



# U.S. NUCLEAR REGULATORY COMMISSION

## STANDARD REVIEW PLAN

### 5.4.2.1 STEAM GENERATOR MATERIALS AND DESIGN

#### REVIEW RESPONSIBILITIES

**Primary** - Organization responsible for the review of component integrity issues related to steam generator tubes

**Secondary** - Organization responsible for the review of fluid-elastic instability in the reactor coolant system.

#### I. AREAS OF REVIEW

The purpose of this review is to ensure that (1) the materials used to fabricate the steam generator are selected, processed, tested, and inspected to appropriate specifications, (2) the design of the steam generator limits the susceptibility of the materials to degradation and corrosion, (3) the fracture toughness of the ferritic materials is adequate, (4) the materials used in the steam generator are compatible with the environment to which they will be exposed, (5) the design of the secondary side of the steam generator permits the chemical or mechanical removal of chemical impurities, and (6) any degradation to which the materials are susceptible (including fracture) is avoided, can be managed through the inservice inspection program, or can be controlled through limits placed on operating parameters. Performing periodic steam

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#### USNRC STANDARD REVIEW PLAN

This Standard Review Plan (SRP), NUREG-0800, has been prepared to establish criteria that the U.S. Nuclear Regulatory Commission (NRC) staff responsible for the review of applications to construct and operate nuclear power plants intends to use in evaluating whether an applicant/licensee meets the NRC regulations. The SRP is not a substitute for the NRC regulations, and compliance with it is not required. However, an applicant is required to identify differences between the design features, analytical techniques, and procedural measures proposed for its facility and the SRP acceptance criteria and evaluate how the proposed alternatives to the SRP acceptance criteria provide an acceptable method of complying with the NRC regulations.

The SRP sections are numbered in accordance with corresponding sections in Regulatory Guide (RG) 1.70, "Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants (LWR Edition)." Not all sections of RG 1.70 have a corresponding review plan section. The SRP sections applicable to a combined license application for a new light-water reactor (LWR) are based on RG 1.206, "Combined License Applications for Nuclear Power Plants (LWR Edition)."

These documents are made available to the public as part of the NRC policy to inform the nuclear industry and the general public of regulatory procedures and policies. Individual sections of NUREG-0800 will be revised periodically, as appropriate, to accommodate comments and to reflect new information and experience. Comments may be submitted electronically by email to [NRO\\_SRP@nrc.gov](mailto:NRO_SRP@nrc.gov).

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generator inspections will ensure that the integrity of the steam generator is maintained at a level comparable to that in the original design requirements.

The specific areas of review are as follows:

1. The selection, processing, testing, and inspection (during fabrication/processing) of the materials used to fabricate the steam generator.
2. The design provisions for limiting the susceptibility of the steam generator to degradation or corrosion.
3. The fabrication and processing of ferritic materials, including the fracture toughness of the ferritic materials used in the steam generator.
4. The fabrication and processing of austenitic stainless steel materials (if austenitic stainless steel is used for reactor coolant pressure boundary (RCPB) or secondary side pressure boundary (SSPB) applications).
5. The compatibility of steam generator materials with the primary (reactor) and secondary coolant and cleanliness control.
6. The provisions for accessing the secondary side of the steam generator for maintenance or cleaning.
7. Inspections, Tests, Analyses, and Acceptance Criteria (ITAAC). For design certification (DC) and combined license (COL) reviews, the staff reviews the applicant's proposed ITAAC associated with the structures, systems, and components (SSCs) related to this Standard Review Plan (SRP) section in accordance with SRP Section 14.3, "Inspections, Tests, Analyses, and Acceptance Criteria." The staff recognizes that the review of ITAAC cannot be completed until after the rest of this portion of the application has been reviewed against acceptance criteria contained in this SRP section. Furthermore, the staff reviews the ITAAC to ensure that all SSCs in this area of review are identified and addressed as appropriate in accordance with SRP Section 14.3.
8. COL Action Items and Certification Requirements and Restrictions. For a DC application, the review will also address COL action items and requirements and restrictions (e.g., interface requirements and site parameters).

For a COL application referencing a DC, a COL applicant must address COL action items (referred to as COL license information in certain DCs) included in the referenced DC. Additionally, a COL applicant must address requirements and restrictions (e.g., interface requirements and site parameters) included in the referenced DC.

### Review Interfaces

Other SRP sections interface with this section as follows:

1. The review of the structural integrity of pressure-retaining components of the steam generator is conducted under SRP Section 3.9.3, "ASME Code Class 1, 2, and 3 Components and Component Supports, and Core Support Structures."
2. The review of the programs for ensuring the integrity of bolting and threaded fasteners is performed under SRP Section 3.13, "Threaded Fasteners - ASME Code Class 1, 2, and 3."
3. The review of the acceptability of pressure-retaining components for compliance with Title 10 of the *Code of Federal Regulations* (10 CFR) 50.55a, "Codes and Standards Rule," is performed under SRP Section 5.2.1.1, "Compliance with American Society of Mechanical Engineers Code Requirements in the Codes and Standards Rule, 10 CFR 50.55a." The review of the code classification for the steam generator components is performed under SRP Section 5.2.1.1. The code classification determines the appropriate American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (ASME Code) requirements that the steam generators must satisfy (e.g., Subsection NB of Section III of the ASME Code specifies requirements for ASME Code Class 1 components, whereas Subsection NC lists requirements for ASME Code Class 2 components).
4. The review of the acceptability of any ASME Code cases that the applicant may have invoked in connection with the materials used for the steam generators is performed under SRP Section 5.2.1.2, "Applicable Code Cases."
5. The review of the suitability and adequacy of RCPB materials, except for reactor vessel materials, is performed under SRP Section 5.2.3, "Reactor Coolant Pressure Boundary Materials."
6. The review of the acceptability of the reactor coolant chemistry and associated chemistry controls (including additives such as inhibitors), as it relates to corrosion control and compatibility with RCPB materials, is performed under SRP Section 9.3.4, "Chemical and Volume Control System (PWR) (Including Boron Recovery System)."
7. The review of the acceptability of the inservice inspection program for the RCPB, excluding the steam generator tubes, is performed under SRP Section 5.2.4, "Reactor Coolant Pressure Boundary Inservice Inspection and Testing."
8. The review of the acceptability of the steam generator program is conducted under SRP Section 5.4.2.2, "Steam Generator Program." The steam generator program requires sufficient access to the steam generator to permit primary and secondary side inspections.
9. The review of the suitability and adequacy of steam and feedwater system materials is performed under SRP Section 10.3.6, "Steam and Feedwater System Materials."
10. The review of the capability of the condensate cleanup system to provide feedwater to the steam generators and thus meet water purity requirements is performed under SRP Section 10.4.6, "Condensate Cleanup System."

11. The review of the capability of the steam generator blowdown system to assist in maintaining the optimum secondary side water chemistry in the steam generators is conducted under SRP Section 10.4.8, "Steam Generator Blowdown System."

The specific acceptance criteria and review procedures are contained in the referenced SRP sections.

## II. ACCEPTANCE CRITERIA

### Requirements

Acceptance criteria are based on meeting the relevant requirements of the following Commission regulations:

1. General Design Criterion (GDC) 1, "Quality Standards and Records," of Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," requires that SSCs important to safety shall be designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions to be performed. Where generally recognized codes and standards are used, they shall be identified and evaluated to determine their applicability, adequacy, and sufficiency and shall be supplemented or modified as necessary to assure a quality product in keeping with the required safety function. A quality assurance program shall be established and implemented in order to provide adequate assurance that these SSCs will perform their safety functions. Appropriate records of the design, fabrication, erection, and testing of SSCs important to safety shall be maintained by or under the control of the nuclear power unit licensee throughout the life of the unit.
2. GDC 4, "Environmental and Dynamic Effects Design Bases," requires in part, that SSCs important to safety shall be designed to accommodate the effects of, and to be compatible with, the environmental conditions associated with normal operation, maintenance, testing, and postulated accidents.
3. GDC 14, "Reactor Coolant Pressure Boundary," requires that the RCPB shall be designed, fabricated, erected, and tested so as to have an extremely low probability of abnormal leakage, of rapidly propagating failure, and of gross rupture.
4. GDC 15, "Reactor Coolant System Design," requires that the reactor coolant system and associated auxiliary, control, and protection systems shall be designed with sufficient margin to assure that the design conditions of the RCPB are not exceeded during any condition of normal operation, including anticipated operational occurrences.
5. GDC 30, "Quality of Reactor Coolant Pressure Boundary," requires, in part, that components which are part of the RCPB shall be designed, fabricated, erected, and tested to the highest quality standards practical.
6. GDC 31, "Fracture Prevention of Reactor Coolant Pressure Boundary," requires, in part, that the RCPB shall be designed with sufficient margin to ensure that—when stressed under operating, maintenance, testing, and postulated accident conditions—the

boundary behaves in a nonbrittle manner and the probability of rapidly propagating fracture is minimized.

7. 10 CFR 50.55a(c), 10 CFR 50.55a(d), and 10 CFR 50.55a(e) generally require certain grouping of components, including those compromising the RCPB or SSPB, to meet the requirements of Section III of the ASME Code.
8. Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants," to 10 CFR Part 50 applies to the steam generator materials. Of particular note is Criterion XIII, which requires, in part, that measures shall be established to control the handling, storage, shipping, cleaning, and preservation of material and equipment in accordance with work and inspection instructions to prevent damage or deterioration.
9. Appendix G, "Fracture Toughness Requirements," to 10 CFR Part 50 requires, in part, that RCPB pressure-retaining components that are made of ferritic materials meet ASME Code requirements for fracture toughness during system hydrostatic tests and any condition of normal operation, including anticipated operational occurrences.
10. 10 CFR 52.47(b)(1) requires, in part, that a DC application contain the proposed ITAAC that are necessary and sufficient to provide reasonable assurance that, if the inspections, tests, and analyses are performed and the acceptance criteria met, a plant that incorporates the DC is built and will be operated in conformity with the DC, the provisions of the Atomic Energy Act, and the U.S. Nuclear Regulatory Commission (NRC) regulations.
11. 10 CFR 52.80(a) requires that a COL application contain the proposed inspections, tests, and analyses, including those applicable to emergency planning, that the licensee shall perform, and the acceptance criteria that are necessary and sufficient to provide reasonable assurance that, if the inspections, tests, and analyses are performed and the acceptance criteria met, the facility has been constructed and will be operated in conformity with the combined license, the provisions of the Atomic Energy Act, and the NRC regulations.

#### SRP Acceptance Criteria

Below are specific SRP acceptance criteria that meet the relevant requirements of the NRC regulations identified above. The SRP is not a substitute for the NRC regulations, and compliance with it is not required. However, an applicant is required to identify differences between the design features, analytical techniques, and procedural measures proposed for its facility and the SRP acceptance criteria and evaluate how the proposed alternatives to the SRP acceptance criteria provide acceptable methods of compliance with the NRC regulations.

#### 1. Selection, Processing, Testing, and Inspection of Materials

The materials selected for the steam generator form portions of the primary and secondary system pressure boundary. In addition, certain materials used for non-pressure-retaining components (including tube supports) can have a direct impact on the integrity of the RCPB (e.g., denting of the steam generator tubes from corrosion of a

tube support or mechanical damage to the tubes from the generation of loose parts). As a result, the materials selected for the steam generator must be fabricated and tested to quality standards commensurate with the importance of the safety functions to be performed, as required by GDC 1. In addition, the materials selected for the RCPB must be fabricated and tested to the highest quality standards practical, as required by GDC 30, "Quality of Reactor Coolant Pressure Boundary."

The materials selected for use in fabricating the steam generator are acceptable from a fabrication/manufacturing standpoint if they comply with 10 CFR 50.55a. In general, this regulation—specifically 10 CFR 50.55a(c), 10 CFR 50.55a(d), and 10 CFR 50.55a(e)—requires that the components satisfy the requirements of Section III of the ASME Code. Provisions in 10 CFR 50.55a(b) permit ASME Code cases, as discussed in Regulatory Guide (RG) 1.84, "Design, Fabrication, and Materials Code Case Acceptability, ASME Section III," to be used to select, fabricate, and test materials for the steam generator.

Section III of the ASME Code establishes—through articles such as NCA-1000, NB-2000 (for Class 1 components), and NC-2000 (for Class 2 components)—requirements for selecting, processing, testing, inspecting (during fabrication/manufacturing), and certifying materials. In general, Section III of the ASME Code references Parts C and D of Section II of the ASME Code for permitted material specifications (e.g., in Articles NB-2120 and NC-2120).

Examples of materials that are currently used for Class 1 components in the steam generator include the following:

Tubing:	ASME SB-163, N06690, Thermally Treated
Pressure Plates:	ASME SA-533, Grade B, Class 1
Pressure Forgings (including nozzles and tubesheet):	ASME SA-508, Grade 3, Class 2 (formerly referred to as Class 3a)
Nozzle Safe Ends:	ASME SA-182, F316LN
Channel Heads:	ASME SA-508, Grade 3, Class 2 (formerly referred to as Class 3a)
Cladding, Buttering, and Welds:	ASME SFA 5.4 (308L, 309L), 5.9 (308L, 309L), 5.11 (ENiCrFe-7), and 5.14 (ERNiCrFe-7)
Pressure Boundary Welds:	Low Alloy Steel, SFA 5.5, 5.23, 5.28
Manway Studs:	ASME SA-193, Grade B7
Manway Nuts:	ASME SA-194

Examples of materials that are currently used for Class 2 components in the steam generator include the following:

Pressure Plates:	ASME SA-533, Grade B, Class 1
Bolting:	ASME SA-193, Grade B7
Tube Support Structures (including anti-vibration bars/fan-bars):	ASME SA-240, Type 405 and Type 410S

In summary, for the purposes of satisfying GDC 1 and GDC 30, the materials used in fabricating the steam generator are acceptable if they are selected, fabricated, tested, and inspected (during fabrication/manufacturing) in accordance with the ASME Code.

## 2. Steam Generator Design

The design of the steam generator should limit the potential for degradation so that the integrity of the steam generator, including the tubes, is maintained during the operating interval between inspections. Some degradation mechanisms must be precluded by design since they propagate rapidly or unpredictably, while other degradation mechanisms can be effectively managed through inservice inspections. Degradation of the steam generator tubes and other secondary side components that could affect tube integrity should be manageable through the steam generator program (reviewed under SRP Section 5.4.2.2).

Degradation of other steam generator RCPB and SSPB materials should be manageable through the inservice inspection program. The RCPB inservice inspection program is reviewed under SRP Section 5.2.4, while the SSPB inservice inspection program is reviewed under SRP Section 6.6, "Inservice Inspection and Testing of Class 2 and 3 Components."

The steam generator design is acceptable from a degradation standpoint if the design:

- A. Precludes degradation that propagates rapidly, unpredictably, or in such a manner that it cannot be managed through the inservice inspection program. Rapid and unpredictable degradation includes degradation mechanisms that result from excitation mechanisms, such as fluid-elastic instability. For fatigue, the steam generator tubes and tube-to-tubesheet welds are considered acceptable if they comply with RG 1.207, "Guidelines for Evaluating Fatigue Analyses Incorporating the Life Reduction of Metal Components Due to the Effects of the Light-Water Reactor Environment for New Reactors." However, acceptable fatigue design does not ensure fluid-elastic instability has been addressed. For degradation mechanisms resulting from a phenomenon such as fluid-elastic instability, the steam generator design and fabrication details should be reviewed on a case-by-case basis as outlined below.

For a degradation mechanism review of a steam generator design that is similar to existing designs, the reviewer should:

1. Confirm that the thermal-hydraulic and flow-induced vibration analyses used modeling software that has been used in nuclear steam generator designs and has resulted in successful steam generator operation, or was benchmarked successfully against such software. The effectiveness of anti-vibration bars at preventing fluid-elastic instability should be considered in the analyses.
2. Confirm that the most limiting location in the tube bundle was evaluated and that the analyses accounted for tube plugging and tube bundle fouling.
3. Confirm that for analyses of the steam generator tubes, the flow-induced vibration model shows that sufficient margin to fluid-elastic instability (i.e., at least 25 percent) has been maintained.

If conditions 1 – 3 are not met, or if the steam generator design is new or unique, a detailed evaluation of the technical basis should be performed. The detailed evaluation may include reviewing scale testing under the expected operating conditions.

- B. Limits the crevice between the tube and the tube supports. This can be accomplished by using openings of various shapes (e.g., trifoil or quatrefoil) in tube support plates or by using lattice grid (eggcrate) tube supports. The design of the tube supports should promote high-velocity flow along the tubes. Limiting the crevices will limit the buildup of corrosion product and sludge, which can lead to corrosion of the tubes and the supports.
- C. Uses appropriate corrosion-resistant materials or employs cladding for materials susceptible to corrosion. To limit the potential for denting the tubes, the tube support structures should use a corrosion-resistant material. Tube denting is a phenomenon associated with corrosion of the tube support structures, creating a hard corrosion product that fills the crevice between the tube and the tube support. Denting of tubes can result in the restriction of primary coolant flow and stress-corrosion cracking of the tubes. To limit the steam generator tube's susceptibility to corrosion, the tubes should be heat-treated (e.g., thermally treated), as needed, to optimize their microstructure from a corrosion resistance standpoint. To reduce residual stresses in the U-bend region of short-radius tubes (and therefore the material's susceptibility to corrosion), the U-bend region of short-radius tubes should be stress-relieved after bending. The materials that support the tubes and other materials on the secondary side should be sufficiently resistant to degradation to ensure that the tubes will remain adequately supported and to reduce the potential for the generation of loose parts, which can result in a loss of tube integrity. The corrosion-resistant cladding on the tubesheet and on other primary side components should be weld-deposited, fabricated, and inspected according to the requirements in Part QW of Section IX of the ASME Code.



- D. Limits the crevice and residual stresses in the tubesheet region. The extent of the tube-to-tubesheet crevice should be limited. This can be accomplished by expanding the tube throughout the tubesheet region, if practical (given other design considerations such as the desired preload in the tube for once-through steam generators). The choice of the method for expansion should consider limiting the stresses in the tube. Limiting the crevices will restrict the buildup of corrosion product and sludge that can lead to corrosion. Limiting the stresses will diminish the potential for stress-corrosion cracking. The tube-to-tubesheet weld should be designed for structural and leakage integrity under operating and design-basis accident conditions. This is generally accomplished through compliance with Section III of the ASME Code.
- E. Includes an appropriate allowance for deterioration (including corrosion) of the steam generator materials. This is accomplished through compliance with Section III of the ASME Code (Articles NB-2160 and NB-3121 for Class 1 components and Articles NC-2160 and NC-3121 for Class 2 components).
- F. Uses bolting material that will perform adequately under the expected service conditions and that is not subject to stress-corrosion cracking. This can be accomplished by following the regulatory positions in RG 1.65, "Materials and Inspections for Reactor Vessel Closure Studs." Although RG 1.65 provides guidance for the design of reactor vessel closure studs, it is also appropriate for the selection of suitable steam generator bolting material. The integrity of bolting and threaded fasteners is also reviewed under SRP Section 3.13, "Threaded Fasteners - ASME Code Class 1, 2, and 3."
- G. Uses a feedwater inlet design that prevents flow-accelerated corrosion (FAC), water hammer, and thermal stratification. The reviewer determines that the feedwater components in the steam generator are resistant to FAC because they are fabricated from chromium-containing low alloy steel or stainless steel. (SRP Section 10.3.6, "Steam and Feedwater System Materials," provides detailed guidance on materials selection to avoid FAC.) The potential for water hammer can be minimized by following the guidance in Branch Technical Position (BTP) 10-2, "Design Guidelines for Avoiding Water Hammers in Steam Generators," (NUREG-0800, Chapter 10). Examples of design features that prevent water hammer in feeding designs include top-discharge feeding tubes, a leak-limiting feeding seal assembly, and leak-tight feeding inspection port covers. Operating experience has shown that thermal stratification in the feedwater inlet nozzle can be prevented by using an elevated feeding design or "gooseneck" inlet design that forces incoming feedwater to fill the inlet nozzle.

The above criteria, in conjunction with the acceptance criteria for interfacing reviews and appropriately performed inservice inspections, as discussed above, provide assurance that (1) the design is compatible with environmental conditions during normal operating, testing, maintenance, and postulated accident conditions, (2) the probability of abnormal leakage, rapidly propagating failure, and gross rupture will be extremely low, (3) the design conditions of the RCPB are not exceeded during operation, and (4) sufficient

margin is available to prevent rapidly propagating failure, consistent with the requirements of GDC 4, 14, 15, and 31.

### 3. Fabrication and Processing of Ferritic Materials

#### A. Fracture Toughness

The steam generator is part of the primary and secondary system pressure boundaries. As a result, the materials selected should be sufficient to avoid rapidly propagating failure and to ensure that the design conditions will not be exceeded during operation, consistent with the requirements of GDC 14, 15, and 31. The pressure-retaining ferritic materials selected for use in steam generators are acceptable from a fracture toughness standpoint if they (1) comply with Appendix G to 10 CFR Part 50 and with 10 CFR Part 50, 10 CFR 50.55a(c), 10 CFR 50.55a(d), and 10 CFR 50.55a(e) and (2) follow the provisions of Appendix G to Section III of the ASME Code.

In general, the regulations cited above require the use of Section III of the ASME Code. Articles NB-2300 and NC-2300 of Section III of the ASME Code address fracture toughness requirements for Class 1 and 2, respectively. Appendix G to Section III of the ASME Code includes additional fracture toughness criteria.

#### B. Welding

The joining of the materials used to fabricate a steam generator is critical to ensuring that it can properly function. Consistent with the requirements of GDC 1 and GDC 30 (for RCPB materials), the welding qualification, weld fabrication processes, and inspection during fabrication and assembly of the steam generator are performed by using quality standards (supplemented and modified, as necessary) commensurate with the importance of the functions to be performed. Ferritic steel welding of steam generator components is acceptable if it complies with 10 CFR Part 50, 10 CFR 50.55a(c), 10 CFR 50.55a(d), and 10 CFR 50.55a(e) and meets the following:

- i. Controls the amount of specified preheat in accordance with the requirements of paragraph D-1210 of Appendix D to Section III of the ASME Code, as supplemented by RG 1.50, "Control of Preheat Temperature for Welding of Low-Alloy Steel."
- ii. Follows RG 1.34, "Control of Electroslag Weld Properties."
- iii. Follows RG 1.71, "Welder Qualification for Areas of Limited Accessibility." With respect to the qualification of the welder or welding operators when limited accessibility is an issue, these qualifications may be waived provided that 100-percent radiographic and/or ultrasonic examination of the completed welded joint is performed. In these cases, the examination procedures and acceptance standards should meet the requirements of Section III of the ASME Code. Records of the examination reports and

radiographs should be retained as part of the quality assurance documentation for the completed weld.

- iv. Follows RG 1.43, "Control of Stainless Steel Weld Cladding of Low-Alloy Steel Components."

4. Fabrication and Processing of Austenitic Stainless Steel (if austenitic stainless steel is used for RCPB or SSPB applications)

A. Limiting Susceptibility to Cracking

Various factors can make austenitic stainless steel susceptible to stress-corrosion cracking. These factors include the yield strength of the material, exposure of the material to contaminants during cleaning and operation, and presence or absence of material sensitization. Consistent with GDC 14, 15, and 31, limiting the potential for stress-corrosion cracking provides assurance that (1) the probability of abnormal leakage, rapidly propagating failure, and gross rupture is extremely low, (2) the RCPB design conditions are not exceeded during any condition of normal operation, including anticipated operational occurrences, and (3) sufficient margin assures that when stressed under operating, maintenance, testing, and postulated accident conditions, the boundary behaves in a nonbrittle manner and the probability of rapidly propagating fracture is minimized.

The fabrication and processing of austenitic stainless steel steam generator components is acceptable if it complies with 10 CFR Part 50, 10 CFR 50.55a(c), 10 CFR 50.55a(d), and 10 CFR 50.55a(e) and meets the following:

- i. Limits the yield strength to 620 megapascal (MPa) (90,000 pounds per square inch (psi)). Laboratory stress-corrosion cracking tests and service experience provide the basis for the criterion that the cold-worked austenitic stainless steels used in the RCPB should have an upper limit on yield strength.
- ii. Follows RG 1.28, "Quality Assurance Program Criteria (Design and Construction)." With respect to the source of water for final cleaning or flushing of finished surfaces, vented tanks with deionized or demineralized water are an acceptable source. The oxygen content of this water need not be controlled; however, the concentrations of other chemical species (e.g., chloride, fluoride) should be limited to the values listed in RG 1.44, "Control of the Processing and Use of Stainless Steel."
- iii. Controls abrasive work on austenitic stainless steel surfaces in accordance with RG 1.28.
- iv. Follows RG 1.44. In addition to the methods discussed in RG 1.44 for verifying that austenitic stainless steel is not sensitized, alternative tests that have been previously accepted, based upon the adequacy of

justifications presented and circumstances of proposed use, include the use of ASTM A-708.

- v. Follows RG 1.36, "Nonmetallic Thermal Insulation for Austenitic Stainless Steel." The thermal insulation is acceptable if either reflective metal insulation is employed or a nonmetallic insulation that meets the criteria of RG 1.36 is used.

## B. Welding

The joining of the materials used to fabricate a steam generator is critical to ensuring that it can properly function. Consistent with the requirements of GDC 1 and GDC 30 (for RCPB materials), the welding qualification, weld fabrication processes, and inspection during fabrication and assembly of the steam generator are performed using quality standards (supplemented and modified, as necessary) commensurate with the importance of the functions to be performed. Austenitic stainless steel welding of steam generator components is acceptable if it complies with 10 CFR Part 50, 10 CFR 50.55a(c), 10 CFR 50.55a(d), and 10 CFR 50.55a(e) and meets the following:

- i. RG 1.31, "Control of Ferrite Content in Stainless Steel Weld Metal"
- ii. RG 1.34, "Control of Electroslag Weld Properties"
- iii. RG 1.71, "Welder Qualification for Areas of Limited Accessibility"
- iv. NUREG-0313, "Technical Report on Material Selection and Processing Guidelines for BWR Coolant Pressure Boundary Piping," which may be appropriate for any austenitic stainless steel steam generator materials.

## 5. Compatibility of Materials with the Primary (Reactor) and Secondary Coolant and Cleanliness Control

The materials used in the steam generator (including the tubes) can degrade. The degree of susceptibility to degradation and the rate of degradation depend, in part, on the materials, water chemistry, and operating environment (e.g., temperature). To ensure that the materials are compatible with the environment, consistent with the requirements of GDC 4, the primary and secondary coolant water chemistry should be controlled.

In addition, material damage or deterioration can occur during construction and operation as a result of improper cleaning or cleanliness control. This damage/deterioration can result from chemical impurities or from particulate matter. As a result, it is important to establish measures to control the cleaning of material and equipment, consistent with the requirements of Criterion XIII of Appendix B to 10 CFR Part 50.

The overall purpose of determining the compatibility of the material with the environment is to ensure that the inservice inspection program is sufficient to manage

any degradation. The intention of this approach is ultimately to ensure that (1) the probability of abnormal leakage, rapidly propagating failure, and gross rupture is extremely low, (2) the RCPB design conditions are not exceeded during operation, and (3) sufficient margin is available to prevent rapidly propagating failure, consistent with the requirements of GDC 14, 15, and 31.

The primary water chemistry program is reviewed under SRP Sections 5.2.3 and 9.3.4. In addition, RG 1.44 discusses appropriate chemistry limits for the reactor coolant.

The secondary water chemistry program is acceptable if (1) the coolant chemistry is maintained and monitored as described in the BTP 5-1, "Monitoring of Secondary Side Water Chemistry in PWR Steam Generator," (2) the secondary water chemistry requirements in the latest revisions of the Standard Technical Specifications, NUREG-1430, "Standard Technical Specifications - Babcock and Wilcox Plants," NUREG-1431, "Standard Technical Specifications - Westinghouse Plants," and NUREG-1432, "Standard Technical Specifications - Combustion Engineering Plants," are incorporated into the facility's Technical Specifications (the secondary water chemistry program in the Standard Technical Specifications meets the requirements of 10 CFR 50.36, "Technical Specifications," and (3) the chemical additives that limit the steam generator's susceptibility to corrosion are such that any degradation to which the steam generator remains susceptible can be managed through the inservice inspection program. The operating environment (temperature, pressure, and flow) includes important variables that must be considered in evaluating the effectiveness of the chemical additives in limiting the steam generator's susceptibility to corrosion.

The onsite cleaning and cleanliness controls of the steam generator are acceptable if they meet the regulatory provisions of RG 1.28, consistent with the requirements of Criterion XIII of Appendix B to 10 CFR Part 50.

#### 6. Provisions for Accessing the Secondary Side of the Steam Generator

Corrosion products (including deposits and sludge) and other contaminants can accumulate in the secondary side of the steam generator. For example, corrosion products and contaminants have been observed along the length of the steam generator tubes, in the crevice between the tube and the tube supports, and at the top of the tubesheet. Depending on the nature of these corrosion products and contaminants, degradation of the tubes (or other components) can occur. Because this degradation could lead to degradation of the RCPB or SSPB, the design of the steam generator should provide access for the removal of these corrosion products and contaminants. These provisions will supplement the removal of corrosion products and contaminants by blowdown, which is reviewed under SRP Section 10.4.8.

In addition to corrosion products and other contaminants, foreign objects (including loose parts) can be introduced into the steam generator. These objects can also lead to degradation of the RCPB or SSPB; therefore, the design of the steam generator should provide access for removing these objects.

The steam generator design is considered acceptable from a secondary-side access standpoint if it provides adequate access to the internals so that tools may be inserted to

inspect and remove (1) corrosion products and contaminants (such as those found on the tubesheet and at the tube-to-tube support crevice) that may lead to corrosion and (2) foreign objects (including loose parts) that may affect tube integrity.

These provisions, in conjunction with appropriately performed inservice inspections, as discussed above, provide assurance that (1) the probability of abnormal leakage, rapidly propagating failure, and gross rupture is extremely low and (2) the RCPB design conditions are not exceeded during any condition of normal operation, including anticipated operational occurrences, consistent with the requirements of GDC 14 and 15.

### Technical Rationale

The technical rationale for application of these acceptance criteria to the areas of review addressed by this SRP section is discussed in the following paragraphs:

The steam generators serve as the boundary between the primary and secondary sides of a pressurized-water reactor. As a result, they serve both as the RCPB and as the containment. Primary leakage into the secondary system could lead to the direct release of radioactivity to the environment. The steam generators are also relied on to perform safety functions such as removing decay heat (emergency core cooling) or supplying steam to engineered safety feature pumps.

The components of the steam generator are divided into two classes. Class 1 includes material for those parts exposed to the primary (reactor) coolant, and Class 2 includes materials for parts exposed to the secondary coolant. Some plants elect to classify the pressure boundary portion of the steam generator that is exposed to secondary coolant (i.e., the SSPB) as Class 1.

The reviewer will select material from the procedures described below, as may be appropriate for a particular case.

These review procedures are based on the identified SRP acceptance criteria. For deviations from these acceptance criteria, the staff should review the applicant's evaluation of how the proposed alternatives provide an acceptable method of complying with the relevant NRC requirements identified in Subsection II.

#### 1. Selection, Processing, Testing, and Inspection of Materials

The reviewer examines the materials selected and their specifications, as given in the safety analysis report (SAR) for Class 1 and Class 2 components of the steam generators, to determine the degree of conformance with the acceptance criteria above. If a material is proposed for a use that Section III of the ASME Code or Regulatory Guide 1.84 does not permit, the acceptability of the material is reviewed on a case-by-case basis—consistent with SRP Section 5.2.1.2 and 10 CFR 50.55a(a)(3)—using insights from similar material specifications (i.e., similar types of material and the use of such materials in similar applications).

2. Steam Generator Design

The reviewer examines the design of the steam generator to determine the degree of conformance with the acceptance criteria above.

3. Fabrication and Processing of Ferritic Materials

The reviewer analyzes the fabrication and processing of the ferritic materials used in the steam generator to ascertain the degree of conformance with the acceptance criteria above.

4. Fabrication and Processing of Austenitic Stainless Steel Materials

The reviewer examines the fabrication and processing of the austenitic stainless steel materials used in the steam generator to determine the degree of conformance with the acceptance criteria above.

The review includes an examination of possible uses of austenitic stainless steels in the sensitized condition. The use of austenitic stainless steels in any condition requires special attention if the oxygen content is high.

5. Compatibility of the Materials with the Primary (Reactor) and Secondary Coolant and Cleanliness Control

The reviewer examines the controls to be placed on the composition of the primary (reactor) and secondary coolants to identify the degree of conformance with the acceptance criteria above. If the materials used on the primary side of the steam generator differ from those in the remainder of the RCPB, an evaluation of the acceptability of these materials in the proposed chemical environment should be performed (otherwise, the compatibility review is essentially the same as that performed under SRP Section 5.2.3). In addition, the reviewer should consider the operating environment (e.g., temperature, pressure, and flow) in evaluating the compatibility of the materials with the secondary coolant. Plants have operated with hot-leg temperatures as high as approximately 332°C (630°F).

Because operating experience has indicated that certain nickel-chromium-iron alloys (e.g., Inconel) are susceptible to stress-corrosion cracking in typical primary and secondary water chemistry regimes, the reviewer verifies that the applicant either identified (based on demonstrated satisfactory use in similar applications) or presented an acceptable technical basis to support use of the material under the expected environmental conditions. Thermally treated Alloy 690 exhibits improved corrosion resistance compared to the Alloy 600 previously used in steam generator applications.

6. Provisions for Accessing the Secondary Side of the Steam Generator

The reviewer examines the provisions for accessing the secondary side of the steam generator to determine the degree of conformance with the acceptance criteria above.

For review of a DC application, the reviewer should follow the above procedures to verify that the design, including requirements and restrictions (e.g., interface requirements and site parameters) set forth in the final safety analysis report (FSAR), meets the acceptance criteria. DCs have referred to the FSAR as the design control document (DCD). The reviewer should also consider the appropriateness of identified COL action items. The reviewer may identify additional COL action items; however, to ensure these COL action items are addressed during a COL application, they should be added to the DC FSAR.

For review of a COL application, the scope of the review is dependent on whether the COL applicant references a DC, an early site permit (ESP) or other NRC approvals (e.g., manufacturing license, site suitability report or topical report).

For review of both DC and COL applications, SRP Section 14.3 should be followed for the review of ITAAC. The review of ITAAC cannot be completed until after the completion of this section.

For license amendment reviews pertaining to steam generators, the NRC staff determines which of the above areas are affected by the amendment and ensures that the acceptance criteria for those areas are still satisfied. For example, sleeves proposed for repairing steam generator tubes should be reviewed under each of the above areas, except for the “provisions for accessing the secondary side of the steam generator.” In the case of power uprate amendments, the review should include the effect of changes in operating parameters (e.g., differential pressure, temperature, and flow rates) on the design (corrosion allowance), fracture toughness, and compatibility with the coolant. In this latter case, the susceptibility of the tube to degradation should be evaluated to ensure that any degradation is manageable through the steam generator program. The level of detail of the review should be determined on a case-by-case basis, depending on operating experience.

#### IV. EVALUATION FINDINGS

The reviewer verifies that the applicant has provided sufficient information and that the review and calculations (if applicable) support conclusions of the following type to be included in the staff's safety evaluation report. The reviewer also states the bases for those conclusions.

1. The staff concludes that the steam generator materials are acceptable and meet the requirements of GDC 1, 4, 14, 15, 30, and 31 of Appendix A to 10 CFR Part 50; the requirements of Appendices B and G to 10 CFR Part 50; and the requirements of 10 CFR 50.55a. This conclusion is based on the staff's review of the SAR.

Degradation that propagates in a manner such that it cannot be managed through the inservice inspection program has been precluded by design. The materials used in the fabrication of the steam generator have been identified and comply with the requirements of 10 CFR 50.55a. (For those materials not allowed by Section III of the ASME Code, the materials were reviewed on a case-by-case basis and determined to be acceptable, consistent with the provisions of 10 CFR 50.55a(a)(3).)\*

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\*Indicates material within parentheses “as applicable.”



2. The primary side of the steam generator is designed and fabricated to comply with ASME Class 1 criteria, and fatigue is addressed per Regulatory Guide 1.207. The secondary side of the steam generator is designed and fabricated to comply with ASME Class 2 criteria. (The SSPB parts of the steam generator will be designed, manufactured, and tested to ASME Class 1 criteria, although the staff-required classification is ASME Class 2.)\*
3. The crevice between the tubesheet and the inserted tube will be limited because the tube will be expanded to the full depth of insertion of the tube in the tubesheet. The tube expansion and subsequent positive contact pressure between the tube and the tubesheet will preclude any buildup of impurities from forming in the crevice region and will reduce the probability of crevice boiling. The tube-to-tubesheet welds comply with ASME Class 1 criteria. The feedwater inlet design, including the feeding, uses materials and design features that resist degradation from flow-accelerated corrosion, water hammer, and thermal stratification.

(The tube support plates will be manufactured from ferritic or martensitic stainless steel material, which laboratory tests have shown to be corrosion resistant to the operating environment.)\* (The tube support plates will be designed and manufactured with noncircular holes (e.g., a quatrefoil-shaped hole) that only come in close contact with the tube at a limited number of locations around the tube's circumference. The noncircular hole design promotes high-velocity flow along the tube, sweeping impurities away from the support plate locations.)\* (The tube support structure manufacture will use a lattice grid design. This design (1) eliminates the narrow annular gap at the tube supports because the support may contact the tube at only four lines on the tube circumference and (2) provides almost complete washing of the tube surface with steam generator water.)\* (The U-bend region of short-radius tubes will be stress-relieved after bending to reduce the residual stresses in this portion of the tube.)\*

4. The fracture toughness of the ferritic materials is acceptable because it conforms with 10 CFR 50.55a, Appendix G to the ASME Code, and Appendix G to 10 CFR Part 50.
5. The welding of the ferritic materials of the steam generator is acceptable because it is performed in accordance with 10 CFR 50.55a, paragraph D-1210 of Appendix D to Section III of the ASME Code, and RG 1.34, 1.43, 1.50, and 1.71.

(The fabrication and processing of austenitic stainless steel is acceptable because these activities are performed in accordance with 10 CFR 50.55a and RG 1.28, 1.31, 1.34, 1.36, 1.44, and 1.71. In addition, the guidance in NUREG-0313 will be followed, and the yield strength of austenitic stainless steel will be limited to 620 MPa (90,000 psi).)\*

6. The requirements of Appendix B to 10 CFR Part 50 have been met with respect to onsite cleaning because the onsite cleaning and cleanliness controls during fabrication will conform to the recommendations of RG 1.28. The controls placed on the secondary coolant chemistry are in agreement with the staff's technical position, and the additives to be used will limit the susceptibility of the steam generators to corrosion given the

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\*Indicates material within parentheses "as applicable."

operating environment so that the inservice inspection program can manage any degradation that may occur. In addition, the secondary water chemistry program is (will be)\* consistent with the latest revision of the Standard Technical Specifications. (The primary coolant water chemistry program is acceptable for the materials unique to the steam generator.)\*

7. The provisions for accessing the secondary side of the steam generator are acceptable because tools may be inserted to inspect and remove (1) corrosion products and contaminants that may lead to corrosion and (2) foreign objects (including loose parts) that may affect tube integrity.
8. Reasonable assurance of the satisfactory performance of steam generator tubing and other steam generator materials is provided by (1) the design provisions and the manufacturing requirements of the ASME Code and (2) rigorous water chemistry monitoring and control. The controls described above—combined with conformance with applicable codes, standards, staff positions, and regulatory guides—constitute an acceptable basis for meeting, in part, the requirements of GDC 1, 4, 14, 15, 30, and 31; Appendices B and G to 10 CFR Part 50; and 10 CFR 50.55a.

For DC and COL reviews, the findings will also summarize the staff's evaluation of requirements and restrictions (e.g., interface requirements and site parameters) and COL action items relevant to this SRP section.

In addition, to the extent that the review is not discussed in other SER sections, the findings will summarize the staff's evaluation of the ITAAC, including design acceptance criteria, as applicable.

## V. IMPLEMENTATION

The staff will use this SRP section in performing safety evaluations of DC applications and license applications submitted by applicants pursuant to 10 CFR Part 50 or 10 CFR Part 52. Except when the applicant proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the staff will use the method described herein to evaluate conformance with Commission regulations.

The provisions of this SRP section apply to reviews of applications submitted six months or more after the date of issuance of this SRP section, unless superseded by a later revision. The referenced regulatory guides include implementation schedules for conformance to parts of the method discussed herein.

## VI. REFERENCES

1. American Society of Mechanical Engineers, *ASME Boiler and Pressure Vessel Code*, Section II, "Materials Specifications," New York, NY.

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\* Indicates material within parentheses "as applicable."

2. American Society of Mechanical Engineers, *ASME Boiler and Pressure Vessel Code*, Section III, "Rules for Construction of Nuclear Facility Components," New York, NY.
3. American Society of Mechanical Engineers, *ASME Boiler and Pressure Vessel Code*, Section IX, "Welding and Brazing Qualifications," New York, NY.
4. American Society for Testing and Materials (ASTM) A-708, "Standard Recommended Practices for Detection of Susceptibility to Intergranular Corrosion in Severely Sensitized Austenitic Stainless Steel," West Conshohocken, PA.
5. *U.S. Code of Federal Regulations*, "Domestic Licensing of Production and Utilization Facilities," Part 50, Chapter 1, Title 10, "Energy," Appendix A, "General Design Criteria for Nuclear Power Plants," General Design Criterion 1, "Quality Standards and Records."
6. *U.S. Code of Federal Regulations*, "Domestic Licensing of Production and Utilization Facilities," Part 50, Chapter 1, Title 10, "Energy," Appendix A, "General Design Criteria for Nuclear Power Plants," General Design Criterion 4, "Environmental and Dynamic Effects Design Bases."
7. *U.S. Code of Federal Regulations*, "Domestic Licensing of Production and Utilization Facilities," Part 50, Chapter 1, Title 10, "Energy," Appendix A, "General Design Criteria for Nuclear Power Plants," General Design Criterion 14, "Reactor Coolant Pressure Boundary."
8. *U.S. Code of Federal Regulations*, "Domestic Licensing of Production and Utilization Facilities," Part 50, Chapter 1, Title 10, "Energy," Appendix A, "General Design Criteria for Nuclear Power Plants," General Design Criterion 15, "Reactor Coolant System Design."
9. *U.S. Code of Federal Regulations*, "Domestic Licensing of Production and Utilization Facilities," Part 50, Chapter 1, Title 10, "Energy," Appendix A, "General Design Criteria for Nuclear Power Plants," General Design Criterion 30, "Quality of Reactor Coolant Pressure Boundary."
10. *U.S. Code of Federal Regulations*, "Domestic Licensing of Production and Utilization Facilities," Part 50, Chapter 1, Title 10, "Energy," Appendix A, "General Design Criteria for Nuclear Power Plants," General Design Criterion 31, "Fracture Prevention of the Reactor Coolant Pressure Boundary."
11. *U.S. Code of Federal Regulations*, "Technical Specifications," § 50.36, Chapter 1, Title 10, "Energy."
12. *U.S. Code of Federal Regulations*, "Codes and Standards," § 50.55a, Chapter 1, Title 10, "Energy."
13. *U.S. Code of Federal Regulations*, "Domestic Licensing of Production and Utilization Facilities," Part 50, Chapter 1, Title 10, "Energy," Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants."

14. *U.S. Code of Federal Regulations*, “Domestic Licensing of Production and Utilization Facilities,” Part 50, Chapter 1, Title 10, “Energy,” Appendix G, “Fracture Toughness Requirements.”
15. U.S. Nuclear Regulatory Commission, “Technical Report on Material Selection and Processing Guidelines for BWR Coolant Pressure Boundary Piping,” NUREG-0313, Revision 2, January 1988, ADAMS Accession No. ML031470422.
16. U.S. Nuclear Regulatory Commission, “Control of Ferrite Content in Stainless Steel Weld Metal,” Regulatory Guide 1.31, October 2013, ADAMS Accession No. ML13211A485.
17. U.S. Nuclear Regulatory Commission, “Control of Electroslag Weld Properties,” Regulatory Guide 1.34, March 2011, ADAMS Accession No. ML101670357.
18. U.S. Nuclear Regulatory Commission, “Nonmetallic Thermal Insulation for Austenitic Stainless Steel,” Regulatory Guide 1.36, May 2015, ADAMS Accession No. ML15026A664.
19. U.S. Nuclear Regulatory Commission, “Quality Assurance Program Criteria (Design and Construction),” Regulatory Guide 1.28, June 2010, ADAMS Accession No. ML100160003.
20. U.S. Nuclear Regulatory Commission, “Control of Stainless Steel Weld Cladding of Low-Alloy Steel Components,” Regulatory Guide 1.43, March 2011, ADAMS Accession No. ML101670458.
21. U.S. Nuclear Regulatory Commission, “Control of the Use of Sensitized Stainless Steel,” Regulatory Guide 1.44, March 2011, ADAMS Accession No. ML101680225.
22. U.S. Nuclear Regulatory Commission, “Control of Preheat Temperature for Welding of Low Alloy Steel,” Regulatory Guide 1.50, March 2011, ADAMS Accession No. ML101870612.
23. U.S. Nuclear Regulatory Commission, “Materials and Inspections for Reactor Vessel Closure Studs,” Regulatory Guide 1.65, April 2010, ADAMS Accession No. ML092050716.
24. U.S. Nuclear Regulatory Commission, “Welder Qualification for Areas of Limited Accessibility,” Regulatory Guide 1.71, March 2007, ADAMS Accession No. ML070320476.
25. U.S. Nuclear Regulatory Commission, “Design, Fabrication, and Materials Code Case Acceptability, ASME Section III,” Regulatory Guide 1.84, August 2014, ADAMS Accession No. ML13339A515.
26. U.S. Nuclear Regulatory Commission, “Guidelines for Evaluating Fatigue Analyses Incorporating the Life Reduction of Metal Components Due to the Effects of the Light-

Water Reactor Environment for New Reactors,” Regulatory Guide 1.207, March 2007, ADAMS Accession No. ML070380586.

27. U.S. Nuclear Regulatory Commission, Branch Technical Position 5-1, “Monitoring of Secondary Side Water Chemistry in PWR Steam Generators,” March 2007, ADAMS Accession No. ML070850019.
28. U.S. Nuclear Regulatory Commission, Branch Technical Position 10-2, “Design Guidelines for Avoiding Water Hammers in Steam Generators,” March 2007, ADAMS Accession No. ML070850324.

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**PAPERWORK REDUCTION ACT STATEMENT**

The information collections contained in the Standard Review Plan are covered by the requirements of 10 CFR Part 50 and 10 CFR Part 52, and were approved by the Office of Management and Budget, approval number 3150-0011 and 3150-0151.

**PUBLIC PROTECTION NOTIFICATION**

The NRC may not conduct or sponsor, and a person is not required to respond to, a request for information or an information collection requirement unless the requesting document displays a currently valid OMB control number.

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**Standard Review Plan Section 5.4.2.1  
Description of Changes**

**Section 5.4.2.1, “Steam Generator Materials and Design”**

The main purpose of this update is to add regulatory review guidance, based on the recommendations from the lessons learned report that was issued following the tube degradation event at the San Onofre Nuclear Generating Station in 2012 (ADAMS Accession No. ML15015A419). The lessons learned report identified a need to clarify the appropriate scope and detail of the regulatory review guidance as it pertains to rapidly propagating degradation mechanisms, such as fluid elastic instability, that cannot be managed through the steam generator program.

The title was changed (by adding “and Design”) to reflect the fact that the SRP continues to include design features in addition to materials selection.

A secondary review responsibility is added for evaluating fluid elastic instability.

Guidance is added for evaluating the design to determine if it precludes degradation that may propagate rapidly, such as fluid-elastic instability, which cannot be managed through the steam generator program in the plant technical specifications.

Guidance for evaluating the structural and leakage integrity of the tube-to-tubesheet welds was added to ensure that these welds have been designed and analyzed appropriately. The staff described this issue in NRC Regulatory Issue Summary RIS-16-02, “Design Basis Issues Related to Tube-to-Tubesheet Joints in Pressurized-Water Reactor Steam Generators.” See ADAMS Accession No. ML15169A543.

Guidance for evaluating provisions to prevent water hammer and thermal stratification were added because these design features are located mostly within the steam generator and may not be evaluated as part of the steam and feedwater systems or piping design.

Additional changes were editorial.