Steam Generator Tube Integrity Operational Assessment

Southern California Edison

San Onofre Nuclear Generating Station Unit 3 Cycle 10

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EXECUTIVE SUMMARY

An operational assessment of steam generator tubing in SONGS Unit 3 was conducted following the cycle 10 refueling outage and is the subject of this report. Operational Assessments are a requirement of the SONGS Steam Generator Program (Reference 1).

The results of a comprehensive eddy current inspection prior to the beginning of Cycles 8 and 9, and at the refueling outage prior to Cycle 10 are the primary inputs to this assessment. The scope and results of this inspection are summarized in this report. Tube degradation at SONGS is prudently managed with end of cycle inspections, in situ pressure testing, repairs, condition monitoring and operational assessments. A mid Cycle 9 bobbin probe inspection monitored tube wear potentially related to eggcrate degradation. The mid Cycle 9 inspection involved a small sample of tubes in each steam generator and the results of that inspection have been included as if they were Cycle 10 outage results for purposes of this operational assessment. Inspection results were used to check and update projections for the following degradation mechanisms:

- Axial freespan ODSCC/IGA degradation
- Axial ODSCC/IGA at sludge pile locations
- Axial ODSCC/IGA at eggcrate intersections
- Circumferential ODSCC and PWSCC at TTS
- Wear

As in the past, a Monte Carlo computer model was used to simulate the processes of crack initiation, crack growth and detection via eddy current inspections over multiple cycles of operation. This allowed calculation of both the conditional probability of tube burst at postulated steam line break conditions and expected leak rates. Comparison of projected and observed degradation severity provided a check of the simulation model.

Observed worst case degradation severity compared well with earlier projections for all types of axial degradation.

The conditional probability of tube burst, given a postulated steam line break after an additional 1.67 EFPY of operation in Cycle 10 is less than 0.01 for each of the corrosion mechanisms. The arithmetical sum of the five mechanisms that were considered in this analysis is 0.0008. The largest contributor is axial ODSCC at eggcrate intersections, with a value of 0.0003. The figures of merit per the NEI 97-06 (Reference 2) are 0.01 for any single mechanism and a total of 0.05 for all mechanisms combined.

The 95/95 leak rate at postulated steam line break is also a result of this analysis. The value that has been calculated is 0.033 gallon per minute (total) at room temperature. The applicable criteria is 0.5 GPM for each steam generator (1.0 GPM total).

The results of previous analyses (Reference 3 and 4) for axial and circumferential corrosion degradation at the top of the tubesheet region plus the present projections demonstrate that required structural and leak rate margins will be maintained for the 1.67 EFPY planned Cycle 10 operating period.

INTRODUCTION

An operational assessment of steam generator tubing in SONGS Unit 3 was conducted for the current Cycle 10 of operation. Five modes of corrosion degradation were considered:

- Axial freespan ODSCC/IGA degradation
- Axial ODSCC/IGA at sludge pile locations
- Axial ODSCC/IGA at eggcrate intersections
- Circumferential ODSCC and PWSCC at TTS
- Wear

Comprehensive eddy current examination at the prior to beginning of Cycle 10 was used to monitor for all forms of tube degradation that were known active or deemed credible.

The onset of axial and circumferential corrosion degradation was observed in SONGS-3 steam generator tubing after about 8.62 EFPY of operation. Circumferential and axial degradation at the top of the tubesheet has been searched for using the RPC eddy current probe prior to Cycle 8, and the Plus Point probe thereafter. Degradation is present on both inside and outside tube diameters.

Tube wear is a known tube degradation mechanism in the SONGS Unit 3 steam generators and accounts for the majority of tube repairs. Historically, wear has been the subject of the majority of tube plugging in certain highly susceptible areas near the center of the bundle and attributed to wear from batwings. These episodes of wear-related tube repairs were early in the life of the unit. However, the rate of new tube wear indications has trended upward in recent outages.

Axial corrosion degradation at freespan and eggcrate regions has been detected with the bobbin probe. Eggcrate axial degradation has been observed only on the outside tube diameters. Inside diameter degradation in these regions similar to that found at SONGS Unit 2 has not been seen at SONGS Unit 3, which also has not exhibited tube deformation similar to SONGS Unit 2. The presence of the eggcrate tube supports, and to a greater degree, tube deformation in the eggcrate regions, tends to make crack detection more difficult using the bobbin probe. The simulation model employed in this work accounts for potential inspection difficulties.

Circumferential tube degradation has been detected at the top-of-tubesheet (TTS) with rotating probe examinations. The indications origins are attributed to the PWSCC at the ID of the tubes and ODSCC from the OD of the tubes. In each case the indication is associated with the geometrical discontinuity at the expansion transition.

An evaluation of the contribution of corrosion degradation to the conditional probability of tube burst at postulated steam line break conditions and determination of the upper bound leak rates expected during postulated accident condition form the main objectives of the work described in this report. NEI 97-06 has established acceptable values for the conditional probability of tube burst at SLB conditions as a measure of required structural margins. Accident-induced leak rates are calculated for comparison with the site-specific acceptable value.

The basic calculational technique employed is one of simulating the processes of crack initiation, crack growth and detection via eddy current inspection using Monte Carlo methods. The Monte Carlo simulation model follows these processes over multiple cycles of operation. This allows benchmarking of the model by comparing calculated results for past inspections with actual observations. The simulation model tracks both detected and undetected populations of cracks and deals with actual crack sizes. When comparisons are made between calculated results and eddy current observations, an eddy current measurement error is applied to convert predicted real crack sizes to predicted eddy current observations.

Actual degradation conditions in terms of number of cracks, real crack depths and lengths can be calculated for any selected time period. Hence, the conditional probability of burst at postulated steam line break conditions can be computed for the operating time of interest. Leak rate during such a postulated accident can be calculated from the simulated numbers and sizes of cracks.

Appendix 1 is a description the structural integrity and leak rate models including of the methods of characterizing crack shapes and critical dimensions for cracking. Also in Appendix 1 are explanations of burst pressure and leak rate calculations. Appendix 2 describes input to the Monte Carlo simulation programs and the simulation steps are discussed.

CYCLE 10 INSPECTION SUMMARY

Planned Inspection Scope

Table 1 summarizes the planned inspection program. Also, when indications by the bobbin probe were non-quantifiable or distorted, the inspection program included inspection with the Plus-Point Probe. Table 3 provides the list of Nondestructive Examination (NDE) techniques utilized for each degradation mechanism.

Inspection Scope Expansion

Table 2 summarizes significant inspection program scope expansion in response to inspection results. The following explanatory details are provided for this expansion.

One small circumferential indication was detected at the top of the cold leg tubesheet. This was the first time that this specific tube location had been examined with a rotating probe, so the time that this indication may have been present cannot be ascertained. An expansion to 100% of these locations in both steam generators did not detect further indications.

<u>TABLE 1</u>
Summary of the Planned Inspection Program for the Unit 3 Cycle 10 Refueling Outage

Planned Inspection Program	Number of Tubes/Percentage of Tubes Steam Generator E-088	E-089
Full length of tube with the bobbin probe	8887 / 100%	8907 / 100%
Hot leg expansion transition at the top-of-tubesheet with the Plus Point Probe	8887 / 100%	8907 / 100%
Cold leg expansion transition at the top-of-tubesheet with the Plus Point Probe	1778 / 20%	1782 / 20%
Tight radius U-bend regions Rows 1, 2 and 3 with the Plus-Point Probe	190 / 100%	179 / 100%
Plus-Point Probe examination of all hot leg eggcrate supports at or below the diagonal bar with dents > or equal to 2 volts and dings at or below the uppermost hot leg eggcrate support that are > or equal to 5 volts	115 / 100%	151 / 100%
Plus-Point Probe examination of all tube support intersections with quantified wear indications by the bobbin probe	739 / 100%	516 / 100%

<u>TABLE 2</u>
Summary of Significant Scope Expansion for the Unit 3 Cycle 10 Refueling Outage

Scope Expansion	Number of Tubes/Percentage of Tubes Steam Generator E-088	E-089
Cold leg expansion transition at the top-of-tubesheet with the Plus-Point Probe	7109 / 100%	7125 / 100%

TABLE 3 - List of Nondestructive Examination (NDE) Techniques Utilized for Each Degradation Mechanism During the Unit 3 Cycle 10 Refueling Outage

Category	Indication Orientation/Location	Probe Type for Detection	Probe Type for Characterization
1	Axially oriented OD (initiated on the outside-diameter of the tubing wall) indications at tube support locations	Bobbin Plus Point (Note 1)	Plus Point Plus Point
2	Axially oriented OD indications not associated with a tube support (freespan)	Bobbin	Plus Point
3	Circumferentially oriented ID indications near the expansion transition at the top of the hot leg tubesheet	Plus Point	Plus Point
4	Circumferentially oriented OD indications near the expansion transition at the top of the hot leg tubesheet	Plus Point	Plus Point
5	Axially oriented indications near the expansion transition at the top of the hot leg tubesheet	Plus Point	Plus Point
6	Axially oriented indications below the inlet top-of-tubesheet	Bobbin	Plus Point
7	Indications of wear at tube support locations	Bobbin	Plus Point
8 and 9	Volumetric indications	Bobbin or Plus Point	Plus Point
10	Circumferentially oriented OD indications near the expansion transition at the top of the cold leg tubesheet	Plus Point	Plus Point
11	Miscellaneous preventative plugging	Bobbin or Plus Point	Plus Point
12	Tubes plugged due to eggcrate tube support degradation	Visual	Visual

Note 1: Plus Point technique is used at Dents > or = to 2 volts, at or below the Diagonal Bar on the Hot leg side (DBH)

INSPECTION RESULTS

Indications of degradation detected during the examination were dispositioned by plugging and in some cases tube sleeving was used. Also, certain of the larger indications was pressure tested in situ to determine if the tube degradation was such that prescribed margins against burst were violated. Table 4 lists the tubes that were repaired and the reasons. Table 5 lists the tubes that were pressure tested in situ. The results of the in situ pressure tests were favorable, that is, no leakage was noted and no tubes exhibited burst.

TABLE 4 - Number of Tubes Repaired and Active Degradation Mechanisms Found During the Unit 3 Cycle 10 Refueling Outage

Category	Indication Orientation/Location	Steam Generator E-088	Steam Generator E-089
1	Tubes with axially oriented OD (initiated on the outside-diameter of the tubing wall) indications at tube support locations (OD Axial @ Support)	1	0
2	Tubes with axially oriented OD indications not associated with a tube support (OD Axial @ Freespan)	0	1
3	Tubes with circumferentially oriented ID indications near the expansion transition at the top of the hot leg tubesheet (ID Circ @ TSH)	3	3
4	Tubes with circumferentially oriented OD indications near the expansion transition at the top of the hot leg tubesheet (OD Circ @ TSH)	0	2
5	Tubes with axially oriented ID indications near the expansion transition at the top of the hot leg tubesheet (ID Axial @ TSH)	2	2
6	Tubes with axially oriented ID indications below the inlet top-of-tubesheet (ID Axial below TSH)	2	0
7	Tubes with indications of wear at tube support locations (Wear @ Support)	51	23
8	Tubes with apparent previous loose part wear (not an active degradation mechanism) (OD Vol @ TSH)	3	1
9	Tubes with miscellaneous volumetric indications (not an active degradation mechanism) (OD Vol @ Miscellaneous)	2	3
10	Tubes with circumferentially oriented OD indications near the expansion transition at the top of the cold leg tubesheet (OD Circ @ TSC)	1	0
11	Miscellaneous preventative plugging (not an active degradation mechanism) (Prevent @ Miscellaneous)	1	0
12	Tubes plugged due to eggcrate tube support degradation (Eggcrate Support)	0	3
	Total	66	38

TABLE 5 - Summary of Results of In-Situ Pressure and Leak Testing for the Unit 3 Cycle 10 Refueling Outage

Steam Generator E-088

TUBE AND EDDY CURRENT INFORMATION										IN-SITU TEST RESULTS			
REGION	TUBE INFORMATION			PLUS POINT DATA				EST. DEPTH	SELECTION CRITERIA	GPM @ NOPD	GPM @ MSLB	GPM @ POST MSLB	MAXIMUM PRESSURE
	ROW	COL	LOCATION	LENGTH	VOLTS	PDA	ORIENTATION						
EGGCRATE	106	118	09H + 0.48	0.54	0.40	NA	OD Axial	56	P	0	0	NA	4753
			09H - 0.37	0.52	0.21	NA	OD Axial	48	NA	0	0	NA	4753
SUPPORT	81	89	VH3 - 0.70	0.77	NA	NA	OD Wear	59	P	0	0	NA	4753
	51	93	DBH - 1.70	1.69	NA	NA	OD Wear	48	NA	0	0	NA	4753
	51	85	DBH + 1.78	2.40	NA	NA	OD Wear	47	NA	0	0	NA	4753

Steam Generator E-089

TUBE AND EDDY CURRENT INFORMATION										IN-SITU TEST RESULTS			
REGION	TUBE INFORMATION			PLUS POINT DATA				EST. DEPTH	SELECTION CRITERIA	GPM @ NOPD	GPM @ MSLB	GPM @ POST MSLB	MAXIMUM PRESSURE
	ROW	COL	LOCATION	LENGTH	VOLTS	PDA	ORIENTATION						
SUPPORT	50	84	DBC + 1.92	4.10	NA	NA	OD Wear	47	NA	0	0	NA	4753

NOTES: The SELECTION CRITERIA column indicates the EPRI In Situ Testing Guidelines' criteria that prompted selection.
P = Pressure testing for structural integrity criteria
L = Testing for criteria for postulation of accident-induced leakage integrity
GPM = Gallons per Minute
NOPD = Normal Operation Pressure Differential
MSLB = Main Steam Line Break Pressure Differential
NA = Not Applicable
OD = Degradation initiated on the outside diameter of the tubing
PDA = Percent degraded area
Wear = Volumetric Wear of Tubing at a Tube Support
EST. DEPTH = Estimated maximum per-cent throughwall depth of the degradation
The test pressure that correlates to 3 times NOPD is 4753 psi.

CONDITION MONITORING

The as-found condition of the steam generator tubes is described in the preceding section. The comprehensive nature of the inspection scope and the methods provide assurance that indications of steam generator tube degradation are found. The inspection met or exceeded prevailing industry standards and good practices.

The as left condition of the steam generator tubes is defined by the plugging and repair scope is stated in the previous section. All crack-like indications were plugged or repaired by tube sleeving. All wear indications exceeding the technical specification limit of 44% through-wall were plugged. As a conservative and preventive tactic – all indications of wear that exceeded 30% through wall were preventively plugged.

IN SITU PRESSURE TESTING

Indications of tubing degradation were screened against the performance criteria to determine candidates for in situ pressure and in situ leak testing. At the end of the operating period there was no known primary-to-secondary leakage attributable to steam generator tube degradation.

The method of screening the NDE data for in situ test candidates was that stated in the Draft EPRI TR-107620 "Steam Generator In Situ Pressure Test Guidelines" dated October 1998 (Reference 5). Specific numerical value criteria for screening indications have been calculated that are directly applicable to the SONGS steam generators. These criteria are the result of work that was performed by the ABB-CE Owners Group (Reference 6).

All degradation modes were included in the screening. Linear indications in the circumferential and the axial directions originating at both the inside and outside surfaces of the tube were the majority of the effort. Volumetric indications and indications of wear were also separate populations that were considered. Additionally, since SONGS has pressure tested 61 tubes in previous outages for some of the types of indications stated above, SONGS experience was also considered in the selection of candidates of tubes for testing.

In situ testing at SONGS has and can be performed on full length tubes as well as on defect specific areas. Bladders may be available for use on tubes when leakage is incurred that exceeds the capacity of the test pump. In each case appropriate correction factors are used in determination of the test pressures that are needed to satisfy the objectives of the in situ test. Correction factors are also applied to account for the effect of test temperature on material properties.

Since the majority of the indications of degradation that have been screened have been linear indications and since each screening has inherent differences in screening methods and/or screening criteria, a brief description of the method used at SONGS follows:

Axial OD

Pressure Test Screening

All OD axial indications at the tubesheet, sludge region and eggcrates were depth-sized by the sizing analyst. OD axial indications occurring in the free span were not depth-sized. All OD axial indications, excluding indications within the free span, were evaluated based on structural length. If an indication was less than the structural length, the selection process was terminated, and pressure testing was not required. However, if the length exceeded the structural length, the depth was used to screen for pressure test candidates.

Freespan OD indications were compared to previous tube pulls, lab analysis and previous in situ pressure test results to determine if the indications were relevant for consideration for in situ pressure testing.

Leak Test Screening

Axial OD indications were screened based on a maximum depth threshold for leakage. All indications exceeding this threshold were evaluated on an individual basis.

Axial ID

Pressure Test Screening

All ID axial indications at the tubesheet transition were depth-sized by the sizing analyst. These indications were evaluated using the ID axial criteria. Because of the strengthening effect of the tubesheet, ID axial indications occurring within the tubesheet were not depth-sized.

Leak Test Screening

Axial ID indications were screened based on a maximum depth threshold for leakage. All indications exceeding this threshold were evaluated on an individual basis.

Circumferential OD

Pressure Test Screening

All OD circumferential indications occurring at the tubesheet were depth-sized. In addition, Percent Degraded Areas (PDAs) were determined for all OD circumferential indications based on the product of maximum depth and length, which was divided (conservatively) by the ID circumference. A PDA threshold was used to determine whether or not an indication was a candidate for pressure testing.

The Flaw Length Degraded Area (FLDA) was not determined for the majority of OD circumferential indications. But, for a few over-conservative PDAs, the Draw Program was used to find FLDA and determine PDA for two OD circumferential indications. The ratio of the crack angle to 360 degrees multiplied by the FLDA resulted in a lower, more accurate PDA calculations for these two indications.

Leak Test Screening

OD circumferential indications were evaluated on an individual basis as candidates for leakage testing.

Circumferential ID

Pressure Test Screening

All ID circumferential indications occurring at the tubesheet were depth-sized using the EPRI appendix H amplitude method. Further, Percent Degraded Areas (PDAs) were determined by two methods. First, given the goal of utilizing the Draw Program to determine FLDA and Crack Angle (CA), the sizing analyst characterized all ID circumferential indications that were not associated with software limiting geometric conditions at the axial elevation of the circumferential indication. PDA was determined by multiplying FLDA (output of the "Draw" program) by the ratio of the crack angle to 360 degrees.

Second, due to the geometric limitations near some of the ID circumferential indications, the sizing analyst had to depth-size using an ID degree curve from the Eddynet® Window. PDA was determined by dividing the product of maximum depth and Resolution Plus Point Length by the ID circumference of the tube.

Leak Test Screening

ID circumferential indications were evaluated on an individual basis as candidates for leakage testing.

Volumetric indications such as "Small volume indications" were also evaluated for in situ pressure testing. Volumetric candidates were screened based on the axial and circumferential extent. These indications were not depth-sized.

In Situ Pressure Test Results

The tubes that were selected for in situ testing, the test pressure and the results are Table 5. In all cases the desired pressures were achieved. No leakage and no failures were experienced in the testing.

OPERATIONAL ASSESSMENT: STRUCTURAL MARGIN AND LEAKAGE EVALUATION

Monte Carlo simulation models were used to project the progress of a corrosion degradation of steam generator tubing in SONGS Unit 3. Five degradation mechanisms were considered in total.

When prudent, but not unduly conservative, choices are made relative to crack growth rate distributions and POD curves, projected and observed numbers of indications at both Cycle 9 and the Cycle 10 inspection are in good agreement.

The results of the structural margin and leakage evaluation are shown in the following chart, Table 6.

TABLE 6
SUMMARY OF STRUCTURAL MARGIN AND PROJECTED SLB LEAK RATES

PROJECTED FOR 13.37 EFPY
(EOC 10)

Degradation Mechanism	Conditional Probability of Burst at Postulated SLB (95% Confidence Level)	Conditional Probability of Burst at 3xNODP (50% Confidence Level)	95/95 Leak Rate at Postulated SLB (GPM at Room Temperature)
Axial ODSCC at Eggcrate Intersections	0.0003	0.0112	0.033
Axial PWSCC at Eggcrate Intersections	N/A	N/A	N/A
Freespan Axial ODSCC	<0.0001	0	0
Circumferential ODSCC/PWSCC at Expansion Transitions	<0.0001	0	0
Sludge Pile Axial	0.0002	0.0034	0
Wear	<0.0001	0.0047	0
Arithmetic Total	**0.0008**	**0.0193**	**0.033**
	0.0006 Boolean Sum	**0.0112 Max Value**	
Acceptance Criteria	**<0.05 Total <0.01 per mechanism**	**None**	**<0.5 gpm**

SUMMARY AND CONCLUSIONS

A probabilistic operational assessment of steam generator tubing in SONGS Unit 3 was conducted for Cycle 10 of operation following a comprehensive eddy current inspection at 11.7 EFPY of operation at the end of cycle 9. Inspection results were used to check and update projections for the following degradation mechanisms:

- Axial freespan ODSCC/IGA degradation
- Axial ODSCC/IGA at sludge pile locations
- Axial ODSCC/IGA at eggcrate intersections
- Circumferential ODSCC and PWSCC at TTS
- Wear

Monte Carlo simulation models were used to project the progress of corrosion degradation of steam generator tubing in SONGS Unit 3. Corrosion degradation was conservatively represented as planar cracking. The processes of crack initiation, crack growth and detection of cracking by eddy current inspections were simulated for multiple cycles of operation. Thus the severity of corrosion degradation was projected for operating cycles and times of interest. Both detected and undetected crack populations are included. Burst and leak rate calculations are based on the total crack population. The simulation model is benchmarked by comparing simulation results with actual eddy current inspection results, notable in situ test results, and pulled tube test data.

Projected levels of corrosion degradation severity allowed calculations of the conditional probability of tube burst and an upper bound accident induced leak rate. At EOC 10, at 13.37 EFPY of operation, the conditional probability of tube burst, given a postulated steam line break event, is less much than 0.01 for each of the five corrosion mechanisms. The arithmetical total conditional probability of tube burst is 0.0008, which is considerably less than the 0.05 criteria from NEI 97-06. The largest contributor to the conditional probability of tube burst is axial ODSCC at eggcrate intersections. The contribution from axial ODSCC degradation in the sludge pile is comparable. The projected 95/95 leak rate total, for each steam generator at postulated SLB conditions is 0.033 gpm at room temperature which compares favorably with the acceptance criteria of 0.5 gpm in each steam generator. All of this total is associated with axial ODSCC at eggcrate intersections.

REFERENCES

1. SO123-SG-1, San Onofre Nuclear Generating Station, "Steam Generator Program", dated December 1998

2. NEI 97-06, Revision 0, "Steam Generator Program Guidelines", dated December 1997.

3. Begley, C.J., Woodman, B.W., and Begley, J.A., "A Probabilistic Operational Assessment of Steam Generator Tube Degradation at Songs Unit 2 for Cycle 9, APTECH Report AES 97043057-1-1, Rev. 2, September, 1997.

4. Begley, C.J and Begley, J. A., "An Updated Probabilistic Operational Assessment For Songs Unit 2, Second Mid Cycle Operating Period, Cycle 9" APTECH Report AES 98033327-1-1, Rev. 0, April, 1998.

5. EPRI Draft Report TR-107620 "Steam Generator In Situ Pressure Test Guidelines; October 1998

6. CE NPSD-1005-P ABB/CEOG "Steam Generator Tube In Situ Pressure Test Guidelines CEOG Task 844"; June 1995

7. Cochet, B., "Assessment of the Integrity of Steam Generator Tubes – Burst Test Results – Validation of Rupture Criteria (FRAMATOME DATA)," Palo Alto, CA, Electric Power Research Institute, NP-6865-L, Vol. 1, June, 1991.

8. "PICEP: Pipe Crack Evaluation Program (Revision 1)", Electric Power Research Institute, December, 1987, NP-3596-SR, Revision 1.

9. Begley, J.A., "Leak Rate Calculations for Axial Cracks in Steam Generator Tubing," APTECH Calculation AES-C-2797-2, dated April, 1997.

10. "PWR Steam Generator Tube Repair Limits - Technical Support Document for Outside Diameter Stress Corrosion Cracking at Tube Support Plates", EPRI Report, TR-00407 Rev.1, August, 1993.

11. Zahoor, A., "Ductile Fracture Handbook", EPRI Report, NP.6301-D, RP 1757-69, June, 1989.

12. "Depth Based Structured Analysis Methods for SG Circumferential Indications", EPRI Report, EPRI TR-107197-P1, Interim Report, November, 1997.

13. "SLB Leak Rate and Tube Burst Probability Analysis Methods for ODSCC at TSP Intersections," Westinghouse Non-Proprietary Class 3 Report, WCAP-14277 Revision 1, December, 1996.

Appendix 1

STRUCTURAL INTEGRITY AND LEAK RATE MODELS

Burst strength and leak rate calculations for tubes exhibiting axial corrosion degradation are based upon idealized crack profiles. Axial degradation is modeled as planar cracking. The planar crack assumption is conservative for use in burst and leak rate calculations. The following paragraphs describe idealized morphologies for axial cracks and corresponding burst and leak rate equations. Note that the pattern of throughwall crack development in the leak rate model has been modified compared to earlier reports. This modification makes calculated leak rates more conservative.

Idealized Axial Crack Profiles

From the perspective of tube burst strength and leak rate calculations, each axial corrosion indication is idealized as a single planar crack. This is conservative in that the strengthening and leak limiting effects of ligaments between crack segments in physical crack arrays are neglected. In addition, the physical depth profile, which typically varies in a non-uniform fashion over the length of the crack, is modeled as a simplified ideal profile for burst and leak calculations.

Figure A1.1 illustrates the idealized crack profiles used for burst and leak calculations, compared to the corresponding physical depth profile as measured during a pulled-tube destructive examination. The idealized burst profile represents the portion of the physical profile that is structurally significant in computing burst pressure. The structurally significant dimensions are determined using the Structural Minimum Method, as follows. The physical profile is discretized over its length using a reasonable number of segments, typically between 20 and 50. For each contiguous portion of the crack (that is, for each potential structurally significant length segment), a corresponding depth is computed by equating the areas under the physical and ideal profiles. Each length and depth pair is then tested using the Framatome burst equation (Reference 7, described below) to find the dimensions that minimize the computed burst pressure. The length and depth that minimize the burst pressure represent the structurally significant dimensions, and hence define the idealized burst profile. It is essential to note that historical measurements have shown that structurally significant length of a crack to be reasonably estimated by the portion of a physical crack length detected by a rotating pancake coil eddy current probe. The axial length detected by the Plus Point eddy current probe is a conservative estimate of the actual structurally significant crack length.

The idealized leak profile length is identical to the structurally significant length computed for the burst profile. The tent-shaped leak profile is then determined by equating the maximum depth penetration for both physical and ideal profiles, and by again balancing the areas under the respective profiles over the structural length. The profile form factor, *F*, is defined to be the ratio of the maximum depth, d_{max}, to the structurally significant depth, d_{st}. The distribution characteristics of this form factor are based on pulled tube destructive examination data. See Figure A1.2.

Crack growth over time is assumed to occur primarily in the depth direction. The structural length for both burst and leak profiles is considered to be constant in time. Compared to previous calculations, an element of conservatism has been added to the leak rate model. In contrast to the earlier leak model, the form factor is assumed to remain constant only until wall penetration occurs. Then, as the crack propagates throughwall, as shown in Figure A1.3, the inclined sides of the crack rotate outward until a limiting throughwall length equal to the structural length is reached. The incremental area of crack advance per unit time created by the rotating crack sides is equal to the specified average depth crack growth rate. The length of the throughwall segment, L_{leak}, is then defined by the geometry of the idealized profile to be:

$$L_{leak} = L_{st} \frac{d_{st} - \frac{t}{F}}{t - \frac{t}{F}}$$

Axial Crack Burst Pressure Calculation

Given the structurally significant length and depth dimensions, the burst pressure for an axially degraded tube is computed via the Framatome (Cochet et. al.) partial throughwall burst equation:

$$P = \frac{0.58St}{R_i}\left[1 - \frac{Ld\ /t}{L\ + 2t}\right],$$

where P is the estimated burst pressure, S the sum of the yield and ultimate tensile strength of the tube material, t the tube thickness, R_i the inner radius of the tube, L the characteristic degradation length, and d the characteristic degradation depth. The Framatome equation, when used with the structurally significant dimensions (L_{st} and d_{st}), produces consistently conservative burst pressure estimates compared to measured burst data, as shown in Figure A1.4. It is an excellent lower bound to an extensive set of pulled tube burst test data.

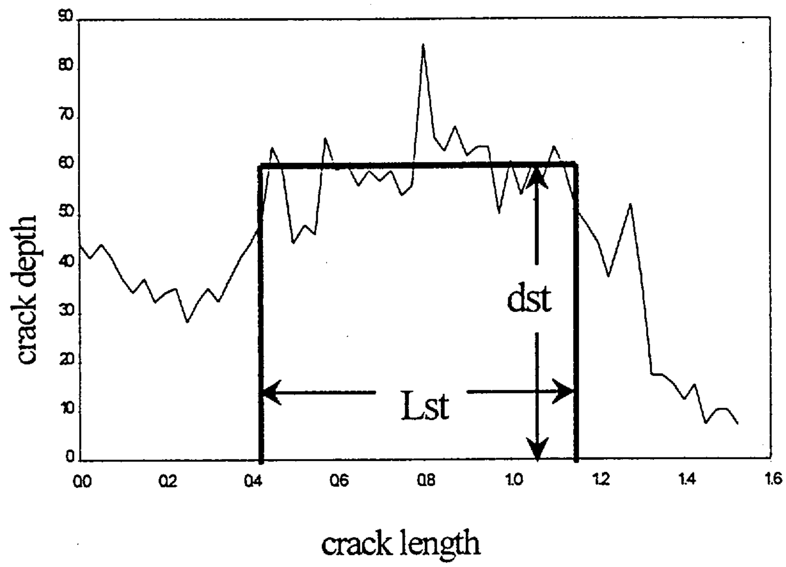
Axial Crack Leak Rate Calculation

As described in Reference 8, Version 3.0 of the PICEP two-phase flow algorithm was used to compute flow rates through cracks as a function of pressure differential (p), temperature (T), crack opening area (A), and total throughwall crack length (L). Friction effects and crack surface roughness were included in the model. Steam line break, room temperature, and normal operating condition leak rates calculated by PICEP were fitted to regression equations. The PICEP-based leak rate regression equation for steam line break conditions is given as:

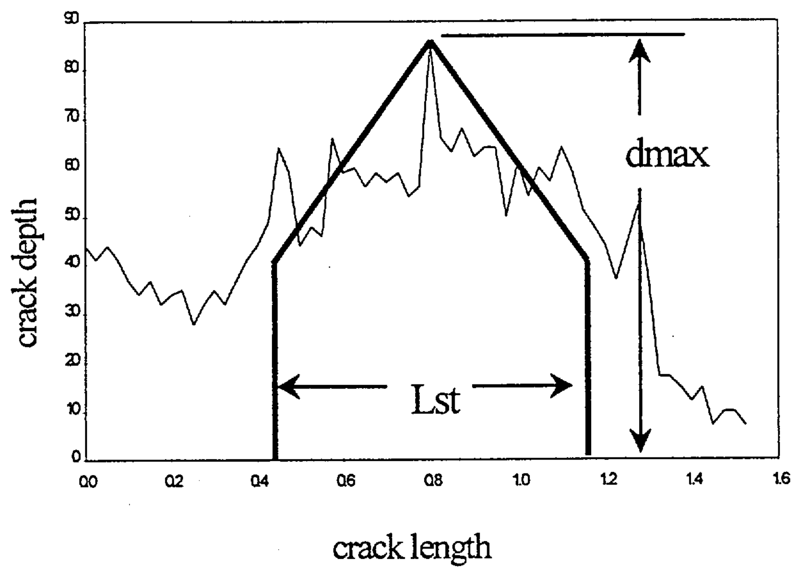
$$Q = \{a + b \exp [c\ (A/L)^{0.451} + d\ (A/L)\ ]\}\ A\ p^{1.333},$$

where *a-d* are regression coefficients as determined by an analysis of PICEP results. The leak rate Q is expressed in terms of gallons per minute at room temperature (70°F). To convert to gallons per minute at any other temperature, the calculated *Q* is multiplied by the ratio of the specific volume of water at temperature (*T*) to the specific volume of water at 70°F. The pressure, *p*, is in units of psi, *A* is in $inches^2$ and *L* (equivalently L_{leak} as defined above) is in inches. The crack opening area is calculated using a twice-iterative plastic zone correction to adjust the linear elastic solution for plasticity effects. Further details of the PICEP regression equations and the crack opening area derivation can be found in References 8, 9, 10 and 11.

A check of the validity of the leak rate equations is provided by a comparison of calculated leak rates versus measured leak rates listed in Reference 10. Measured leak rates at typical normal operating steam generator conditions are available for axial fatigue cracks in steam generator tubing and axial stress corrosion cracks in steam generator tubing. Leak rates through stress corrosion cracks are less than those through fatigue cracks of the same length because of the more torturous cracking in stress corrosion samples. A good conservative leak rate calculation methodology is considered to be one which is a closer match to leak rate results from fatigue cracks rather than stress corrosion cracks. Figure A1.5 shows that this criteria is met by the chosen methodology. Calculated leak rates, illustrated by the dotted lines, serve as a good bound to data from stress corrosion cracked samples of the same tubing dimensions. The calculated leak rates are just below the measured data for fatigue cracked samples.



(a)



(b)

Figure A1.1 Idealized Crack Profiles for Burst (a) and Leakage (b)

Figure A1.2 Maximum Depth vs. Structurally Significant Depth – Pulled Tube Data

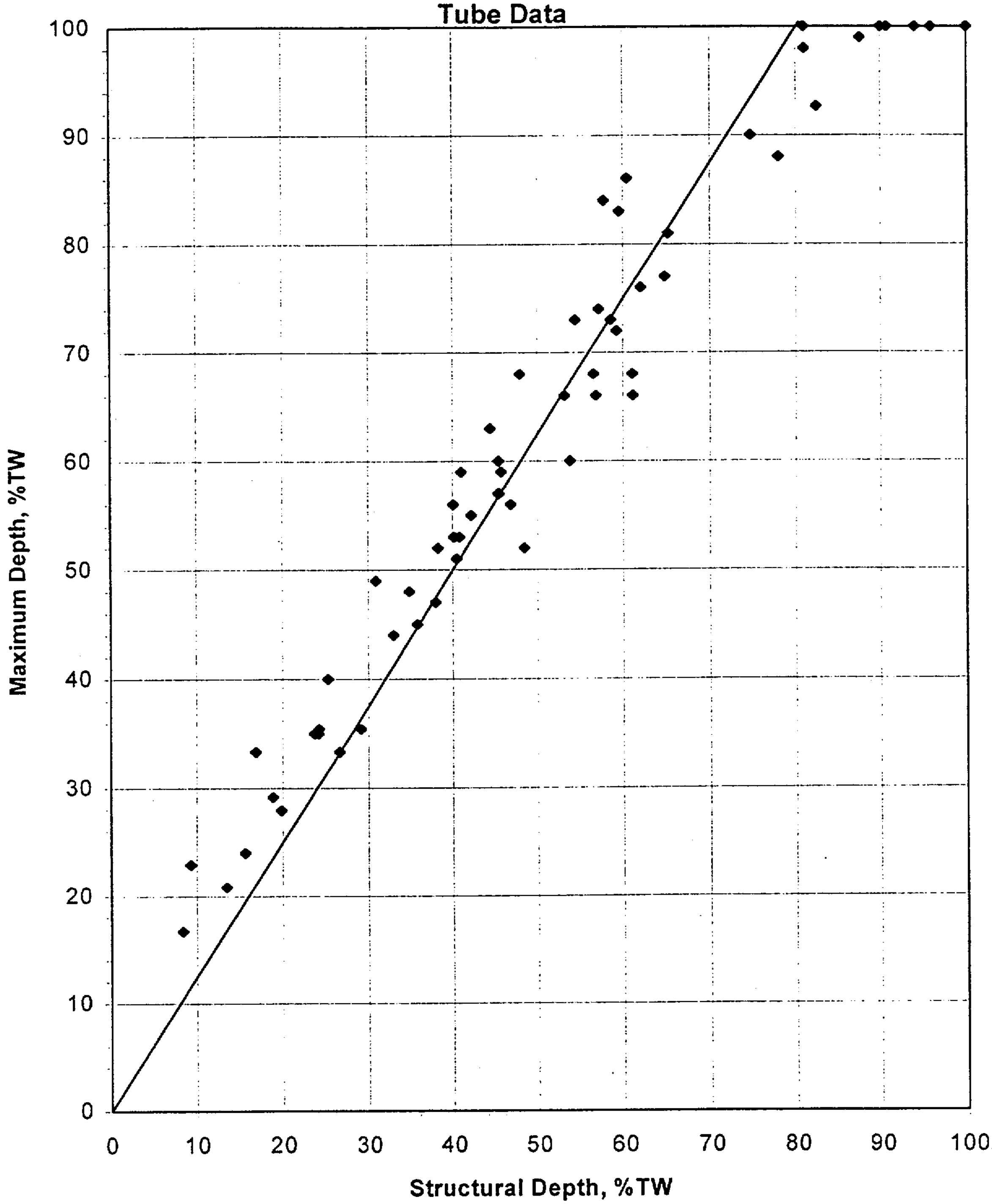
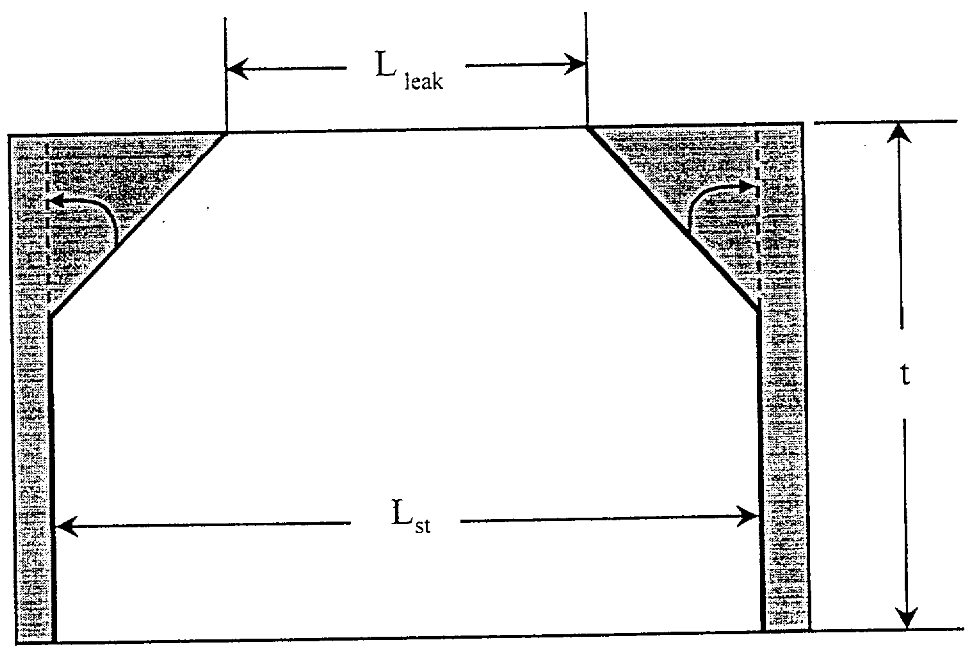


Figure A1.3 Idealized Leakage Crack Profile After Throughwall Penetration



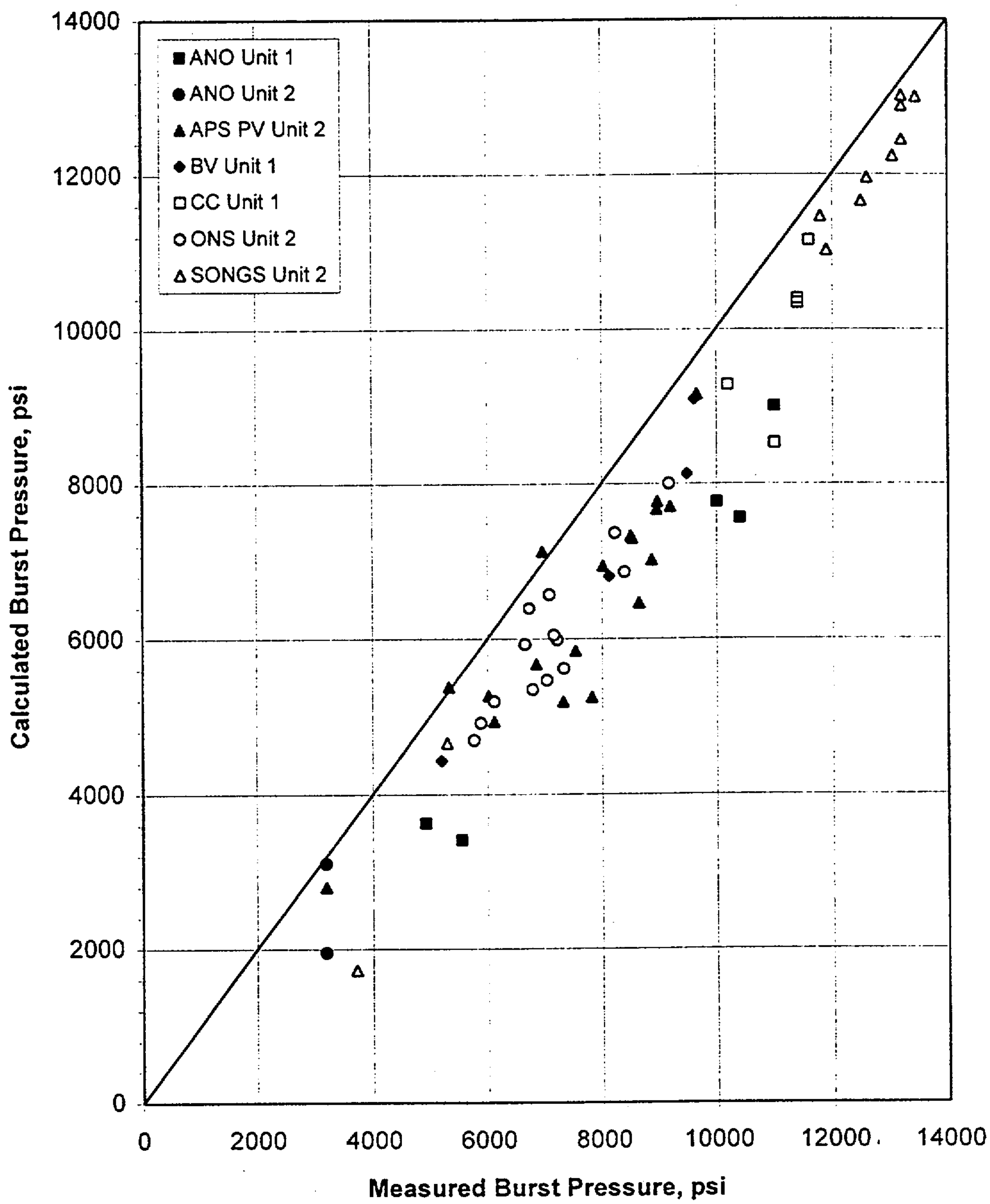


Figure A1.4 Burst Pressure

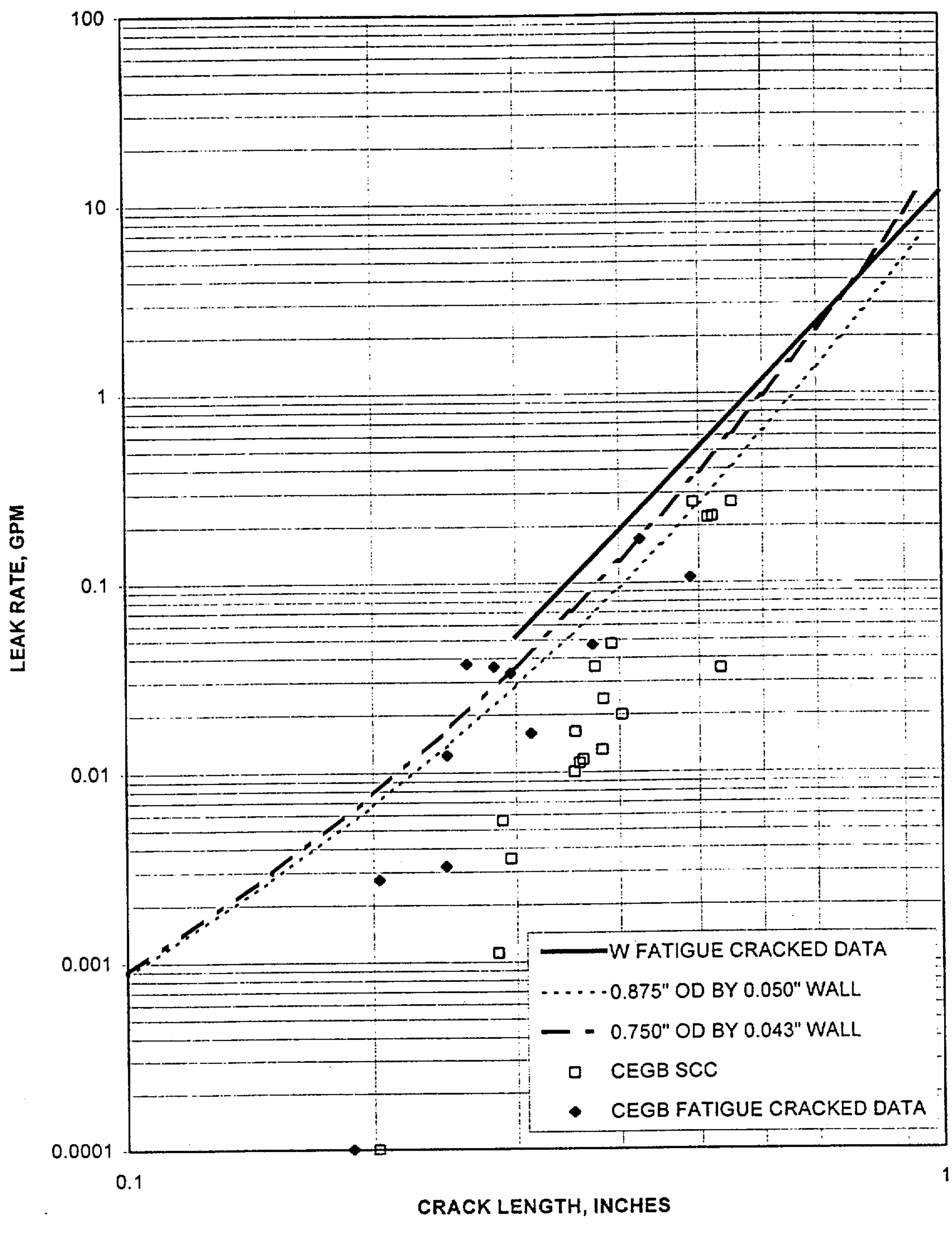


Figure A1.5 Calculated and Measured Leak Rates for Axial Cracks in Alloy 600 Tubing at Normal Operating Conditions

Circumferential Crack Idealized Morphologies

The parameter chosen to define the severity of circumferential degradation is the percentage of the tube crossectional area, which suffers corrosion degradation. Hence the term PDA or percent degraded area. As with axial degradation, a planar crack morphology is the idealized representation of circumferential degradation. For burst calculations it is practical to consider the worst case crack morphology for a given value of PDA. Here a single dominant crack is assumed and all of the degraded area is assigned to a single throughwall crack. This assumption is conservative but not unreasonable for burst calculations". For leak rate calculations, always assuming this single throughwall crack geometry is grossly unreasonable. If this absolute worst case morphology is always assumed, then cracks which do not change the burst pressure from its undegraded value would be assumed to leak at more than 0.5 gpm at postulated steam line break conditions. Clearly a more practical approach to the conservative estimation of leaking crack lengths and leak rates is needed.

A reasonable yet conservative estimation of end of cycle circumferential leaking crack lengths must be based on observed crack profiles. A thorough study of circumferential crack profiles was conducted as part of the EPRI/ANO Circumferential Crack Program dealing with circumferential degradation at expansion transitions. These results are summarized as follows. The morphology of circumferential degradation shows a substantial variation but it is remarkably consistent irrespective of ID or OD initiation or expansion transition type. The general picture is one of multiple crack initiation sites distributed around the tube circumference. The axial extent of this band of circumferential initiation sites ranges from 0 to 0.2 inches. This initiation morphology gives rise to a latter morphology of deep crack segments against a background of relatively shallow degradation.

A deep crack segment is considered to be a region where the local depth is more than twice the background depth. On this basis, the number of deep crack segments per degraded tube circumference was found to range between 0 to 4 from pulled tube examinations. 'A roughly uniform depth profile is obtained when the number of deep crack segments is either 0 or 4. Typically, 1, 2 or 3 deep crack segments are encountered as a degraded tube circumference is traversed. The probability of 1, 2 or 3 deep crack segments is about the same: 0.32. The probability of 0 or 4 deep cracks is taken to be 0.02 based on pulled tube data.

The circumferential extent of an individual deep crack segment varies from 40" to 360'. The distribution of individual deep crack segment lengths can be estimated from pulled tube data and from field eddy current inspection results. This has been done in the EPRI/ANO program. One check of the idealized circumferential crack morphology description is to predict the distribution of total arc lengths of circumferential degradation detected by pancake eddy current inspections from the frequency of occurrence of deep crack segments and the selected distribution of individual deep crack segments. As shown in Reference 12, predictions and measurements are in very good agreement. The idealized circumferential degradation morphology, together with the probability of occurrence of the number of deep crack segments and the distribution of deep crack segment lengths, provide for reasonable yet conservative projections of through-wall leaking crack lengths needed for leak rate calculations. The leak rate calculations are discussed in a following section.

Circumferential Crack Burst Pressure Calculation

Data in the literature and testing conducted as part of the EPRI/ANO Circumferential Crack Program shows that the burst pressure of tubing with circumferential degradation is bounded by the single planar, throughwall crack idealization. Further, in the region of interest hear steam line break pressure differentials, the burst mode is dominated by tensile overload of the net remaining section. In this region of extensive degradation, a lower bound representation of the burst pressure is given by equating the average net section axial stress to the material flow strength. The burst pressure for a tube with outside diameter circumferential degradation, in the tensile burst mode region, is then given as:

$$P_O = ((R_O^2 - R_i^2) / R_i^2)(1\text{-PDA})(S/2)$$

where P_O is the burst pressure, PDA is percent degraded area, S is the sum of yield and ultimate strength at the temperature of interest, R_O is the tube outer radius and R_i is the tube inner radius. For inside diameter circumferential cracking, the pressure on the crack face itself reduces the burst pressure and dictates a correction factor in the burst pressure equation:

$$P_i = P_O R_i^2/(R_i^2 + (R_O^2 - R_i^2)\,\text{PDA}),$$

where P_i is the burst pressure corrected for ID degradation.

Circumferential Crack Leak Rate Calculations

The PICEP based formula presented in an earlier section can be used for either axial or circumferential cracks if the appropriate expression for crack opening area is used. For circumferential cracks, a formulation for crack opening area from the Ductile Fracture Handbook" was used. A plastic zone correction to the crack length was applied. Calculated crack opening areas matched actual measurements made as part of the EPRI/ANO Circumferential Crack Program. Hence crack opening area calculations are well benchmarked. Since the basic conservative nature of the PICEP based leak rate equation is demonstrated by the comparison of measured and calculated leak rates presented in section an earlier section, the lone remaining input for circumferential cracking is the projected end of cycle leaking crack lengths. This projection is developed from calculations of the end of cycle PDA values. The preceding description of circumferential crack morphology provides a picture of deep crack segments against a shallower background of corrosion degradation. Leakage will develop as these deep crack segments penetrate the wall thickness. A conservative estimate of leaking crack lengths is provided by assuming that all of the degraded area is assigned to deep crack segments in a sequence that produces the largest total leak rate. In most cases, a shallower background level of degradation exists but, in order to be conservative for leak rate calculations, all degradation is assigned to deep crack segments until all segments in a given tube are driven throughwall.

A crack morphology simulator program has been written using the data of the previous section. A PDA value for a tube is selected, the number of deep crack segments is sampled according to the observed frequency of occurrence and deep crack segment lengths are sampled from an appropriate Weibul distribution. The program then apportions the PDA to the deep crack segments to determine if wall penetration is possible. If wall penetration is possible, the program determines, with the given number and lengths of deep crack segments, the largest leak rate, which can be produced.

Appendix 2

ANALYSIS INPUT PARAMETERS

A number of input parameters are needed for the Monte Carlo simulation model. A range of material properties is considered rather than a lower bound strength value. Hence the distribution of tensile properties of the steam generator tubing is needed. The distribution of structurally significant axial crack lengths is equated to the distribution of measured lengths as found by the RPC eddy current probe. Thus a sampling distribution of axial crack lengths is needed. The simulation model conducts virtual inspections. This requires knowledge of the probability of detection of degradation as a function of degradation severity for the various eddy current probes that are used. Since degradation growth is simulated, distributions of crack growth rates for both axial and circumferential degradation are required.

Inputs to the are constant throughout with different mechanisms are:

- **Tube dimensions**
- **Mechanical Properties for the tube material**
  - ⇒ 95/95 Strength at temperature – Maximum, minimum, mean and standard deviation
  - ⇒ Young's Modulus
- **Number of tubes at risk**
- **Number of sites per tube at risk**
- **Pressure differential for Main Steam Line Break**
- **Pressure differential for Normal, Steady State operation**
- **Primary to Secondary Leak Limit**

Inputs to the calculational program that varied with different mechanisms are:

- Inspection Cycles
- **POD**
  - ⇒ Intercepts
  - ⇒ Slopes
- **Growth**
  - ⇒ Logarithm Mean (Ln)
  - ⇒ Maximum
  - ⇒ Standard Deviation
  - ⇒ Fraction Zero
- **Crack Initiation Parameters**
  - ⇒ Slope
  - ⇒ Scale
  - ⇒ Set Back
- **Sizing Error**
  - ⇒ Mean
  - ⇒ Standard Deviation
  - ⇒ Maximum

Tubing Mechanical Properties

Figure A2.1 shows a histogram of tube strength for both steam generators at SONGS Unit 3. An adjustment has been made to correct for operating temperature. A normal distribution was fitted to the data of Figure A2.1 for application in the simulation model. This distribution was truncated at the measured extremes of the tensile property database.

Degradation Length Distribution

During the recent eddy current inspection at SONGS Unit 3, crack length measurements were recorded for axial degradation at various locations in the steam generators. Experience has shown that length measurements made with the Plus Point probe tend to over-estimate the structurally significant portion of a crack; hence a best-fit length distribution based on the Plus Point measured lengths adds a degree of conservatism to the simulation. However, this degree of conservatism is grossly unrealistic for freespan axial ODSCC/IGA, as verified by pulled tube burst tests. Therefore, the Plus Point determined eggcrate crack length distribution is applied in analyses of freespan degradation. Figure A2.2 shows a plot of the cumulative distribution function used as a crack length sampling distribution. It is based on a log normal fit to the eggcrate Plus Point data from EOC 8. Figure A2.2 shows that the modeling assumption of a constant distribution of EOC crack lengths, independent of the cycle length, is justified.

Detection Capabilities of Eddy Current Probes

In Monte Carlo simulations, a probability of detection (POD) function is used to model the detection capability of an eddy current probe. Because the effectiveness of the eddy current probe dictates the percentage of cracks that are able to grow deep enough to threaten the structural integrity of the steam generator, it is important to employ a POD function that accurately reflects actual inspection practices.

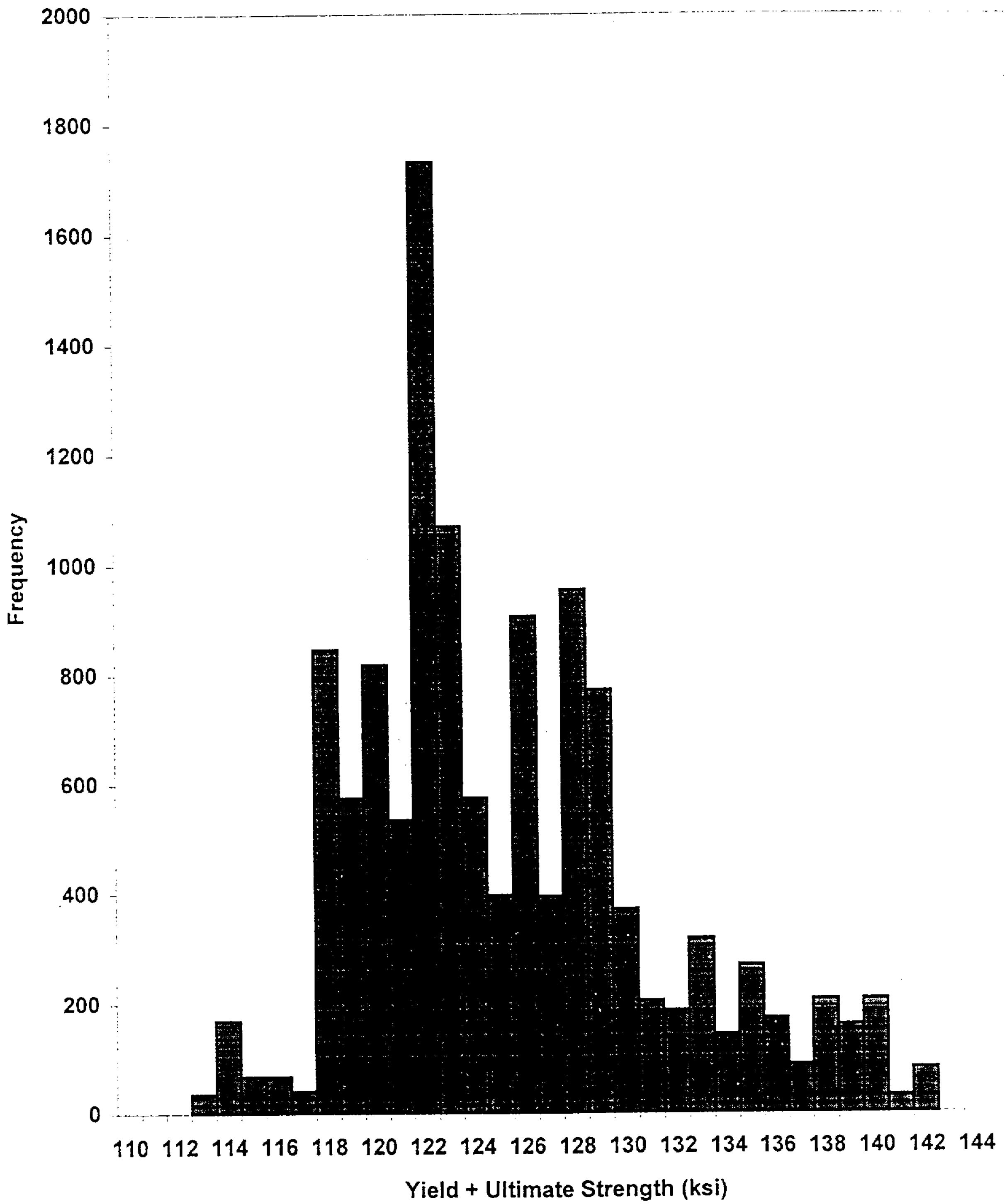
Freespan and eggcrate regions were inspected using a bobbin probe at both Cycle 9 (EOC 8) and the Cycle 10 (EOC 9). This information was used for the construction of curves of probability of detection versus crack depth.

It is recognized that eddy current signals from eggcrate supports can add to the difficulty of detecting degradation in these locations. In this sense POD curves for freespan ODSCC/IGA can be expected to be somewhat better than those for ODSCC/IGA at support structures. Sensitivity studies have shown that, in the context of the present ODSCC/IGA analysis with the observed numbers of indications and growth rate distribution, there was no observable impact of changes in POD curves of a magnitude likely to be associated with the presence or absence of tube support structures. In contrast, when PWSCC is observed at support structure locations, the interaction of tubes with these structures is a defining consideration.

Historically, bobbin probe detection and sizing capability has been referenced to maximum degradation depths. As noted in Appendix 1, the structurally significant average depth is the parameter of interest for burst pressure prediction. Figure A1.2 shows the relationship of structurally significant depth to maximum axial crack depth. The typically ratio of maximum to structural depth is 1.28. This factor was used to convert maximum depth to structural depth in construction of the probability of detection curves.

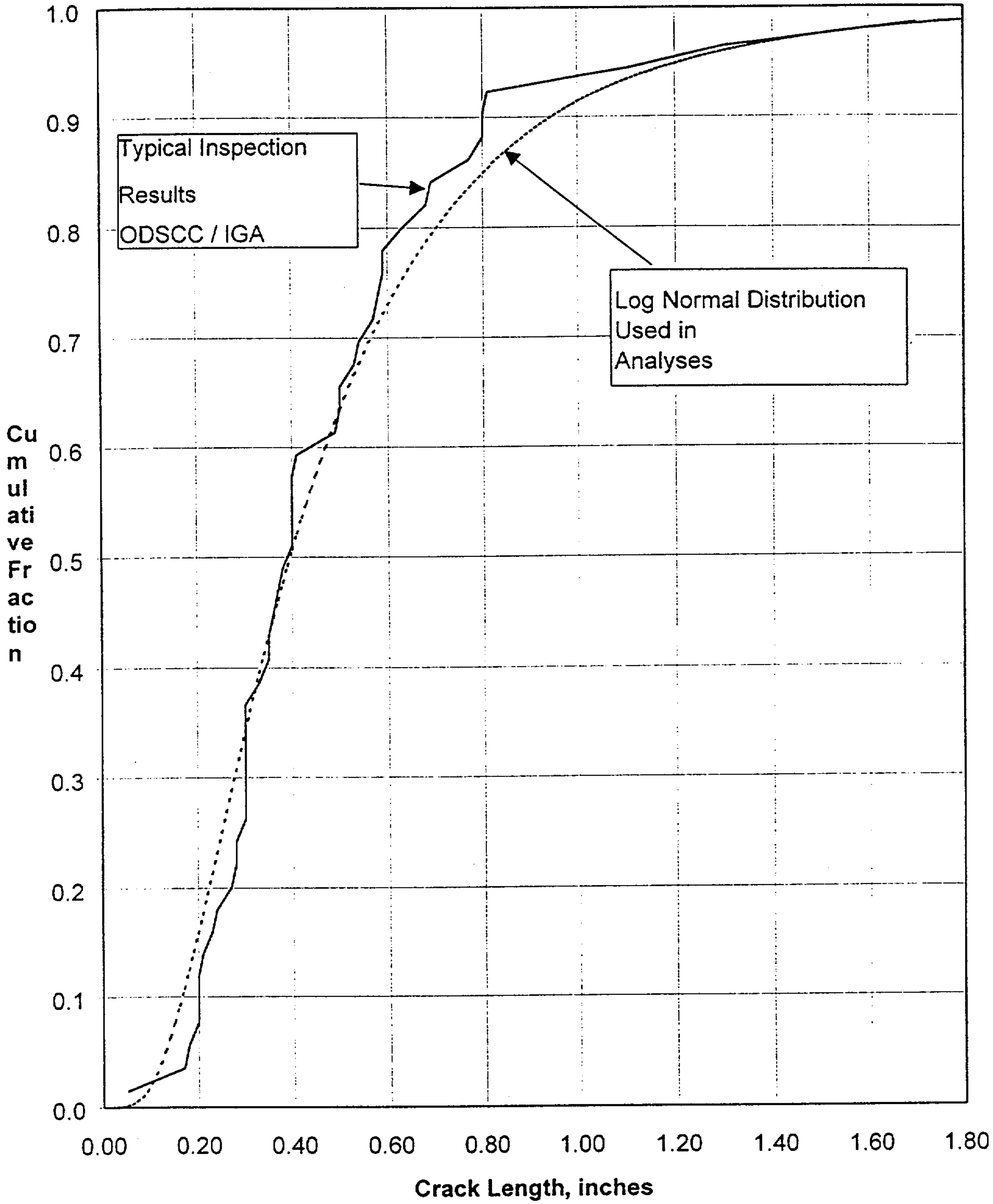
Degradation Growth Rates

During the simulation process, crack growth rates are sampled from a distribution of crack growth rates.



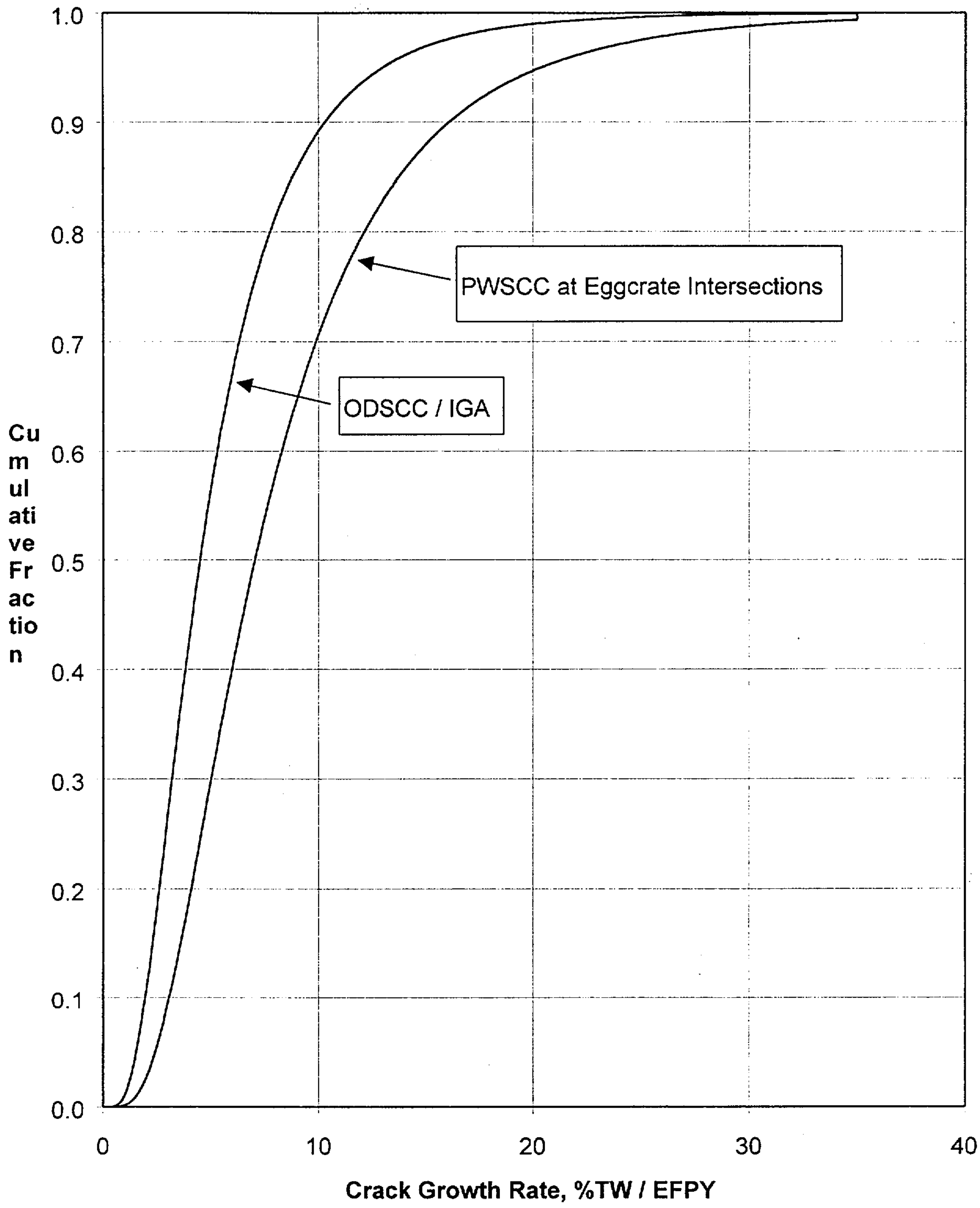
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Frequency
110 112 114 116 118 120 122 124 126 128 130 132 134 136 138 140 142 144
Yield + Ultimate Strength (ksi)

FIGURE A2.1



1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Cumulative Fraction
Typical Inspection Results ODSCC / IGA
Log Normal Distribution Used in Analyses
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
Crack Length, inches

FIGURE A2.2



COMPARISON OF EGGCRATE ODSCC/IGA (TYPICAL)

Figure A2.3 Sampling Distributions For ODSCC / IGA and PWSCC Crack Growth Rates

Appendix 3 - PROBABILISTIC MODEL

The probabilistic run-time model projects the processes that have contributed to tube degradation over the history of a steam generator in order to assess the structural condition of the generator at a future inspection. Specifically, Monte Carlo simulation of the processes of crack initiation, crack growth, eddy current inspection, and removal or repair of degraded tubes provides information necessary to estimate the probability of tube burst and the magnitude of leakage at the next scheduled inspection, given a postulated steam line break event.

The state of degradation of the steam generator tubing is simulated by a defect population that is defined by several parameters. These are: the size of the population at risk, the initiation function that describes crack inception, the distributions of the defect geometries, and the growth rate distribution that determines the change in crack depth over time.

The population at risk, in combination with the initiation function, determines the total number of defects simulated in the analysis. The choice of population size primarily influences the computational time and memory requirements of the simulation. In cases where the choice of population at risk is not obvious from physical considerations, care must be taken to avoid an unreasonably low value that can prematurely exhaust the initiated defect population. For degradation near expansion transitions the obvious population at risk is the number of tubes in the bundle. For cracking at eggcrate intersections, some multiple of the number of tubes in the bundle is appropriate. If the total population of degraded sites is small compared to the total number of sites at risk, then the choice of the number of sites at risk is not of concern other than perhaps creating unwarranted

Distributions For ODSCC / IGA and PWSCC Crack Growth Rates

memory requirements.

The initiation function for defects is based on a modified Weibull function, which requires a scale parameter and a slope parameter. The scale parameter reflects the length of time required to initiate a given percentage of all potential crack sites. This parameter may be on the order of several decades. The slope parameter is a measure of the rate of increase in initiated defects over time. The scale and slope parameters are adjusted iteratively until the number of indications produced by the simulation matches the actual number of flaws detected at recent plant inspections. Having matched the number in indications observed at recent inspections, other key benchmarking items include: predicting the measured severity of degradation, confirming notable in situ test results, and reproducing observed inspection transients.

A probabilistic analysis of degradation within a steam generator includes many thousands of simulations that track the condition of the steam generator through several past inspection periods to develop benchmark statistics. The model then projects the degradation mechanism through the current operating cycle in order to predict the structural condition of the generator as a function of cycle duration. The present study considers all past inspections for which eddy current inspection results are available.

Each mock operating cycle and inspection event within a single steam generator simulation consists of several steps that trace the initiation and development of individual cracks. For each potential crack site, a crack initiation time is drawn at random from a cumulative initiation function. A certain percentage of the crack sites will have initiated during or prior to the operating cycle of interest.

For each initiated crack, a set of descriptive parameters is drawn at random from appropriate distributions to describe the crack in detail. These parameters include the crack length, the crack form factor, and the strength properties of the tube in which the crack resides. The crack retains these particular features throughout its entire life. A growth rate is then sampled from the growth rate distribution. The growth rate is applied to the crack depth over the interval of time between inspections. The growth is assumed to be linear in time. A new growth rate is sampled after each simulated inspection and applied over the ensuing operating cycle, which accounts for potential changes in local growth environments due to start-up transients. The average depth of the crack increases with time, and the maximum depth is correspondingly adjusted according to the crack form factor.

Simulated inspections are performed according to the plant-specific inspection schedules. The crack depth at the end of a completed operating cycle, together with the POD curve, determine the probability that a particular crack will be detected during an inspection. A random number is drawn from a uniform distribution and compared to the POD. If the random draw is less than the POD, the crack is detected and removed from service. Undetected cracks are left in service and allowed to grow throughout the following operating cycle, and the process is repeated at subsequent inspections.

All cracks, whether detected or undetected, are examined at the end-of-cycle inspections to assess the probability of tube burst and leakage under steam line break conditions. The algorithm records a burst if the accident pressure differential exceeds the burst pressure for a particular flawed tube. If the maximum crack depth exceeds the tube thickness, the flaw is considered to be leaking. A potentially high leak rate can result from a "pop-through" event, which occurs when the length of a particular defect is not sufficient to cause a full burst, but the average depth of the crack is such that the crack breaks through-wall over its entire structural length.

When all initiated cracks have been inspected over the course of prescribed past and future operating cycles, a single Monte Carlo trial of the steam generator is complete. Many thousands of such trials are necessary to generate the distributions of tube burst and leakage rates required in the structural margin assessments.

The output from the simulation algorithm consists of a record of all tubes that have burst during the simulation, and all defects that have penetrated through-wall and are assumed to be leaking. Other pertinent data such as the operating cycle during which the burst or leak event occurred, the tube material properties, flaw length, and form factor are also recorded.

For a given operating cycle of interest, the number of burst events are tallied and a 95% upper confidence bound for the probability of burst is computed using an appropriate F-distribution, as in Reference 13. For example, if 10,000 simulations of the steam generator produce 1 or more bursts in 30 of the trials, the 95% confidence probability of burst is calculated to be PoB = 0.00407.

A leak rate is assigned to each throughwall defect according to the methods presented in Appendix 2. The total leak rate for each steam generator simulation is then computed, the simulation leak rates are sorted in ascending order, and the 95/95 probability/confidence leak rate is determined as described in Reference 13. For example, for 10,000 steam generator simulations, the 9537th highest computed leak rate represents the 95th percentile leak rate with 95% confidence.

Summary of Structural Margin and Leak Rate Evaluations

A summary of calculated conditional probabilities of tube burst and upper bound accident induced leak rates is provided in Table 6 for the five corrosion degradation mechanisms considered in this evaluation. The limiting mode of degradation is ODSCC at eggcrate intersections relative to conditional probability of tube burst. In terms of projected leak rates at postulated accident conditions, ODSCC at eggcrate intersections is also the dominant consideration. Calculated conditional probabilities of tube burst and projected upper bound SLB leak rates at EOC 10 meet the requirements of NEI 97-06.

Appendix 4

ODSCC/IGA at Eggcrate Intersections

ODSCC/IGA degradation at eggcrate locations were efficiently removed from service during each outage. This was the expectation since the outage inspection was critically focused on eggcrate and freespan locations. The predicted probability of burst at MSLB for this mechanism following 1.67 EFPY of operation in cycle 10 is 0.0003 and the corresponding leak rate at MSLB is 0.026 gpm.

Inputs:

Inspection	POD		Growth				Initiation			Sizing Error		
Data from Outages	Intercept	Slope	Mean Ln	MAX	Std Dev	Fract Zero	Slope	Scale	Set Back	Mean	Std Dev	Max
8, 9, & 10	12.742 19.72	-8.139 -14.09	1.60	100	0.90	0	4.5	47	0	0	0.0375	1

VERSION AxMulti1b.exe 5/5/98

Indications Observed

Mechanism	SG 88/89			
	3C8	3C9	3M9	3C10
ODSCC @ EGGCRATES	0-2	0-2	N/A	3-4

Simulation Predictions

Mechanism	Mean				Standard Deviation			
	3C8	3C9	3M9	3C10	3C8	3C9	3M9	3C10
ODSCC @ EGGCRATES	1	1	N/A	4	1	1	N/A	2

Input File Name	D:\OPCON_050798\AxMulti\odtsp80.out			

# Sims	20000	Initiation Slope	4.5
# Tubes	9350	Initiation Scale	47
Sites/Tube	1	Initiation Setback	0
SLB	2.575	Mean Error	0
NOP	1.46	Error Std Dev	0.0375
Leak Limit	0.01	Max Error	1
Tube Wall	0.048	Tube OD	0.75
Mean Strength	124.87	Strength Std Dev	5.9
Max Strength	142	Min Strength	113
Young's Modulus	28700000		
Mean Ln(Growth Rate)	1.6	Std Dev of Mean	0.9
Max Growth Rate	100	Fraction Zero Growth	0

Cycle, EFPY	Fraction Inspct.	Repair Limit	POD Fit	POD Intercept	POD Slope
8.62	1.0	-99.0	L/L	12.742	-8.139
10.08	1.0	-99.0	L/L	12.742	-8.139
11.7	1.0	-99.0	L/L	19.72	-14.089
13.37	1.0	-99.0	L/L	19.72	-14.089

OUTPUT FILE:"D:\OPCON_050798\AxMulti\odtsp80.out"

Cycle, EFPY	8.62	10.08	11.7	13.37
POL at SLB	0.0576	0.0309	0.0795	0.128
POL >Limit at SLB	0.0358	0.0148	0.0405	0.0677
POL >Limit at NOP	0.0334	0.0112	0.0343	0.0564
95/95 Leak at SLB, NOP	0.001	0	0.004	0.033
# Sims w/Bursts	0	0	0	2
POB at SLB (95%)	0.0001	0.0001	0.0001	0.0003
POB at 3DP	0.0049	0.0022	0.0075	0.0112
Initiated	4.52	4.67	8.71	14.81
In Service	4.52	8.66	16.42	27.61
Mean # Detected	0.52	0.95	3.62	5.69
Std Dev, # Detected	0.69	0.98	1.88	2.38
Mean # Known In Service	0.52	0.95	3.62	5.69
Std Dev, # Known In Servic	0.69	0.98	1.88	2.38
Cumulative # Detected, Me	0.52	1.47	5.09	10.79
Cumulative # Detected, Stc	0.69	1.23	2.26	3.24
Mean # Plugged	0.52	0.95	3.62	5.69
Std Dev, # Plugged	0.69	0.98	1.88	2.38
Cumulative # Plugged, Mea	0.52	1.47	5.09	10.79
Cumulative # Plugged, Std	0.69	1.23	2.26	3.24
Mean Maximum Depth	0.295	0.33	0.459	0.533
Std Dev, Maximum Depth	0.343	0.192	0.221	0.253

TRUE DEPTH

TRUE Depth, % Through Wall	8.62	10.08	11.7	13.37
5	2.14	3.59	6.31	10.41
10	0.91	1.74	3.09	5.34
15	0.49	1.13	2.12	3.72
20	0.29	0.75	1.52	2.71
25	0.19	0.5	1.07	1.87
30	0.13	0.32	0.74	1.21
35	0.09	0.21	0.51	0.75
40	0.06	0.14	0.34	0.48
45	0.05	0.09	0.22	0.31
50	0.04	0.06	0.15	0.2
55	0.03	0.04	0.1	0.14
60	0.02	0.03	0.07	0.1
65	0.02	0.02	0.05	0.07
70	0.02	0.01	0.04	0.05
75	0.01	0.01	0.03	0.04
80	0.01	0.01	0.02	0.03
85	0.01	0.01	0.01	0.02
90	0.01	0	0.01	0.02
95	0	0	0.01	0.02
100	0.04	0.01	0.04	0.07

DETECTED DEPTH

DETECTED Depth, % Through Wall	8.62	10.08	11.7	13.37
5	0	0	0	0
10	0.01	0.02	0.01	0.02
15	0.02	0.05	0.14	0.25
20	0.04	0.11	0.5	0.88
25	0.06	0.15	0.73	1.27
30	0.06	0.14	0.65	1.06
35	0.05	0.12	0.48	0.72
40	0.05	0.1	0.33	0.47
45	0.04	0.07	0.22	0.3
50	0.03	0.05	0.15	0.2
55	0.03	0.03	0.09	0.14
60	0.02	0.03	0.07	0.1
65	0.02	0.02	0.05	0.07
70	0.01	0.01	0.04	0.05
75	0.01	0.01	0.03	0.04
80	0.01	0.01	0.02	0.03
85	0.01	0.01	0.01	0.02
90	0.01	0	0.01	0.02
95	0	0	0.01	0.02
100	0.04	0.01	0.04	0.07

MEASURED DEPTH

MEASURED Depth, % Through Wall	8.62	10.08	11.7	13.37
5	0	0.01	0.01	0.01
10	0.01	0.02	0.05	0.08
15	0.02	0.06	0.2	0.35
20	0.04	0.11	0.47	0.81
25	0.06	0.13	0.65	1.11
30	0.06	0.14	0.62	1.01
35	0.05	0.12	0.49	0.75
40	0.05	0.1	0.34	0.49
45	0.04	0.07	0.23	0.32
50	0.03	0.05	0.15	0.21
55	0.02	0.04	0.1	0.14
60	0.02	0.03	0.07	0.1
65	0.02	0.02	0.05	0.07
70	0.01	0.01	0.04	0.05
75	0.01	0.01	0.03	0.04
80	0.01	0.01	0.02	0.03
85	0.01	0.01	0.02	0.02
90	0.01	0.01	0.02	0.03
95	0	0	0	0.01
100	0.04	0.01	0.04	0.06

TRUE DEPTH

TRUE Depth, % Through Wall	8.62	10.08	11.7	13.37
5	0.4693	0.41407	0.38359	0.37772
10	0.66886	0.61476	0.57143	0.57148
15	0.77632	0.7451	0.7003	0.70646
20	0.83991	0.8316	0.79271	0.80479
25	0.88158	0.88927	0.85775	0.87264
30	0.91009	0.92618	0.90274	0.91655
35	0.92982	0.9504	0.93374	0.94376
40	0.94298	0.96655	0.95441	0.96118
45	0.95395	0.97693	0.96778	0.97242
50	0.96272	0.98385	0.9769	0.97968
55	0.9693	0.98847	0.98298	0.98476
60	0.97368	0.99193	0.98723	0.98839
65	0.97807	0.99423	0.99027	0.99093
70	0.98246	0.99539	0.99271	0.99274
75	0.98465	0.99654	0.99453	0.99419
80	0.98684	0.99769	0.99574	0.99528
85	0.98904	0.99885	0.99635	0.99601
90	0.99123	0.99885	0.99696	0.99673
95	0.99123	0.99885	0.99757	0.99746
100	1	1	1	1

DETECTED DEPTH

DETECTED Depth, % Through Wall	8.62	10.08	11.7	13.37
5	0	0	0	0
10	0.01923	0.02128	0.00279	0.00349
15	0.05769	0.07447	0.0419	0.04712
20	0.13462	0.19149	0.18156	0.2007
25	0.25	0.35106	0.38547	0.42234
30	0.36538	0.5	0.56704	0.60733
35	0.46154	0.62766	0.70112	0.73298
40	0.55769	0.73404	0.7933	0.81501
45	0.63462	0.80851	0.85475	0.86736
50	0.69231	0.8617	0.89665	0.90227
55	0.75	0.89362	0.92179	0.9267
60	0.78846	0.92553	0.94134	0.94415
65	0.82692	0.94681	0.95531	0.95637
70	0.84615	0.95745	0.96648	0.9651
75	0.86538	0.96809	0.97486	0.97208
80	0.88462	0.97872	0.98045	0.97731
85	0.90385	0.98936	0.98324	0.9808
90	0.92308	0.98936	0.98603	0.98429
95	0.92308	0.98936	0.98883	0.98778
100	1	1	1	1

MEASURED DEPTH

MEASURED Depth, % Through Wall	8.62	10.08	11.7	13.37
5	0	0.01042	0.00278	0.00176
10	0.01961	0.03125	0.01667	0.01582
15	0.05882	0.09375	0.07222	0.07733
20	0.13725	0.20833	0.20278	0.21968
25	0.2549	0.34375	0.38333	0.41476
30	0.37255	0.48958	0.55556	0.59227
35	0.47059	0.61458	0.69167	0.72408
40	0.56863	0.71875	0.78611	0.81019
45	0.64706	0.79167	0.85	0.86643
50	0.70588	0.84375	0.89167	0.90334
55	0.7451	0.88542	0.91944	0.92794
60	0.78431	0.91667	0.93889	0.94552
65	0.82353	0.9375	0.95278	0.95782
70	0.84314	0.94792	0.96389	0.96661
75	0.86275	0.95833	0.97222	0.97364
80	0.88235	0.96875	0.97778	0.97891
85	0.90196	0.97917	0.98333	0.98243
90	0.92157	0.98958	0.98889	0.9877
95	0.92157	0.98958	0.98889	0.98946
100	1	1	1	1

LEAK RATE

Leak Rate, gpm	8.62EFPY	10.08EFPY	11.7EFPY	13.37EFPY
1.80E-07	0.9428	0.9696	0.9217	0.8732
3.20E-07	0.9431	0.9697	0.922	0.8737
5.60E-07	0.9432	0.9698	0.9223	0.8738
1.00E-06	0.9433	0.9699	0.9226	0.8742
1.80E-06	0.9434	0.9704	0.923	0.8749
3.20E-06	0.9436	0.9707	0.9236	0.8758
5.60E-06	0.9437	0.9709	0.9245	0.8768
1.00E-05	0.9442	0.9714	0.9254	0.878
1.80E-05	0.9448	0.9717	0.9264	0.8795
3.20E-05	0.9456	0.9722	0.9275	0.8811
5.60E-05	0.9463	0.9728	0.9294	0.8835
1.00E-04	0.9477	0.974	0.9309	0.8866
1.80E-04	0.9489	0.9747	0.9331	0.8901
3.20E-04	0.9505	0.9758	0.936	0.8944
5.60E-04	0.9516	0.9767	0.9394	0.8988
1.00E-03	0.9534	0.9781	0.943	0.9049
1.80E-03	0.9559	0.9799	0.9464	0.9113
3.20E-03	0.9579	0.9813	0.9498	0.9173
5.60E-03	0.9599	0.9831	0.9542	0.9244
1.00E-02	0.9642	0.9852	0.9596	0.9324
1.80E-02	0.9683	0.9879	0.9646	0.9416
3.20E-02	0.9736	0.99	0.9704	0.9517
5.60E-02	0.9791	0.9925	0.9766	0.9623
1.00E-01	0.9847	0.9944	0.9831	0.9728
1.80E-01	0.9889	0.9959	0.9878	0.9806
3.20E-01	0.992	0.9969	0.9914	0.9857
5.60E-01	0.9942	0.998	0.9937	0.9896
1.00E+00	0.9962	0.9987	0.9955	0.9931
1.80E+00	0.9974	0.9991	0.997	0.9957
3.20E+00	0.9986	0.9994	0.9981	0.9974
5.60E+00	0.9989	0.9998	0.9988	0.9985
1.00E+01	0.9993	0.9998	0.9992	0.999
1.80E+01	0.9996	0.9998	0.9995	0.9995
3.20E+01	0.9997	0.9998	0.9998	0.9996
5.60E+01	0.9998	0.9999	0.9998	0.9998
1.00E+02	0.9998	1	0.9998	0.9998
1.80E+02	0.9999	1	0.9999	0.9998
3.20E+02	0.9999	1	0.9999	0.9998
5.60E+02	0.9999	1	0.9999	0.9998
1.00E+03	1	1	1	1

BURST PRESSURE

Burst Pressure, psi	8.62EFPY	10.08EFPY	11.7EFPY	13.37EFPY
250	0.0032	0.0003	0.0006	0.0006
500	0.0034	0.0003	0.0007	0.0006
750	0.0037	0.0004	0.0007	0.0007
1000	0.0039	0.0005	0.0008	0.0008
1250	0.0043	0.0005	0.0009	0.0009
1500	0.0048	0.0005	0.001	0.001
1750	0.0051	0.0006	0.0011	0.0011
2000	0.0055	0.0007	0.0012	0.0013
2250	0.006	0.0008	0.0014	0.0014
2500	0.0064	0.001	0.0016	0.0016
2750	0.007	0.0012	0.0019	0.0018
3000	0.0075	0.0013	0.0021	0.0021
3250	0.0081	0.0014	0.0024	0.0024
3500	0.0087	0.0017	0.0027	0.0027
3750	0.0094	0.0021	0.003	0.0031
4000	0.0102	0.0024	0.0035	0.0035
4250	0.0112	0.0029	0.0041	0.004
4500	0.0124	0.0033	0.0047	0.0046
4750	0.0139	0.0039	0.0054	0.0052
5000	0.0156	0.0046	0.0063	0.0061
5250	0.0174	0.0055	0.0075	0.0071
5500	0.0194	0.0065	0.009	0.0083
5750	0.0217	0.0078	0.0107	0.0099
6000	0.0242	0.0095	0.0128	0.0117
6250	0.0273	0.0115	0.0155	0.014
6500	0.0312	0.0141	0.0189	0.017
6750	0.0355	0.0175	0.0236	0.0207
7000	0.0405	0.0219	0.0293	0.0255
7250	0.0472	0.0273	0.0367	0.0319
7500	0.0545	0.0347	0.0466	0.0402
7750	0.0639	0.0455	0.0595	0.0517
8000	0.0756	0.0593	0.0766	0.0671
8250	0.0903	0.0772	0.0987	0.0879
8500	0.1092	0.1008	0.1272	0.1159
8750	0.133	0.1331	0.1643	0.1527
9000	0.1646	0.1749	0.2106	0.2006
9250	0.2091	0.2316	0.2704	0.2631
9500	0.2762	0.3094	0.349	0.3446
9750	0.3701	0.4099	0.4466	0.4454
10000	0.4891	0.5282	0.56	0.5609
10250	0.6242	0.6564	0.6824	0.6836
10500	0.7555	0.7794	0.7963	0.7984
10750	0.8627	0.8787	0.8877	0.8888
11000	0.9356	0.9424	0.9474	0.9483
11250	0.975	0.977	0.9799	0.9798
11500	0.9916	0.9929	0.9938	0.9937
11750	0.9982	0.9984	0.9986	0.9986
12000	0.9999	0.9999	0.9999	0.9999
12250	1	1	1	1
12500	1	1	1	1

Appendix 5

Axial PWSCC at "Dented" Eggcrate Intersections

To date, no axial PWSCC at eggcrate intersections has been detected at SONGS Unit 3. This mechanism was the limiting form of degradation at SONGS Unit 2. As noted previously, PWSCC, on mechanistic grounds, is associated with deformed or dented eggcrate intersections, even if there is no detectable denting via eddy current inspection. The observed dented eggcrate intersections occur twenty times more frequently at SONGS Unit 2 compared to SONGS Unit 3. Axial PWSCC at eggcrate intersections is not an active damage mechanism for SONGS Unit 3.

Appendix 6

Axial ODSCC/IGA at Freespan Locations

Axial ODSCC/IGA was detected at SONGS Unit 3 at freespan locations at the EOC 7 inspection. This is not unexpected in view of the performance of similar steam generators. This degradation was discovered by the bobbin probe. Plus Point inspections were performed in tubes with bobbin probe indications. The low signal amplitudes of Plus Point indications argued for mild severity of freespan axial degradation. This was confirmed by burst tests of pulled tubes from SONGS Unit 2. The burst strength of pulled tube sections with axial freespan indications was in excess of 10,000 psi. The magnitude of Plus Point voltages of freespan indications at the EOC 9 inspection is smaller than those of the EOC 8 inspection. The calculated 95/95 SLB leak rate is zero.

Inputs:

Inspection	POD		Growth				Initiation			Sizing Error		
Data from Outages	Intercept	Slope	Mean Ln	MAX	Std Dev	Fract Zero	Slope	Scale	Set Back	Mean	Std Dev	Max
8, 9 & 10	12.742 19.72	-7.5 -14.09	1.40	100	0.1	0	1.5	990	0	0	0.0375	1

VERSION AxMulti1b.exe 5/5/98

Indications Observed

Mechanism	SG 88/89			
	3C8	3C9	3M9	3C10
FREESPAN ODSCC	0-1	0-6	N/A	0-1

Simulation Predictions

Mechanism	Mean				Standard Deviation			
	3C8	3C9	3M9	3C10	3C8	3C9	3M9	3C10
FREESPAN ODSCC	1	3	N/A	2	1	2	N/A	1

Input File Name	D:\OPCON_050798\AxMulti\odfs208.out				
# Sims	20000		Initiation Slope	1.5	
# Tubes	9350		Initiation Scale	990	
Sites/Tube	1		Initiation Setback	0	
SLB	2.575		Mean Error	0	
NOP	1.46		Error Std Dev	0.0375	
Leak Limit	0.01		Max Error	100	
Tube Wall	0.048		Tube OD	0.75	
Mean Strength	124.87		Strength Std Dev	5.9	
Max Strength	142		Min Strength	113	
Young's Modulus	28700000				
Mean Ln(Growth Rate)	1.4		Std Dev of Mean	0.1	
Max Growth Rate	100		Fraction Zero Growth	0	
Cycle, EFPY	Fraction Inspct.	Repair Limit	POD Fit	POD Intercept	POD Slope
8.62	1.0	-99.0	L/L	12.742	-7.5
10.08	1.0	-99.0	L/L	19.72	-14.09
11.7	1.0	-99.0	L/L	19.72	-14.09
13.37	1.0	-99.0	L/L	19.72	-14.09

OUTPUT FILE:"D:\OPCON 050798\AxMulti\odfs208.out"

Cycle, EFPY	8.62	10.08	11.7	13.37
POL at SLB	0	0	0	0
POL >Limit at SLB	0	0	0	0
POL >Limit at NOP	0	0	0	0
95/95 Leak at SLB, NOP	0	0	0	0
# Sims w/Bursts	0	0	0	0
POB at SLB (95%)	0.0001	0.0001	0.0001	0.0001
POB at 3DP	0	0	0	0
Initiated	7.61	1.96	2.42	2.72
In Service	7.61	9.03	8.36	9.13
Mean # Detected	0.54	3.08	1.95	2.05
Std Dev, # Detected	0.73	1.75	1.4	1.38
Mean # Known In Service	0.54	3.08	1.95	2.05
Std Dev, # Known In Servic	0.73	1.75	1.4	1.38
Cumulative # Detected, Me	0.54	3.62	5.57	7.62
Cumulative # Detected, Stc	0.73	1.89	2.36	2.74
Mean # Plugged	0.54	3.08	1.95	2.05
Std Dev, # Plugged	0.73	1.75	1.4	1.38
Cumulative # Plugged, Mea	0.54	3.62	5.57	7.62
Cumulative # Plugged, Std	0.73	1.89	2.36	2.74
Mean Maximum Depth	0.273	0.316	0.253	0.248
Std Dev, Maximum Depth	0.06	0.062	0.06	0.049

TRUE DEPTH

TRUE Depth, % Through Wall	8.62	10.08	11.7	13.37
5	1.57	1.71	1.85	2
10	1.44	1.58	1.73	1.87
15	1.32	1.46	1.61	1.76
20	1.14	1.31	1.44	1.61
25	0.97	1.11	1.06	1.2
30	0.71	0.88	0.49	0.54
35	0.36	0.6	0.16	0.13
40	0.08	0.29	0.04	0.02
45	0.01	0.07	0.01	0
50	0	0.01	0	0
55	0	0	0	0
60	0	0	0	0
65	0	0	0	0
70	0	0	0	0
75	0	0	0	0
80	0	0	0	0
85	0	0	0	0
90	0	0	0	0
95	0	0	0	0
100	0	0	0	0

DETECTED DEPTH

DETECTED Depth, % Through Wall	8.62	10.08	11.7	13.37
5	0	0	0	0
10	0.01	0.01	0.01	0.01
15	0.03	0.1	0.11	0.12
20	0.08	0.44	0.47	0.53
25	0.14	0.76	0.72	0.82
30	0.17	0.78	0.43	0.48
35	0.12	0.57	0.15	0.12
40	0.04	0.28	0.04	0.02
45	0	0.07	0.01	0
50	0	0.01	0	0
55	0	0	0	0
60	0	0	0	0
65	0	0	0	0
70	0	0	0	0
75	0	0	0	0
80	0	0	0	0
85	0	0	0	0
90	0	0	0	0
95	0	0	0	0
100	0	0	0	0

MEASURED DEPTH

MEASURED Depth, % Through Wall	8.62	10.08	11.7	13.37
5	0	0	0	0
10	0.01	0.03	0.04	0.04
15	0.04	0.16	0.18	0.19
20	0.08	0.44	0.44	0.5
25	0.13	0.68	0.59	0.66
30	0.15	0.71	0.43	0.46
35	0.11	0.55	0.19	0.18
40	0.05	0.3	0.06	0.04
45	0.01	0.11	0.02	0.01
50	0	0.02	0	0
55	0	0	0	0
60	0	0	0	0
65	0	0	0	0
70	0	0	0	0
75	0	0	0	0
80	0	0	0	0
85	0	0	0	0
90	0	0	0	0
95	0	0	0	0
100	0	0	0	0

TRUE DEPTH

TRUE Depth, % Through Wall	8.62	10.08	11.7	13.37
5	0.20658	0.18958	0.2205	0.21906
10	0.39605	0.36475	0.4267	0.42388
15	0.56974	0.52661	0.61859	0.61665
20	0.71974	0.67184	0.79023	0.79299
25	0.84737	0.7949	0.91657	0.92442
30	0.94079	0.89246	0.97497	0.98357
35	0.98816	0.95898	0.99404	0.99781
40	0.99868	0.99113	0.99881	1
45	1	0.99889	1	1
50	1	1	1	1
55	1	1	1	1
60	1	1	1	1
65	1	1	1	1
70	1	1	1	1
75	1	1	1	1
80	1	1	1	1
85	1	1	1	1
90	1	1	1	1
95	1	1	1	1
100	1	1	1	1

DETECTED DEPTH

DETECTED Depth, % Through Wall	8.62	10.08	11.7	13.37
5	0	0	0	0
10	0.01695	0.00331	0.00515	0.00476
15	0.0678	0.03642	0.06186	0.0619
20	0.20339	0.18212	0.30412	0.31429
25	0.44068	0.43377	0.67526	0.70476
30	0.72881	0.69205	0.89691	0.93333
35	0.9322	0.88079	0.97423	0.99048
40	1	0.97351	0.99485	1
45	1	0.99669	1	1
50	1	1	1	1
55	1	1	1	1
60	1	1	1	1
65	1	1	1	1
70	1	1	1	1
75	1	1	1	1
80	1	1	1	1
85	1	1	1	1
90	1	1	1	1
95	1	1	1	1
100	1	1	1	1

MEASURED DEPTH

MEASURED Depth, % Through Wall	8.62	10.08	11.7	13.37
5	0	0	0	0
10	0.01724	0.01	0.02051	0.01923
15	0.08621	0.06333	0.11282	0.11058
20	0.22414	0.21	0.33846	0.35096
25	0.44828	0.43667	0.64103	0.66827
30	0.7069	0.67333	0.86154	0.88942
35	0.89655	0.85667	0.95897	0.97596
40	0.98276	0.95667	0.98974	0.99519
45	1	0.99333	1	1
50	1	1	1	1
55	1	1	1	1
60	1	1	1	1
65	1	1	1	1
70	1	1	1	1
75	1	1	1	1
80	1	1	1	1
85	1	1	1	1
90	1	1	1	1
95	1	1	1	1
100	1	1	1	1

LEAK RATE

Leak Rate, gpm	8.62EFPY	10.08EFPY	11.7EFPY	13.37EFPY
1.80E-07	1	1	1	1
3.20E-07	1	1	1	1
5.60E-07	1	1	1	1
1.00E-06	1	1	1	1
1.80E-06	1	1	1	1
3.20E-06	1	1	1	1
5.60E-06	1	1	1	1
1.00E-05	1	1	1	1
1.80E-05	1	1	1	1
3.20E-05	1	1	1	1
5.60E-05	1	1	1	1
1.00E-04	1	1	1	1
1.80E-04	1	1	1	1
3.20E-04	1	1	1	1
5.60E-04	1	1	1	1
1.00E-03	1	1	1	1
1.80E-03	1	1	1	1
3.20E-03	1	1	1	1
5.60E-03	1	1	1	1
1.00E-02	1	1	1	1
1.80E-02	1	1	1	1
3.20E-02	1	1	1	1
5.60E-02	1	1	1	1
1.00E-01	1	1	1	1
1.80E-01	1	1	1	1
3.20E-01	1	1	1	1
5.60E-01	1	1	1	1
1.00E+00	1	1	1	1
1.80E+00	1	1	1	1
3.20E+00	1	1	1	1
5.60E+00	1	1	1	1
1.00E+01	1	1	1	1
1.80E+01	1	1	1	1
3.20E+01	1	1	1	1
5.60E+01	1	1	1	1
1.00E+02	1	1	1	1
1.80E+02	1	1	1	1
3.20E+02	1	1	1	1
5.60E+02	1	1	1	1
1.00E+03	1	1	1	1

BURST PRESSURE

Burst Pressure, psi	8.62EFPY	10.08EFPY	11.7EFPY	13.37EFPY
250	0	0	0	0
500	0	0	0	0
750	0	0	0	0
1000	0	0	0	0
1250	0	0	0	0
1500	0	0	0	0
1750	0	0	0	0
2000	0	0	0	0
2250	0	0	0	0
2500	0	0	0	0
2750	0	0	0	0
3000	0	0	0	0
3250	0	0	0	0
3500	0	0	0	0
3750	0	0	0	0
4000	0	0	0	0
4250	0	0	0	0
4500	0	0	0	0
4750	0	0	0	0
5000	0	0	0	0
5250	0	0	0	0
5500	0	0	0	0
5750	0	0	0	0
6000	0	0	0	0
6250	0	0.0001	0	0
6500	0	0.0003	0.0001	0
6750	0.0002	0.0011	0.0003	0
7000	0.0007	0.0037	0.0007	0.0002
7250	0.0027	0.0095	0.0018	0.0006
7500	0.0079	0.0215	0.0044	0.0019
7750	0.0197	0.0415	0.0101	0.0065
8000	0.0423	0.0722	0.0215	0.017
8250	0.0769	0.1158	0.0446	0.0386
8500	0.1282	0.1709	0.0829	0.0768
8750	0.194	0.2393	0.1402	0.1338
9000	0.2737	0.3195	0.2188	0.2134
9250	0.3666	0.4098	0.315	0.3115
9500	0.4715	0.5102	0.4267	0.4255
9750	0.5817	0.6139	0.5474	0.5487
10000	0.6926	0.7161	0.668	0.6694
10250	0.7936	0.8098	0.7791	0.78
10500	0.8768	0.8865	0.8692	0.8691
10750	0.9354	0.9415	0.9323	0.9329
11000	0.9717	0.9743	0.9704	0.9707
11250	0.9896	0.9905	0.9891	0.9895
11500	0.9971	0.997	0.9967	0.9968
11750	0.9994	0.9993	0.9992	0.9994
12000	1	1	1	1
12250	1	1	1	1

Appendix 7

Circumferential Degradation at the Top of the Tubesheet

Circumferential degradation at expansion transitions at the top of the tubesheet has been observed at SONGS Unit 3 at EOC 7, EOC 8 and EOC 9 inspections. Both ID and OD degradation has been observed. Use of the Plus Point probe at EOC-8 rather than the previous RPC pancake probe led to an inspection transient which was included in that simulation model. The measure of severity for circumferential degradation is the percent degraded area of the tube annular cross section. PDA values at EOC 8 and EOC 9 were obtained following an EPRI voltage normalization procedure. As in the case of the top of the tubesheet axial cracking, both ID and OD circumferential cracking was considered together using an appropriately conservative growth rate distribution.

Inputs:

Inspection	POD		Growth				Initiation			Sizing Error		
Data from Outages	Intercept	Slope	Mean Ln	MAX	Std Dev	Fract Zero	Slope	Scale	Set Back	Mean	Std Dev	Max
8, 9 & 10	2.07 0.885	-2.75 -2.4	0.6	100	0.3	0	2.9	171	10	0	0.13	1

VERSION CircMulti1a.exe 10/4/98

Indications Observed

Mechanism	SG 88/89			
	3C8	3C9	3M9	3C10
TTS CIRC	0-1	12-12	N/A	3-5

Simulation Predictions

Mechanism	Mean				Standard Deviation			
	3C8	3C9	3M9	3C10	3C8	3C9	3M9	3C10
TTS CIRC	2	12	N/A	6	1	3	N/A	2

Input File Name	D:\OPCON_050798\CircMulti\acirc095.out				
# Sims	20000		Initiation Slope	2.9	
# Tubes	9350		Initiation Scale	171	
Sites/Tube	1		Initiation Setback	10	
SLB	2.575		Mean Error	0	
NOP	1.46		Error Std Dev	0.13	
Leak Limit	0.01		Max Error	1	
Tube Wall	0.048		Tube OD	0.75	
Mean Strength	124.87		Strength Std Dev	5.9	
Max Strength	142		Min Strength	113	
Young's Modulus	28700000				
Mean Ln(Growth Rate)	0.6		Std Dev of Mean	0.3	
Max Growth Rate	100		Fraction Zero Growth	0	
Cycle, EFPY	Fraction Inspct.	Repair Limit	POD Fit	POD Intercept	POD Slope
8.62	0.2	-99.0	L/L	2.07	-2.75
10.08	1.0	-99.0	L/L	0.885	-2.48
11.7	1.0	-99.0	L/L	0.885	-2.48
13.37	1.0	-99.0	L/L	0.885	-2.48

OUTPUT FILE:"D:\OPCON 050798\CircMulti\acirc095.out"

Cycle, EFPY	8.62	10.08	11.7	13.37
POL at SLB	0.0031	0.0067	0.0006	0.0001
POL >Limit at SLB	0.0002	0.0002	0	0
POL >Limit at NOP	0	0.0001	0	0
95/95 Leak at SLB	0	0	0	0
# Sims w/Bursts	0	0	0	0
POB at SLB (95%)	0.0001	0.0001	0.0001	0.0001
POB at 3DP	0	0	0	0
Initiated	15.2	3.65	4.7	5.62
In Service	15.2	17.33	9.95	10.03
Mean # Detected	1.52	12.08	5.54	5.05
Std Dev, # Detected	1.21	3.57	2.31	2.24
Mean # Known In Service	1.52	12.08	5.54	5.05
Std Dev, # Known In Servic	1.21	3.57	2.31	2.24
Cumulative # Detected, Me	1.52	13.6	19.14	24.19
Cumulative # Detected, Stc	1.21	3.76	4.44	5.09
Mean # Plugged	1.53	12.08	5.54	5.05
Std Dev, # Plugged	1.21	3.57	2.31	2.24
Cumulative # Plugged, Mea	1.53	13.6	19.15	24.2
Cumulative # Plugged, Std	1.21	3.76	4.44	5.09
Mean Maximum Depth	0.209	0.23	0.143	0.092
Std Dev, Maximum Depth	0.052	0.052	0.061	0.044

TRUE DEPTH

TRUE Depth, % Through Wall	8.62	10.08	11.7	13.37
5	5.72	6.34	6.66	7.78
10	4.02	4.49	2.05	1.91
15	2.97	3.09	0.72	0.28
20	1.58	2.01	0.34	0.07
25	0.55	0.87	0.14	0.03
30	0.15	0.27	0.05	0.01
35	0.04	0.07	0.01	0
40	0.01	0.02	0	0
45	0	0	0	0
50	0	0	0	0
55	0	0	0	0
60	0	0	0	0
65	0	0	0	0
70	0	0	0	0
75	0	0	0	0
80	0	0	0	0
85	0	0	0	0
90	0	0	0	0
95	0	0	0	0
100	0	0	0	0

DETECTED DEPTH

DETECTED Depth, % Through Wall	8.62	10.08	11.7	13.37
5	0.28	2.85	2.83	3.34
10	0.47	3.47	1.56	1.45
15	0.42	2.66	0.62	0.24
20	0.25	1.8	0.3	0.06
25	0.09	0.8	0.13	0.02
30	0.03	0.25	0.04	0.01
35	0.01	0.06	0.01	0
40	0	0.02	0	0
45	0	0	0	0
50	0	0	0	0
55	0	0	0	0
60	0	0	0	0
65	0	0	0	0
70	0	0	0	0
75	0	0	0	0
80	0	0	0	0
85	0	0	0	0
90	0	0	0	0
95	0	0	0	0
100	0	0	0	0

MEASURED DEPTH

MEASURED Depth, % Through Wall	8.62	10.08	11.7	13.37
5	0.53	4.26	2.53	2.64
10	0.21	1.6	0.78	0.75
15	0.22	1.6	0.71	0.63
20	0.19	1.42	0.57	0.46
25	0.16	1.14	0.39	0.31
30	0.11	0.81	0.26	0.18
35	0.07	0.52	0.14	0.09
40	0.04	0.3	0.07	0.04
45	0.02	0.15	0.03	0.02
50	0.01	0.07	0.02	0.01
55	0	0.03	0.01	0
60	0	0.01	0	0
65	0	0.01	0	0
70	0	0	0	0
75	0	0	0	0
80	0	0	0	0
85	0	0	0	0
90	0	0	0	0
95	0	0	0	0
100	0	0	0	0

TRUE DEPTH

TRUE Depth, % Through Wall	8.62	10.08	11.7	13.37
5	0.38032	0.36946	0.668	0.77183
10	0.64761	0.63112	0.87362	0.96131
15	0.84508	0.81119	0.94584	0.98909
20	0.95013	0.92832	0.97994	0.99603
25	0.9867	0.97902	0.99398	0.99901
30	0.99668	0.99476	0.999	1
35	0.99934	0.99883	1	1
40	1	1	1	1
45	1	1	1	1
50	1	1	1	1
55	1	1	1	1
60	1	1	1	1
65	1	1	1	1
70	1	1	1	1
75	1	1	1	1
80	1	1	1	1
85	1	1	1	1
90	1	1	1	1
95	1	1	1	1
100	1	1	1	1

DETECTED DEPTH

DETECTED Depth, % Through Wall	8.62	10.08	11.7	13.37
5	0.18065	0.23929	0.51548	0.65234
10	0.48387	0.53065	0.79964	0.93555
15	0.75484	0.75399	0.91257	0.98242
20	0.91613	0.90512	0.96721	0.99414
25	0.97419	0.97229	0.99089	0.99805
30	0.99355	0.99328	0.99818	1
35	1	0.99832	1	1
40	1	1	1	1
45	1	1	1	1
50	1	1	1	1
55	1	1	1	1
60	1	1	1	1
65	1	1	1	1
70	1	1	1	1
75	1	1	1	1
80	1	1	1	1
85	1	1	1	1
90	1	1	1	1
95	1	1	1	1
100	1	1	1	1

MEASURED DEPTH

MEASURED Depth, % Through Wall	8.62	10.08	11.7	13.37
5	0.33974	0.35738	0.45917	0.51462
10	0.47436	0.49161	0.60073	0.66082
15	0.61538	0.62584	0.72958	0.78363
20	0.73718	0.74497	0.83303	0.87329
25	0.83974	0.8406	0.90381	0.93372
30	0.91026	0.90856	0.951	0.96881
35	0.95513	0.95218	0.97641	0.98635
40	0.98077	0.97735	0.98911	0.99415
45	0.99359	0.98993	0.99456	0.99805
50	1	0.99581	0.99819	1
55	1	0.99832	1	1
60	1	0.99916	1	1
65	1	1	1	1
70	1	1	1	1
75	1	1	1	1
80	1	1	1	1
85	1	1	1	1
90	1	1	1	1
95	1	1	1	1
100	1	1	1	1

LEAK RATE

Leak Rate, gpm	8.62EFPY	10.08EFPY	11.7EFPY	13.37EFPY
1.80E-07	0.9969	0.9933	0.9994	1
3.20E-07	0.9969	0.9933	0.9994	1
5.60E-07	0.9969	0.9933	0.9994	1
1.00E-06	0.9969	0.9933	0.9994	1
1.80E-06	0.9969	0.9933	0.9994	1
3.20E-06	0.9969	0.9933	0.9994	1
5.60E-06	0.9969	0.9933	0.9994	1
1.00E-05	0.9969	0.9933	0.9994	1
1.80E-05	0.9969	0.9933	0.9994	1
3.20E-05	0.9969	0.9933	0.9994	1
5.60E-05	0.9969	0.9933	0.9994	1
1.00E-04	0.9969	0.9933	0.9994	1
1.80E-04	0.9969	0.9933	0.9994	1
3.20E-04	0.9969	0.9933	0.9994	1
5.60E-04	0.9969	0.9933	0.9994	1
1.00E-03	0.9969	0.9933	0.9994	1
1.80E-03	0.9969	0.9933	0.9994	1
3.20E-03	0.9969	0.9933	0.9994	1
5.60E-03	0.9969	0.9933	0.9994	1
1.00E-02	0.9998	0.9998	1	1
1.80E-02	1	1	1	1
3.20E-02	1	1	1	1
5.60E-02	1	1	1	1
1.00E-01	1	1	1	1
1.80E-01	1	1	1	1
3.20E-01	1	1	1	1
5.60E-01	1	1	1	1
1.00E+00	1	1	1	1
1.80E+00	1	1	1	1
3.20E+00	1	1	1	1
5.60E+00	1	1	1	1
1.00E+01	1	1	1	1
1.80E+01	1	1	1	1
3.20E+01	1	1	1	1
5.60E+01	1	1	1	1
1.00E+02	1	1	1	1
1.80E+02	1	1	1	1
3.20E+02	1	1	1	1
5.60E+02	1	1	1	1
1.00E+03	1	1	1	1

BURST PRESSURE

Burst Pressure, psi	8.62EFPY	10.08EFP\	11.7EFPY	13.37EFPY
250	0	0	0	0
500	0	0	0	0
750	0	0	0	0
1000	0	0	0	0
1250	0	0	0	0
1500	0	0	0	0
1750	0	0	0	0
2000	0	0	0	0
2250	0	0	0	0
2500	0	0	0	0
2750	0	0	0	0
3000	0	0	0	0
3250	0	0	0	0
3500	0	0	0	0
3750	0	0	0	0
4000	0	0	0	0
4250	0	0	0	0
4500	0	0	0	0
4750	0	0	0	0
5000	0	0	0	0
5250	0	0	0	0
5500	0	0	0	0
5750	0	0	0	0
6000	0	0	0	0
6250	0	0	0	0
6500	0	0	0	0
6750	0	0	0	0
7000	0	0	0	0
7250	0	0	0	0
7500	0	0	0	0
7750	0	0	0	0
8000	0	0	0	0
8250	0	0	0	0
8500	0	0	0	0
8750	0	0	0	0
9000	0	0	0	0
9250	0.0001	0.0001	0	0
9500	0.0001	0.0001	0	0
9750	0.0001	0.0001	0	0
10000	0.0001	0.0002	0	0
10250	0.0002	0.0003	0	0
10500	0.0003	0.0004	0.0001	0
10750	0.0004	0.0005	0.0001	0
11000	0.0006	0.0008	0.0002	0
11250	0.0007	0.0011	0.0003	0
11500	0.0011	0.0015	0.0004	0
11750	0.0015	0.0022	0.0005	0.0001
12000	0.0021	0.0031	0.0007	0.0001
12250	0.0028	0.0044	0.001	0.0002
12500	0.0039	0.006	0.0014	0.0002
12750	0.0055	0.0082	0.0021	0.0003
13000	0.0074	0.0113	0.003	0.0004
13250	0.01	0.0156	0.0042	0.0006
13500	0.0137	0.021	0.0056	0.0009
13750	0.0188	0.0278	0.0075	0.0013
14000	0.025	0.0364	0.0101	0.0017
14250	0.0334	0.0474	0.013	0.0022
14500	0.0437	0.0607	0.017	0.0029
14750	0.0564	0.0767	0.0216	0.0038
15000	0.0726	0.0958	0.0269	0.005
15250	0.0917	0.1175	0.0333	0.0065
15500	0.1153	0.1421	0.0411	0.0086
15750	0.1416	0.1697	0.0505	0.0111
16000	0.1718	0.2	0.0614	0.0148
16250	0.2054	0.2326	0.074	0.0198
16500	0.2427	0.2687	0.0897	0.0272
16750	0.2834	0.3073	0.1089	0.0383
17000	0.3269	0.3485	0.1321	0.0547
17250	0.3741	0.3936	0.1613	0.0781
17500	0.4244	0.441	0.1993	0.1106
17750	0.4785	0.4922	0.2456	0.1553
18000	0.5335	0.5455	0.2996	0.211
18250	0.5899	0.6003	0.3606	0.2753
18500	0.6472	0.6552	0.4298	0.3514
18750	0.7036	0.7097	0.5049	0.4342
19000	0.7584	0.7627	0.5847	0.5228
19250	0.8088	0.8115	0.6627	0.6117
19500	0.8538	0.8553	0.7357	0.6962
19750	0.892	0.8938	0.8019	0.7725
20000	1	1	1	1

Appendix 8
Axial Degradation at the Top of the Tubesheet – Sludge Pile

Axial degradation near expansion transitions at the top of the tubesheet was first detected at SONGS Unit 3 in the inspection at EOC-8. Crack lengths evaluated from the response of the Plus Point probe substantially overstate the crack length relative to the structurally significant crack length. Even when conservatively equating the structurally significant crack length to the Plus Point crack length, the severity of the axial top of the tubesheet degradation is mild. Very few of the indications are long enough to challenge the SLB burst pressure with the bounding assumption of 100% throughwall cracking.

Inputs:

Inspection	POD		Growth				Initiation			Sizing Error		
Data from Outages	Intercept	Slope	Mean Ln	MAX	Std Dev	Fract Zero	Slope	Scale	Set Back	Mean	Std Dev	Max
8, 9, & 10	9.25	-7.26	1.40	100	0.9	0	6.6	33	0	0	0.0375	1

VERSION AxMulti1b.exe 5/5/98

Indications Observed

Mechanism	**SG 88/89**			
	3C8	3C9	3M9	3C10
TTS OD AXIAL	0-0	0-1	N/A	0-3

Simulation Predictions

Mechanism	**Mean**				**Standard Deviation**			
	3C8	3C9	3M9	3C10	3C8	3C9	3M9	3C10
TTS OD AXIAL	0	1	N/A	2	0	1	N/A	1

Input File Name	D:\OPCON_050798\AxMulti\odslg0119b.out

# Sims	20000	Initiation Slope	6.6
# Tubes	9350	Initiation Scale	33
Sites/Tube	1	Initiation Setback	0
SLB	2.575	Mean Error	0
NOP	1.46	Error Std Dev	0.0375
Leak Limit	0.01	Max Error	100
Tube Wall	0.048	Tube OD	0.75
Mean Strength	124.87	Strength Std Dev	5.9
Max Strength	142	Min Strength	113
Young's Modulus	28700000		
Mean Ln(Growth Rate)	1.4	Std Dev of Mean	0.9
Max Growth Rate	100	Fraction Zero Growth	0

Cycle, EFPY	Fraction Inspct.	Repair Limit	POD Fit	POD Intercept	POD Slope
8.62	1.0	-99.0	L/L	9.25	-7.26
10.08	1.0	-99.0	L/L	9.25	-7.26
11.7	1.0	-99.0	L/L	9.25	-7.26
13.37	1.0	-99.0	L/L	9.25	-7.26

OUTPUT FILE:"D:\OPCON 050798\AxMulti\odslg0119b.out"

Cycle, EFPY	8.62	10.08	11.7	13.37
POL at SLB	0.0056	0.0041	0.0146	0.0388
POL >Limit at SLB	0.0032	0.0022	0.0069	0.0204
POL >Limit at NOP	0.0029	0.0018	0.0054	0.0164
95/95 Leak at SLB, NOP	0	0	0	0
# Sims w/Bursts	1	0	0	1
POB at SLB (95%)	0.0002	0.0001	0.0001	0.0002
POB at 3DP	0.0003	0.0003	0.001	0.0034
Initiated	1.31	2.42	6.25	14.04
In Service	1.31	3.57	9.29	21.72
Mean # Detected	0.17	0.52	1.62	4.17
Std Dev, # Detected	0.41	0.71	1.31	2.1
Mean # Known In Service	0.17	0.52	1.62	4.17
Std Dev, # Known In Servic	0.41	0.71	1.31	2.1
Cumulative # Detected, Me	0.17	0.7	2.31	6.48
Cumulative # Detected, Stc	0.41	0.82	1.57	2.59
Mean # Plugged	0.17	0.52	1.62	4.17
Std Dev, # Plugged	0.41	0.71	1.31	2.1
Cumulative # Plugged, Mea	0.17	0.7	2.31	6.48
Cumulative # Plugged, Std	0.41	0.82	1.57	2.59
Mean Maximum Depth	0.066	0.139	0.25	0.359
Std Dev, Maximum Depth	0.101	0.121	0.156	0.198

TRUE DEPTH

TRUE Depth, % Through Wall	8.62	10.08	11.7	13.37
5	0.83	2.07	5.08	11.27
10	0.24	0.7	1.86	4.45
15	0.1	0.35	1	2.51
20	0.05	0.19	0.56	1.43
25	0.03	0.1	0.3	0.81
30	0.02	0.05	0.17	0.45
35	0.01	0.03	0.1	0.28
40	0.01	0.02	0.06	0.17
45	0.01	0.01	0.04	0.11
50	0	0.01	0.02	0.07
55	0	0	0.02	0.04
60	0	0	0.01	0.03
65	0	0	0.01	0.02
70	0	0	0.01	0.02
75	0	0	0.01	0.01
80	0	0	0	0.01
85	0	0	0	0.01
90	0	0	0	0
95	0	0	0	0.01
100	0	0	0.01	0.02

DETECTED DEPTH

DETECTED Depth, % Through Wall	8.62	10.08	11.7	13.37
5	0	0.01	0.03	0.06
10	0.02	0.07	0.19	0.47
15	0.04	0.12	0.36	0.91
20	0.03	0.12	0.34	0.88
25	0.03	0.08	0.24	0.64
30	0.02	0.05	0.15	0.4
35	0.01	0.03	0.09	0.26
40	0.01	0.02	0.05	0.17
45	0.01	0.01	0.04	0.11
50	0	0.01	0.02	0.07
55	0	0	0.02	0.04
60	0	0	0.01	0.03
65	0	0	0.01	0.02
70	0	0	0.01	0.02
75	0	0	0.01	0.01
80	0	0	0	0.01
85	0	0	0	0.01
90	0	0	0	0
95	0	0	0	0.01
100	0	0	0.01	0.02

MEASURED DEPTH

MEASURED Depth, % Through Wall	8.62	10.08	11.7	13.37
5	0.01	0.03	0.07	0.17
10	0.02	0.07	0.19	0.47
15	0.03	0.11	0.31	0.79
20	0.03	0.11	0.31	0.83
25	0.03	0.08	0.24	0.64
30	0.02	0.05	0.16	0.42
35	0.01	0.03	0.1	0.27
40	0.01	0.02	0.06	0.17
45	0.01	0.01	0.04	0.11
50	0	0.01	0.02	0.07
55	0	0.01	0.02	0.05
60	0	0	0.01	0.03
65	0	0	0.01	0.02
70	0	0	0.01	0.02
75	0	0	0	0.01
80	0	0	0	0.01
85	0	0	0	0.01
90	0	0	0	0.01
95	0	0	0	0
100	0	0	0.01	0.02

TRUE DEPTH

TRUE Depth, % Through Wall	8.62	10.08	11.7	13.37
5	0.63846	0.5864	0.5486	0.51888
10	0.82308	0.7847	0.74946	0.72376
15	0.9	0.88385	0.85745	0.83932
20	0.93846	0.93768	0.91793	0.90516
25	0.96154	0.96601	0.95032	0.94245
30	0.97692	0.98017	0.96868	0.96317
35	0.98462	0.98867	0.97948	0.97606
40	0.99231	0.99433	0.98596	0.98389
45	1	0.99717	0.99028	0.98895
50	1	1	0.99244	0.99217
55	1	1	0.9946	0.99401
60	1	1	0.99568	0.9954
65	1	1	0.99676	0.99632
70	1	1	0.99784	0.99724
75	1	1	0.99892	0.9977
80	1	1	0.99892	0.99816
85	1	1	0.99892	0.99862
90	1	1	0.99892	0.99862
95	1	1	0.99892	0.99908
100	1	1	1	1

DETECTED DEPTH

DETECTED Depth, % Through Wall	8.62	10.08	11.7	13.37
5	0	0.01923	0.01899	0.01449
10	0.11765	0.15385	0.13924	0.12802
15	0.35294	0.38462	0.36709	0.34783
20	0.52941	0.61538	0.58228	0.56039
25	0.70588	0.76923	0.73418	0.71498
30	0.82353	0.86538	0.82911	0.81159
35	0.88235	0.92308	0.88608	0.8744
40	0.94118	0.96154	0.91772	0.91546
45	1	0.98077	0.94304	0.94203
50	1	1	0.9557	0.95894
55	1	1	0.96835	0.9686
60	1	1	0.97468	0.97585
65	1	1	0.98101	0.98068
70	1	1	0.98734	0.98551
75	1	1	0.99367	0.98792
80	1	1	0.99367	0.99034
85	1	1	0.99367	0.99275
90	1	1	0.99367	0.99275
95	1	1	0.99367	0.99517
100	1	1	1	1

MEASURED DEPTH

MEASURED Depth, % Through Wall	8.62	10.08	11.7	13.37
5	0.05882	0.0566	0.04487	0.04126
10	0.17647	0.18868	0.16667	0.15534
15	0.35294	0.39623	0.36538	0.34709
20	0.52941	0.60377	0.5641	0.54854
25	0.70588	0.75472	0.71795	0.70388
30	0.82353	0.84906	0.82051	0.80583
35	0.88235	0.90566	0.88462	0.87136
40	0.94118	0.9434	0.92308	0.91262
45	1	0.96226	0.94872	0.93932
50	1	0.98113	0.96154	0.95631
55	1	1	0.97436	0.96845
60	1	1	0.98077	0.97573
65	1	1	0.98718	0.98058
70	1	1	0.99359	0.98544
75	1	1	0.99359	0.98786
80	1	1	0.99359	0.99029
85	1	1	0.99359	0.99272
90	1	1	0.99359	0.99515
95	1	1	0.99359	0.99515
100	1	1	1	1

LEAK RATE

Leak Rate, gpm	8.62EFPY	10.08EFPY	11.7EFPY	13.37EFPY
1.80E-07	0.9944	0.9959	0.9856	0.9619
3.20E-07	0.9945	0.9959	0.9856	0.962
5.60E-07	0.9946	0.9959	0.9856	0.9621
1.00E-06	0.9946	0.9959	0.9857	0.9623
1.80E-06	0.9946	0.9959	0.9858	0.9625
3.20E-06	0.9946	0.9959	0.9859	0.9628
5.60E-06	0.9946	0.9959	0.9861	0.9633
1.00E-05	0.9947	0.9959	0.9861	0.9637
1.80E-05	0.9948	0.996	0.9864	0.9644
3.20E-05	0.9948	0.9961	0.987	0.965
5.60E-05	0.9949	0.9961	0.9876	0.966
1.00E-04	0.995	0.9964	0.9879	0.9669
1.80E-04	0.9953	0.9967	0.988	0.9677
3.20E-04	0.9954	0.9968	0.9884	0.9688
5.60E-04	0.9956	0.9969	0.9888	0.9706
1.00E-03	0.9959	0.997	0.9894	0.9719
1.80E-03	0.996	0.9972	0.9903	0.973
3.20E-03	0.9963	0.9974	0.9912	0.9749
5.60E-03	0.9964	0.9977	0.992	0.9771
1.00E-02	0.9968	0.9979	0.9931	0.9797
1.80E-02	0.9971	0.998	0.994	0.9827
3.20E-02	0.9977	0.9983	0.9951	0.9855
5.60E-02	0.998	0.9989	0.9964	0.9888
1.00E-01	0.9986	0.9992	0.9976	0.992
1.80E-01	0.9991	0.9994	0.9985	0.9945
3.20E-01	0.9996	0.9995	0.999	0.9958
5.60E-01	0.9998	0.9996	0.9994	0.9972
1.00E+00	0.9998	0.9997	0.9997	0.9982
1.80E+00	0.9999	0.9999	0.9998	0.9989
3.20E+00	0.9999	1	0.9999	0.9991
5.60E+00	1	1	0.9999	0.9996
1.00E+01	1	1	1	0.9998
1.80E+01	1	1	1	0.9998
3.20E+01	1	1	1	1
5.60E+01	1	1	1	1
1.00E+02	1	1	1	1
1.80E+02	1	1	1	1
3.20E+02	1	1	1	1
5.60E+02	1	1	1	1
1.00E+03	1	1	1	1

BURST PRESSURE

Burst Pressure, psi	8.62EFPY	10.08EFPY	11.7EFPY	13.37EFPY
250	0.0009	0.0002	0.0001	0.0002
500	0.0009	0.0002	0.0002	0.0002
750	0.001	0.0002	0.0002	0.0003
1000	0.0011	0.0002	0.0002	0.0003
1250	0.0012	0.0002	0.0002	0.0003
1500	0.0014	0.0002	0.0002	0.0003
1750	0.0015	0.0003	0.0003	0.0004
2000	0.0016	0.0003	0.0003	0.0005
2250	0.0017	0.0003	0.0004	0.0005
2500	0.0017	0.0004	0.0004	0.0006
2750	0.002	0.0005	0.0005	0.0007
3000	0.0021	0.0005	0.0006	0.0007
3250	0.0024	0.0006	0.0007	0.0009
3500	0.0025	0.0006	0.0008	0.001
3750	0.0027	0.0007	0.0009	0.0011
4000	0.0029	0.0008	0.001	0.0013
4250	0.0032	0.0009	0.0012	0.0014
4500	0.0034	0.001	0.0015	0.0017
4750	0.004	0.0012	0.0018	0.0019
5000	0.0044	0.0015	0.0021	0.0023
5250	0.0049	0.0019	0.0025	0.0026
5500	0.0058	0.0022	0.0029	0.0032
5750	0.007	0.0025	0.0035	0.0039
6000	0.0078	0.0031	0.0043	0.0046
6250	0.0092	0.0038	0.0051	0.0055
6500	0.011	0.0045	0.0062	0.0068
6750	0.013	0.0055	0.0074	0.0084
7000	0.0153	0.0069	0.0093	0.0105
7250	0.0183	0.0087	0.0115	0.0135
7500	0.0218	0.0114	0.0147	0.0175
7750	0.026	0.0149	0.0192	0.0227
8000	0.0318	0.0196	0.0254	0.0303
8250	0.0389	0.0267	0.0347	0.0405
8500	0.0482	0.0372	0.0475	0.0549
8750	0.0614	0.0529	0.0661	0.0761
9000	0.0826	0.0767	0.0941	0.1069
9250	0.1171	0.1157	0.1356	0.1524
9500	0.1696	0.1789	0.2026	0.2216
9750	0.257	0.274	0.3006	0.3214
10000	0.376	0.4001	0.4248	0.4458
10250	0.5248	0.5496	0.5713	0.5892
10500	0.6814	0.7026	0.7182	0.7308
10750	0.8155	0.8318	0.841	0.8478
11000	0.9101	0.9203	0.9244	0.9274
11250	0.965	0.9686	0.9702	0.9716
11500	0.9896	0.9896	0.9904	0.9909
11750	0.9973	0.9976	0.9976	0.9978
12000	0.9998	0.9999	0.9998	0.9999
12250	1	1	1	1
12500	1	1	1	1

Appendix 9

Tube Wear

Tube wear was modeled in the current assessment. This degradation mode has not been modeled in earlier operational assessments. The method for modeling included the use of a plugging limit – this is different from the previous, "crack-like" mechanisms which are treated as "plug on detection".

The rate of new tube wear indications has tended upward in recent outages.

Inputs:

Inspection	POD		Growth				Initiation			Sizing Error		
Data from Outages	Intercept	Slope	Mean Ln	MAX	Std Dev	Fract Zero	Slope	Scale	Set Back	Mean	Std Dev	Max
8, 9, & 10	24	-20	0.6	100	0.7	0	5.8	10	0	0	0.04	1

VERSION AxMulti1b.exe 5/5/98

Indications Observed

Mechanism	SG 88/89			
	3C8	3C9	3M9	3C10
WEAR >30%	5-17	17-31	*	35-68

* 3M9 data included with 3C10 data since 3M9 inspection was partial

Simulation Predictions

Mechanism	Mean				Standard Deviation			
	3C8	3C9	3M9	3C10	3C8	3C9	3M9	3C10
WEAR >30%	14	17		51	4	4		7

Input File Name	D:\OPCON_050798\AxMulti\awear91.out

# Sims	20000	Initiation Slope	5.8
# Tubes	9350	Initiation Scale	10
Sites/Tube	1	Initiation Setback	0
SLB	2.575	Mean Error	0
NOP	1.46	Error Std Dev	0.04
Leak Limit	0.01	Max Error	100
Tube Wall	0.048	Tube OD	0.75
Mean Strength	124.87	Strength Std Dev	5.9
Max Strength	142	Min Strength	113
Young's Modulus	28700000		
Mean Ln(Growth Rate)	0.6	Std Dev of Mean	0.7
Max Growth Rate	100	Fraction Zero Growth	0

Cycle, EFPY	Fraction Inspct.	Repair Limit	POD Fit	POD Intercept	POD Slope
8.62	1.0	0.3	L/L	24.0	-20.0
10.08	1.0	0.3	L/L	24.0	-20.0
11.7	1.0	0.3	L/L	24.0	-20.0
13.37	1.0	0.3	L/L	24.0	-20.0

OUTPUT FILE:"D:\OPCON 050798\AxMulti\awear91.out"

Cycle, EFPY	8.62	10.08	11.7	13.37
POL at SLB	0.1472	0.004	0.0183	0.0379
POL >Limit at SLB	0.0599	0.0006	0.005	0.0091
POL >Limit at NOP	0.0456	0.0004	0.0029	0.0062
95/95 Leak at SLB, NOP	0.023	0	0	0
# Sims w/Bursts	2	0	1	0
POB at SLB (95%)	0.0003	0.0001	0.0002	0.0001
POB at 3DP	0.0163	0.0004	0.0026	0.0047
Initiated	3221.96	2844.24	2504.04	737.17
In Service	3221.96	6052.09	8539.32	9225.4
Mean # Detected	129.65	254.5	753.24	1524.29
Std Dev, # Detected	11.54	15.46	27.28	35.36
Mean # Known In Service	129.65	370.03	1106.47	2579.65
Std Dev, # Known In Servic	11.54	18.93	30.77	42.63
Cumulative # Detected, Me	129.65	384.15	1137.39	2661.67
Cumulative # Detected, Stc	11.54	19.5	31.12	42.65
Mean # Plugged	14.12	16.8	51.1	142.51
Std Dev, # Plugged	3.71	4.18	7.02	11.68
Cumulative # Plugged, Mea	14.12	30.92	82.02	224.52
Cumulative # Plugged, Std	3.71	5.66	9.09	14.43
Mean Maximum Depth	0.62	0.402	0.48	0.539
Std Dev, Maximum Depth	0.207	0.077	0.1	0.103

TRUE DEPTH

TRUE Depth, % Through Wall	8.62	10.08	11.7	13.37
5	2598.05	4190.39	4265.55	2291.06
10	433.71	1312.66	2650.24	3359.97
15	116.8	372.3	1065.74	2105.24
20	40.79	117.25	369.59	935.68
25	16.67	41.75	129.28	363.13
30	7.68	14.74	43.33	124.26
35	3.81	4.11	11.84	33.32
40	2.04	0.98	3.14	8.47
45	1.13	0.28	1.03	2.63
50	0.67	0.11	0.41	0.99
55	0.4	0.05	0.18	0.42
60	0.25	0.02	0.08	0.19
65	0.16	0.01	0.04	0.1
70	0.11	0.01	0.02	0.05
75	0.07	0	0.01	0.03
80	0.05	0	0.01	0.01
85	0.04	0	0	0.01
90	0.02	0	0	0.01
95	0.02	0	0	0
100	0.05	0	0	0.01

DETECTED DEPTH

DETECTED Depth, % Through Wall	8.62	10.08	11.7	13.37
5	0.04	0.1	0.16	0.13
10	7.87	26.63	64.44	99.7
15	50.78	169.75	499.94	1049.92
20	37.9	111.67	352.12	897.04
25	16.55	41.64	128.9	362.32
30	7.67	14.74	43.31	124.23
35	3.81	4.11	11.84	33.32
40	2.04	0.98	3.14	8.47
45	1.13	0.28	1.03	2.63
50	0.67	0.11	0.41	0.99
55	0.4	0.05	0.18	0.42
60	0.25	0.02	0.08	0.19
65	0.16	0.01	0.04	0.1
70	0.11	0.01	0.02	0.05
75	0.07	0	0.01	0.03
80	0.05	0	0.01	0.01
85	0.04	0	0	0.01
90	0.02	0	0	0.01
95	0.02	0	0	0
100	0.05	0	0	0.01

MEASURED DEPTH

MEASURED Depth, % Through Wall	8.62	10.08	11.7	13.37
5	3.22	10.81	28.38	51.05
10	16.55	55.26	155.72	310.31
15	35.7	115.62	342.43	750.03
20	34.79	105.41	323.6	780.52
25	19.88	53.5	166.19	437.88
30	9.36	20.32	61.65	172.42
35	4.52	6.59	19.54	55.34
40	2.33	1.85	5.53	15.34
45	1.28	0.48	1.61	4.28
50	0.74	0.15	0.55	1.4
55	0.44	0.06	0.23	0.54
60	0.27	0.03	0.1	0.24
65	0.17	0.01	0.05	0.12
70	0.11	0.01	0.03	0.06
75	0.08	0	0.01	0.03
80	0.05	0	0.01	0.02
85	0.04	0	0.01	0.01
90	0.04	0	0.01	0.01
95	0.01	0	0	0
100	0.05	0	0	0.01

TRUE DEPTH

TRUE Depth, % Through Wall	8.62	10.08	11.7	13.37
5	0.80622	0.69209	0.49945	0.24834
10	0.9408	0.90889	0.80977	0.61254
15	0.97705	0.97038	0.93455	0.84074
20	0.98971	0.98975	0.97783	0.94216
25	0.99488	0.99665	0.99296	0.98152
30	0.99726	0.99908	0.99804	0.99499
35	0.99845	0.99976	0.99942	0.9986
40	0.99908	0.99992	0.99979	0.99952
45	0.99943	0.99997	0.99991	0.9998
50	0.99964	0.99999	0.99996	0.99991
55	0.99976	0.99999	0.99998	0.99996
60	0.99984	1	0.99999	0.99998
65	0.99989	1	1	0.99999
70	0.99992	1	1	0.99999
75	0.99994	1	1	1
80	0.99996	1	1	1
85	0.99997	1	1	1
90	0.99998	1	1	1
95	0.99998	1	1	1
100	1	1	1	1

DETECTED DEPTH

DETECTED Depth, % Through Wall	8.62	10.08	11.7	13.37
5	0.00031	0.00027	0.00014	0.00005
10	0.06102	0.07222	0.05843	0.0387
15	0.45275	0.53088	0.5106	0.44571
20	0.74512	0.83261	0.82908	0.79346
25	0.87279	0.94512	0.94567	0.93392
30	0.93196	0.98495	0.98484	0.98207
35	0.96135	0.99606	0.99555	0.99499
40	0.97709	0.9987	0.99839	0.99827
45	0.98581	0.99946	0.99932	0.99929
50	0.99097	0.99976	0.99969	0.99968
55	0.99406	0.99989	0.99986	0.99984
60	0.99599	0.99995	0.99993	0.99991
65	0.99722	0.99997	0.99996	0.99995
70	0.99807	1	0.99998	0.99997
75	0.99861	1	0.99999	0.99998
80	0.999	1	1	0.99999
85	0.99931	1	1	0.99999
90	0.99946	1	1	1
95	0.99961	1	1	1
100	1	1	1	1

MEASURED DEPTH

MEASURED Depth, % Through Wall	8.62	10.08	11.7	13.37
5	0.02484	0.02921	0.02567	0.01979
10	0.15251	0.17852	0.16651	0.14008
15	0.42791	0.49092	0.47622	0.43084
20	0.69629	0.77574	0.7689	0.73341
25	0.84965	0.92029	0.91921	0.90316
30	0.92185	0.9752	0.97496	0.97
35	0.95672	0.993	0.99264	0.99145
40	0.9747	0.998	0.99764	0.99739
45	0.98457	0.9993	0.9991	0.99905
50	0.99028	0.9997	0.99959	0.9996
55	0.99367	0.99986	0.9998	0.99981
60	0.99576	0.99995	0.99989	0.9999
65	0.99707	0.99997	0.99994	0.99995
70	0.99792	1	0.99996	0.99997
75	0.99853	1	0.99997	0.99998
80	0.99892	1	0.99998	0.99999
85	0.99923	1	0.99999	0.99999
90	0.99954	1	1	1
95	0.99961	1	1	1
100	1	1	1	1

LEAK RATE

Leak Rate, gpm	8.62EFPY	10.08EFPY	11.7EFPY	13.37EFPY
1.80E-07	0.8547	0.9963	0.9822	0.9632
3.20E-07	0.855	0.9963	0.9824	0.9634
5.60E-07	0.8558	0.9963	0.9826	0.9639
1.00E-06	0.8566	0.9964	0.9827	0.9643
1.80E-06	0.8579	0.9966	0.9829	0.9647
3.20E-06	0.8595	0.9967	0.983	0.9653
5.60E-06	0.8615	0.9968	0.9833	0.966
1.00E-05	0.8633	0.9969	0.9837	0.9666
1.80E-05	0.8662	0.997	0.9841	0.9678
3.20E-05	0.8696	0.9972	0.9849	0.9696
5.60E-05	0.874	0.9976	0.9859	0.9707
1.00E-04	0.8788	0.998	0.9866	0.9729
1.80E-04	0.8848	0.9981	0.9873	0.9752
3.20E-04	0.8903	0.9984	0.9885	0.9775
5.60E-04	0.8986	0.9986	0.9896	0.9794
1.00E-03	0.9059	0.9986	0.9904	0.9813
1.80E-03	0.9127	0.9989	0.992	0.984
3.20E-03	0.9233	0.999	0.9931	0.9866
5.60E-03	0.9316	0.9992	0.9942	0.9885
1.00E-02	0.9402	0.9994	0.995	0.9909
1.80E-02	0.9483	0.9994	0.9961	0.9928
3.20E-02	0.9584	0.9996	0.9969	0.9941
5.60E-02	0.9676	0.9998	0.9978	0.9954
1.00E-01	0.977	0.9998	0.9983	0.9968
1.80E-01	0.9832	0.9999	0.9988	0.9974
3.20E-01	0.9878	0.9999	0.9991	0.9978
5.60E-01	0.9916	0.9999	0.9992	0.9983
1.00E+00	0.994	0.9999	0.9994	0.9988
1.80E+00	0.9958	0.9999	0.9995	0.999
3.20E+00	0.997	1	0.9997	0.9995
5.60E+00	0.9982	1	0.9998	0.9996
1.00E+01	0.9989	1	0.9999	0.9997
1.80E+01	0.9993	1	0.9999	0.9998
3.20E+01	0.9995	1	0.9999	0.9999
5.60E+01	0.9996	1	0.9999	1
1.00E+02	0.9998	1	1	1
1.80E+02	0.9999	1	1	1
3.20E+02	0.9999	1	1	1
5.60E+02	0.9999	1	1	1
1.00E+03	1	1	1	1

BURST PRESSURE

Burst Pressure, psi	8.62EFPY	10.08EFPY	11.7EFPY	13.37EFPY
250	0	0	0	0
500	0	0	0	0
750	0	0	0	0
1000	0	0	0	0
1250	0	0	0	0
1500	0	0	0	0
1750	0	0	0	0
2000	0	0	0	0
2250	0	0	0	0
2500	0	0	0	0
2750	0	0	0	0
3000	0	0	0	0
3250	0	0	0	0
3500	0	0	0	0
3750	0	0	0	0
4000	0	0	0	0
4250	0	0	0	0
4500	0	0	0	0
4750	0.0001	0	0	0
5000	0.0001	0	0	0
5250	0.0001	0	0	0
5500	0.0001	0	0	0
5750	0.0001	0	0	0
6000	0.0002	0	0	0
6250	0.0002	0	0	0.0001
6500	0.0003	0	0	0.0001
6750	0.0004	0	0.0001	0.0001
7000	0.0005	0	0.0001	0.0002
7250	0.0007	0.0001	0.0002	0.0005
7500	0.001	0.0002	0.0004	0.001
7750	0.0015	0.0004	0.0009	0.0022
8000	0.0022	0.0009	0.0019	0.0049
8250	0.0033	0.0019	0.0041	0.0107
8500	0.0052	0.0041	0.0089	0.0228
8750	0.0085	0.0087	0.0189	0.0465
9000	0.015	0.0186	0.0394	0.0899
9250	0.029	0.0409	0.0802	0.1629
9500	0.0668	0.092	0.1547	0.2711
9750	0.1441	0.1825	0.2664	0.4091
10000	0.2617	0.3132	0.4122	0.5646
10250	0.4232	0.4796	0.5774	0.715
10500	0.6043	0.6542	0.734	0.8376
10750	0.7679	0.8034	0.8565	0.9209
11000	0.886	0.9062	0.935	0.9676
11250	0.9539	0.9631	0.9756	0.9891
11500	0.9849	0.9883	0.9926	0.9971
11750	0.9962	0.9972	0.9984	0.9995
12000	0.9998	0.9998	0.9999	1
12250	1	1	1	1
12500	1	1	1	1