ATTACHMENT

SUMMARY REPORT
ON THE EXAMINATION OF THE
STEAM GENERATOR TUBE R11-C14

NORTH ANNA POWER STATION

UNIT 1

PREPARED BY:

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FOR

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SUMMARY ON THE EXAMINATION OF NORTH ANNA UNIT 1 STEAM GENERATOR TUBE R11-C14

Tube R11-C14 from Steam Generator B of North Anna Unit 1 was cut below the second hot leg support plate and pulled for examination to characterize corrosion cracking suspected to exist at the first support plate crevice region. This summary provides preliminary examination data that is considered significant. A more complete description of the data obtained and its analysis will be presented in the final report.

Nondestructive Examination

Visual examination of the pulled tube showed circumferential cracking at and just below the location of the first support plate top edge. The crack networks existed at two locations, one centered near 45^{0} and the other centered near 220^{0}. (Zero degrees faces the steam generator divider plate and 90^{0} is clockwise of 0^{0} when looking in the primary flow or upward direction.) Dimensional characterization showed a maximum ovality of 0.028 inches at this location with the apex of the ovality occurring near the centers of the crack networks. Dimensional characterization also showed that the dented support plate (denting was observed by field eddy current data prior to the tube pull) acted as a die during the tube pull, reducing the tube diameter above the support plate approximately 0.008 inches. At the tubesheet top, the explosive expansion transition was approximately 0.75 inches long with a diametrical expansion of 0.018 inches. The center of the expansion transition was located approximately 0.1 inches above the estimated location of the tubesheet top.

X-Ray radiography clearly showed a complex network of circumferential cracking between 0.0 and 0.2 inches below the support plate top edge. The cracking appeared to be almost continuous around the circumference. In addition, faint radiographic indications of circumferential cracking were sporadically observed around the circumference at the support plate bottom edge location. The cracking at the bottom edge location appeared to be restricted to a more narrow band than the cracking at the top edge location. No crack indications were observed at the tubesheet top location.

Laboratory eddy current testing was performed using bobbin and RPC probes. Bobbin probe data showed a 99% deep indication at the first support plate crevice region. RPC examinations found two major circumferential cracks at the support plate top edge location, the same as in the field examinations. The cracks were 160^{0} and 140^{0} long. The cracking at the top edge location had RPC signals that were approximately 30 volts in size. In contrast, 5 to 6 volt readings were obtained in the field, indicating that the cracks were significantly opened by the tube pull. At the support plate bottom edge location, laboratory RPC examinations found 3 to 5 regions around the circumference with circumferential crack indications. The largest of these indications was 80^{0} long and had a signal strength of 3.7 volts. A review of the field RPC data showed that at least one, possibly two, of these regions were

observed at the support plate bottom location. No field or laboratory eddy current indications were called at the tubesheet top location.

Ultrasonic testing (UT) in the laboratory showed circumferential indications near the support plate top edge and smaller circumferential indications near the bottom edge in both the radial and axial aim scans. No axial indications were detected in the circumferential aim scan. Similar to the RPC data, two major circumferential indications were found at the top edge location where they were almost continuous around the circumference. At the bottom edge, four to five locations, more or less uniformly located around the circumference, had circumferential indications; the largest was 80 to 90° long. In addition, two small circumferential indications were observed at other locations. One was located within the center of the support plate crevice region near 40° and the other 0.7 inches above the support plate top edge near 140°. (Destructive examination showed that these latter indications were not caused by corrosion.) A number of axial and circumferential indications were observed above, below and near the tubesheet top location where the expansion transition was located. Only one of these was judged likely to be a corrosion related indication. It was a 0.2 inch long axial indication located 1 inch above the tubesheet top near 50°. (Subsequent destructive examination showed that this indication location did not have corrosion degradation.) The remaining UT indications at the tubesheet top region were judged to represent tube pulling marks and/or surface deposits.

Destructive Examination

The first support plate crevice region was found to have two regions with circumferential cracking of OD origin. One was located at the support plate top edge and the other at the support plate bottom edge. No cracks were found within the support crevice region between the cracking at the support plate edges. The more extensive corrosion occurred at the support plate top edge where the cracking was located from the support plate top edge to 0.2 inches below. The microcrack network at the support plate top edge formed a continuous 360° macrocrack with two regions with deep (greater than 40% deep) penetrating microcracks. One of the two regions with deeper cracks was 124° long and was located from 348° to 112°. The other was 113° long and was located from 168° to 281°. Both regions had locations were the cracking was throughwall. The maximum length of throughwall cracking was 90°. The two regions were more or less diametrically opposite and were centered near the apex of the tube ovality. Table 1 and Figure 1 present a summary of the crack depths at selected locations by SEM fractography.

The circumferential cracking at the support plate bottom edge occurred in two separate microcrack networks which formed two continuous macrocracks separated by regions without any cracking. The cracking was located from the support plate bottom edge to 0.15 inches above the bottom. One region with cracking was 135° long and was located from 315° through 360/0° to 90°. The second region was 112° long and was located from 135° to 247°. Again, the two regions were centered near the apex of the local ovality. Table 1 and Figure 1 present a summary of crack depths found at the support plate bottom edge. The crack depths for one of the two cracking regions was determined by SEM fractography. At the other

region, where the cracking was judged to be less deep based on visual examination of deformed tube sections, the crack depths were determined by metallography. Consequently, the depth of cracking is not as extensively characterized in comparison to SEM fractographic observations. The maximum depth of cracking at the support plate bottom edge was 98% throughwall.

The morphology of the individual circumferential microcracks within the support plate crevice region varied from pure IGSCC to IGSCC with significant IGA components. Where the individual microcracks joined together, only intergranular features were usually observed. Only in a few cases did dimple rupture features predominate on the ledges located between the numerous individual microcracks.

At the tubesheet top location, within the center of the expansion transition, a semi-continuous network of circumferential and axial, OD origin, microcracks was found. The maximum length of axial cracking was 0.04 inches. The maximum length of continuous circumferential cracking was approximately 80^{0}. The circumferential cracking was deeper than the axial cracking and the maximum depth of circumferential cracking was 21% throughwall. Table 1 presents a summary of crack depths found at the tubesheet top region. The depths at the tubesheet top region were determined by both SEM fractography (on the half of the tube circumference judged to have the deepest cracks based on visual examination of deformed tube sections) and by metallography. The cracking at the tubesheet top was intergranular; but since the metallographic sections went through locations where the cracks were never deeper than 3 to 4% throughwall, it was difficult to determine the extent that the morphology was either SCC or IGA. As a consequence, the more generic term of intergranular corrosion (IGC) is chosen to describe the morphology.

Chemical Analyses

Energy dispersive spectrometry (EDS) was performed on the tube OD surfaces adjacent to cracks and on crack fracture faces. Of the elements detected, only K, Cu, Cl, and Pb are judged as candidate elements which might have been involved in corrosion degradation. While all four of these elements were present in at least 50% of the areas examined by EDS at the tubesheet top, only Cu was observed in at least 50% of the areas examined at the first support plate crevice region. However, Pb was found in 3 of 7 areas examined by EDS at the support plate crevice region. Electron probe microanalyses (EPMA) of cross sections of the tube wall showed that Pb was concentrated in a 0.0001 inch thick layer that was present on the tube. Also present in this layer were the base metal elements, as well as O, Si, Al, Mg, Ca and Zn. At the one location where a thicker surface deposit was present on top this base layer, Na and S were also detected.

X-ray diffraction of OD deposits collected from the first support plate crevice region of Tube R11-C14 indicated the presence of magnetite, copper metal (not oxide), and two forms of magnesium silicate minerals. Since magnesium silicate minerals can not exist in acidic environments, the minerals must have formed in a neutral or basic environment. Since no hematite or copper oxide was found, a reducing environment is indicated.

Electron Spectrometry for Chemical Analysis (ESCA) was performed on the OD

deposits adjacent to a support plate crevice region crack at both the surface of the deposits and at deeper locations reached by sputtering. Elements detected were Mg, Cr, Fe, Ni, Zn, C, O, Cu, Si, Al, Na and Pb. Sodium was incorporated into the oxide in the 0.1 to 0.8 weight percent range. Lead ranged between 0.2 and 2.0%. Little, if any, carbonate was present. Silicon was present as silicates. Most oxygen showed silicate or hydroxide bonding rather than oxide bonding. The iron and nickel photoelectron signals also indicated surface hydroxides. The copper was metallic even at the surface. The presence of hydroxides further supports the presence of either a caustic or a neutral environment.

ESCA was also performed on the crack face. Elements detected were Mg, Cr, Fe, Zn, C, O, Si, Al, Na, Pb, S, Cl and B. Metal hydroxides predominated. Lead was oxidized rather than metallic. Sulfur was present in both oxidized and reduced forms. Boron was bonded to oxygen. Chlorine could have been present as a transition metal chloride or an organic.

Auger Electron Spectrometry (AES) was also performed on the crack face. Boron distribution was spotty. Sulfur and chlorine were found on both the crack face and on the lab fracture, indicating that they were laboratory contaminants. Depth profiles of Ni, Fe and Cr showed Cr depletion at both the crack tip and the crack center. Chromium depletion occurs in caustic environments, but the extent of Cr depletion was small and the observations could be used to support either a neutral or a caustic environment.

<u>Summary and Conclusions</u>

Intergranular, OD origin, circumferential stress corrosion cracking was found at the top and bottom edges of the first support plate crevice region of Tube R11-C14. The morphology of the cracking ranged from SCC to SCC with significant IGA components. The cracking at the top edge was the deeper and the more extensively located. The cracking was continuously located around the circumference. Two regions, of 124° and 113° lengths, had cracking that was greater than 40% deep. The maximum length of throughwall cracking was 90°. The cracking at the bottom support plate edge was also significant and had a similar distribution. The regions with the deepest cracks were centered near the apex of the tube ovality. The tube within the support plate region was dented (0.028 inches).

At the tubesheet top region, minor circumferential and axial, OD origin, intergranular corrosion was sporadically present near the center of the expansion transition which was 0.75 inches long with a diametrical expansion of 0.018 inches. The circumferential cracking was the deeper and more extensively distributed. It was up to 21% throughwall.

Eddy current data provided an accurate description of the degradation found at the support plate top edge. At the support plate bottom edge, eddy current data, especially the field eddy current data, provided a less complete description of the degradation even though the cracking was deep. Ultrasonic testing in the laboratory provided slightly more complete description of the cracking, but it also generated indications not caused by corrosion degradation.

The chemistry data obtained was consistent with either a caustic or a neutral environment. It is suspected that local alkaline environments were responsible for the cracking observed; however, it is also possible that Pb played a role in the cracking.

TABLE 1

DEPTH PROFILES OF OD ORIGIN IGSCC IN TUBE R11-C14HL

ORIENTATION (DEGREES)	1ST SP TOP EDGE		1ST SP BOTTOM EDGE		TUBESHEET EXPANSION TRANSITION	
0	92	First Crack Network* (centered near 50°)	98	First Crack Network* (centered near 22°)	0	
11	≤100		80		4M	Cracking also present in this region, especially from 11° to 90°
22	≤100		80		3M	
33	100		66			
45	100		80			
56	100		76			
67	100		76			
78	100		72			
90	100		64			
101	100		0			
112	67		0			
123	8		0			
135	12			Second Crack Network* (centered near 200°)		
146	12		53M			
157	12		61M			
168	71	Second Crack Network* (centered near 225°)	58M			
180	92				2	
191	≤100				8	
202	91		44M		6	
213	96		43M		5	
225	≤100		48M		8	
236	100				8	
247	89				21	
258	96		0		8	
270	81		0		0	
281	70		0		4	
292	33		0		6	
303	17		0		2	
315	12		40	Continuation First Network	12	
326	8		72		4	
337	21		78		8	
348	42	Continuation First Network	80		8	

*Crack network location defined for cracks greater than 40% throughwall. The cracking was continuously present within the circumferential band shown. All depths were determined by SEM fractography unless "M" follows the depth. In the later case, the depth was determined by metallography.

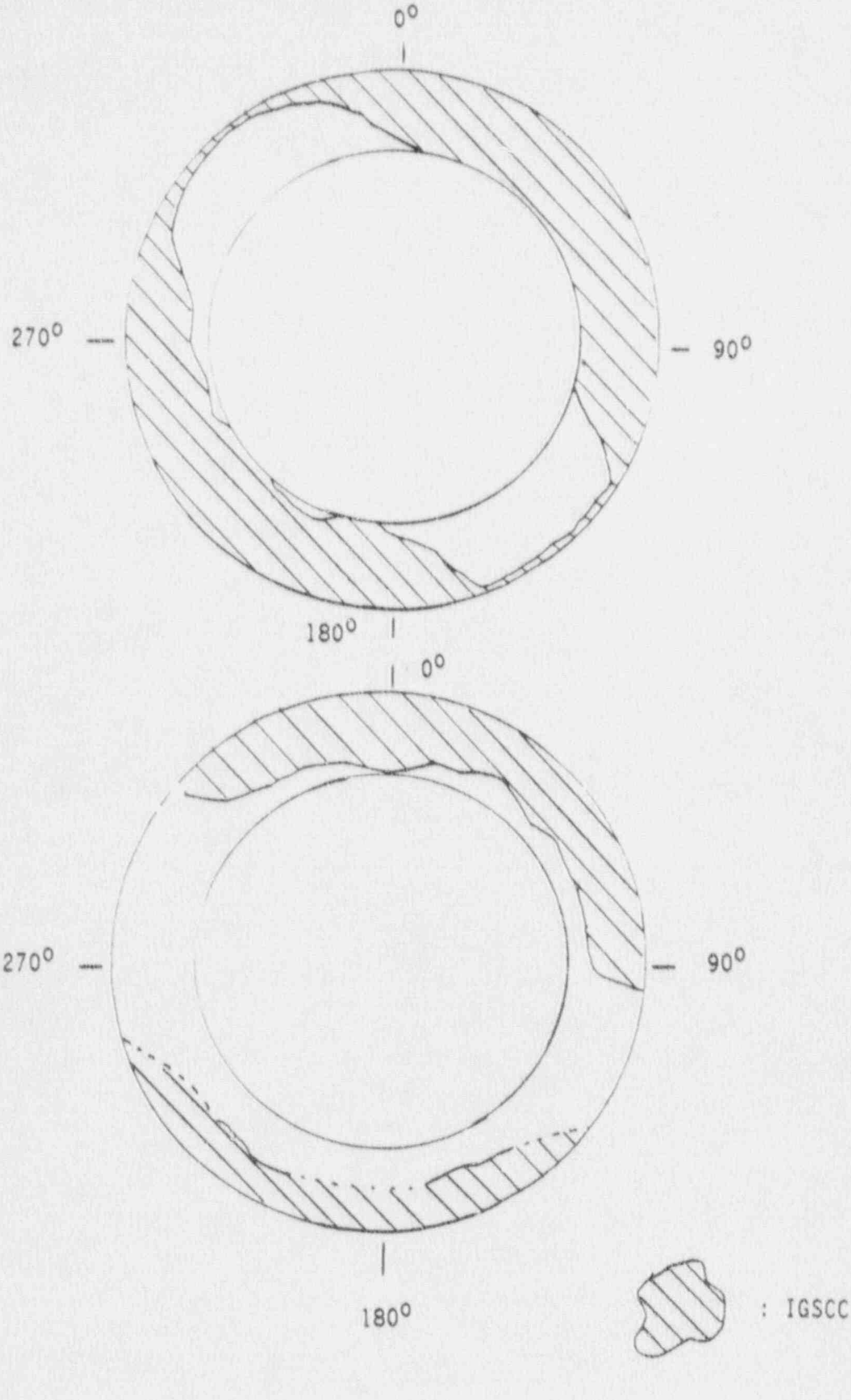

Figure 1 Sketch of OD origin IGSCC found at the top edge (top sketch) and at the bottom edge (bottom sketch) of the first support plate crevice region of Tube R11-C14. Crack front positions are based on SEM fractography except for crack front on bottom sketch near 180° which is based solely on metallography.