CAROLINA POWER AND LIGHT COMPANY

H. B. ROBINSON SEG PLANT, UNIT NO. 2

1983 INTERIM CYCLE

STEAM GENERATOR INSPECTION REPORT

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I. STEAM GENERATOR INSPECTIONS

I.1 Eddy Current Inspection of Steam Generator (S/G) Tubing

I.1.1 Inspection Scope

The initial inspection program selected was as described in CP&L transmittal letter dated January 28, 1983, from Mr. S. R. Zimmerman to Mr. S. A. Varga. This program was designed to ensure the inspection of all regions in the S/G's where tubewall degradation was observed during the previous inspections and to obtain a representative sample of regions where no degradation was observed. This initial program required inspection of all unplugged tubes from the inlet and outlet sides of each S/G to varying extents (heights) as required to cover the areas of concern. The final inspection scope is shown in Figures I.1.1-1 through I.1.1-6. The final scope reflects scope expansions made on the basis of the inspection results. One tube in "B" S/G was not inspected due to schedule considerations. This tube was plugged as a conservative measure.

I.1.2 Inspection Technique

The inspections were performed using multi-frequency eddy current equipment. The inspection frequencies utilized were 400 KHz differential, 200 KHz differential, 210 KHz absolute, and 100 KHz absolute. Signal frequency mixes were utilized to aid in the detection of tubewall degradation.

I.1.3 Results

The results of the eddy current inspections indicated the presence of degraded and/or defective tubing in four distinct regions of the S/G tube bundles.

I.1.3.a Crevice Region

The central region of the tube bundle on the inlet side (hot leg) of each S/G exhibited corrosion indicative of a cracking mechanism in the unrolled length (crevice) of tubing in the tubesheet. This is assumed to be intergranular attack (IGA) consistent with the degradation observed in the same region of a tube sample removed from the "B" S/G in August, 1981.

I.1.3.b Top of Tubesheet/Above Tubesheet (TTS/ATS Region)

The central area of the tube bundle on the inlet and outlet sides of the S/G's exhibited tube wall thinning attributed to phosphate wastage in the length of tubing from the top of the tubesheet up to approximately 35 inches above the tubesheet. This corrosion is attributed to the presence of phosphate rich sludge and phosphate precipitate in the S/G. The region affected is consistent with the region where phosphate precipitation is anticipated. Phosphate wastage has been observed and carefully monitored in the TTS/ATS region since 1973-1974. The number and severity of the indications has generally been observed to increase at a relatively slow rate. However, this inspection revealed a significant quantity of new indications in the S/G's.

I.1.3.c Tube Support Region

The section of tubing which passes through the tube support plates (TSP) exhibited wall degradation on the inlet and outlet sides of the S/G's primarily in the peripheral low (feedwater) flow regions. The wall degradation is located at or just above the tube support plates and is attributed to phosphate wastage. The statistical spread of the eddy current indications supports this conclusion.

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I.1.3.d U-bend Region

The U-bend section of tubing in some peripheral tubes exhibited wall degradation typical of phosphate wastage. This occurred primarily on the inlet side of the S/G's from 2½ inches above the sixth tube support plate (beginning of bend transition) up to approximately 35 inches above the sixth tube support plate. The same general groups of tubes also exhibited wastage where the tube passes through the anti-vibration bars.

A complete listing of all eddy current results for each S/G is provided in Attachment VII to Appendix I.

I.1.4 Evaluation of E/C Results

An evaluation of the E/C inspection results was performed by Westinghouse for CP&L. Appendix I contains a summary of this evaluation and the statistical data generated.

This evaluation revealed that tube wall corrosion had occurred at previously "clean" tube locations in the same general regions of the tube bundles where past corrosion has occurred (ie: a significant number of new indications were detected). This corrosion occurred primarily in the cold leg TSP, hot leg and cold leg TTS/ATS and U-bend regions. The majority of the new indications occurred in the cold leg TTS/ATS region. This "new" corrosion is attributed to phosphate thinning. This conclusion is supported by the statistical spread of the indication depths as shown by the histograms included in Appendix I.

Tube wall corrosion at tube locations where E/C indications had existed previously in the U-bend, TSP and TTS/ATS regions was observed at rates generally lower than in the previous operating cycle.

Corrosion continued in the tubesheet crevice region during the last operating period. Reduced temperature operation appears to have been of minimal benefit at this time in reduction of the corrosion rate.

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The cracking phenomenon observed above the tubesheet in the August 1981 inspection was not observed this inspection. This conclusion is supported by the distribution of the eddy current indications with respect to number and size. The elimination of the cracking above the tubesheet is attributed to secondary chemistry improvements, frequent crevice flushing, sludge lancing and low temperature operation.

I.1.5 Tube Wall Corrosion Rates

Tube wall corrosion rates were calculated by Westinghouse for the S/G region which exhibited corrosion and are presented in Appendix I.

Corrosion rates were calculated and are presented for both the new and old indication population in the TTS/ATS regions. Also, a combined rate using both the new and old population was calculated. These calculations were performed with the pluggable tubes included and with the pluggable tubes deleted. All of the corrosion rates calculated are presented in Table 6 of Appendix I.

As described in Appendix I, a location criteria of ± 1 inch was used to differentiate between new and old indications. (ie, if no previous indication existed within ± 1 inch from an indication, the indication was classified as "new.") Some indications, therefore, which could have been classified as old were classified as new and are consequently assigned a larger growth. This is due to the inaccuracies in determining precise indication locations. However, this results in a conservative rate calculation for the combined new and old population.

I.1.6 Return to Power Evaluation

I.1.6.a Introduction

The Return to Power Evaluation was developed by Westinghouse for the H. B. Robinson SEG Plant. This evaluation provides the justification for the continued operation of the H. B. Robinson Steam Generators for an additional 4.5 EFPM beginning May 26, 1983. Tube bundle integrity was established on the basis of eddy current testing (ECT) of the tubes, in combination with conservative tube plugging criteria. Tube plugging criteria were determined using the structural limit for the remaining tube wall to withstand normal and accident condition loadings and a determination of the degradation rate for the upcoming operating interval.

CP&L feels that a minimum operating period of 4.5 EFPM is required to provide the operating flexibility needed to plan and schedule future inspection and refueling activities. Using the highest corrosion rate presented in Section I.1.6.b, operation for 4.5 EFPM could result in 21% additional tube wall corrosion. For the worse case of a tube having an indication of 47%, this would result in a 68% indication at the end of 4.5 EFPM operation. The following evaluation demonstrates that adequate structural integrity would exist for this case at normal and accident condition loadings.

I.1.6.b Tube Plugging Criteria

On the basis of extensive testing of typical PWR tubing, it has been demonstrated that the strength requirement to safeguard against tube burst or rupture during a postulated steam line break (SLB) is always more limiting (ie. indicates the minimum required wall thickness) than either that of operating conditions or that of tube collapse following a postulated loss of coolant accident (LOCA). In other words, if a tube with thinning can withstand the internal pressure during a SLB accident, it would also withstand, with adequate margin, the maximum secondary pressure differential during a LOCA or the normal primary to secondary pressure differential.

As SLB accident loads are limiting, for the reduced temperature operation at H. B. Robinson Unit 2, the maximum acceptable steam generator tube degradation to maintain structural integrity during a faulted SLB + SSE has been evaluated to be 70 percent of the wall thickness.

Under normal operation, the criteria based on R. G. 1.121, Section C.2.a.(2) and C.2.a.(4) that requires a margin of safety against tube burst failure of not less than 3 (ie., 58 percent allowable tube degradation) is considered to be excessively conservative in that it assumes that a steam generator tube experiencing "thinning" corrosion degrades uniformly both circumferentially and axially. The typical thinned tube which has been examined in the laboratory is not uniformly thinned about its circumference nor is it uniformly thinned axially. Regulatory Guide 1.121 does not recognize the reinforcing effect of limited axial length thinning although this reinforcement has been demonstrated in laboratory tests.

The length of degradation is very important in determining the burst pressure for a fixed degradation depth. the longer the extent of the degradation the lower the burst pressure. If the uniformly thinned area on a tube is very long, the burst pressure would be equivalent to the burst pressure for an undegraded tube having the same wall thickness and outside diameter as the thinned region of the tube. It appears that a uniform 1.5 in. degradation length is long enough to be considered infinite. Eddy current test data reported to Westinghouse from the May 1983 inspection show the average axial extent of a typical indication just above the tube-sheet on the cold leg at H. B. Robinson Unit 2 to be under 1.5 in. Assuming the axial extent of the average indication to be 1.5 in., for a 68 percent through-wall indication, this corresponds to an approximate burst pressure of 3750 psig. Under the present reduced power operation at H. B. Robinson Unit 2, the pressure differential across the steam generator tubes is approximately 1660 psi. This correlates to a margin to burst of 2.3.

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Making an allowance for nonuniform tube degradation due to phosphate thinning and recognizing that monitoring for primary to secondary leaks is an additional means of ascertaining the integrity of the steam generator tubes and that postulated tube rupture under normal operating conditions does not preclude an orderly shutdown, an alternate factor of safety of 2.3 is proposed as reasonable and adequate for normal operation of H. B. Robinson Unit 2. Therefore, conservatively, 68 percent maximum allowable tube degradation may be used as the limiting structural requirement to maintain steam generator tube integrity over the full range of normal operating, transient, and postulated accident conditions at H. B. Robinson Unit 2.

A comparison was made of the tubes that were inspected during this outage and the last outage to determine the rate of corrosion in the steam generators. The average corrosion rates calculated for the three steam generators at H. B. Robinson Unit 2 are given in the following table (for conservatism, the average corrosion rates were obtained by combining the data base of indications from the top of the tube sheet to, but not including, the steam generator first support plate). These data include both the new and old populations of degraded tubes left in service following the May 1983 Outage.

S/G	Number of Indications	Corrosion Rate (% Degradation/EFPM)		
A	194	HL	-	1.34
	182	CL	-	4.07
B	232	HL	-	1.59
	472	CL	-	2.82
C	499	HL	-	2.81
	975	CL	-	4.61

These data show that the highest corrosion occurs in the cold log of steam generator C.

Using the current H. B. Robinson technical specification plugging limit of 47 percent wall loss, the largest indication left in service was a 47% wall loss. This provides for a margin of 21 percent additional tube wall penetration before the faulted condition maximum tube wall degradation of 68 percent is reached.

In general, a 9 percent allowance for eddy current measurement variance is assumed; however, for thinning indications above the tube sheet, metallurgical evaluation of tubes removed from other operating plants with in-plant ECT measurements has consistently shown that ECT overestimates thinning degradation. This effect has been coroborated by laboratory simulations in which the depth of known, tapered thinned regions is overestimated using the ASME drilled-hole calibration standards. For this reason, for the thinning indications, it is not necessary to include an allowance for ECT variance. (Ref. Attachment 1, 1982 Steam Generator Eddy Current Inspection Report, dated September 24, 1982, submitted to Mr. S. A. Varga.) This application of the 9% variance was previously acknowledged by NRC in HBR Technical Specification Ammendment 73 dated December 10, 1982.

The limiting plugging criteria evaluation is thus established by the following conditions: 47 percent existing wall loss, 4.61 percent wall degradation per EFPM, 0 percent ECT variance, and a 68 percent structural limit for wall loss. Utilizing the above criteria, the following operating intervals have been established.

S/G		Corrosion Rate % / EFPM	Corrosion Margins	Operating Interval
A	HL	1.34	21	15.67
	CL	4.07	21	5.16
B	HL	1.59	21	13.21
	CL	2.82	21	7.45
C	HL	2.81	21	7.47
	CL	4.61	21	4.55

These data show that the most restrictive operating interval arises from the S/G "C" cold leg corrosion rate. Conservatively, a 4.5 EFPM operating interval is an acceptable time period to the next tube inspection.

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I.1.6.c Leakage Sureveillance Program

During the remaining fuel cycle, the following steam generator tube leakage criterion will be utilized. Specifically, the Plant will be shut down if the verified primary to secondary leakage in one steam generator exceeds any of the following:

(1) A sudden increase of 0.1 gpm if the total leak rate in a given steam generator exceeds 0.2 gpm.

(2) If the leakage rate in a given steam generator exceeds 0.2 gpm and an upward trend in excess of 0.02 gpm per day is verified. This trend will be established using at least five valid consecutive daily samples.

I.1.6.d Conclusions

The integrity of the steam generator tube bundles has been established by plugging all tubes with ECT indications greater than the H. B. Robinson Unit 2 technical specification plugging limit criteria. Tube bundle integrity has been demonstrated with a pre-operational pressure test.

May 1983 ECT inspection data show that the most restrictive operating interval arises from the S/G "C" cold leg corrosion rates. The corrosion rate for S/G "C" cold leg has been calculated to be 4.61 percent degradation per EFPM. Assuming a corrosion allowance of 21 percent above the largest indication left in service (47 percent), the latter corresponds to a 4.5 EFPM operating interval prior to the next tube inspection.

Acceptable criteria (ie., plugging limits) have been established such that degraded tubing will provide adequate structural margins over the full range of normal operating, transient, and postulated accident conditions. Moreover, an additional requirement has been implemented by H. B. Robinson Unit 2 to provide further verification of tube bundle integrity above the tube sheet crevice region. Specifically, allowable limits on primary-to-secondary leakage have been established beyond which the Plant must be shut down for appropriate corrective action. Therefore, with the above plugging limit criteria, reduced operating conditions, and tight leakage criteria, reasonable assurance exists that continued operation of H. B. Robinson for an additional 4.5 EFPM is acceptable.

I.2 Tubesheet Inspection of "A" S/G

I.2.1 Inspection Scope

This inspection was performed to determine the general condition of the tubesheet base material and to determine if clad separation had occurred in the vicinity of the inlet end of tube Row 8, column 52. This inspection was considered necessary due to the carbon steel tubesheet base material exposed to the primary coolant as a result of the special repair performed on this tube end during the 1982 refueling outage. (Refer Section II.3 titled "Special Repairs," in the "1982 Steam Generator Eddy Current Inspection Report" transmitted to Mr. S. A. Varga on September 24, 1982, via CP&L letter, Serial: RSEP/82-1544.)

I.2.2 Inspection Technique

The inspection consisted of a visual inspection of the clad and base material, measurement of the clad surface position, generation of a photographic record of the clad at Row 8, Column 52 and the surrounding tube ends, and a leak inspection.

The clad surface position measurement was made with a special dial indicator and mount designed to reference off the mechanical plug installed in the tube end. Measurements were taken every 59° around the tube end. These measurements were intended to identify any relatively gross clad separation via comparison of position to position readings. Clad separation of a much lesser degree will be detectable via comparison of these (baseline) readings to readings from subsequent inspections.

The leak inspection of Row 8, Column 52 was performed at 200 psi secondary to primary pressure concurrent with the post plugging leak test of the entire tube bundle.

I.2.3 Inspection Results

This inspection revealed no significant base material corrosion and no separation of the clad from the base tubesheet material.

This leak inspection revealed a four drop per minute leak rate from the vicinity of Row 8, Column 52. This is essentailly unchanged from the five drop per minute rate observed at the same pressure differential during the 1982 refueling outage post-plugging leak test of "A" S/G.

I.3 Secondary Side Inspections

I.3.1 Inspection Scope

The secondary side of "A" and "C" S/G's were inspected for tube bundle damage and foreign objects capable of causing tube bundle damage. These inspections were performed due to recent industry experiences with loose parts in S/G's and per INPO recommendations. These inspections were not performed based on any suspicion of the presence of loose parts in these S/G's.

The region inspected was the annulus between the S/G outer shell and the tube bundle from the top of the tubesheet up to about eight inches above the tubesheet. This region also extended into the tube bundle to a depth of two to three tubes. In addition, the tube lane of all three S/G's was inspected prior to closeout of the secondary side per normal site practices.

I.3.2 Inspection Technique

The annulus inspection was performed through the S/G handholes using mirrors and a fiberscope. The tube lane inspection by site QA personnel was performed visually.

I.3.3 Inspection Results

These inspections revealed no evidence of tube bundle damage or loose parts in the S/G's.

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II. STEAM GENERATOR REPAIRS

II.1 Mechanical Tube Plugging

Mechanical tube plugging was performed to remove from service all tubes with eddy current indications greater than 47%. This plugging limit is consistent with Plant Technical Specification requirements. In addition, all tubes with detectable indications in the tubesheet crevice region were plugged regardless of the indicated penetration depth for unit reliability reasons. One tube in "B" S/G was plugged in lieu of being inspected due to schedule considerations. This tube had not exhibited a reportable indication in the previous inspection. One tube in "A" S/G, which had exhibited leakage during a pre-inspection leak test, was also plugged although no pluggable eddy current indication was found. A list of tubes plugged in each S/G is provided in Figure II.1-1.

III. SUMMARY

The H. B. Robinson Unit No. 2 S/G's were subjected to a state-of-the-art eddy current inspection to detect and quantify tube wall corrosion in all tube bundle regions which have exhibited corrosion. This inspection revealed tube degradation in several distinct regions of each S/G where degradation has been observed in the past. In the regions subject to phosphate wastage, degradation was observed to have continued at corrosion rates generally lower than in the previous operating period at tube wall locations where degradation was known to be on-going. However, phosphate wastage was observed at a significant number of tube locations where it had not been present in the past. This degradation occurred in the same regions of the tube bundle subject to wastage in the past, but at previously "clean" tube locations.

The eddy current inspection results were evaluated to determine corrosion rates and to establish a safe operating period to maintain tube integrity under normal and accident conditions. This evaluation revealed that the S/G's can be operated for at least a 4.5 EFPM period at reduced temperature (T_{HOT}= 560°F) and maintain tube integrity. Prior to exceeding this period, therefore, an eddy current inspection will be performed.

The "A" and "C" S/G's were also subjected to a secondary side inspection to identify any foreign objects capable of causing damage to the tube bundle. No foreign objects were detected, nor was there any evidence of mechanical damage on the exterior of the tubes inspected.

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Sludge lancing and crevice flushing was performed on the S/G's to remove sludge deposits and improve the S/G chemistry.

Maintenance performed on the S/G's consisted of mechanical plugging of all tubes with eddy current indications in excess of the Technical Specification plugging limit. In addition, all tubes with detectable indications in the tubesheet crevice region were plugged for unit reliability and some previous plugging errors were corrected. A total of 16 tubes were plugged in "A" S/G, 139 in "B" S/G, and 208 in "C" S/G.

Leak tests were performed on each S/G prior to close-out of the primary side to verify tube bundle integrity. These tests were performed at 200 psi secondary to primary pressure differential with satisfactory results.

The inspections and repairs performed will provide reasonable assurance that the H. B. Robinson S. E. Plant can be safely operated for 4.5 EFPM.

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