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INSERVICE INSPECTION OF PRESSURIZED WATER REACTOR STEAM GENERATOR TUBES

A. INTRODUCTION

General Design Criteria 14 and 31 of Appendix A "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50, "Licensing of Production and Utilization Facilities," require that the reactor coolant pressure boundary have an extremely low probability of abnormal leakage, of rapidly propagating failure, and of gross rupture. General Design Criterion 15 requires that the reactor coolant system and associated auxiliary, control, and protection systems be designed with sufficient margin to assure that the design conditions of the reactor coolant pressure boundary are not exceeded during any condition of normal operation, including anticipated operational occurrences. Furthermore, General Design Criterion 32 requires that components which are part of the reactor coolant pressure boundary be designed to permit periodic inspection and testing of critical areas to assess their structural and leaktight integrity.

Failure[1] of the steam generator tubes, which constitute a portion of the reactor coolant pressure boundary, resulting from stress corrosion cracking, wastage, or fretting could permit release of radioactive materials to the secondary coolant system. In addition, the weakening of these tubes due to the same processes could, in the event of a loss-of-coolant accident (LOCA), result in failure of tubes and release of the energy in the secondary system into the containment. This guide describes a method acceptable to the Regulatory staff for implementing these criteria with regard to minimizing the probability and consequences of massive propagation of steam generator tube failures in the event of a LOCA, steam line break accident, or similar incident through the early detection of defects and deterioration by periodic inservice inspection. This guide applies only to pressurized water reactors (PWRs). The Advisory Committee on Reactor Safeguards has been consulted concerning this guide and has concurred in the regulatory position.

[1]Failure is defined as full penetration of the pressure boundary with subsequent leakage.

B. DISCUSSION

The heat transfer area of the steam generators associated with pressurized water reactors can comprise well over 50% of the total primary system pressure-retaining boundary. The thin-walled steam generator tubing therefore represents an integral part of a major barrier against fission product release to the environment. The steam generator tubing also represents a barrier against steam release to the containment in the event of a LOCA, and the integrity of this barrier is related to its freedom from cracks, perforations, and general deterioration. The design criteria used to establish the structural integrity of the steam generator tubing should include definition of the minimum allowable tube wall thickness which can sustain the pressure and thermal loading resulting from the worst postulated LOCA in combination with a safe shutdown earthquake (SSE).[2]

The chemical environment of the secondary side of the steam generator has been identified as the prime source of steam generator tube degradation and failure. There is evidence that principal factors in steam-side corrosion attack are restricted flow areas that permit

[2]As defined in Appendix A, "Seismic and Geologic Siting Criteria for Nuclear Power Plants," to 10 CFR Part 100, "Reactor Site Criteria."

high local concentration of free caustic, phosphates, and other impurities that may enter the steam generator through condenser inleakage. Therefore, water chemistry specifications must take into account materials of construction in the secondary system, and the supporting auxiliary chemical feed system must be designed to maintain balanced feedwater quality to each steam generator. During normal operations as well as inactive periods, effective monitoring of water chemistry by means of in-line continuous analytical instrumentation, supported by plant laboratory sampling analysis, of steam, condensate return, and feedwater is necessary to ensure that water quality is not degraded below acceptable limits by such events as condenser inleakage or chemical feed system maloperation that could promote tube degradation.

Mechanical or flow-induced vibrations can cause fretting or fatigue damage to steam generator tubes which could also lead to tube failures.

A program of periodic inservice inspection of steam generators is essential in order to monitor the integrity of the tubing and to maintain surveillance in the event that there is evidence of mechanical damage or progressive deterioration due to design, manufacturing errors, or chemical imbalance. Inservice inspection of steam generator tubing also provides a means of characterizing the nature and cause of any tube degradation so that corrective measures can be taken.

Inspection and subsequent possible repair to steam generator tubing in operating plants generally involves potential radiation exposure to personnel. Prior to undertaking such an inspection, careful pre-job planning is required to assure that radiation exposures are maintained as low as practicable. The use of temporary shielding, decontamination, special tooling, jigs and fixtures for remote inspection, and other design and procedural considerations as outlined in Regulatory Guide 8.8, "Information Relevant to Maintaining Occupational Radiation Exposure as Low as Practicable (Nuclear Reactors)," should be considered prior to such inspections.

This guide is applicable to current "typical" once-through and U-bend steam generators that use Ni-Cr-Fe and stainless steel tubing. The steam generator tubing is seamless, cold drawn, and annealed and is manufactured and tested in accordance with specifications of American Society of Mechanical Engineers (ASME) and American Society for Testing and Materials (ASTM).

Additional testing of manufactured tubing consists of hydrostatic, eddy current, and ultrasonic tests. After tube-to-tube-sheet welding is performed, the welds are inspected visually and by dye penetrant techniques and finally leak tested.

During reactor operation, steam generator tube leaks are detected by monitoring the secondary system for radioactivity through instrument analysis of steam or boiler feed samples. Once leaks are detected they can usually be located by eddy current examination of suspect tubing. The use of eddy currents as probing media is based on the presence of defect-caused variations in effective electrical conductivity and/or magnetic permeability of the material being tested. The eddy current probing technique has excellent sensitivity in nonmagnetic materials, so that decreases in effective conductivity due to a discontinuity in a tube wall are measured directly by increases in coil voltage in the probe. Eddy current probes designed for testing from the inside are suitable for steam generator tubing inspection. Scanning of steam generator tubes from the inside with an eddy current probe has proven successful in locating defect areas in a failed tube and in ascertaining the overall condition of the tubing in numerous operating PWRs.

Radiography is an alternative method for inservice inspection of steam generator tubing. While radiography does not offer the flexibility of eddy current methods, it can supplement eddy current testing for defect characterization on a limited basis.

Leaking tubes and tubes with unacceptable defects are taken out of service by blocking both ends of the tube in the tube sheet with plugs. Two methods are available for plugging: (1) manually welding plugs and (2) explosive plugging.

Experience has indicated that each steam generator design has critical areas (e.g., crevices, lowflow areas, and regions that allow steam blanketing) where, when the secondary water chemistry is not properly maintained, attack and degradation of the steam generator tubes may occur. Mechanical damage to steam generator tubes may also occur in those areas subject to flow-induced vibrations. Typically, the number of tubes that are contained in these critical areas constitute less than 20% of the total steam generator tubes.

Preoperational inspections to establish a baseline should examine all accessible steam generator tubes, and baseline inspections for operating plants should sample tubes on a random basis. Subsequent inspections should concentraie on any critical areas identified, so that defects found in these regions will represent a significantly high proportion of the total defects which may exist in the entire steam generator. This selection method can be expected to result in a ratio of tube defects found to total tubes inspected considerably higher than the ratio of defective tubes to total tubes in the steam generator.

C. REGULATORY POSITION

A program for inservice inspection of steam generator tubing should be established and should include the following features:

1. Access for Inspection

a. Steam generators in pressurized water reactors should be designed so that inspection of individual tubes can be performed.

b. Sufficient access should be provided for personnel to perform these inspections and tube plugging as required.

c. Provisions for examination should ensure that personnel radiation exposure is maintained as low as practicable.

2. Examination Equipment and Procedures

a. Inservice inspection should include nondestructive examination by eddy current testing or other equivalent techniques. The equipment should be capable of locating and identifying defects due to stress corrosion cracking and due to tube wall thinning by mechanical damage, chemical wastage, or other causes.

b. The inspection equipment should provide a sensitivity that will detect defects with a penetration of 20% or more of the minimum allowable as-manufactured tube wall thickness.

c. A suitable eddy current inspection system should consist of (1) an internal sensing probe, (2) a two-channel eddy current tester, (3) a viewing oscilloscope, (4) a conventional two-channel strip chart recorder, and (5) a magnetic tape data recorder.

d. Test data should be stored and maintained for the operating life of the facility.

e. Standards consisting of similar as-manufactured steam generator tubing with known defects should be used to establish sensitivity and for calibration. Reference flaws should simulate defects based not only on depth but also on length and shape of flaw and be characteristic of prior defect history.

f. The equipment should have the capability of examining the entire length of the steam generator tubing in once-through designs and, to the extent practical, the U-bend area in U-bend designs.[3]

g. To the extent practical, the equipment used for eddy current testing should be designed so that operators may be shielded or the equipment may be operated as far from high radiation fields as practicable.

h. Personnel either directing or interpreting the results of the eddy current inspection should be tested and qualified in accordance with American Society for Nondestructive Testing standard SNT-TC-1A and supplements.[4]

i. The examinations should be conducted using written procedures.

3. Baseline Inspection

a. Plants not having an operating license as of the effective date of this guide should undergo a preoperational inspection of 100% of the accessible tube area to establish the baseline condition of the steam generator tubing. This inspection should be performed after the field hydrostatic test and prior to initial plant startup. Such examinations should be conducted under conditions and with equipment and techniques equivalent to those expected to be employed in the subsequent inservice examinations.

b. For operating plants, the first inspection performed according to Regulatory Positions C.4 and C.5 should be considered as constituting the baseline condition for subsequent inspections.

c. The condition of the steam generator tubing at baseline and subsequent inspections should always be compared to typical as-built tubing.

4. Sample Selection and Testing

Selection and testing of tubes from each steam generator should be made on the basis of the following:

a. No fewer than 3% of the total number of steam generator tubes should undergo eddy current examination during each inservice inspection. (see Regulatory Positions C.3 and C.6)

b. Tubes for the baseline inspection for operating plants should be selected on a random basis except that one-third of the tubes in U-bend designs should be inspected from the cold-leg side of the generator.

[3] In regard to the length of tube to be examined, for U-bend designs, entry from either the hot-leg side or the cold-leg side with examination from the point of entry up to the midpoint of the bend (or as close to the midpoint as practical) is considered sufficient to constitute a tube inspection.

[4] SNT-TC-1A and Supplements, "Recommended Practice for Nondestructive Testing Personnel Qualification and Certification." Copies may be obtained from the American Society for Nondestructive Testing, 914 Chicago Avenue, Evanston, Illinois 60202.

c. Inspection of U-bend design steam generators should routinely concentrate on the hot-leg side of the generator after the first two inservice inspections.

d. Every inspection subsequent to the baseline inspection should include all tubes which previously had defect indications (not including plugged tubes) and should also consider tubes in those areas (including the cold-leg side) where design and experience have indicated potential problems.

5. **Supplementary Sampling Requirements**

a. If the eddy current inspection pursuant to Regulatory Position C.4 indicates that more than 10%[5] of the inspected tubes have detectable wall penetration (>20%) or that one or more of the inspected tubes have an indication of an unacceptable defect (see Regulatory Position C.7.a), (1) the steam generator should be considered unacceptable for continued service until additional examinations are conducted and (2) an additional 3% of the tubes should be inspected, concentrating on tubes in those areas of the tube sheet array where tubes with defects were found.

b. If in the inspection made in Regulatory Position C.5.a.(2) above, more than 10% of the inspected tubes have detectable wall penetration (>20%) or one or more of the inspected tubes has an indication of an unacceptable defect, additional tubes (no less than 3% of the total tubes in the steam generator) in the area of the defect should be inspected.

6. **Inspection Intervals**

a. Scheduled inservice inspection of steam generators should be performed at intervals of not less than 12 or more than 20 calendar months, except that the first scheduled inspection after the baseline inspection should be at the first extended outage but should not be made before 6 months of operation, and the 20-calendar-month interval should not be exceeded.

b. Inspections may be made coincident with refueling outages or any shutdown for plant repair and maintenance in accordance with the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section XI.[6]

c. If two consecutive inspections, excluding the baseline inspection, result in no additional tubes with detectable wall penetration (>20%) and no significant (>5%) further penetration of tubes with previous indications, the inspection frequency should be as defined in the ASME Code (three 40-month intervals in a 10-year period) except that the cold-leg side of U-bend steam generators may be inspected as in Regulatory Position C.6.d, below.

d. If two consecutive inspections of the cold-leg side of U-bend steam generators result in no additional tubes with detectable wall penetration (>20%) and no significant (>5%) further penetration of tubes with previous indications, the inspection interval may be extended to 10-year periods for cold-leg tubes.

e. Unscheduled inspections should be conducted in the event of primary-to-secondary leaks which exceed technical specifications, a seismic occurrence greater than an operating basis earthquake,[2] a loss-of-coolant accident requiring actuation of engineered safeguards, or a major steam line or feed water line break.

7. **Acceptance Limits**

a. An unacceptable defect is defined as one which would result in not satisfying the calculated acceptable minimum tube wall thickness that can sustain a LOCA in combination with a safe shutdown earthquake.

b. If in the inspection performed under Regulatory Position C.4, less than 10% of the tubes inspected have detectable wall penetration (>20%) and no tube has an unacceptable defect, plant operation may resume.

c. If in the inspections performed under Regulatory Position C.5, less than 10% of the total tubes inspected have detectable wall penetration (>20%) and no more than three tubes have unacceptable defects, plant operation may resume after required corrective measures have been taken.

d. If in the inspections performed under Regulatory Position C.5, more than 10% of the total tubes inspected have detectable wall penetration (>20%) or more than three of the tubes inspected have unacceptable defects, the situation should be immediately reported to the Commission in accordance with the facility license for resolution and approval of the proposed remedial action. Additional sampling and more frequent inspections may be required.

8. **Corrective Measures**

All tubes with unacceptable defects should be plugged.

9. **Reporting**

The results of the inservice inspection should be included in the Semiannual Operating Reports described

[5] In all inspections, previously degraded tubes that exhibit significant (>5%) further wall penetration must be included in the 10%.

[6] Hereinafter referred to as ASME Code. Copies may be obtained from the American Society of Mechanical Engineers, United Engineering Center, 345 East 47th Street, New York, N.Y. 10017.

in Regulatory Guide 1.16, "Reporting of Operating Information."

D. IMPLEMENTATION

The purpose of this section is to provide guidance to applicants and licensees regarding implementation of an acceptable schedule for inservice inspection of steam generator tubes of operating plants. Other programs of inspection of tubes proposed to the Commission by applicants and licensees may be determined to be acceptable if they provide a comparable level of inspection.

1. The effective date of this guide is September 1, 1974.

2. Operating plants should implement the baseline inspection recommendations of Regulatory Position C.3.b at the first extended outage, but within a period not to exceed twelve months after the effective date of this guide.

a. Operating plants which have their first extended outage scheduled within a 120-day period after the effective date of this guide may perform the recommended inspection at the next scheduled outage.

b. Operating plants which have had an inservice inspection of at least 3% of the total tubes in each steam generator within the 12-month period prior to the effective date of this guide need not undertake a baseline inspection if the inspection methods and results meet the recommendations of Regulatory Positions C.2 and C.7.b.

c. Operating plants which had special inservice inspection requirements related to steam generators imposed by the Commission prior to the effective date of this guide may be considered to have initiated implementation of this guide if the last inspection under the special program meets the recommendations of Regulatory Position C.7.b. The last of these special inservice inspections may be considered a baseline inspection for subsequent inspections.

d. Inspections subsequent to the baseline inspection should be implemented according to the recommendations of Regulatory Position C.6.

3. Plants not having an operating license as of the effective date of this guide should implement the preoperational inspection recommendations of Regulatory Position C.3.a except that those plants scheduled for commercial operation within the 120-day period after the effective date of this guide may forgo the preoperational baseline inspection if an inservice inspection cannot be scheduled prior to commercial operation. These plants should meet the recommendations of paragraph D.2 above.

4. Technical specifications for assuring inspection and reporting as recommended in Regulatory Position C should be incorporated in operating licenses as soon as practical.