SOUTHERN CALIFORNIA EDISON COMPANY

SAN ONOFRE UNIT 2

STEAM GENERATOR RUN TIME ANALYSIS
CYCLE 9

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1.0 INTRODUCTION

The purpose of this report is to describe Southern California Edison's (SCE's) condition monitoring and operational assessment of steam generator (SG) tubing at San Onofre Nuclear Generating Station (SONGS) Unit 2. Condition monitoring is applicable to the previous Cycle 8 of operation, and operational assessment applies to the current Cycle 9 of operation. Steam generator tube performance has been evaluated based on the results of extensive Eddy Current (ECT) examinations, pressure testing, and analyses described in this report.

This run time analysis uses guidance and criteria in NRC Regulatory Guide 1.121 "Bases for Plugging Degraded Pressurized Water Reactor Steam Generator Tubes," Rev 0, August 1976 (Reference 1), NRC Draft Regulatory Guide X.XX "Steam Generator Tube Integrity," November 1996 (Reference 2), and applicable portions of Generic Letter (GL) 95-05 "Voltage Based Repair Criteria for Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking," August 3, 1995 (Reference 3). The objective of the run time analysis is t determine the duration which the San Onofre Unit 2 SGs can be safely operated within the criteria in References 1, 2 and 3.

The next planned inspection of tubes for degradation at the top of the tubesheet will occur during the next refueling outage. The structural integrity performance criteria and the accident leakage criteria of the above described regulatory documents can be met throughout a full cycle of operation without this particular inspection during a mid-cycle outage.

The next planned inspection of the full length of all tubes with a bobbin probe will occur during a mid-cycle outage. The purpose of this is to project meeting of the structural integrity criteria for axially oriented primary water stress corrosion cracking at dented eggcrate intersections. The probability of burst for this degradation is projected to be within the structural integrity criteria until the mid-cycle inspection. The mid-cycle outage provides an opportunity to identify tubes effected by this degradation and remove them from service. With this action taken, the probability of burst for this degradation is projected to be within the structural integrity criteria at the end of the cycle.

The next planned inspection of the full length of all tubes with a bobbin probe during the mid-cycle outage will also address axial cracking in tubing freespans and axial cracking at undented eggcrate supports. Affected tubes will be identified and removed from service. This will provide added assurance of safe operation. However, this degradation is considered to be within the criteria that would not indicate a need for a mid-cycle inspection.

The primary applicability of GL 95-05 is to voltage based repair criteria for Westinghouse SGs. San Onofre does not apply this repair criteria to it's Asea Brown Boveri/Combustion Engineering (ABB/CE) SGs. Nonetheless, the operational assessment employs the guidance provided in GL 95-05 and a physically based, statistical model.

A mid-cycle inspection outage is planned so that the inspection interval for the bobbin probe will be less than 0.92 effective full power years (EFPY). The conditional probability of tube burst for all degradation mechanisms, 1.45×10^{-2}, is lower than the draft RG X.XX criteria of 5×10^{-2}. The maximum conditional probability of tube burst for an individual mechanism is 0.96×10^{-2} and is lower than the GL 95-05 and draft RG X.XX criteria of 1×10^{-2}. Postulated accident leakage is acceptable.

Therefore, Cycle 9 operation for the San Onofre Unit 2 steam generators with a mid-cycle outage is acceptable. Acceptability has been determined using guidance contained in RG 1.121, GL 95-05, and draft RG X.XX.

2.0 BACKGROUND

2.1 Commitment

On February 6, 1997 Southern California Edison (SCE) provided a Special Report to the U.S. Nuclear Regulatory Commission regarding inservice inspection of steam generator tubes that was completed at San Onofre Unit 2 on January 24, 1997 (Reference 4). Technical Specifications 5.7.2.C required this report. In this report SCE made the following commitment:

> "The initial inspection results indicate that an additional inspection should be performed after about 12 months of operation. Edison will submit a final assessment of the enclosed inspection results within 180 days of the end of the Unit 2 Cycle 9 refueling outage. Because Unit 2 Cycle 9 is scheduled for about 24 months of operation, Edison is planning a mid-cycle outage to complete this inspection."

The purpose of this evaluation is to fulfill the commitment to submit a final assessment of the steam generator inspection results for the Unit 2 Cycle 9 refueling outage. Unit 2 entered Mode 2 at the end of the refueling outage on March 29, 1997. Thus, this assessment is due to be submitted to the NRC by September 25, 1997.

2.2 Steam Generator Description

The San Onofre Unit 2 design includes two recirculating ASEA Brown Boveri Combustion Engineering (CE) designed and manufactured Steam Generators (SG) which are vertical U-tube and shell heat exchangers. The SGs are designed and fabricated per ASME Code, Section III through Summer 1971 Addenda. Each SG contains 9,350 Alloy 600, high temperature, mill annealed tubes which are 3/4 inch OD and have a nominal wall thickness of 0.048 inches. The tubes are explosively expanded into the tubesheet for the entire tubesheet thickness. The tubes are arranged in rows, with all tubes in a given row having the same length. The rows are staggered, forming a triangular pitch arrangement. The shorter tubes, which have 180° bends, are at the center of the tube bundle in the first 18 rows. All subsequent rows have double 90° bends. The vertical tube lengths are supported by seven full diameter eggcrates (lattice bars), and one to three partial eggcrates for the longer tubes. The bends and horizontal lengths are supported by batwings and vertical lattice supports, respectively.

2.3 History of Tube Degradation

Two tube degradation mechanisms were identified during the first refueling outage. One of these mechanisms was related to inadequate heat treatment of portions of certain tubes. The inadequate heat treatment could be identified by eddy current bobbin testing; thus, the full length of all (100%) of the tubes was tested. The identified tubes were removed from service. The other degradation mechanism was wear of the tubing at tube supports (batwings and vertical lattice supports). The degradation mechanism of tubing wear has continued to be active throughout the operating lifetime of this unit.

In 1989 tube denting and cracking was identified in a single tube. This mechanism was related to tie rod corrosion. This mechanism is possible on a small number of tubes. This mechanism is managed by focused inspections each refueling outage.

In 1993 the following tubing degradation mechanisms were identified on the inlet (hot leg) side of the tubes:

- circumferentially oriented cracking at the top of the tubesheet.
- axially oriented cracking in the vicinity of the top of the tubesheet.
- axially oriented cracking at eggcrate tube supports.

These degradation mechanisms continue to occur.

In 1997 the following tubing degradation mechanisms were identified on the inlet (hot leg) side of the tubes:

- axially oriented cracking in freespan regions (not at tube supports).
- axially oriented cracking at dented eggcrate tube supports.

Also, in 1997, systematic trending of denting indicated that the number of dents in tubing at hot leg supports was increasing.

The new degradation mechanisms identified in 1997 and the continuance of axial cracking at eggcrate supports prompted this detailed assessment.

2.4 Water Chemistry

The following actions have been taken in the last year to improve the secondary side water chemistry environment for the steam generator tubing. These actions have been reviewed by a panel of industry experts for application at San Onofre. The panel concurs with the following measures:

- Chemical Cleaning of the Entire Tube Bundle (Full Bundle)

- Addition of an Inhibitor (Titanium dioxide) for Inter Granular Attack/Stress Corrosion Cracking (IGA/SCC) immediately after the Chemical Cleaning, for maximum crevice penetration potential

- Use of Ethanolamine to reduce deposition on the tubing

- Planning for Plant Modifications for Boric Acid Addition to the secondary side to help reduce denting and stress corrosion cracking of tubing

San Onofre Unit 2 has operated with all volatile chemistry since startup in August 1983 and accumulated approximately 10.1 effective full power years of operation through the end of Cycle 8 operation on November 30, 1996. The condensers are seawater cooled. The feedwater system has a state-of-the-art, full-flow, deep bed, condensate polisher system that was placed in service during the second cycle of operation. The condensate polisher system is operated continuously for maximum protection of the steam generators from cooling water in-leakage. Improvements in secondary chemistry control have paralleled industry developments with implementation of the EPRI PWR Secondary Water Chemistry Guidelines (Reference 5) and subsequent revisions.

2.5 Steam Generator Tube Inspections

A history of ECT inspections and tube plugging is provided in Appendix 1.

The following time line is provided to summarize significant historical innovations in San Onofre Unit 2 Steam Generator Tube Inspections.

<u>BOBBIN PROBE</u>

1987 - Full Length sampling increased from 3% to 20%

1995 - Implemented examination of the Full Length of 100% of the tubing

<u>ROTATING PROBE</u>

1984 - During the first refueling outage, used as a characterization tool for indications of significance

1989 - More wide usage as a characterization tool, and used in all tubes adjacent to tie rods

1993 - 100% examination of hot leg top-of-tubesheet expansion transitions with "3-coil" probe, including the 0.115 inch diameter pancake coil

1997 - Use of Plus-Point® coil probe for rotating probe applications.

The most recent SG inspection was completed at the end of Cycle 8 in early 1997. The detailed scope and the results of that inspection were previously summarized in a Special Report to the NRC (Reference 4). The tube plugging table from that Special Report is repeated here for completeness (Table 1).

2.6 Conservative Tube Plugging

The only tubing degradation mechanism for which SCE uses an eddy current technique for sizing is mechanically induced wear of tubing at tube supports. Tubes are plugged for wear based on sizing results. Other indications of tubing degradation are plugged upon detection, without the use of a sizing technique to justify leaving affected tubes inservice. Tube plugging was performed by FRAMATOME Technologies, Inc. Corrosion resistant, thermally treated alloy 690 material is used for plugging. Plugs are installed mechanically using a qualified rolling process. Welded alloy 690 plugs are used in a few special cases, such as when a tube is removed.

Table 1 - SONGS UNIT 2 - Tubes Plugged CYCLE 9 OUTAGE - 1997

Indication Orientation and Location	Steam Generator	
	E-088	E-089
Mixed mode (circumferential and axial oriented indications) that intersect in the tube and are near the expansion transition at the hot leg top-of-tubesheet	0	1
Both circumferential and axial oriented indications that do not intersect and are near the expansion transition at the hot leg top-of-tubesheet	5	3
Circumferentially oriented indications near the expansion transition at the hot leg top-of-tubesheet	88	49
Axially oriented indications in the upper bundle (typically above 7H), and not associated with a tube support (Freespan)	0	3
As above, but located at a tube support	0	1
Axially oriented indications in the lower bundle (typically below elevation 07H), and not associated with a tube support (Freespan)	5	21
Axially oriented indications at a hot leg eggcrate tube support location	2	6
Axially oriented indications at a dented hot leg eggcrate tube support location	4	4
Axially oriented indications near the expansion transition at the hot leg top-of-tubesheet	58	50
Preventive plugging of tubes adjacent to a tie rod	6	0
Indications of wear at a tube support location	2	7
Volumetric indication at a miscellaneous location in a tube	3	4
Preventive plugging based on presence of a foreign object	0	3
Highest growth rate dent	1	0
Miscellaneous preventive plugging	4	2
Total	**178**	**154**

2.7 Operational Leakage Monitoring

Primary-to-secondary leakage monitoring at San Onofre has been reviewed against available guidance to ensure that leakage monitoring measures are effective at detecting leakage and reducing the potential for tube rupture. Detection of low level leakage is accomplished primarily by chemical sampling and the condenser air ejector radiation alarm. Nitrogen-16 monitoring is available to assist in diagnosis of low-level leakage. Action levels and leakage limits in San Onofre Abnormal Operating Instructions are consistent with the "EPRI PWR Primary-to-Secondary Leak Guidelines" (Reference 6).

The potential for tube rupture. detection, measurement, and assessment of rapidly increasing leakage is required by San Onofre procedures. San Onofre procedures require unit shutdown for rates of change of steam generator tube leakage equal to 60 gpd in any one hour period. Operator responses to leakage and rates of change of leakage are specified in San Onofre procedures. These procedures and responses have been reviewed against available guidance and historical leakage events.

3.0 DEGRADATION ASSESSMENT

3.1 Circumferential Indications

Circumferential stress corrosion cracking initiated at both the outside and inside surface of the SG tubing was first detected at the tube expansion transition in the hot legs of the San Onofre Unit 2 SGs during the 1993 inspection. Rotating coil inspection has been routinely performed for this region since that time. SCE data analysis guidelines have been continually updated to incorporate industry experience and evolving technology. No indications of this type were identified in a similar examination of a sample of tubes on the cold leg side of the steam generators. SCE has used EPRI sizing techniques that are available and appropriate for San Onofre to determine that indications have met the structural criteria of RG 1.121.

3.2 Free Span Axial Indications

Subsequent to a tube rupture in March of 1993 at Palo Verde Unit 2 (CE System 80) it was determined that upper bundle deposits may act as a precursor to free span axial cracking. Thermal hydraulic evaluations of steam generators, completed since the tube rupture indicate that certain upper bundle regions have higher potential for deposit accumulation. Axial indications have recently been reported in the free span region of ABB/CE designed units with more operation time than San Onofre Unit 2.

The San Onofre Unit 2 and 3 SG tube bundle regions most susceptible to deposit accumulation were estimated. This was done by review of industry experience and computer modeling of thermal hudraulic conditions. (Reference 7)

In 1997 SCE implemented inspection plan changes to include rotating Plus-Point* probe inspection of 20% of the tubes in selected regions in both San Onofre Unit 2 SGs. The region was defined based on thermal-hydraulic considerations. No indications were found in SG 88. In response to axial indications in SG 89, the sampling program of 609 tubes was expanded to an approximate total of 1409 tubes. The results in the expanded sample indicated no need for further sample expansion in the selected region of the tube bundles.

Axial cracking was identified in freespan parts of the tubing during the most recent examination. Indications were detected in 26 tubes in the 100% bobbin probe examination of the tubing. The location of this cracking could not be readily correlated with results of the thermal hydraulic evaluation of tube bundle regions susceptible to deposit accumulation.

3.3 Axial Indications at Eggcrates and in the Sludge Pile

SCE has utilized a bobbin coil technique for detection of outside-diameter-initiated, stress corrosion cracking (ODSCC) indications at these locations. The technique used is EPRI qualified in accordance with Appendix H of the EPRI PWR Steam Generator Examination Guidelines (Reference 6). SCE has only used the detection portion of this qualification. SCE has conservatively "plugged on detection," and thus has not used the sizing portion of this qualification to leave tubes in service. However, the sizing portion of this qualification provides one tool in estimation of the structural integrity significance of such indications per RG 1.121.

Further, SCE has enhanced detection capabilities in the sludge pile by performing rotating Plus-Point* coil inspection of all tubing in the vicinity of hot leg expansion transitions.

3.4 Axial Indications at Dented Hot Leg Eggcrate Support Intersections

SCE uses the full length bobbin exam of 100% of the tubes to identify dents at tube support intersections and dings in tubing freespan. SCE uses the voltage normalization technique in widest industry usage, consistent with EPRI Guidelines and GL 95-05 (all bobbin frequency channel voltages normalized to 4 volts on the prime frequency for 20% drill holes). For the 1997 inspection SCE implemented a practice of inspection with the rotating Plus-Point* coil of all hot leg dents and dings that are greater than 5 volts by bobbin.

3.5 Tubing Wear

San Onofre Unit 2 experiences tubing wear that is typical for this particular design of ABB/CE SGs. A technique that is qualified in accordance with Appendix H of the EPRI PWR Steam Generator Examination Guidelines is used for detection and sizing of indications.

4.0 IN-SITU PRESSURE TESTING

In-situ pressure testing was conducted during the most recent inspection to verify that RG 1.121 structural margins were maintained. Twenty-one in-situ pressure tests were completed using a full tube hydrostatic or defect-specific hydrostatic test method. The full tube method was performed on most of these tubes. The defect specific method was used for 2 tubes in which the eddy current indications being tested were circumferential or axial indications at tube expansion transitions. A summary table of locations tested and results was previously provided in a special report to the NRC (Reference 4). This information has been supplemented to include information on the eddy current indications at each location and is included here as Table 2.

4.1 Criteria

Several criteria were used in screening candidate eddy current indications for in-situ pressure testing. The selection process included review of bobbin and rotating probe data for estimated maximum through wall depth, maximum voltage, and length. Percent degraded area (PDA) was also calculated for candidate circumferential defects to assure that indications tested are bounding. Finally, lead ECT data analyst recommendations were considered.

In-situ testing target pressures include an adjustment for testing at ambient temperature rather than the maximum design temperature of 650°F. For circumferential indications, pressures are also adjusted to account for assumed, locked tube support conditions. Acceptance criteria are those specified by regulatory guidance.

4.2 Results

One of the in-situ pressure tested tubes in Steam Generator 89 (Row 13 Column 117) experienced axial cracking at the sixth hot leg eggcrate support. The eddy current bobbin probe amplitude of the the crack was 4.49 volts and the space associated dent was 23 volts. The axial cracking at this dented location exhibited leakage of 0.24 gallons per minute (gpm) at a pressure comparable to a Main Steam Line Break (MSLB) accident, and exceeded the leakage capabilities of test equipment at a pressure of 3150 psi. The Condition Monitoring Assessment Section of this report addresses the significance of these results.

All of the other twenty in-situ pressure tested tubes demonstrated leaktightness and structural integrity at all test pressures.

Table 2 - San Onofre Unit 2 In-Situ Pressure Test Results

TUBE AND EDDY CURRENT INFORMATION										IN-SITU TEST RESULTS - Ambient Temperature			
REGION	TUBE INFORMATION				PLUS POINT DATA			BOBBIN	Comments	GPM@ NOPD	GPM@ MSLB Pressure	GPM@NOPD Post MSLB	[illegible]
	ROW	COL	Location	Length	Volts	PDA	Orientation	Volts					
Steam Generator 88													
EGGCRATE	44	56	07H - 0.07	1.14	[illegible]	NA	ID SAI	DNT/15V	Highest Plus Pt Volts	0	0	N/A	4746
MID-BUNDLE	11	169	04H + 28.94 04H + 4.93 04H + 6.01	0.95 0.26 0.2	[illegible] [illegible] [illegible]	NA NA NA	OD SAI OD SAI OD SAI	NDD 0.85 0.78	Highest Plus Pt & Bobbin Voltages; 2nd Highest Bobbin %TW	0	0	N/A	4746
TUBESHEET/ SLUDGE PILE	52	70	TSH + 0.10	1	0.33	52	OD SCI	NDD	Highest PDA	0	0	N/A	5292
	53	111	TSH + 0.68 TSH + 1.41	0.21 0.39	0.09 2.15	NA NA	OD SAI OD SAI	0.28 2.04	Highest Plus Pt, Bobbin, & Pancake Voltages	0	0	N/A	4746
Steam Generator 89													
EGGCRATE	13	117	06H - 0.33	0.9	4.86	NA	?? SAI	4.49	2nd Voltage; Dented	0	0.24	0.051	N/A
	92	128	02H - 0.30	0.66	0.7	NA	OD SAI	1.08	Calculation	0	0	N/A	4746
	94	110	08H + 0.22	0.15	0.27	NA	OD SAI	NDD	Calculation	0	0	N/A	4746
MID-BUNDLE	16	166	04H + 21.97 05H + 13.87 06H + 9.21	23 34 11	0.29 0.31 0.38	NA NA NA	OD MAI OD MAI OD MAI	0.33 0.28 0.51	Longest Length	0	0	N/A	4746
	15	15	05H + 9.3 05H + 33.74	9.0 2.3	0.83 0.36	NA NA	OD MAI OD MAI	0.4 0.34	Calculation	0	0	N/A	4746
	23	15	05H + 5.64 05H + 11.26	3.7 0.85	0.56 0.44	NA NA	OD MAI OD MAI	0.4 0.6	Calculation	0	0	N/A	4746
	31	17	06H + 6.4	0.3	0.23	NA	OD SAI	0.58	Calculation	0	0	N/A	4746
	82	24	06H + 17.79 07H + 8.53 08H + 9.03	16 4.9 4.3	0.23 0.13 0.16	NA NA NA	OD MAI OD MAI OD MAI	0.47 0.44 0.75	Highest Plus Pt Depth	0	0	N/A	4746
	92	34	05H + 25.11	17	0.45	NA	OD MAI	0.51	Calculation	0	0	N/A	4746
	106	38	06H + 17.71 06H + 21.01 06H + 27.82 06H + 8.32	0.4 1.4 4.3 14	0.33 0.21 0.33 1.08	NA NA NA NA	OD SAI OD SAI OD SAI OD MAI	0.24 0.16 0.13 0.73	Highest Plus Pt Voltage	0	0	N/A	4746
	110	42	06H + 4.90	4.9	0.69	NA	OD MAI	0.9	Highest Pancake Volts	0	0	N/A	4746
	112	36	06H + 16.78 06H + 20.23	0.4 4.5	0.18 0.57	NA NA	OD SAI OD SAI	0.74 1.34	Highest Bobbin Voltage & Highest %TW	0	0	N/A	4746
UPPER BUNDLE	122	112	08H + 6.21	0.67	0.35	NA	OD SAI	NDD	U-Bend	0	0	N/A	4746
	122	120	08H + 13.27 08H + 5.17 08H + 7.34 08H + 9.67	1.2 0.59 0.89 2.4	0.32 0.27 0.26 0.44	NA NA NA NA	OD SAI OD SAI OD SAI OD SAI	NDD NDD NDD NDD	U-Bend	0	0	N/A	4746
TUBESHEET/ SLUDGE PILE	40	56	TSH - 1.31	0.54	1.4	NA	OD SAI	1.12	Highest Pancake Volts	0	0	N/A	4746
	59	79	TSH + 0.13 TSH + 0.22	0.51 0.12	0.48 0.26	19 NA	OD SCI OD SAI	NDD NDD	Mixed Axial & Circ	0	0	N/A	5292
	94	86	TSH + 1.16	0.23	0.3	NA	OD SAI	NDD	Calculation	0	0	N/A	4746

5.0 TUBE REMOVAL, LABORATORY BURST TESTING, AND SUPPLEMENTAL EDDY CURRENT PERFORMANCE DEMONSTRATION

Three tubes were removed from San Onofre Unit 2 SG 89 during the 1997 outage. Tubes were removed to characterize degradation mechanisms, demonstrate eddy current bobbin detection capabilities for axial cracking in freespan regions, determine pressure test leak/burst behavior, and determine the physical and metallurgical characteristics of the tubes. The selection criteria for the removed tubes considered the worst case indications at tube supports. The degradation mechanism-specific details are provided below. One of the removed tubes (Row 94 Column 32) had indications of two types of degradation mechanisms at different areas of the tube.

Detailed examination of the physical, chemical, and metallurgical properties of these three tubes led to the conclusion that they had microstructures that were not consistent with industry expectations for High Temperature Mill Annealed (HTMA) Alloy 600 tubing. The requirements of ASME SB-163 were supplemented by ABB/CE specification requirements for a maximum yield strength of 55,000 psi (which required a relatively high annealing temperature). The microstructural characterization indicated a microstructure with relatively small grains (ASTM grain sizes 10 to 12), rather than the expected grain sizes of ASTM 5 to 6. The carbon content was higher than anticipated, but within the tubing manufacturing specifications. The microstructure of the pulled tubes revealed random carbide precipitation within the grains and on the grain boundaries. It should be noted that a microstructure acceptance criteria, in terms of grain size and carbide precipitation, was not contained in the tubing specification when it was developed.

5.1 Axial Cracking in Freespan Regions of Tubing

Two of these tubes were removed to gain information on this degradation mechanism. One of the removed tubes (Row 16 Column 164) was affected by this degradation mechanism from below the fourth hot leg eggcrate support to above the sixth hot leg support. Another removed tube (Row 94 Column 32) was affected by this degradation mechanism from above the fifth hot leg eggcrate support to above the sixth hot leg support.

Laboratory Leakage and Burst Testing were performed on removed tubing sections with eddy current indications of this mechanism. The same testing was done on additional adjacent removed sections to demonstrate bounding of the affected region. Table 3 provides the results of this testing. In summary, for this degradation mechanism there was no leakage at pressures comparable to accident conditions, and tubes significantly exceeded the structural integrity margins addressed in RG 1.121. In fact, tubing structural margin was demonstrated similar to that of unflawed tubing.

This freespan axial cracking consists of relatively small (typically less than 35% through-wall) outside-diameter-initiated short axial microcracks that are distributed around the tube. This characteristic gives this freespan axial cracking a different visual appearance than that observed in other affected tubes removed from ABB/CE designed steam generators.

A "supplemental performance demonstration," described in draft RG X.XX, was performed to demonstrate the eddy current bobbin probe detection capabilities for this freespan axial cracking. This demonstration used eddy current indications (nondestructive examination data) with corresponding metallurgical laboratory data (destructive examination data) in sections of pulled tubes. The most significant result of this demonstration, a Probability of Detection (POD) Curve, is illustrated in Figure 1. This figure shows a reference POD which is the technique limit and individual team performances which reflect human factors considerations. More detail is provided in Appendix 2, which is a summary of the purposes and protocol of this demonstration. POD results are considered in the Probabilistic Operational Assessment.

Indications of the secondary side chemical environment were limited due to the secondary side cleaning of the steam generators just prior to tube removal. The degradation environment may have been formed within deposits on the tubing surface. Heat transfer performance degradation and the amount of material removed during chemical cleaning corroborated the existence of significant deposits. Deposits have been suspected of creating an environment that allows deleterious chemical species to concentrate near the tube in a manner contributing to ODSCC.

Table 3 - Laboratory Leak and Burst Test Results

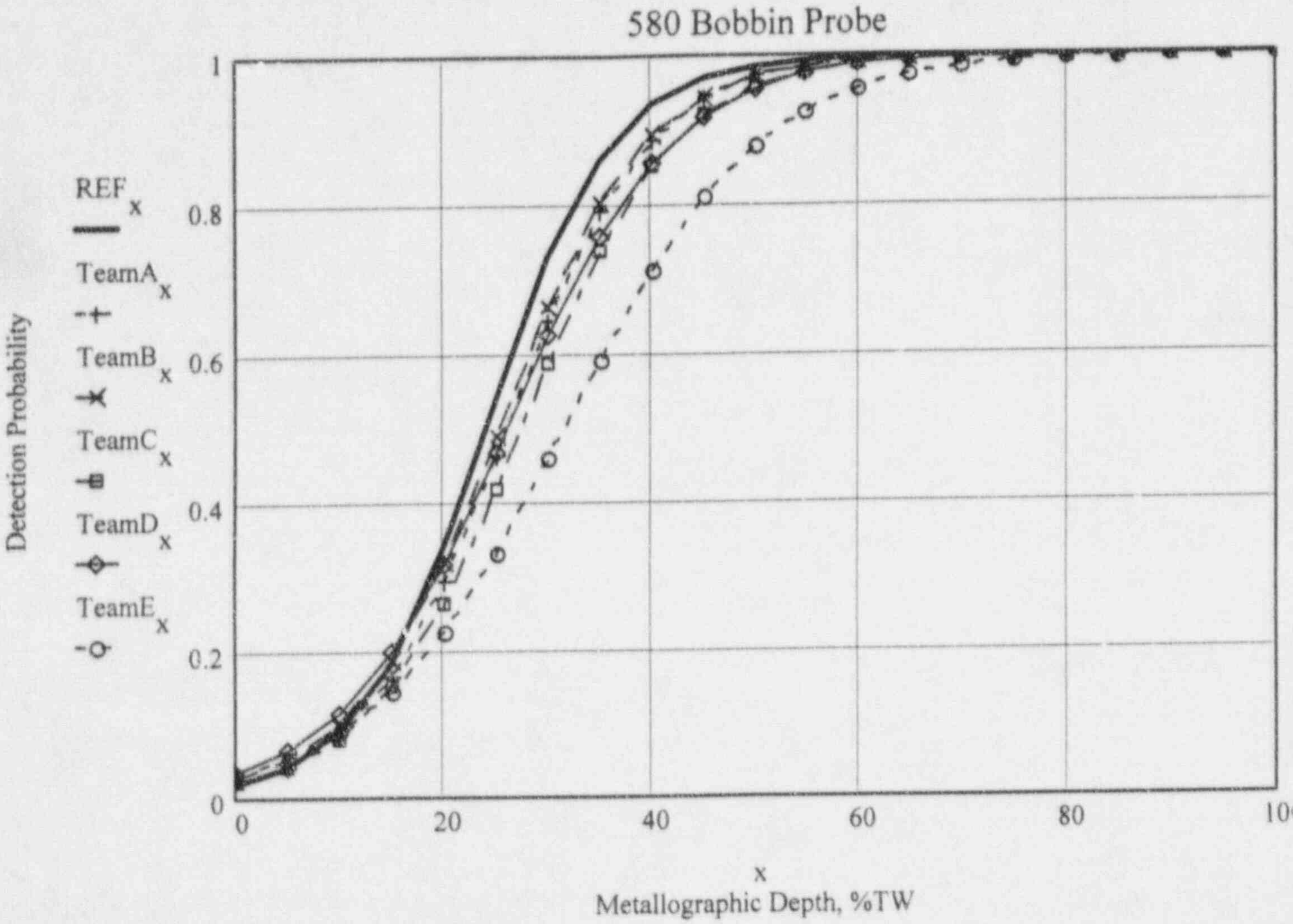
Unit 2 Steam Generator E-089							
Tube				Leak and Burst Test Results			
Row	Col	Location	Orientation (Note 1)	GPM@ MSLB Pressure	Max Pressure Achieved (Note 2)	Comments
16	164	7H-6H	FSA	0	12,600	
		6H	FSA	0	11,900	
		5H	FSA	0	11,800	
		5H-4H	FSA	0	12,500	
		4H	FSA	0	13,200	
		3H	NDD	0	13,450	
		2H-3H	NDD	0	13,400	
94	32	6H	FSA	0	13,050	
		6H-5H	FSA	0	13,200	
		5H	NDD	0	13,200	
		5H-4H	NDD	0	13,800	
		4H	EA	0	5,300	(6 Volt Dent) No leakage till endpoint & None at 5 min. hold at 4800 psig.
		3H	NDD	0	13,700	
61	111	7H	EA	1.35	3,515	
		7H-6H	NDD	0	10,650	Endpoints occurred in the area welded to the tube for sealing with the test gear (not in the tubing). Testing complete with the objective favorably met.
		6H	NDD	0	11,900	
		5H	NDD	0	13,500	
		4H	NDD	0	14,000	

Notes:

1. Abbreviations:
   FSA Axial cracking in the freespan
   EA Axial cracking at an eggcrate
   NDD No detectable degradation

2. Lab testing pressure that is equivalent to SONGS 2 normal operation differential pressure multiplied by a safety factor of 3 is 4746 psi.

Figure 1. Probability of Detection (POD) Curve - Freespan Axial Cracking



5.2 Axial Cracking of Tubing at a Dented Eggcrate Support

One tube was removed to gain information on this degradation mechanism. One of the three removed tubes (Row 94 Column 32) was affected by inside-diameter-initiated axial cracking at the fourth hot leg eggcrate support. This cracking had been detected by the eddy current bobbin probe, and was confirmed and further characterized with a rotating probe with a Plus-Point* coil and a high-frequency shielded pancake coil.

The eddy current bobbin probe amplitude of the associated dent was 6 volts. The dent was dimensionally measured in the laboratory with a dial calipers as an 11 mil dent (0.011 inches calculated as the average freespan tubing outside diameter minus the minimum dented tubing outside diameter).

The length/depth profile of this degradation, determined by scanning electron microscopy, is illustrated in Figure 2.

Laboratory Leakage and Burst Testing was performed at this location. The results at this location are shown in Table 3. The axial cracking at this dented location did not exhibit leakage at a pressure comparable to MSLB accident conditions, and met the structural integrity margins addressed in RG 1.121.

5.3 Axial Cracking of Tubing at an Undented Eggcrate Support

One tube was removed to gain information on this degradation mechanism. One of the three removed tubes (Row 61 Column 111) was affected by inside-diameter-initiated axial cracking at the seventh hot leg eggcrate support. This cracking had been detected by the eddy current bobbin probe, and was confirmed and further characterized with a rotating probe with a Plus-Point* coil and a high-frequency shielded pancake coil.

The length/depth profile of this degradation, determined by scanning electron microscope, is illustrated in Figure 3. The eddy current bobbin probe indicated there was no denting. Dimensional measurements in the laboratory corroborated that there was no detectable denting.

Laboratory leakage and burst testing results are shown in Table 3. These results and associated calculations indicate that the axial cracking at this location exhibited leakage of 1.35 gpm at a pressure comparable to MSLB accident conditions. Calculation of this leakage was necessary because it exceeded the capabilities of test equipment at a pressure of 2100 psi. Structural integrity at MSLB accident conditions was demonstrated. Maximum achievable test pressure was 3515 psi, which is below the target pressure of 4746 psi. The pressure of 4746 psi would have demonstrated structural integrity at a pressure simulating normal operating differential pressure multiplied by a factor of 3.

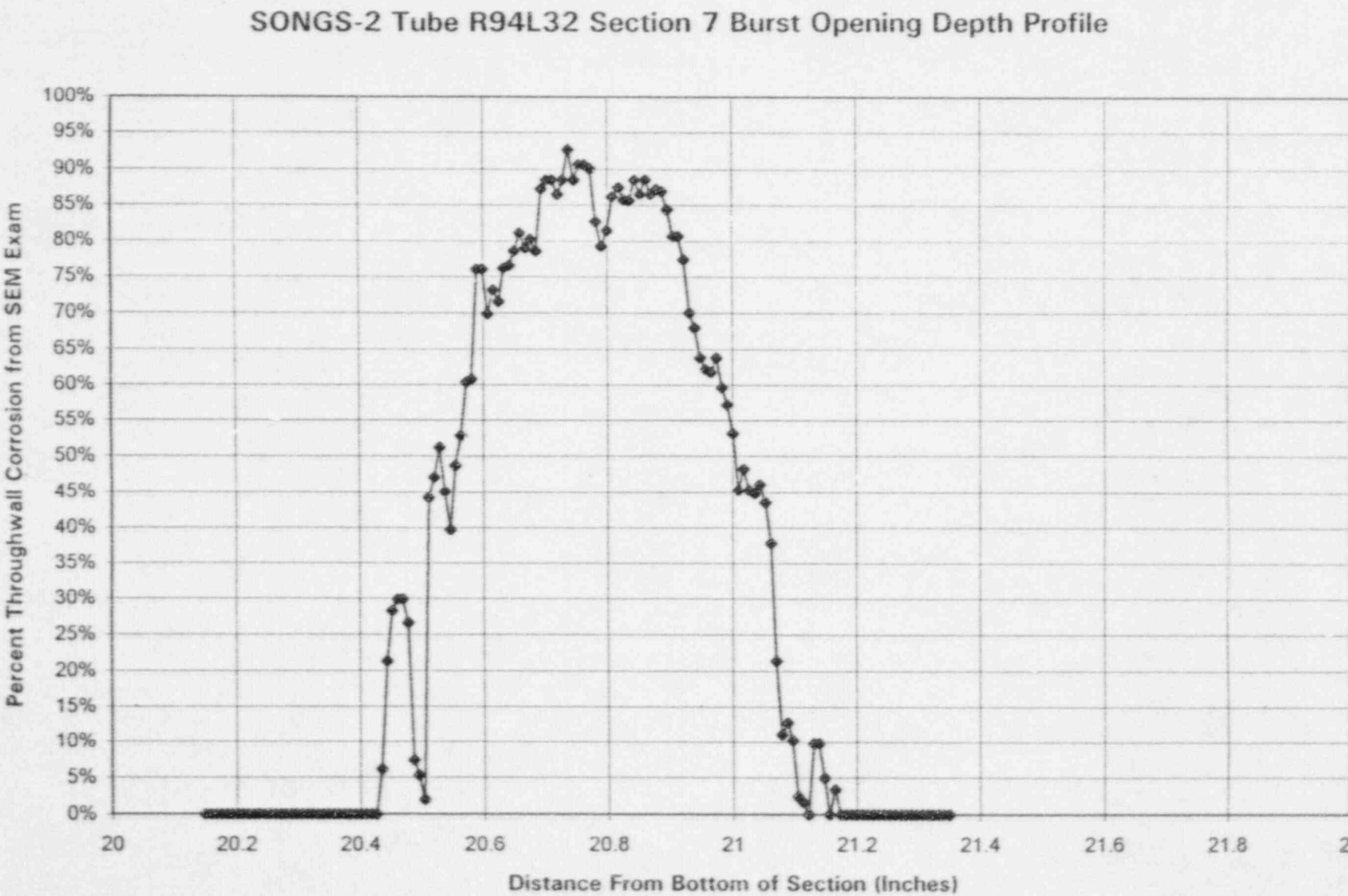


Figure 2, Profile of Axial Degradation at Dented Eggcrate Support Location in R94 C32

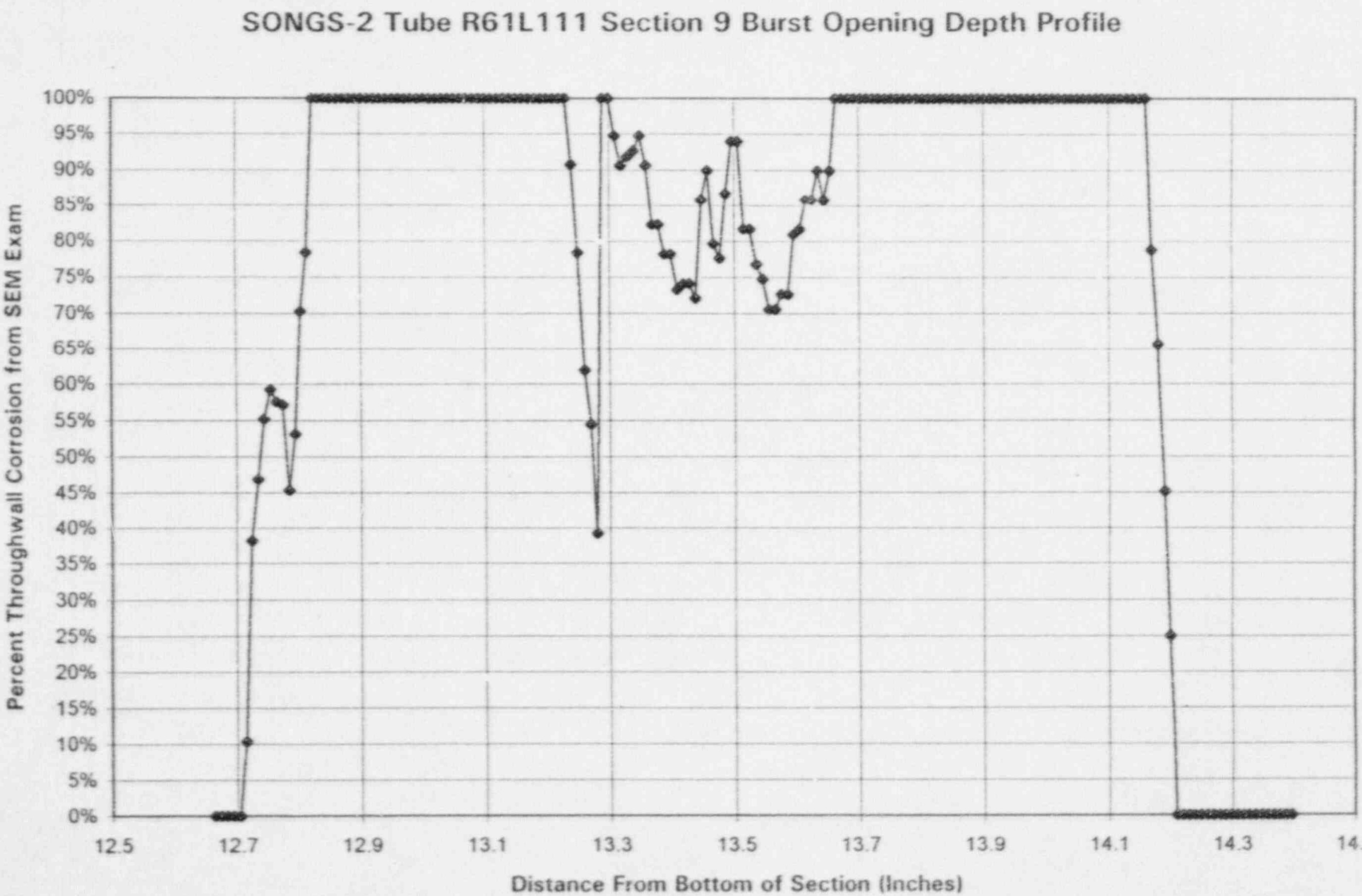


Figure 3, Profile of Axial Degradation Undented Eggcrate Support Location in R61 C111

6.0 CONDITION MONITORING ASSESSMENT

The purpose of this "backward looking" assessment is to confirm that adequate tube integrity has been maintained during the operating period before the inspection. Qualified "depth-sizing" techniques were only available for two degradation mechanisms (inside diameter-initiated, stress corrosion cracking (IDSCC) at expansion transitions, and mechanically induced wear at tube supports). All available eddy current information was considered for other degradation mechanisms.

6.1 Methodology

The first step was review of eddy current depth-sizing information for mechanically induced wear at tube supports. All these indications met criteria for structural and leakage integrity.

The next step for other degradation mechanisms was a review of bobbin and rotating probe data for estimated maximum through wall depth, maximum voltage, and length. Percent degraded area (PDA) was also calculated for applicable circumferential indications. Finally, lead ECT data analyst recommendations were considered. The output of this review consisted of a general ranking of the most significant indications, based on the degradation mechanism/location. This general ranking was then used as a leading input into the tube selection processes for in-situ pressure testing and tube removal. Leakage and burst testing was used to obtain condition monitoring information on both the most significant eddy current indications and also some less significant indications to demonstrate that the results were bounding for other indications. Results of in-situ pressure testing and laboratory leak/burst testing (on removed tubes) were consistent with expectations formed during the tube selection processes. This is considered an indication of the effectiveness of the selection process.

6.2 Test Results

In-situ pressure testing identified one dented eggcrate/tubing intersection for which structural integrity (at a pressure simulating normal operating differential pressure multiplied by a factor of 3) could not be demonstrated due to leakage that exceeded the makeup capabilities of the test equipment. Structural integrity at MSLB accident conditions was demonstrated. The axial cracking at this location exhibited leakage of 0.24 gpm at a pressure comparable to MSLB accident conditions.

Laboratory Leak/Burst Testing identified one undented eggcrate/tubing intersection for which structural integrity (at a pressure simulating normal operating differential pressure multiplied by a factor of 3) was not demonstrated. This intersection lost structural integrity at 3515 psi, which was below the target pressure of 4746 psi. Structural integrity at MSLB accident conditions was demonstrated. The axial cracking at this location exhibited leakage of 1.35 gpm at a pressure comparable to MSLB accident conditions.

The inspection and operational enhancements that address these test results are provided in Section 8.0.

6.3 Analysis

The criteria for Condition Monitoring Assessment postulated accident leakage performance are that the calculated potential primary-to-secondary leak rate during limiting postulated events should:

(1) not exceed the total charging pump capacity of the primary coolant system

(2) be such that the offsite radiological dose consequences do not exceed 10CFR Part 100 guidelines and radiological consequences to control room personnel are in accordance with General Design Criteria 19.

The additive leakage of 1.59 gpm for one steam generator (at MSLB pressure) for the 2 tubes exhibiting leakage during leak testing is considered to be the best available indicator of postulated MSLB accident leakage at the end of Cycle 8, just prior to inspection. Leakage solely in these 2 tubes was consistent with expectations formed during the selection of tubes for in-situ pressure testing and tube removal for laboratory leak and burst testing. The other tubes selected for these two leak testing processes did not leak. These other non-leaking tubes had been selected based on eddy current characteristics to demonstrate the leak integrity of the remainder of lesser magnitude indications that were not leak tested. There would be 0 gallons per minute primary-to-secondary leakage the other steam generator under MSLB accident conditions.

This leakage of 1.59 gpm (at MSLB pressure) is a very small fraction of the total charging pump capacity of the San Onofre Unit 2 primary system. The pre-trip MSLB analysis, with a concurrent single failure, was analyzed for the maximum break size outside of containment in keeping with NUREG-0800 Standard Review Plan (SRP) 3.6 and Branch Technical Positions MEB 3-1 and ASB 3-1. The assumed primary-to-secondary leak rate was 1.59 gpm to the unaffected steam generator and 0.0 gpm to the affected steam generator for the entire duration of the event. The primary-to-secondary leakage activity profile was consistent with 4.41% failed fuel and the maximum allowed Technical Specification primary coolant steady state activity limits (consistent with NUREG-0800 SRP 15.1.5 guidance for this event with fuel failures). The dose analysis assumed a 30 minute release from the main steam line break location to the environment with a steam generator iodine Partition Factor (PF) of 1.0

for botn steam generators. Initial secondary activity levels were assumed to be at the maximum allowed by Technical Specification limits and were assumed to be released out of the break during the first 30 minutes of the MSLB. No Emergency Feedwater Actuation System (EFAS) actuation prior to 30 minutes was credited in the dose analysis. At the end of 30 minutes the operators were assumed tr isolate the steam generators and initiate a controlled plant cooldown via the unaffected steam generator atmospheric dump value (ADV). The releases for the remainder of the event are from the unaffected steam generator ADV with an assumed steam generator iodine PF of 0.01. The noble gas PF is 1.0 for the entire event duration. The calculation of the resultant doses, presented below, were performed using RG 1.109 dose conversion factors.

PRE-TRIP MSLB-OUTSIDE CONTAINMENT DOSES

DOSE LOCATION	REGULATORY DOSE CRITERIA (Rem)	CALCULATED DOSES (Rem)
Control Room (event duration dose)		
Thyroid Inhalation	30	23.3
Whole Body Gamma Immersion + shine	5	4.2
Beta-Skin Immersion	30	16.1
EAB (2-hour dose)		
Thyroid Inhalation	300	82.6
Whole Body Gamma Immersion	25	0.8
Beta-Skin Immersion	no dose criterion	0.3
LPZ (event duration dose)		
Thyroid Inhalation	300	2.8
Whole Body Gamma Immersion	25	< 0.1
Beta-Skin Immersion	no dose criterion	< 0.1

The results of Condition Monitoring indicated that the significance of these results to future operation could best be assessed by a "Probabilistic Operational Assessment."

7.0 PROBABILISTIC OPERATIONAL ASSESSMENT SUMMARY

The purpose of this "forward looking" assessment is to demonstrate reasonable assurance that tube integrity performance criteria will be met throughout the period prior to the next scheduled inspection. Since a significant amount of guidance for this type of assessment is provided in GL 95-05, an appendix to this assessment has been prepared that reformats this assessment to correlate with GL 95-05. This is attached as Appendi~ 3.

The significance of corrosion degradation to the performance of steam generator tubing at San Onofre Unit 2 was evaluated in a Probabilistic

Operational Assessment. Probabilistic methods were applied to make projections throughout an assumed operating period of the structural and leakage integrity of the steam generator tubing, under postulated accident conditions (MSLB). A detailed report of this assessment is provided as Appendix 4. However, a brief overview of it is provided below.

7.1 Degradation Modes

Testing of steam generator tubing at San Onofre Unit 2 has indicated corrosion degradation. Eddy current inspection data and pulled tube examinations have been tools in characterizing the degradation. Five modes of corrosion were considered in this assessment:

(1) Circumferential degradation at the top of the tubesheet

(2) Axial degradation at the top of the tubesheet

(3) Axial freespan degradation

(4) Axial ODSCC/IGA at undented eggcrate intersections

(5) Axial PWSCC at dented eggcrate intersections

7.2 Methods

The basic calculational technique employed in the Probabilistic Operational Assessment is one of simulating the processes of crack initiation, crack growth, leakage, and detection via eddy current inspection. Monte Carlo simulation methods also provide an approach for accounting for the various sources of uncertainty.

Several probabilistic run time models were employed. Modeling included two operational periods, because there are 2 distinctly different types of inspections. It was necessary to determine the most appropriate operational period between inspections during the next cycle for these 2 different inspections:

(a) Inspection of the vicinity of expansion transitions at the top of the tubesheet is the principal detection tool for circumferential and axial degradation in this location. Results indicate that a full cycle of operation is an appropriate interval between these inspections.

(b) Inspection of the full length of the tubing with a standard differential bobbin probe is the principal detection tool for axial degradation in the remainder of the tubing. Results indicate that inspection during a mid-cycle outage is appropriate for these inspections.

7.3 Structural Integrity Assessment Description

The Probabilistic Operational Assessment provides a projection of the structural integrity of the steam generator tubing. This projection is commonly referred to as "conditional probability of burst" (POB). It is generally defined as the probability that the burst pressures associated with one or more indications of degradation will be less than the maximum pressure differential across the tubing associated with a postulated MSLB that is assumed to occur at the end of an assumed period of operation, just prior to a tubing inspection.

7.3.1 Criteria for Structural Integrity Performance

The conditional POB criteria that is applicable to any one degradation mechanism is 1×10^{-2}. The conditional POB criteria that is applicable to the total conditional POB for all degradation mechanisms is 5×10^{-2}.

7.3.2 Structural Integrity Assessment Results

The dominant contributor to the conditional probability of burst is axial degradation at dented eggcrate supports. This is largely a function of the eddy current probability of detection (POD).

The Operational Assessment results for conditional POB are shown in Table 4 and are well within the above POB criteria.

7.4 Accident Leakage Assessment Description

The Probabilistic Operational Assessment also provides a projection of the leakage integrity of the steam generator tubing. The basis of this projection is a probabilistic calculation for each degradation mechanism of its postulated accident condition (MSLB) leak rate for the end of an operating period, just prior to inspection. Modeling projects maximum crack depths for this point in time, identifies those that have reached the full tube thickness (through wall), and finally models their corresponding leakage. Monte Carlo methods provide a way to account for uncertainties, and accordingly, the calculated leakage is an upper 95-percent probability at an upper 95-percent confidence bound.

Table 4 - San Onofre Unit 2 Cycle 9 - Probability of Burst

Degradation Mechanism	Projected Duration (EFPY)	Probability of Burst at Postulated MSLB (95% Confidence)
Circumferential ODSCC/PWSCC at Expansion Transitions	2.0	0.0005
Axial ODSCC at Expansion Transitions	2.0	0.0033
Axial ODSCC at Undented Eggcrate Intersections	0.92	0.0008
Axial PWSCC at Dented Eggcrate Intersections	0.92	0.0096
Freespan Axial ODSCC	0.92	0.0003

7.4.1 Criteria for Accident Leakage Assessment

The criteria are that calculated potential primary-to-secondary leak rate during limiting postulated events should:

(1) not exceed the total charging pump capacity of the primary coolant system

(2) be such that the offsite radiological dose consequences do not exceed 10CFR Part 100 guidelines and radiological consequences to control room personnel are in accordance with General Design Criteria 19.

7.4.2 Accident Leakage Assessment Results

The projected MSLB accident leak rates are shown in Table 5.

Table 5 - San Onofre Unit 2 Cycle 9 - Accident Leakage Evaluation

Degradation Mechanism	Projected Duration (EFPY)	95/95 Leak Rate at Postulated MSLB (GPM at 600°F
Circumferential ODSCC/PWSCC at Expansion Transitions	2.0	0.38
Axial ODSCC at Expansion Transitions	2.0	0.009
Axial ODSCC at Undented Eggcrate Intersections	0.92	0
Axial PWSCC at Dented Eggcrate Intersections	0.92	0.0044
Freespan Axial ODSCC	0.92	0

The maximum total projected 95%/95% probability/confidence leak rate is less than 0.40 gallons per minute at the end of a full cycle. Note that this total was computed for a cycle that includes a mid-cycle inspection outage. This projected leak rate is a very small fraction of the total charging pump capacity of the San Onofre Unit 2 primary system and is bounded by the primary-to-secondary leak rate assumption of 0.5 gallons per minute per steam generator used in the MSLB licensing event, as stated in the San Onofre 2/3 Updated Final Safety Analysis Report (UFSAR) Section 15.1.3a.

8.0 INSPECTION AND OPERATIONAL ENHANCEMENTS

Significantly shortening the operational period between inspections to address axial cracking in the tubing freespans and axial cracking of tubing at supports will provide assurance that the requirements of RG 1.121 will be met throughout the present operating cycle.

Inspection practices at San Onofre have been routinely updated to incorporate industry experience and recommendations. One such example is the use of a rotating probe at hot leg dented eggcrate tube support intersections for improved POD for indications. Further, thorough in-situ pressure testing has been implemented. These actions will serve to decrease the potential for a tube failing to meet criteria in regulatory guidance.

Three tubes have been removed from a steam generator and characterized in the laboratory. The purposes of this was to characterize degradation mechanisms, demonstrate eddy current bobbin detection capabilities for axial cracking in freespan regions, determine pressure test leakage/burst behavior, and determine the physical and metallurgical characteristics of the tubes.

Actions have been taken to improve the secondary side water chemistry environment for the steam generator tubing. These actions have been reviewed by a panel of industry experts for application at San Onofre. The expert panel concurs with these measures. These actions are: 1) Chemical cleaning of the entire tube bundle (Full Bundle), 2) Addition of an inhibitor (titanium dioxide) for IGA/SCC immediately after the chemical cleaning, for maximum crevice penetration potential, 3) Use of Ethanolamine, and 4) Planning for plant modifications for boric acid addition in the secondary side to help reduce denting of tube supports and stress corrosion cracking of tubing.

Plant operators have procedures consistent with EPRI guidelines to detect and respond to changes in steam generator primary to secondary leakage. Specifically, they have guidance for shutdown of the unit prior to a significant leak or tube rupture, should tube degradation exceed expected values.

State of the art probabilistic models have been developed to demonstrate that a planned mid-cycle inspection outage for the steam generators will maintain the safety margins in regulatory guidance. A probabilistic leakage model has been developed to assess the end of inspection interval leakage that would result from postulated accident conditions. The leakage model demonstrates that the postulated leakage for Cycle 9 is bounded by the primary-to-secondary leakage assumption of 0.5 gallons per minute per steam generator used in the MSLB licensing event, UFSAR 15.1.3a.

9.0 CONCLUSIONS

It is SCE's conclusion that the San Onofre Unit 2 steam generators will fully support safe operation for the period until a mid-cycle inspection outage, and then further throughout the full Cycle 9 operating period.

The following enhancements are appropriate to address the indications of tube degradation that were found at San Onofre Unit 2 following Cycle 8 operation.

- Significantly shortening the interval to the next inspection (a mid cycle inspection outage)
- Improvements in inspection practices
- In-situ pressure testing
- Tube removal and testing
- Improvements to the secondary side environment
- Tube leakage monitoring review
- Modeling and analysis

This report demonstrates that the operation, inspection, and repair program described herein constitutes a conservative approach which ensures that adequate structural and leakage integrity is maintained for normal operations, transients, and postulated accident conditions for the period until a mid-cycle inspection outage, and then further throughout the full Cycle 9 operating period for the San Onofre Unit 2 steam generators.

10.0 REFERENCES

1. Regulatory Guide 1.121, "Bases for Plugging Degraded Pressurized Water Reactor Steam Generator Tubes," Rev 0, August 1976.

2. NRC Draft Regulatory Guide X.XX "Steam Generator Tube Integrity," Distributed November 1996.

3. NRC Generic Letter 95-05, Voltage Based Repair Criteria for Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking," August 3, 1995.

4. Letter from Southern California Edison to the US Nuclear Regulatory Commission "Special Report: "Inservice Inspection of Steam Generator Tubes, San Onofre Nuclear Generating Station, Unit 2," Dated February 6, 1997.

5. EPRI Guidelines, TR-106589-V1 Rev. 4, 1996, "PWR Steam Generator Tube Examination Guidelines," dated June 1996 and the Final Draft of Revision 5.

6. EPRI Guidelines, TR-104788 "Primary to Secondary Leak Guidelines;" dated May 1995.

7. ABB-CE Report, "Tube Bundle Thermal-Hydraulic Analysis to Assist the Development of Eddy Current Test Plans for the Songs Unit 2 Steam Generators," A-SONGS-9419-1118, REV. 00; dated October 15, 1996.

8. EPRI Guidelines, TR-102134-R4, Revision 4, "PWR Secondary Water Chemistry Guidelines," dated November 1996.

Appendix 1 - History of ECT Inspections and Tube Plugging

SAN ONOFRE UNIT 2 STEAM GENERATOR EDDY CURRENT & TUBE PLUGGING HISTORY				
Exam Date	**BOBBIN EXAM**	**ROTATING PROBE EXAM**	**TUBES PLUGGED**	**RESULTS & COMMENTS**
MFG	100%	--	21	Preservice Shop Plugs
1984	<1%	--	1	Leak Outage, Improper Annealing
1985	100%	--	330	Batwing Wear Improper Annealing, Pulled 2 tubes
1986	SG 88: 6%	--	1	Batwing Wear
1987	6%	--	142	Batwing Wear
1989	23%	Approx. 84 HL Expan. Trans. (Tie Rod Related)	62	Batwing Wear Tie Rod Denting
1991	23%	< 84 HL Expan. Trans. (Tie Rod Related)	41	Batwing Wear Tie Rod Denting
1993	66%	100% HL Expan. Trans. Approx. 668 tubes for Freespan Axial Check Approx. 184 tubes for Bobbin Follow up	32	Circ SCC - HL Expan. Trans.
1995	100%	100% HL Expan. Trans. 7% CL Expan. Trans. Approx 160 tubes for Bobbin Follow up	45	Circ SCC - HL Expan. Trans.
1997	100%	100% HL Expan. Trans. 7% CL Expan. Trans. 20% Row 1&2 U-bends Approx. 2018 tubes for Freespan Axial Check 1916 HL Dents & Dings Approx 304 tubes for Bobbin Follow up	332	Circ SCC - HL Expan. Trans. Axial SCC - Sludge Pile & Supports & Freespan Pulled 3 tubes
TOTAL TUBES - TOTAL PLUGS -		Each = 9350 S/G 88 = 477 (5.1%) S/G 89 = 545 (5.8%)	PLUG MARGIN -	1000 Tubes each S/G

APPENDIX 2 - SUPPLEMENTAL PERFORMANCE DEMONSTRATION OF THE EDDY CURRENT BOBBIN PROBE FOR FREESPAN AXIAL CRACKING

PURPOSE
The purposes of this demonstration were to:

1. Quantitatively assess flaw detection performance (using pulled tube metallography and fractography "ground truth") to demonstrate the reliability of this inspection at San Onofre Units 2 and 3.

2. Provide Probability of Detection (POD) performance input for the Condition Monitoring and Operational Assessments.

PROTOCOL
This is a summary of the protocol of this demonstration.

A. APTECH Engineering, Inc. and FRAMATOME Technologies, Inc. provided consultation and review of the Destructive Examination Planning for the San Onofre Unit 2 Pulled Tubes. This maximized the applicability of fractography and metallography results to this effort.

B. The following tasks were performed by APTECH:

- Assembly of a written protocol for the demonstration
- Assembly of orientation and practice materials
- Selection of flawed and unflawed data for both practice and the demonstration
- Briefing of participants on the purpose and protocol
- Assisting participants during analysis of practice data, as required.
- Proctoring the demonstration
- Reporting results for POD input into assessments

C. FRAMATOME Technologies, Inc. provided Qualified Data Analysts who served as "Primary" data analysts.

D. ANATEC International, Inc. provided Qualified Data Analysts who served as "Secondary" data analysts.

E. Use of these suppliers, in these roles, replicated historical actual practice. All analysts had completed San Onofre site specific performance demonstration and participated in an actual inspection in 1997.

F. The same data collection (or acquisition) technique was used for all data in the performance demonstration.

G. Data analysis was performed as a "blind" test. Tube identification numbers were changed to enhance this aspect.

H. Only eddy current indications that were quantified by metallography or fractography, after removal from the steam generator, were used as the "grading unit flaws" for evaluating POD.

I. The data contained a sufficient number of flawed and unflawed grading units to permit POD to be evaluated at an appropriate level of confidence. The number of grading units exceeded that recommended in the EPRI PWR Steam Generator Examination Guidelines for personnel and technique qualification.

J. The latest revision of the existing San Onofre Unit 2 and 3 data analysis guidelines was used. This guideline specifically delineates analyst responsibilities and their roles within the production analysis and resolution analysis process.

K. Primary and Secondary Analysis was done in separate rooms. Communication between teams was not allowed, and analysts were not allowed to re-visit a tube after results were reported.

L. Twenty data analysts participated in this demonstration. Five different analysis teams were used to demonstrate the repeatability of this technique. Each of the five analysis teams consisted of:

- a primary "production" analyst
- a secondary "production" analyst
- a primary "resolution" analyst
- a secondary "resolution" analyst

APPENDIX 3 - NRC GENERIC LETTER 95-05 EVALUATION

NRC Generic Letter (GL) 95-05, *Voltage-Based Repair Criteria for Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking*, was issued to give guidance to licensees who may wish to implement alternate steam generator tube repair criteria. Although San Onofre Unit 2 does not have Westinghouse steam generators, does not use voltage-based repair criteria, and is not requesting a license amendment to implement such an alternate steam generator tube repair criteria, this document is used as guidance to evaluate steam generator tube performance and predict plant operating capabilities as discussed in the Probabilistic Operational Assessment of Appendix 4.

To generally follow the guidance identified in GL 95-05, this evaluation used the format and criteria delineated in the generic letter. These criteria and the corresponding San Onofre Unit 2 applicable response are provided below (Note that GL Attachment 1 identified in the following criteria refers to Attachment 1 of GL 95-05):

Criterion 1) "Implementation of the applicability requirements discussed in Section 1 of GL Attachment 1. The applicability requirements ensure that the repair criteria are applied only to those intersections for which the voltage-based repair criteria were developed."

The only tubing degradation mechanism for which SCE uses an eddy current technique for sizing is mechanically induced wear of tubing at tube supports. Other tubes which have degradation detected by eddy current testing are plugged upon detection, without the use of a sizing technique to justify leaving affected tubes inservice.

A "supplemental performance demonstration" was performed to demonstrate the eddy current bobbin probe detection capabilities for freespan axial cracking. "Graded" data in this demonstration consisted of eddy current indications (nondestructive examination data) with corresponding metallurgical laboratory data (destructive examination data) in sections of pulled tubes. Appendix 2 provides a summary of the methodology of this demonstration. The Probability of Detection (POD) results are applied to the conditional probability of burst analyses and integrated leakage assessments as part of the Probabilistic Operational Assessment.

Criterion 2) "Implementation of the inspection guidance discussed in Section 3 of GL Attachment 1. The inspection guidance ensures that the techniques used to inspect steam generator tubes are consistent with the techniques used to develop the voltage-based repair criteria."

As stated in Item 1, a "supplemental performance demonstration" was performed to demonstrate the eddy current bobbin probe detection capabilities for freespan axial cracking. This demonstration was consistent with the Draft RG X.XX. "Graded" data in this demonstration consisted of eddy current indications (nondestructive examination data) with corresponding metallurgical laboratory data (destructive examination data) in sections of pulled tubes. The Probability of Detection (POD) results are applied to the conditional probability of burst analyses and integrated leakage assessments as part of the Probabilistic Operational Assessment.

Criterion 3) "Calculation of leakage according to the guidance discussed in Section 2.b of GL Attachment 1. This calculation, in conjunction with the use of licensing basis assumptions for calculating offsite and control room doses, enables licensees to demonstrate that the applicable limits of 10 CFR Part 100 and GDC 19 continue to be met. This calculation is performed using the projected EOC voltage distribution for the next cycle of operation. If it is not practical to complete this calculation prior to returning the steam generators to service, the measured EOC voltage distribution can be used (from the previous cycle of operation) as an alternative (refer to Section 2.c of GL Attachment 1) for the purposes of determining whether the reporting criteria of Section 6.a.1 apply."

A Probabilistic Operational Assessment (a "forward looking" assessment) has been completed. One output of the analysis for this assessment is calculated leakage rate during a postulated accident condition (MSLB) that is assumed to occur at the end of an assumed period of operation, just prior to a tubing inspection. Assessment output includes individual leakage rates for specific degradation mechanisms, which are also combined to provide a total calculated leakage rate.

Please refer to the discussion in Section 7.4 regarding this aspect of Probabilistic Operational Assessment, including the Assessment Results. When all corrosion mechanisms are considered and a mid-cycle inspection outage is planned, the projected value of leakage during a postulated MSLB accident remains well within available NRC criteria and guidance throughout the cycle.

Criterion 4) "Calculation of conditional burst probability according to the guidance discussed in Section 2.a of GL Attachment 1. This is a calculation to assess the voltage distribution for the next cycle of operation. The results are compared against a threshold value. This calculation is performed using the projected voltage distribution for the next cycle of operation. If it is not practical to complete this calculation prior to returning the steam generators to service, the measured end of cycle (EOC) voltage distribution can be used (from the previous cycle of operation) as an alternative (refer to Section 2.c) for the purposes of determining whether the reporting criteria of Section 6.a.3 apply."

The "conditional probability of burst" refers to the probability that the burst pressures associated with one or more indications will be less than the maximum pressure differential across the tubing associated with a postulated MSLB that is assumed to occur at the end of an assumed period of operation, just prior to a tubing inspection.

Please refer to the discussion in Section 7.3 regarding this aspect of Probabilistic Operational Assessment, including the Assessment Results. When all corrosion mechanisms are considered and a mid-cycle inspection outage is planned, the projected conditional probability of burst remains well within available NRC criteria guidance throughout the cycle.

Criterion 5) "Implementation of the operational leakage monitoring program according to the guidance discussed in Section 5 of GL Attachment 1. The operational leak rate monitoring program is a defense-in-depth measure that provides a means for identifying leaks during operation to enable repair before such leaks result in tube failure."

Primary-to-secondary leakage monitoring at San Onofre has been reviewed against available guidance to ensure that leakage monitoring measures are effective at detecting leakage and reducing the potential for tube rupture. Detection of low level leakage is accomplished primarily by chemical sampling and the condenser air ejector radiation alarm. Nitrogen-16 monitoring is available to assist in diagnosis of low-level leakage. Action levels and leakage limits in San Onofre Abnormal Operating Instructions are consistent with the "EPRI PWR Primary-to-Secondary Leak Guidelines."

The potential for tube rupture is addressed by San Onofre procedures. San Onofre procedures require unit shutdown for rates of change of steam generator tube leakage equal to 60 gpd in any one hour period. Operator responses to increases in steady-state leakage and rapid rates of change of leakage are specified in the San Onofre procedures. These procedures and responses have been reviewed against available guidance and historical leakage events.

Criterion 6) "Acquisition of tube pull data according to the guidance discussed in Section 4 of GL Attachment 1."

Three tubes were removed (pulled) from San Onofre Unit 2 to increase understanding of the following degradation mechanisms:

- Axial Cracking in Freespan Regions of Tubing
- Axial Cracking of Tubing at a Dented Eggcrate Support
- Axial Cracking of Tubing at an Undented Eggcrate Support

The following objectives, similar to those discussed in Section 4 of GL 95-05 Attachment 1, were achieved during nondestructive and destructive analysis of this tubing:

- Obtain information on the morphology of the degradation
- Obtain data on leakage and structural integrity for Condition Monitoring
- Obtain information for comparison with pulled tube information from other similar units, and for comparison with any pulled tube data that may be obtained in the future
- Assess inspection capability

The selection criteria for those tubes to be removed included the following from Section 4.b of GL 95-05 Attachment 1:

- An emphasis on removing tube intersections with large voltage indications (notably, tubes removed included the axially oriented indications with a large eddy current voltage at both a dented and undented eggcrate intersection)
- The removed tubing covered the available range of eddy current voltages

Laboratory Examination and Testing of the removed tubing included the following activities discussed in Section 4.c of GL 95-05 Attachment 1:

- Removed tubing was subjected to leak and burst tests under simulated MSLB conditions, and 3 times normal operating differential pressure to obtain leakage information at simulated MSLB conditions and to confirm the orientation of degradation. The leak rate and burst data were normalized to reflect the appropriate pressure and temperature assumptions for a postulated MSLB.

Specifically, testing pressure was increased 13% above postulated MSLB pressure to account for the testing being done at room temperature.

- Subsequent to burst testing, removed tubing was destructively examined to obtain information on degradation morphology. The destructive examination included the techniques of metallography and scanning electron microscope (SEM) fractography to characterize the degradation morphology and to characterize the largest crack networks with regard to their orientation, length, depth, and ligaments.

Criterion 7) "Reporting of results according to the guidance discussed in Section 6 of GL Attachment 1."

This report provides similar information. Notably, inspection during a planned mid-cycle outage has been shown by the Probabilistic Operational Assessment to provide a calculated conditional probability of burst (POB) that does not exceed 1×10^{-2} under postulated accident conditions (MSLB) for a single degradation mechanism at the end of the operating period.

APPENDIX 4

APTECH ENGINEERING SERVICES REPORT