

Draft for Comment



U.S. NUCLEAR REGULATORY COMMISSION DESIGN-SPECIFIC REVIEW STANDARD FOR NuScale SMR DESIGN

5.4.2.1 STEAM GENERATOR MATERIALS

REVIEW RESPONSIBILITIES

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

Secondary - None

I. AREAS OF REVIEW

The NuScale integral pressurized water small modular reactor (SMR) design includes a once-through helical coil steam generator with the primary coolant outside the tubes and the secondary coolant inside the tubes. This design is significantly different than the steam generators at U.S. plants, including those plants proposed or licensed but not yet built. Despite the design differences, the purpose of the review is the same as in Standard Review Plan (SRP) Section 5.4.2.1.

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 fracture toughness of the ferritic materials is adequate, (3) the design of the steam generator limits the susceptibility of the materials to degradation and corrosion, (4) the materials used in the steam generator are compatible with the environment to which they will be exposed, (5) the design of the primary and secondary sides 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 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 pressure boundary applications).

5. The compatibility of steam generator materials with the primary (reactor) and secondary coolant and cleanliness control.
6. The provisions for accessing the primary and secondary sides 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 Design Specific Review Standard (DSRS) section in accordance with Standard Review Plan (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 DSRS 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 and DSRS sections interface with this section as follows:

1. The review of the programs for ensuring the integrity of bolting and threaded fasteners is performed under DSRS Section 3.13, "Threaded Fasteners – ASME Code Class, 1, 2, and 3."
2. The review of testing and analysis of dynamic effects on the steam generator, such as flow-induced vibration, is performed under SRP Section 3.9.2, "Dynamic Testing and Analysis of Systems, Structures, and Components."
3. 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, or 3, Components, and Component Supports, and Core Support Structures."
4. The review of the acceptability of pressure-retaining components for compliance with 10 CFR 50.55a is performed under SRP Section 5.2.1.1, "Compliance with the Codes and Standards Rule, 10 CFR 50.55a." The review of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code) classification for the steam generator components is performed under SRP Section 5.2.1.1. The ASME Code classification determines the appropriate 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).

5. 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."
6. The review of the suitability and adequacy of reactor coolant pressure boundary (RCPB) materials, except for reactor vessel materials, is performed under SRP Section 5.2.3, "Reactor Coolant Pressure Boundary Materials."
7. The review of the acceptability of the inservice inspection program for the RCPB, excluding the steam generator tubes, is performed under DSRS 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 DSRS 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 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 DSRS Section 9.3.4, "Chemical and Volume Control System (PWR) (Including Boron Recovery System)."
10. 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."
11. 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 DSRS Section 10.4.6, "Condensate Cleanup System."
12. 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."
13. Review of proposed ITAAC associated with SSCs for steam generator component materials is performed under SRP Section 14.3.
14. Review of the reliability assurance program is coordinated and performed under SRP Section 17.4, "Reliability Assurance Program (RAP)."
15. Review of quality assurance requirements is performed under SRP Section 17.5, "Quality Assurance Program Description – Design Certification, Early Site Permit and New License Applicants."
16. Review of steam generator tube component material operations support and maintenance is performed under SRP Section 17.6, "Maintenance Rule."
17. Review of probabilistic risk assessments evaluating risk significance of the NuScale steam generator is coordinated and performed under SRP Chapter 19, "Severe Accidents."

II. ACCEPTANCE CRITERIA

Requirements

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

1. General Design Criterion (GDC) 1 of Appendix A to Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50 requires, in part, 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. If generally recognized codes and standards are used, they shall be identified and evaluated to determine their applicability, adequacy, and sufficiency and shall be supplemented to provide adequate assurance that these SSCs will perform their safety functions and that records will be maintained.
2. GDC 4 requires, in part, that SSCs important to safety should 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 requires that the RCPB should be designed, fabricated, erected, and tested to have an extremely low probability of abnormal leakage, rapidly propagating failure, and gross rupture.
4. GDC 15 requires that the reactor coolant system and associated auxiliary control and protection systems should be designed with sufficient margin to ensure that the design conditions of the RCPB are not exceeded during any condition of normal operation, including anticipated operational occurrences.
5. GDC 30 requires, in part, that components that are part of the RCPB should be designed, fabricated, erected, and tested to the highest quality standards practical.
6. GDC 31 requires, in part, that the RCPB should 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, thereby minimizing the probability of rapidly propagating fracture.
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 pressure boundary, to meet the requirements of Section III of the ASME Code.
8. Appendix B 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 cleaning of material and equipment in accordance with work and inspection procedures to prevent damage or deterioration.
9. Appendix G to 10 CFR Part 50 requires 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), which requires 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 facility

that incorporates the design certification has been constructed and will be operated in conformity with the design certification, the provisions of the Atomic Energy Act (AEA), and the U.S. Nuclear Regulatory Commission's (NRC's) regulations.

11. 10 CFR 52.80(a), which 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 operate in conformity with the combined license, the provisions of the Atomic Energy Act (AEA), and the NRC's regulations.

DSRS Acceptance Criteria

Specific DSRS acceptance criteria acceptable to meet the relevant requirements of the NRC's regulations identified above are set forth below. The DSRS is not a substitute for the NRC's regulations, and compliance with it is not required. As an alternative, and as described in more detail below, an applicant may identify the differences between a DSRS section and the design features (DC and COL applications only), analytical techniques, and procedural measures proposed in an application and discuss how the proposed alternative provides an acceptable method of complying with the NRC regulations that underlie the DSRS acceptance criteria.

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 pressure boundary (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, as required by GDC 1. In addition, the materials selected for the RCPB must be fabricated and tested to the highest quality standards, as required by GDC 30.

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 1.84, 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 ASME Code Class 1 components in steam generators include the following:

Tubing	ASME SB-163, N06690, Thermally Treated
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Pressure Plates	ASME SA-533, Grade B, Class 1
Pressure Forgings	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), SFA 5.9 (308L, 309L), SFA 5.11 (ENiCrFe-7), and SFA 5.14 (ERNiCrFe-7)
Pressure Boundary Welds	Low Alloy Steel, ASME 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 ASME Code Class 2 components in steam generators include the following:

Pressure Plates	ASME SA-533, Grade B, Class 1
Bolting	ASME SA-193, Grade B7
Tube Support Structures (including antivibration bars)	ASME SA-240, Type 409 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. Degradation of the steam generator tubes and other primary or secondary side components that could affect tube integrity should be manageable through the steam generator program (reviewed under DSRS Section 5.4.2.2). Degradation of other steam generator pressure boundary materials should be manageable through the inservice inspection program (the RCPB inservice inspection program is reviewed under DSRS Section 5.2.4).

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

- A. Limits crevices - between tubes and other tubes or structures – that could allow accumulation of corrosion products or other solid materials that could cause corrosion or physical damage to the tubes or support structures. The design of supports should promote adequate velocity along the tubes to prevent accumulation of corrosive or particulate materials.

- B. 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 coolant flow and stress corrosion cracking of the tubes. To limit the steam generator tubes' susceptibility to corrosion, the tubes should be heat treated (e.g., thermally treated), as needed, to optimize their microstructure from a corrosion resistance standpoint. The residual stresses from tube bending should be evaluated, and relieved as needed. The materials that support the tubes and other materials 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. Any corrosion-resistant cladding should be weld deposited, fabricated, and inspected according to the requirements in Section III of the ASME Code.
- C. 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 products and sludge that can lead to corrosion. Limiting the stresses will diminish the potential for stress corrosion cracking.
- D. 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).
- E. 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. 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 DSRS Section 3.13.

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 probability of abnormal leakage, rapidly propagating failure, and gross rupture will be extremely low, (2) the design conditions of the RCPB 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.

3. Fabrication and Processing of Ferritic Materials

A. Fracture Toughness

The steam generator is part of the primary and secondary system pressure boundary. 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 50.55a, 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 ASME Code Class 1 and 2 Systems, 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 50.55a, 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.
- ii. Follows RG 1.34.
- iii. Follows RG 1.71. 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.

4. Fabrication and Processing of Austenitic Stainless Steel (if austenitic stainless steel is used for pressure boundary 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 operation, and (3) sufficient margin is available to prevent rapidly propagating failure.

The fabrication and processing of austenitic stainless steel steam generator components is acceptable if it complies with 10 CFR 50.55a 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. 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.
- iii. Controls abrasive work on austenitic stainless steel surfaces in accordance with Position C.5 of RG 1.28, at a minimum.
- 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. 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 50.55a and meets the following:

- i. RG 1.31
- ii. RG 1.34
- iii. RG 1.71
- iv. NUREG-0313, 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 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 DSRS Sections 5.2.3 and 9.3.4. In addition, Regulatory Guide 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 Branch Technical Position, BTP 5-1, "Monitoring of Secondary Side Water Chemistry in PWR Steam Generator," (2) the secondary water chemistry requirements in the latest revision of the Standard Technical Specifications (NUREG-1430, -1431, and -1432) is 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), 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 Primary and Secondary Sides of the Steam Generator

Corrosion products (including deposits and sludge) and other contaminants can accumulate in the primary and secondary sides of steam generators. For example, in steam generators with secondary coolant outside the tubes, corrosion products and contaminants have been observed along the length of the tubes, in the crevice between the tube and the tube supports, and at the top of the tubesheet. For the NuScale design, the type, location, and quantity of corrosion product and contaminant accumulation must be identified. Depending on the nature of these corrosion products and contaminants, degradation of the tubes (or other components) can occur, and possibly degrade the pressure boundary. Corrosion products and contaminants could also restrict flow in the

tubes or interfere with tube inspection. Therefore, the design of the steam generator should provide access for the removal of these corrosion products and contaminants. These provisions typically supplement the removal of corrosion products and contaminants by blowdown, which is reviewed under SRP Section 10.4.8. If there is no blowdown system, then the importance of these provisions for secondary side access may be greater.

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 pressure boundary; therefore, the design of the steam generator should provide access for removing these objects.

The steam generator design is considered acceptable from a primary- and 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 operation, consistent with the requirements of GDC 14 and 15.

7. 10 CFR 52.47(b)(1) specifies that the application of a design certification should contain proposed ITAAC for SSCs necessary and sufficient to assure the plant is built and will operate in accordance with the design certification. 10 CFR 52.80(a) specifies that the COL Applicant identifies the ITAAC for SSCs 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 Act, and Commission's rules and regulations. SRP 14.3 provides guidance for reviewing the ITAAC. The requirements of 10 CFR 52.47(b)(1) and 10 CFR 52.80(a) will be met, in part, by identifying inspections, tests, analyses, and acceptance criteria of the top-level design features of steam generator materials in the design certification application and the combined license, respectively.

Technical Rationale

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

The NuScale steam generator serves as the boundary between the primary and secondary sides of the iPWR. As a result, it serves 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 components of the steam generator are divided into two classes. ASME Code Class 1 includes material for those parts exposed to the primary (reactor) coolant, and ASME Code 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 secondary side pressure boundary) as ASME Code Class 1.

III. REVIEW PROCEDURES

These review procedures are based on the identified DSRS 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.

These review procedures are based on the identified DSRS 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. Selected Programs and Guidance - In accordance with the guidance in NUREG-0800, "Introduction - Part 2: Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: Integral Pressurized Water Reactor Edition" (NUREG-0800 Intro Part 2) as applied to this DSRS Section, the staff will review the information proposed by the applicant to evaluate whether it meets the acceptance criteria described in Subsection II of this DSRS. As noted in NUREG-0800 Intro Part 2, the NRC requirements that must be met by an SSC do not change under the SMR framework. Using the graded approach described in NUREG-0800 Intro Part 2, the NRC staff may determine that, for certain structures, systems, and components (SSCs), the applicant's basis for compliance with other selected NRC requirements may help demonstrate satisfaction of the applicable acceptance criteria for that SSC in lieu of detailed independent analyses. The design-basis capabilities of specific SSCs would be verified where applicable as part of completion of the applicable ITAAC. The use of the selected programs to augment or replace traditional review procedures is described in Figure 1 of NUREG-0800, Introduction - Part 2. Examples of such programs that may be relevant to the graded approach for these SSCs include:

- 10 CFR Part 50, Appendix A, General Design Criteria (GDC), Overall Requirements, Criteria 1 through 5
- 10 CFR Part 50, Appendix B, Quality Assurance (QA) Program
- 10 CFR 50.49, Environmental Qualification of Electrical Equipment (EQ) Program
- 10 CFR 50.55a, Code Design, Inservice Inspection and Inservice Testing (ISI/IST) Programs
- 10 CFR 50.65, Maintenance Rule requirements
- Reliability Assurance Program (RAP)
- 10 CFR 50.36, Technical Specifications
- Availability Controls for SSCs Subject to Regulatory Treatment of Non-Safety Systems (RTNSS)
- Initial Test Program (ITP)
- Inspections, Tests, Analyses, and Acceptance Criteria (ITAAC)

This list of examples is not intended to be all-inclusive. It is the responsibility of the technical reviewers to determine whether the information in the application, including the degree to which the applicant seeks to rely on such selected programs and guidance, demonstrates that all acceptance criteria have been met to support the safety finding for a particular SSC.

2. In accordance with 10 CFR 52.47(a)(8),(21), and (22), and 10 CFR 52.79(a)(17), (20)

and (37), for design certification or combined license applications submitted under Part 52, the applicant is required to (1) address the proposed technical resolution of unresolved safety issues and medium- and high-priority generic safety issues which are identified in the version of NUREG 0933 current on the date up to 6 months before the docket date of the application and which are technically relevant to the design; (2) demonstrate how the operating experience insights have been incorporated into the plant design; and, (3) provide information necessary to demonstrate compliance with any technically relevant portions of the Three Mile Island requirements set forth in 10 CFR 50.34(f), except paragraphs (f)(1)(xii), (f)(2)(ix), and (f)(3)(v) for a DC application, and except paragraphs (f)(1)(xii), (f)(2)(ix), (f)(2)(xxv), and (f)(3)(v) for a COL application. These cross-cutting review areas should be addressed by the reviewer for each technical subsection and relevant conclusions documented in the corresponding safety evaluation report (SER) section.

3. 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 ASME Code 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 DSRS 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).

4. Steam Generator Design

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

5. 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.

6. 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 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.

7. 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 DSRS 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 Inconel Alloy 690 exhibits improved corrosion resistance compared to the Inconel Alloy 600 previously used in steam generator applications.

8. Provisions for Accessing the Primary and Secondary Sides of the Steam Generator

The reviewer examines the provisions for accessing the primary and secondary sides 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. 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 application.

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 impacted 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.
2. The materials used in the fabrication of the steam generator have been identified and conform 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).)*
3. The primary side of the steam generator is designed and fabricated to comply with ASME Code Class 1 criteria. The secondary side of the steam generator is designed and fabricated to comply with ASME Code Class 2 criteria. (The secondary-side pressure boundary parts of the steam generator will be designed, manufactured, and tested to ASME Code Class 1 criteria, although the staff-required classification is ASME Code Class 2.)*
4. 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 support plates will be manufactured from ferritic 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.)*

5. The fracture toughness of the ferritic materials is acceptable because they conform with 10 CFR 50.55a, Appendix G to the ASME Code, and Appendix G to 10 CFR Part 50.
6. 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.

*Indicates material within parentheses "as applicable."

(The fabrication and processing of austenitic stainless steel is acceptable because these activities are performed in accordance with 10 CFR 50.55a and RG 1.31, 1.34, 1.36, 1.28, 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).)*

7. 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 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.)
8. The provisions for accessing the primary and secondary sides 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.
9. 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 DSRS 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 regulations in 10 CFR 52.17(a)(1)(xii), 10 CFR 52.47(a)(9), and 10 CFR 52.79(a)(41) establish requirements for applications for ESPs, DCs, and COLs, respectively. These regulations require the application to include an evaluation of the site (ESP), standard plant design (DC), or facility (COL) against the Standard Review Plan (SRP) revision in effect six months before the docket date of the application. While the SRP provides generic guidance, the staff developed the SRP guidance based on the staff's experience in reviewing applications for construction permits and operating licenses for large light-water nuclear power reactors. The proposed small modular reactor (SMR) designs, however, differ significantly from large light-water nuclear reactor power plant designs.

*Indicates material within parentheses "as applicable."

In view of the differences between the designs of SMRs and the designs of large light-water power reactors, the Commission issued SRM- COMGBJ-10-0004/COMGEA-10-0001, "Use of Risk Insights to Enhance the Safety Focus of Small Modular Reactor Reviews," dated August 31, 2010 (ML102510405) (SRM). In the SRM, the Commission directed the staff to develop risk-informed licensing review plans for each of the SMR design reviews, including plans for the associated pre-application activities. Accordingly, the staff has developed the content of the DSRS as an alternative method for the evaluation of a NuScale-specific application submitted pursuant to 10 CFR Part 52, and the staff has determined that each application may address the DSRS in lieu of addressing the SRP, with specified exceptions. These exceptions include particular review areas in which the DSRS directs reviewers to consult the SRP and others in which the SRP is used for the review. If an applicant chooses to address the DSRS, the application should identify and describe all differences between the design features (DC and COL applications only), analytical techniques, and procedural measures proposed in an application and the guidance of the applicable DSRS section (or SRP section as specified in the DSRS), and discuss how the proposed alternative provides an acceptable method of complying with the regulations that underlie the DSRS acceptance criteria.

The staff has accepted the content of the DSRS as an alternative method for evaluating whether an application complies with NRC regulations for NuScale SMR applications, provided that the application does not deviate significantly from the design and siting assumptions made by the NRC staff while preparing the DSRS. If the design or siting assumptions in a NuScale application deviate significantly from the design and siting assumptions the staff used in preparing the DSRS, the staff will use the more general guidance in the SRP as specified in 10 CFR 52.17(a)(1)(xii), 10 CFR 52.47(a)(9), or 10 CFR 52.79(a)(41), depending on the type of application. Alternatively, the staff may supplement the DSRS section by adding appropriate criteria in order to address new design or siting assumptions.

VI. REFERENCES

1. 10 CFR Part 50, Appendix A, GDC 1, "Quality Standards and Records."
2. 10 CFR Part 50, Appendix A, GDC 4, "Environmental and Dynamic Effects Design Bases."
3. 10 CFR Part 50, Appendix A, GDC 14, "Reactor Coolant Pressure Boundary."
4. 10 CFR Part 50, Appendix A, GDC 15, "Reactor Coolant System Design."
5. 10 CFR Part 50, Appendix A, GDC 30, "Quality of Reactor Coolant Pressure Boundary."
6. 10 CFR Part 50, Appendix A, General Design Criterion 31, "Fracture Prevention of the Reactor Coolant Pressure Boundary."
7. 10 CFR 50.36, "Technical Specifications."
8. 10 CFR 50.55a, "Codes and Standards."
9. 10 CFR Part 50, Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants."
10. 10 CFR Part 50, Appendix G, "Fracture Toughness Requirements."

11. NUREG-0313, Rev. 2, "Technical Report on Material Selection and Processing Guidelines for BWR Coolant Pressure Boundary Piping."
12. NUREG-1430, "Standard Technical Specifications for Babcock and Wilcox Pressurized Water Reactors."
13. NUREG-1431, "Standard Technical Specifications for Westinghouse Pressurized Water Reactors."
14. NUREG-1432, "Standard Technical Specifications for Combustion Engineering Pressurized Water Reactors."
15. RG 1.31, "Control of Ferrite Content in Stainless Steel Weld Metal."
16. RG 1.34, "Control of Electroslag Weld Properties."
17. RG 1.36, "Nonmetallic Thermal Insulation for Austenitic Stainless Steel."
18. RG 1.28, "Quality Assurance Program Criteria (Design and Construction)."
19. RG 1.43, "Control of Stainless Steel Weld Cladding of Low-Alloy Steel Components."
20. RG 1.44, "Control of the Use of Sensitized Stainless Steel."
21. RG 1.50, "Control of Preheat Temperature for Welding of Low Alloy Steel."
22. RG 1.65, "Materials and Inspections for Reactor Vessel Closure Studs."
23. RG 1.71, "Welder Qualification for Areas of Limited Accessibility."
24. RG 1.84, "Design, Fabrication, and Materials Code Case Acceptability, ASME Section III."
25. BTP 5-1, "Monitoring of Secondary Side Water Chemistry in PWR Steam Generators."
26. ASME Boiler and Pressure Vessel Code, Section II, "Materials Specifications."
27. ASME Boiler and Pressure Vessel Code, Section III, "Rules for Construction of Nuclear Facility Components."
28. ASME Boiler and Pressure Vessel Code, Section IX, "Welding and Brazing Qualifications."
29. 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."
30. NUREG-0933, "A Prioritization of Generic Safety Issues."