New Requirements for Ensuring Steam Generator Tube Integrity in Pressurized Water Reactors in the United States

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ABSTRACT

This paper provides the background, rationale, and description of new, performance-based regulatory requirements currently being put into place for pressurized-water reactors (PWRs) in the United States to ensure steam generator (SG) tube integrity. The objective of these new requirements is to focus regulation directly on maintaining tube integrity rather than on the specific measures used to achieve this objective. Under these new requirements, PWR utilities must implement a program that ensures the maintenance of tube integrity. Tube integrity is defined in terms of performance criteria for structural integrity and also for operational and accident leakage integrity. Utilities must periodically demonstrate that they have met these performance criteria. The scope, frequency, and methods of inspection must be such as to ensure the maintenance of tube integrity until the next scheduled inspection. In addition to these performance-based requirements, the U.S. Nuclear Regulatory Commission (NRC) is specifying upper limits on inspection interval and tube repair criteria in recognition of the uncertainties associated with making projections of tube integrity. The NRC staff believes that these new requirements will provide a more effective regulatory approach for ensuring SG tube integrity while, at the same time, giving utilities the flexibility needed to implement cost-effective measures to achieve this goal.

INTRODUCTION

The NRC requirements for the inservice inspection and repair of SG tubes are contained in the plant technical specifications (TS). Until recently, these TS requirements were entirely prescriptive in nature, consisting of specified sampling plans for tube inspection, specified inspection intervals, and flaw acceptance limits (termed tube repair limits) beyond which the tube must be removed from service by plugging or repaired. The TS defined the SGs to be operable when the facility met these requirements. However, in reality, satisfying these requirements and meeting the overall goal of ensuring tube integrity had no direct relationship. For this reason, to ensure the maintenance of adequate tube integrity, utilities frequently found it necessary to implement measures beyond minimum TS requirements.

To address this shortcoming, the NRC and the industry have agreed on new TS requirements intended to ensure SG tube integrity. As this paper describes, these new requirements include a performance-based strategy focused directly on the overall goal of maintaining SG tube integrity. Most U.S. PWRs have already incorporated these new requirements into their TS. The NRC staff expects that these requirements will be in place at all U.S. PWRs by the end of 2007.

BACKGROUND

Assuring SG tube integrity is important because the tubing constitutes a significant fraction of the reactor coolant pressure boundary (RCPB). The SG tubing is unique in that a loss of tube integrity translates to a small loss-of-coolant accident (LOCA) bypassing containment. Additional failures of mitigating systems could lead to a direct release of radioactive fission products. If a severe accident produces conditions leading to a loss of tube integrity, significant radiological releases could occur.

Title 10 of the *Code of Federal Regulations* (10 CFR) [1] establishes the fundamental regulatory requirements for RCPB integrity. To ensure RCPB integrity in accordance with these regulations, 10 CFR Part 50.55a, "Codes and Standards," requires that the RCPB be designed in accordance with the American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code), Section III for Class 1 components [2]. Also in accordance with 10 CFR 50.55a, the RCPB is subject to the inservice inspection requirements of the ASME Code, Section XI [3]. The plant TS address inservice inspection requirements for the SG tubes more extensively than does Section XI of the ASME Code. In accordance with 10 CFR 50.55a, the SG tube surveillance requirements in the plant TS take precedence over any potentially conflicting requirements applicable to the tubing that are in the ASME Code, Section XI.

Before the new TS, the limiting conditions for operation (LCOs) applicable to SG tube integrity were the LCOs governing reactor coolant system (RCS) loop operability and RCS operational leakage. RCS loop operability was tied to having SG operability which, in turn, was tied to completion of the SG tube surveillance program. The SG surveillance program required periodic tube inspections, in intervals ranging from 12 to 40 calendar months, depending on the number and size of flaw indications found during the previous inspection. The required sample size for tube inspections ranged from 3 percent to 100 percent of the tube population, depending on the number and size of flaw indications being found. All tubes found by inspection to exceed the tube repair criteria, typically 40 percent of the nominal tube wall thickness, were required to be plugged or repaired. The tube repair limits were developed to ensure that degraded tubes (1) maintain factors of safety against gross rupture consistent with the plant design basis (i.e., consistent with the stress limit criteria of the ASME Code, Section III) and (2) maintain leakage integrity consistent with the plant licensing basis, while at the same time accounting for potential flaw size measurement error and flaw growth rate between SG inspections.

The LCO limits governing RCS operational leakage include limits on primary-to-secondary leakage. Should such leakage occur, these limits are intended to maintain leakage at less than the values assumed in the licensing-basis accident analyses and, in conjunction with the SG tube surveillance program, to provide added assurance that the plant will be shut down before a tube rupture occurs.

As part of the plant licensing basis, applicants for PWR licenses are required to analyze the consequences of postulated design-basis accidents (DBAs), such as an SG tube rupture (SGTR) and main steamline break (MSLB). These analyses consider the primary-to-secondary leakage through the tubing that may occur during these events. The analyses must show that the offsite radiological consequences do not exceed the applicable limits of the guidelines for offsite doses in 10 CFR 50.67, “Accident Source Term,” or 10 CFR Part 100, “Reactor Site Criteria”; General Design Criterion (GDC) 19, “Control Room” (in 10 CFR Part 50, “Domestic Licensing of Production and Utilization Facilities,” Appendix A, “General Design Criteria for Nuclear Power Plants”) for control room operator doses; or some fraction thereof as appropriate to the accident, or the NRC-approved licensing basis (e.g., a small fraction of these limits).

GENESIS OF NEW PERFORMANCE-BASED REQUIREMENTS

Although the old TS SG tube surveillance requirements were intended to ensure SG tube integrity in accordance with the design and licensing bases, operating experience has shown that these requirements, in and of themselves, did not necessarily ensure that facilities would meet this objective. For example, the required minimum tube inspection sample sizes and eddy current test flaw detection performance were sometimes insufficient to ensure the timely detection of flaws before the desired margins against burst and leak tightness were compromised. In addition, eddy current test measurement errors and flaw growth rates sometimes exceeded those allowed for by the tube repair criteria. Thus, the surveillance requirements alone did not necessarily ensure that the scope, frequency, and methods of inspection would be sufficient to confirm SG tube integrity.

In view of these shortcomings, licensees experiencing significant degradation problems have frequently found it necessary to implement measures beyond minimum TS requirements to ensure the maintenance of adequate tube integrity. Until the 1990s, these measures tended to be ad hoc. In the meantime, the industry and the NRC staff began initiatives to improve the effectiveness and consistency of the utility programs to ensure SG tube integrity. In 1997, the Nuclear Energy Institute (NEI) issued NEI 97-06, “Steam Generator Tube Integrity Guidelines” [4] which provided general, high-level guidelines for a programmatic, performance-based approach to ensuring SG tube integrity. NEI 97-06 references a number of detailed guideline documents from the Electric Power Research Institute for programmatic details concerning SG tube inspections, SG tube integrity assessment, in situ pressure testing, and monitoring of operational primary-to-secondary leakage. The NEI 97-06 approach was inspired by and is similar to an approach developed by the NRC staff in a draft regulatory guide, “Steam Generator Tube Integrity,” published as DG-1074 in December 1998 [5]. All U.S. PWR utilities committed to NEI to implement the NEI 97-06 initiative no later than the first refueling outage starting after January 1, 1999.

Subsequent to the initial issuance of NEI 97-06, the NRC staff worked extensively with the industry to address issues associated with the industry initiative and to identify needed changes to the plant TS to ensure maintenance of tube integrity. These efforts culminated in agreement between the NRC staff and the industry on a generic template for new TS [6] incorporating a programmatic, performance-based approach which is in general alignment with NEI 97-06. NEI has recently updated NEI 97-06 consistent with the TS generic template [7].

OVERVIEW—NEW REQUIREMENTS FOR ENSURING SG TUBE INTEGRITY

The new TS contain three conditions (i.e., LCOs) which require plant shutdown if not met:

1) SG tube integrity shall be maintained.
2) All SG tubes satisfying the tube repair criteria (i.e., tubes with measured flaw sizes that exceed the tube repair criteria) shall be plugged in accordance with the SG program.

3) Operational primary-to-secondary leakage shall not exceed 555 liters/day (150 gallons/day) through any one SG.

Condition 1 is a new requirement that makes maintaining tube integrity a direct requirement. It replaces the earlier requirement that the SGs are operable upon completion of specified tube surveillance actions which are not directly related to maintaining tube integrity. As discussed in more detail below, tube integrity must be confirmed during each SG inservice inspection, and the inspections are to be performed in a manner that ensures the maintenance of tube integrity until the next scheduled inspection.

Condition 2 is equivalent to the earlier requirement that the SGs are operable only after plugging of all tubes found by inspection to satisfy the tube repair limit. This condition is not needed if Condition 1 is met. It is included in the TS to ensure that if tubes satisfying the tube repair criteria are inadvertently not plugged or repaired before plant restart, the utility will be required to do an analysis within a 7-day period to demonstrate that the affected tubes will maintain their integrity until the next scheduled inspection. If the utility cannot demonstrate this, then the plant must be shut down.

Condition 3 is similar to earlier leakage limit requirements, except with a reduced, more restrictive limit. Earlier limits typically included an 1850 liters/day limit per SG and a 5328 liters/day limit on total leakage in all SGs. Primary-to-secondary leakage is the only tube integrity indicator, albeit an indirect one, available to the operator while the plant is actually operating. Such leakage may be symptomatic of unanticipated tube degradation or it may indicate that previously identified degradation is proceeding at a rate higher than previously anticipated. Thus, Condition 3 is intended to complement Condition 1, providing additional assurance that tube integrity will be maintained.

The new TS also require that an SG program be established and implemented to ensure the maintenance of SG tube integrity. The TS do not provide specific details on how this objective is to be met; it is the licensee's responsibility to ensure that the program will meet the stated objective. Industry guidelines in NEI 97-06 and other guidance referenced therein provide a resource to utilities for meeting this objective. However, the TS do define a general programmatic framework for the SG program, which is discussed in the remainder of this paper. The programmatic elements that must be included as part of the SG program include the following:

- performance criteria for SG tube integrity
- provisions for condition monitoring
- provisions for tube repair criteria
- provisions for SG tube inspections
- provisions for monitoring primary-to-secondary leakage

PERFORMANCE CRITERIA FOR SG TUBE INTEGRITY

The new TS require that SG tube integrity shall be maintained by meeting the performance criteria for tube structural integrity, accident-induced leakage, and operational leakage.

The NRC staff's bases for evaluating the acceptability of these performance criteria are that meeting these criteria is sufficient to ensure that tube integrity is within the plant design and licensing bases and that meeting these criteria in conjunction with implementation of the SG program ensures no significant increase in risk. The staff also evaluated these performance criteria in the context of the overall SG program such that if the performance criteria are inadvertently exceeded, the consequences will be tolerable until the facility identifies and corrects the situation. In addition, the performance criteria must be expressed in terms of parameters that are directly or indirectly measurable.

Structural Integrity Performance Criterion

The structural integrity criterion is as follows:

> All inservice steam generator tubes shall retain structural integrity over the full range of normal operating conditions (including startup, operation in the power range, hot standby, cooldown, and all anticipated transients included in the design specification) and design basis accidents. This includes maintaining a safety factor of 3.0 against burst under normal steady state full power operation primary-to-secondary pressure differential and a safety factor of 1.4 against burst applied to design basis accident primary-to-secondary pressure differentials. Apart from the above requirements, additional loading considerations associated with design basis accidents, or combination of accidents in accordance with the design and licensing basis, shall also be evaluated to determine if the associated loads contribute significantly to burst or collapse. In the assessment of tube integrity, those loads that do significantly affect burst or collapse shall be determined and assessed in combination with the loads due to differential pressure with a safety factor of 1.2 on the combined primary loads and 1.0 on axial secondary loads.

The "safety factor of three" criterion stems from Section III of the ASME Code which, in part, limits primary membrane stress under design conditions to one-third of ultimate strength. The proposed structural integrity criterion would limit application of the "safety factor of three" criterion to only those pressure loadings existing during normal full-power, steady-state operating conditions. Differential pressures under this condition are plant-specific, ranging from 8.3 MPa (1250 psi) to 10.3 MPa (1500 psi). However, differential pressure loadings can be considerably higher during normal operating transients, ranging between 11 MPa (1600 psi) to 14.8 MPa (2150 psi) during plant heatups and cooldowns. Given a factor of safety equal to 3 under normal full-power conditions, the factor of safety during heatups and cooldowns can be as low as about 2 for some plants. However, these safety factors are consistent with the safety factors implicit in the specified tube repair limit of 40 percent of the nominal tube wall thickness which has been in the TS since the 1970s and, thus, does not change the safety factors implicit in the licensing basis.

The proposed safety factor of 1.4 against burst applied to design-basis primary-to-secondary pressure differentials derives from the 0.7 times ultimate strength limit for primary membrane stress in the ASME Code, Appendix F, F-1331.1(a). This criterion is also consistent with the stress limit criteria used to develop the standard 40-percent tube repair limit in the TS and, thus, does not change the plant licensing basis.

The structural criterion requires that, apart from the safety factor requirements applying to pressure loads, additional loads associated with DBAs, or combination of accidents in accordance with the design and licensing bases, shall also be evaluated to determine whether these loads contribute significantly to burst or collapse. Examples of such additional loads include bending moments during LOCA, MSLB, or safe-shutdown earthquake (SSE) and axial, differential thermal loads in once-through SG tubing. "Combination of accidents" refers to the assumption in the design and licensing basis for many plants that DBAs, such as LOCA and MSLB, occur concurrently with SSE. The NRC staff explicitly considered such nonpressure sources of primary stress under accident conditions relative to ASME Code, Appendix F, stress limits in the development of the 40-percent tube repair criterion.

Where nonpressure loads are determined to contribute significantly to burst or collapse, the proposed structural criterion requires that such loads be determined and assessed in combination with the loads resulting from pressure with a safety factor of 1.2 on the combined primary loads and a 1.0 safety factor on axial secondary loads. The 1.2 safety factor for combined primary loads was derived from the ratio of burst or collapse load divided by allowable load from the ASME Code for faulted conditions. Burst or collapse load was assumed to be equal to the material flow stress, assuming the Code's minimum yield and ultimate strength values and a flow stress coefficient of 0.5. Allowable load was determined from ASME Code, Section III, Appendix F, F-1331.3.a, which defines an allowable primary membrane plus bending load for service level d (faulted) conditions. The proposed 1.0 safety factor for axial secondary loads (resulting from differential thermal, axial loads) goes beyond what is required by the design basis in Section III of the ASME Code, since Section III assumes that a one-time application of such a load cannot lead to burst or collapse. (This is not necessarily the case for once-through SG tubes with circumferential cracks which can lead to tube severance under axial, differential thermal loads. In such cases, it is conservative to treat such loads as primary.) The proposed safety factor criterion of 1.0 is conservative for loads that behave as secondary since it ignores the load relaxation effect associated with axial yielding before tube severance (burst) occurs.

Not only are these criteria consistent with the current licensing basis, but they are also important to avoiding undue risk. NRC risk studies indicate that maintaining the performance criteria safety factors is particularly important in avoiding risk associated with severe accident scenarios involving a fully pressurized primary system and depressurized secondary system where the tubes may heat to temperatures well above design-basis values and significantly reduce the strength of the tubes [8].

Exceeding the above safety margin criteria would not likely lead to intolerable consequences provided that such an occurrence is infrequent and that if it occurs, the facility promptly detects and corrects it to ensure that risk is limited. Even if a tube should degrade to the point of rupture under normal operating conditions, such an occurrence is an analyzed condition with reasonable assurance that the radiological consequences will be acceptable. Finally, the structural performance criterion is expressed in terms of parameters that are measurable. Specifically, structural margins can be directly demonstrated through in situ pressure testing or can be calculated from burst prediction models using as input flaw size measurements obtained by inspection.

Accident Leakage Performance Criterion

The accident-induced leak rate criterion is as follows:

> The primary-to-secondary accident induced leakage rate for any design basis accident, other than a SG tube rupture, shall not exceed the leakage rate assumed in the accident analysis in terms of total leakage rate for all SGs and leakage rate for an individual SG. Leakage is not to exceed 3.7 liters/day (1 gallon/day) per SG.

This performance criterion for accident-induced leak rate is consistent with leak rates assumed in the licensing-basis accident analyses for purposes of demonstrating that the consequences of DBAs meet the limits in 10 CFR 100 for offsite doses, GDC 19 for control room operator doses, or some fraction thereof as appropriate to the accident, or the NRC-approved licensing basis (e.g., a small fraction of these limits). This criterion does not apply to design-basis SGTR accidents for which the analysis assumes leakage corresponding to a postulated double-ended rupture of a tube. The proposed criterion ensures that from the standpoint of accident-induced leakage, the plant will be operated within its analyzed condition.

For certain severe accident sequences involving high primary-side pressure and a depressurized secondary system, primary-to-secondary leakage may lead to more heating of the leaking tube than would be the case if it were not leaking, thus increasing the potential for failure of that tube and a consequent large early release. The proposed accident-induced leakage criterion ensures that the potential for induced leakage during severe accidents will be maintained at a level that will not increase risk.

Exceeding this criterion is not likely to lead to intolerable consequences provided that such an occurrence is infrequent and that if it occurs, the plant promptly detects and corrects it so as to ensure that risk is minimized. It should be noted that the criterion applies to leakage that could be induced by an accident in the unlikely event that such an accident occurs. Finally, the accident leakage performance criterion is expressed in terms of parameters that are measurable, both directly and indirectly. Specifically, structural margins can be directly demonstrated through in situ pressure testing or can be calculated using leakage prediction models using flaw size measurements obtained by inservice inspection as input.

Operational Leakage Performance Criterion

The operational leakage performance criterion is equivalent to the TS LCO limit on operational primary-to-secondary leakage discussed earlier. Given the TS LCO limit, a separate performance criterion for operational leakage is unnecessary for ensuring prompt shutdown if the limit is exceeded. However, operational leakage is an indicator of tube integrity performance, although it is not a direct indicator. It is the only indicator that can be monitored while the plant is operating. Maintaining leakage within the limit provides added assurance that the plant is meeting structural and accident leakage performance criteria. Thus, inclusion of the TS leakage limit among the set of tube integrity performance criteria is appropriate from the standpoint of completeness of the performance criteria.

CONDITION MONITORING ASSESSMENT

The new TS require that the SG program include provisions for condition monitoring assessments as follows:

> Condition monitoring assessment means an evaluation of the “as found” condition of the tubing with respect to the performance criteria for structural and accident induced leakage integrity. The “as found” condition refers to the condition of the tubing during a SG inspection outage, as determined from the inservice inspection results or by other means, prior to the plugging of tubes. Condition monitoring assessments shall be conducted during each outage during which the SG tubes are inspected or plugged to confirm that the performance criteria are being met.

The requirement for condition monitoring assessments addresses an essential element of any performance-based strategy—the need to monitor performance relative to the performance criteria. Confirmation that the tube integrity criteria are met shows that the plant has achieved the overall programmatic goal of maintaining tube integrity to that point in time. However, failure to meet the tube integrity criteria indicates potential shortcomings in the effectiveness of the utility’s SG program and the need for corrections to the program to ensure the maintenance of tube integrity in the future. Failure to meet either the structural or accident leakage performance criterion is reportable pursuant to 10 CFR 50.72 and 50.73 in accordance with guidelines in NUREG-1022, “Event Reporting Guidelines 10 CFR 50.72 and 50.73” [9]. In addition, the NRC regional office would follow up on such an occurrence as appropriate consistent with the NRC Reactor Oversight Program [10] and the risk significance of the occurrence.

INSERVICE INSPECTION

The new TS require that the SG program include periodic tube inspections. This includes a new performance-based requirement that the scope, methods, and intervals of the inspection ensure the maintenance of SG tube integrity until the next inspection. This is a performance-based requirement that complements the requirement for condition monitoring from the standpoint of ensuring that tube integrity is maintained. The requirement for condition monitoring is backward looking in that it is intended to confirm that tube integrity has been maintained up to the time the assessment is performed. The inspection requirement, by contrast, is forward looking as it is intended to ensure that tube inspections, in conjunction with plugging of tubes, are performed so as to ensure that the plant will continue to meet the performance criteria until the next SG inspection. Tube inspections would be followed again by condition monitoring at the next SG inspection to confirm that the performance criteria were in fact met, and so on.

With respect to scope and methods of inspection, the new TS also require that the number and portions of tubes inspected and method of inspection be chosen with the objective of detecting flaws of any type (for example, volumetric flaws and axial and circumferential cracks) that may be present along the length of the tube, from the tube-to-tubesheet weld at the tube inlet to the tube-to-tubesheet weld at the tube outlet, and that may satisfy the applicable tube repair criteria. Furthermore, the inspection will assess degradation to determine the type and location of flaws to which the tubes may be susceptible and, based on this assessment, to determine which inspection methods should be used and at what locations.

Under the new TS, the required frequency of inspection in conjunction with inspection scope and inspection methods shall be such as to ensure the maintenance of tube integrity until the next SG inspection. This addresses shortcomings in the current requirements in that it requires inspection frequency to be part of a management strategy aimed at ensuring tube integrity. The TS bases state that inspection frequency will be determined, in part, by operational assessments which utilize additional information on existing degradation and flaw growth rates to determine an inspection frequency that provides reasonable assurance that the tubing will meet the SG performance criteria at the next SG inspection.

The NRC staff also notes, however, that any assessment or projection of the future condition of the SG tubing based on the existing condition of the tubing and anticipated flaw growth rates can involve significant uncertainty that may be difficult to conservatively and reliably bound. For this reason, the new TS supplement the performance-based requirement concerning inspection frequencies with a set of prescriptive requirements adding assurance that tube integrity will be maintained.

The new prescriptive requirements include the following:

- Inspect 100 percent of the sample during first refueling outage or first refueling outage following SG replacement.
- For SGs with alloy 600 mill-annealed tubes, inspect 100 percent of the tubes in sequential periods of 60 effective full-power months (EFPM) following the first refueling outage. No SG shall operate more than 24 EFPM or one refueling cycle without being inspected.
- For SGs with alloy 600 thermally treated (TT) tubes, inspect 100 percent of the tubes in sequential periods of 120, 90, and, thereafter, 60 EFPM following the first refueling outage. No SG shall operate more than 48 EFPM or two refueling cycles without being inspected.
- For SGs with alloy 690 TT tubes, inspect 100 percent of the tubes in sequential periods of 144, 108, 72, and, thereafter, 60 EFPM following the first refueling outage. No SG shall operate more than 72 EFPM or three refueling cycles without being inspected.
- If crack indications are found in any SG tube, inspect each SG for the specific mechanism that caused the crack at intervals not to exceed 24 EFPM or one refueling cycle.

The proposed prescriptive requirements for inspection frequency are based on qualitative engineering considerations and experience. They reflect the improved resistance to stress-corrosion cracking of alloy 690 TT tubing compared to that of alloy 600 TT tubing and particularly compared to that of alloy 600 mill-annealed tubing. The requirements also reflect the increase in the potential for cracking with increasing time in service and the particular challenges associated with the management of stress-corrosion cracking with respect to satisfying the tube integrity performance criteria.

TUBE REPAIR CRITERION

The new TS retain the current TS tube repair criterion (termed "plugging limits" in the old TS requirements). Specifically, the new TS require that tubes found by inspection to contain flaws with a depth equal to or exceeding 40 percent of the nominal tube wall thickness be plugged. This criterion is fully consistent with the tube integrity performance criteria in that flaws not exceeding the tube repair criterion satisfy the performance criteria. In addition, the criterion provides an allowance for flaw size measurement error and incremental crack growth between inspections. The repair criterion is prescriptive rather than performance based. It provides added assurance that tube integrity will be maintained, given the performance-based strategy to be followed under the new TS. Its inclusion as part of the new TS also ensures that the NRC staff has the opportunity to review any risk implications of future licensee-proposed license amendments for alternate tube repair criteria, in conjunction with alternate tube integrity performance criteria.

CONCLUSIONS

Effective management of SG tube integrity can be achieved through a performance-based strategy focused on satisfying tube integrity performance criteria. Projections of tube integrity performance involve considerable uncertainty and, thus, supplementing a performance-based strategy with upper bound limits on inspection intervals and specified plugging limits is appropriate. The new TS requirements being adopted in the United States provide reasonable assurance that tube integrity will be maintained, while at the same time giving utilities the flexibility needed to implement cost-effective measures to achieve this goal.

REFERENCES

1. Title 10 of the *Code of Federal Regulations*, Revised as of January 1, 2006.
2. American Society of Mechanical Engineers, Boiler and Pressure Vessel Code (ASME Code), Section III.
3. American Society of Mechanical Engineers, Boiler and Pressure Vessel Code (ASME Code), Section XI.
4. Nuclear Energy Institute, “Steam Generator Tube Integrity Guidelines,” NEI 97-06 (Original), December 1997.
5. U.S. Nuclear Regulatory Commission, “Steam Generator Tube Integrity,” Draft Regulatory Guide, DG-1074, December 1998.
6. *Federal Register*, May 6, 2005 (Volume 70, No. 87, pages 24126–24127).
7. Nuclear Energy Institute, “Steam Generator Tube Integrity Guidelines,” NEI 97-06 (Revision 2), May 2005.
8. U.S. Nuclear Regulatory Commission, “Risk Assessment of Severe Accident-Induced Steam Generator Tube Rupture,” NUREG-1570, March 1998.
9. U.S. Nuclear Regulatory Commission, “Event Reporting Guidelines 10 CFR 50.72 and 50.73,” NUREG-1022, Revision 2, October 31, 2000.[1]
10. U.S. Nuclear Regulatory Commission, “Reactor Oversight Process,” NUREG-1649, Revision 4, December 2006.

[1] On September 24, 2004, the *Federal Register* published a notice (69 FR 57367) of the issuance of an errata to Revision 2 of NUREG-1022. The errata states that SG tube degradation is considered serious if either of the two criteria specified in Section 3.2.4(A)(3) of NUREG-1022, Revision 2 (i.e., the structural and accident leakage performance criteria), are not satisfied.