November 26, 2002

Mr. Mark E. Warner, Site Vice President
c/o Mr. James M. Peschel
Seabrook Station
P.O. Box 300
Seabrook, NH 03874

SUBJECT: SUMMARY OF OCTOBER 9, 2002, CONFERENCE CALL WITH NORTH ATLANTIC ENERGY SERVICE CORPORATION REGARDING THE SEABROOK STATION STEAM GENERATOR TUBE LABORATORY EXAMINATION RESULTS (TAC NO. MB5299)

Dear Mr. Warner:

On October 9, 2002, the Nuclear Regulatory Commission staff participated in a conference call with North Atlantic Energy Service Corporation representatives regarding the Seabrook Station steam generator tube laboratory examination results. Enclosed with this letter is a summary of that conference call.

Sincerely,

/RA/

Robert D. Starkey, Project Manager, Section 2
Project Directorate I
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Docket No. 50-443

Enclosure: Summary of Conference Call

cc w/encl: See next page

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SUMMARY OF CONFERENCE CALL

WITH

NORTH ATLANTIC ENERGY SERVICE CORPORATION

REGARDING THE SEABROOK STEAM GENERATOR TUBE

LABORATORY EXAMINATION RESULTS

Background

The Nuclear Regulatory Commission (NRC) staff participated in conference calls with North Atlantic Energy Service Corporation (the licensee) representatives on May 20 and May 23, 2002, regarding the steam generator tube inspection findings at Seabrook during its eighth refueling outage. During these calls, the licensee discussed the identification of axial outside diameter (OD) indications detected in the “D” steam generator. The NRC staff issued a summary of these calls (ADAMS accession no. ML021800003) and an NRC Information Notice 2002-21, “Axial Outside-Diameter Cracking Affecting Thermally Treated Alloy 600 Steam Generator Tubing,” dated June 25, 2002. The staff also participated in a conference call on August 27, 2002, to discuss the preliminary results of the root cause analysis including the laboratory examination results (ADAMS accession no. ML022590328).

As described in the previous call summaries, the licensee detected 42 locations in 15 tubes with OD axial indications. The indications were found at tube to tube support plate (TSP) intersections from TSP 2 through TSP 6 on the hot leg side and from TSP 3 through TSP 5 on the cold leg side. The indications were confined to the portion of the tube within the thickness of the TSP. The indications were within the first ten rows in steam generator D. Tubes in the first ten rows were subjected to a stress relief process through a special heat treatment before the installation of the tubes in the steam generator. The licensee pulled two of these tubes for metallurgical examinations and root-cause analysis. The preliminary results of the laboratory destructive examination revealed that 1) the axial OD indications were intergranular stress corrosion cracks (IGSCC), 2) the overall microstructure in the pulled tube specimens is not “ideal” when compared to typical Alloy 600 thermally treated (TT) material, and 3) no conclusive cause for the degradation had been identified.

The NRC staff participated in a follow-up call with the licensee on October 9, 2002, to discuss information gathered from the root-cause analysis. A summary of this call is documented below.

Results of Root-Cause Analysis

As a result of the investigations to-date, the licensee indicated that the root cause of the degradation was high residual stress left in the tube during the manufacturing process. A contributing factor for the degradation was the chemistry conditions at Seabrook. This high level of residual stress combined with the operating load are sufficient to cause the early initiation of stress corrosion cracking in these tubes.

Enclosure

Discussion of Examination Results

The licensee indicated that the root cause analysis was performed by the North Atlantic Root-Cause Team, Westinghouse Laboratory and Altran Inc. A professor from the Massachusetts Institute of Technology performed the third party oversight of these activities. Details of the root cause analysis are discussed below.

1. Residual Stress Test

The licensee performed split ring tests on the pulled tube specimens to analyze the extent of residual stresses on the tube surface. The results showed that the average residual stress is in the range of 20 to 26 ksi (thousand pounds per square inch). The licensee indicated that the residual stresses on the outside surface may be a factor of 2 to 3 times these values (i.e., 40 to 50 ksi). Westinghouse repeated the test on these specimens and found the results to be identical, between 20 to 25 ksi. Lambda Corporation, an independent contractor, also performed residual stress measurements using X-ray diffraction. The results were the same.

The typical residual stress in TT Alloy 600 tubes is 1 to 2 ksi and for mill annealed Alloy 600 tubes the residual stresses are typically 10 ksi based on literature. Testing of archived tube specimens removed from Byron 2 confirmed the typical residual stresses for TT tubes. The licensee also measured the residual stresses of archived tube material from Heat No. 1374, the same heat number as the pulled tube. Results from these tests indicated the residual stresses are typical of TT tubes (i.e., 1 to 2 ksi).

During the normal manufacturing process for TT tubes, the tubes are formed and straightened. Following the straightening, the tubes are mill-annealed followed by a thermal treatment. After this process, the tubes are bent to form a U-shaped tube. The U-bend region of the tubes in the low row tubes (typically rows 1 through 10) is then subject to a thermal stress relief. This process results in low residual stress in the low row tubes because the straight portion was TT (there was no subsequent cold-working) and the U-bend was stress relieved. For the higher row tubes there are some residual stresses in the U-bend region as a result of the bending process (since the U-bend was not stress relieved followed bending). These residual stresses are generally considered acceptable from a tube degradation standpoint.

The exact reason of how the residual stresses were introduced into the tubes at Seabrook is not known. The licensee speculated that the residual stresses may have been introduced during cold-working (e.g., straightening) of the tubes following the initial thermal treatment of the tubes. The manufacturing process called for an additional thermal treatment if the tubes were “re-worked.”

The pulled tubes were confirmed to be TT.

2. Chemical Analysis

Chemical analysis of the pulled tube specimens indicated that there were no concentrations of detrimental species detected. Analysis from the crack fracture surface detected elemental copper, but nothing significant. The licensee stated that the chemical analysis did not provide any evidence to indicate environmental factors were the cause of degradation.

3. Metallurgical Analysis

The licensee performed metallurgical analysis on samples from the two pulled tubes as well as samples from archived Alloy 600 TT tube material. The analysis showed that the axial indications in the pulled tubes are a result of outside diameter stress corrosion cracking. The cracking is intergranular in nature.

The metallurgical analysis also showed that the overall microstructure in the pulled tube specimens was not “ideal” as compared to typical Alloy 600 TT material. In addition, the carbon content for the pulled tube is 0.048%, which is higher than typical Alloy 600 TT material but met the specification of a maximum carbon content of 0.055%. The carbon content of the archived tube from heat No. 1374 is 0.044%. The microstructure of this archived tube is identical to the pulled tubes. The archived specimens from heat numbers 1456 and 1457 which contain 0.030 to 0.032% carbon are typical of alloy 600 TT microstructure. However, the licensee stated that these elements are not significant enough to cause IGSCC.

The carbon content of the other two heats of material which exhibited cracking was in the expected range (0.032 to 0.033%). These values were based on archived specimens from these heats.

4. Eddy Current Analysis Related to Residual Stress

Cold-working increases a material’s hardness which leads to an increase in resistivity. Since changes in resistivity can be observed in eddy current data, the licensee reviewed the eddy current data on the tubes with cracks and other tubes with no degradation. The analysis revealed that there is a “signal offset” in the 150 kHz absolute channel of the eddy current data in the degraded tubes (i.e., the tubes with the axial indications). All 15 tubes with axial indications showed a “signal offset” going from the U-bend region (which essentially has zero stress from the thermal stress relief process following bending) to the straight portion of the tube (not subjected to the thermal stress relief process). The licensee attributes this signal offset to changes in the material’s resistivity (which indicates the material has a higher residual stress in the straight portion of the tube). Analysis of the eddy current data for all of the low row tubes (rows 1 through 10), which equates to about 4000 tubes in all four steam generators resulted in identifying four other tubes from the “D” steam generator with the “signal offset” characteristics. The other tubes (approximately 3996 tubes) did not show this offset. These results indicate that potentially 19 tubes may have been cold-worked following the thermal treatment process resulting in higher residual stresses. These higher residual stresses led to cracking in 15 of these tubes. No crack indications were observed in the other four tubes with this “signal offset.”

Given that the source of the cold-working was not identified, the licensee recognized that higher residual stress (i.e., similar eddy current signals) could also be present in higher row tubes. As a result, they reviewed the eddy current data for the higher row tubes and no significant offset was seen; however, analysis of the higher row tubes is more difficult since there are residual stresses in the U-bend region as a result of the bending process. Since the U-bends in the higher row tubes were not thermally stress relieved following bending as was the case for the lower row tubes, an offset eddy current signal would be more difficult to detect. This is because the U-bends of low row tubes have essentially no residual stresses (because of the thermal stress relief) so any substantial increase in residual stress going from the U-bend to the straight span is readily evident; whereas for the higher row tubes (especially the smaller radius tubes of this group (i.e., row 11)) the residual stresses in the U-bend are higher (because they were not thermally stress relieved) making any differences between the U-bend and straight portion more difficult to detect. As a result, the licensee is considering developing a more quantitative technique for analyzing the eddy current data for the higher row tubes (i.e., rows 11 and higher).

The eddy current data for low row tubes (i.e., rows 1 through 10) for two other plants with TT Alloy 600 tubes was also reviewed. This review did not identify any tubes with a signal offset such as that observed in the 19 tubes at Seabrook.

The screening criteria used in analyzing for the signal offset for the low row tubes was reviewed by the Non-Destructive Examination Center at the Electric Power Research Institute.

Summary

The intergranular stress corrosion cracks were caused by high residual stresses introduced during fabrication of the steam generator. The exact cause of the higher than normal stresses has not been identified; however, the licensee established a method to identify tubes with high residual stresses using eddy current data. This technique is useful for the low row tubes, but for the higher row tubes a more quantitative method is needed and is in the process of being developed. The licensee indicated they would be finalizing their root cause report in the near future.