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Subject: Arkansas Nuclear One - Unit 1
Docket No. 50-313
License No. DPR-51
Steam Generator Tube Pull Examination Results and
Information on Second Dent Indication Detected During 1R13

Gentlemen:

During the thirteenth refueling outage (1R13) at Arkansas Nuclear One, Unit 1 (ANO-1), sections from six steam generator tubes from the "B" steam generator were removed and sent to the Westinghouse Science and Technology Center for evaluation of corrosion indications detected by field eddy current inspections. Results of the metallurgical examinations performed on these sections are complete. Chemical analysis to determine the root cause of the corrosion is ongoing. Based upon conversations with the NRC staff, we understand the NRC is interested in the metallurgical results for the purpose of describing damage affecting B&W steam generators in future generic correspondence. To facilitate this need, Attachment 1 provides a summary of the metallurgical results.

In correspondence dated February 5, 1997 (1CAN029702), Entergy Operations provided a response to a request for additional information (RAI) from the NRC dated January 7, 1997 (1CNA129603), regarding the inservice inspection performed on the ANO-1 steam generators during 1R13. In response to the second question of the RAI it was noted that one indication was identified in a dented location during the 100% bobbin examination. The response provided details associated with this indication. This response failed to provide details associated with a second indication identified in a dented location. These details are provided in Attachment 2.

If you have any questions concerning this submittal, please call me.

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Very truly yours,

Dwight C. Mims

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Director, Nuclear Safety

DCM/dej

attachments

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Attachment 1
ANO-1 Steam Generator Tube Pull Examination Results

INTRODUCTION

Sections from six steam generator tubes from the "B" steam generator of Arkansas Nuclear One, Unit 1 (ANO-1), were removed during the thirteenth refueling outage (1R13) and sent to the Westinghouse Science and Technology Center for evaluation of corrosion indications detected by field eddy current inspection. The tube sections were from the lower tubesheet (LTS) crevice region to just below the first tube support plate (TSP1) region of tubes R27L36 and R31L40, tubing from the upper tubesheet (UTS) crevice region to just above the TSP15 region of tubes R79L63, R80L18 and R83L47, and tubing from the UTS crevice region of tube R53L116.

The tubing from the LTS region of Tubes R27L36 and R31L40 had axial outside diameter (OD) indications in the sludge pile region at the top of the LTS. These LTS indications were new indications which had not been present in prior field inspections. These two tubes were among an isolated cluster of nine tubes exhibiting similar eddy current signals. The indications in the removed tubing bounded all other indications in this group. The tubing from the UTS region of Tubes R79L63, R80L18 and R83L47 had small areas with OD volumetric type corrosion indications within the full depth tubesheet crevice region. These UTS indications were old indications which had been present for many years with no suggestion of active growth. Previous tube examinations, beginning in 1978, found local intergranular attack (IGA) degradation in the UTS crevice regions. The three UTS crevice region specimens were pulled to support an alternate repair criteria submittal for these type flaws and to further support sizing qualification of the eddy current bobbin probe for similar flaws within the UTS region. The tubing from the UTS region of Tube R53L116 had an inside diameter (ID) axial indication in the roll transition region near the top of the UTS. Twenty-four total tubes with similar indications were identified during a 21% sampling of the "A" and "B" steam generators. These transitions were stress relieved as part of the original manufacturing of the steam generators.

LEAK, BURST AND TENSILE DATA

Elevated temperature leak testing was performed on specimens from the top of the LTS of Tubes R27L36 and R31L40 at differential pressures ranging from normal operating conditions (NOC) to main steam line break (MSLB) conditions. Table 1 presents a summary of the leak test data. The R27L36 specimen produced very low leakage: leak rates ranged from 0.00055 gpm at NOC to $\geq$ 0.0079 gpm at MSLB conditions. Some decrease in the leak rate was visually observed near the end of the first MSLB test of R27L36, where an overall leak rate of 0.0079 gpm was measured. As a consequence, the MSLB test conditions were repeated after a 30 minute holding period during which the pressure differential was maintained while the apparent leak rate stabilized. The leak rate for the second MSLB test appeared to be relatively constant during the test, but the leak rate was 37% lower than for the first MSLB test (0.005 gpm). Decreasing leak rates occur relatively infrequently during leak tests and are hypothesized to be caused by ID crud particles becoming displaced and partially sealing the crack. This hypothesis is supported by previous test observations where instances of jarring the specimen caused a restoration of higher leak rates. The hypothesis is further supported by the observation that when differing rates occur, lower leak rates as a function of time have always been produced. The measured leak rates for the top of the LTS of Tube R31L40 were also considered small, although larger than for R27L36. The leak rate ranged from 0.0013 gpm at NOC to 0.074 gpm at MSLB conditions.

Table 1
ANO Unit 1 Leak Test Data

Specimen	Test Type: Differential Pressure	Leak Rate (gpm)	Pp (psig)	Ps (psig)	Tp (F°)	Ts (F°)
R27L36, LTS Top	NOC: 1230	0.00055	2279	1049	612	615
	ITC: 1845	0.0016	2459	614	598	604
	MSLB1: 2541	0.0079	2754	213	574	538
	MSLB2 2561	0.0050	2774	213	568	554
R31L40, LTS Top	NOC: 1228	0.0013	2238	1010	601	605
	ITC: 1872	0.0073	2504	632	594	573
	MSLB1: 2437	0.072	2706	269	578	474
	MSLB2: 2553	0.074	2821	268	592	416

ITC = intermediate test conditions; P_P = pressure - primary side; P_S = pressure - secondary side; T_P = temperature - primary side; T_S = temperature - secondary side

Table 2 presents a summary of room temperature burst test results for the pulled tubes, including burst test data for free span sections from the pulled tubing where no corrosion was expected or subsequently observed during post-burst test stereoscopic examinations. The nondestructive examination (NDE) indication locations on the tubes were not covered by a simulated tubesheet during the burst tests. All areas with NDE indications were burst tested, except for the roll transition region of Tube R53L116 which had an ID axial indication in the roll transition of the UTS. (The indication was too close to the end of the specimen to test or to weld on an extension to the specimen to produce a modified burst specimen.) All burst specimens developed axial burst openings and had burst pressures that exceeded MSLB limits and the conservatively established structural limit of three times the normal operating differential pressure (3765 psi). The burst pressures for the top of the LTS specimens were a factor of two lower than for the UTS crevice region burst specimens, as would be expected since the UTS indications were short.

Table 2 also presents a summary of room temperature tensile data obtained on free span sections of the pulled tubing. All tensile strength data appeared to be normal for sensitized mill annealed tubing of this vintage and manufacture.

Table 2
Room Temperature Burst and Tensile Data for ANO-1 Steam Generator Tubing

Specimen	Burst Pressure, (psig)	0.2% Offset Yield Strength (psi)	Tensile Ultimate Strength, (psi)	Tensile Elongation, (%)
R27L36, FS R27L36, LTS top*	11,800 5,550	50,960	107,810	33.6
R31L40, FS R31L40, LTS top*	11,400 4,920	46,940	104,140	34.5
R79L63, FS R79L63, UTS crevice**	11,100 10,400	44,470	105,720	32.2***
R80L18, FS R80L18, UTS crevice**	11,200 11,000	47,850	104,860	32.6***
R83L47, FS R83L47, UTS crevice**	10,700 10,000	45,820	102,730	35.4

FS = freespan (nonflawed area)

* Tested with foils and bladders inserted into specimens. In addition, the specimen used a semi-restraint, in which a 2 inch high restraint plate was placed 2 inches below the bottom most indication and a loose restraint plate was placed 46 inches above the indication. The lateral restraint simulates the expected restraint in a steam generator and prevents any circumferential cracks from opening excessively during tube bowing and causing artificially low burst pressure.

** Tested with bladders inserted into the specimens, but no foils or lateral restraint system were utilized

*** Tensile test broke outside of gage length, possibly reducing the reported tensile elongation.

DESTRUCTIVE EXAMINATIONS

Scanning electron microscope (SEM) fractography was performed on all burst opening cracks and on the secondary corrosion regions opened and made visible after burst testing. If the corrosion region was not opened by the burst it was mechanically fatigued open.

For the deep OD origin corrosion in the LTS sludge pile region, fractography revealed features typical of axial intergranular stress corrosion cracking (IGSCC). The intergranular corrosion macrocracks were composed of numerous intergranular axial microcracks that were interconnected by ligaments. Most of these ligaments only had intergranular corrosion features showing that the microcracks had interconnected by corrosion during plant operation. Some of the ligaments had tensile tearing (ductile) features indicating that they tore during tube pulling or subsequent burst testing or destructive examination specimen preparation.

The five OD origin cracks at the LTS top region were all axial cracks. Three of the five axial cracks were examined by fractography. The OD surfaces adjacent to the axial crack fracture faces had varying degrees of shallow intergranular corrosion that was three dimensional in nature (IGA). Many of the affected grains were no longer present, resulting in the removal of tube material and generating the appearance of shallow wastage. In the case of the burst crack at the top of the LTS of Tube R31L40, this IGA type of degradation was very shallow to negligible in depth. For the other two LTS fracture faces at the LTS region of Tube R27L36, the IGA wastage attack was distinctly visible, but still relatively shallow. Later metallurgical examination of the remaining two axial cracks showed that IGA wastage was also associated with them. The LTS sludge pile region IGA wastage was more in the form of meandering grooves or gullies that sometimes appeared as "worm tracks". (Based on NDE observations, the "worm tracks" appeared to be located at or near sharp edges of surface deposits.) Metallurgical observations suggest that the two dimensional axial cracks originated at the bottom of the relatively shallow IGA wastage zones. Once the cracks penetrated the shallow IGA zone, no significant IGA was found in association with the cracks.

All five of the LTS sludge pile region axial cracks were throughwall. The largest crack (from a throughwall viewpoint) was on the burst opening of Tube R27L36. This crack was throughwall for 0.16 inches with a total length of 0.29 inches. It averaged 85% throughwall. The remaining LTS region axial cracks were not significantly smaller. The deepest IGA wastage in the LTS sludge pile was >11% to <24% throughwall.

SEM fractography and metallography showed that the OD origin corrosion present in the UTS crevice region was three dimensional IGA, most typically present as small patches no more than 0.1 to 0.2 inches in diameter. From a corrosion morphological viewpoint, no "true" two dimensional cracking was present. Occasionally, the patches were elongated and had either axial, oblique or circumferential orientations. A total of thirteen patches were recognized following burst testing of the UTS crevice region specimens. (Note that some of the major patches were composed of groups of close together, smaller patches of IGA.) Three of the major patches were present on the burst openings of the three UTS crevice region burst specimens and nine of the remaining ten major patches were opened in the laboratory in order to perform depth profiling by SEM fractography. The two deepest patches of IGA were located 3.7 to 3.8 inches above the UTS bottom of Tube R79L63 (a 0.16 inch long patch that averaged 29% deep with a maximum depth of 88%) and 6.8 to 6.9 inches above the UTS bottom of Tube R83L47 (a 0.161 inch long patch that averaged 34% deep with a maximum depth of 83%). The aspect ratios (width or length/depth) of these IGA patches typically ranged from 2 to 8.

For the UTS crevice region IGA patch depth profiles, it should be noted that due to the absence of many grains in the center of the patches, a clearly defined OD edge was not always visible. As a consequence, an OD edge frequently was estimated. This estimation undoubtedly resulted in an increase in depth measurement scatter. It is estimated that the tolerance band for depth measurements for these IGA patches is + 5% throughwall.

Finally, SEM fractography was performed on the major ID origin crack found approximately 0.15 to 0.23 inch below the top end of Tube R53L116, or near the center of the roll transition. Deformation of the nearby tube material found several smaller axial cracks in the same local area as the major axial crack. The examined major crack was typical of ID origin IGSCC in that it was a simple crack with no adjacent IGA components to the crack or ductile ligaments within the overall macrocrack. It was 0.083 inch long, averaged 46% deep with a maximum depth of 65%.

CONCLUSIONS

Three distinct types of corrosion were found on the mill annealed Alloy 600 steam generator tubes removed from ANO-1: local OD origin IGA degradation (either in the form of small patches in the UTS crevice region or in meandering narrow tracks in the LTS sludge pile), axial OD origin IGSCC in the LTS sludge pile and axial ID IGSCC in the roll transition of the UTS region. None of the IGA degradation was throughwall. In the LTS sludge pile it was shallow (< 24% deep) and in the UTS crevice region it was deeper (up to 88% deep). The UTS crevice region IGA patches had aspect ratios which typically ranged from 2 to 8, with most patches ranging from 0.1 to 0.2 inch in diameter. The axial IGSCC observed in the LTS sludge pile was deep (all five cracks were throughwall) with a maximum overall length of 0.29 inch. The axial IGSCC in the UTS roll transition region had a maximum depth of 65% and averaged 46% over a length of 0.083 inch.

Field and laboratory eddy current inspection readily detected all of the above corrosion. In the LTS sludge pile, field and laboratory bobbin and motorized rotating pancake coil eddy current probes accurately located and accurately predicted the deep depths of the axial IGSCC. Lengths of the IGSCC were somewhat over predicted due the relatively blunt ends of the deep cracks. Even the relatively shallow local IGA degradation in the LTS sludge pile was observed in the form of an unidentifiable signal in the 35 kHz bobbin data. In the UTS crevice region, all of the IGA patches were detected. Bobbin depth calls were fairly good at predicting the average depths of these IGA patches.

Elevated temperature leak tests performed on the throughwall axial corrosion located in the LTS sludge pile region produced small leak rates. The maximum leakage observed was for Tube R31L40 where the two throughwall axial cracks produced a leak rate of 0.0013 GPM at normal operating conditions and a leak rate of 0.074 GPM at steam line break conditions. Burst tests showed that the pulled tubes met safety requirements. The throughwall axial cracks at the LTS top produced the lowest burst pressures. The lowest was for Tube R31L40 where its burst pressure was 4,920 psi or 43% of its free span control. The UTS crevice region degradation had little effect on burst properties with the lowest burst pressure being 10,000 psi (Tube R83L47) or 93% of its free span control. The very high burst pressures for the UTS crevice region degradation, even though relative deep IGA corrosion was present (88% deep for Tube R79L63 and 83% for Tube R83L47) is related to the patch nature of the degradation. The small patches were separated by significant distances and not interconnected. With significant structurally sound metal separating the isolated IGA patches, they could not interconnect during burst testing to significantly lower burst pressures. Effectively the IGA patches acted as pits during the burst test, and generally pits do not significantly lower burst pressures.

Attachment 2
Information on Second Dent Indication Detected During 1R13

Question 2 from NRC Request for Additional Information (1CNA129603):

"For the tubes in the "A" and "B" OTSG with free-span axial indications at dented locations, please state whether these indications were found during routine examinations using bobbin coil probe and/or the MRPC probe. Please discuss the nature and the size estimates made for these degraded conditions (i.e., address the structural and leakage integrity of these indications). For the dents with degraded indications, discuss the "size" of the dents with indications in comparison with the size of other dents in the steam generators. Discuss the expansion criteria used and the technical basis for the criteria."

Response:

A motorized rotating pancake coil (MRPC) sample inspection of dented locations was performed in response to Generic Letter 95-03 (letter dated October 12, 1995 (0CAN109506). The sample examined consisted of the following:

- A 10% sample of known dings at the 15th tube support plate and the upper tubesheet. The sample concentrated on the largest dings at these elevations, as determined by bobbin coil signal amplitudes.

- A 10% sample of the lower tubesheet dings concentrating on the largest dings at this elevation, as determined by bobbin coil signal amplitudes.

No indications were identified in this inspection. Two indications were identified in dented locations during the 100% bobbin examination. One of these indications was incorrectly omitted from Entergy Operation's letter dated February 5, 1997 (1CAN029702), to the NRC. Since these indications were found as part of a 100% inspection, no expansion was necessary.

The bobbin examination identified the indication as outside diameter (OD) initiated with an associated depth of 47% throughwall on the 600 kHz bobbin channel. Historical records show the restriction in the tubing (ding) was present as far back as 1982. The MRPC examination confirmed the indication to be OD initiated. The MRPC examination revealed two axial flaws with a tube ligament between the flaws. MRPC length estimates are 0.43" and 0.50" for the two (2) flaws.

Structural and leakage integrity of the flaw was not directly addressed. In-situ pressure testing was performed on the larger indication within a ding (Ref. letter 1CAN029702). The testing of this larger indication is considered bounding for the smaller indication.