Public Service
Electric and Gas
Company

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United States Nuclear Regulatory Commission
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Washington, D.C. 20555

Gentlemen:

RESPONSE TO GENERIC LETTER 95-03
CIRCUMFERENTIAL CRACKING OF STEAM GENERATOR TUBES
SALEM GENERATING STATION UNITS 1 AND 2
FACILITY OPERATING LICENSE NOS. DPR-70 AND DPR-75
DOCKET NOS. 50-272 AND 50-311

Generic Letter (GL) 95-03, Circumferential Cracking of Steam Generator Tubes, requested Public Service Electric and Gas Company (PSE&G) to:

1) Evaluate recent operating experience with respect to the detection and sizing of circumferential indications to determine the applicability to the plants.

2) On the basis of the evaluation in Item 1 above, past inspection scope and results, susceptibility to circumferential cracking, threshold of detection, expected or inferred crack growth rates, and other relevant factors, develop a safety assessment justifying continued operation until the next scheduled steam generator tube inspections are performed.

3) Develop plans for the next steam generator tube inspections as they pertain to the detection of circumferential cracking. The inspection plans should address, but not be limited to, scope (including sample expansion criteria, if applicable), methods, equipment, and criteria (including personnel training and qualification).

PSE&G's response to Items 1 through 3 above is provided in Attachment 1. The NRR Licensing Project Manager granted an extension of the due date for submittal of this response until July 17, 1995 to allow PSE&G sufficient time to review generic input received from the industry, and incorporate this information into the attached response. This extension also

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allowed PSE&G to develop plans for steam generator tube inspections as they pertain to detection of circumferential cracking to address Item 3 above during the ongoing Salem Unit 1 and 2 outages. These plans are discussed in detail in Attachment 1.

Should you have any questions regarding this request, please do not hesitate to contact us.

Sincerely,

Attachment (1)
Affidavit

C Mr. T. T. Martin, Administrator - Region I
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REF: LR-N95096

STATE OF NEW JERSEY)
) SS.
COUNTY OF SALEM)

J. Hagan, being duly sworn according to law deposes and says:

I am Vice President - Nuclear Operations of Public Service Electric and Gas Company, and as such, I find the matters set forth in the above referenced letter, concerning Salem Generating Station Unit Nos. 1 and 2, are true to the best of my knowledge, information and belief.

[signature]

Subscribed and Sworn to before me
this 17th day of July, 1995

[signature]
Notary Public of New Jersey

My Commission expires on KIMBERLY JO BROWN NOTARY PUBLIC OF NEW JERSEY My Commission Expires April 21, 1998

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1.0 INTRODUCTION

Recent examination of steam generator tubing at Maine Yankee has identified a large number of circumferential indications at the top-of-tubesheet region. These most recent inspection findings, coupled with previously documented inspection results regarding circumferential cracking, have led to the issuance of NRC Generic Letter 95-03, "Circumferential Cracking of Steam Generator Tubes" on April 28, 1995. The information detailed herein will address the requested actions of Generic Letter 95-03 as they pertain to Westinghouse designed and manufactured steam generators in general, and specifically to Salem Units 1 and 2.

The most recent inspection findings concerning steam generator tube expansion regions (Maine Yankee and Arkansas Nuclear One Unit 2) appear to have impacted those steam generators using the Combustion-Engineering (C-E) EXPLANSION process more than others. While there are similarities between the C-E EXPLANSION process and the Westinghouse WEXTEX process, the degree to which the Westinghouse units, regardless of expansion process, have been affected by circumferential cracking is significantly less than the most recent experience of the C-E units. Furthermore, the reported sludge pile height at Maine Yankee (which may have influenced detectability) is not representative of currently operating Westinghouse units or the Salem Units.

Available historical information shows that, for some Westinghouse plants, circumferential indications have been detected in the tubesheet region at the tube expansion transition, at the Row 1 and 2 U-bend tangent points, and at one plant (two twin units), at dented tube support plate intersections. There have also been indications detected in the parent tube of sleeved joints. Additionally, high cycle fatigue failures of tubes at dented upper tube support plates combined with an unsupported condition (no Anti-Vibration Bar (AVB) contact) are locations of concern for circumferential cracking in Westinghouse steam generators.

Many of the Westinghouse units, including both the Salem Units, have implemented specific measures to mitigate the recognized susceptibility of these regions of the steam generator tube bundle to the potential for circumferential cracking. These measures include: 1) The tube expansion transition region (WEXTEX) at the top of tube sheet has been shot peened; 2) The short radius Row 1 tubes have been administratively plugged, and the Row 2 tube U-bends have been stress relief heat treated (UBHT); 3) Tubes potentially susceptible to high cycle fatigue have been administratively plugged; and 4) Augmented inspections are routinely performed on regions of the tube bundle susceptible to circumferential cracking.

Due in part to the measures implemented at many units, successive inspection results using Rotating Pancake Coil (RPC) probes for Westinghouse plants with explosively expanded tubes have indicated a steadily declining numbers of new indications, declining angular extent and, to the degree determined, very low growth rates. The only occurrences of significant levels of circumferential cracking have been found when plants perform the first large scale RPC inspection.

2.0 SAFETY ASSESSMENT

Generic Letter 95-03 requested licensees to develop a safety assessment justifying continued plant operation until the next steam generator tube inspections are performed. Both Salem units are currently in an outage, therefore, a safety assessment to justify continued operation until the next steam generator tube inspections are performed does not apply. During these outages, PSE&G will complete inspection of the Salem Unit 1 and 2 steam generator tubes as discussed in Section 5.0.

Collectively, the items discussed above and detailed in the following text, combined with the use of qualified eddy current inspection techniques and properly implemented analysis criteria, provide for the safe, continued operation for the Salem Units' steam generators.

3.0 OPERATING EXPERIENCE FOR THE U.S. POPULATION OF WESTINGHOUSE STEAM GENERATORS SIMILAR TO THE SALEM DESIGN

The Salem Units use Westinghouse Model 51 steam generators with explosively expanded (WEXTEX) tube expansions. The table below lists other plants with the type of steam generators using a similar tube expansion process. The steam generators at Salem use Alloy 600 MA tubing. The nominal tube OD is 7/8 inch x .050 inch nominal wall thickness.

WEXTEX Explosive Expansion Plants Alloy 600 Mill Annealed (MA) Tubing				
Plant	Startup	First Time Circ. Cracking	Location	Tube Pull and Results
Beaver Valley Unit 1/51	1976	1/95	Exp. Transition	No
Diablo Canyon Unit 1/51	1984	10/92	Row 1 U-Bend	No
		3/94	Exp. Transition	No
Diablo Canyon Unit 2/51	1985	3/93	Exp. Transition	No
Farley Unit 1/51	1977	3/91	Exp. Transition	No
		3/91	Row 1 U-Bend	No
Salem Unit 1/51	1976	3/91	Exp. Transition	No
Salem Unit 2/51	1980	11/91	Exp. Transition	No
Sequoyah Unit 1/51	1980	3/90	Exp. Transition	No
Sequoyah Unit 2/51	1981	4/88	Row 1 U-Bend	No
		8/90	Exp. Transition	No
Comanche Peak Unit 1[(a)]/ D4	1990	None	N/A	N/A
North Anna Unit 1[(b)]/51	1978	1987	Exp. Transition	Yes, segmented Circ. PWSCC
		1991	Dented TSPs	Yes, Circ. Axial ODSCC
North Anna Unit 2[(b)]/51	1980		Exp. Transition	No
			Dented TSPs	No

(a): A total of 3839 tubes were removed in the shop to facilitate a stayrod modification. When the tubing was replaced, WEXTEX expansion was used.

(b): Original steam generators

3.1 WEXTEX Tube Expansions

The WEXTEX tube expansion process uses an explosive charge to produce tube-to-tubesheet contact throughout the tubesheet region. WEXTEX tube expansion generally produces lower residual stresses within the expanded-to-unexpanded tube transition region than mechanical rolling processes. The WEXTEX process has been implemented only on Alloy 600 MA tubing.

Circumferential indications were first detected at North Anna Unit 1 in 1987. Two tubes with circumferential crack indications in the WEXTEX transition region were subsequently removed from the North Anna Unit 1 plant in 1987. These tubes pulled from North Anna Unit 1 had an angular extent of 176° and 128° and a maximum throughwall depth of 90% and 100% respectively. The measured burst pressures of 10,700 psi and 9250 psi, respectively, are well in excess of Regulatory Guide (RG) 1.121 minimum requirements to demonstrate structural integrity.

A burst correlation was developed for throughwall circumferential crack extents. The burst correlation was then applied to define the structural limit on throughwall crack extents (angles) that satisfy the RG 1.121 burst margin for 3 times normal operating pressure differential. A development program was conducted by the WOG during the time period (1987-1992) when circumferentially oriented degradation began to appear in WEXTEX expanded tubes. In this program, the crack simulation was performed by slitting tube samples using an EDM process. Utilizing the burst correlations developed from EDM data and analytical models, the structural limits for throughwall circumferential indications were developed as given for the crack models in the following table.

7/8 Inch Tubing
EOC Structural Limits for Circumferentially Oriented Degradation

	Single Throughwall Crack Model	Single TW Crack with 50% Degraded Ligament	Segmented Throughwall Crack Model
3ΔP=4500 psi	210°	210°	264°
3ΔP=4300 psi	226°	226°	269°
SLBΔP=2560 psi	321°	283°	318°

As indicated in the table above, a circumferential crack with significant angular extent is needed to encroach on the RG 1.121 limits. Based on the industry data, it can be concluded that all circumferential indications found in WEXTEX transitions to date have had burst capability exceeding RG 1.121 requirements. Additionally, continued inspections have not identified large crack angles or growth rates and operating experience shows no

WEXTEX region primary to secondary leakage since the North Anna experience in 1987. Therefore, using RPC technology in accordance with WEXTEX inspection guidelines, it is unlikely that large indications have gone undetected.

3.2 Circumferential Cracking at U-bends, Dented TSP Intersections and High Cycle Fatigue

Incidence of circumferential indications at the Row 1 and 2 U-bends on Westinghouse steam generators similar to Salem has not been significant, both in numbers of indications and indicated RPC angle. Utilities have administratively plugged these rows, heat treated the U-bends (UBHT), or performed a combination of plugging and UBHT. Additionally, plants have applied UBHT and recovered tubes previously administratively plugged. Experience has determined that the UBHT process is successful in reducing new indications in this location. Circumferential cracking at dented Tube Support Plate (TSP) intersections has been detected at only one plant (two twin units). The Salem Units have dented TSPs and are potentially susceptible to degradation at this location.

Pursuant to NRC Bulletin 88-02, all domestic Westinghouse steam generators with carbon steel support plates have been analyzed for the potential to experience high cycle fatigue. Plants, including Salem, have plugged and stabilized tubes to address this issue. As a result of the Bulletin 88-02 evaluation for Salem Unit 1, no tube plugging was required. For Salem Unit 2, 10 tubes were plugged and stabilized as a result of the Bulletin 88-02 evaluation.

4.0 SALEM STEAM GENERATORS

4.1 Design, Modifications and Operation

Several years ago, a subgroup of the Westinghouse Owners Group (WOG) known as the WEXTEX subgroup identified parameters which made Steam Generators susceptible to cracking in the expansion transition area. WEXTEX recommended corrective actions to mitigate this degradation mechanism. To reduce the residual tensile stresses on the ID surface of the tubes, shot peening can be performed to apply compressive stresses to the ID surface. This technique was applied to the expansion transition area of all unplugged hot leg tubes in Salem Units 1 and 2 in 1993 and 1994, respectively.

Considering WEXTEX region growth rates of 10° to 64° per cycle, without shot peening, and when factoring in the industry accepted detection thresholds for throughwall circumferential degradation, structural integrity would be expected to be maintained during future operating cycles. Furthermore, inspections in accordance with the WEXTEX guidelines are expected to be sufficient to detect the presence of throughwall circumferential length indications which would challenge tube integrity.

The Salem units have performed sludge lancing routinely during refueling outages and operate at a lower operating T_{hot} temperature. Because of the lower operating T_{hot} and no hardened sludge pile on top of the tube sheet (which acts as an insulator), degradation in this area has been observed to be minimal.

Row 1 and 2 U-bend tube cracking was an industry concern in the second half of the 1980's. Salem Units 1 & 2 had the Row 1 tubes administratively plugged in 1989 and 1988, respectively. Row 2 U-bends were heat treated in 1991 and 1990, respectively. The heat treatment process reduces residual stresses thus reducing the susceptibility to cracking. There has been no plugging attributed to observed U-bend circumferential cracking in either unit.

There have also been indications detected in the parent tube of sleeved joints. Salem steam generator tubes do not have sleeved joints, and therefore this degradation mechanism is not a concern.

Salem Units 1 & 2 have operated since 1976 and 1981, respectively. In 1977, the Steam Generator Owners Group (SGOG) was formed to address premature degradation of steam generator tubing and components from mechanisms, including but not limited to: vibration, fretting, stress corrosion cracking, intergranular attack and denting. The original work the SGOG performed over a five year period resulted in a number of recommendations to minimize the various degradation mechanisms. Additional remedial actions developed by groups, such as the WEXTEX Owner's Group, and implemented at Salem will help to maintain the steam generators for the remaining licensed life of the units. The following items have helped to minimize degradation:

1) Salem operates at 602°F T_{hot} while other plants operate up to 620°F. Temperature is attributed as a key factor in tube crack initiation.

2) Salem Units 1 and 2 use full flow condensate polishing for removal of corrosion products which are detrimental to Steam Generators.

3) Operating Procedure limits on secondary water chemistry require timely corrective actions or plant shutdown if limits are exceeded. These controls minimize the amount of contaminants entering the Steam Generators.

4) Tube expansion transitions on the hot leg were shot peened to address WEXTEX region tube degradation. Shot peening reduces the residual stress on the Inside Diameter (ID) of the tube in the transition area.

5) Copper, one of the major contributors to denting, was systematically removed from the Feedwater and Condensate System, including the Condenser tubing and Moisture Separator Reheater high pressure tube bundles. Feedwater Heater design did not include copper tubing.

6) Practice of performing sludge lancing of each S/G during refueling outages.

4.2 Salem Inspection Practices and History

Salem has contracted Westinghouse for past steam generator tube inspections. Many of the analysts return to the site each outage. During the Unit 1 10th refueling outage (Fall of 1993), approximately 50% of the data analysts were Qualified Data Analysts (QDA) in accordance with EPRI Appendix G Guidelines. More recently during the Unit 2 8th refueling outage, all data analysts were QDAs. For both outages, data analysts reviewed PSE&G plant specific guidelines to familiarize themselves with plant operating experience and known defect mechanisms. The guidelines ensure a uniform and consistent examination, and interpretation of results. A plant specific performance demonstration for data analysts is an option which has not been adopted by PSE&G.

Although not entirely in accordance with EPRI or WEXTEX guidelines, PSE&G has performed the following augmented RPC inspections for the presence of circumferential cracking on each units steam generators:

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1. Since 1990, augmented RPC inspections of the steam generator hot leg tube expansion zones have been performed to detect WEXTEX related circumferential cracking.

- During 2R6, 50% of the hot leg tubes in 21 and 23 steam generators were inspected. The majority of the tubes inspected were in Zone 4, with a sampling in Zones 1-3.

- During 2R7, 100% of the hot leg tubes were inspected in 22 and 24 steam generators.

- During 2R8, inspections were performed as follows:

  21 steam generator - 100% of the hot leg tubes were inspected.

  22 steam generator - approximately 21% of the hot leg tubes were inspected in Zone 4.

  23 steam generator - approximately 21% of the hot leg tubes were inspected in Zone 4.

  24 steam generator - approximately 27% of the hot leg tubes were inspected in Zone 4.

- During 1R9, 20% of each steam generator hot leg tubes in Zone 4 were inspected.

- During 1R10, 20% of each steam generator hot leg tubes were inspected in Zone 4.

- During 1R11, inspections were performed as follows:

  11 steam generator - approximately 39% of the hot leg tubes were inspected in Zone 4.

  12 steam generator - approximately 21% of the hot leg tubes were inspected in Zone 4.

  13 steam generator - 100% of the hot leg tubes were inspected.

  14 steam generator - approximately 21% of the hot leg tubes were inspected in Zone 4.

To date, a total of five tubes have been plugged due to circumferential indications associated with this degradation mechanism (four in Salem Unit 1 and one in Salem Unit 2). These five circumferential indications were within the structural integrity limits discussed in Section 3.1. Axial indications identified during the augmented inspections were evaluated for structural integrity and removed from service.

2. Since 1993, augmented RPC inspections of the steam generator hot leg dented tube support plate intersections have been performed to detect the presence of circumferential cracking within the tube support plate region. No tubes have been plugged due to this degradation mechanism. However, five tubes with axial indications were identified in this region for Salem Unit 1 (1993 inspection) which were plugged.

5.0 SALEM UNITS 1 AND 2 FUTURE INSPECTION PLANS

Both Salem units are currently in an extended outage. During these outages, PSE&G will complete inspection of the Salem Unit 1 and 2 steam generator tubes. The current inspection plans exceed minimum plant Technical Specification surveillance requirements for steam generator examinations. The scope of steam generator examinations meet and/or exceed EPRI and WEXTEX sampling plan guidelines. Augmented inspections for the presence of circumferential cracking will be completed as follows for each steam generator:

Unit 1

1. 100% of Zone 4 hot leg tube expansion transitions, plus 200 random hot leg tube expansion transitions from Zones 1, 2 & 3.

2. 100% of the 1st, 2nd and 3rd hot leg dented tube support plate intersections (signal > 5 volts), and 20% random inspection of 4th hot leg dented tube support plate intersections (signal > 5 volts), for axial and circumferential cracking.

3. 20% RPC inspection of the Row 2 (small radius) U-bends for PWSCC.

Unit 2

1. 100% of Zone 4 hot leg tube expansion transitions, plus 200 random hot leg tube expansion transitions from Zones 1, 2 & 3.

2. 20% random inspection of the 1st hot leg dented tube support plate intersections (signal > 5 volts) for axial and circumferential cracking.

3. 20% RPC inspection of the Row 2 (small radius) U-bends for PWSCC.

The augmented eddy current inspections in accordance with 1 and 2 above for both units will be performed using state of the art eddy current probes (e.g., Cecco 5 and Plus Point) which meet EPRI Appendix H qualifications for the detection of stress corrosion cracks. Item 3 above will utilize a RPC probe meeting EPRI Appendix H qualifications.

All analysts will be QDA qualified to EPRI Examination Guidelines, Appendix G requirements. The EPRI recommendation to develop and implement a site specific performance demonstration for data analysts is still an option under consideration by PSE&G.

6.0 CONCLUSIONS

PSE&G has taken appropriate measures consistent with industry guidance to address steam generator tube cracking issues. The scope outlined above is an effective examination program to assess those areas of the steam generator susceptible to circumferential cracking. The program meets and/or exceeds recommended industry sampling plan guidelines. An effective program in conjunction with the use of qualified probes, QDAs, and site specific data analysis guidelines to ensure uniform and consistent examination and interpretation of results provides continued assurance that tube integrity will not be challenged during future operating cycles.