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CONFIRMATORY RESEARCH FOR EXPERIMENTAL DETERMINATION OF FAILURE PRESSURES OF STEAM GENERATOR TUBES

NRR requests RES to experimentally evaluate the margins to failure of degraded PWR steam generator tubes under normal operating and postulated accident conditions. This task is proposed to be accomplished in two phases. The first phase which is described in the following paragraphs consists of burst and collapse tests of artificially defected tubing in a simulated steam generator environment and determination of leakage rates through cracked tubes. The results from the first phase are needed expeditiously to enable an independent verification of test data provided by the three major U.S. PWR reactor vendors, and to resolve the apparent inconsistencies in their results. NRR will utilize this data in determining acceptable design allowances required in processing reactor licensing applications. The second phase of the program would include tests in such areas as combined membrane and bending, fatigue properties of degraded tubes, and critical fracture toughness data. This part of the program may be formulated and described at a subsequent date. The results of this second phase may be provided over a longer term than the first phase.

Status of the Problem

Steam generator tubes constitute a major portion of the reactor coolant pressure boundary. Degradation of the tubes could result in either thru-wall penetration of the wall or rupture of the tube, which would release radioactive coolant into the secondary system and thence into the environment. In the event of a Loss of Coolant Accident (LOCA) a thru-wall penetration or rupture could release steam from the secondary side into the containment or into the reactor vessel. Therefore, it is important that the margins to failure of degraded tubes be known, and that design allowable stresses be established with a high degree of confidence.

The three major steam generator manufacturers use four different tube sizes in their different designs. Only Westinghouse and Combustion Engineering have conducted collapse and burst pressure test programs with artificially defected tubes. These tests were conducted in

connection with specific plants, for example R. E. Ginna, H. B. Robinson and Palisades. No experimental test data exists regarding the margins of safety of B & W steam generator tube size. For the purpose of establishing design allowable stresses, it is necessary to obtain statistically significant results over a wider range of tube degradation parameters.

Information Deficiencies and Proposed Program

Based on an evaluation of the test data obtained by Westinghouse and Combustion Engineering on the collapse and burst strengths of their steam generator tubes, it is apparent that additional testing is necessary within the next year. NRR strongly recommends that an NRC funded test program should be developed in the following areas:

1. Burst and Collapse Pressure Data

Provide an independent verification of the experimental predictions of burst and collapse pressures of Inconel 600 (ASME SB-163 Alloy 600) degraded steam generator tubing under biaxial tensile and compressive loads on the four sizes of tubing (.875 in. OD x 0.05", 0.75" x 0.043", 0.75" x 0.048" and 0.625 x 0.034") used in the Westinghouse, Combustion Engineering and B & W steam generators. The test specimens should be artificially defected to simulate general thinning due to wastage, stress corrosion cracking and superimposed cracks on thinned regions. The depths of penetration of both the cracked and wastage type defects should range from 80 percent remaining wall thickness to thru-wall defects. The number of tests should be sufficiently large so as to be statistically significant. Westinghouse and Combustion Engineering have used different types of artificial defects to simulate thinning due to wastage. A standardized artificial defect should be established for simulating wastage, stress corrosion cracking and superimposed cracking on thinned tubes. A uniform rate of loading should be established for both burst pressure tests and collapse tests to simulate transient loadings during postulated accident conditions. The burst pressure tests for thru wall cracks should be carried beyond the point of a plastic bulge appearing around the simulated defect. The rupture pressure when the cracked section foliates and has an area opening at least equal to the original tube cross section, should be obtained in these tests. This information has not been obtained by either Westinghouse or Combustion Engineering in their test programs, and it is considered highly significant in determining actual margins to failure.

The test data should be obtained at temperatures and other conditions prevailing in a steam generator environment. A majority of the test results provided by the vendors were obtained at room temperatures.

2. Leak Rate Tests

Leakage flow rates from primary side to secondary and vice versa should be obtained for a range of cracked geometries under operating conditions as well as postulated accident conditions. These tests should be conducted at temperatures and with chemistry conditions prevailing in a steam generator environment.

3. Determination of Material Properties of Tubes Prior to Start of Test Program

Inconel 600 tubes purchased prior to August 1971, as per ASME Code Section III - SB 163, were required to have a minimum yield strength of 35,000 psi. This specification was modified by Code Case 1484 in August 1971, and the minimum yield strength requirement was changed to 40,000 psi with a maximum of 65,000 psi. The procurement specifications should identify the materials for the test specimens. Consideration should also be given to differences between actual material properties versus specified minimum values, variances in properties from different sources and variances from the same source such as lot-to-lot variations.

Additional considerations that should be accounted for in this initial test program are the design flexibility and instrumentation to allow subsequent investigation of the following:

a. Determination of degraded tube strengths under combined pressure and bending loads.

b. Determination of the collapse strength of degraded tubes with specified ovality.

c. Determination of critical fracture toughness and other parameters for Inconel 600 required in analytical calculations of margins to failure.

These items will be included in the second phase of the test program.

Completion Date

Initial program results consisting of collapse and burst test data should be available to NRR in 6 to 9 months. The leak rate data should be completed within one year. Results of ongoing tests should be provided to NRR as they become available.

Licensing Impact

At a recent ASLB hearing the board raised questions regarding the failure pressures and design margins for steam generator tubes under various operating and postulated accident conditions. These and similar questions which have a significant impact on the licensing process can only be satisfactorily answered on the basis of experimental data obtained using uniform and consistent procedures for producing artificial defects and testing under simulated accident conditions.

The information to be generated by the proposed program is fundamentally applicable to all steam generators of PWR plants. Design allowances for current steam generator tube designs are evaluated on the basis of the limited experimental and theoretical data available at this time. It is anticipated that once the margins to failure of degraded steam generator tubes have been determined more precisely as a result of this proposed test program, the design allowances can be evaluated on a more realistic basis.

Magnitude of Research Effort

Staff members of the Mechanical Engineering Branch, Division of Systems Safety, have had preliminary discussions with David Taylor Naval Ship R & D Center, Annapolis, MD. and have visited their facilities. We believe that DTNSRDC, Annapolis has the test facilities, experience and personnel necessary to conduct an independent confirmatory research program to meet our needs. They have expressed their willingness to conduct tests within a time frame which will commence in FY 1976 and which is expected to be completed by March 1977. It is estimated that this initial phase of research effort will cost approximately $150 K.

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