U.S. NUCLEAR REGULATORY COMMISSION

STANDARD REVIEW PLAN

10.3.6 STEAM AND FEEDWATER SYSTEM MATERIALS

REVIEW RESPONSIBILITIES

Primary - Organization responsible for review of component integrity issues related to reactor coolant pressure boundary

Secondary - Organization responsible for the review of materials engineering issues related to flaw evaluation and welding

I. AREAS OF REVIEW

The materials selection, fabrication, and fracture toughness of American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (hereafter "the Code"), Section III, Class 2 and 3 pressure boundary components of the steam and feedwater systems are reviewed to verify they meet the relevant requirements of the Commission's regulations, as well as addressing issues identified in relevant operating experience.

The specific areas of review are as follows:

1. Materials Selection and Fabrication of Class 2 and 3 Components

   A. The materials selected for all Class 2 and 3 components and their fabrication are reviewed.

   B. For all components the following points are reviewed:

      i. The qualification procedures for welds in areas of limited accessibility are reviewed.

ii. The welding preheat temperatures are reviewed.

iii. The controls placed on welding procedures are reviewed.

iv. The cleaning procedures are reviewed.

v. For tubular products, the nondestructive examination procedures are reviewed for conformance with the ASME Code.

C. For carbon and low alloy steel components or cast austenitic stainless steel components, the controls placed on welding procedures are reviewed.

2. Fracture Toughness of Class 2 and 3 Components The fracture toughness properties of ferritic materials used for Class 2 and 3 components are reviewed. Typical components in this review include carbon or low-alloy steel portions of steam and feedwater lines in both pressurized water reactors (PWRs) and boiling water reactors (BWRs). If cast austenitic stainless steel material is proposed for use, the adequacy of the material fracture toughness properties to withstand thermal aging over the design life of the component is reviewed.

3. Flow-Accelerated Corrosion (FAC) (previously referred to as Erosion-Corrosion). To address operating experience insights presented in NRC generic correspondence, including Generic Letter (GL) 89-08, “Erosion-Corrosion-Induced Pipe Wall Thinning,” the following aspects of FAC mitigation for the steam and feedwater systems are reviewed:

A. Utilization of materials resistant to FAC.

B. Specification of an adequate corrosion allowance.

C. Piping design measures to minimize the effects of FAC.

The terms FAC and erosion-corrosion (EC) have often been used interchangeably because early cases of FAC (high-energy carbon steel piping failures) were initially attributed to EC. GL 89-08 and the associated NUREG-1344 were written to address those piping failures, which are now recognized as FAC. FAC and EC are two distinct thinning mechanisms related to flow. FAC results from mass transfer and corrosion effects; EC results from mechanical and corrosion effects. Since FAC and EC are both related to flow effects, some licensees manage FAC as a subset of a comprehensive EC program. Computer programs designed for FAC management (e.g., CHECWORKS) are unlikely to accurately model corrosion rates for other forms of flow-related thinning such as EC. The subject of this review area is FAC.

4. 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 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.

5. 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 adequacy of programs for assuring the integrity of bolting and threaded fasteners is performed under SRP Section 3.13, “Threaded Fasteners - ASME Code Class 1, 2, and 3.”

2. The review of the acceptability of the seismic and quality group classifications for system components is performed under SRP Sections 3.2.1, “Seismic Classification,” and 3.2.2, “System Quality Group Classification.”

3. The review of the material selection and fabrication process controls for stainless steel is performed under SRP Section 5.2.3, “Reactor Coolant Pressure Boundary Materials.”

4. The review of materials considerations for steam generators is performed under SRP Section 5.4.2.1, “Steam Generator Materials.”

5. The review of surveillance programs to verify inclusion of FAC monitoring of steam and feedwater system materials is performed under SRP Section 6.6, “Inservice Inspection of Class 2 and 3 Components.”

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

II. ACCEPTANCE CRITERIA

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

1. 10 CFR 50.55a, "Codes and Standards,” which requires that SSCs shall be designed, fabricated, erected, constructed, tested, and inspected to quality standards commensurate with the importance of the safety function to be performed.

2. 10 CFR Part 50, Appendix A, GDC 1, "Quality Standards and Records," which 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. GDC 1 also requires that 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.

3. 10 CFR Part 50, Appendix A, GDC 35 - "Emergency Core Cooling," which requires that a system be provided to supply abundant emergency core cooling such that damage to reactor core components is minimal following any loss of reactor coolant. GDC 35 also requires that the system will have containment capabilities to assure that the emergency core cooling function can be accomplished, assuming a single failure. For pressure-containing components of a critical nature, their containment capability, i.e., their structural integrity, including freedom from brittle fracture, can only be assured by

requiring minimum fracture toughness performance of the materials of which they are fabricated. This is a standard industrial practice which is frequently used in construction codes of significant steel structures.

4. 10 CFR Part 50, Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants," which establishes quality assurance requirements for the design, construction, and operation of those SSCs of nuclear power plants that prevent or mitigate the consequences of postulated accidents that could cause undue risk to the health and safety of the public.

5. 10 CFR 52.47(b)(1), which requires that a DC application contain the proposed inspections, tests, analyses, and acceptance criteria (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 design certification is built and will operate in accordance with the design certification, the provisions of the Atomic Energy Act, and the NRC's regulations;

6. 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, and the NRC's regulations.

The following Regulatory Guides provide information, recommendations, and guidance and in general describe a basis acceptable to the staff that may be used to implement the requirements of 10 CFR 50.55a; 10 CFR Part 50, Appendix A, GDC 1 and 35; and 10 CFR Part 50, Appendix B.

1. Regulatory Guide 1.37, "Quality Assurance Requirements for Cleaning of Fluid Systems and Associated Components of Water-Cooled Nuclear Power Plants," describes methods acceptable to the staff for control of the cleaning of material and equipment in accordance with work and inspection instructions to prevent damage or deterioration.

2. Regulatory Guide 1.71, "Welder Qualification for Areas of Limited Accessibility," describes methods acceptable to the staff for providing better control of welder technique in production welding.

3. Regulatory Guide 1.84, "Design, Fabrication, and Materials Code Case Acceptability, ASME Section III ," lists those ASME Section III Code Cases that are generally acceptable to the NRC staff.

SRP Acceptance Criteria

Specific SRP acceptance criteria acceptable to meet the relevant requirements of the NRC's regulations identified above are as follows for the review described in this SRP section. The SRP is not a substitute for the NRC's 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. Materials Selection and Fabrication of Class 2 and 3 Components

   A. The materials specified for use in Class 2 and 3 components should conform to Appendix I to Section III of the Code and to Parts A, B, and C of Section II of the Code.

   B. Regulatory Guide 1.84, describes acceptable Code Cases that may be used in conjunction with the above specifications. Appendix IV to Section III of the Code provides requirements for approval of new materials.

   C. Regulatory Guide 1.71 provides the following guidelines for assuring the integrity of welds in locations of restricted direct physical and visual accessibility.

      i. The performance qualification should require testing of the welder under simulated conditions when conditions of accessibility to production welds are less than 30 to 35 cm (12 to 14 inches) in any direction from the joint.

      ii. Requalification should be required for significantly different restricted accessibility conditions or when any essential welding variables listed in Code Section IX are changed.

   D. Regulatory Guide 1.50 provides methods to control preheat temperatures for welding low alloy steel. For carbon steel and low alloy steel materials, Section III, Appendix D, Article D-1000 of the ASME Code specifies preheat temperatures.

   E. Regulatory Guide 1.37 and ANSI Standard N45.2.1-1973, "Cleaning of Fluid Systems and Associated Components During Construction Phase of Nuclear Power Plants," describe acceptable procedures for cleaning and handling Class 2 and 3 components of the steam and feedwater systems.

   F. Acceptance criteria for nondestructive examination of tubular products are provided in the relevant paragraphs of Subsections NC and ND of Section III of the ASME Code.

2. Fracture Toughness of Class 2 and 3 Components

   The fracture toughness properties of the ferritic materials of these components should meet the following requirements of the editions and addenda of Section III of the Code, as specified in 10 CFR 50.55a:

   A. NC-2300, "Fracture Toughness Requirements for Material" (Class 2)

   B. ND-2300, "Fracture Toughness Requirements for Material" (Class 3)

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:

1. GDC 1 and 10 CFR 50.55a require that SSCs be designed, fabricated, erected, constructed, tested, and inspected to the highest quality standards commensurate with the importance of the safety function to be performed. The steam and feedwater systems may be relied upon to perform safety functions such as removing decay heat or supplying steam to engineered safety feature pumps. This SRP reviews the selection of and specifications for materials used for these two systems. Regulatory Guide 1.71

provides specific guidance for assuring the quality and integrity of welds with limited direct physical and visual accessibility. Regulatory Guide 1.84 provides guidance for application of ASME Code Cases to materials selection and fabrication. Meeting the requirements of GDC 1 and 10 CFR 50.55a and the positions of Regulatory Guides 1.71 and 1.84 assures system integrity and the ability to support emergency core cooling.

2. GDC 35 requires that an emergency core cooling system be provided that can remove decay heat following a loss of reactor coolant. The steam and feedwater systems may be utilized to perform safety functions such as removing decay heat or supplying steam to engineered safety feature (ESF) pumps. This SRP evaluates steam and feedwater materials including material fracture toughness properties. By verifying that steam and feedwater system materials meet GDC 35 requirements, assurance is provided that steam and feedwater system integrity will be maintained, thereby allowing these systems to fulfill their safety functions of removing decay heat and supplying steam to ESF pumps.

3. Appendix B of 10 CFR Part 50 provides quality assurance requirements for the design, construction, and operation of safety-related SSCs of a nuclear plant. The steam and feedwater systems may be relied upon to perform safety functions such as removing decay heat or supplying steam to engineered safety feature pumps. Regulatory Guide 1.37 provides acceptable quality assurance procedures for cleaning and handling of safety-related materials. Meeting the criteria of 10 CFR Part 50, Appendix B, and the positions of Regulatory Guide 1.37, provides assurance that the steam and feedwater system materials are designed and selected to established quality assurance standards, thus providing a high degree of certainty that safety functions will be performed and the health and safety of the public will be protected.

III. REVIEW PROCEDURES

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. Materials Selection and Fabrication of Class 2 and 3 Components. The reviewer determines that the materials proposed for the steam and feedwater systems are in conformance with Appendix I to Section III and to Parts A, B, and C of Section II of the Code.

   A. The reviewer verifies the acceptability of any proposed material that is not included in Appendix I to Section III and Parts A, B, and C of Section II of the ASME Code or in Regulatory Guide 1.84.

   B. The reviewer determines that the methods for qualifying welders for making welds in locations of restricted direct physical and visual accessibility, and the methods for monitoring and certifying production welds in such areas are in accordance with the acceptance criteria stated in subsection II.1(C) of this SRP section.

   C. The reviewer verifies the adequacy of controls placed on the welding procedures for carbon or low alloy steel components. The reviewer confirms that the

preheat temperatures used for welding are in accordance with the references specified in subsection II.1.D of this SRP section, or that justification has been provided for alternatives to these specified preheat temperatures.

D. The reviewer determines that the methods for cleaning and handling the Class 2 and 3 components are in accordance with acceptance criteria stated in subsection II.1.(E) of this SRP section.

E. The reviewer verifies that the tubular products are examined in accordance with acceptance criteria stated in subsection II.1.F of this SRP section.

F. If austenitic stainless steel materials are used in the design of the steam or feedwater systems, the reviewer verifies that the applicant has adequately addressed the potential for IGSCC. The reviewer uses the applicable criteria of SRP Section 5.2.3, "Reactor Coolant Pressure Boundary Materials," as they relate to material selection and fabrication process controls for austenitic stainless steel.

2. Fracture Toughness of Class 2 and 3 Components The reviewer determines that fracture toughness properties of components in the steam and feedwater systems are in conformance with subsection II.2 of this SRP section.

3. Flow-Accelerated Corrosion The reviewer verifies that the applicable operating experience pertaining to FAC resistance has been considered in the design of steam and feedwater systems such that the effects of FAC are minimized for the lifetime of the plant. In addition to design considerations, GL 89-08 stressed the importance of implementing formalized procedures or administrative controls to ensure continued long-term implementation of an FAC monitoring program for piping and components within its design basis. Guidelines provided by EPRI in NSAC-202L-R2 include procedures or administrative controls to assure that the structural integrity of all carbon steel lines containing high-energy fluids (two-phase, as well as single-phase) is maintained by minimizing FAC effects.

A. The reviewer verifies that piping subject to FAC degradation has been designed using materials resistant to FAC .

B. The reviewer verifies that the applicant has specified a corrosion allowance that covers the design life of the plant and meets Section III of the ASME Code.

C. The reviewer verifies that the design and layout of piping minimizes the FAC effects from system piping and component configuration and geometry, water chemistry, piping and component material, fluid temperature (including flash points), and fluid velocity.

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.

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.

> The staff concludes that the main steam and feedwater system materials are acceptable and meet the relevant requirements of 10 CFR 50.55a, 10 CFR Part 50, Appendix A, General Design Criteria 1 and 35, and 10 CFR Part 50, Appendix B. This conclusion is based on the following:
>
> > The applicant has selected materials for Class 2 and 3 components of the steam and feedwater systems that satisfy Appendix I of Section III of the ASME Boiler and Pressure Vessel Code, and meet the requirements of Parts A, B, and C of Section II of the Code. The applicant has also met the recommendations of Regulatory Guide 1.84, which describes acceptable Code Cases that may be used in conjunction with this industry standard.
> >
> > When required, the fracture toughness properties of ferritic steel materials satisfy the requirements of the Code. Where the Code allows fracture toughness testing to be optional, the applicant provided reasonable justification for not requiring fracture toughness testing of ferritic steel components of the main steam and feedwater systems. These fracture toughness tests and mechanical properties required by the Code provide reasonable assurance that ferritic materials will have adequate safety margins against the possibility of nonductile behavior or rapidly propagating fracture.
> >
> > The applicant has met the requirements of Regulatory Guide 1.71, "Welder Qualification for Areas of Limited Accessibility," by meeting the regulatory positions in Regulatory Guide 1.71 or providing and meeting an alternative to the regulatory positions in Regulatory Guide 1.71 that the staff has reviewed and found to be acceptable. The onsite cleaning and cleanliness controls during fabrication satisfy the position given in Regulatory Guide 1.37, "Quality Assurance Requirements for Cleaning of Fluid Systems and Associated Components of Water-Cooled Nuclear Power Plants," and the requirements of ANSI Standard N45.2.1-1973, "Cleaning of Fluid Systems and Associated Components During Construction Phase of Nuclear Power Plants."
> >
> > The applicant has considered system piping and component size, configuration, and geometry, water chemistry, piping and component material, fluid temperature (including flash points), and fluid velocity in its evaluation of flow-accelerated corrosion.

For design certification and combined license reviews, the findings will also summarize (to the extent that the review is not discussed in other safety evaluation report sections) the staff's

evaluation of the ITAAC, including design acceptance criteria (DAC), as applicable, and interface requirements and combined license action items relevant to this SRP Section.

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.

VI. REFERENCES

1. 10 CFR 50.55a, "Codes and Standards."

2. 10 CFR Part 50, Appendix A, General Design Criterion 1, "Quality Standards and Records."

3. 10 CFR Part 50, Appendix A, General Design Criterion 35, "Emergency Core Cooling."

4. 10 CFR Part 50, Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants."

5. Regulatory Guide 1.37, "Quality Assurance Requirements for Cleaning of Fluid Systems and Associated Components of Water-Cooled Nuclear Power Plants."

6. Regulatory Guide 1.50, "Control of Preheat Temperature for Welding of Low-Alloy Steel."

7. Regulatory Guide 1.71, "Welder Qualification for Areas of Limited Accessibility."

8. Regulatory Guide 1.85, "Design, Fabrication, and Materials Code Case Acceptability, ASME Section III ."

9. NSAC-202L-R2, "Recommendations for an Effective Flow Accelerated Corrosion Program," Electric Power Research Institute, Palo Alto, CA, April 8, 1999.

10. ANSI Standard N45.2.1-1973, "Cleaning of Fluid Systems and Associated Components During Construction Phase of Nuclear Power Plants."

11. ASME Boiler and Pressure Vessel Code, Section II, Parts A, B, and C, Section III, subsections NB, NC, and ND, Article D-1000, and Appendix I, and Section IX; American Society of Mechanical Engineers.

12. NRC letter to All holders of operating licenses or construction permits for nuclear power plants, "Erosion/Corrosion-Induced Pipe Wall Thinning (Generic Letter No. 89-08)," May 2, 1989.

13. NUREG-1344, *Erosion/Corrosion-Induced Pipe Wall Thinning in U.S. Nuclear Power Plants,* P. C. Wu, U.S. Nuclear Regulatory Commission, April 1989.

14. 10 CFR 52.47(a)(1)(vi), which requires ITAAC (for design certification) sufficient to assure that the SSCs in this area of review will operate in accordance with the certification.

15. 10 CFR 52.97(b)(1), which requires ITAAC (for combined licenses) sufficient to assure that the SSCs in this area of review have been constructed and will be operated in conformity with the license and the Commission regulations.