April 18, 2003

MEMORANDUM TO: John A. Zwolinski, Director
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

FROM: Michael E. Mayfield, Director ***/RA/***
Division of Engineering Technology
Office of Nuclear Regulatory Research

SUBJECT: ISSUANCE OF NUREG/CR-6774, "VALIDATION OF FAILURE AND LEAK-RATE CORRELATIONS FOR STRESS CORROSION CRACKS IN STEAM GENERATOR TUBES," AND NUREG/CR-6789, "RESULTS FROM PRESSURE AND LEAK-RATE TESTING OF LABORATORY-DEGRADED STEAM GENERATOR TUBES."

The NRC has conducted research on steam generator tube integrity and inspection since 1977. As part of this program, the NRC is conducting research that will aid in the refinement of a performance based regulatory framework to assure steam generator tube integrity. A main purpose for this research is to provide tools to assist in condition monitoring and operational assessments. Condition monitoring is an assessment of the current state of the steam generator (SG) relative to the performance criteria for structural integrity. An operational assessment is an analysis to assess the condition of the steam generator at the end of the next inspection cycle.

The research described in these reports addressed Item A 2 of User Need NRR-2002-019. This item, in part, requested that RES, "Complete the tests on laboratory and service-degraded tubes and validate correlations for predicting leak rates, failure pressures, and failure modes of degraded tubes under normal operating, accident, and severe accident conditions, and issue the final report." Additional refinements are in progress in all of these areas and the refinements will be reported in future NUREG reports.

The product is related to the Strategic Plan Strategies by providing a basis for establishing improved plugging guidelines to reduce the probability that there will be releases of radioactivity from nuclear reactors. The current plugging guidelines call for plugging when an infinitely long flaw reaches 40 percent though wall or when an alternative plugging criteria is used such as the bobbin coil voltage based criteria. This research could eventually lead to a combination length and through wall depth combination and a plugging criteria.

The value of these NUREG/CR reports to the user office is to improve the understanding of the leak rate, failure pressure, and potential effects of jet impingement on adjacent tubes as a function of flaw characteristics. This information should improve the NRC staff's ability to independently evaluate industry submittals. This information may eventually be incorporated into the NEI guidelines.

The data provided in these reports provides a means of evaluating predictions of leak rates and failure pressures for idealized flaws, orifices, and cracks from models previously developed. The data for complex flaws and flaws containing ligaments indicates that the models for estimating leak rates and failure pressures for these types of flaws may not be conservative. Additional research is in progress on tubes containing complex flaws and the results of this research will be used to refine the models based on the test results and refinements to the models.

Two facilities were constructed as part of this program. One of these facilities is a high temperature and pressure facility that can operate at temperatures up to 650^{o}F, pressures up to 3000 psi, and flow rates up to 400 gpm. The other facility is the room temperature, high pressure facility that operates at pressures up to 7,500 psi at flow rates up to 12.8 gpm.

The initial set of tests for evaluating leak rates were conducted on tubes containing idealized circular orifices, which have a precisely defined geometry. The tests were conducted in both the room temperature and high temperature facilities. Under the given test conditions, the flow behaved like single-phase incompressible flow with no evidence that the water flashed to steam. The flow rates for these defects could be accurately predicted using a standard correlation for incompressible flow through a sharp edged circular orifice. Additional tests are planned using smaller diameter orifices and with tight flaws.

The next tests were conducted on tubes containing electrodischarge machined (EDM) notches tested in both the high temperature facility and the high pressure facility. A large series of tests was conducted in the high pressure facility on more complex flaw geometries with the flaws produced by laser-cutting. The flow rates through the as-machined and highly opened notches could be accurately predicted using the previously developed models.

Other tests were conducted on tubes with laboratory produced stress corrosion cracks (NUREG/CR-6674, NUREG/CR-6789) to verify the structural analysis models previously developed to describe the behavior of flawed tubes as reported in NUREG/CR-6664, “Pressure and Leak-Rate Tests and Models for Predicting Failure of Flawed Steam Generator Tubes.” Additional research is in progress to determine if there is an effect of pressurization rate on failure pressure.

Tests were also conducted on tubes removed from the retired McGuire SG (NUREG/CR-6774). The six tubes were inspected using Eddy Current (EC) testing prior to pressure and leak testing. The results from the pressure and leak testing indicate that the predicted results are consistent with the observed results using fractography. Both the test results and the predictions show that there is a rapid increase in the leak rate with pressure immediately after ligament rupture. Most of the stress corrosion cracks (SCCs) were shallow and did not rupture during the tests, this was consistent with the prediction using the actual flow stress for these tubes. Additional tests on flawed tubes taken from the McGuire retired steam generator are under way. These results will be reported in a future NUREG/CR.

The uncertainty for models used to predict leak rates for circular orifices and machined notches is low and predictions are accurate. The results on tubes containing laboratory grown SCC flaws indicate that there is no criterion currently available for predicting the time dependent failure of complex cracks with highly nonuniform thickness of the remaining ligament. Complex defects were found to leak at pressures significantly lower than predicted using the models previously developed. In flawed specimens with nonuniform ligament thickness, initial leakage occurred at pressures significantly lower than those predicted based on an average ligament thickness. Additional research is needed to gain a better understanding of the role of ligament rupture on failure and leak rate. Research in this area is planned using complex machined notches and laboratory grown SCC and is scheduled to be completed by the fourth quarter of FY2004.

During main steam line break (MSLB) conditions, fluid jets may produce damage on adjacent tubes either by droplet impact or cavitation. Tests were conducted to determine the susceptibility of steam generator tubes to erosion damage from impacting jets of superheated water or steam leaking from adjacent tubes (NUREG/CR-6774). Most of the tests were conducted using jets leaking from circular holes, but one test was conducted on a tube containing a SCC. Impingement tests were conducted for a period of two hours with a tube internal pressure of 2432 psig over a range of temperatures that included cold leg and hot leg temperatures. Tests showed that impact erosion depth increases as water temperature decreases. However, the total erosion penetration after the two hour test was less than 20% through wall at temperatures typical of the cold leg and less than five percent at temperatures typical of the hot leg. Because the erosion depths were low and the test conditions more aggressive than MSLB conditions, failure of the tubes by jet impingement is considered extremely unlikely. Tests conducted using the tube containing the SCC produced only slight burnishing and no erosion damage. Studies conducted under severe-accident conditions have been reported in NUREG/CR-6575.

Attached for your information and use are NUREG/CR-6774, “Validation of Failure and Leak-Rate Correlations for Stress Corrosion Cracks in Steam Generator Tubes,” and NUREG/CR-6789, “Results from Pressure and Leak-Rate Testing of Laboratory-Degraded Steam Generator Tubes,” If you have any questions, please contact James Davis on 301-415-6987 or jad@nrc.gov.

Attachments: As stated

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