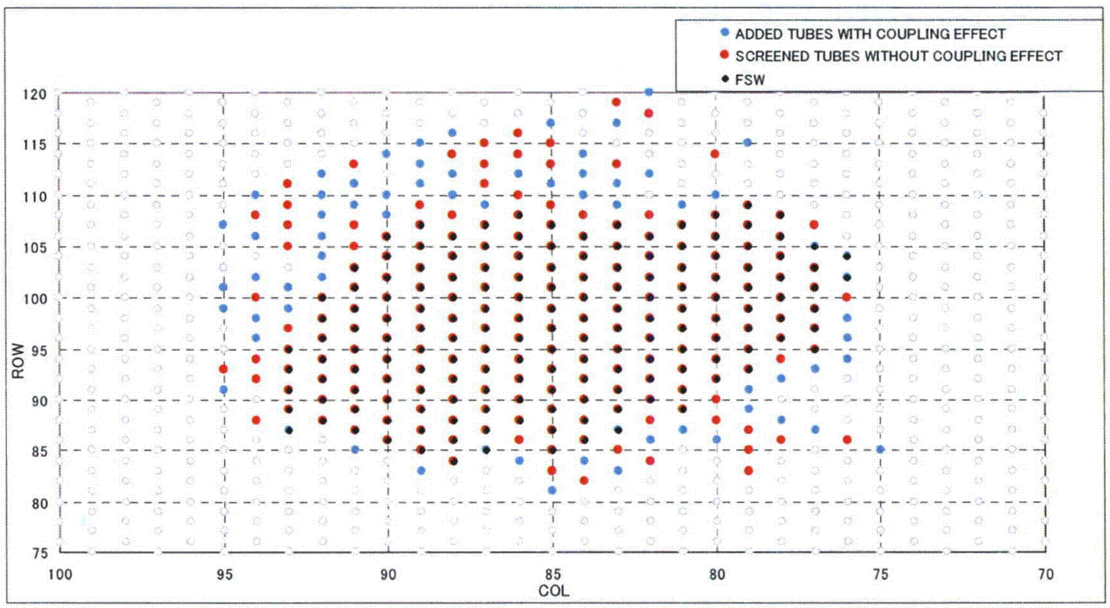
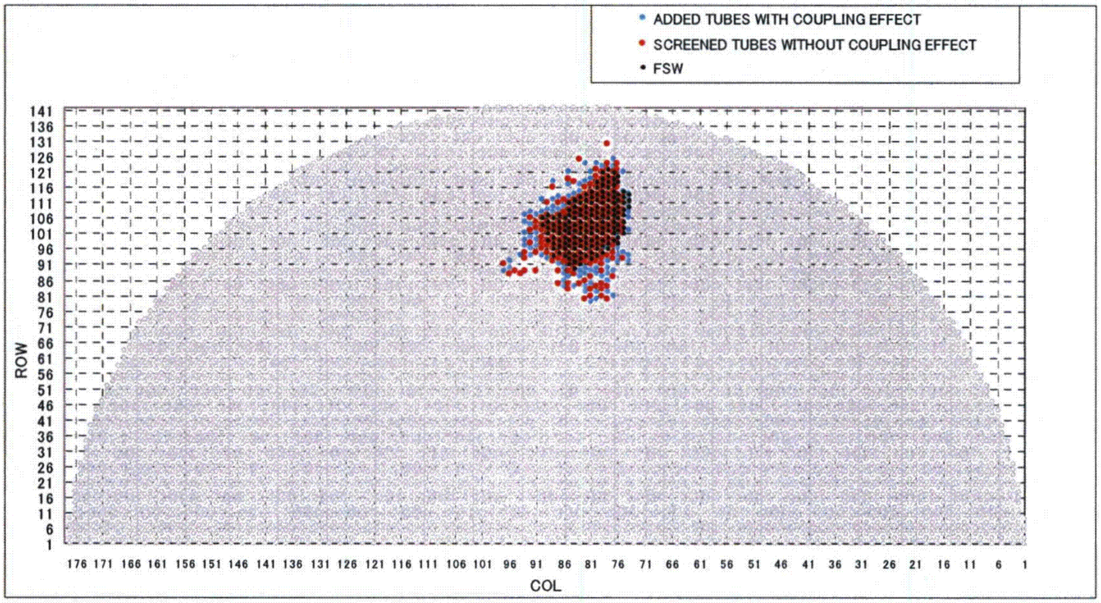


Figure 12 (1/2) False positive check (Unit 3A)

Unit 3B



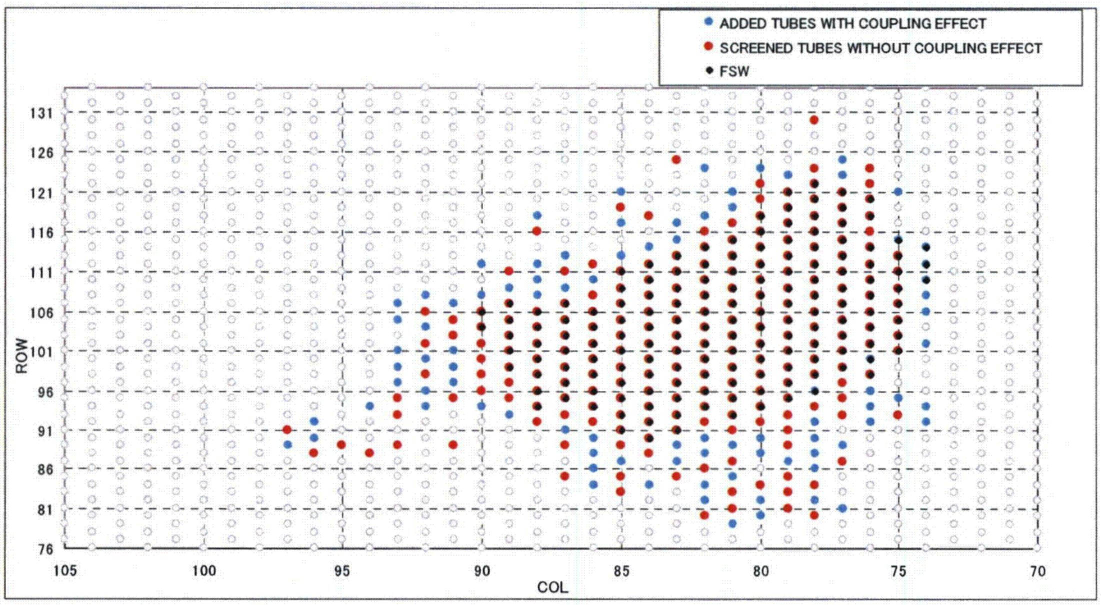


Figure 12 (2/2) False positive check (Unit 3B)

Table 12 (1/2) False positive check (Unit 3A)

	3A					
	Number of tubes (incl. FSW tubes)	Number of FSW tubes		Number of NOT FSW tubes		ratio of FSW/All tubes [B/A] [%]
	Number [A]	Number of FSW [B]	Cumulative ratio [%]	Number of NOT FSW	Cumulative ratio [%]	
Tube point 16 or over	207	159	96	48	7	77
Coupling effect	68	6	4	62	9	9
Total	275 /894	165 /165	100	110 /729	15	60

Table 12 (2/2) False positive check (Unit 3B)

	3B					
	Number of tubes (incl. FSW tubes)	Number of FSW tubes		Number of NOT FSW tubes		ratio of FSW/All tubes [B/A] [%]
	Number [A]	Number of FSW [B]	Cumulative ratio [%]	Number of NOT FSW	Cumulative ratio [%]	
Tube point 16 or over	225	155	96	70	9	69
Coupling effect	88	6	4	82	11	7
Total	313 /918	161 /161	100	152 /757	20	51

5 Screening results of Unit 2 steam generators

MHI selected a value of 16 points to apply as the screening criteria for the Unit 2 steam generators. Table 13 shows the number of tubes that screened-in without the coupling effect. Table 14 shows the number of tubes that screened-in, including tubes added with the coupling effect. A listing of all tubes in the Unit 2 steam generators with tube scores greater than 16 points and tubes added with the coupling effect is included in Tables 15 and 16 with the point break down. The screened tubes are shown in Figure 13. 6

The number of screened tubes for each point category on each criterion is counted and compared to the number of tubes with wear indications. If a tube has a high number of points the tubes were screened-in (See Tables 17 to 24.)

Table 13 Number of screened tubes of Unit 2 without coupling effect

without coupling effect	2A	2B
	Total Tubes	Total Tubes
16 points +	115	36
15 points	9	8
14 points	31	24
13 points	13	8
12 points	19	14
11 points	28	33
10 points	13	18
9 points	38	67
8 points	33	86
7 points	10	18
6 points	57	37
5 points	36	33
4 points	39	19
3 points	168	157
2 points	56	32
1 points	33	20
0 points	157	110
Total	855	720

Note: Previously plugged tubes related to retainer bar wear (6 tubes in 2A-SG and 12 tubes in 2B-SG) and over 30% AVB wear (4 tubes in 2B-SG) are not included in total tubes in both steam generators.

Table 14 (1/2) Number of screened tubes of Unit 2A with coupling effect

	2A					
	Number of tubes (incl. FSW tubes)	Number of FSW tubes		Number of NOT FSW tubes		ratio of FSW/All tubes [B/A] [%]
	Number [A]	Number of FSW [B]	Cumulative ratio [%]	Number of NOT FSW	Cumulative ratio [%]	
Tube point 16 or over	115	0	0	115	13	0
Coupling effect	88	2	100	86	10	2
Total	203 /855	2 /2	100	201 /853	24	1

Table 14 (2/2) Number of screened tubes of Unit 2B with coupling effect

	2B					
	Number of tubes (incl. FSW tubes)	Number of FSW tubes		Number of NOT FSW tubes		ratio of FSW/All tubes [B/A] [%]
	Number [A]	Number of FSW [B]	Cumulative ratio [%]	Number of NOT FSW	Cumulative ratio [%]	
Tube point 16 or over	36			36	5	
Coupling effect	63			63	9	
Total	99 /720	0 /0		99 /720	14	

Additional tubes in 2A-SG and 2B-SG were selected for preventative plugging even though they were below the screening level of 16 points (see Tables 15 and 16). These tubes were selected for preventative plugging because they had seven or more AVB indications. All other tubes with seven or more AVB indications screened in.

Table 15 Tubes recommended for plugging in Unit 2A

	Tube		Tube-to-AVB friction		Vibration frequency		In-plane tube motion		Void fraction	Regional effect	Coupling effect	
No.	Row	Col	COUNT	HOT COUNT	HIGH/LOW	CONTINOUS	TSP (Max Wear Rate at #5-#7TSP)	MAX LENGTH on AVB WEAR	VOID	REGION	COUPLING	Total
1	88	86	6	3	0	5	0	2	2	1	0	19
2	90	82	1	0	0	2	0	3	2	1	10	19
3	90	84	1	0	0	2	9	0	2	1	10	25
4	91	81	1	0	0	2	0	2	2	1	10	18
5	91	83	6	3	0	5	0	0	2	1	10	27
6	91	85	6	3	0	5	0	2	2	1	10	29
7	92	80	1	0	0	2	0	0	2	1	10	16
8	92	82	1	3	0	5	8	3	2	1	10	33
9	92	84	6	3	0	5	0	0	2	1	10	27
10	92	86	1	3	0	2	0	0	2	1	10	19
11	93	81	1	0	0	2	8	2	2	1	10	26
12	93	83	1	0	0	2	0	2	2	6	10	23
13	93	85	1	3	0	5	0	3	2	6	10	30
14	93	87	1	0	0	2	8	1	2	6	10	30
15	94	80	6	3	0	5	0	0	2	1	5	22
16	94	82	1	0	0	2	0	7	2	6	10	28
17	94	84	1	3	0	2	0	2	2	6	10	26
18	94	86	6	3	0	5	8	3	2	6	10	43
19	94	88	6	3	0	5	0	0	2	6	10	32
20	95	81	1	0	0	2	0	1	2	6	10	22
21	95	83	1	0	0	2	0	2	2	6	10	23
22	95	85	1	3	0	2	9	3	2	6	10	36
23	95	87	0	0	0	2	8	0	2	6	10	28
24	95	89	6	3	0	5	8	1	2	6	5	36
25	96	80	1	0	0	2	0	0	2	6	5	16
26	96	82	1	3	0	2	0	0	2	6	10	24
27	96	84	1	0	0	2	0	1	2	6	10	22
28	96	86	1	3	0	2	0	0	2	6	10	24
29	96	88	1	3	0	2	0	0	2	6	10	24
30	97	79	1	0	0	2	0	0	2	6	5	16
31	97	81	1	0	0	2	0	0	2	6	10	21
32	97	83	1	0	0	5	0	0	2	6	10	24
33	97	85	6	3	0	5	0	0	2	6	10	32
34	97	87	1	3	0	5	8	0	2	6	10	35
35	97	89	1	3	0	2	0	0	2	6	10	24
36	98	80	1	0	0	2	0	0	2	6	10	21
37	98	82	6	3	0	5	0	0	2	6	10	32
38	98	84	6	3	0	5	0	1	2	6	10	33
39	98	86	6	3	0	5	0	0	2	6	10	32
40	98	88	6	3	0	5	0	0	2	6	10	32
41	98	92	1	3	0	2	9	0	2	1	0	18
42	99	79	1	3	0	5	0	1	2	6	0	18
43	99	81	6	3	0	5	0	2	2	6	10	34
44	99	83	6	3	0	5	0	3	2	6	10	35
45	99	85	6	3	0	5	0	7	2	6	10	39
46	99	87	1	3	0	5	0	2	2	6	10	29
47	99	89	6	3	0	5	0	2	2	6	10	34
48	99	91	1	0	0	2	0	2	2	6	5	18
49	100	78	1	0	0	2	0	0	2	6	10	21
50	100	80	1	0	0	2	0	2	2	6	10	23
51	100	82	1	0	0	5	0	7	2	6	10	31
52	100	84	6	3	0	5	0	3	2	6	10	35
53	100	86	1	3	0	5	0	1	2	6	10	28
54	100	88	6	3	0	5	0	1	2	6	10	33
55	100	90	1	0	0	2	0	1	2	6	10	22
56	101	79	1	0	0	2	0	0	2	6	10	21
57	101	81	1	3	0	5	0	0	2	6	10	27
58	101	83	6	9	0	5	8	3	2	6	10	49
59	101	85	6	3	0	5	0	5	2	6	10	37
60	101	87	1	0	0	2	0	0	2	6	10	21
61	101	89	6	3	0	5	0	0	2	6	10	32
62	102	78	1	0	0	2	0	5	2	6	0	16
63	102	80	1	0	0	2	0	3	2	6	5	19
64	102	82	6	3	0	5	0	3	2	6	10	35
65	102	84	6	3	0	5	0	3	2	6	10	35
66	102	86	6	3	0	5	0	3	2	6	10	35
67	102	88	6	3	0	5	0	1	2	6	10	33
68	102	90	1	0	0	2	0	0	2	6	10	21
69	102	94	1	0	0	2	0	1	2	1	10	17
70	103	77	1	3	0	2	0	0	2	6	5	19
71	103	81	1	0	0	2	0	1	2	6	10	22
72	103	83	1	3	0	5	0	2	2	6	10	29
73	103	85	1	3	0	5	0	5	2	6	10	32
74	103	87	1	3	0	5	0	1	2	6	10	28
75	103	89	1	3	0	5	0	0	2	6	10	27
76	103	93	0	0	0	0	9	0	2	6	0	17
77	103	95	1	3	0	2	8	0	2	1	0	17
78	104	78	1	0	0	2	0	1	2	6	5	17
79	104	82	1	3	0	5	0	1	2	6	10	28
80	104	84	1	3	0	5	0	2	2	6	10	29
81	104	86	6	3	0	5	0	2	2	6	10	34
82	104	88	1	3	0	5	0	1	2	6	10	28
83	104	90	1	3	0	2	0	0	2	6	10	24
84	104	92	1	3	0	2	0	1	2	6	5	20
85	105	81	1	0	0	2	0	3	2	6	10	24
86	105	83	6	3	0	5	0	5	2	6	10	37
87	105	85	6	9	0	5	9	5	2	6	10	52
88	105	87	1	3	0	2	0	3	2	6	10	27
89	105	89	1	3	0	2	0	2	2	6	10	26
90	105	91	0	0	0	2	0	3	2	6	5	18
91	105	95	0	0	0	0	0	3	2	1	10	16
92	106	82	1	3	0	5	0	1	2	6	10	28
93	106	84	6	3	0	5	0	1	2	6	10	33
94	106	86	1	3	0	2	8	0	2	6	10	32
95	106	88	1	0	0	5	0	0	2	6	10	24
96	106	90	1	3	0	2	0	0	2	6	10	24
97	107	81	1	0	0	2	0	3	2	6	10	24
98	107	83	1	3	0	2	0	0	2	6	10	24
99	107	85	6	3	0	5	0	0	2	6	10	32
100	107	87	1	0	0	2	0	7	2	6	10	28
101	107	89	1	3	0	2	0	0	2	6	10	24
102	107	91	1	0	0	2	0	5	2	6	10	26
103	107	95	1	3	0	2	9	0	2	1	0	18
104	108	78	1	0	0	2	0	2	2	6	5	18
105	108	82	6	9	0	5	0	3	2	6	10	41

	Tube		Tube-to-AVB friction		Vibration frequency		In-plane tube motion		Void fraction	Regional effect	Coupling effect	Total
No.	Row	Col	COUNT	HOT COUNT	HIGH/LOW	CONTINOUS	TSP (Max Wear Rate at #5-#7TSP)	MAX LENGTH on AVB WEAR	VOID	REGION	COUPLING	
106	108	84	1	0	0	2	0	1	2	6	10	22
107	108	86	1	3	0	5	0	0	2	6	10	27
108	108	88	1	0	0	2	0	0	2	6	10	21
109	108	90	1	3	0	5	0	2	2	6	10	29
110	108	92	1	0	0	0	0	0	2	6	10	19
111	109	77	1	0	0	2	0	1	2	6	10	22
112	109	81	1	0	0	2	9	0	2	6	10	30
113	109	83	6	3	0	5	0	1	2	6	10	33
114	109	85	1	0	0	2	8	0	2	6	10	29
115	109	87	1	3	0	2	0	1	2	6	10	25
116	109	89	1	3	0	5	0	0	2	6	10	27
117	109	91	1	3	0	2	8	1	2	6	10	33
118	109	95	0	0	0	0	9	0	2	1	5	17
119	109	97	0	0	0	0	9	0	2	1	5	17
120	110	78	1	0	0	2	9	7	2	6	5	32
121	110	80	1	0	0	2	0	1	2	6	10	22
122	110	82	1	3	0	2	0	3	2	6	10	27
123	110	84	1	3	0	5	0	1	2	6	10	28
124	110	86	1	3	0	2	8	1	2	6	10	33
125	110	88	1	3	0	5	0	2	2	6	10	29
126	110	90	0	0	0	0	0	0	2	6	10	18
127	110	98	1	3	0	2	9	0	2	1	0	18
128	111	77	1	3	0	5	0	1	2	6	5	23
129	111	79	0	0	0	0	0	0	2	6	10	18
130	111	81	1	0	0	2	0	0	2	6	10	21
131	111	83	1	0	0	2	0	0	2	6	10	21
132	111	85	1	0	0	2	0	0	2	6	10	21
133	111	87	0	0	0	2	0	0	2	6	10	20
134	111	89	1	3	0	5	8	0	2	6	10	35
135	112	78	1	0	0	2	0	0	2	6	10	21
136	112	80	0	0	0	0	8	0	2	6	0	16
137	112	82	6	3	0	5	8	1	2	6	10	41
138	112	84	6	3	0	5	8	1	2	6	10	41
139	112	86	1	3	0	2	0	1	2	6	10	25
140	112	88	6	3	0	5	0	1	2	6	10	33
141	112	90	1	3	0	2	0	0	2	6	10	24
142	112	98	0	0	0	0	8	0	2	1	5	16
143	113	81	0	0	0	2	0	0	2	6	10	20
144	113	83	6	3	0	5	0	0	2	6	10	32
145	113	85	6	3	0	5	0	2	2	6	10	34
146	113	87	1	0	0	5	0	0	2	6	10	24
147	113	89	1	3	0	5	0	0	2	6	10	27
148	113	91	0	0	0	0	0	0	2	6	10	18
149	114	80	0	0	0	0	0	0	2	6	10	18
150	114	82	1	3	0	2	0	0	2	6	10	24
151	114	84	6	9	0	5	0	0	2	6	10	38
152	114	86	1	0	0	2	8	0	2	6	10	29
153	114	88	6	0	0	5	8	0	2	6	10	37
154	114	90	1	3	0	5	0	0	2	6	10	27
155	114	92	1	3	0	2	0	0	2	6	5	19
156	114	94	1	3	0	2	8	0	2	1	5	22
157	115	81	6	3	0	5	0	0	2	6	5	27
158	115	83	6	3	0	5	0	0	2	6	10	32
159	115	85	6	9	0	5	0	0	2	6	10	38
160	115	87	1	3	0	5	0	0	2	6	10	27
161	115	89	1	3	0	2	8	0	2	6	10	32
162	115	91	0	0	0	2	9	0	2	6	10	29
163	115	93	1	3	0	2	0	0	2	1	10	19
164	115	95	1	0	0	2	0	0	2	1	10	16
165	116	82	1	3	0	2	8	0	2	6	10	32
166	116	84	6	3	0	5	0	0	2	6	10	32
167	116	86	1	3	0	5	8	0	2	6	10	35
168	116	88	1	3	0	5	0	0	2	6	10	27
169	116	90	1	3	0	5	8	0	2	6	10	35
170	116	92	1	3	0	5	0	0	2	1	5	17
171	116	94	1	3	0	5	8	0	2	1	5	25
172	117	81	1	0	0	5	0	0	2	6	10	24
173	117	83	1	0	0	2	0	0	2	6	10	21
174	117	85	6	3	0	5	0	1	2	6	10	33
175	117	87	1	0	0	2	8	0	2	6	10	29
176	117	89	1	3	0	2	0	0	2	6	10	24
177	117	91	0	0	0	0	0	0	2	6	10	18
178	118	82	1	3	0	5	0	0	2	6	10	27
179	118	84	1	3	0	2	0	0	2	6	10	24
180	118	86	1	3	0	2	0	0	2	6	10	24
181	118	88	1	0	0	2	0	0	2	6	10	21
182	118	90	1	3	0	2	0	1	2	6	5	20
183	119	81	1	3	0	2	0	0	2	6	10	24
184	119	83	1	3	0	2	0	0	2	6	10	24
185	119	85	0	0	0	2	0	0	2	6	10	20
186	119	87	1	0	0	2	0	0	2	6	5	16
187	120	82	1	3	0	5	0	2	2	6	10	29
188	120	84	1	3	0	5	0	0	2	6	0	17
189	121	81	1	0	0	2	0	0	2	1	10	16
190	121	83	1	0	0	0	0	3	2	6	10	22
191	121	85	1	0	0	2	0	0	2	6	5	16
192	122	82	6	3	0	5	0	2	2	1	5	24
193	123	91	6	3	0	5	0	0	2	1	0	17
194	126	84	1	3	0	2	8	0	2	1	0	17
195	127	85	6	3	0	2	0	0	2	1	5	19
196	128	84	1	3	0	5	0	0	2	1	5	17
197	129	87	1	3	0	5	8	0	2	1	0	20
198	130	86	1	0	0	2	8	0	2	1	5	19
199	130	90	1	3	0	2	0	3	2	1	5	17
200	131	89	1	0	0	2	8	1	2	1	5	20
201	132	84	6	0	0	5	8	1	0	1	0	21
202	132	90	6	3	0	5	0	2	0	1	5	22
203	134	90	6	3	0	5	8	0	0	1	5	28
204	122*	86*	6	0	0	5	0	0	2	1	0	14
205	138*	88*	6	3	0	5	0	0	0	0	0	14

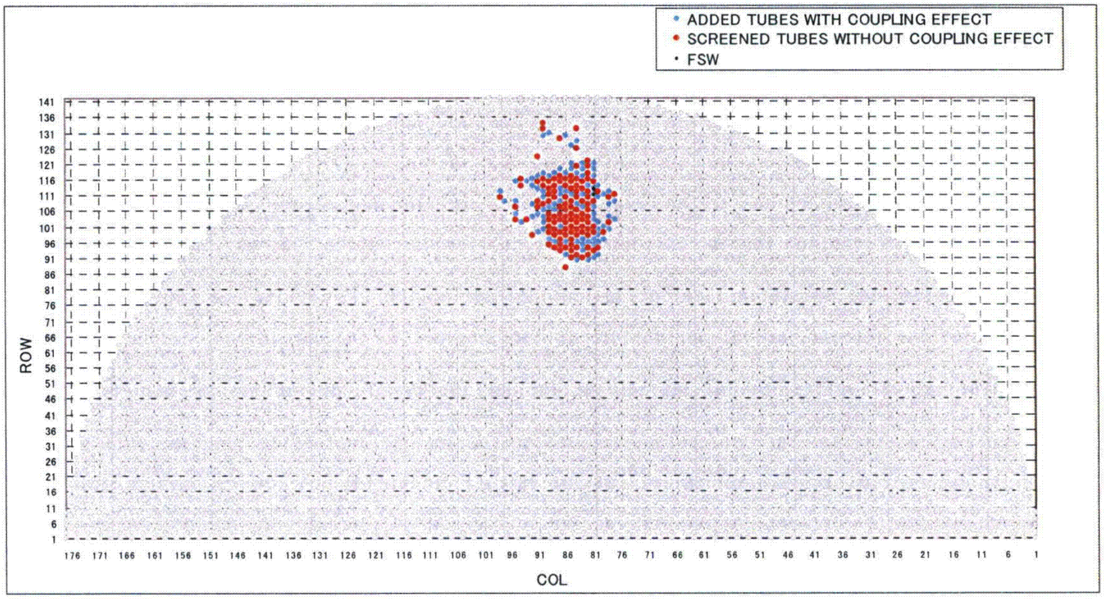
*This tube is additionally selected.

Table 16 Tubes recommended for plugging in Unit 2B

	Tube		Tube-to-AVB friction		Vibration frequency		In-plane tube motion		Void fraction	Regional effect	Coupling effect	Total
No.	Row	Col	COUNT	HOT COUNT	HIGH/LOW	CONTINOUS	TSP (Max Wear Rate at #5-#7TSP)	MAX LENGTH on AVB WEAR	VOID	REGION	COUPLING	
1	94	90	6	3	0	5	0	3	2	1	0	20
2	94	94	6	3	0	5	8	3	2	1	0	28
3	95	89	1	3	0	5	0	0	2	1	5	17
4	95	91	1	3	0	2	0	2	2	1	5	16
5	97	85	6	3	0	5	0	1	2	1	0	18
6	98	86	1	3	0	5	0	0	2	1	5	17
7	98	92	1	0	0	2	0	7	2	1	5	18
8	99	85	1	3	0	5	0	1	2	1	5	18
9	99	93	6	3	0	5	9	7	2	1	0	33
10	100	86	1	3	0	5	0	1	2	1	5	18
11	100	88	1	3	0	2	0	1	2	6	5	20
12	100	90	1	3	0	2	0	1	2	6	5	20
13	100	92	1	0	0	2	0	1	2	1	10	17
14	101	87	1	3	0	5	0	0	2	6	0	17
15	101	89	1	0	0	0	0	0	2	6	10	19
16	101	91	0	0	0	2	0	0	2	6	10	20
17	101	93	1	0	0	5	0	0	2	1	10	19
18	102	86	0	0	0	0	0	0	2	6	10	18
19	102	88	1	3	0	2	0	1	2	6	10	25
20	102	90	1	3	0	2	8	0	2	6	10	32
21	102	92	6	3	0	5	8	2	2	6	5	37
22	103	85	1	0	0	0	0	2	2	6	10	21
23	103	87	0	0	0	2	0	0	2	6	10	20
24	103	89	6	3	0	5	0	1	2	6	10	33
25	103	91	1	3	0	2	0	5	2	6	10	29
26	103	93	1	0	0	2	0	3	2	6	5	19
27	104	84	1	3	0	5	0	0	2	6	10	27
28	104	86	1	3	0	5	0	2	2	6	5	24
29	104	88	1	0	0	2	0	1	2	6	10	22
30	104	90	6	3	0	2	0	0	2	6	10	29
31	104	92	1	0	0	5	0	1	2	6	10	25
32	105	83	0	0	0	0	0	0	2	6	10	18
33	105	85	6	3	0	5	0	0	2	6	10	32
34	105	87	1	3	0	2	0	1	2	6	5	20
35	105	89	1	3	0	5	0	2	2	6	10	29
36	105	91	0	0	0	0	0	1	2	6	10	19
37	106	84	6	3	0	5	0	0	2	6	10	32
38	106	86	1	0	0	0	0	0	2	6	10	19
39	106	88	1	0	0	5	0	1	2	6	5	20
40	106	90	0	0	0	0	0	0	2	6	10	18
41	106	92	1	0	0	2	9	0	2	6	0	20
42	107	83	0	3	0	0	0	0	2	6	5	16
43	107	85	6	3	0	5	0	3	2	6	10	35
44	107	89	1	0	0	2	0	3	2	6	5	19
45	107	91	1	0	0	2	0	2	2	6	5	18
46	107	93	1	0	0	2	0	1	2	6	5	17
47	108	84	1	0	0	2	0	0	2	6	10	21
48	108	86	1	3	0	2	0	0	2	6	5	19
49	108	92	0	0	0	0	0	0	2	6	10	18
50	109	91	1	0	0	2	0	0	2	6	5	16
51	110	88	1	0	0	2	0	0	2	6	10	21
52	110	90	1	0	0	2	0	1	2	6	5	17
53	110	92	1	0	0	0	8	0	2	6	5	22
54	111	87	1	3	0	5	0	2	2	6	0	19
55	111	89	1	3	0	2	0	2	2	6	0	16
56	111	91	1	0	0	2	0	3	2	6	10	24
57	111	93	0	0	0	0	0	1	2	6	10	19
58	112	86	1	3	0	2	0	0	2	6	10	24
59	112	90	1	3	0	2	0	0	2	6	10	24
60	112	92	6	3	0	5	0	1	2	6	10	33
61	113	87	1	0	0	2	0	1	2	6	10	22
62	113	89	1	0	0	2	0	1	2	6	10	22
63	113	91	6	3	0	5	0	1	2	6	10	33
64	114	86	6	3	0	5	0	0	2	6	0	22
65	114	88	1	3	0	2	0	0	2	6	5	19
66	114	90	1	3	0	2	8	0	2	6	10	32
67	114	92	0	0	0	0	0	0	2	6	10	18
68	115	85	1	0	0	2	0	0	2	6	5	16
69	115	87	1	0	0	5	0	0	2	6	5	19
70	115	89	6	3	0	5	0	2	2	6	5	29
71	115	91	1	0	0	2	0	0	2	6	10	21
72	116	86	1	3	0	2	0	0	2	6	5	19
73	116	88	1	0	0	2	0	0	2	6	10	21
74	116	90	1	3	0	2	0	0	2	6	10	24
75	116	92	6	3	0	5	0	0	2	6	5	27
76	117	89	1	0	0	5	0	0	2	6	10	24
77	117	91	1	0	0	2	0	0	2	6	10	21
78	117	93	1	0	0	2	0	0	2	6	10	21
79	118	88	6	3	0	5	0	0	2	6	0	22
80	118	92	6	3	0	5	0	0	2	6	5	27
81	119	89	1	0	0	2	0	0	2	6	5	16
82	120	82	0	0	0	0	8	0	2	1	5	16
83	120	88	0	0	0	2	0	0	2	6	10	20
84	121	81	1	3	0	2	9	0	2	1	0	18
85	121	85	0	0	0	0	0	0	2	6	10	18
86	121	87	1	3	0	2	0	0	2	6	10	24
87	121	89	0	0	0	0	0	0	2	6	10	18
88	122	84	0	0	0	2	9	0	2	6	0	19
89	122	86	1	3	0	5	0	0	2	6	0	17
90	122	88	1	3	0	5	0	0	2	6	5	22
91	123	85	1	3	0	2	0	0	2	6	10	24
92	123	87	0	0	0	0	0	0	2	6	10	18
93	123	89	1	0	0	2	9	0	2	6	5	25
94	124	86	0	0	0	0	0	0	2	6	10	18
95	124	88	0	0	0	0	0	0	2	6	10	18
96	125	87	1	3	0	2	0	0	2	6	5	19
97	126	86	6	3	0	5	0	0	2	1	0	17
98	129	93	1	3	0	5	8	0	2	1	0	20
99	133	85	6	3	0	5	9	0	0	1	0	24
100	127*	89*	6	3	0	2	0	0	2	1	0	14
101	136*	92*	6	3	0	2	0	1	0	1	0	13

*This tube is additionally selected.

Unit 2A



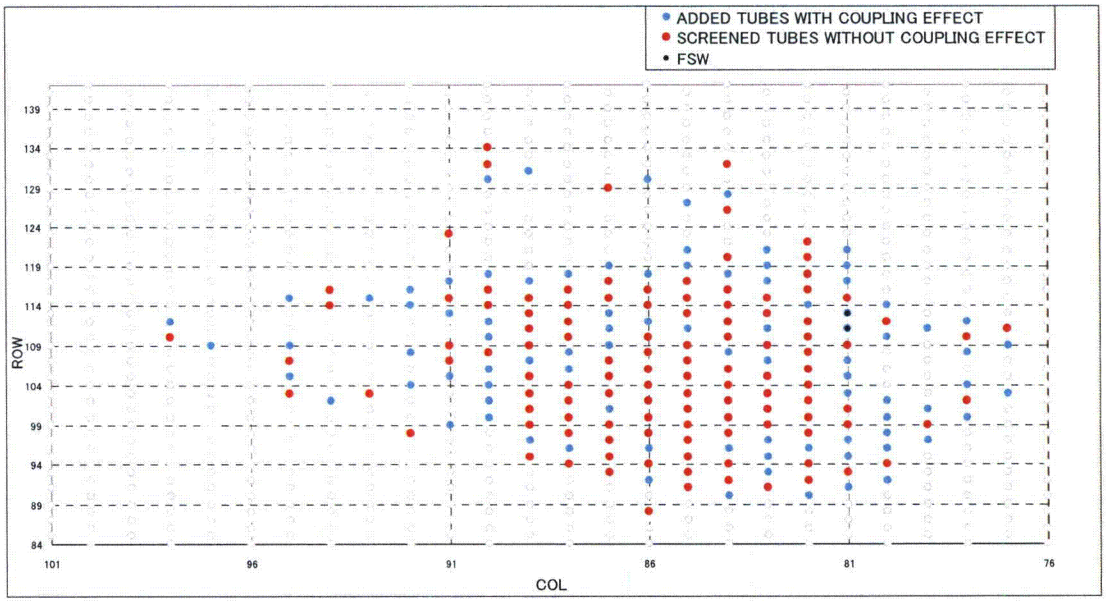
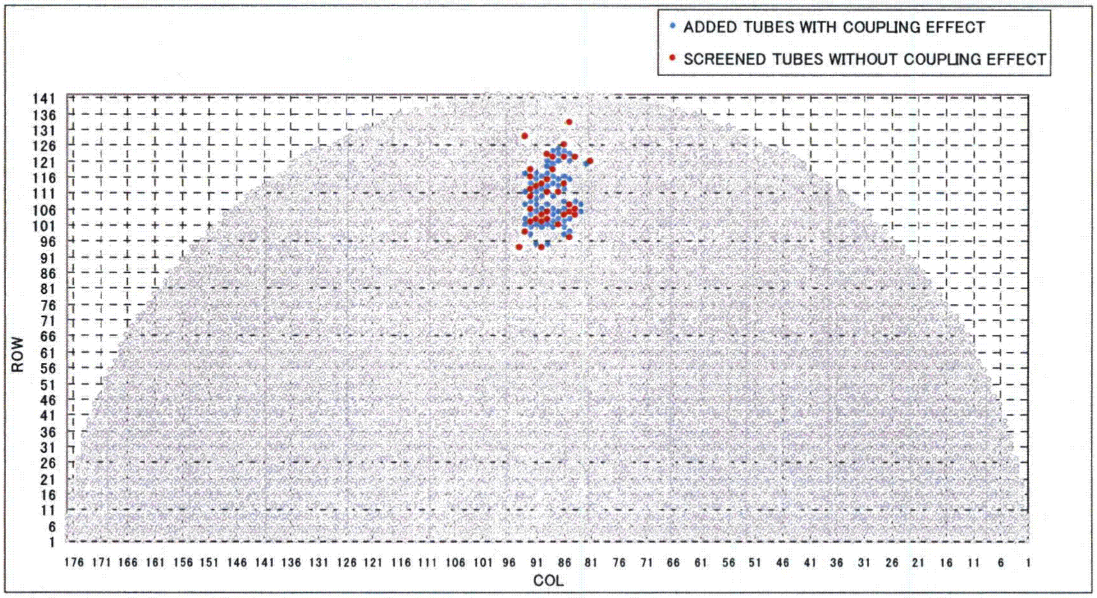


Figure 13 (1/2) Screened tubes (Unit 2A)

Unit 2B



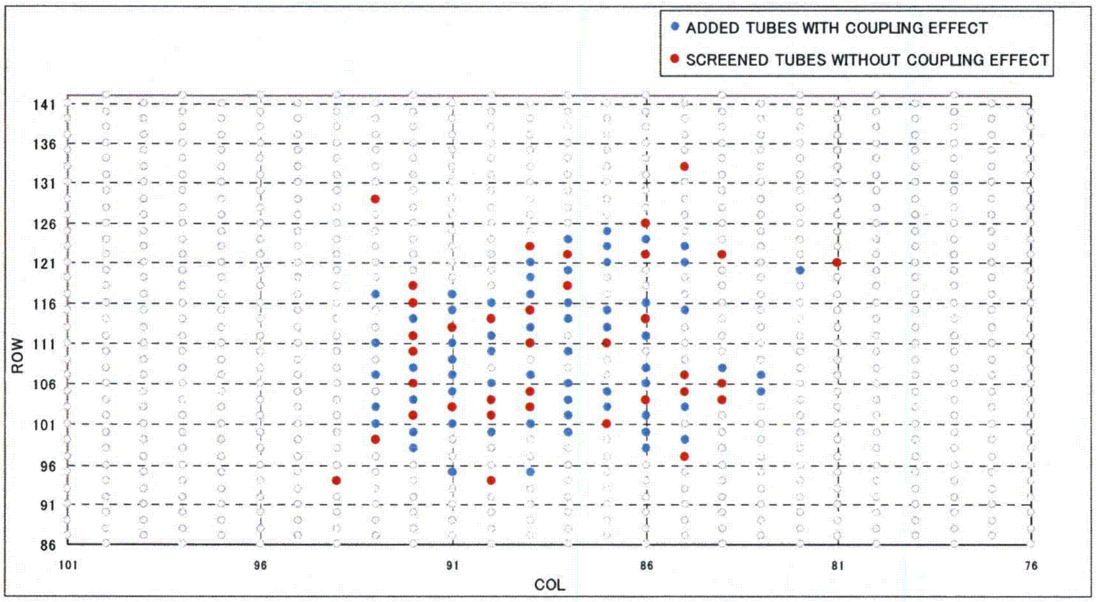


Figure 13 (2/2) Screened tubes (Unit 2B)

Table 17 Number of AVB indications (COUNT)

	2A			2B		
Number of AVB Indications	Number of Tubes [A1]	Break down of screened Tubes [B1]	Rate [B1]/[A1] %	Number of Tubes [A2]	Break down of screened Tubes [B2]	Rate [B2]/[A2] %
0	8923	0	0	9136	0	0
1	207	1	0	176	2	1
2	131	3	2	110	6	5
3	136	13	10	98	10	10
4	127	36	28	75	14	19
5	87	51	59	74	23	31
6	63	48	76	37	25	68
7	32	30	94	17	15	88
8	20	20	100	4	4	100
9	1	1	100	0	0	0
10	0	0	0	0	0	0
11	0	0	0	0	0	0
12	0	0	0	0	0	0
Total	9727	203		9727	99	

Table 18 Number of hot side AVB indications (HOT COUNT)

	2A			2B		
Number of AVB Indications	Number of Tubes [A1]	Break down of screened Tubes [B1]	Rate [B1]/[A1] %	Number of Tubes [A2]	Break down of screened Tubes [B2]	Rate [B2]/[A2] %
0	9103	0	0	9302	5	0
1	285	14	5	200	11	6
2	195	65	33	137	32	23
3	84	68	81	69	41	59
4	55	51	93	19	10	53
5	5	5	100	0	0	0
6	0	0	0	0	0	0
Total	9727	203		9727	99	

Table 19 AVB wear indications at B01/B02 or B11/B12 positions (HIGH/LOW)

	2A			2B		
Number of AVB Indications	Number of Tubes [A1]	Break down of screened Tubes [B1]	Rate [B1]/[A1] %	Number of Tubes [A2]	Break down of screened Tubes [B2]	Rate [B2]/[A2] %
0	9727	203	2	9727	99	1
1	0	0	0	0	0	0
2	0	0	0	0	0	0
Total	9727	203		9727	99	

Table 20 Number of continuous AVB indications (CONTINUOUS)

	2A			2B		
Number of AVB Indications	Number of Tubes [A1]	Break down of screened Tubes [B1]	Rate [B1]/[A1] %	Number of Tubes [A2]	Break down of screened Tubes [B2]	Rate [B2]/[A2] %
0	8923	0	0	9136	0	0
1	260	4	2	226	7	3
2	165	9	5	136	11	8
3	114	25	22	92	18	20
4	101	37	37	51	8	16
5	66	38	58	45	20	44
6	56	48	86	25	19	76
7	25	25	100	13	13	100
8	17	17	100	3	3	100
9	0	0	0	0	0	0
10	0	0	0	0	0	0
11	0	0	0	0	0	0
12	0	0	0	0	0	0
Total	9727	203		9727	99	

Table 21 TSP wear (TSP)

	2A			2B		
Indication at #7TSP	Number of Tubes [A1]	Break down of screened Tubes [B1]	Rate [B1]/[A1] %	Number of Tubes [A2]	Break down of screened Tubes [B2]	Rate [B2]/[A2] %
YES	40	23	58	32	8	25
NO	9687	180	2	9695	91	1
Total	9727	203		9727	99	
Indication at #6TSP	Number of Tubes [A1]	Break down of screened Tubes [B1]	Rate [B1]/[A1] %	Number of Tubes [A2]	Break down of screened Tubes [B2]	Rate [B2]/[A2] %
YES	30	18	60	40	1	3
NO	9697	185	2	9687	98	1
Total	9727	203		9727	99	
Indication at #5TSP	Number of Tubes [A1]	Break down of screened Tubes [B1]	Rate [B1]/[A1] %	Number of Tubes [A2]	Break down of screened Tubes [B2]	Rate [B2]/[A2] %
YES	30	12	40	47	6	13
NO	9697	191	2	9680	93	1
Total	9727	203		9727	99	

Table22 Wear length (LENGTH)

	2A			2B		
Max. AVB Wear Length for Each Tube [mm]	Number of Tubes [A1]	Break down of screened Tubes [B1]	Rate [B1]/[A1] %	Number of Tubes [A2]	Break down of screened Tubes [B2]	Rate [B2]/[A2] %
<25	9576	112	1	9623	61	1
25	73	36	49	59	20	34
26	41	23	56	23	9	39
27	26	21	81	15	6	40
28	6	6	100	4	1	25
29	5	5	100	3	2	67
30 or over	0	0	0	0	0	0
Total	9727	203		9727	99	

Table23 Void fraction (VOID)

	2A			2B		
Void Fraction Range [-]	Number of Tubes [A1]	Break down of screened Tubes [B1]	Rate [B1]/[A1] %	Number of Tubes [A2]	Break down of screened Tubes [B2]	Rate [B2]/[A2] %
[						
						]

Table 24 Regional effect (REGION)

Regional Range [−]	2A			2B		
	Number of Tubes [A1]	Break down of screened Tubes [B1]	Rate [B1]/[A1] %	Number of Tubes [A2]	Break down of screened Tubes [B2]	Rate [B2]/[A2] %
0	8958	0	0	9078	0	0
1	570	39	7	486	17	3
6	199	164	82	163	82	50
Total	9727	203		9727	99	

6 References

1. Letter RSG-SCE/MHI-12-5749, from D. Calhoun (SCE) to T. Kodama (MHI), August 3, 2012, Subject: "Updated ECT Data for Input to Return to Service and Repair Design Documents." 6

2. Letter RSG-SCE/MHI-12-5688, from D. Calhoun (SCE) to T. Kodama (MHI), March 22, 2012, Subject: "ECT Data for Input to Return to Service and Repair Design Documents."

Appendix-1
Screening results for Unit 3 Steam Generators

A listing of all tubes in the Unit 3 steam generators with tube scores greater than 16 and added tubes with the coupling effect is included in Table A-1, A-2 with the point break down.

Appendix-1

Table A-1 Screened tubes for Unit 3A

	Tube		Tube-to-AVB friction		Vibration frequency		In-plane tube motion		Void fraction	Regional effect	Coupling effect	
No.	Row	Col	COUNT	HOT COUNT	HIGH/LOW	CONTINOUS	TSP (Max Wear Rate at #5-#7TSP)	MAX LENGTH on AVB WEAR	VOID	REGION	COUPLING	Total
1	81	85	1	0	0	2	0	0	2	1	10	16
2	82	84	6	3	0	5	0	0	2	1	5	22
3	83	79	1	3	0	2	8	0	2	1	5	22
4	83	83	1	3	0	2	0	0	2	1	10	19
5	83	85	6	9	0	5	0	0	2	1	10	33
6	83	89	1	3	0	2	0	0	2	1	10	19
7	84	82	1	3	0	5	8	0	2	1	5	25
8	84	84	1	3	0	5	0	0	2	1	10	22
9	84	86	1	0	0	2	9	0	2	1	10	25
10	84	88	1	3	0	2	8	0	2	1	10	27
11	85	75	1	0	0	0	9	0	0	1	5	16
12	85	79	1	3	0	2	9	0	2	1	10	28
13	85	83	6	3	0	5	0	2	2	1	10	29
14	85	85	1	3	0	2	9	0	2	1	10	28
15	85	87	0	0	0	0	9	0	2	1	10	22
16	85	89	1	3	0	2	9	10	2	1	10	38
17	85	91	0	0	0	0	8	0	2	1	10	21
18	86	76	1	3	0	5	9	7	0	1	0	26
19	86	78	1	3	0	2	8	1	2	1	10	28
20	86	80	1	3	0	5	0	1	2	1	10	23
21	86	82	1	3	0	5	0	1	2	1	10	23
22	86	84	6	3	0	5	8	5	2	1	10	40
23	86	86	0	0	0	0	8	5	2	6	10	31
24	86	88	6	3	0	2	9	10	2	6	10	48
25	86	90	1	3	0	2	9	7	2	1	10	35
26	87	77	1	0	0	2	0	0	2	1	10	16
27	87	79	1	3	0	2	8	0	2	1	10	27
28	87	81	1	0	0	2	8	0	2	1	10	24
29	87	83	1	0	0	2	8	0	2	1	10	24
30	87	85	6	9	9	10	9	10	2	6	10	71
31	87	87	6	9	9	10	9	10	2	6	10	71
32	87	89	6	3	9	2	9	5	2	6	10	52
33	87	91	1	3	0	0	9	10	2	1	10	36
34	87	93	0	0	0	0	8	0	2	1	10	21
35	88	78	1	3	0	2	0	0	2	1	10	19
36	88	80	1	3	0	2	8	0	2	1	10	27
37	88	82	1	3	0	2	9	2	2	1	10	30
38	88	84	1	3	0	2	9	3	2	6	10	36
39	88	86	6	9	9	5	9	10	2	6	10	66
40	88	88	10	9	9	5	9	10	2	6	10	70
41	88	90	6	3	9	5	9	10	2	6	10	60
42	88	92	6	3	0	5	9	10	2	1	10	46
43	88	94	0	0	0	0	8	5	2	1	5	21
44	89	79	1	3	0	2	0	0	2	1	10	19
45	89	81	6	3	0	2	8	2	2	1	10	34
46	89	83	1	3	9	2	9	0	2	6	10	42
47	89	85	10	9	9	10	9	3	2	6	10	68
48	89	87	6	9	9	2	9	7	2	6	10	60
49	89	89	10	9	9	10	9	2	2	6	10	67
50	89	91	6	9	9	5	9	5	2	6	10	61
51	89	93	1	3	0	0	9	0	2	1	10	26
52	90	80	6	9	9	5	8	3	2	1	10	53
53	90	82	6	3	0	2	9	0	2	6	10	38
54	90	84	6	9	9	5	9	5	2	6	10	61
55	90	86	10	9	10	10	9	10	2	6	10	76
56	90	88	10	9	10	10	9	10	2	6	10	76
57	90	90	6	9	9	2	9	0	2	6	10	53
58	90	92	1	3	0	0	9	2	2	6	10	33
59	91	79	0	0	0	0	9	0	2	1	10	22
60	91	81	10	9	9	10	9	7	2	6	10	72
61	91	83	6	9	9	10	9	10	2	6	10	71
62	91	85	10	9	9	10	9	10	2	6	10	75
63	91	87	10	9	10	10	9	10	2	6	10	76
64	91	89	10	9	10	5	9	10	2	6	10	71
65	91	91	10	9	10	10	9	10	2	6	10	76
66	91	93	6	9	9	2	9	10	2	6	10	63
67	91	95	1	3	0	2	0	2	2	1	10	21
68	92	78	1	0	0	2	8	1	2	1	10	25
69	92	80	1	3	0	0	9	10	2	6	10	41
70	92	82	10	9	10	10	9	10	2	6	10	76
71	92	84	6	9	9	5	9	10	2	6	10	66
72	92	86	10	9	10	5	9	10	2	6	10	71
73	92	88	6	9	9	10	9	10	2	6	10	71
74	92	90	10	9	9	10	9	10	2	6	10	75
75	92	92	6	9	9	10	9	10	2	6	10	71
76	92	94	0	0	0	0	8	0	2	6	10	26
77	93	77	0	0	0	0	9	0	2	1	10	22
78	93	79	1	9	0	2	9	10	2	1	10	44
79	93	81	10	9	9	10	9	10	2	6	10	75
80	93	83	10	9	9	10	9	10	2	6	10	75
81	93	85	10	9	10	10	9	10	2	6	10	76
82	93	87	10	9	9	10	9	10	2	6	10	75
83	93	89	10	9	10	10	9	10	2	6	10	76
84	93	91	10	9	10	5	9	10	2	6	10	71
85	93	93	10	9	9	10	9	10	2	6	10	75
86	93	95	6	3	0	5	0	0	2	1	10	27
87	94	76	0	0	0	0	9	0	2	1	5	17
88	94	78	1	3	0	2	9	0	2	1	10	28
89	94	80	10	9	9	10	9	10	2	6	10	75
90	94	82	6	9	9	5	9	10	2	6	10	66
91	94	84	6	9	9	2	9	5	2	6	10	58
92	94	86	10	9	10	10	9	10	2	6	10	76
93	94	88	6	9	9	5	9	10	2	6	10	66
94	94	90	10	9	10	10	9	10	2	6	10	76
95	94	92	6	9	9	2	9	10	2	6	10	63
96	94	94	1	0	0	5	0	2	2	6	10	26
97	95	77	0	3	0	2	9	0	2	1	10	27
98	95	79	6	3	0	5	8	5	2	6	10	45
99	95	81	6	3	0	5	9	10	2	6	10	51
100	95	83	10	9	9	10	9	10	2	6	10	75

Appendix-1

	Tube		Tube-to-AVB friction		Vibration frequency		In-plane tube motion		Void fraction	Regional effect	Coupling effect	
No.	Row	Col	COUNT	HOT COUNT	HIGH/LOW	CONTINOUS	TSP (Max Wear Rate at #5-#7TSP)	MAX LENGTH on AVB WEAR	VOID	REGION	COUPLING	Total
101	95	85	10	9	9	10	9	10	2	6	10	75
102	95	87	10	9	10	10	9	10	2	6	10	76
103	95	89	10	9	10	5	9	10	2	6	10	71
104	95	91	10	9	9	10	9	10	2	6	10	75
105	95	93	6	9	0	5	9	3	2	6	10	50
106	96	76	1	3	0	2	0	0	0	1	10	17
107	96	78	1	3	0	2	9	2	2	1	10	30
108	96	80	1	3	0	2	9	10	2	6	10	43
109	96	82	10	9	9	10	9	7	2	6	10	72
110	96	84	10	9	10	5	9	10	2	6	10	71
111	96	86	10	9	10	10	9	10	2	6	10	76
112	96	88	10	9	10	10	9	10	2	6	10	76
113	96	90	10	9	10	10	9	10	2	6	10	76
114	96	92	6	9	9	10	9	10	2	6	10	71
115	96	94	0	0	0	0	0	0	2	6	10	18
116	97	77	6	3	0	2	9	3	2	1	10	36
117	97	79	6	9	0	5	9	10	2	6	10	57
118	97	81	10	9	10	10	9	10	2	6	10	76
119	97	83	10	9	10	10	9	10	2	6	10	76
120	97	85	10	9	10	10	9	10	2	6	10	76
121	97	87	10	9	10	5	9	10	2	6	10	71
122	97	89	10	9	10	10	9	10	2	6	10	76
123	97	91	10	3	10	5	9	10	2	6	10	65
124	97	93	6	3	0	5	9	10	2	6	10	51
125	98	76	0	0	0	0	0	7	2	1	10	20
126	98	78	10	9	10	10	9	10	2	1	10	71
127	98	80	10	9	9	10	9	5	2	6	10	70
128	98	82	10	9	9	10	9	10	2	6	10	75
129	98	84	10	9	10	2	9	10	2	6	10	68
130	98	86	10	9	10	10	9	10	2	6	10	76
131	98	88	10	9	10	10	9	10	2	6	10	76
132	98	90	10	9	10	10	9	10	2	6	10	76
133	98	92	10	9	9	10	9	10	2	6	10	75
134	98	94	0	3	0	2	0	0	2	6	10	23
135	99	77	6	3	0	2	9	5	2	1	10	38
136	99	79	10	9	9	10	9	10	2	6	10	75
137	99	81	10	3	9	10	9	10	2	6	10	69
138	99	83	10	9	10	5	9	10	2	6	10	71
139	99	85	10	9	9	10	9	10	2	6	10	75
140	99	87	10	9	10	5	9	10	2	6	10	71
141	99	89	10	9	10	10	9	10	2	6	10	76
142	99	91	10	9	9	10	9	10	2	6	10	75
143	99	93	0	0	0	0	0	5	2	6	10	23
144	99	95	1	0	0	0	0	5	2	6	5	19
145	100	76	1	3	0	2	0	10	2	1	10	29
146	100	78	10	9	9	10	8	7	2	1	10	66
147	100	80	6	9	0	5	9	10	2	6	10	57
148	100	82	10	9	9	10	9	10	2	6	10	75
149	100	84	6	9	10	2	9	10	2	6	10	64
150	100	86	10	9	10	10	9	10	2	6	10	76
151	100	88	10	9	10	10	9	10	2	6	10	76
152	100	90	10	9	10	10	9	10	2	6	10	76
153	100	92	6	9	0	5	9	10	2	6	10	57
154	100	94	1	0	0	2	8	1	2	6	0	20
155	101	77	6	3	0	2	9	3	2	1	10	36
156	101	79	6	9	9	2	9	10	2	6	10	63
157	101	81	10	9	9	5	9	7	2	6	10	67
158	101	83	10	9	10	10	9	10	2	6	10	76
159	101	85	10	9	10	10	9	10	2	6	10	76
160	101	87	10	9	10	10	9	10	2	6	10	76
161	101	89	10	9	9	5	9	10	2	6	10	70
162	101	91	6	3	0	5	9	10	2	6	10	51
163	101	93	1	3	0	2	0	0	2	6	10	24
164	101	95	1	0	0	2	0	0	2	6	5	16
165	102	76	1	0	0	0	8	1	2	1	10	23
166	102	78	10	3	9	10	9	10	2	1	10	64
167	102	80	10	9	10	10	9	10	2	6	10	76
168	102	82	6	3	0	5	9	7	2	6	10	48
169	102	84	6	3	9	2	9	10	2	6	10	57
170	102	86	10	9	10	10	9	10	2	6	10	76
171	102	88	10	9	10	10	9	10	2	6	10	76
172	102	90	6	9	9	5	9	10	2	6	10	66
173	102	92	1	3	0	2	0	1	2	6	10	25
174	102	94	1	3	0	2	0	0	2	6	5	19
175	103	77	1	0	9	2	9	10	2	1	10	44
176	103	79	6	9	0	10	9	10	2	6	10	62
177	103	81	10	9	9	2	9	10	2	6	10	67
178	103	83	10	9	10	10	9	10	2	6	10	76
179	103	85	10	9	10	10	9	10	2	6	10	76
180	103	87	10	9	10	5	9	10	2	6	10	71
181	103	89	6	3	0	2	9	10	2	6	10	48
182	103	91	1	0	0	2	8	2	2	6	10	31
183	104	76	1	3	0	2	0	5	2	1	5	19
184	104	78	6	0	0	2	9	10	2	1	10	40
185	104	80	10	9	9	2	9	10	2	6	10	67
186	104	82	6	9	0	5	9	5	2	6	10	52
187	104	84	10	9	10	10	9	10	2	6	10	76
188	104	86	6	9	0	2	9	10	2	6	10	54
189	104	88	6	9	0	5	9	7	2	6	10	54
190	104	90	6	9	9	2	9	1	2	6	10	54
191	104	92	1	3	0	2	0	0	2	6	10	24
192	105	77	1	0	0	2	9	0	2	1	10	25
193	105	79	6	9	9	5	9	10	2	6	10	66
194	105	81	6	3	0	5	9	3	2	6	10	44
195	105	83	10	9	10	10	9	10	2	6	10	76
196	105	85	10	9	10	5	9	10	2	6	10	71
197	105	87	10	9	10	5	9	5	2	6	10	66
198	105	89	1	3	9	0	8	5	2	6	10	44
199	105	91	1	3	0	5	0	0	2	6	10	27
200	105	93	6	3	0	5	0	0	2	6	5	27

Appendix-1

	Tube		Tube-to-AVB friction		Vibration frequency		In-plane tube motion		Void fraction	Regional effect	Coupling effect	
No.	Row	Col	COUNT	HOT COUNT	HIGH/LOW	CONTINOUS	TSP (Max Wear Rate at #5-#7TSP)	MAX LENGTH on AVB WEAR	VOID	REGION	COUPLING	Total
201	106	78	6	3	0	5	9	5	2	1	10	41
202	106	80	6	9	9	2	9	10	2	6	10	63
203	106	82	6	9	0	10	9	7	2	6	10	59
204	106	84	6	9	0	2	9	0	2	6	10	44
205	106	86	6	9	0	2	9	7	2	6	10	51
206	106	88	6	3	0	5	8	2	2	6	10	42
207	106	90	6	9	9	2	0	3	2	6	10	47
208	106	92	1	3	0	2	0	0	2	6	10	24
209	106	94	1	3	0	2	0	0	2	6	10	24
210	107	77	1	0	0	2	8	10	2	1	10	34
211	107	79	6	9	0	5	9	10	2	6	10	57
212	107	81	10	3	9	10	8	7	2	6	10	65
213	107	83	10	9	10	10	8	10	2	6	10	75
214	107	85	6	9	9	2	8	10	2	6	10	62
215	107	87	10	9	9	10	9	10	2	6	10	75
216	107	89	6	9	0	2	0	10	2	6	10	45
217	107	91	1	3	0	5	0	3	2	6	10	30
218	107	93	1	3	0	2	0	2	2	6	10	26
219	107	95	0	3	0	2	0	0	2	6	5	18
220	108	78	6	3	0	2	8	5	2	1	10	37
221	108	80	1	9	0	2	8	10	2	6	10	48
222	108	82	1	3	0	2	0	7	2	6	10	31
223	108	84	6	9	9	5	0	10	2	6	10	57
224	108	86	6	9	0	5	0	0	2	6	10	38
225	108	88	1	3	0	2	8	0	2	6	10	32
226	108	90	1	3	0	2	0	0	2	6	10	24
227	108	92	1	0	0	2	0	2	2	6	10	23
228	108	94	1	0	0	2	0	5	2	6	10	26
229	109	79	1	3	0	2	9	3	2	1	10	31
230	109	81	1	0	0	2	0	0	2	6	10	21
231	109	83	0	0	0	0	0	0	2	6	10	18
232	109	85	1	3	0	5	9	0	2	6	10	36
233	109	87	0	3	0	2	0	0	2	6	10	23
234	109	89	1	3	0	2	0	2	2	6	10	26
235	109	91	1	0	0	2	0	0	2	6	5	16
236	109	93	1	3	0	5	0	0	2	6	10	27
237	110	80	1	3	0	2	0	0	2	6	10	24
238	110	84	1	3	0	2	0	0	2	6	10	24
239	110	86	0	3	0	2	0	3	2	6	10	26
240	110	88	1	3	0	2	0	0	2	6	10	24
241	110	90	1	3	0	2	0	0	2	6	5	19
242	110	92	1	0	0	0	0	0	2	6	10	19
243	110	94	0	0	0	0	0	0	2	6	10	18
244	111	83	1	3	0	2	0	0	2	6	5	19
245	111	85	1	3	0	2	0	0	2	6	10	24
246	111	87	1	9	0	2	0	0	2	6	10	30
247	111	89	1	3	0	2	0	0	2	6	5	19
248	111	91	1	0	0	5	0	0	2	6	5	19
249	111	93	1	3	0	5	0	0	2	6	5	22
250	112	82	1	3	0	0	0	0	2	6	5	17
251	112	84	1	3	0	2	0	0	2	6	10	24
252	112	86	1	0	0	2	0	0	2	6	10	21
253	112	88	1	3	0	2	0	0	2	6	10	24
254	112	92	1	3	0	2	0	0	2	6	10	24
255	113	83	6	9	0	10	0	0	2	6	0	33
256	113	85	6	9	0	5	0	0	2	6	10	38
257	113	87	6	3	0	5	0	0	2	6	10	32
258	113	89	1	3	0	0	0	0	2	6	5	17
259	113	91	1	3	0	5	0	0	2	6	0	17
260	114	80	6	3	0	5	0	0	2	1	0	17
261	114	84	1	0	0	2	0	2	2	6	10	23
262	114	86	1	3	0	2	0	2	2	6	10	26
263	114	88	1	3	0	2	0	2	2	6	10	26
264	114	90	1	0	0	2	0	0	2	6	5	16
265	115	79	1	3	0	2	0	5	2	1	5	19
266	115	85	1	3	0	2	9	0	2	6	10	33
267	115	87	6	3	0	5	0	0	2	6	10	32
268	115	89	1	3	0	0	0	3	2	6	5	20
269	116	86	6	9	0	10	0	0	2	6	10	43
270	116	88	1	3	0	0	0	0	2	6	10	22
271	117	83	1	3	0	0	0	0	2	1	10	17
272	117	85	1	0	0	2	0	0	2	1	10	16
273	118	82	6	3	0	5	0	0	2	1	5	22
274	119	83	6	3	0	5	0	0	2	1	5	22
275	120	82	1	0	0	2	0	0	2	1	10	16
276	83*	77*	6	3	0	5	0	0	0	1	0	15
277	97*	75*	6	3	0	5	0	0	0	1	0	15

*This tube is additionally selected.

Appendix-1

Table A-2 Screened tubes for Unit 3B

	Tube		Tube-to-AVB friction		Vibration frequency		In-plane tube motion		Void fraction	Regional effect	Coupling effect	
No.	Row	Col	COUNT	HOT COUNT	HIGH/LOW	CONTINOUS	TSP (Max Wear Rate at #5-#7TSP)	MAX LENGTH on AVB WEAR	VOID	REGION	COUPLING	Total
1	79	81	1	3	0	2	0	0	0	1	10	17
2	80	78	6	3	0	5	0	1	0	1	5	21
3	80	80	1	3	0	2	0	0	0	1	10	17
4	80	82	6	3	0	5	0	0	2	1	5	22
5	81	77	6	3	0	5	0	0	0	1	5	20
6	81	79	6	3	0	5	0	2	2	1	10	29
7	81	81	6	3	0	5	0	0	2	1	10	27
8	82	78	1	3	0	2	0	0	2	1	10	19
9	82	80	1	3	0	2	0	0	2	1	10	19
10	82	82	0	3	0	2	0	0	2	1	10	18
11	83	79	6	3	0	5	0	3	2	1	10	30
12	83	81	6	3	0	5	0	0	2	1	10	27
13	83	85	1	3	0	2	0	7	2	1	5	21
14	84	78	6	3	0	5	0	2	2	1	10	29
15	84	80	6	3	0	5	0	1	2	1	10	28
16	84	82	1	3	0	2	0	0	2	1	10	19
17	84	84	1	0	0	5	0	0	2	1	10	19
18	84	86	1	0	0	2	0	3	2	1	10	19
19	85	79	6	3	0	5	0	1	2	1	10	28
20	85	81	1	3	0	0	0	0	2	1	10	17
21	85	83	6	3	0	5	0	2	2	1	5	24
22	85	85	1	3	0	5	8	7	2	1	5	32
23	85	87	1	3	0	2	8	1	2	1	0	18
24	86	78	1	3	0	2	0	0	2	1	10	19
25	86	82	6	3	0	5	0	1	2	1	10	28
26	86	86	1	0	0	2	0	1	2	1	10	17
27	87	77	6	3	0	5	0	1	2	1	0	18
28	87	79	1	3	0	2	0	1	2	1	10	20
29	87	81	6	3	0	5	8	0	2	1	5	30
30	87	83	1	0	0	2	0	0	2	1	10	16
31	87	85	0	0	0	2	0	10	2	1	10	25
32	88	78	1	3	0	2	0	3	2	1	10	22
33	88	80	1	3	0	2	0	3	2	1	10	22
34	88	82	0	3	0	2	0	3	2	1	10	21
35	88	84	6	3	0	5	0	2	2	1	10	29
36	88	86	0	0	0	0	0	3	2	1	10	16
37	88	94	1	0	0	2	8	3	2	1	10	27
38	88	96	0	0	0	0	8	10	2	1	5	26
39	89	77	1	3	0	2	0	5	2	1	5	19
40	89	79	6	3	0	5	0	10	2	1	5	32
41	89	81	1	3	0	2	0	0	2	1	10	19
42	89	83	1	3	0	2	0	3	2	1	10	22
43	89	85	1	0	0	2	8	7	2	6	10	36
44	89	87	6	3	0	5	0	3	2	6	0	25
45	89	91	6	3	0	5	8	5	2	1	0	30
46	89	93	6	3	0	5	0	2	2	1	5	24
47	89	95	1	0	0	0	8	5	2	1	10	27
48	89	97	1	3	0	2	0	3	2	1	10	22
49	90	78	1	0	0	2	0	3	2	1	10	19
50	90	80	1	3	0	5	0	2	2	1	10	24
51	90	82	1	0	0	5	0	2	2	1	10	21
52	90	84	1	3	0	2	0	3	2	6	10	27
53	90	86	0	3	0	2	0	1	2	6	10	24
54	90	96	0	0	0	0	8	0	2	1	10	21
55	91	79	6	3	0	5	8	0	2	1	10	35
56	91	81	10	9	0	10	8	3	2	1	10	53
57	91	83	1	3	0	2	9	1	2	6	10	34
58	91	85	0	0	0	2	8	1	2	6	10	29
59	91	87	1	3	0	2	0	0	2	6	10	24
60	91	97	6	3	0	5	0	0	2	1	0	17
61	92	74	1	3	0	2	8	0	0	1	5	20
62	92	76	1	3	0	2	0	0	2	1	10	19
63	92	78	1	0	0	0	8	0	2	1	10	22
64	92	80	6	3	0	5	0	1	2	1	10	28
65	92	82	1	3	0	5	0	0	2	6	10	27
66	92	84	10	9	9	5	9	7	2	6	10	67
67	92	86	1	0	0	2	8	5	2	6	10	34
68	92	88	6	3	0	5	8	5	2	6	10	45
69	92	96	0	0	0	0	9	0	2	1	5	17
70	93	75	1	3	0	5	8	0	0	1	0	18
71	93	77	1	3	0	2	8	0	2	1	10	27
72	93	79	6	3	0	5	0	5	2	1	10	32
73	93	81	1	3	0	2	8	2	2	6	10	34
74	93	83	6	9	10	2	9	10	2	6	10	64
75	93	85	6	3	9	5	9	10	2	6	10	60
76	93	87	1	3	0	2	9	1	2	6	10	34
77	93	89	1	0	0	0	0	0	2	6	10	19
78	93	93	1	3	0	5	9	0	2	1	5	26
79	94	74	1	3	0	2	8	0	0	1	5	20
80	94	76	1	3	0	2	0	0	2	1	10	19

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	Tube		Tube-to-AVB friction		Vibration frequency		In-plane tube motion		Void fraction	Regional effect	Coupling effect	
No.	Row	Col	COUNT	HOT COUNT	HIGH/LOW	CONTINOUS	TSP (Max Wear Rate at #5-#7TSP)	MAX LENGTH on AVB WEAR	VOID	REGION	COUPLING	Total
81	94	78	1	3	0	5	8	1	2	1	10	31
82	94	80	6	3	0	2	9	5	2	6	10	43
83	94	82	10	9	10	10	9	10	2	6	10	76
84	94	84	10	3	10	5	9	10	2	6	10	65
85	94	86	6	3	0	5	9	10	2	6	10	51
86	94	88	0	0	0	2	9	0	2	6	10	29
87	94	90	0	0	0	0	0	0	2	6	10	18
88	94	92	0	0	0	0	0	3	2	6	10	21
89	94	94	0	0	0	0	8	1	2	1	10	22
90	95	75	1	3	0	2	8	0	0	1	5	20
91	95	77	6	9	0	5	0	1	2	1	10	34
92	95	79	6	3	0	5	8	10	2	6	10	50
93	95	81	10	9	10	10	9	10	2	6	10	76
94	95	83	6	9	10	2	9	10	2	6	10	64
95	95	85	10	9	10	10	9	10	2	6	10	76
96	95	87	6	3	0	2	9	0	2	6	10	38
97	95	89	0	0	0	0	8	0	2	6	10	26
98	95	91	1	3	0	2	8	0	2	6	5	27
99	95	93	0	0	0	2	8	2	2	6	5	25
100	96	76	1	3	0	2	8	0	0	1	10	25
101	96	78	6	3	0	2	0	0	2	1	10	24
102	96	80	10	9	10	10	9	10	2	6	10	76
103	96	82	10	9	10	10	9	10	2	6	10	76
104	96	84	10	9	9	5	9	10	2	6	10	70
105	96	86	6	3	10	2	9	10	2	6	10	58
106	96	88	10	9	10	5	9	10	2	6	10	71
107	96	90	0	0	0	0	8	0	2	6	10	26
108	96	92	0	0	0	0	0	0	2	6	10	18
109	97	77	1	3	0	2	8	3	2	1	10	30
110	97	79	10	9	9	10	9	10	2	6	10	75
111	97	81	10	9	10	10	9	10	2	6	10	76
112	97	83	10	9	10	10	9	10	2	6	10	76
113	97	85	10	9	10	5	9	10	2	6	10	71
114	97	87	10	9	9	2	9	10	2	6	10	67
115	97	89	1	3	0	2	9	10	2	6	10	43
116	97	91	1	0	0	2	0	0	2	6	10	21
117	97	93	0	0	0	0	0	0	2	6	10	18
118	98	76	1	0	0	2	8	3	2	1	10	27
119	98	78	6	3	9	5	9	10	2	6	10	60
120	98	80	10	9	10	5	9	10	2	6	10	71
121	98	82	10	9	10	2	9	10	2	6	10	68
122	98	84	10	9	10	5	9	10	2	6	10	71
123	98	86	10	9	10	10	9	10	2	6	10	76
124	98	88	6	3	9	5	9	10	2	6	10	60
125	98	90	1	0	0	2	8	3	2	6	10	32
126	98	92	6	0	0	5	8	1	2	6	0	28
127	99	77	1	3	0	2	8	10	2	1	10	37
128	99	79	10	9	9	10	9	10	2	6	10	75
129	99	81	10	9	10	2	9	10	2	6	10	68
130	99	83	10	9	10	10	9	10	2	6	10	76
131	99	85	10	9	10	10	9	10	2	6	10	76
132	99	87	10	9	10	10	9	10	2	6	10	76
133	99	89	1	0	0	2	8	10	2	6	10	39
134	99	91	1	0	0	2	0	0	2	6	10	21
135	99	93	1	0	0	2	0	0	2	6	5	16
136	100	76	1	0	0	2	8	1	2	1	10	25
137	100	78	10	9	9	10	9	10	2	6	10	75
138	100	80	10	9	10	10	9	10	2	6	10	76
139	100	82	10	9	10	10	9	10	2	6	10	76
140	100	84	10	3	10	5	9	10	2	6	10	65
141	100	86	10	9	10	5	9	10	2	6	10	71
142	100	88	10	9	9	10	9	10	2	6	10	75
143	100	90	6	3	0	10	8	7	2	6	10	52
144	100	92	1	0	0	2	0	0	2	6	10	21
145	101	75	0	3	0	2	8	1	2	1	10	27
146	101	77	6	3	0	2	9	10	2	1	10	43
147	101	79	10	9	10	5	9	10	2	6	10	71
148	101	81	10	9	10	10	9	10	2	6	10	76
149	101	83	10	9	10	10	9	10	2	6	10	76
150	101	85	10	9	10	10	9	10	2	6	10	76
151	101	87	10	3	10	5	9	10	2	6	10	65
152	101	89	1	0	0	0	8	5	2	6	10	32
153	101	91	0	0	0	0	0	0	2	6	10	18
154	101	93	1	3	0	2	0	0	2	6	5	19
155	102	74	1	0	0	2	8	0	2	1	10	24
156	102	76	10	3	9	10	9	10	2	1	10	64
157	102	78	10	9	10	10	9	7	2	6	10	73
158	102	80	10	9	10	5	9	10	2	6	10	71
159	102	82	10	9	10	10	9	10	2	6	10	76
160	102	84	10	9	10	2	9	10	2	6	10	68

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No.	Tube: Row	Tube: Col	Tube-to-AVB friction: COUNT	Tube-to-AVB friction: HOT COUNT	Vibration frequency: HIGH/LOW	Vibration frequency: CONTINOUS	In-plane tube motion: TSP (Max Wear Rate at #5-#7TSP)	In-plane tube motion: MAX LENGTH on AVB WEAR	Void fraction: VOID	Regional effect: REGION	Coupling effect: COUPLING	Total
161	102	86	10	9	10	10	9	10	2	6	10	76
162	102	88	6	3	9	5	9	10	2	6	10	60
163	102	90	1	3	0	2	8	3	2	6	10	35
164	102	92	0	0	0	0	8	2	2	6	5	23
165	103	75	1	0	9	0	9	1	2	1	10	33
166	103	77	10	9	10	10	9	10	2	1	10	71
167	103	79	10	9	10	10	9	10	2	6	10	76
168	103	81	10	9	10	10	9	10	2	6	10	76
169	103	83	6	9	10	2	9	10	2	6	10	64
170	103	85	10	9	10	10	9	10	2	6	10	76
171	103	87	10	3	10	5	9	10	2	6	10	65
172	103	89	0	0	0	0	8	0	2	6	10	26
173	103	91	0	0	0	0	8	7	2	6	10	33
174	104	76	10	9	10	5	9	7	2	1	10	63
175	104	78	10	9	10	10	9	10	2	6	10	76
176	104	80	10	9	10	10	9	10	2	6	10	76
177	104	82	10	9	10	10	9	10	2	6	10	76
178	104	84	10	9	10	10	9	10	2	6	10	76
179	104	86	10	9	10	5	9	7	2	6	10	68
180	104	88	6	3	9	5	9	10	2	6	10	60
181	104	90	0	0	0	0	9	0	2	6	10	27
182	104	92	0	0	0	0	0	0	2	6	10	18
183	105	75	10	9	10	5	9	10	2	1	10	66
184	105	77	10	9	10	10	9	10	2	1	10	71
185	105	79	10	9	10	10	9	10	2	6	10	76
186	105	81	10	9	10	2	9	10	2	6	10	68
187	105	83	10	9	10	5	9	10	2	6	10	71
188	105	85	10	9	10	5	9	10	2	6	10	71
189	105	87	10	9	9	10	9	10	2	6	10	75
190	105	89	1	3	0	2	8	2	2	6	10	34
191	105	91	0	0	0	0	8	0	2	6	10	26
192	105	93	1	3	0	2	0	0	2	6	5	19
193	106	74	0	0	0	0	8	0	2	1	10	21
194	106	76	10	9	10	10	9	10	2	1	10	71
195	106	78	10	9	10	5	9	10	2	6	10	71
196	106	80	10	9	10	10	9	10	2	6	10	76
197	106	82	10	9	10	10	9	10	2	6	10	76
198	106	84	10	9	10	10	9	10	2	6	10	76
199	106	86	6	9	9	2	9	10	2	6	10	63
200	106	88	6	3	0	5	9	2	2	6	10	43
201	106	90	1	3	0	0	9	1	2	6	10	32
202	106	92	1	0	0	2	8	0	2	6	5	24
203	107	75	6	3	10	2	9	10	2	1	10	53
204	107	77	10	9	10	5	9	10	2	1	10	66
205	107	79	10	9	10	10	9	10	2	6	10	76
206	107	81	10	9	10	10	9	10	2	6	10	76
207	107	83	10	9	10	5	9	10	2	6	10	71
208	107	85	10	9	10	10	9	10	2	6	10	76
209	107	87	1	9	9	5	9	7	2	6	10	58
210	107	89	1	9	0	2	8	10	2	6	10	48
211	107	91	1	0	0	0	0	0	2	6	10	19
212	107	93	1	3	0	0	0	0	2	6	5	17
213	108	74	0	0	0	0	8	0	2	1	10	21
214	108	76	10	9	10	5	9	10	2	1	10	66
215	108	78	10	9	10	10	9	10	2	6	10	76
216	108	80	10	9	10	10	9	10	2	6	10	76
217	108	82	10	9	10	5	9	10	2	6	10	71
218	108	84	10	9	10	5	9	10	2	6	10	71
219	108	86	10	9	9	5	9	2	2	6	10	62
220	108	88	1	3	0	2	0	0	2	6	10	24
221	108	90	1	0	0	2	0	0	2	6	10	21
222	108	92	0	0	0	2	0	2	2	6	5	17
223	109	75	10	3	10	5	9	10	2	1	10	60
224	109	77	10	9	10	5	9	10	2	1	10	66
225	109	79	10	9	10	10	9	10	2	6	10	76
226	109	81	10	9	10	2	9	10	2	6	10	68
227	109	83	10	9	9	10	9	10	2	6	10	75
228	109	85	1	3	0	0	9	10	2	6	10	41
229	109	87	1	0	0	5	0	0	2	6	10	24
230	109	89	1	3	0	2	0	0	2	6	10	24
231	110	74	1	0	0	0	8	1	2	1	10	23
232	110	76	10	3	10	5	9	10	2	1	10	60
233	110	78	10	9	10	10	9	10	2	6	10	76
234	110	80	10	9	10	5	9	10	2	6	10	71
235	110	82	10	9	10	5	9	10	2	6	10	71
236	110	84	1	0	0	2	9	10	2	6	10	40
237	110	86	0	0	0	0	0	0	2	6	10	18
238	110	88	0	0	0	0	0	0	2	6	10	18
239	111	75	1	3	0	2	9	5	2	1	10	33
240	111	77	10	9	10	5	9	10	2	1	10	66

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	Tube		Tube-to-AVB friction		Vibration frequency		In-plane tube motion		Void fraction	Regional effect	Coupling effect	Total
No.	Row	Col	COUNT	HOT COUNT	HIGH/LOW	CONTINOUS	TSP (Max Wear Rate at #5-#7TSP)	MAX LENGTH on AVB WEAR	VOID	REGION	COUPLING	
241	111	79	10	9	10	10	9	10	2	6	10	76
242	111	81	10	9	10	5	9	10	2	6	10	71
243	111	83	10	9	10	10	9	10	2	6	10	76
244	111	85	1	0	0	2	0	10	2	6	10	31
245	111	87	1	3	0	5	0	0	2	6	5	22
246	111	89	1	3	0	2	8	2	2	6	0	24
247	112	74	0	0	0	0	8	0	2	1	10	21
248	112	76	1	0	9	2	9	5	2	1	10	39
249	112	78	6	3	10	2	9	10	2	1	10	53
250	112	80	10	9	10	2	9	10	2	6	10	68
251	112	82	6	9	10	2	9	10	2	6	10	64
252	112	84	6	9	0	10	8	10	2	6	10	61
253	112	86	6	9	9	5	0	0	2	6	10	47
254	112	88	1	0	0	0	0	0	2	6	10	19
255	112	90	1	0	0	2	0	0	2	6	5	16
256	113	75	0	3	0	0	8	2	2	1	10	26
257	113	77	6	9	0	5	8	7	2	1	10	48
258	113	79	6	3	9	2	9	10	2	6	10	57
259	113	81	10	9	10	2	9	10	2	6	10	68
260	113	83	1	3	0	2	8	5	2	6	10	37
261	113	85	1	3	0	2	0	0	2	6	10	24
262	113	87	1	3	0	2	0	0	2	6	10	24
263	114	74	0	0	0	0	8	0	2	1	5	16
264	114	76	6	3	0	2	8	7	2	1	10	39
265	114	78	6	0	9	5	9	10	2	1	10	52
266	114	80	10	9	10	10	9	10	2	6	10	76
267	114	82	6	9	0	10	0	10	2	6	10	53
268	114	84	1	3	0	0	0	0	2	6	10	22
269	115	75	1	0	0	0	8	0	2	1	10	22
270	115	77	6	9	9	2	8	5	2	1	10	52
271	115	79	10	9	10	10	9	10	2	1	10	71
272	115	81	6	9	0	5	8	10	2	6	10	56
273	115	83	1	3	0	2	0	0	2	6	10	24
274	116	76	1	9	0	2	8	2	2	1	10	35
275	116	78	6	9	9	2	9	10	2	1	10	58
276	116	80	10	9	10	10	9	10	2	1	10	71
277	116	82	1	0	0	2	8	1	2	6	10	30
278	116	88	1	3	0	2	8	0	2	6	0	22
279	117	77	6	9	0	5	9	7	2	1	10	49
280	117	79	10	9	10	10	9	10	2	1	10	71
281	117	81	6	9	9	5	0	2	2	1	10	44
282	117	83	1	3	0	2	0	0	2	6	10	24
283	117	85	1	0	0	2	0	0	2	6	10	21
284	118	76	1	3	0	2	8	1	2	1	10	28
285	118	78	10	9	9	10	9	10	2	1	10	70
286	118	80	10	9	9	10	0	7	2	1	10	58
287	118	82	0	0	0	0	9	1	2	1	10	23
288	118	84	6	9	0	5	0	0	2	6	5	33
289	118	88	1	0	0	2	0	0	2	6	5	16
290	119	77	10	9	9	10	9	10	2	1	10	70
291	119	79	10	9	9	10	9	10	2	1	10	70
292	119	81	1	3	0	2	0	2	2	1	10	21
293	119	85	0	0	0	0	9	1	2	6	5	23
294	120	76	1	3	0	2	8	1	2	1	10	28
295	120	78	10	9	10	10	9	10	2	1	10	71
296	120	80	6	9	0	5	8	2	2	1	10	43
297	121	75	1	3	0	2	0	1	2	1	10	20
298	121	77	1	3	0	2	9	7	2	1	10	35
299	121	79	6	3	0	10	9	5	2	1	10	46
300	121	81	1	3	0	2	0	1	2	1	10	20
301	121	85	1	3	0	2	0	2	2	1	5	16
302	122	76	6	3	0	2	0	3	2	1	10	27
303	122	78	1	3	0	2	8	2	2	1	10	29
304	122	80	6	3	0	5	0	5	2	1	10	32
305	123	77	1	3	0	2	0	0	2	1	10	19
306	123	79	1	3	0	0	0	2	2	1	10	19
307	124	76	1	3	0	2	8	0	2	1	5	22
308	124	78	6	3	0	5	0	2	2	1	5	24
309	124	80	1	3	0	2	0	2	2	1	5	16
310	124	82	1	3	0	5	0	0	2	1	5	17
311	125	77	1	3	0	2	0	0	2	1	10	19
312	125	83	1	3	0	2	8	0	2	1	0	17
313	130	78	6	3	0	5	0	1	2	1	0	18

Appendix-2
Evaluation of Void Fraction Distribution of U-bend Region

Appendix-2

1. Purpose

This appendix provides evaluation of void fraction distribution of tubes in U-bend region of San Onofre Units 2 and 3 Replacement Steam Generators (RSGs)

2. Conclusion

The distribution of the void fraction is shown in Fig.6-1.

3. Assumption

(1) The void fraction is analyzed utilizing the "ATHOS/SGAP" code (Ref. 1). Therefore, the assumptions used in the ATHOS/SGAP code apply to this document. Two-phase flow is represented by using a drift flux model which is the standard model of two-phase flow analysis. The mathematical models in the ATHOS/SGAP are constituted under the following assumptions: (Ref. 1)

(2) The analysis is performed at the steady state conditions of 100% power (1729MW/SG) and the beginning of life (BOL). That is, the steam pressures are 838 psia for 598 deg.F of the primary inlet temperature.

(3) All dimensions in analysis are assumed in the cold metal condition because the effect of heat expansion of metals on the calculation results is negligible.

Appendix-2

4. Design Inputs

The nominal dimensions are obtained from the design drawings (Ref.2 to 19) and the manufacturing tolerances are not considered. Flow characteristics are obtained from 3 dimensional thermal and hydraulic analysis.

5. Methodology

Based on the design input of the operating conditions, the calculation of the circulation ratio is performed by evaluating the pressure loss and the recirculation head with SSPC, which is a 1 dimensional Thermal and Hydraulic parameter calculation code (Ref.20). Using ATHOS/SGAP (Ref. 1 and 21), the thermal hydraulic analysis is performed to obtain the 3 dimension flow distribution which includes the void fraction.

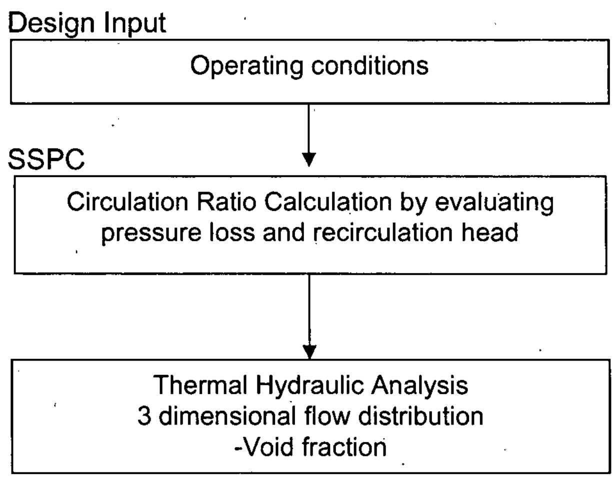

Fig.5-1 Flow of the evaluation

5.1 Evaluation cases

The operating parameters used for the calculation are shown in Table 5-1.

Table 5-1 Basic parameters for calculation

Plugging	
Thermal power (MWt/SG)	
T_{cold} (°F)	
$T_{sg\text{-}out}$ (°F)	
T_{hot} (Tsg-in) (°F)	
$T_{feedwater}$ (°F)	
Saturation Steam Pressure (psia)	
Steam Mass Flow (lb/hr)	
Circulation ratio	

6. Results

The average value of the void fraction of U-bend region of each tube is calculated and the distribution is shown in Fig.6-1. The region where the void fraction is high is concentrated on the region of center columns and the outer rows.

Appendix-2

Fig.6-1 Distribution of average void fraction

7. References

1) Analysis of Thermal Hydraulics of Steam Generators/Steam Generator Analysis Package, Ver.3.1, 1016564, EPRI
2) L5-04FU001 the latest revision, Component and Outline Drawing 1/3
3) L5-04FU002 the latest revision, Component and Outline Drawing 2/3
4) L5-04FU003 the latest revision, Component and Outline Drawing 3/3
5) L5-04FU021 the latest revision, Tube Sheet and Extension Ring 1/3
6) L5-04FU022 the latest revision, Tube Sheet and Extension Ring 2/3
7) L5-04FU023 the latest revision, Tube Sheet and Extension Ring 3/3
8) L5-04FU051 the latest revision, Tube Bundle 1/3
9) L5-04FU052 the latest revision, Tube Bundle 2/3
10) L5-04FU053 the latest revision, Tube Bundle 3/3
11) L5-04FU111 the latest revision, AVB assembly 1/9
12) L5-04FU112 the latest revision, AVB assembly 2/9
13) L5-04FU113 the latest revision, AVB assembly 3/9
14) L5-04FU114 the latest revision, AVB assembly 4/9
15) L5-04FU115 the latest revision, AVB assembly 5/9
16) L5-04FU116 the latest revision, AVB assembly 6/9
17) L5-04FU117 the latest revision, AVB assembly 7/9
18) L5-04FU118 the latest revision, AVB assembly 8/9
19) L5-04FU119 the latest revision, AVB assembly 9/9
20) L5-04GA510 the latest revision, Thermal and Hydraulic Parametric Calculations
21) L5-04GA565, the latest revision, Selection of Thermal Hydraulic Analysis (ATHOS) model

Appendix-3
Additional details about the number of tube wear indications

Appendix-3

This appendix explains the number of tube wear indications used in the analysis. In the In-Service Inspection records, SCE included only bobbin ECT data for AVB and TSP indications in Unit-2 and Unit-3 SGs as follows, informed by the project letter (Ref.1).

SCE inclusion method

- AVB Indications: Evaluation only by bobbin ECT
- TSP Indications: Evaluation only by bobbin ECT
- FSW Indications, Retainer Bar (RB) Indications, Foreign Object Indications: Evaluation only by rotated ECT

The numbers of tubes with wear indications counted based on SCE inclusion method mentioned above are summarized in Table (a). 6

Table (a) Numbers of tubes with wear indication by SCE*

Wear Type	Pick-up manner	SG 2A (2E −089)	SG 2B (2E −088)	SG 3A (3E −089)	SG 3B (3E −088)	Total (Unit-2)	Total (Unit-3)
Type 1 (FSW)	Evaluation only by Rotational ECT	2	0	165	161	2	326
Type 2 (AVB wear)	Evaluation only by Bobbin ECT	802	595	706	735	1397	1441
Type 3 (TSP wear)	Evaluation only by Bobbin ECT	53	135	15	20	188	35
Type 4 (RB wear)	Evaluation only by Rotational ECT	4	2	1	3	6	4
Foreign Object	Evaluation only by Rotational ECT	0	2	0	0	2	0
Total	-	861	734	887	919	1595	1806

*: Each tube is only counted once with the priority given to Type 1 followed by Type 2, Type 3, Type 4 and Foreign Material.

On the other hand, MHI uses both bobbin ECT and rotated ECT data for AVB and TSP indications, because any tubes with wear indications based on only rotated ECT data are not included in the data for AVB and TSP indications. MHI considered that both bobbin ECT and rotated ECT data should be included for more conservative treatment than only bobbin ECT data. The numbers of tubes with wear indications in Unit-2 and Unit-3 SGs are based on the following inclusion method by using both bobbin ECT and rotated ECT data as follows, informed by the project letter (Ref.2).

MHI inclusion method

- AVB Indications: Evaluation by bobbin ECT and rotated ECT, larger one is used
- TSP Indications: Evaluation by bobbin ECT and rotated ECT, larger one is used
- FSW Indications, Retainer Bar (RB) Indications, Foreign Object Indications: Evaluation only by rotated ECT

Appendix-3

The numbers of tubes with wear indications counted based on MHI method mentioned above are summarized in Table (b).

Table (b) Numbers of tubes with wear indication by MHI*

Wear Type	Pick-up manner	SG 2A (2E -089)	SG 2B (2E -088)	SG 3A (3E -089)	SG 3B (3E -088)	Total (Unit-2)	Total (Unit-3)
Type 1 (FSW)	Evaluation only by Rotational ECT	2	0	165	161	2	326
Type 2 (AVB wear)	Evaluation by Bobbin ECT and Rotational ECT, larger one is used	802	595	714	737	1397	1451
Type 3 (TSP wear)	Evaluation by Bobbin ECT and Rotational ECT, larger one is used	53	137	15	20	190	35
Type 4 (RB wear)	Evaluation only by Rotational ECT	4	2	1	3	6	4
Foreign Object	Evaluation only by Rotational ECT	0	2	0	0	2	0
Total	-	861	736	895	921	1597	1816

*: Each tube is only counted once with the priority given to Type 1 followed by Type 2, Type 3, Type 4 and Foreign Material.

6

In the comparison between Table (a) and (b), the tubes selected by MHI method which are not selected by SCE method are listed below.

(AVB Wear)

○Unit-3A

Row.83 Col.95

Row.86 Col.94

Row.95 Col.73

Row.99 Col.73

Row.103 Col.73

Row.105 Col.75

Row.106 Col.76

Row.111 Col.77

○Unit-3B

Row.89 Col.89

Row.110 Col.90

(TSP Wear)

○Unit-2B

Row.118 Col.134

Row.126 Col.128

Appendix-3

Reference

1. Letter RSG-SCE/MHI-12-5749, from D. Calhoun (SCE) to T. Kodama (MHI), August 3, 2012, Subject: "Updated ECT Data for Input to Return to Service and Repair Design Documents." 6

2. Letter RSG-SCE/MHI-12-5688, from D. Calhoun (SCE) to T. Kodama (MHI), March 22, 2012, Subject: "ECT Data for Input to Return to Service and Repair Design Documents."

ATTACHMENT 6

SONGS U2C17
Steam Generator Operational Assessment

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SONGS U2C17
STEAM GENERATOR OPERATIONAL ASSESSMENT

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Record of Revision

Revision No.	Pages/Sections/ Paragraphs Changed	Brief Description / Change Authorization
0	Initial Issue	Initial Issue

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* [Proprietary Information Redacted]

ABBREVIATIONS AND ACRONYMS

2E-089	Unit 2 Steam Generator E-089
AILPC	Accident-Induced Leakage Performance Criteria
ASME	American Society of Mechanical Engineers
ATHOS	Analysis of Thermal-Hydraulics of Steam Generators
AVB	Anti-Vibration Bar
CE	Combustion Engineering
ECT	Eddy Current Testing
EFPY	Effective Full Power Year
EOC	End of Cycle (fuel)
EPRI	Electric Power Research Institute
ETSS	Examination Technique Specification Sheet
FEI	Fluid Elastic Instability
FOSAR	Foreign Object Search and Retrieval
gpd	Gallons Per Day
gpm	Gallons Per Minute
MHI	Mitsubishi Heavy Industries, Ltd.
NEI	Nuclear Energy Institute
NODP	Normal Operating Differential Pressure
NRC	Nuclear Regulatory Commission
OA	Operational Assessment
POB	Probability of Burst
RCS	Reactor Coolant System
SCE	Southern California Edison
SIPC	Structural Integrity Performance Criteria
SG	Steam Generator
SONGS	San Onofre Nuclear Generating Station
SR	Stability Ratio
T/H	Thermal-Hydraulic
TS	Technical Specifications
TSP	Tube Support Plate
TTW	Tube-to-Tube Wear
U2C17	Unit 2 Cycle 17
UNS	Unified Numbering System
WEC	Westinghouse Electric Company

EXECUTIVE SUMMARY

On January 31, 2012, a leak was detected in a Unit 3 Steam generator (SG) at San Onofre Nuclear Generating Station (SONGS). Southern California Edison (SCE) operators promptly shut down the unit in accordance with approved operating procedures. The resulting small radioactive release to the environment was well below the allowable federal limits. Subsequently, on March 27, 2012, the Nuclear Regulatory Commission (NRC) issued a Confirmatory Action Letter [1] to SCE describing actions that the NRC and SCE agreed would be completed prior to returning Units 2 and 3 to service. Since that time, SCE's technical team supplemented by a team of experts in the field of thermal-hydraulics and in SG design, manufacture, operation, and maintenance have performed extensive investigations into the causes of the tube leak and have assisted in the development of compensatory measures and corrective actions that will prevent a loss of SG tube integrity.

As required by the SONGS Technical Specifications (TS) [3], SONGS SG Program [2], and industry guidelines [5], an Operational Assessment (OA) must be performed to ensure that SG tubing will meet established performance criteria for structural and leakage integrity during the operating period prior to the next planned inspection. Because of the unusual and unexpected nature of the SG tube-to-tube wear (TTW) at SONGS, SCE commissioned three independent OAs [Appendices B, C, and D] by experienced vendors applying diverse methodologies. The non-TTW degradation mechanisms have been addressed by a separate OA included in this report [Appendix-A]. Each of these methodologies demonstrates that SCE has implemented compensatory measures and corrective actions to ensure that Unit 2 will operate safely with substantial conservative margin. This report contains the OAs that have been performed to demonstrate that those compensatory measures and corrective actions will prevent a loss of SG tube integrity.

1.0 PURPOSE

In accordance with the SONGS SG Program [2] an OA is performed to ensure that SG tubing meets established performance criteria for structural and leakage integrity during the interval prior to the next planned inspection. The OA projects and evaluates tube degradation mechanisms which have affected the SGs. The performance criteria are defined in plant TS [3] [4] and are based on NEI-97-06 [5].

This summary of the OAs establishes operational limits for Unit 2 and provides reasonable assurance, as required by NRC regulations, that Unit 2 will operate safely.

2.0 SONGS STEAM GENERATOR DESIGN FEATURES

The steam generator is a recirculating, vertical U-tube type heat exchanger converting feedwater into saturated steam. The steam generator vessel pressure boundary is comprised of the channel head, lower shell, middle shell, transition cone, upper shell and upper head. The steam generator internals include the divider plate, tubesheet, tube bundle, feedwater distribution system, moisture separators, steam dryers and integral steam flow limiter installed in the steam nozzle. The channel head is equipped with one reactor coolant inlet nozzle and two outlet nozzles. The upper vessel is equipped with the feedwater nozzle, steam nozzle and blowdown nozzle. In the channel head, there are two 18 inch access manways. In the upper shell, there are two 16 inch access manways. The steam generator is equipped with six (6) handholes and 12 inspection ports providing access for inspection and maintenance. In addition, the steam generators are equipped with several instrumentation and minor nozzles for layup and chemical recirculation intended for chemical cleaning (See Figure 2-1 and Figure 2-2).

Note: The SG design information is provided in References [6] [7] [8] [9] [10] [11] [12].

Figure 2-1: AVB Arrangement for SONGS Steam Generators

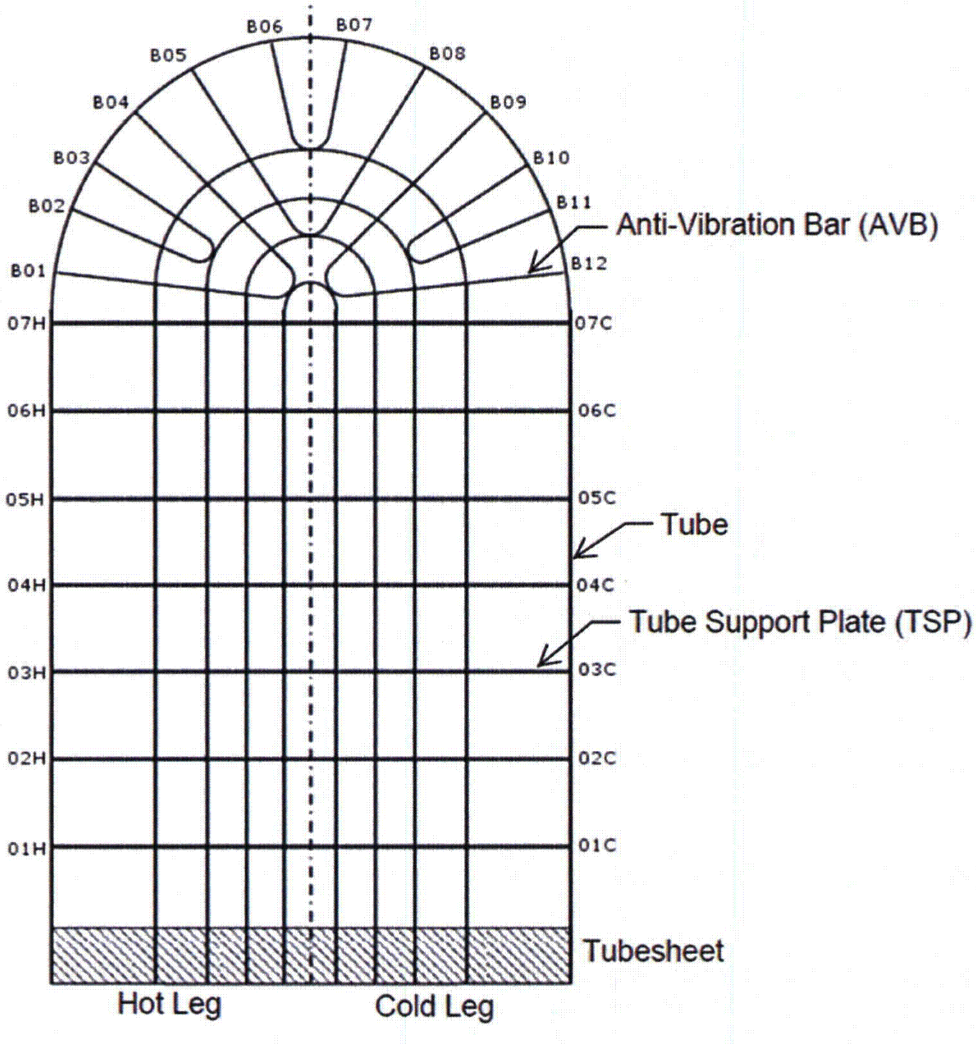


Figure 2-2: Details of AVBs, Retaining Bars, Bridges, and Retainer Bars

3.0 OPERATIONAL ASSESSMENT

As defined in NEI 97-06, the OA is a forward looking evaluation of the SG tube conditions that is used to ensure that the structural integrity and accident leakage performance will not be exceeded during the next inspection interval [5]. The OA projects the condition of SG tubes to the time of the next scheduled inspection outage and determines their acceptability relative to the TS tube integrity performance criteria.

As documented in the "SONGS U2C17 Steam Generator Condition Monitoring Report" [13], the Unit 2 SGs satisfied the three performance criteria specified in the TS for the previous operating period. The SG Program requires an OA to be completed for the next inspection interval within 90 days after initial entry into MODE 4 (MODE is defined in the station TS). This summary of the OAs establishes operational limits for Unit 2 and provides reasonable assurance, as required by NRC regulations, that Unit 2 will operate safely.

The structural integrity performance criteria (SIPC) and accident-induced leakage performance criteria (AILPC) applicable to wear mechanisms are [14]:

> Structural Integrity — "All in-service steam generator tubes shall retain structural integrity over the full range of normal operating conditions (including startup, operation in the power range, hot standby, and cool down and all anticipated transients included in the design specification) and design basis accidents. This includes retaining a safety factor of 3.0 against burst under normal steady state full power operation primary-to-secondary pressure differential and a safety factor of 1.4 against burst applied to the design basis accident primary-to-secondary pressure differentials. Apart from the above requirements, additional loading conditions associated with the design basis accidents, or combination of accidents in accordance with the design and licensing basis, shall also be evaluated to determine if the associated loads contribute significantly to burst or collapse. In the assessment of tube integrity, those loads that do significantly affect burst or collapse shall be determined and assessed in combination with the loads due to pressure with a safety factor of 1.2 on the combined primary loads and 1.0 on axial secondary loads."
>
> Accident-Induced Leakage — "The primary to secondary accident leakage rate for the limiting design basis accident shall not exceed the leakage rate assumed in the accident analysis in terms of total leakage rate for all steam generators and leakage rates for an individual steam generator."

The acceptance standard for structural integrity is [14]:

> The worst-case degraded tube shall meet the SIPC margin requirements with at least a probability of 95% at 50% confidence.

The acceptance standard for accident leakage integrity is [14]:

> The probability for satisfying the limit requirements of the AILPC shall be at least 95% at 50% confidence.

The OA may utilize either a deterministic (also known as simplified arithmetic) or a probabilistic methodology.

SCE has assessed all tube wear mechanisms in Unit 2, including TTW. Given the significance of TTW observed in Unit 3, SCE used the experience and expertise of multiple independent companies that routinely perform OAs for the US nuclear industry. AREVA, Westinghouse Electric Company (WEC), and Intertek developed independent OAs to address the TTW found at SONGS. These diverse analyses fulfilled the TS requirement to ensure that SG tube integrity is maintained until the next SG inspection.

- Section 3.1 provides a summary of the OA prepared by AREVA evaluating all degradation mechanisms found in Unit 2 SGs with the exception of TTW. This OA demonstrates there is reasonable assurance that the SIPC and AILPC for non-TTW will be satisfied for 18 months at 100% power.

- Section 3.2 provides a summary of the OA prepared by AREVA. This OA deterministically evaluates the potential for TTW for the limiting condition of no in-plane support. The OA also evaluates probabilistically the potential for in-plane Fluid Elastic Instability (FEI) occurring in Unit 2 based on an analysis of the contact forces between tubes and AVBs. The deterministic results demonstrate all tubes are stable (will not experience Thermal-Hydraulic (T/H) conditions that cause FEI) at 70% power for 18 months of operation without relying on the AVBs for in-plane support. Therefore, this OA demonstrates that the SIPC and AILPC for TTW will be satisfied for 18 months at 70% power. The probabilistic results demonstrate a low probability of FEI at 70% power for approximately 8 months of operation even when additional conservatisms are introduced.
- Section 3.3 provides a summary of the OA prepared by Intertek following "traditional" industry guidelines for assessing SG tube degradation. This OA evaluates the probability that TTW caused by FEI will not exceed the SG SIPC. This OA demonstrates there is a reasonable assurance that the SIPC and AILPC for TTW will be satisfied for 16 months at 70% power level.
- Section 3.4 provides a summary of the OA prepared by WEC based on an alternate interpretation of the inspection results. This OA determines the TTW in Unit 2 was caused by out-of-plane vibration between two tubes in close proximity. The OA evaluates the potential for in-plane instability and concludes the Unit 2 SG tubes were stable in-plane at 100% power. This OA demonstrates there is reasonable assurance that the SIPC and AILPC for TTW will be satisfied for 18 months at 70% power.

3.1 OA for Degradation Mechanisms Other than TTW

The "SONGS U2C17 Outage – Steam Generator Operational Assessment" report [Appendix-A] addresses all degradation mechanisms found in Unit 2 SGs with the exception of TTW. Due to the relatively large number of AVB and TSP wear indications, identified during the U2C17 outage, a probabilistic approach was used to complete the OA for these mechanisms, which included:

- Tube Wear at AVB Locations
- Tube Wear at TSP Locations
- Tube Wear at Retainer Bar Locations
- Tube Wear as a Result of Foreign Object Wear

The objective of this OA is to ensure that structural and leakage performance criteria will be met over the length of the upcoming inspection interval. The OA tube structural integrity requirement is that the projected worst case degraded tube for each existing degradation mechanism shall meet the limiting structural performance parameter with a 95% probability at 50% confidence [3].

AVB and TSP Wear

Because the tube wear indications are flat and long in the axial direction, the limiting requirement for the inspection interval length is structural integrity (i.e. tube burst at 3x NODP). The projected accident-induced leak rates for tube wear will not be limiting since leakage due to ligament pop-through will not precede burst condition at 3x NODP.

The OA uses a probabilistic method to calculate the growth at End of Cycle (EOC) of each indication by randomly sampling from the growth rate distribution yielding one estimate of the EOC depth for each indication. The burst pressure of the worst case degraded tube is calculated and compared with the value of 3 times NODP. This process is repeated thousands of times in order to develop a probability of burst for the worst case degraded tube. If the probability of burst of the worst case degraded tube is less than 5%, then the plugging criteria and inspection interval are satisfactory.

The projected EOC probabilities of burst for the population of indications in each damage mechanism category were calculated for Unit 2 at 100% power for a full cycle of operation (1.577 Effective Full Power Years, EFPY). The projected EOC probabilities are compared with the 95% probability 50% confidence EPRI guidelines [14] criteria to demonstrate the OA structural integrity criteria for AVB and TSP wear are satisfied for a full fuel cycle of operation at 100% reactor power.

Retainer Bar Wear

Because of the potential for continued retainer bar wear of Unit 2, tubes adjacent to retainer bars have been removed from service. Tubes with retainer bar wear indications were stabilized with U-bend cable stabilizers. The tubes on either side of all retainer bars, at each end of the retainer bars, and at the center of the retainer bars, were also stabilized with U-bend cable stabilizers. These corrective actions provide reasonable assurance that retainer bar wear will not challenge the structural and leakage integrity performance criteria during the remaining life of the SGs. In addition, the stabilization of these tubes provides reasonable assurance that a tube severance event will not occur as a result of retainer bar wear. The SG Program [2] will monitor the tubes adjacent to these plugged tubes during future SG inspections.

Foreign Object Wear

All Unit 2 SG tubes were examined full length with Eddy Current Testing (ECT) bobbin coil probes. Two adjacent tubes in SG 2E-089 were identified with foreign object wear indications. The foreign object was identified as weld slag and retrieved from the SG. No other foreign objects were found. The foreign object is not indicative of degradation of secondary side internals.

Because the foreign object has been removed, no potential exists for degradation to progress at these locations. After removal of the object, the affected indications were inspected with ECT. Since the indications are below the SONGS plugging limit and the object was removed, these tubes are left in service.

Based on ECT inspections, secondary side visual examinations, and FOSAR, no foreign objects capable of causing tube degradation remain in the Unit 2 SGs. There is reasonable assurance that foreign objects will not cause the structural or leakage integrity performance criteria to be exceeded prior to the next tube inspection in each SG.

OA for Degradation Mechanisms Other than TTW Conclusion

The OA demonstrates there is reasonable assurance that the SIPC and AILPC for non-TTW will be satisfied for 18 months at 100% power.

3.2 TTW OA Using Tube-to-AVB Support Conditions and Contact Force

The "SONGS U2C17 Steam Generator Operational Assessment for Tube-to-Tube Wear" [Appendix-B] assesses the TTW degradation mechanism deterministically, without taking credit for in-plane support. The OA also implements a probabilistic approach using tube to AVB contact forces for defining an effective tube support. The OA predicts the probability of in-plane FEI and compares this value to the probabilistic SIPC (95% probability at 50% confidence).

The deterministic approach uses Stability Ratios (SRs) as the criterion for susceptibility to FEI. The SR is calculated conservatively using Thermal-Hydraulic (T/H) and tube support conditions on the secondary side of the SG. The T/H conditions are determined using an ATHOS computer model.

The deterministic approach demonstrates in-plane stability (SR less than 1.0) at 70% power with no effective in-plane AVB supports. This demonstrates TTW will not occur and SIPC limits will be met.

As discussed above, a SR of less than 1.0 indicates the SG tubes will be stable. To demonstrate margin, a probabilistic evaluation was performed assuming instability may occur at a calculated SR as low as 0.75. In the probabilistic approach, the number of effective AVB supports for each tube uses a probabilistic contact force distribution and criteria for determining whether a support is effective for a given contact force. A finite element model of tubes, AVBs, tube-to-AVB gaps, and support structures is used to calculate contact forces at AVB locations. Tube wear inputs to the finite element model are determined from actual wear observed in Units 2 and 3. Results from published technical literature, confirmed by benchmarking the FEI probability model to Unit 3 TTW, indicate that effective supports have a contact force that exceeds a specified value.

SRs are determined for each U-bend tube as a function of the number of consecutive ineffective supports and power level. The distributions of contact forces are calculated for each AVB location in the bundle. Tube wear at AVB locations decreases the contact force at those locations. The required contact force for an AVB support to be considered effective is calculated for each AVB location.

Using the above as inputs, Monte Carlo trials of a SG are simulated. The probability of instability is the number of trials where the SG contained one or more unstable tubes divided by the total number of trials.

TTW OA Using Tube-to-AVB Support Conditions and Contact Force Assessment Conclusion

The deterministic approach demonstrates FEI will not occur. Using a SR of <1.0 at 70% power, the SIPC and AILPC are satisfied for an 18 month inspection interval. The probabilistic approach also demonstrates that there is safety margin in the planned inspection interval of 150 cumulative days at power. The approach demonstrates that if instability is assumed to initiate at a calculated SR of 0.75, rather than a value of 1.0, the SIPC acceptance standard is satisfied for approximately 8 months at 70% power.

3.3 "Traditional" Probabilistic OA for TTW

The "Operational Assessment for SONGS Unit 2 SG for Upper Bundle Tube-to-Tube Wear Degradation at End of Cycle 16" [Appendix-C] uses established industry methods for assessing degradation mechanisms. This OA uses empirical models for degradation growth and engineering models for determining burst pressure and through-wall leak rates. The non-traditional aspect of this OA is to characterize the presence and severity of TTW degradation indications using wear indices defined by the state of AVB and TSP wear for a specific tube.

Unit 3 wear data establish the initiation and growth of TTW indications in Unit 2 SG. An empirical correlation using a wear index (a measure of the state of wear degradation in each tube) provides the method for comparing the Unit 3 wear to Unit 2. A probabilistic model representing the high-wear region of the tube bundle evaluates TTW for inspection interval. Tube burst and leakage probabilities are calculated by Monte Carlo simulation for initiation and growth of TTW.

Two OA cases are evaluated using the sizing techniques that define the Unit 3 TTW depths. Case 1 evaluates eddy current indication sizing using EPRI ECT Examination Technique Specification Sheet (ETSS) 27902.2 to establish the TTW depth distributions. In Case 2, the TTW depths were determined using a more representative calibration standard.

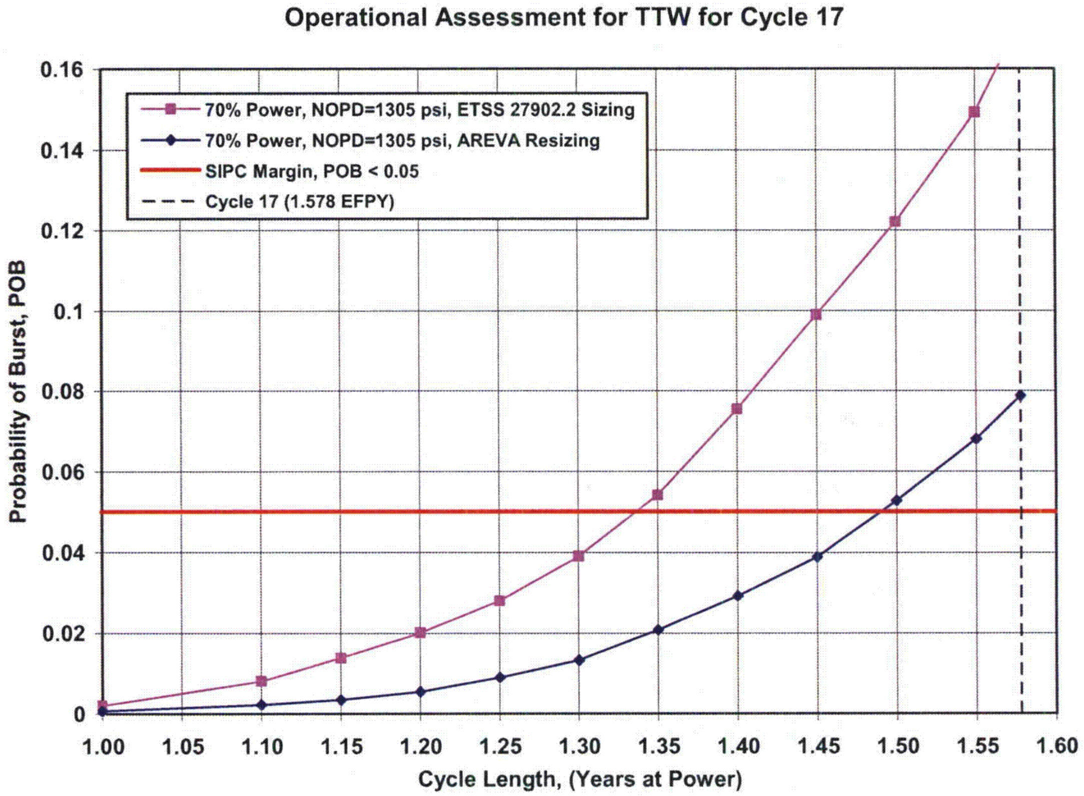
"Traditional" Probabilistic OA for TTW Conclusion

The results for Case 1 indicate that the SIPC margin requirements are satisfied for an inspection interval of 16 months at 70% power. In Case 2, the SIPC margins are met for a cycle length of 17 months at 70% power. The results of this analysis are displayed in Figure 3-1. The figure identifies the probability of burst as a function of operating cycle length (inspection interval) and power.

The SIPC (Tube burst at 3xNOPD) is the limiting requirement for the inspection interval. The AILPC is satisfied since burst margins at 3xNOPD are maintained during the inspection interval.

This OA demonstrates there is a reasonable assurance that the SIPC and AILPC for TTW will be satisfied for 16 months at 70% power level.

Figure 3-1: Traditional Operational Assessment Results



3.4 Deterministic TTW OA

A deterministic TTW OA [Appendix-D] was completed for tube wear at AVBs and TTW. Tube wear projections for in-service tubes confirm the SG performance criteria will be satisfied during the inspection interval. Tube wear projections for plugged tubes confirm that severance will not occur during the inspection interval.

Evaluation of TTW of the two tubes in SG 2E-089 concludes the wear did not result from in-plane vibration of the tubes. ECT data demonstrate the tube wear indications at AVBs did not extend beyond the width of the AVBs in Unit 2. Wear extending beyond the width of AVBs was strongly correlated with Unit 3 tubes with TTW. In-plane SRs indicate that the two Unit 2 tubes with TTW are stable at 100% power. Pre-service inspection data indicates these two tubes were in close proximity prior to SG operation. The OA postulates that during operation out-of-plane vibration and/or turbulence caused the two tubes to wear.

The potential for in-plane vibration leading to TTW in Unit 2 is evaluated by calculating in-plane SRs. The OA methodology predicts in-plane vibration in Unit 3 and confirms the absence of in-plane vibration in Unit 2.

This OA projects the depth of indications to the next inspection using current inspection data. ATHOS results provide the T/H inputs for flow velocity, density, and void fraction along the length of the tube. These conditions are used in the Flow Induced Vibration analysis to generate the SR for out-of-plane and in-plane vibration of the tube for various tube support conditions. The support conditions define whether or not a support location such as an AVB intersection is effective, meaning that the structure provides adequate support with respect to motion of the tube due to vibration. Presence of tube-to-AVB wear indicates an ineffective support.

The vibration analysis results and support conditions are used to make wear projections in the next operating cycle. This calculation is based on empirical test results and involves several input assumptions related to tube-to-AVB gap, the AVB twist, and the wear coefficient between the tube and AVB. The expected ranges of these parameters are known from test results, published data and experience. Wear depth projection is made taking into consideration the inspection results at the current outage. After setting the inputs to match the inspection results for a given indication, the wear calculations are extended to determine the projected wear depth at the next inspection.

Deterministic TTW OA Conclusion

The OA demonstrates there is reasonable assurance that the SIPC and AILPC for TTW will be satisfied for 18 months at 70% power.

3.5 Evaluation of Leakage Integrity

The AREVA non-TTW OA [Appendix-A], Section 6.3, discussed the evaluation of leakage integrity for both in-service and plugged tubes. Since the preparation of the AREVA non-TTW OA, SCE plugged five additional tubes. The five additional tubes resulted in a negligible change to the postulated operational and accident-induced leakage attributed to all of the tube plugs using the methodology from the AREVA non-TTW OA.

The operational leakage performance criterion is met through the plant monitoring program. The accident-induced leakage performance criterion is met by projecting leakage attributed to all degradation mechanisms along with postulated plug leakage and comparing the projected leakage to the allowable accident-induced leak rate limit. For tubes returned to service, the onset of pop-through and leakage for axially oriented indications with limited circumferential extent – the nature of the degradation identified in the Unit 2 SGs – is coincident with burst. None of the identified degradation mechanisms in Unit 2 are projected to exceed the structural performance criteria prior to the next scheduled inspection. The accident-induced leakage is only attributed to postulated plug leakage through out-of-service tubes. There is reasonable assurance the accident-induced leakage performance criteria will not be exceeded prior to the next inspection of the Unit 2 SGs.

3.6 Summary of All OA Conclusions

The OA provide reasonable assurance, as required by NRC regulations that Unit 2 will operate safely at 70% power for 150 cumulative days. The OAs (See Table 3-1) summarized in Sections 3.1 and 3.2 conclude the SIPC and AILPC are satisfied. The alternative OA methodologies summarized in Sections 3.3 and 3.4 also confirm the SG tube integrity will be maintained during the inspection interval.

Table 3-1: OA Approach and Results Comparison

OA Description	OA for Degradation Mechanisms Other Than TTW	TTW OA With No Effective AVB Supports	"Traditional" Probabilistic OA Prepared for TTW	Deterministic TTW OA
Reference Appendix	A	B	C	D
Degradation Mechanisms Addressed	All but TTW	TTW	TTW	TTW & AVB Wear
Type	Probabilistic	Deterministic	Probabilistic	Deterministic
Thermal Power Assumption	100%	70%	70%	70%
Resulting Inspection Interval	18 months	18 months	16 months	18 months

As identified in Table 3-1 above, the OAs result in an acceptable inspection interval of at least 16 months at 70% power. These OAs determined that at 70% power, the T/H conditions that cause FEI will be eliminated from the SONGS Unit 2 SGs. As discussed in Section 3.2, an additional probabilistic evaluation, assuming a calculated SR of 0.75, was performed to demonstrate margin. The approach assumes instability initiates at a calculated SR of 0.75 (rather than a SR of 1.0). Using this approach, the SIPC acceptance standard is satisfied for approximately 8 months at 70% power.

Accordingly, the 150 cumulative day inspection interval being implemented by SCE demonstrates substantial conservative margin using any of the OA methodologies.

4.0 REFERENCES

1. Confirmatory Action Letter 4-12-001 – "San Onofre Nuclear Generating Station, Units 2 and 3, Comments to Address Steam Generator Tube Degradation," March 27, 2012
2. SONGS Steam Generator Program, SO23-SG-1
3. SONGS Technical Specifications Sections 5.5.2.11, "Steam Generator (SG) Program," Amendment 204
4. SONGS Technical Specifications Section 3.4.12, "RCS Operational Leakage," Amendment 204
5. NEI 97-06, "SG Program Guidelines," Rev. 3, January 2011
6. AREVA NP Document 51-9176667-001, "SONGS 2C17 & 3C17 Steam Generator Degradation Assessment."
7. SCE Drawing SO23-617-1-D116 Rev. 2, "San Onofre Nuclear Generating Station Unit 2 & 3 Replacement Steam Generators – Design Drawing – Tube Bundle 1/3" (MHI Drawing L5-04FU051 Rev. 1)
8. SCE Drawing SO23-617-1-D507 Rev. 5, "San Onofre Nuclear Generating Station Unit 2 & 3 Replacement Steam Generators – Design Drawing – Anti-Vibration Bar Assembly 1/9" (MHI Drawing L5-04FU111 Rev. 2)
9. SCE Drawing SO23-617-1-D542 Rev. 9, "San Onofre Nuclear Generating Station Unit 2 & 3 Replacement Steam Generators – Design Drawing – Anti-Vibration Bar Assembly 7/9" (MHI Drawing L5-04FU117 Rev. 9)
10. SCE Drawing SO23-617-1-D296 Rev. 3, "San Onofre Nuclear Generating Station Unit 2 & 3 Replacement Steam Generators – Design Drawing – Tube Support Plate Assembly 3/3" (MHI Drawing L5-04FU108 Rev. 3)
11. SCE Drawing SO23-617-1-D117 Rev. 2, "San Onofre Nuclear Generating Station Unit 2 & 3 Replacement Steam Generators – Design Drawing – Tube Bundle 2/3" (MHI Drawing L5-04FU052 Rev. 1)
12. SCE Drawing SO23-617-1-D118 Rev. 4, "San Onofre Nuclear Generating Station Unit 2 & 3 Replacement Steam Generators – Design Drawing – Tube Bundle 3/3" (MHI Drawing L5-04FU053 Rev. 3)
13. AREVA NP Document 51-9182368-003, "SONGS 2C17 Steam Generator Condition Monitoring Report"
14. EPRI Report 1019038, "Steam Generator Management Program: Steam Generator Integrity Assessment Guidelines: Revision 3", November 2009.

ATTACHMENT 6 – Appendix A

SONGS U2C17 Outage –
Steam Generator Operational Assessment

[Proprietary Information Redacted]

AREVA

AREVA NP Inc.

Engineering Information Record

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SONGS U2C17 Outage - Steam Generator Operational Assessment

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000	All	Original Release
001	Sections 2.0 and 5.2.1.3	Section 2.0; changed Mode 4 to Mode 2 Section 5.2.1.3; last sentence; inserted "2C17" before "depth distribution"
002	All	Added Section 2.0 and Table 2-1 Added References 13 through 20 Incorporated other miscellaneous comments throughout remainder of document

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1.0 PURPOSE

In accordance with the SONGS Steam Generator Program [18] and EPRI Steam Generator Integrity Assessment Guidelines [2], an operational assessment (OA) must be performed to ensure that steam generator (SG) tubing will meet established performance criteria for structural and leakage integrity during the operating period prior to the next planned inspection. The OA evaluates and projects tube degradation mechanisms which have affected the SGs to date. The performance criteria are defined in plant Technical Specifications [13] [14]. The performance criteria are based on NEI 97-06 [1] (see Section 4.0 below).

This report documents the OA performed during the SONGS Unit 2 C17 Refueling Outage. This OA addresses the detected tube degradation OTHER THAN tube-to-tube wear (TTW). TTW will be addressed in a separate OA [15]. This OA concludes that operation at full power for a full cycle of 1.577 Effective Full Power Years (EFPY) is justified based on detected tube degradation other than TTW. The OA for TTW [15] may prescribe operation at reduced power and/or a shorter inspection interval. The more conservative OA shall govern plant operation.

2.0 ABBREVIATIONS AND ACRONYMS

The following table provides a listing of abbreviations and acronyms used throughout this report.

Table 2-1: Abbreviations and Acronyms

Abbreviation or Acronym	Definition
01C to 07C	Tube Support Plate Designations for Cold Leg (7 Locations)
01H to 07H	Tube Support Plate Designations for Hot Leg (7 Locations)
2E-088	Unit 2 Steam Generator 88
2E-089	Unit 2 Steam Generator 89
3E-088	Unit 3 Steam Generator 88
3E-089	Unit 3 Steam Generator 89
3 NOPD	3 Times Normal Operating Pressure Differential
AILPC	Accident Induced Leakage Performance Criterion
ASME	American Society of Mechanical Engineers
AVB	Anti-Vibration Bar
C	Column
CE	Combustion Engineering
CL or C/L	Cold Leg
CM	Condition Monitoring
DA	Degradation Assessment
ECT	Eddy Current Testing
EFPD	Effective Full Power Days
EOC	End of Operating Cycle
EPRI	Electric Power Research Institute

Table 2-1: Abbreviations and Acronyms

Abbreviation or Acronym	Definition
ETSS	Examination Technique Specification Sheet
FOSAR	Foreign Object Search and Retrieval
GPD	Gallons per Day
GPM	Gallons per Minute
HL or H/L	Hot Leg
KSI	Thousand Pounds per Square Inch
MHI	Mitsubishi Heavy Industries
MSLB	Main Steam Line Break
NDE	Non Destructive Examination
NEI	Nuclear Energy Institute
NN	Nuclear Notification
NOPD	Normal Operating Pressure Differential
NRC	Nuclear Regulatory Commission
OA	Operational Assessment
PSI	Pounds per Square Inch
PSIG	Pounds per Square Inch Gage
PWR	Pressurized Water Reactor
QA	Quality Assurance
R	Row
RB	Retainer Bar
RCS	Reactor Coolant System
SCE	Southern California Edison
SG	Steam Generator
SIPC	Structural Integrity Performance Criteria
SLB	Steam Line Break
SONGS	San Onofre Nuclear Generating Station
SSI	Secondary Side Inspection
TEC	Tube End Cold
TEH	Tube End Hot
TSP	Tube Support Plate
TTS	Top of Tubesheet
TTW	Tube to Tube Wear
TW	Through Wall
UB	U-bend

3.0 SCOPE

This evaluation pertains to the SONGS Unit 2 replacement steam generators which are reactor coolant system components. This report addresses all tube degradation mechanisms except for TTW. The OA for TTW will be addressed separately. In accordance with Reference 10, the OA documented in this report is required to be completed prior to plant entry into Mode 2 during start up from the current outage.

Note that the required SG condition monitoring (CM) assessment is documented in a separate report [11] and is summarized below in Section 5.3.

4.0 PERFORMANCE CRITERIA

The Unit 2 performance criteria, based on NEI 97-06 [1] are shown below. The structural integrity and accident-induced leakage criteria were taken from Section 5.5.2.11 [13] from the Unit 2 Technical Specifications. The operational leakage criterion was taken from Section 3.4.13 [14] of the Unit 2 Technical Specifications.

- *Structural Integrity Performance Criterion (SIPC)*: All in-service steam generator tubes shall retain structural integrity over the full range of normal operating conditions (including startup, operation in the power range, hot standby, and cooldown, and all anticipated transients included in the design specification) and design basis accidents. This includes retaining a safety factor of 3.0 against burst under normal steady state full power operation primary-to-secondary pressure differential and a safety factor of 1.4 against burst applied to the design basis accident primary-to-secondary pressure differentials. Apart from the above requirements, additional loading conditions associated with the design basis accidents, or combination of accidents in accordance with the design and licensing basis, shall also be evaluated to determine if the associated loads contribute significantly to burst or collapse. In the assessment of tube integrity, those loads that do significantly affect burst or collapse shall be determined and assessed in combination with the loads due to pressure with a safety factor of 1.2 on the combined primary loads and 1.0 on axial secondary loads.
- *Accident Induced Leakage Performance Criterion (AILPC)*: The primary to secondary accident induced leakage rate for any design basis accident, other than a SG tube rupture, shall not exceed the leakage rate assumed in the accident analysis in terms of total leakage rate for all SGs and leakage rate for an individual SG. Leakage is not to exceed 0.5 gpm per SG and 1 gpm through both SGs.
- *Operational Leakage Performance Criterion (OLPC)*: RCS operational leakage shall be limited to 150 gallons per day primary to secondary leakage through any one steam generator."

5.0 BACKGROUND

5.1 Steam Generator Design

SONGS Unit 2 is a two loop Combustion Engineering (CE) Pressurized Water Reactor (PWR) plant which began commercial operation in 1983. The original CE steam generators were replaced in 2009-2010 with new SGs designed and manufactured by Mitsubishi Heavy Industries (MHI). The replacements, referred to by MHI as model 116TT-1, incorporate thermally treated Inconel Alloy 690 (I-690TT) tubing which has demonstrated, through laboratory testing and industry experience, superior resistance to stress corrosion cracking as compared with the I-600 tubing used in the original SGs. Other design features include full tubesheet depth hydraulic tube expansion and seven stainless steel trefoil broached Tube Support Plates (TSPs) which are features chosen primarily to minimize the potential for tube corrosion.

There are 9727 tubes in each SG, in 142 rows and 177 columns, in a triangular pitch arrangement. The tubes in rows 1-13 are thermally stress-relieved to further minimize the potential for in-service stress corrosion cracking in the U-bends. The tube bundle U-bend region is supported by a floating Anti-Vibration Bar (AVB) structure consisting of six V-shaped flat-bar AVBs between each tube column. The AVBs were fabricated from ASME SA-479, Type 405 ferritic stainless steel and are equipped with two Alloy 690 (ASME SB-168 UNS N06690) end caps. Each AVB end cap is welded to an Alloy 690 retaining bar. The retaining bars with AVBs attached are supported by twenty four chrome-plated Alloy 690 retainer bars that anchor the assembly to the tubes. Thirteen Alloy 690 bridges run perpendicular to the retaining bars and retainer bars, and hold the entire assembly together. The AVB structure is not attached to any other steam generator component. Figure 5-1 illustrates the general layout of the tube support structures. Figure 5-2 and Figure 5-3 illustrate the retainer bar and retaining bar arrangement.

5.2 Tube-to-Tube Wear Finding

During the U2C17 outage, SONGS Unit 3 was shut down due to a primary-to-secondary SG tube leak. Eddy current inspections of the Unit 3 steam generators revealed that the cause of the leak was TTW in the U-bend region of the tube bundle. A root cause evaluation has concluded that the tube-to-tube wear in the SONGS steam generators was caused by tube movement caused by fluid-elastic instability (FEI) [16]. No indications of TTW were reported during the initial inspections of the Unit 2 steam generators which included full-length inspections of all tubes with bobbin coil probes. However, to apply the Unit 3 experience to Unit 2 steam generators, supplemental +Point™ inspections of the U-bends were performed in Unit 2. These supplemental inspections included the full-length of the U-bend for a group of tubes in the same tube bundle region which experienced TTW in Unit 3. These supplemental inspections resulted in the finding of two adjacent tubes with shallow (14% TWD as measured with +Point™) tube-to-tube wear in the 2E-089 SG.

5.3 Condition Monitoring Assessment Summary

A detailed description of the SG scope of work and findings, and the CM assessment of SG tube condition as determined during the U2C17 outage are documented in Reference 11. The U2C17 inspections revealed many indications of wear. Wear indications were reported at anti-vibration bars (AVBs), tube support plates (TSPs), retainer bars (RB), and due to a foreign object. In addition, as discussed above, tube-to-tube wear in the U-bend region was also reported in two adjacent tubes in the 2E-089 SG.

Except for one retainer bar wear indication, all tubes passed CM analytically. The tube with the deep RB wear indication was in-situ pressure tested and successfully met all performance criteria.

The CM assessment evaluated all SG tube degradation detected during the U2C17 outage against the three SONGS technical specification performance criteria in References 13 and 14. Through a combination of eddy current inspection, analytical evaluation, in-situ pressure testing, and operational leakage monitoring, it was determined that all three of the performance criteria were met.

Figure 5-1: SONGS Steam Generator Support Structure Layout

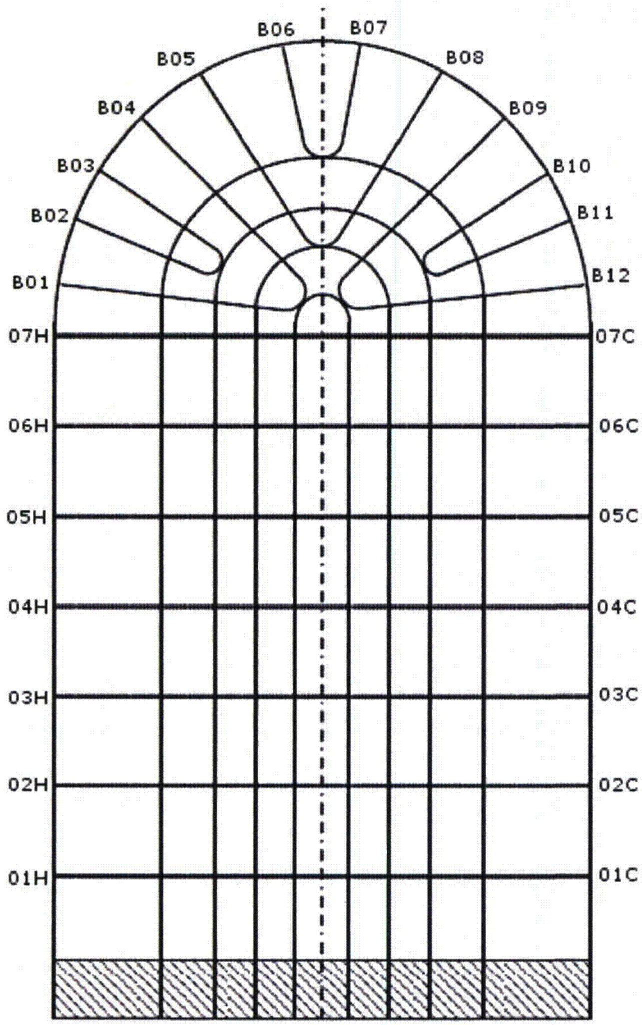


Figure 5-2: View From Above Bundle Showing Retainer Bar Locations

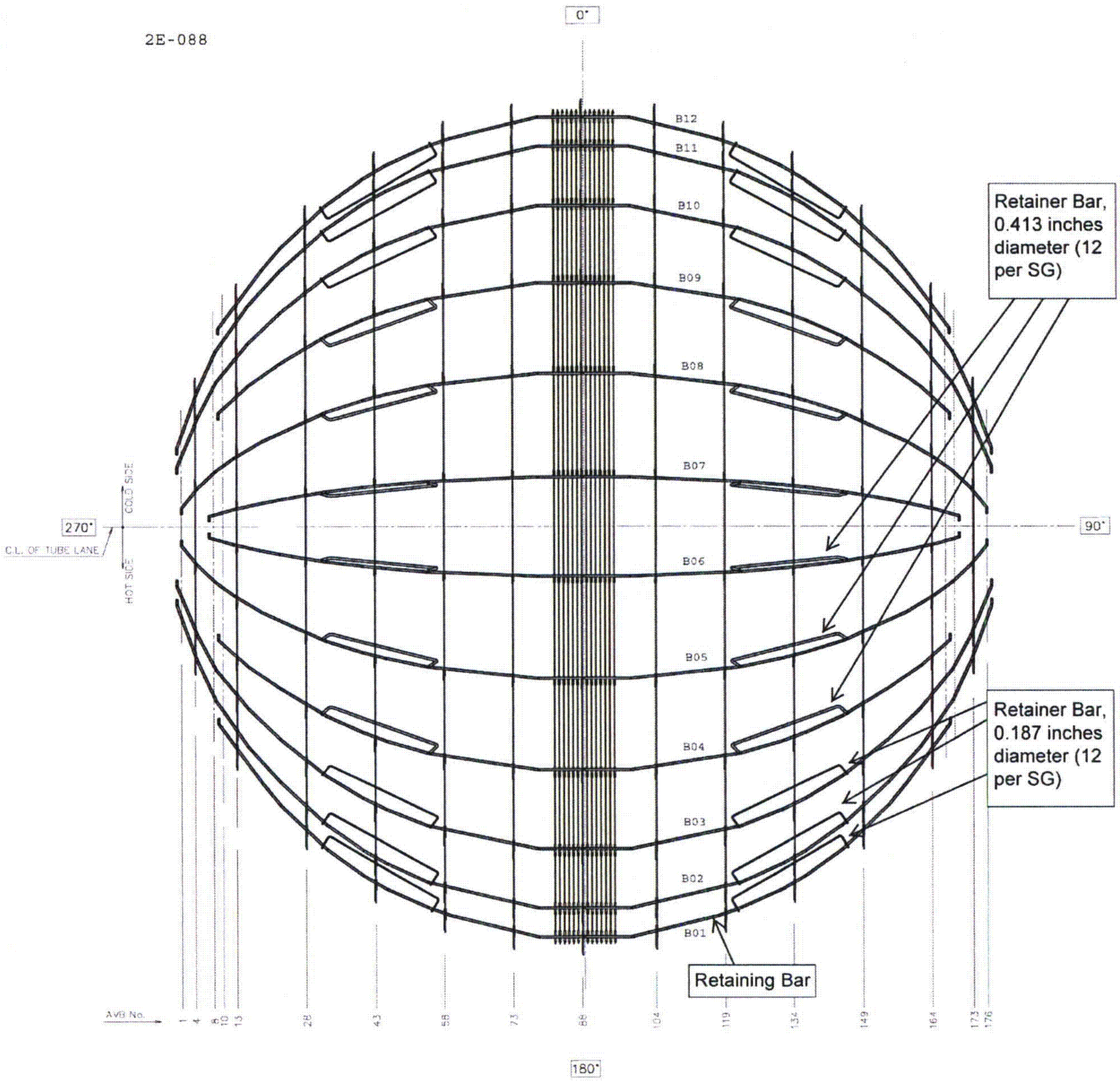
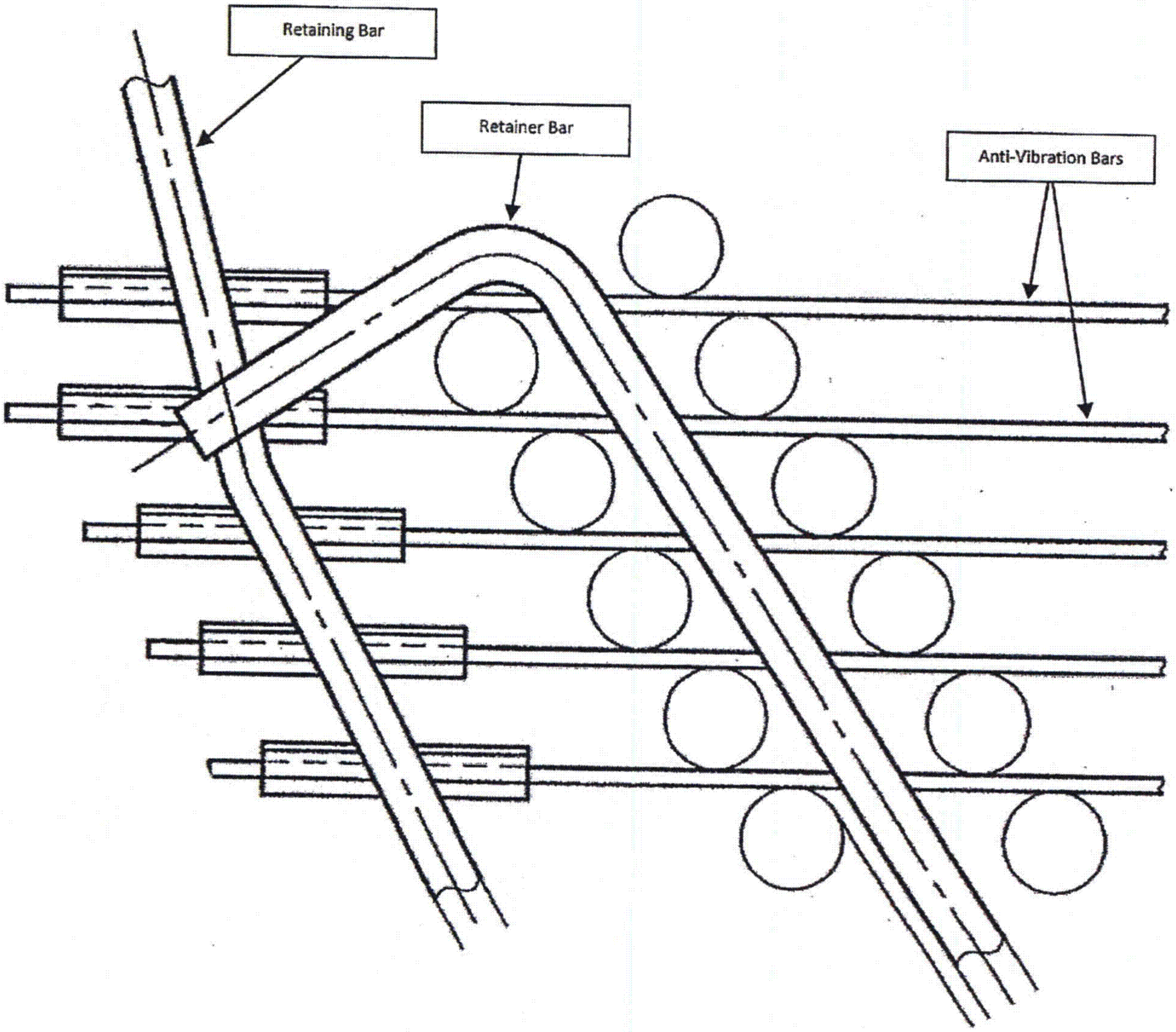


Figure 5-3: Sketch Showing Retainer/Retaining Bar Configuration



6.0 OPERATIONAL ASSESSMENT

The SONGS SG Program requires that a “forward looking” operational assessment (OA) be performed in accordance with Reference 2 to determine if the SG tubing will continue to meet the structural and leakage integrity requirements prior to the next inspection. The OA is based upon an evaluation of the degradation mechanisms observed during the current inspection. As discussed in Reference 11, the following tube degradation mechanisms were identified during the U2C17 outage:

- Anti-vibration bar (AVB) wear
- Tube support plate (TSP) wear
- Retainer bar (RB) wear
- Foreign object wear
- Tube-to-tube wear (TTW)

The degradation mechanisms covered by this operational assessment are being evaluated assuming a full cycle of operation at 100% reactor power. Per Reference 7, the upcoming fuel cycle is planned to be 576 EFPD (Effective Full Power Days). Converting this to EFPY gives a length for Cycle 17 of 1.577 EFPY. As discussed previously, this report addresses all degradation mechanisms except for TTW. The OA for TTW will be documented separately. In the TTW OA, the permissible reactor power level and inspection interval may be reduced from that evaluated in this document. The more conservative OA shall govern plant operation.

6.1 Input Parameters

Table 6-1 and Table 6-2 identify the input parameters used to perform the operational assessment. Consistent with the structural integrity criteria described in Section 4.0, the limiting pressure loading occurs at a value of three times the normal operating pressure differential (NOPD). For Unit 2 at full power, this value is 4290 pounds per square inch differential (psid) and is based on a conservative assessment of Unit 2 secondary side steam pressure during the previous operating cycle. A review of the secondary side steam pressures for the previous operating cycle showed a secondary side steam pressure of about 820 pounds per square inch absolute (psia). With a primary side pressure of 2250 psia, a 3 NOPD value of 4290 psid is obtained. As discussed earlier, it is possible that operation during the next inspection interval will be at reduced power. Operation at reduced power will increase the secondary side steam pressure. Therefore, the 3 NOPD value will be also reduced by operation at reduced power levels and using the 4290 psid value bounds the potential operating conditions for the upcoming operating period.

In addition to pressure loads, the OA must also consider the impact of non-pressure accident loads if they could have a significant effect on the burst pressure of the degraded tubes. The CM assessment [11] provides the basis for concluding that design basis, non-pressure accident loads are not limiting for the tube wear mechanisms identified for the Unit 2 SG tubes. Consequently, the limiting loading scenario for evaluation of structural and leakage integrity is that involving pressure loads evaluated with a safety factor of three (i.e., 3 NOPD).

In order for a degraded tube to be returned to service, the degradation must be measured using a qualified Eddy Current Testing (ECT) sizing technique and the degradation must be evaluated as acceptable for continued operation. The ECT sizing techniques qualified for use at Unit 2 are identified in the degradation assessment [5] and their sizing performance parameters are summarized in Table 6-2. The techniques are identified by their EPRI ETSS (Examination Technique Specification Sheet) numbers. If tube degradation cannot be sized with appropriate sizing confidence, the tube is plugged upon degradation detection. All degradation identified during the current outage was measured with a qualified ECT technique.

Table 6-1: Unit 2 Steam Generator Input Values

Parameter	***Value***
Desired probability of meeting burst pressure limit	0.95
Tubing wall thickness	0.043 inch, [7]
Tubing outer diameter	0.750 inch, [7]
Mean of the sum of yield and ultimate strengths at temperature	116000 psi, [8]
Standard deviation of the sum of yield and ultimate strengths	2360 psi, [8]
3 Normal Operating Pressure Differential (3 NOPD)	4290 psid, [7]
MSLB Pressure Differential	2560 psid, [9]
EFPD from SG Replacement until U2C17 Refueling Outage	627.11 EFPD, [7]
Operating interval for upcoming fuel cycle as evaluated in this OA*	1.577 EFPY

* This OA only addresses detected degradation mechanism other than TTW. The OA for TTW will be documented separately. The OA for TTW may prescribe operation at lower reactor power and a shorter inspection interval. Whichever OA is more conservative shall govern plant operation.

Table 6-2: Eddy Current ETSS Input Values [4]

Parameter	***ETSS 96004.1***	***ETSS 10908.4***	***ETSS 27903.1***	***ETSS 27901.1***	***ETSS 27902.2***	***ETSS 96910.1***
Probe Type	Bobbin Coil	+Point™	+Point™	+Point™	+Point™	+Point™
NDE depth sizing regression parameters	Slope = 0.98 Intercept = 2.89 %TW	Slope = 1.06 Intercept = 0.13 %TW	Slope = 0.97 Intercept = 2.80 %TW	Slope = 1.05 Intercept = -1.97 %TW	Slope = 1.02 Intercept = 0.94 %TW	Slope = 1.01 Intercept = 4.30 %TW
NDE depth sizing technique uncertainty (standard deviation)	4.19 %TW	3.78 %TW	2.11 %TW	2.30 %TW	2.87 %TW	6.68 %TW
NDE depth sizing analysis uncertainty (standard deviation)	2.10 %TW	1.89 %TW	1.06 %TW	1.15 %TW	1.44 %TW	3.34 %TW
Total NDE (Sizing and Technique) (standard deviation)*	4.69 %TW	4.23 %TW	2.36 %TW	2.60 %TW	3.22 %TW	7.48 %TW

* Total uncertainty is the technique and analysis uncertainties combined via the square root of the sum of the squares.

6.2 Evaluation of Structural Integrity

The fundamental OA structural integrity criteria is that the projected worst case degraded tube for each existing degradation mechanism must meet the limiting structural performance parameter with a 95% probability and 50% confidence [2]. Due to the relatively large number of AVB wear and TSP wear indications identified during the U2C17 outage, a probabilistic approach for analysis of the full bundle is necessary and was used to perform the OA for these mechanisms in accordance with Section 8.3 of Reference 2.

6.2.1 AVB Wear and TSP Wear

With the finding of TTW in Unit 2, over 300 tubes were preventatively plugged in Unit 2 in the region deemed most susceptible to fluid-elastic instability. These tubes contained a significant number of AVB wear indications. Therefore, the number of AVB wear indications returned to service for the next operating interval is significantly less than the number of indications reported during the U2C17 inspection. The quantities of indications detected and returned to service are shown in Table 6-3.

The typical deterministic approach for performing an OA for wear is to identify the worst case flaw during the current outage, apply an upper bound growth rate to reflect growth during operation prior to the next inspection, and compare the resulting depth (i.e., the end-of-cycle (EOC) depth) to the CM limit curve. This is generally appropriate for degradation mechanisms which involve a small number of indications. However, when a large number of indications of a particular mechanism are expected to develop or are left in-service, it is not conservative to perform a deterministic OA evaluation of this type. A probabilistic approach addresses the fact that the presence of a large number of in-service flaws increases the probability that one or more of the flaws will grow to a structurally significant depth by the EOC. Hence, this evaluation approach will yield a lower plugging limit for a SG which has a large population of flaws than would a typical deterministic approach. For the Unit 2 AVB wear and TSP wear, it is prudent to use a probabilistic approach. Consequently, the OA for AVB and TSP wear was performed using AREVA's full tube bundle probabilistic OA tool [6].

AREVA's full-bundle probabilistic OA tool was developed specifically for wear at support structures using the flaw model from Section 5.3.3 of Reference 3 and the Monte Carlo approach from Reference 2. This tool receives as key inputs: 1) the population of wear flaws identified, 2) the growth rate distribution anticipated during the next operating period, 3) Non-Destructive Examination (NDE) Examination Technique Specification Sheet (ETSS) regression and uncertainty parameters, 4) a conservative estimation of the number of flaws present, but not detected, during the U2C17 outage inspection, and 5) newly initiated flaws expected during the next operating period. The tool "grows" each flaw that is left in-service by randomly sampling from the growth rate distribution, yielding one estimate of the EOC depth for each flaw. In addition, the entire population of expected newly initiated flaws is added to the EOC flaw population. From this EOC combined population the burst pressure of the worst case degraded tube is calculated and compared with the value of 3 NOPD. This process is repeated thousands of times (via a Monte Carlo process) in order to develop a probability of survival for the worst case degraded tube. This value must be at least 95% to satisfy the fundamental OA criteria. If the result is less than 95%, a lower plugging limit must be implemented. The calculation also considers uncertainties associated with material strength, ECT sizing, the ratio of maximum flaw depth to structurally significant flaw depth, and the burst equation itself. Within the full bundle OA tool, AVB and TSP wear are evaluated using the EPRI Flaw Handbook [3] degradation model for axial part-throughwall degradation less than 135° in circumferential extent, subjected to pressure loading of 3 NOPD. The basis for the use of this flaw model is discussed in the CM assessment [11].

6.2.1.1 Growth Rates

One of the underlying assumptions implemented within the full bundle OA tool is that growth rates going forward are random with respect to the current wear depth. Because the Unit 2 SGs have operated for only one cycle and have only one in-service inspection, it is not known if or to what extent this behavior will manifest itself in the future. Consequently, AVB wear was evaluated as two separate populations: flaws >20%Through Wall (TW) in one population, and flaws ≤20%TW in the other population. Flaws >20%TW are assumed to continue to grow at a rate based on their growth during the first operating cycle. In the evaluation, this forces deeper flaws to grow at a higher rate. Likewise, flaws ≤20%TW are grown at a rate based on their growth during the first cycle. TSP wear flaws sized >10%TW were similarly evaluated as a separate population from those sized ≤10%TW. Because there are very few TSP flaws sized >20%TW, a cutoff value of 10%TW was chosen. The selections of the breakpoints at 20%TW for AVB wear and 10%TW for TSP wear were based on AREVA Engineering experience and the numbers of flaws being returned to service in each depth category.

For AVB wear, 2E-088 has the limiting growth distribution. Therefore, the 2E-088 growth distribution was applied to both SGs. Due to the relatively small population of TSP wear indications, the growth rate distribution used in the OA was based on a combined data set from both SGs.

Prior to developing a growth rate distribution, the measured depths of the wear reported must be adjusted to account for the tendency of the EPRI sizing technique in ETSS 96004.1 to undersize flaw depth. This systematic sizing bias need not be considered when growth rate distributions are developed from two consecutive inspections because the sizing bias drops out when calculating depth change. However, because only one inspection result is available this adjustment is necessary. Another way to understand this is to recognize that prior to initial operation of the SGs the *actual* flaw depths were zero. To obtain an unbiased estimate of the growth during the first cycle of operation, the best estimate of *actual* depth during the U2C17 outage is required. Consequently, the through wall depths were adjusted upward by applying the sizing regression for ETSS 96004.1.

In addition, an adjustment was also made to account for the fact that, as the flaw deepens, the wear contact area increases. The volume of tube material removed is proportional to the wear work rate [19]. If the wear work rate is assumed to be constant (i.e., constant volume removal), then the growth rate, as measured in terms of through wall depth, will decrease because more tube material must be removed for a given increase in flaw depth. Based on an evaluation of tube geometry, with constant work rate and a second operating period of the same length as the first period, the growth in depth would be about 60% of the growth in the first cycle. Therefore, based on the assumption of constant volume loss, the first operating period growth rate could be adjusted by a factor of 0.6 to reflect the expectation of constant volume growth rate. For tapered wear such as that observed at the TSPs, this factor would be expected to be even lower since a tapered wear scar would also grow in length with increasing depth. For the OA, full credit for this growth rate reduction was not taken. Instead, a factor of 0.7 was applied to the AVB and TSP wear growth rates. Data from recent replacement steam generators with tube-to-support wear and multiple inspections support the constant volume loss assumption.

Because the upcoming operating period could be at a reduced power level due to TTW, the effect of power level on growth rate of AVB and TSP wear was also evaluated. A reduction in power level will change the velocities and densities on the secondary side of the tube bundle. The growth rate for wear indications is expected to be roughly proportional to the square of the dynamic pressure (where dynamic pressure = ρV^2; density times the square of velocity) [19]. As power level is decreased, the density increases. However, the increase in density is more than offset by the decrease in velocity.

Therefore, if there is any noticeable change in growth rate, it is expected to be a decrease in the observed growth rate. For this OA, no adjustment to the growth rate was made to account for any potential change in power level.

The growth rate distributions applicable to AVB wear and TSP wear are provided in Figure 6-1 through Figure 6-4. The AVB wear growth rates are based upon the data for 2E-088 which exhibited a slightly higher growth rate than 2E-089. For TSP wear, the data from the two SGs were combined due to the relatively low number of TSP wear indications.

6.2.1.2 Structural Depths and Lengths

Structural depths and lengths were obtained for 22 AVB wear indications that were line-by-line sized with the +Point™ probe using EPRI ETSS 10908.4. These structurally equivalent dimensions correspond to a rectangular flaw which would burst at the same pressure as the measured flaw; determined using the methods described in Section 5.1.5 of Reference 3. The selection of indications for line-by-line sizing was based on depth of the indication with emphasis placed on the deeper indications. Since the results of the operational assessment are highly dependent on the deepest flaws returned to service, use of the structural lengths and depths from 22 of the deeper indications is justified. The structural depths were compared to the maximum depths for each flaw to obtain a ratio of structural to maximum depth. The ratio of structural depth to maximum depth ranged from a low of 0.76 to a high of 0.94. The average and the standard deviation of this ratio are 0.882 and 0.052, respectively. These values were used as inputs to the full bundle OA tool for the AVB wear evaluations. Using the distribution of structural to maximum depth ratios, the OA tool randomly applies a ratio value, sampled from this normal distribution, to each postulated maximum depth at the EOC. The sampled ratio value is constrained to a minimum and maximum of 0.8 and 1.0, respectively. For TSP wear, a fixed value of 1.0 was conservatively used for the ratio of structural to maximum depth.

For the structural length, a fixed value of 0.7" was used for AVB wear. This is conservative since the width of the AVB is only 0.59". This conservative value was selected based on the observation that some of the AVB wear flaws in Unit 3 extended outside the confines of the AVB intersection. This phenomenon in Unit 3 is believed to be due to the in-plane motion of the affected tubes. No AVB wear indications in Unit 2 were observed to extend outside the AVB intersection. However, based on the Unit 3 observation and the fact that shallow TTW was observed in Unit 2, a conservative length of 0.7" was applied for AVB wear indications in Unit 2.

The structural length for TSP wear was set to a fixed value of 1.6" which is longer than the 1.38" thickness of the TSPs. Again, this conservative value was selected based on the observation that some of the TSP wear flaws in Unit 3 extended outside of the TSP intersection.

6.2.1.3 Initiation and Depth Distribution of New Indications

Based on industry experience with other replacement SGs experiencing relatively large quantities of wear during early operation, it is likely that another operating period of equal length at SONGS would produce fewer new wear flaws than the number reported during the U2C17 inspection. However, for this OA it was assumed that the cumulative number of wear flaws will trend linearly with the cumulative operating EFPY. In addition, it was conservatively assumed that the depth distribution of new indications anticipated after a full fuel cycle of operation will be the same as that observed during the U2C17 outage for the flaw category under evaluation (i.e., AVB wear >20%TW, AVB wear <20%TW, etc.). Again, the OA for AVB and TSP wear is being performed as if a full cycle of operation at 100% power will occur prior to the next inspection. For each category, the flaw population used to model growth was also used to model new flaw size. Figure 6-5 and Figure 6-6 provide histograms illustrating the overall U2C17 depth distribution of each degradation mechanism.

6.2.1.4 Results of Probabilistic OA for AVB Wear and TSP Wear

The fundamental OA structural integrity criterion is that the projected worst case degraded tube for each existing degradation mechanism must meet the limiting structural performance parameter with a 95% probability and 50% confidence. The results of the probabilistic OA for AVB wear and TSP wear are provided in Table 6-3. The values provided in the table represent the projected probability of non-burst for the entire population of flaws in the specified group. These values compare directly with the 95/50 OA criteria. Note that the combined probability of non-burst is simply the product of the probabilities for the different groups evaluated (e.g., 0.9997 x 0.9921 x 0.9996 x 0.9992 = 0.9906). In all cases, the OA structural integrity criteria for AVB and TSP wear is satisfied for a full cycle of operation at 100% reactor power. The operational assessment for TTW will be documented separately. In the TTW OA, the permissible reactor power level and inspection interval may be reduced from that evaluated in this document. The more conservative OA shall govern plant operation.

Table 6-3: Projected Probability of Non-Burst

Flaw Category	No. of Indications Detected		No. of Indications Returned to Service		End-of-Cycle Tube Degradation Probability of Non-Burst*	
	2E-088	2E-089	2E-088	2E-089	2E-088	2E-089
AVB Wear >20%	66	64	24	22	0.9997	0.9996
AVB Wear ≤20%	1691	2527	1157	1407	0.9921	0.9902
TSP Wear >10%	77	59	68	31	0.9996	0.9997
TSP Wear ≤10%	148	80	127	49	0.9992	0.9996
AVB & TSP Wear Combined	1982	2730	1376	1509	**0.9906**	**0.9891**

* Results shown are for a full cycle of operation (1.577 EFPY) at full power. The operational assessment for TTW will be documented separately. In the TTW OA, the permissible reactor power level and inspection interval may be reduced from that evaluated in this document. The more conservative OA shall govern plant operation.

Figure 6-1: Adjusted Growth Rate Distribution, AVB Wear >20%TW

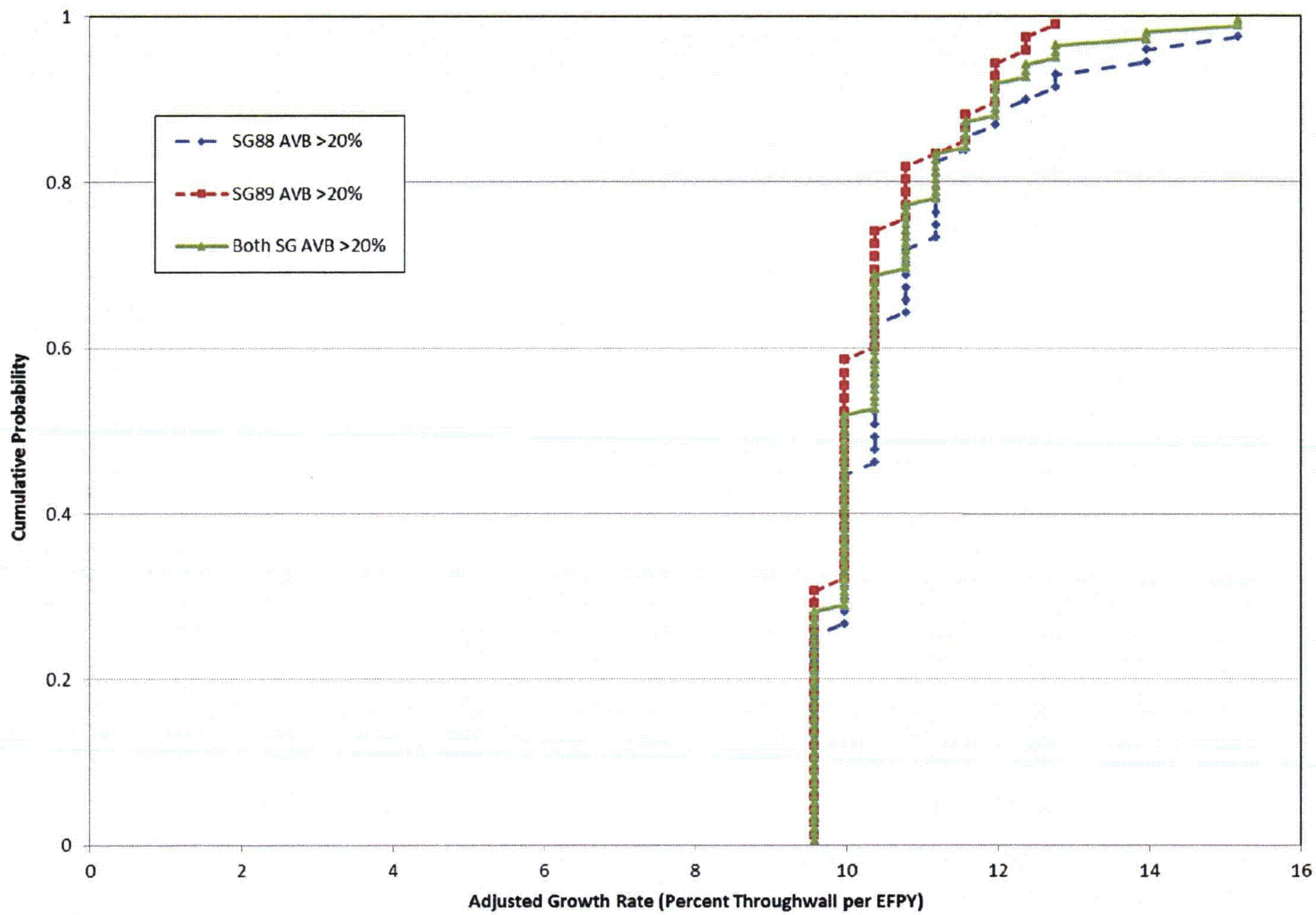


Figure 6-2: Adjusted Growth Rate Distribution, AVB Wear <u><</u>20%TW

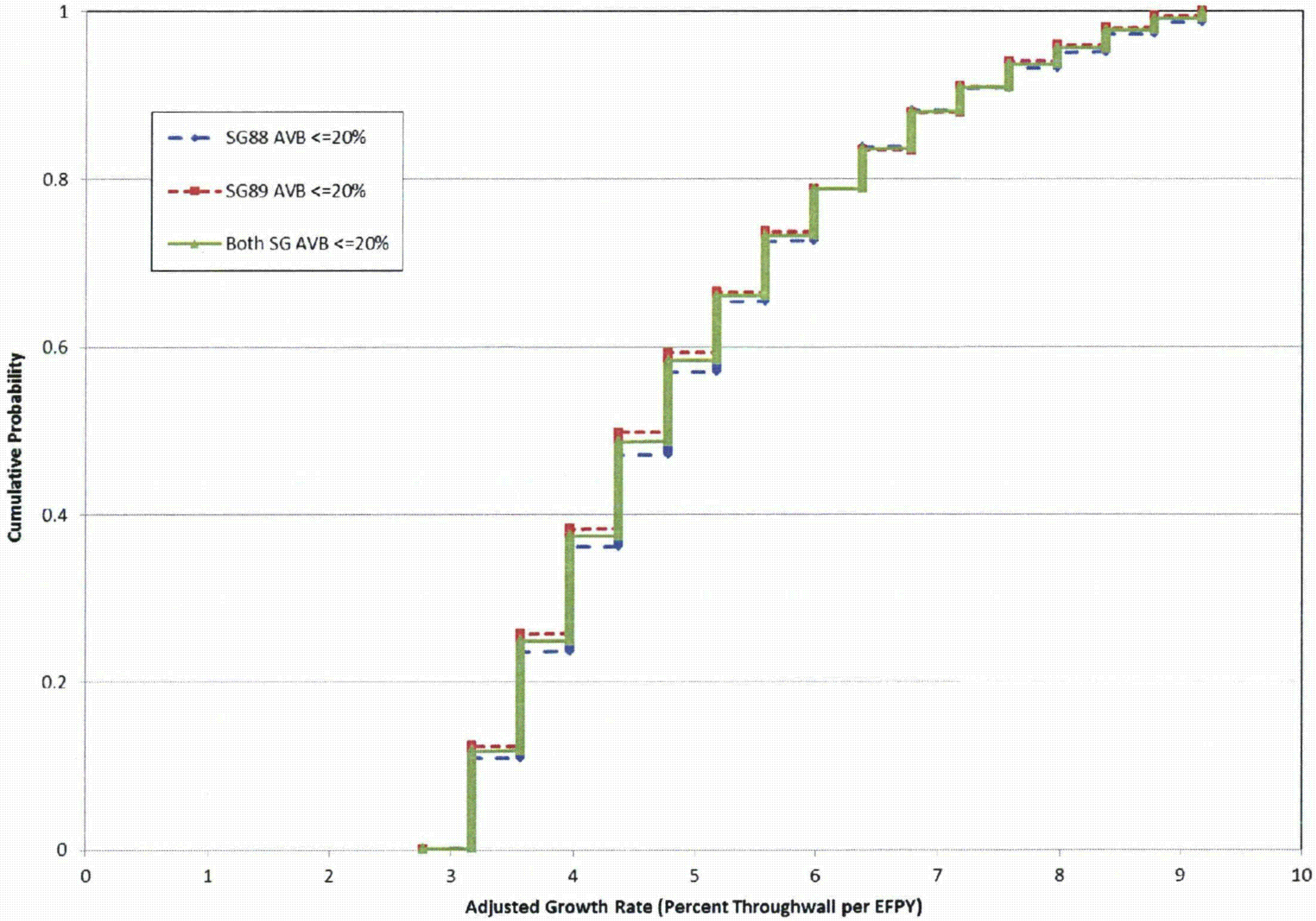


Figure 6-3: Adjusted Growth Rate Distribution, TSP Wear >10%TW

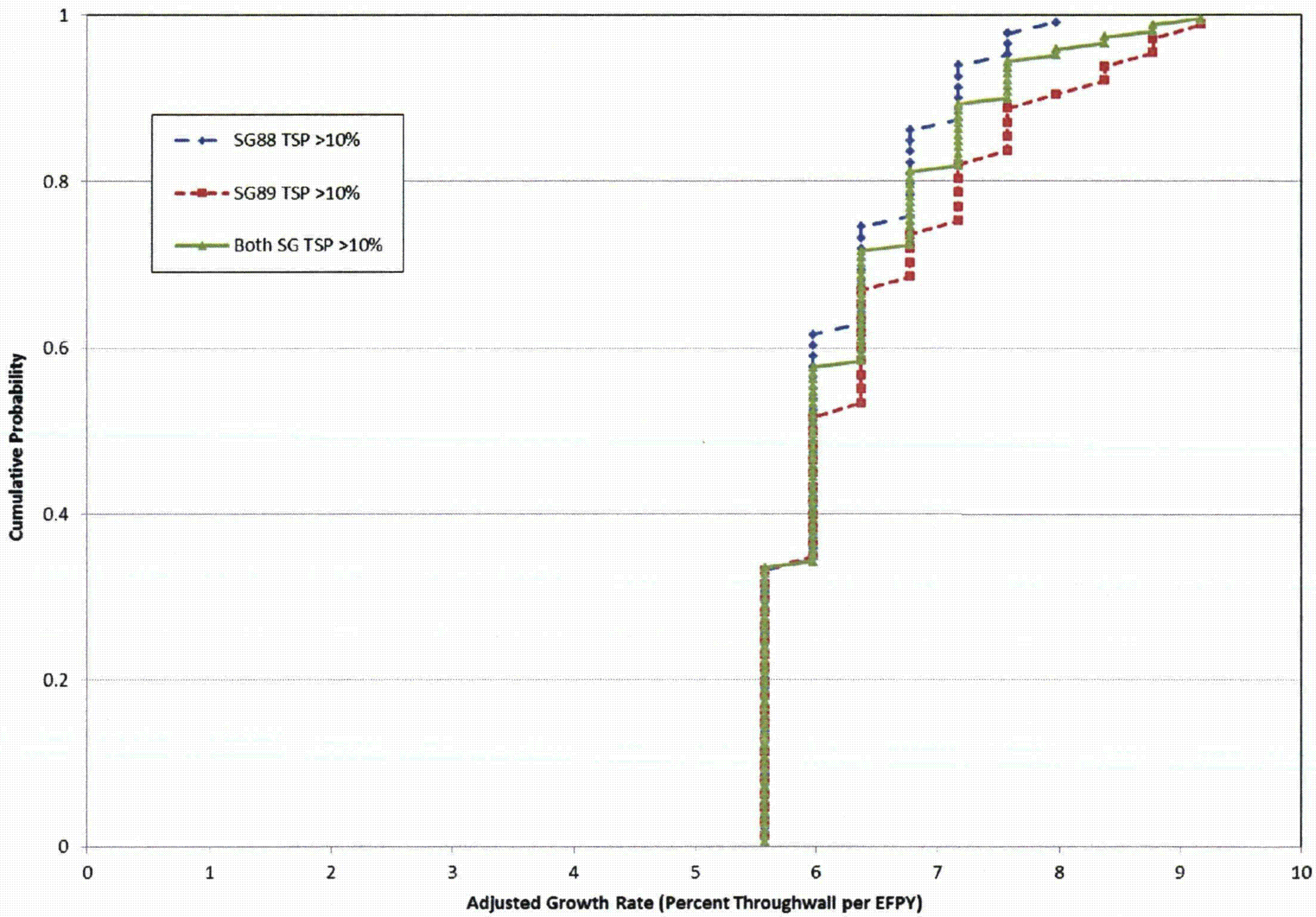


Figure 6-4: Adjusted Growth Rate Distribution, TSP Wear ≤10%TW

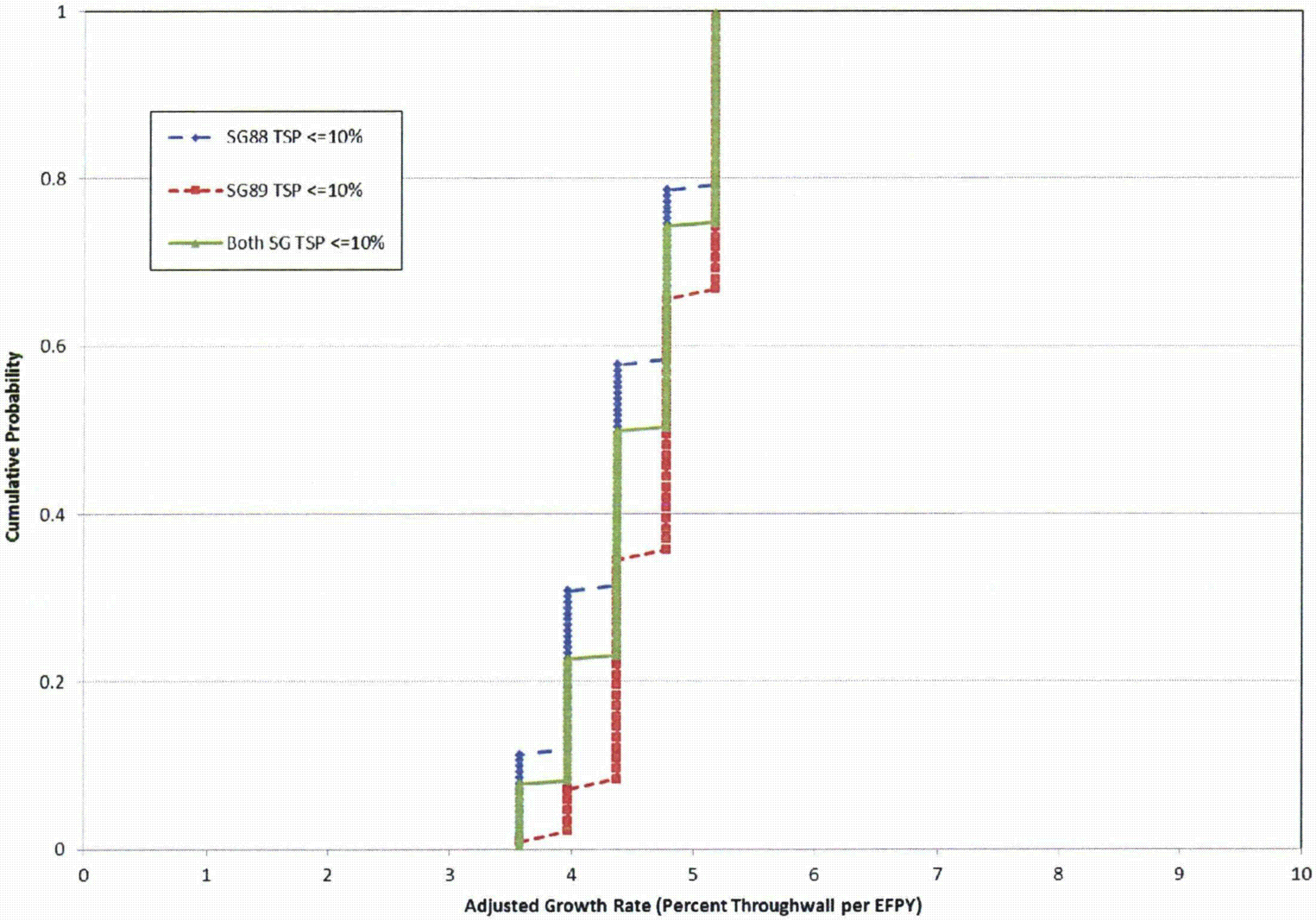


Figure 6-5: AVB Wear Depth Histogram

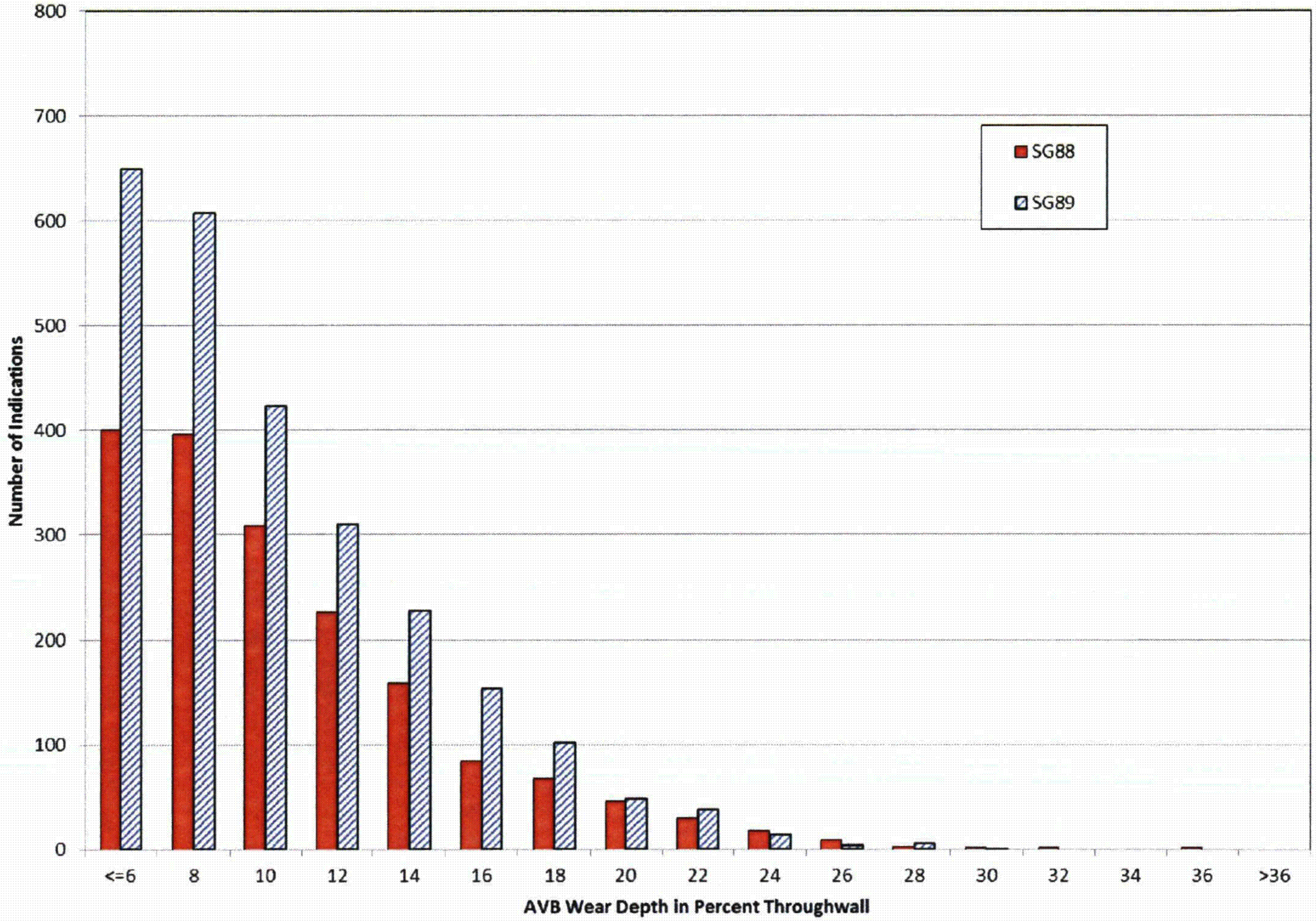
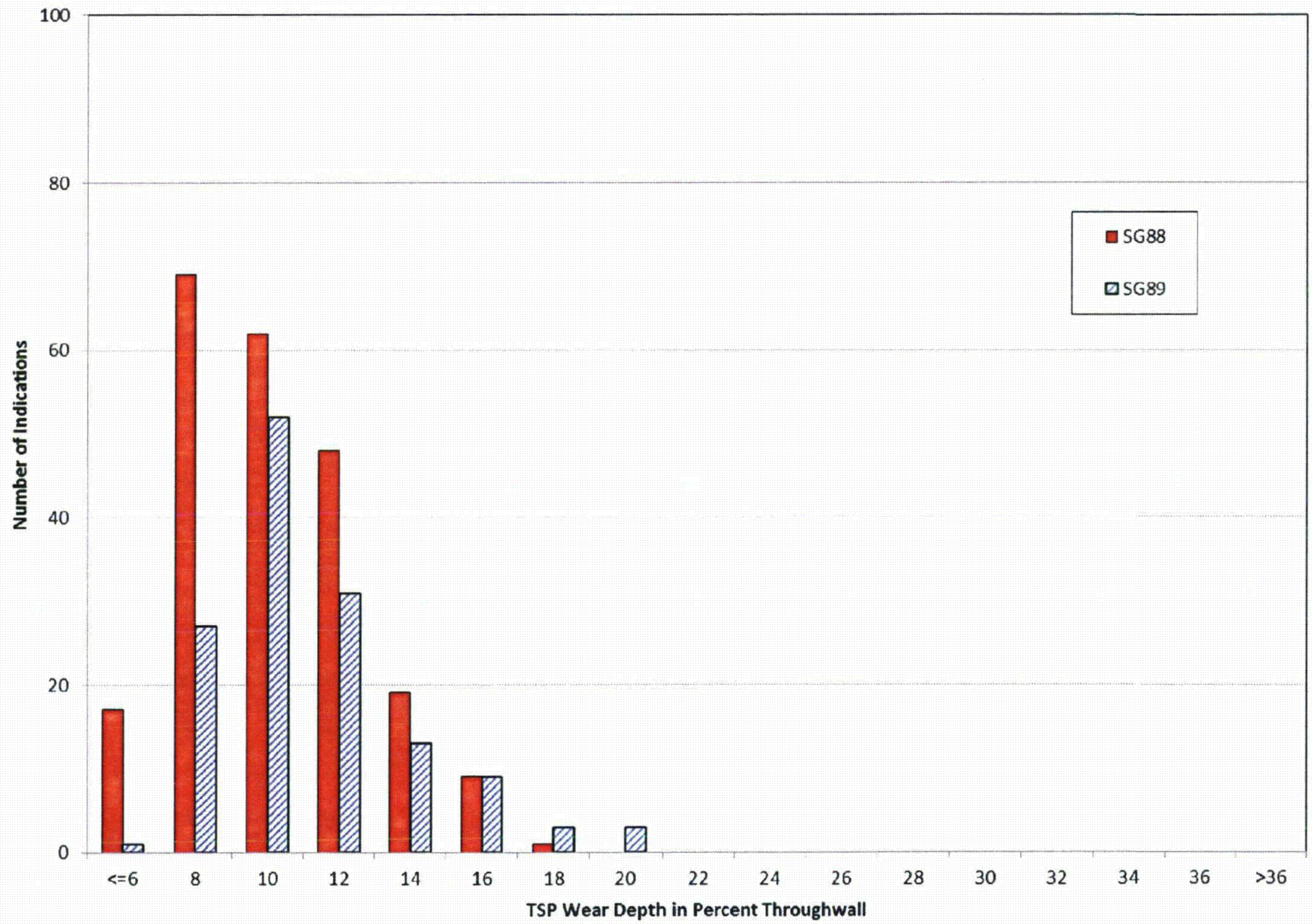


Figure 6-6: TSP Wear Depth Histogram



6.2.2 Retainer Bar Wear

To eliminate the potential for future RB wear in in-service tubes, all tubes adjacent to the retainer bars have been plugged in both SGs. Prior to plugging, all tubes with RB wear indications were stabilized with U-bend cable stabilizers. The tubes on either side of all retainer bars, at each end of the retainer bars, and at the center of the retainer bars, were also stabilized prior to plugging in both SGs. This augmented stabilization provides additional material volume to resist continued RB wear, and provides added assurance that the retainer bars will not interact with in-service tubes. These corrective actions provide reasonable assurance that retainer bar wear will not challenge the structural and leakage integrity performance criteria during the remaining life of the SGs. In addition, the stabilization of these tubes provides reasonable assurance that a tube severance event will not occur as a result of RB wear during the remaining life of the SGs. Monitoring of the tubes adjacent to these plugged tubes must be performed on a periodic basis during future SG inspections.

6.2.3 Tube-to-Tube Wear

As discussed earlier and in Reference 11, shallow TTW was detected in two tubes in the 2E-089 SG. The inspections that led to the finding of TTW in Unit 2 were performed based on the finding of significant TTW in SONGS Unit 3. Although the numbers and depths of indications between the two units are vastly different, it has been found that Unit 2 was susceptible to TTW. The locations of the indications along with the measured depths and lengths are provided in Table 6-4.

The OA for TTW will be documented separately. In the TTW OA, the permissible reactor power level and inspection interval may be reduced from that evaluated in this document. The more conservative OA shall govern plant operation.

Table 6-4: U2C17 Tube-to-Tube Wear Indications

SG	Row	Col	Location	Maximum Depth (%TW)	Length (in.)	Structural Depth (%TW)	Structural Length (in)
2E-089	111	81	B09 +1.63 to +7.95	15	6.32	14.0	2.28
2E-089	113	81	B09 +2.03 to +8.22	14	6.19	13.7	1.67

6.2.4 Foreign Object Wear

All Unit 2 SG tubes were examined full length with bobbin coil probes. Two tubes in the 2E-088 SG were identified with foreign object and foreign object wear indications. The object which caused the foreign object indication and associated wear was retrieved from the SG. Consequently, there is no possibility for this degradation to progress during future operation. After removal of the object, the affected locations were inspected with a +Point™ technique qualified for depth sizing (with the object not present). Neither indication exceeded the SONGS 35%TW plugging limit. Since the indications were below the SONGS plugging limit and the object was removed, these tubes were left in service. No other foreign objects or foreign object wear flaws were identified during the ECT inspection.

Subsequent analysis by SCE identified the object as weld metal debris. Therefore, the presence of this object was not indicative of degradation of secondary side internals.

The SG work activities performed during this refueling outage included post sludge lancing, secondary side visual inspections of the top-of-tubesheet (TTS) annulus and no-tube lane regions in both SGs, and visual inspections of the upper bundle, including the retainer bars, and the retainer bar-to-retaining bar and AVB end cap-to-retaining bar welds. Other than the object discussed above, these examinations identified no foreign objects, loose parts or conditions which could credibly generate foreign objects or loose parts capable of impacting tube integrity.

In summary, based on extensive ECT inspections augmented by secondary side visual inspections and Foreign Object Search and Retrieval (FOSAR), no foreign objects or loose parts capable of causing tube degradation are known to remain in the Unit 2 SGs. Hence, there is reasonable assurance that foreign objects or loose parts will not cause the structural or leakage integrity performance criteria to be exceeded prior to the next tube inspection.

6.3 Evaluation of Leakage Integrity

All tubes with degradation exceeding the Technical Specification plugging limit have been removed from service by plugging. In addition, many additional tubes were preventatively plugged. For the tubes that were removed from service, primary-to-secondary leakage past the plugs must be considered.

applying this value to each plug and adjusting the leak rate to the normal operating and accident differential pressures, gives the postulated leak rates provided in Table 6-5. All leak rate values are provided at room temperature conditions because the SONGS leakage performance criteria are specified as volumetric leak rates at room temperature conditions. These values are well below the allowable leak rates as shown in this table.

For the tubes returned to service, per Reference 2, the onset of pop-through and leakage for axially oriented volumetric flaws with limited circumferential extent - the nature of the degradation identified in the Unit 2 SGs - is coincident with burst. Because none of the identified degradation mechanisms are projected to exceed the structural performance criteria prior to the next scheduled inspection in each SG, there is reasonable assurance that neither the operational, nor the accident-induced leakage performance criteria will be exceeded prior to the next inspection of the Unit 2 SGs.

Table 6-5: Postulated Plug Leakage

	2E-088	2E-089
Number of Tubes Plugged	205	305
Total Number of Plugs	410	610
Allowable Accident-Induced Leak Rate (gpm at room temperature)	0.5	0.5

6.4 Secondary Side Internals

No degradation of SG secondary side internals was identified during this outage. No tube support degradation or misplacement was identified during the ECT or secondary side visual inspections.

7.0 OPERATIONAL ASSESSMENT CONCLUSION

This report documents the OA for all detected degradation mechanisms except for TTW. This OA concludes that there is reasonable assurance that the performance criteria for the non-TTW degradation will be met if Unit 2 were to operate for a full fuel cycle of 1.577 EFPY at 100% reactor power.

The TTW OA will be documented separately. Operation at reduced reactor power and a shorter inspection interval may be prescribed in the TTW OA. The more conservative OA shall govern plant operation.

8.0 REFERENCES

1. NEI 97-06, "SG Program Guidelines," Rev. 3, January 2011.
2. EPRI Report 1019038, "SG Integrity Assessment Guidelines: Revision 3", November 2009.
3. EPRI Report 1019037 "Steam Generator Degradation Specific Management Flaw Handbook, Revision 1", December 2009.
4. EPRI, SG Management Project, "sgmp.epriq.com".
5. AREVA Document 51-9176667-001, "SONGS 2C17 & 3C17 Steam Generator Degradation Assessment".
6. AREVA Document 32-9104082-002, "MATHCAD Implementation of SG Full Probabilistic Operational Assessment".
7. *Matheny, Southern California Edison, "Numerical Values for the SG OAs, SONGS Units 2 and 3," February 8, 2012.
8. *SONGS Unit 2 Replacement Steam Generator Receipt Inspection QA Document Review Package.
9. *SONGS UFSAR Chapter 5.
10. NRC, "Confirmatory Action Letter – SONGS Units 2 and 3, Commitments to Address SG Tube Degradation," CAL 4-12-001, March 27, 2012.
11. AREVA Document 51-9182368-002, "SONGS 2C17 Steam Generator Condition Monitoring Report".
12. AREVA Document 51-1177797-009, "0.750 Mechanical Rolled Plug Design Verification Report – Alloy 690".
13. *SONGS Technical Specifications Section 5.5.2.11, "Steam Generator (SG) Program", Amendment 204
14. *SONGS Technical Specifications Section 3.4.13, "RCS Operational Leakage", Amendment 204.
15. AREVA Document 51-9187230-000, "SONGS 2C17 Steam Generator Operational Assessment for Tube-to-Tube Wear".
16. *Root Cause Evaluation, San Onofre Nuclear Generating Station, Condition Report: 201836127, "Unit 3 Steam Generator Tube Leak and Tube-to-Tube Wear", Revision 0, 5/7/2012.
17. *Root Cause Evaluation NN 201843216, "Steam Generator Tube Wear, San Onofre Nuclear Generating Station, Unit 2".
18. *SONGS Steam Generator Program, S023-SG-1.

19. Au-Yang, M.K., “Flow-Induced Vibration of Power and Process Plant Components: A Practical Workbook”, ASME Press, 2001.

20. *SONGS RGR-U2/3-C17, “SONGS Units 2/3 Cycle 17 Reload Ground Rules”, Item X.003, Revision 2.

*Documents are not retrievable from the AREVA document control system, but can be retrieved from the SCE document control system. Therefore, these are acceptable reference per AREVA Administrative Procedure 0402-01, Attachment 8, as authorized by the Project Manager's signature on page 2.

ATTACHMENT 6 – Appendix B

SONGS U2C17
Steam Generator Operational Assessment
for Tube-to-Tube Wear

[Proprietary Information Redacted]

AREVA

AREVA NP Inc.

Engineering Information Record

Document No.: 51 - 9187230 - 000 (NP)

SONGS U2C17 Steam Generator Operational Assessment for Tube-to-Tube Wear

Supplier Status Stamp

VPL No: 1814-AU651-M0160	Rev No: 0	QC N/A
☐ DESIGN DOCUMENT ORDER NO. 800918458		
☒ REFERENCE DOCUMENT–INFORMATION ONLY ☐ VIRP IOM MANUAL		
MFG MAY PROCEED: ☐ YES ☐ NO ☒ N/A		
STATUS - A status is required for design documents and is optional for reference documents. Drawings are reviewed and approved for arrangements and conformance to specification only. Approval does not relieve the submitter from the responsibility of adequacy and suitability of design, materials, and/or equipment represented. ☐ 1. APPROVED ☐ 2. APPROVED EXCEPT AS NOTED - Make changes and resubmit. ☐ 3. NOT APPROVED - Correct and resubmit for review. NOT for field use.		
APPROVAL: (PRINT / SIGN / DATE) RE: E. GRIBBLE 10/2/12		
FLS:		
Other:		

SCE DE(123) 5 REV. 3 07/11 REFERENCE: SO123-XXIV-37.8.26

Safety Related? ☒ YES ☐ NO

Does this document contain assumptions requiring verification? ☐ YES ☒ NO

Does this document contain Customer Required Format? ☐ YES ☒ NO

Signature Block

Name and Title/Discipline	Signature	P/LP, R/LR, A/A-CRF, A/A-CRI	Date	Pages/Sections Prepared/Reviewed/ Approved or Comments
[		]	9/25/12	All
			9/25/12	Figures in Sections 4, 5, 6, and 8.
			9/25/12	All
			9/25/12	All

Note: P/LP designates Preparer (P), Lead Preparer (LP)
R/LR designates Reviewer (R), Lead Reviewer (LR)
A/A-CRF designates Approver (A), Approver of Customer Requested Format (A-CRF)
A/A-CRI designates Approver (A), Approver - Confirming Reviewer Independence (A-CRI)

References 1, 3, 4, 8, 9, 10, 11, 18, 20, 21, 22, 24, and 27 identified in Section 11.0 are available from Southern California Edison (SCE) and are approved for use as required by AREVA NP procedure 0402-01.

[ ] 9/25/12

Name & Title Signature Date

Record of Revision

Revision No.	Pages/Sections/ Paragraphs Changed	Brief Description / Change Authorization
000	All	Original Release

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List of Abbreviations

Abbreviation	Definition
01C to 07C	Tube Support Plate Designations for Cold Leg (7 Locations)
01H to 07H	Tube Support Plate Designations for Hot Leg (7 Locations)
2E-088	Unit 2 Steam Generator 88
2E-089	Unit 2 Steam Generator 89
3E-088	Unit 3 Steam Generator 88
3E-089	Unit 3 Steam Generator 89
3 NOPD	3 Times Normal Operating Pressure Differential
ABAQUS	A finite-element structural analysis program sold by Dassault Systemes
AILPC	Accident Induced Leakage Performance Criterion
ASME	American Society of Mechanical Engineers
AVB	Anti-Vibration Bar
BOC	Beginning of Operating Cycle
C	Column
CDF	Cumulative Distribution Function
CE	Combustion Engineering
CL or C/L	Cold Leg
CM	Condition Monitoring
DA	Degradation Assessment
ECT	Eddy Current Testing
EFPD	Effective Full Power Days
EOC	End of Operating Cycle
EPRI	Electric Power Research Institute
ETSS	Examination Technique Specification Sheet
FEA	Finite Element Analysis
FEI	Fluid-elastic Instability
FOSAR	Foreign Object Search and Retrieval
FSM	Fluid-elastic Stability Margin
GPD	Gallons per Day
GPM	Gallons per Minute
HL or H/L	Hot Leg
kHz	kilohertz
KSI	Thousand Pounds per Square Inch
MHI	Mitsubishi Heavy Industries
MSLB	Main Steam Line Break
NDE	Non Destructive Examination
NEI	Nuclear Energy Institute

List of Abbreviations
(continued)

Abbreviation	Definition
N	Newtons (a measure of force in metric units)
NN	Nuclear Notification
NOPD	Normal Operating Pressure Differential
NRC	Nuclear Regulatory Commission
OA	Operational Assessment
PSI	Pounds per Square Inch
PSI	Pre-service Inspection
PSIA	Pounds per Square Inch Absolute
PSIG	Pounds per Square Inch Gage
PWR	Pressurized Water Reactor
QA	Quality Assurance
R	Row
RB	Retainer Bar
RCS	Reactor Coolant System
RxxxCyyy	Steam Generator tube location, where xxx is the row number and yyy is the column number
SCE	Southern California Edison
SG	Steam Generator
SIPC	Structural Integrity Performance Criteria
SLB	Steam Line Break
SONGS	San Onofre Nuclear Generating Station
SR	Stability Ratio
SSI	Secondary Side Inspection
TEC	Tube End Cold
TEH	Tube End Hot
TSP	Tube Support Plate
TTS	Top of Tubesheet
TTW	Tube-to-tube Wear
TW	Through Wall
U2C17	SONGS Unit 2 End-of-Cycle 17 Outage
UB	U-bend
UT	Ultrasonic Testing

1.0 PURPOSE

In accordance with the SONGS Steam Generator Program [1] and EPRI Steam Generator Integrity Assessment Guidelines [2], an operational assessment (OA) must be performed to ensure that steam generator (SG) tubing will meet established performance criteria for structural and leakage integrity during the operating period prior to the next planned inspection. The OA projects and evaluates tube degradation mechanisms which have affected the SGs to date. The performance criteria are defined in plant technical specifications [3] & [4] and are based on NEI 97-06 [5].

This report documents the OA developed for tube-to-tube wear (TTW) that was discovered during the 2012 SONGS Unit 2 C17 outage. This OA considers the TTW identified in the SONGS-3 steam generators and determines the operating power level and associated inspection interval that provides the required margin relative to the onset of in-plane fluid-elastic instability and thus prevent TTW. This OA only addresses TTW. The OA for all other degradation is documented in a separate report [6].

2.0 BACKGROUND

Note: The steam generator design information in this section is taken from References [7], [8], [9], and [10].

[

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MHI Proprietary

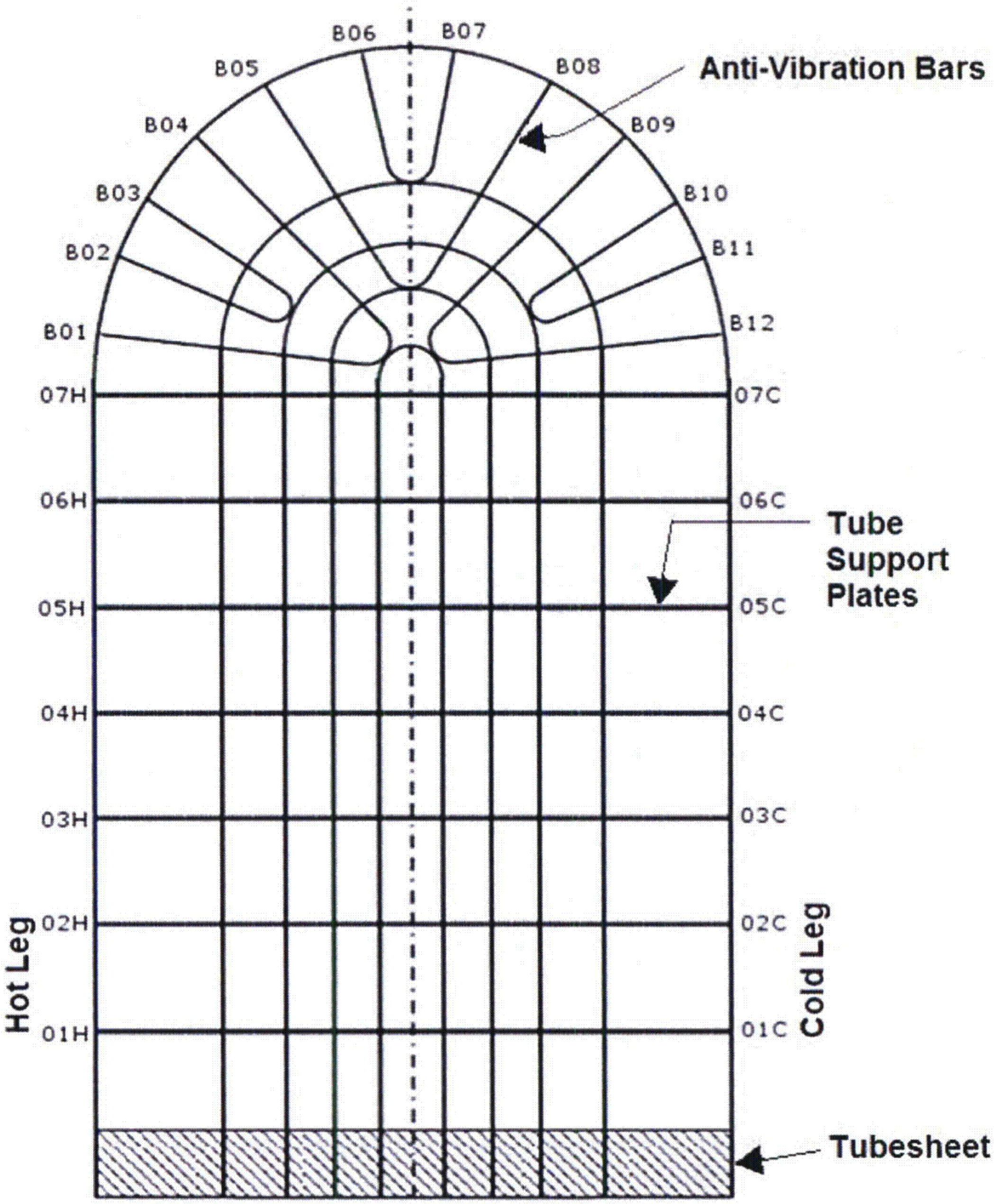

Figure 2-1: AVB Arrangement for SONGS Steam Generators

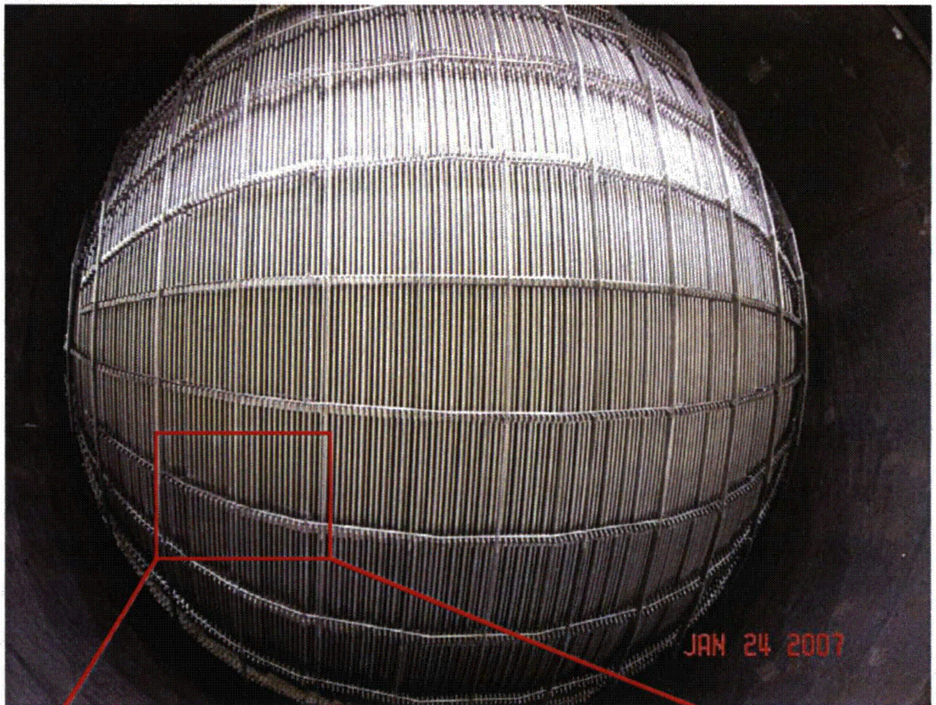

Figure 2-2: View of Top of Bundle

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Figure 2-3: Ends of AVBs Attached to Retaining Bars, Bridges and Retainer Bars Also Shown