Tennessee Valley Authority, Post Office Box 2000, Soddy-Daisy, Tennessee 37379

October 6, 2000

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, D.C. 20555

Gentlemen:

In the Matter of) Docket No. 50-327
Tennessee Valley Authority)

SEQUOYAH NUCLEAR PLANT (SQN) - SPECIAL REPORT ON STEAM GENERATOR(SG) ACTIVITIES COMPLETED DURING THE UNIT 1 CYCLE 10 (U1C10)REFUELING OUTAGE

References:

(1) TVA letter to NRC dated July 7, 2000, "Sequoyah Nuclear Plant (SQN) Steam Generator (SG) 120-Day Report for Dented Tube Support Plate Axial Primary Water Stress Corrosion Cracking - Alternate Repair Criteria (ARC) - Results of Condition Monitoring and Operational Assessements"

(2) NRC letter to TVA dated June 21, 2000, "Summary - May 15, 2000, Meeting to Discuss TVA's Inspection of Sequoyah Unit 1 Steam Generator Tubes During the Cycle 10 Refueling Outage.

(3) TVA letter to NRC dated June 9, 2000, "Sequoyah Nuclear Plant (SQN) - Steam Generator (SG) 90-Day Report for Voltage-Based Alternate Repair Criteria"

(4) TVA letter to NRC dated March 17, 2000, "Sequoyah Nuclear Plant (SQN) - Unit 1 Steam Generator (SG) Tube Plugging Report and Notification of Unit 1 SG Tube Inspections - Unit 1 Cycle 10 Refueling Outage"

In accordance with the requirements of SQN TS SRs 4.4.5.5.b and 4.4.5.5.c, TVA is submitting the enclosed report that includes the results of SG inservice inspections performed during the U1C10 refueling outage and the written followup information for SQN SGs categorized as C-3.

In accordance with NRC request for information during a May 15, 2000 meeting between TVA and NRC staff (reference 4), TVA has included within the subject report an operational assessment for circumferencial cracking at tube support plates (TSPs). A Westinghouse Topical Report is also provided as a separate enclosure and contains test data for mixed mode cracking.

Enclosure 1 provides SQN's U1C10 SG Inspection Report. Enclosures 2 and 3 provide copies of the proprietary and nonproprietary versions of the Westinghouse Topical Report, "Burst Pressure Data for Steam Generator Tubes with Combined Axial and Circumferential Cracks," (WCAPs 15579 and 15580, respectively).

Enclosure 4 provides the application for withholding and affidavit (CAW-00-1423) letter signed by Westinghouse, the owner of the information, as well as the proprietary information notice and copyright notice. The application for withholding and the affidavit set forth the basis on which the information may be withheld from public disclosure by NRC and addresses the considerations listed in Paragraph (b)(4), Section 2.790 of NRC regulations.

Accordingly, it is respectfully requested the information that is proprietary to Westinghouse be withheld from public disclosure in accordance with 10 CFR, Section 2.790.

Correspondence, with respect to the copyright or proprietary aspects of the subject report or the supporting Westinghouse affidavit, should reference CAW-00-1423 and should be addressed to:

John S. Galembush
Regulatory and Licensing Engineering
Westinghouse Electric Company
Box 355
Pittsburgh, Pennsylvania 15230-0355

TVA anticipates having a followup meeting with NRC in February 2001, to discuss the Westinghouse Topical Report and TVA's plan for mixed mode cracks.

Other required SG reports associated with SQN's U1C10 SG inspections were previously provided to NRC by references 1, 2, and 3.

If you have any questions, please call me at (423) 843-7170 or Jim Smith at (423) 843-6672.

Pedro Salas
Licensing and Industry Affairs Manager

Enclosures
cc (Enclosures):

Mr. R. W. Hernan, Project Manager
U.S. Nuclear Regulatory Commission
One White Flint, North
11555 Rockville Pike
Rockville, Maryland 20852-2739

NRC Resident Inspector (w/o Enclosures)
Sequoyah Nuclear Plant
2600 Igou Ferry Road
Soddy-Daisy, Tennessee 37379-3624

Regional Administrator
U.S. Nuclear Regulatory Commission
Region II
Atlanta Federal Reserve
61 Forsyth St., SW, Suite 23T85
Atlanta, Georgia 30303-3415

ENCLOSURE 1

TENNESSEE VALLEY AUTHORITY
SEQUOYAH NUCLEAR PLANT (SQN)

UNIT 1

Unit 1 Cycle 10 Refueling Outage

Steam Generator Inspection Report

(Report Includes Operational Assessment for Circumferential Cracks at Dented TSPs)

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(WCAP 15579, Revision 0, "Burst Pressure Data for Steam Generator Tubes with Combined Axial and Circumferential Cracks," dated September 2000 is provided by separate enclosure.)

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INTRODUCTION

During the scheduled Sequoyah Nuclear Plant (SQN) Unit 1 End of Cycle 10 (EOC-10) refueling outage, extensive inservice inspections were conducted in all four steam generators (SGs) to address all active and potential damage mechanisms identified in the Unit 1 Degradation Assessment. The results of the inspections were classified as follows:

	SG1	SG2	SG3	SG4
Bobbin	C-2	C-2	C-2	C-2
TTS RPC	C-2	C-2	C-2	C-2
Freespan Dents	C-1	C-1	C-1	C-1
U-Bend +Point	C-2	C-2	C-3	C-3

Dented intersection inspections are not applicable to the categorization above. A critical area/buffer zone inspection scope has been utilized since EOC-8 consistent with commitments to the NRC.

Alternate Repair Criteria (ARC) for axial outside diameter stress corrosion cracking (ODSCC) at tube support plates (TSPs) continued during this inspection. A report was issued 90 days after restart with details of this implementation. Also included in this report were the details of the C-3 categorization of the U-Bend inspection in accordance with Technical Specification (TS) Section 4.4.5.5.c for C-3 reporting.

ARC for axial primary water stress corrosion cracking (PWSCC) at dented TSPs was implemented this inspection. A report was issued 120 days after restart with details of this implementation.

This report fulfills the reporting requirements of SQN TS Section 4.4.5.5.b for reporting results of SG inservice inspection. This report also provides the NRC staff with the requested operational assessment for circumferential cracking at TSPs and test data for mixed mode cracking. (WCAP 15579 dated September 2000).

SG TUBE INSERVICE INSPECTION SCOPE

The SQN SG tube inservice inspection (ISI) initial sample and expansion for all SGs and all damage mechanisms was as follows:

100% full-length bobbin examination in all 4 SGs

100% hot leg top of tubesheet (TTS) (WEXTEX transition region) examination in all 4 SGs with +Point probe.

100% Row 1 and 2 U-Bend examinations in all 4 SGs with magnetic biased ZETEC plus point Row 1&2 U-Bend probe.

100% >=2 volt hot leg dented TSP intersections in all 4 SGs with +Point probe.

100% of <2 volt dented TSP intersections were examined during the bobbin coil examination utilizing the qualified technique for detection of PWSCC. This requires extensive analyst training and testing.

20% sample of hot leg freespan dents from TTS to second hot leg TSP

All test techniques used for detection were EPRI Appendix H qualified examination techniques and validated for use at SQN. Sizing techniques were also Appendix H qualified where available. If qualified sizing techniques did not exist, the best available technique was used.

Due to bobbin coil indications in the <2 volt dented TSP intersections, an additional 1,647 +Point exams were completed as diagnostic exams. A total of 48 axial PWSCC indications were confirmed from this inspection, which is consistent with the high overcall rates experienced during the performance demonstration.

SG TUBE INSPECTION RESULTS

As a result of plugging 200 tubes EOC-10, Unit 1 SGs are 7% plugged. Status of each SG is described in Table 1 below:

Table 1

	SG1	SG2	SG3	SG4	Total
Previously Plugged	87	127	260	281	755
Plugged EOC-10	31	48	70	51	200
Total Tubes Plugged	118	175	330	332	955

Main steam line differential pressure is 2560 psi, and three times normal differential pressure is 4110 psi.

Degradation Mechanisms Detected

AVB Wear

Based on past indications and growth rate data from past outages, three tubes were predicted to be plugged for AVB wear. A total of 62 indications were detected. None exceeded the 40% repair limit. The 40% repair limit is conservative for SQN Unit 1 SGs for structural and leakage performance criteria. The limiting indication was 37% maximum depth, which has a calculated burst pressure of 6380 psi.

Cold Leg Wastage

Four tubes were predicted to be plugged for cold leg wastage. A total of 27 indications were detected with no indications exceeding the repair limit of 40% through wall. The 40% repair limit is conservative for SQN Unit 1 SGs for structural and leakage performance criteria. The limiting indication was 39% maximum depth, which has a calculated burst pressure of 6185 psi.

ODSCC TTS

ODSCC at TTS was predicted based on SQN and industry experience. A total of 13 axial indications were identified in 12 tubes, and 4 circumferential indications in 3 tubes.

All ODSCC TTS indications were plugged on detection and sized using the +Point probe. No indication exceeded structural or leakage screening criteria.

Condition Monitoring for ODSCC TTS

The limiting ODSCC axial TTS indication is SG1 R17 C58 located at HTS -0.33. This indication was 0.44" long and had an average depth of 31.57% and a maximum depth of 52% and maximum volts 0.27. The calculated burst pressure for this indication is 5204 psi.

The only TTS circumferential ODSCC that was large enough to size was SG2 R22 C33 located at HTS-0.12. This indication measured 3.56% PDA and 44° with a maximum depth of 50%. The calculated burst pressure for this indication is 8021 psi.

All TTS ODSCC met condition monitoring performance criteria.

ODSCC TSP

The ARC for axial ODSCC at TSPs continued to be implemented this inspection and a detailed report was submitted to the staff 90 days after restart.

SQN Unit 1 experience with circumferential ODSCC associated with TSP dents was projected to increase this outage based on industry experience. A total of 22 circumferential ODSCC indications were detected at dented TSP intersections in 18 tubes. All indications were within the TSP.

All circumferential ODSCC TSP indications were plugged on detection and sized using the +Point probe. No indication exceeded structural or leakage screening criteria.

Condition Monitoring for Circumferential ODSCC TSP

The limiting circumferential ODSCC TSP indication is SG3 R25 C67. This indication measured 6.36% PDA and 53° with a maximum depth of 69%. The calculated burst pressure for this limiting indication is 7823 psi.

All circumferential ODSCC TSP indications met condition monitoring performance criteria.

An operational assessment is included in this report for circumferential ODSCC at dented TSPs as requested by the NRC staff.

PWSCC TTS

TTS PWSCC was predicted in the degradation assessment based on SQN and industry experience. A total of 9 axial indications were identified in 8 tubes, and a total of 53 circumferential indications were identified in 52 tubes.

All PWSCC TTS indications were plugged on detection and sized using the +Point probe. No indication exceeded structural or leakage screening criteria.

Condition Monitoring for PWSCC TTS

All TTS axial PWSCC indications were inside the tubesheet. The limiting indication in terms of size is SG1 R1 C7. This indication was 0.51" long and had an average depth of 62.08% and a maximum depth of 85% and maximum volts 0.64. This indication was 1.07" inside the tubesheet. The calculated burst pressure for this indication is 4228 psi. The next longest indication is 0.21" long.

The limiting TTS circumferential PWSCC is SG1 R11 C33 located at HTS-0.12. This indication measured 6.35% PDA and 88° with a maximum depth of 52%. The calculated burst pressure for this indication is 7771 psi.

All TTS PWSCC met condition monitoring performance criteria.

PWSCC TSP

An ARC was approved and implemented during the EOC-10 inspection, and a detailed condition monitoring and operational assessment for axial PWSCC at dented TSPs was submitted to the NRC 120 days after startup.

PWSCC circumferential cracking in dented TSP was predicted in the degradation assessment and 45 indications were identified in 40 tubes.

All PWSCC TSP circumferential indications were plugged on detection and sized using the +Point probe. All indications were inside the TSP. No indication exceeded structural or leakage screening criteria.

Condition Monitoring for Circumferential PWSCC TSP

The limiting circumferential PWSCC TSP indication is SG4 R6 C68. This indication measured 6.3% PDA and 73° with a maximum depth of 62%. The calculated burst pressure for this limiting indication is 7764 psi.

All circumferential PWSCC TSP indications met condition monitoring performance criteria.

An operational assessment is included in this report for circumferential PWSCC at dented TSPs as requested by the NRC staff.

PWSCC U-Bend

A low occurrence of PWSCC in the Row 1 U-bend area was predicted in the degradation assessment. Row 1 and 2 U-Bends were heat treated in situ March 1987, however, they operated several cycles prior to heat treating. It is believed that cracking initiated in the first few cycles in Row 1 and continues to grow to detectable levels. No degradation has been identified at Row 2.

A total of 2 axial PWSCC indications in 2 tubes and 9 circumferential PWSCC indications in 4 tubes were identified.

All U-Bend indications were plugged on detection and sized using the +Point probe. At least two of the indications that were plugged were more likely geometry changes in the tubing; however, the indications were sized and evaluated as cracks and the tubes were plugged. No indication exceeded structural or leakage screening criteria.

Condition Monitoring for U-Bend PWSCC

The limiting U-Bend axial PWSCC indication is SG3 R1 C77. This indication was 0.25" long and had an average depth of 46.56% and a maximum depth of 63%. The calculated burst pressure for this limiting indication is 6899 psi. The limiting U-Bend circumferential PWSCC is SG2 R1 C67. This tube had three circumferential indications at H07+8.00, H07+7.50, and H07+7.00. These indications are more likely geometry changes in the tubing due to the U-bending process and were present in the past and evaluated as geometry. All three were very small. The largest indication measured 6.79% PDA and 53° with a maximum depth of 72%. The calculated burst pressure for this limiting indication is 8942 psi.

All U-Bend PWSCC met condition monitoring performance criteria.

Mixed Mode Cracking

Mixed mode cracking at dented TSPs is addressed in the Operational Assessment for Circumferential Cracking at Dented TSPs in this report.

Other Plugged Tubes

One tube, SG3 R15 C56, was plugged due to two indications that could potentially be scratches above and below the second hot leg TSP. They were conservatively evaluated as OD axial freespan indications. One was located 0.8" down from the center of the TSP and measured 0.78" with an average depth of 14.85% and a maximum depth of 48%. The other was located 0.8" up from the center of the TSP and measured 0.66" with an average depth of 33.6% and a maximum depth of 62%.

(Other Plugged Tubes Continued)

If analysts determine that permeability variation could be masking flaws, tubes are preventively plugged. Twenty-nine tubes were preventively plugged due to permeability variation.

Five tubes were preventively plugged due to volumetric indications.

OPERATIONAL ASSESSMENT FOR CIRCUMFERENTIAL CRACKING AT DENTED TSPs

Circumferential cracking has been observed at dented TSP intersections at SQN Unit 1 for the past several cycles of operation. However, axial ODSCC and PWSCC are the limiting degradation mechanisms of concern at TSP intersections. Circumferential cracking has a much lower frequency of occurrence than axial cracking, the extent of circumferential degradation is self-limiting with very slow growth rates, and the circumferential cracking is all contained within the support plate. This combination produces very large structural margins.

At the EOC-10 eddy current inspection, circumferential cracking was identified in three TSP intersections where the dent voltage was less than 2.0 volts. Since the only inspection procedure applied to most of TSP intersections with less than 2.0 volt dents utilizes the bobbin probe, the issue of possible undetected circumferential degradation at TSP intersections with less than 2.0 volt dents has been evaluated and is described below. It should be noted that SQN's dent calling threshold is 2 volts, which is consistent with most of the industry; therefore, a dent population below 2 volts was not deteremined prior to EOC-10 inspection.

A total of 67 circumferential indications were identified at TSP intersections in all four SGs during the EOC-10 inspection. Of these, 45 were ID (PWSCC) and 22 were OD (ODSCC). The most affected SG was SG3 with 29 PWSCC and 10 ODSCC indications.

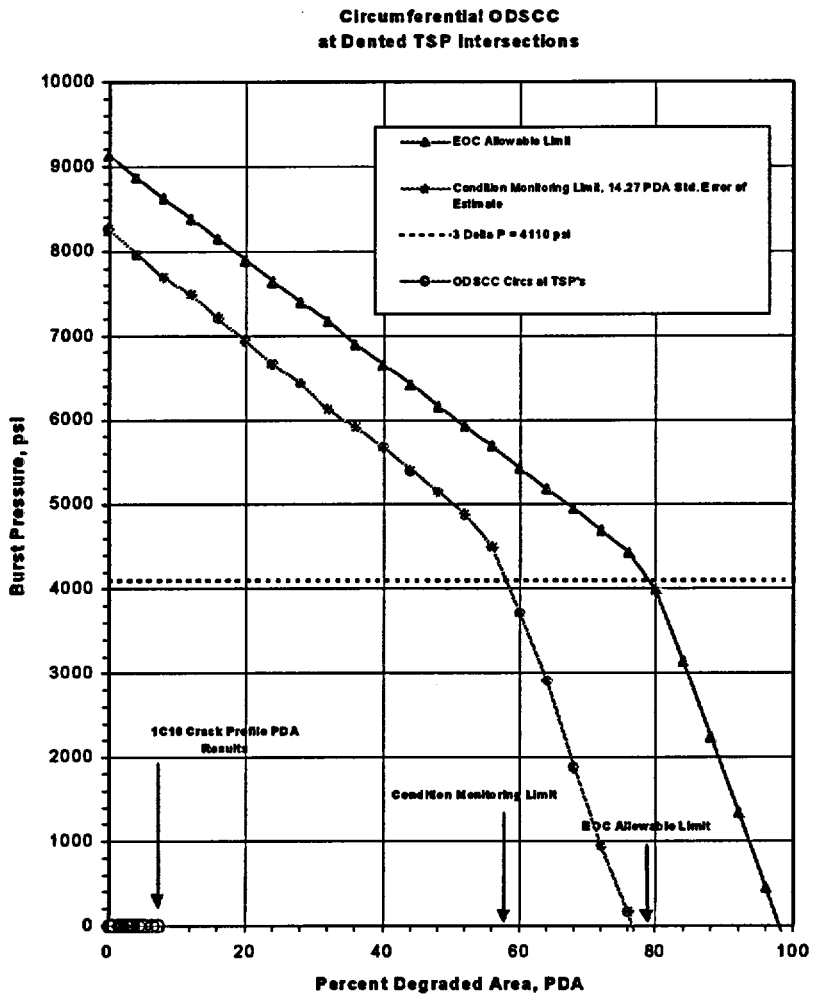
STRUCTURAL INTEGRITY EVALUATION

The very mild nature of circumferential degradation at dented TSP intersections is illustrated by the fact that the largest circumferential indication occupied only 6.36 percent of the tube annular cross-section. This represents a minor decrease in strength compared to an undegraded condition and immediately suggests that no condition monitoring or operational assessment structural issues will arise.

Condition Monitoring

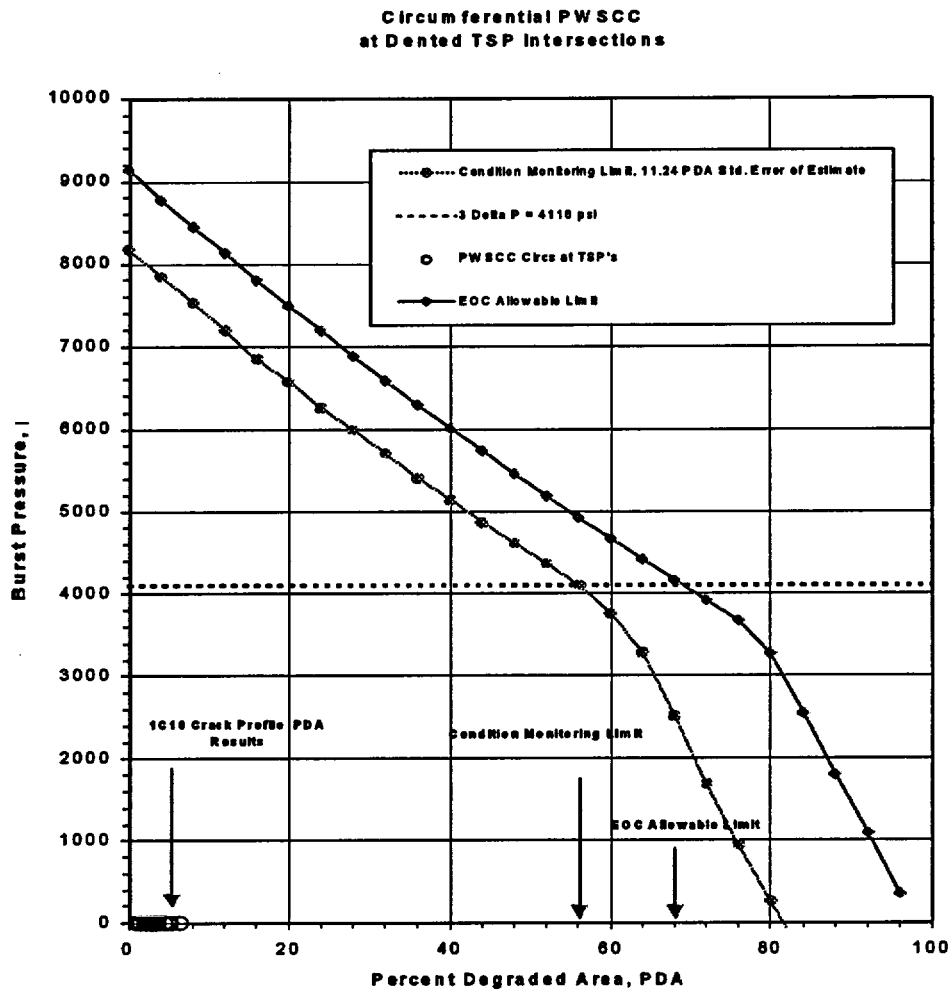
Figure 1 shows a plot of OD degraded tube burst pressure versus percent degraded area (PDA). The upper curve considers burst equation uncertainty and variation in tube tensile properties and provides the degraded tube burst pressure with a probability of 0.95 at 95% confidence when actual PDA values are specified. The lower curve includes NDE measurement uncertainty as well. It specifies the NDE measured values of PDA providing the indicated burst pressure with a probability of 0.95 at 50% confidence. This latter curve is the condition monitoring curve. Circumferential cracks on the OD with measured PDA values less than or equal to 58.2% meet the required minimum degraded tube burst pressure of 4110 psi, SQN Unit 1 performance criteria. The plotted EOC-10 inspection results are very far removed from the condition monitoring structural limit.

Figure 1



Circumferential cracking on the ID exposes the crack faces to an internal pressure which is not fully balanced by the external pressure. This additional component of loading was considered in constructing the results of Figure 2. The ID crack face pressure correction results in a lower burst pressure for an ID circumferential crack than for an OD circumferential crack with the same PDA value. Because the NDE measurement uncertainty is less for ID circumferential cracks than for OD circumferential cracks the condition monitoring structural limit for circumferential PWSCC, at 55.4% PDA, is nearly the same as for circumferential ODSCC. NDE sizing uncertainties were taken from ETSS 96702 for circumferential PWSCC and EPRI Report 107197 for circumferential ODSCC. As for circumferential ODSCC, the plotted EOC-10 inspection results for circumferential PWSCC are very far removed from the condition monitoring structural limit. For PWSCC the worst case measured PDA value is 6.30%.

Figure 2



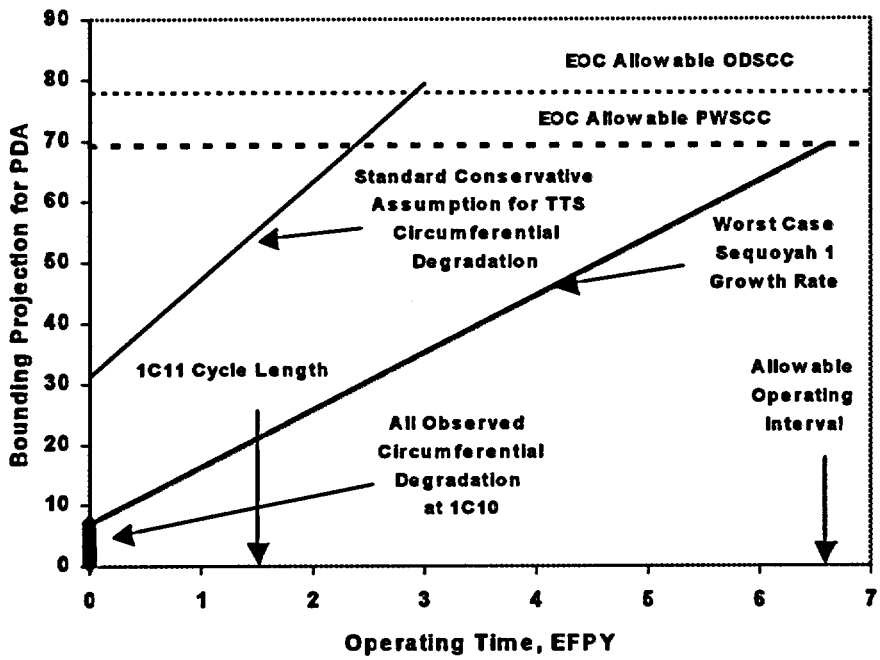
Considering all uncertainties, condition monitoring structural intergrity requirements are met for circumferential degradation at dented TSP intersections.

Operational Assessment

The upper curves of Figures 1 and 2 show that the required 3DP burst pressure will be maintained if the actual end of cycle degraded areas are less than or equal to 69.3 PDA for circumferential PWSCC or 78.0% PDA for circumferential ODSCC. A review of SQN Unit 1 data over several cycles of operating leads to a maximum growth rate for circumferential degradation of 9.4% PDA/EFPY. Even if the largest observed circumferential indication was left in service, the projected worst case would be a PDA value of 20.3% at EOC-11. This is based on an expected cycle length of 1.48 EFPY. Clearly, present or worst case projected PDA values do not challenge the minimum burst strength requirement

Figure 3 below plots circumferential degradation versus operating time. The top line is a conservative, standard, bounding approach usually applied to circumferential cracking at tubesheet expansion transitions. Structural integrity requirements are easily met for the next cycle of operation. Circumferential degradation at dented TSP intersections has exhibited better detectability, slower growth rates and much less circumferential extent compared to typical PWSCC or ODSCC at expansion transitions. The lower line in Figure 3 plots the expected worse case behavior at SQN Unit 1 for circumferential degradation at dented TSP intersections. A circumferential crack growing at the projected worst case rate could be present for 4 or more cycle of operations without becoming a structural integrity issue. Hence, possible circumferential cracking in TSP intersections with less than 2.0 volt dents, does not pose a threat to structural integrity requirements.

Figure 3



Combined Axial and Circumferential Cracks

At the EOC-10 inspection there was a total of 7 occurrences of both axial and circumferential indications at the same TSP intersection. This occurred most frequently in SG3 with 5 incidents. A tip to tip separation distance of about 0.25 inches is sufficient to neglect interaction effects at the 3DP pressure levels of interest. This is true even for 100% TW cracks. In three cases, the axial and circumferential cracks were close enough to consider them as possibly interacting. None of the interacting mixed mode cracks were close to being 100% TW, and no individual component cracks presented a near challenge to the 3DP minimum burst pressure requirement. As discussed in WCAP 15579, this fact

alone is sufficient to rule out any interaction as significant to structural integrity requirements.

The 3 possible interacting geometries had "L" shapes. The maximum effective length of the circumferential component was 0.21 inches and the maximum effective length of the axial component was 0.28 inches. Even if both cracks had been 100% TW, test results on configurations of this type point to burst pressures on the order of 7000 psi. From a condition monitoring perspective, mixed mode cracks are far from being a structural integrity issue.

In terms of an operational assessment perspective, a similar low frequency of axial and circumferential cracks in close enough proximity to be considered as interacting can be expected. Also, the same 95th percentile sizes can be expected. Table 2 identifies the 95th percentile circumferential crack length from EOC-10 inspection to be 0.27 inches and the PWSCC 95th percentile axial crack length is 0.44 inches. The bounding 95th percentile average depth is 57% TW.

Table 2

Degradation Mechanism	Upper 95th Percentile Effective Length	Upper 95th Percentile Effective Depth	Upper 95th Percentile Maximum Depth
Axial PWSCC	0.44"	42%	56%
Circumferential PWSCC	0.24"	55%	69%
Circumferential ODSCC	0.27"	57%	77%

Test results in WCAP 15579 show that mixed mode interactions, assuming all components at 95th percentile worst case levels, will not violate minimum strength requirements. The preceding arguments assume a freespan condition. Mixed mode interactions leading to significant strength reductions require radial outward displacement of the tube wall. This is not a likely circumstance with dented TSP intersections, even under accident conditions. From an operational assessment perspective, mixed mode cracks are not a structural integrity issue.

In terms of axial ODSCC cracks possibly interacting with circumferential cracks, projected bobbin voltage levels must first be converted to degraded tube burst pressures. The worst case projected axial ODSCC bobbin voltage is about 3.1 volts. This converts to an estimated burst pressure of about 6400 psi. For axial crack dimensions in the range indicated by this burst pressure, test data in WCAP 15579 points to about a 10% strength reduction for an interaction with a 100% TW circumferential crack with a length of 0.24 inches. The upper 95th percentile circumferential crack length at EOC was 0.24 inches but the upper 95th percentile circumferential crack depth was 57% TW.

Hence, an assumed strength reduction of 10% is conservative. Clearly, interaction of 95th percentile worst case axial ODSCC cracks and circumferential cracks does not produce a challenge to required minimum burst strengths of 3ΔP or 1.43 SLB. Given the very low frequency of axial and circumferential cracks being close enough to even consider interaction, an assumed interaction at the 95th percentile crack size is very conservative. Additionally, the low bobbin voltage levels at SQN Unit 1 argue against the possibility of axial and circumferential crack depths needed to consider possible interactions strong enough to challenge minimum strength requirements.

In summary, all circumferential indications, single or mixed mode, meet structural integrity performance criteria for condition monitoring and operational assessment.

LEAKAGE INTEGRITY EVALUATION

In terms of leakage integrity at EOC-10, the maximum reported circumferential crack depth is 77 %TW and the maximum Plus Point voltage is 1.09 volts. There is no challenge to leakage integrity on either basis. However, an operational assessment of leakage integrity was performed to specifically consider possible contributions to projected leak rates from circumferential degradation at TSP intersections with less than 2.0 volt dents. The following paragraphs describe this analysis and projected leak rate integrity for cycle 11. The possible effect of interacting axial and circumferential cracks increasing leak rates is considered.

EOC-11 Indication Projections

Because the bobbin coil probe is the technology utilized to detect degradation in less than 2 volt dented intersections, it is necessary to estimate a number of potentially missed indications in this population. An estimate can be made based on comparison to the observed statistics for axial PWSCC indications.

It is acceptable to use the experience of axial PWSCC for projecting circumferential PWSCC and circumferential ODSCC because of the similarities in crack morphology. One method of characterizing crack shape is the ratio of maximum depth to structural average depth. The range of crack shapes or morphologies is characterized by the standard deviation of the maximum depth to structural depth shape ratio. As expected, axial crack profiles at dented TSP intersections had an average shape ratio of about 1.28 in agreement with an extensive database of pulled tube results and laboratory specimen data. Figures 4 and 5 show plots of maximum depth versus structural average depth for circumferential cracks determined in the same manner. Figure 4 shows that circumferential PWSCC at dented TSP intersections exhibits the same morphology as does axial PWSCC. The data points for circumferential crack profiles follow the best fit line for axial crack profiles. Figure 5 shows that the same is true for circumferential ODSCC crack profiles.

Figure 4

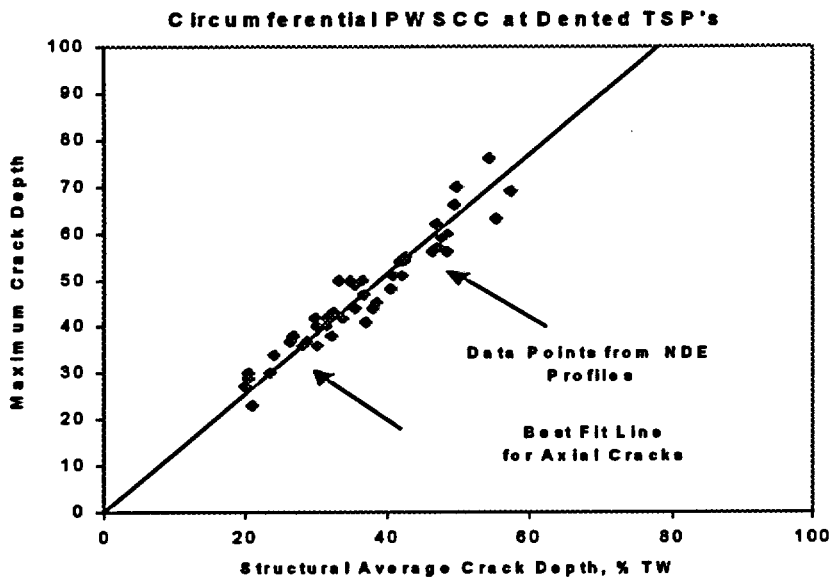
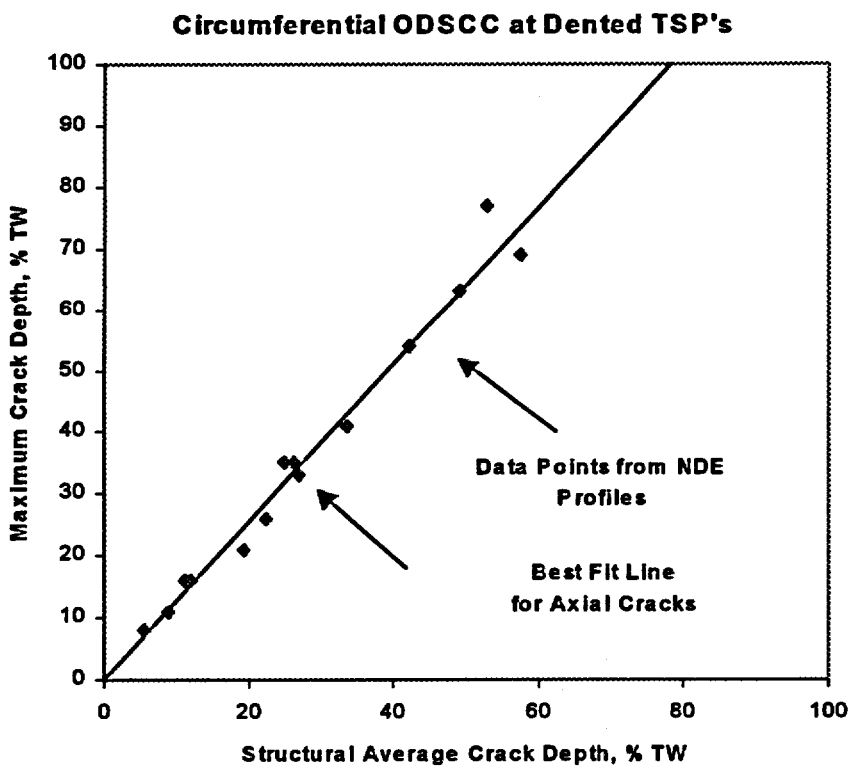


Figure 5



The similarity in crack profiles between axial and circumferential cracks at dent TSP intersections is further illustrated by Figures 6 through 8 below. Profiles for all ID and OD circumferential cracks are plotted in Figures 6 and 7 respectively. All axial profiles are plotted for SG3 on Figure 8. Circumferential profiles for PWSCC and ODSCC are essentially equivalent. Circumferential cracks are shorter than the axial cracks shown in Figure 8, which is expected due to the localized strain.

Figure 6

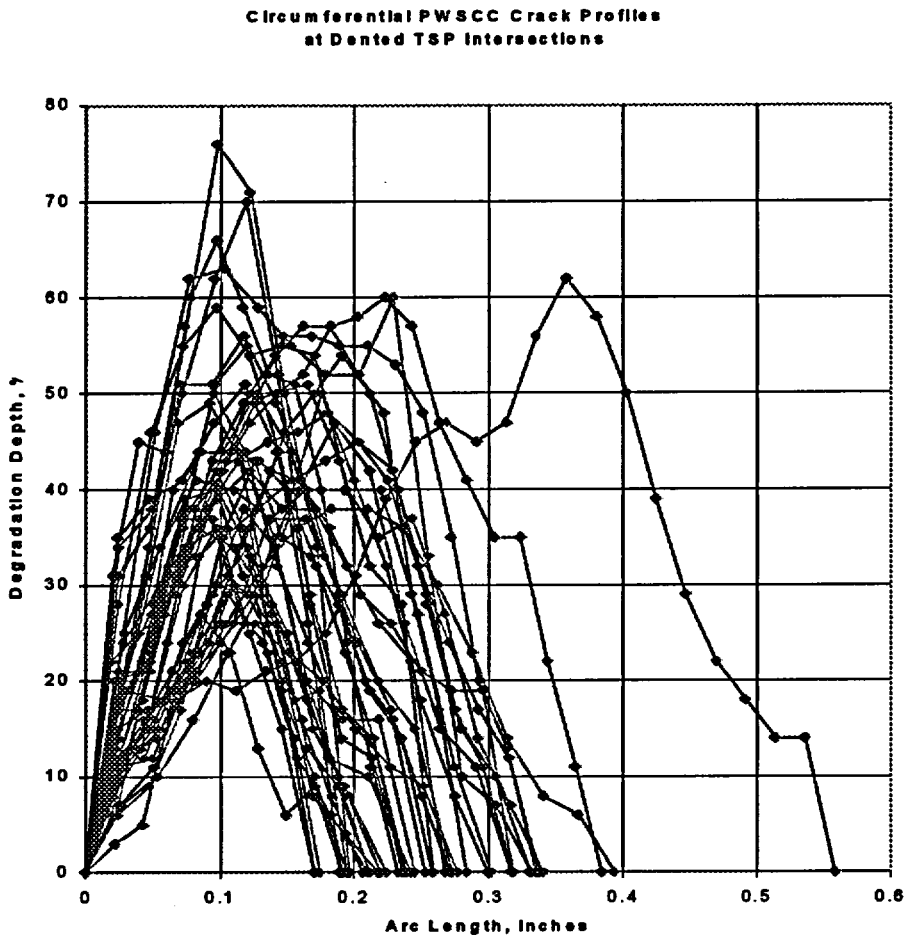


Figure 7

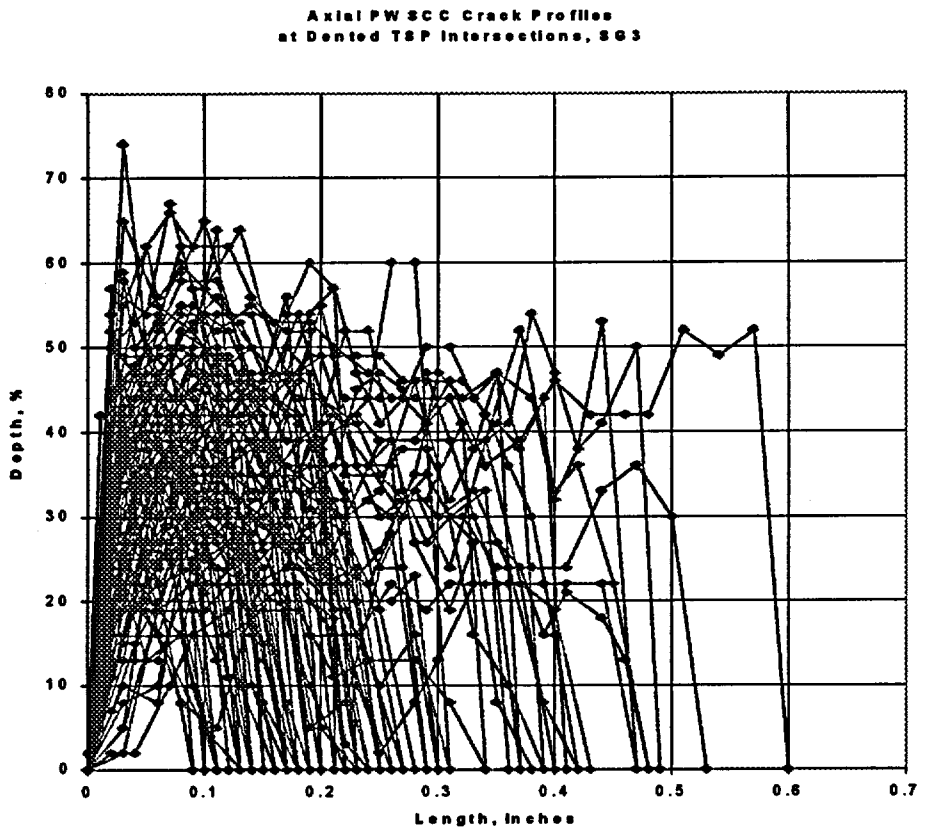
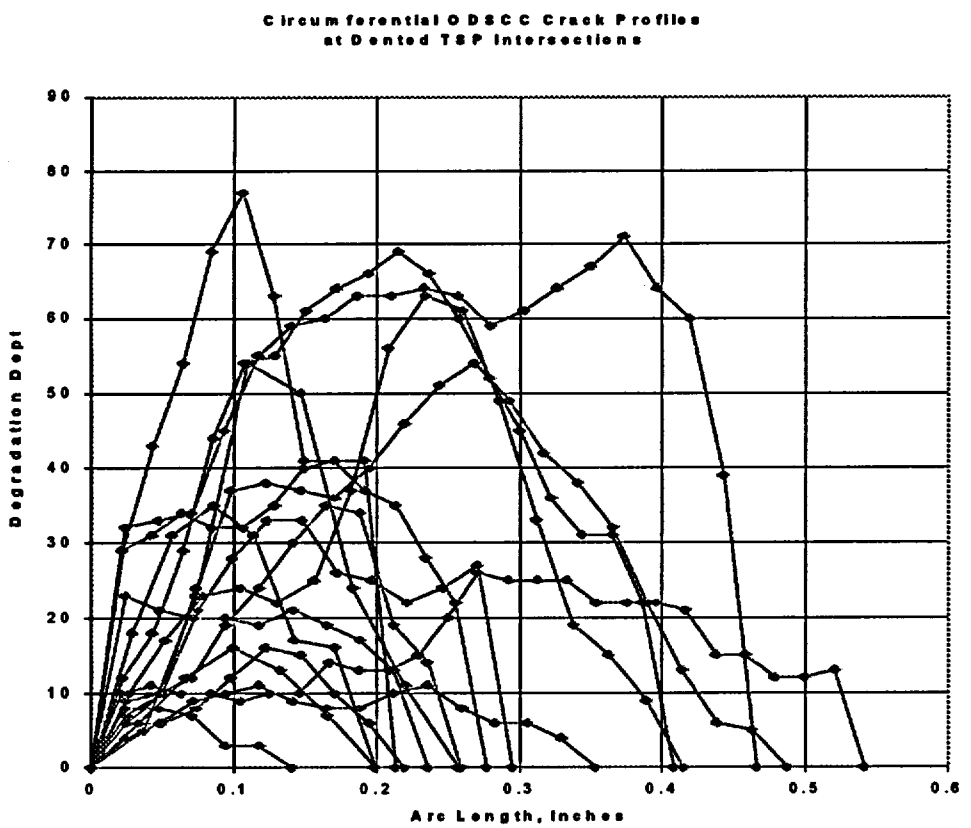
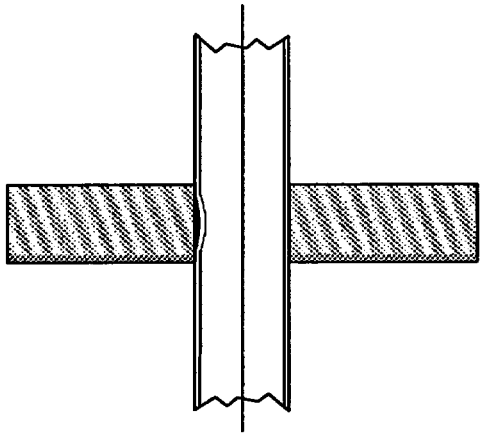


Figure 8



The similarity of axial and circumferential crack profiles at dented TSP intersections is a consequence of the mode of loading. Denting at SQN Unit 1 intersections consists of local regions of radial loading on the OD of the tubing. Figure 9 illustrates this type of denting.

Figure 9



The limited circumferential extent of the dents dictate short circumferential crack lengths. As the tube deforms radially inward, axial tensile stresses develop on both the ID and OD of the tubing but at different axial locations. Hence both ID and OD circumferential cracks may develop. The cyclindrical tube geometry leads to tube distortions which are longer in the axial direction than in the circumferential direction. This is consistent with longer axial cracks compared to circumferential cracks. Further, all circumferential cracks were contained within the TSP crevice, which is also expected.

Over the last four inspections at SQN Unit 1, about 74% of the total number of axial PWSCC indications have appeared at intersections with greater than or equal to 2.0 volt dents. At EOC-10 this value was 70%. It is reasonable to assume that the percentage of circumferential indications at intersections with less than 2.0 volt dents will be about the same as the percentage of circumferential indications at intersections with greater than or equal to 2 volt dents since denting drives the ocurrence of both axial and circumferential cracking. Dividing the number of circumferential indications found at TSP intersections with dents greater than 2.0 volts by 0.7 provides the best estimate of the total number of circumferential indications that would have been identified if all dented intersections, irrespective of dent voltage, had been inspected using the Plus Point probe. This would increase the number of cracks present in dented TSPs at EOC-10 from 67 to 96.

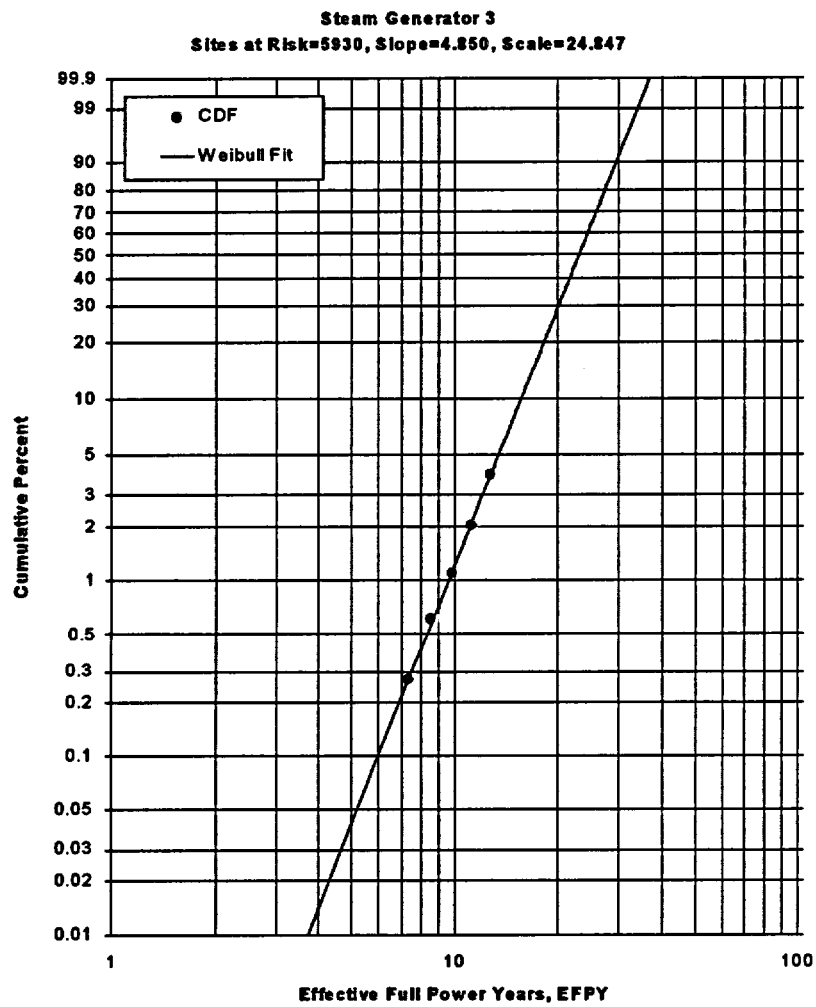
The nature of loading at dents at SQN Unit 1 and observed crack morphologies support the contention that circumferential ODSCC at dented TSP intersections is dent driven in the same manner as axial and circumferential PWSCC. Hence the number of ODSCC and PWSCC circumferential indications at dented TSP intersections can be combined. This has been done to create Table 3, which summarizes the history of circumferential cracking at dented TSP intersections.

Table 3

	EOC-7		EOC-8		EOC-9		EOC-10		EOC-11
SG	Detected	Estimated	Detected	Estimated	Detected	Estimated	Detected	Estimated	Estimated for 100% Inspection
1	7	10	1	1	2	3	9	13	21
2	0	0	1	1	2	3	5	7	14
3	11	16	14	20	20	29	39	56	112
4	7	10	51	73	15	21	14	20	27
Total	25	36	67	95	39	56	67	96	174

Using these assumptions, a Weibull plot of the sum of detected plus estimated undetected indications versus operating time for the limiting SG is shown in Figure 10.

Figure 10



Using this plot, the projected number of indications expected at EOC-11 is a total of 112 circumferential indications for the worst case, SG3, at EOC-11. This is a best estimate approach and is also included on Table 3.

A worst case approach can also be developed by assuming the number of undetected circumferential cracks in less than 2.0 volt dented intersections is about equal to the number of axial cracks found at these locations, which we know to be conservative. Following this logic, the worst case projection for the worst case SG at EOC-11 is approximately 180 circumferential cracks at dented TSP intersections.

MultiCycle Analysis Approach

The general methodology for the multi cycle analysis approach is simply a Monte Carlo simulation of the physical processes of initiation and growth of corrosion degradation. Computer simulations of eddy current inspections are performed at time periods corresponding to actual past inspections and planned future inspections. Computer generated projections of the number of degradation sites and the severity of degradation (eg. length and depth of circumferential cracks) can be compared with actual past observations to benchmark the calculations. When computer calculations agree with past observations, one can be confident that projections for future operation are reliable.

Multicycle Monte Carlo projections deal with simulations of actual degradation severity. When degradation is detected, sizing by eddy current methods is employed. This act of measurement introduces a measurement error. Monte Carlo simulations add a simulated measurement error to the projected actual degradation dimensions. Thus computer simulated sizing measurements can be compared directly with actual results of eddy current inspections. This is the key benchmark in the multicycle analysis approach. If the projected distributions of degradation sizes match actual observed NDE results, then the Monte Carlo simulations accurately reflect the actual state of degradation, both detected and undetected, in the SG of interest. Matching requires use of realistic detection, growth and NDE sizing parameters since these processes interact over multiple cycles of operation to produce the actual state of tubing degradation present in a SG.

In present calculations, detected circumferential degradation is removed from further SG simulations to model the plug on detection repair scenario that is followed at SQN Unit 1. The scope of eddy current inspection can be selected for each inspection. This feature of the multi cycle approach is especially useful for the evaluation of possibly undetected circumferential PWSCC and circumferential ODSCC in dented TSP intersections. Analyses were performed for a wide range of inspection coverages in past cycles of operaton going back to EOC-7. The key question is the number of indications that will be found if all possible sites of circumferential degradation at TSP intersections are inspected

at EOC-11 with a +Point coil. This number establishes the true extent of circumferential degradation at TSP intersections.

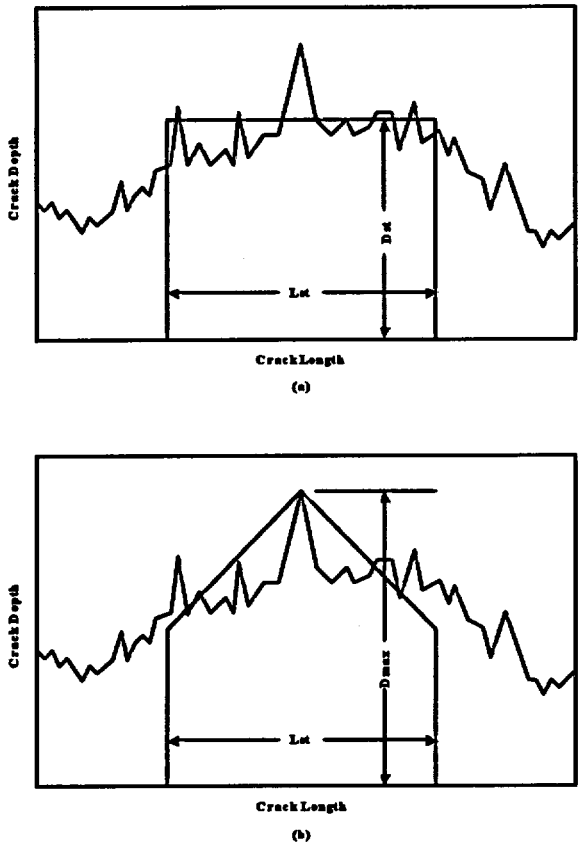
The simulated levels of degradation allow computation of the leak rate of all degraded tubes projected to be present in a SG. This includes detected as well as undetected degradation. Simulations also include degradation that was not detected because it was not inspected with a +Point coil. Calculations are performed for projected conditions at each simulated inspection time period. Since many simulations are performed, data is provided for complete statistical and probabilistic evaluations.

Leak Rate Projections

The site specific growth rates of circumferential degradation, both PWSCC and ODSCC, are small. The small changes in percent degraded areas are consistent with a self-limited circumferential extent and length and depth growth rates which match that of axial PWSCC. Hence, axial length and depth growth rates used in applications of a PWSCC ARC, as updated with the latest SQN Unit 1 growth rates, were applied in the leakage analyses of circumferential degradation.

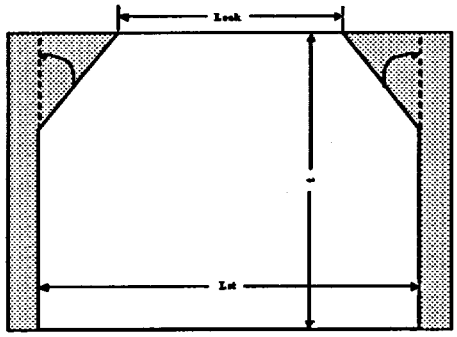
Circumferential cracks were grown in length and depth using the multicycle Monte Carlo simulation approach. Crack profiles were characterized by a structural effective length, a structural average depth and a shape ratio. The shape ratio is the ratio of maximum depth to structural average depth. Figure 11 illustrates this characterization process and illustrates the method by which wall penetration and throughwall leaking crack lengths are determined. The area under the idealized tent shape crack increases according to the Monte Carlo selected structural average depth growth rate.

Figure 11



When the tip of the idealized crack reaches the tube wall, any further increases in crack area are created by rotation of the sloping sides of the crack (Figure 12 below).

Figure 12

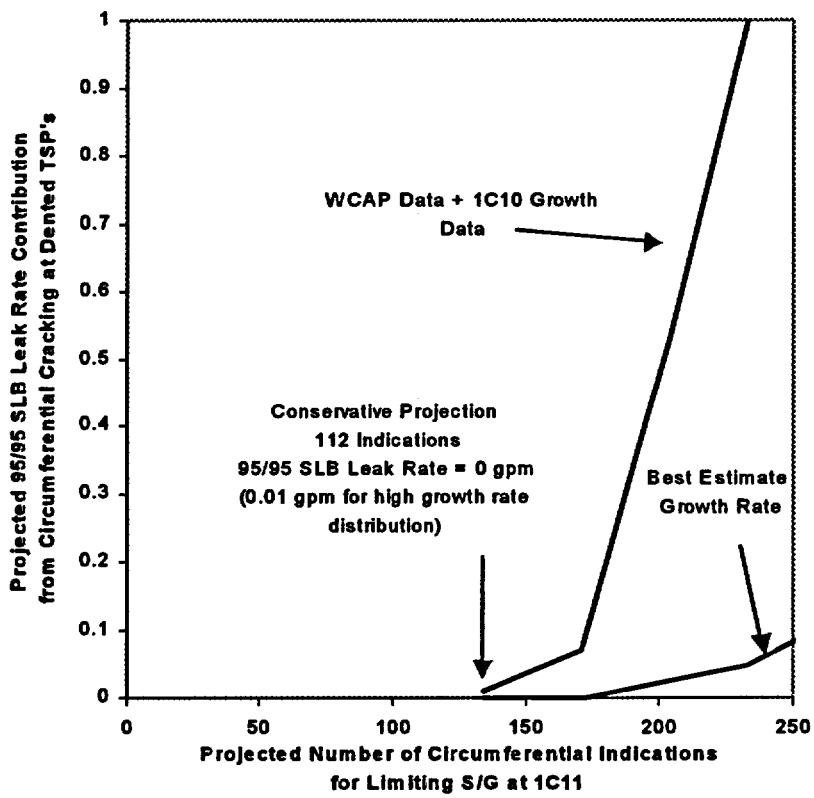


This maximizes the extent of throughwall crack length generated by an increase in crack area and hence maximizes the calculated leak rate. Mechanical tearing contributions to throughwall crack lengths are included via a circumferential crack tearing equation found in the EPRI Flaw Handbook. It is a modified version of the equation used for axial cracks, commonly referred to as the Cochet or Framatome equation. No strengthening effects of non planar ligaments were considered.

Given a throughwall crack length, determined by the processes just described, crack opening areas were calculated using standard formulations in the EPRI Ductile Fracture Handbook. Crack tip plasticity contributions to the crack opening areas were included according to equations verified by experimental measurements. Upper bound leak rates were then calculated using the leak rate equations described in EPRI Report TR-107197. Since many simulations of a SG operating cycles were performed, distributions of projected end of cycle leak rates at postulated SLB conditions could be constructed.

Calculations were performed for the worst case SG, SG3. Upper 95th percentile projected SLB leak rates at 95% confidence versus number of circumferential indications is plotted in Figure 13. The expected number if all dented TSP intersections are inspected is 112. That is, if all possible degraded sites (in the time frame of interest) are inspected.

Figure 13



From Figure 13, the best estimate of the 95/95 projected SLB leak rate at EOC-11 is 0.0 gpm from circumferential cracking, either PWSCC or ODSCC, at dented TSP intersections. Detected and undetected cracks over multiple cycles of operation are all included in this calculation. The best estimate number of indications with the worst growth rate distribution gives a 95/95 SLB leak rate of 0.01 gpm and the worst case number of indications (most uninspected locations in the past) with the worst case growth rate distribution leads to a worst/worst case 95/95 SLB leak rate projection of 0.07 gpm. Even the worst/worst case scenario is a modest, managable leak rate and well below 1 gpm.

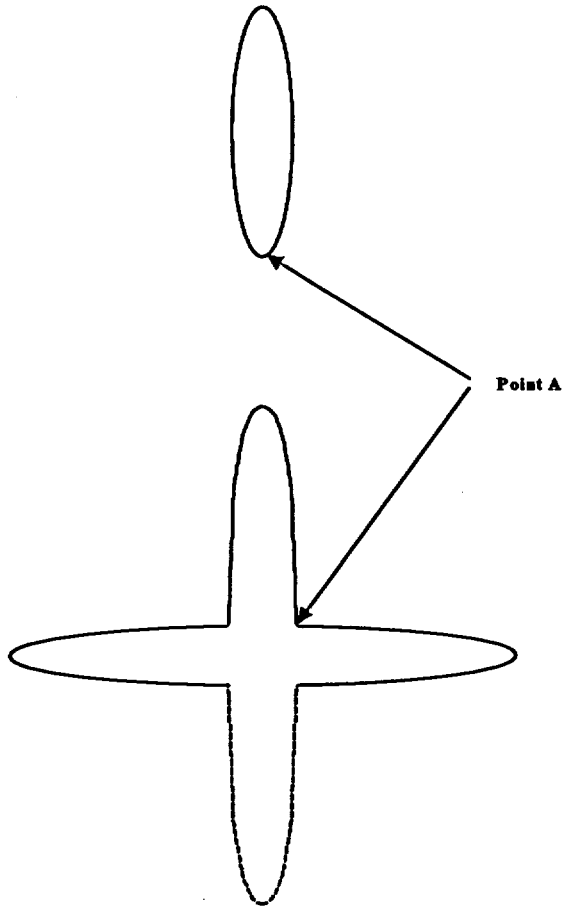
An independent analysis performed by Westinghouse considering growth of specific profiles supports the present conclusion of essentially neglible leakage under projected accident conditions.

Effects of Intersecting Axial and Circumferential Cracks

As discussed earlier, there are few instances of intersections with potentially interacting axial and circumferential cracks at dented TSP intersections and there is no structural integrity issue. In terms of leakage integrity, the differential pressure of interest is 2560 psi. If both intersecting axial and circumferential cracks are 100% TW, an unlikely scenario, increased crack opening areas will develop and thus leak rates will increase. If radial displacements are not possible due to dented intersections, then intersection of axial and circumferential cracks cannot cause flap type openings. If freespan conditions are conservatively assumed, flap type openings are not an issue at 2560 psi given the limited throughwall crack lengths involved. However, intersecting axial and circumferential cracks can lead to increased in-plane crack opening areas and thus increased leak rates.

Given the nature of loading, an intersected crack will not experience much in the way of increased crack opening if the intersection point is some distance away from the crack tip. If the tip of one crack intersects a significantly longer crack, the situation is related to a crack intersecting a free surface. This is shown in Figure 14.

Figure 14



The crack tip is released and the tip springs open. A straightforward center cracked/edge cracked panel fracture mechanics analysis shows that the upper bound effect is to develop a released tip crack opening equal to the center opening of a crack twice as long. The elastic crack opening area essentially doubles. Figure 15 illustrates the increase in leak rates calculated by assuming the released crack tip leak rate is equivalent to one half of the leak rate of a crack twice as long. This increase ratio (released tip condition to isolated single crack) is a function of crack length. Also, the full free surface release effect is only realized if the released tip has intersected a crack much longer than itself.

Figure 15

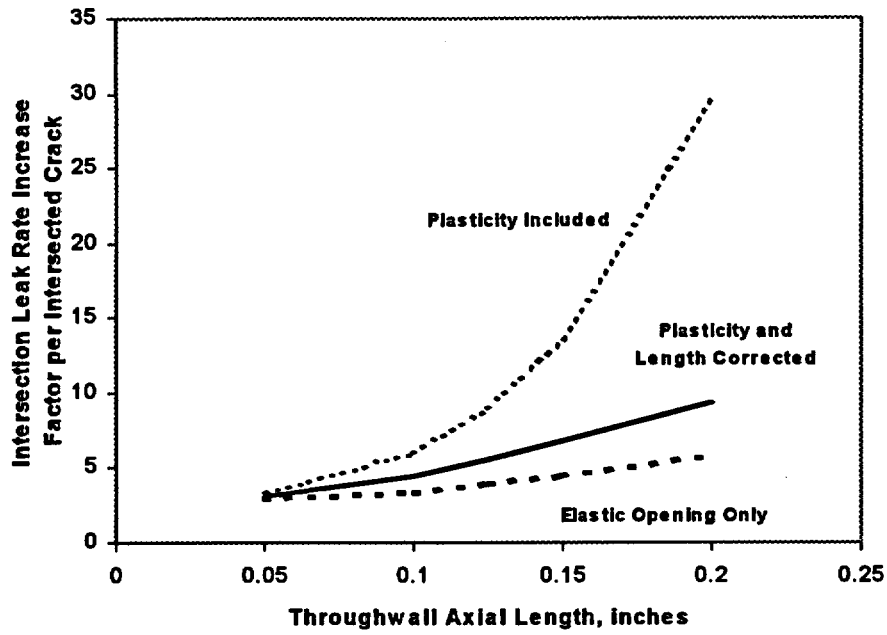
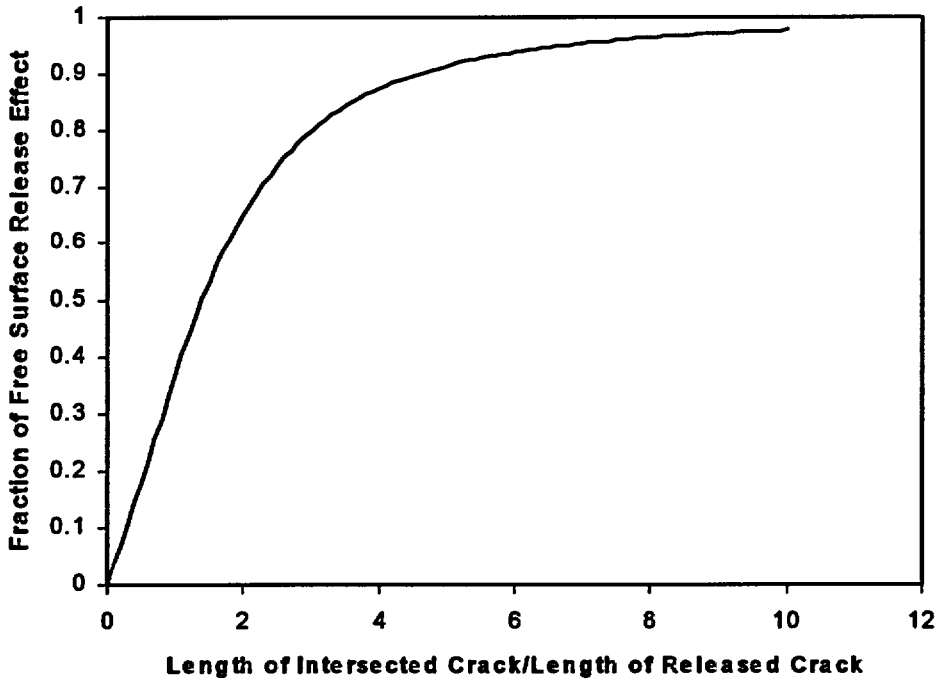


Figure 16 illustrates the fraction of the free surface released effect actually observed as a function of ratio of the length of intersected crack to the length of the crack with a released crack tip.

Figure 16



The solid line in Figure 15 combines plasticity effects on crack opening and assumes that all axial cracks intersect circumferential cracks with an upper 95th percentile length of 0.25 inches and a depth 100% TW. Accounting for plasticity is the same as lengthening the crack, hence the true leak rate increase factor for single cracks will be between the solid line and lower dotted line in Figure 15. A leak rate increase by a factor of about 10 is a conservative approach for axial cracks which undergo crack tip release. Using the same calculation, a leak rate increase of about 5 is obtained for circumferential cracks intersecting longer axial cracks.

The multiplying factor to be applied to the projected SLB leak rates for axial degradation at TSP intersections, both the axial PWSCC ARC and axial ODSCC bobbin voltage ARC, to account for the possibility intersecting cracks, is derived below. The following definitions, on a per SG basis, are used:

Q = projected ARC SLB leak rate
N = number of axial cracks
N_L = number of leaking axial cracks
N_i = number of leaking axial cracks intersected by a circumferential crack
f = frequency of intersecting axial and circumferential cracks
Q_T = total projected ARC SLB leak rate including interaction effects
$M_L = Q_T/Q$
$\alpha = N_L/N$
q_i = leak rate for an intersected crack.

The leak rate for an intersected crack is taken as 10 times the average crack leak rate, that is,

$$q_i = 10 \bullet Q/N_L$$

The intersections with a leaking crack is equal to the total number of crack intersections times the probability that the intersected crack is a leaker.

$$N_i = \alpha \bullet f \bullet N$$

The total leak rate is the sum of leak rates for cracks with intersections plus the leak rates of cracks without intersections.

$$Q_T = q_i \bullet N_i + Q/N_L \bullet (N_L - N_i)$$

$$Q_T = 10 \bullet Q/N_L \bullet N_i + Q/N_L \bullet (N_L - N_I)$$

$$Q_T = 10 \bullet Q/N_L \bullet \alpha \bullet f \bullet N + Q \bullet (1 - \alpha \bullet f \bullet N/N_L)$$

Since $\alpha = N_L/N$, then:

$$Q_T = 10 \bullet Q \bullet f + Q \bullet (1 - f)$$
$$Q_T = Q \bullet (1 - 9 \bullet f)$$
$$M_L = 1 + 9 \bullet f$$

In the worse case SG, SG3, the frequency of occurrence of axial and circumferential cracks at the same dented TSP intersection is 0.031. Given that an axial crack is present, there is a 0.031 chance of a circumferential crack also being present. Based on this same data, there is a 0.015 chance that the axial and circumferential cracks will be close enough to intersect. If 100% TW cracking is assumed, then an intersection frequency of 0.015 with a factor of 10 leak rate increase for intersections leads to a total leak rate increase by a factor of 1.13. That is, the projected leak rates for axial ODSCC and axial PWSCC should be multiplied by a factor of 1.13 to account for the effects of intersecting axial and circumferential cracks.

A number of other assumptions could be reasonably applied to the problem of possibly intersecting axial and circumferential cracks. The present argument is not that the leak rate increase factor should be exactly 1.13, but that the contribution of possibly intersecting axial and circumferential cracks is small and manageable. It is essentially covered by the conservatism within the bobbin ARC and the axial PWSCC ARC leak rate analyses.

In conclusion, all ODSCC and PWSCC circumferential cracks, either single or in a mixed mode configuration, meet condition monitoring and operational assessment performance criteria. Total projected leakage from the ODSCC ARC and PWSCC ARC have been increased by a factor of 1.13 and still remain well under limits.

SECONDARY SIDE INSPECTION SCOPE AND RESULTS

Cracked Support Plate Indications

Cracked tube support plate indications (CSIs) are indications of cracks in the tube support plates and not necessarily indicative of tube degradation. These are detected during 100% automated analysis of bobbin data.

SQN Unit 1 SGs do not have extensive support plate cracking. Cracked TSPs were evaluated for potential star drop-out conditions and none were identified. Therefore, design basis function of the support plate has not been lost. There is also no evidence of wrapper drop or wrapper degradation.

Upper Internals Inspection

No upper internals inspection was necessary during this inspection.

Sludge Lancing

Sludge lancing was performed on all four SGs: 51 pounds of sludge was removed from SG1, 49 pounds from SG2, 56 pounds from SG3, and 90 pounds from SG4. A post-lance inspection confirmed that the top of the tubesheet on all generators was clean.

Foreign Object Search and Retrieval (FOSAR)

Foreign object search and retrieval was completed on all four SGs prior to closure and all identified foreign objects were retrieved.

CONCLUSIONS

The NDE testing completed on the SQN Unit 1 SGs and plugging of defective tubes met the Technical Specification and ASME Section XI code requirements for inservice inspection and structural and leakage integrity has been demonstrated; therefore, each SG has been demonstrated operable.

Alternate Repair Criteria was implemented in accordance with the Unit 1 Technical Specification License Condition 2.C(9)(d) and SQN Technical Specification Change 99-12.

Based on the criteria of 10 CFR 50.59 and utilizing the criteria of Draft Regulatory Guide 1.121, TVA concludes that the integrity of the SQN Unit 1 SGs was maintained during Cycle 10 operation and will be maintained through full Cycle 11 and does not represent an unreviewed safety question.

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ENCLOSURE 3

TENNESSEE VALLEY AUTHORITY
SEQUOYAH NUCLEAR PLANT (SQN)

UNIT 1

WCAP-15580, Revision 0

"Burst Pressure Data for Steam Generator Tubes with Combined Axial and Circumferential Cracks"

(Westinghouse Non-Proprietary Class 3)