MEMORANDUM TO: Edmund J. Sullivan, Jr., Chief
NDE and Metallurgy Section
Materials and Chemical Engineering Branch

FROM: Louise Lund
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SUBJECT: SUMMARY OF THIRD STEAM GENERATOR TUBE INTEGRITY RESEARCH PROGRAM TECHNICAL COORDINATION GROUP MEETING

**INTRODUCTION**

From May 16 - 17, 2000, Argonne National Laboratory (ANL) hosted a meeting for participants involved in the Steam Generator Tube Integrity Research Program (SGTIP). SGTIP is a international cooperative research program that was organized by the Office of Nuclear Regulatory Research (RES) at the Nuclear Regulatory Commission. I attended both days of the meeting, representing the Office of Nuclear Reactor Regulation (NRR). Dr. Joseph Muscara, the RES program manager for this activity, chaired the meeting.

The focus of the meeting was to discuss contributions made by each of the active participants since the previous meeting held in November 1999. Representatives from ANL, Canada, Korea, the Electric Power Research Institute (EPRI), Westinghouse, and the NRC attended the meeting. A list of attendees is included in the attachment to this memorandum. The following provides a brief summary of the highlights from each of the organizations contributing to the SGTIP.

**PRESENTATIONS FROM SGTIP PARTICIPANTS**

<u>Assessment of Inspection Reliability (Steam Generator Mockup and Round Robin)</u>

Presented by D. Kupperman, ANL

The presenter discussed progress in the inspection reliability round robin that is underway. The current status is that seven teams have inspected the mockup. Three more are expected to participate in June/July. Preliminary analysis of the results is ongoing, but results will not be made available until all of the teams have participated, and true state has been estimated using advanced non-destructive examination (NDE) techniques. The final results are expected by December 2000. Emerging technology will be evaluated on mockup (e.g., X-probe, ultrasonic testing). The X-probe development was discussed later by AECL in another presentation.

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The tube inspection plan was also discussed. Tubes are inspected by bobbin coil on 100% of all tubes full length. Tubes are inspected by +Point on 100% of all tubes at the tube sheet, 100% of all bobbin coil calls > 2.0V at dents and dings, 100% of all distorted support signals, and 100% of all freespan bobbin indications.

Research on ISI Technology (Analysis of Eddy Current Inspection Results)

Presented by S. Bakhtiari, ANL

The presenter discussed refinement of algorithms for data analysis, especially for enhanced imaging of C-scan data. Work is in progress incorporating digital filters in the analysis process, to better suppress the artifacts and background fluctuations, improve signal to noise ratio, and to enhance spatial resolution and sizing accuracy. The current version of the algorithm has been set aside to aid in characterization of mockup tubes. They are beginning work in improving signal processing using 2-D suppression by spectral decomposition.

Research on Degradation Modes and Integrity (Production of Laboratory Degraded Tube Specimens)

Presented by J. Park, ANL

The presenter discussed their work in introducing various types of flaws into hundreds of 22.2-mm-diameter Alloy 600 tubes. These flaws include ID and OD axial SCC, ID and OD circumferential SCC, and ID and OD skewed SCC. These flaws exist as a mixture of axial and circumferential SCC, single or multiple cracks per tube, in the roll transition or dents, and can be continuous or segmented. The EC sizing was compared to fractography results, and in most cases, the EC results were consistent with the fractography. The ANL presenters did note that, in many cases, the plus point probe underpredicted the length of the circumferential cracks and overpredicted the length of the axial cracks. They discussed this finding with the eddy current equipment manufacturer and other eddy current practitioners, and some others had noted the same trend.

Research on Degradation Modes and Integrity (High-Pressure Test Facility and Pressure and Leak-Rate Testing/ Flawed Steam Generator Tube High-Pressure Test Facility Activities)

Presented by K. Kasza, ANL

The presenter indicated that since the last group meeting, facility shakedown, tuneup and establishment of test protocols has been completed. ANL tested a series of laser-cut flaws, which provide more complex flaws than EDM flaws. They tested 24 alloy 600 tubes of 7/8-in-diameter with laser-cut OD flaws consisting of simple single axial and circumferential notches as well as complex OD patterns of axial and circumferential notches separated by various ligament sizes. Ten different generic flaw geometries were tested, including mixed mode

intersecting flaws. Photographs were presented of crack opening after burst for each geometry. The presenter discussed the results of the burst pressure and flow rate for each geometry. Results were also presented for series of tests on 14 SCC flawed Alloy 600 tubes tested in the High Pressure Test Facility. The tubes underwent extensive pretest and post test characterization.

Research on Degradation Modes and Integrity (Analyses of Steam Generator Tubes Under Design-Basis Accident and Severe Accident Conditions)

Presented by S. Majumdar, ANL

The presenter reviewed low temperature and high temperature failure models for steam generator tubes. ANL developed a flow stress model for Electrosleeved tubes subjected to severe accidents, by analyzing ANL and FTI tests on Electrosleeved tubes with partial and completely throughwall flaws in parent tubes.

Westinghouse Tube Fouling Algorithm

Presented by C. Hu, Westinghouse

The presenter discussed an evaluation of tube fouling in operating steam generators, and the development of an algorithm to describe the fouling in terms of boiling by Westinghouse. The evaluation included gathering historical data on the tube fouling factor, water chemistry analysis, and tube scale analysis, which provided insight on the way the boiling conditions change with the morphology of the tube scale. He found that the fouling factor increased rapidly in some plants after tube cleaning. The micro-fouling of the tubes by boiling induced precipitates of dissolved chemicals seemed to be responsible for the post-cleaning increase in the tube fouling factor. Compounds such as calcium sulfate reduced bubble nucleation sites and increased the tube fouling factor. Micro-fouling of magnetite deposit seemed to eventually decrease the tube fouling factor, because the porous deposit increased the bubble nucleation sites. After one to two years, the fouling factor was reduced to a value equal to or lower than the value just before cleaning.

Development of a Model for the Evolution of SCC on the Secondary Side of PWR Steam Generators (Modeling and Predicting Initiation on the Secondary Side of Steam Generators)

Presented by R. Staehle, Consultant

The presenter discussed his modeling efforts for SCC initiation based on Weibull distribution of parameters. To support his modeling efforts, he presented data on various reactor materials in reactor-specific environments to show correlations of parameters with crack initiation.

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Heated Crevice Program

Presented by N. Torigoe, EPRI

The Ohi Heated Crevice operated for 700 hours in 2000, but is not currently operating due to problems with Raman spectra system. Previous data were incorporated into secondary water chemistry guidelines, which showed a linear correspondence between the accumulation of impurities in a crevice and the "exposure" of the crevice to those impurities. They plan to install a diamond line optical filter to see if it fixes the problem they are experiencing obtaining meaningful spectra. If successful, the crevice will continue to operate through March, 2001.

EPRI Integrated Exposure Activity (Crevice Chemistry Control in the EPRI Secondary Water Chemistry Guidelines, Revision 5)

Presented by N. Torigoe, EPRI

EPRI has developed an integrated exposure (IE) approach to assess the risk that concentration of impurities in crevices and the time of exposure poses to the steam generators. A few plants have already implemented IE in their steam generator management. This approach does not supersede EPRI's current action levels for impurities, and expected risk to steam generators remains the same with this new approach. Methodology is provided in the Appendix to Revision 5 of the EPRI Secondary Water Chemistry Guidelines. The next revision of the guidelines will evaluate IE as a control parameter.

Steam Generator Tube Testing Project

Presented by M. Kozluk, Ontario Power Generation

The presenter discussed results from structural integrity tests, leak-rate tests, and material characterization tests performed in 1999. The objectives for 1999 were to validate the flaw model for flat-bar fret scars, quantify the leak rate from the flat-bar fret scars, and validate the axial flaw model in the fitness-for-service guidelines for the steam generators.

AECL Steam Generator Tube Corrosion Studies

Presented by R. Tapping, AECL

The presenter discussed fouling and deposition experience in steam generators, and modeling to predict fouling as a function of amine, $O_2$, quality, particle size, T, flow, pH, and type of oxide. Based on scratch tests, they have established "safe zones" of electrochemical potential (ECP) versus crevice pH for Inconel 800 tubes. They determined that approximately 10 ppm $N_2H_4$ can prevent ECP shift, and wet layup with $\leq$10 ppm $N_2H_4$ causes least surface degradation compared to no $N_2H_4$ and dry conditions.

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X-Probe Development and Defect Detectability

Presented by L. Obrutsky, AECL

The presenter discussed the development of an advanced Cecco probe with transmit and receive probe capabilities. On a single head, the X-probe contains a C3 probe for circumferential crack detection, a C4 probe for axial crack detection, a C5 probe with equal sensitivity to axial and circumferential cracks but no discrimination capabilities, and a bobbin probe. Tests with the new probe have shown a tenfold signal-to-noise improvement over impedance probes at geometrically distorted areas. This probe will be tested at the round robin mockup at Argonne, and qualified through EPRI and in Canada.

Nondestructive Examination Experience on Pulled Tubes from Korean Nuclear Power Plants

Presented by S. Hwang, KAERI

The presenter discussed data from rotating pancake coil examination of Alloy 600 thermally treated steam generator tubes. The data compares the voltages to the crack lengths and depths for steam generator tubes affected by primary water stress corrosion cracking (PWSCC). The tubes that were examined were from a Framatome PWR with Framatome 51B steam generators. Approximately 20% of the steam generator tubes at this plant had been affected by PWSCC.

KINS Steam Generator Program (Structural Integrity Evaluation of Steam Generator Tube Containing Two Parallel Axial Through-wall Cracks; Finite Element Modeling and Neural Network Analysis of Eddy Current SG Tube Inspection)

Presented by M. Song, KINS

The presenter discussed research results for two steam generator programs currently underway. The first program was developed to gain a better understanding of how to perform a structural integrity evaluation when multiple cracks are found in a tube during inspections. Their NDE results in Ulchin #1 and #2 indicated that multiple cracks were found in the SG tubes, and their current evaluation methods apply a single crack criterion. They are working on a crack coalescence criterion for two thru-wall axial cracks based on interaction effects between cracks. The criterion is based on coalescing multiple cracks as a single larger crack for analysis purposes. The coalescence criterion is based on plastic regions from the cracks just touching. This results in cracks that are reasonably far apart being treated as one crack. NRC and ANL staff pointed out that these findings appeared too conservative, and were not consistent with experiments and analysis performed at ANL.

The second program was developed to develop systematic analysis tools to incorporate finite element modeling in the signal acquisition and neural networks into the characterization of the defects. The finite element modeling is intended to predict the defect signals. The neural network approach is intended to aid in the classification and sizing of defects.

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# ATTENDEES

| Name | Organization |
|---|---|
| Dwight Diercks | Argonne National Laboratory |
| William Shack | Argonne National Laboratory |
| Michael J. Kozluk | Ontario Power Generation |
| J. Ernesto Indacochea | University of Illinois at Chicago |
| Nikki Torigoe | Electric Power Research Institute |
| Gary Elder | Westinghouse Nuclear Services |
| Jim Benson | Electric Power Research Institute |
| Ken Kasza | Argonne National Laboratory |
| Jangyul Park | Argonne National Laboratory |
| Saurin Majumdar | Argonne National Laboratory |
| Laura Obrutsky | AECL, Canada |
| Robert Tapping | AECL, Canada |
| Sasan Bakhtiari | Argonne National Laboratory |
| Seong Sik Hwang | KAERI, Korea |
| Myung-Ho Song | KINS, Korea |
| Chris Hu | Westinghouse |
| Louise Lund | USNRC |
| Roger W. Staehle | Consultant |
| Dave Kupperman | Argonne National Laboratory |
| Joe Muscara | USNRC |

ATTACHMENT