U.S. NUCLEAR REGULATORY COMMISSION

STANDARD REVIEW PLAN

4.5.1 CONTROL ROD DRIVE STRUCTURAL MATERIALS

REVIEW RESPONSIBILITIES

Primary - Organization responsible for the review of control drive structural materials

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

I. AREAS OF REVIEW

General Design Criterion (GDC) 26 requires that one of the reactivity control systems use control rods, preferably with a positive means for inserting the rods, and be capable of reliably controlling reactivity changes for assurance that fuel design limits are not exceeded under conditions of normal operation, including anticipated operational occurrences. The review areas are similar to those of Standard Review Plan (SRP) Section 5.2.3, "Reactor Coolant Pressure Boundary Materials." For purposes of this SRP section, the control rod system is comprised of the Control Rod Drive Mechanism (CRDM) and extends only to the coupling interface with the reactivity control (poison) elements in the reactor vessel; it does not include the electrical and hydraulic systems necessary to actuate the CRDMs.

The specific areas of review are as follows:

1. Materials Specifications. The properties of the control rod drive materials are reviewed for adequate performance throughout the design life of the plant (or component). Materials commonly used include austenitic stainless steels (which may be cold-worked), chromium-plated stainless steels, martensitic stainless steels, precipitation-hardening stainless steels like 17-4 PH, and such other special-purpose materials as cobalt-base alloys (Stellites), Inconel-750, Colmonoy-6, and Graphitar-14.

2. Austenitic Stainless Steel Components. Areas of review for austenitic stainless steel components are similar to the applicable subsections of SRP Section 5.2.3 for fabrication and processing of austenitic stainless steels.

   The use of sensitized stainless steels is reviewed and should be controlled to prevent stress-corrosion cracking of the material during plant operation. Welding procedures are reviewed and should be controlled to reduce the probability of sensitization and micro-fissure formation. The use of cold-worked stainless steel is reviewed, and to reduce the probability of stress-corrosion cracking during plant operation, cold-worked stainless steels should not have high-yield stress higher than 90,000 psi.

3. Other Materials. Special requirements for materials other than austenitic stainless steels include tempering and aging temperatures for martensitic and precipitation-hardening stainless steels to prevent their deterioration by stress corrosion during plant operation. The compatibility of these materials with the reactor coolant is reviewed for whether they will continue to perform satisfactorily throughout the life of the component.

   The staff reviews to ensure that metallic and non-metallic materials used in the CRDM that are not included in Section III, Appendix I, Division 1 of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section II, "Materials," Parts A, B, C, and D; and Section III, "Rules for Construction of Nuclear Plant Components," Division 1, including Appendix I (hereinafter "the ASME Code"), are identified.

4. Cleaning and Cleanliness Control. Cleaning and cleanliness control procedures are reviewed to confirm that proper care should be taken in handling the materials and parts of the CRDM during fabrication, shipping, and onsite storage for assurance that all cleaning solutions, processing compounds, degreasing agents, and other foreign materials are removed completely and that all parts are dried and properly protected following any flushing treatment with water.

5. 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.

6. 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. Section 3.13: review of the adequacy of programs for assuring the integrity of bolting and threaded fasteners.

2. Section 3.9.4: review of the mechanical aspects of the control rod drive system other than the reactivity control elements.

3. Section 4.2: review of the mechanical design, thermal performance, and chemical compatibility of the reactivity control elements.

4. Section 5.2.3: review of control rod drive system portions that are part of the reactor coolant pressure boundary (RCPB); verification of whether materials of construction and fabrication controls satisfy criteria for RCPB materials.

5. Section 5.3.1: review of control rod drive portions that are reactor vessel attachments or appurtenances; verification of whether materials of construction and related fabrication controls satisfy the criteria for reactor vessel materials.

6. Sections 5.4.8, "Reactor Water Cleanup System (BWR)," and 9.3.4, "Chemical and Volume Control System (PWR)": review of the acceptability of the reactor coolant chemistry and chemistry controls (including such additives as inhibitors) as to corrosion control and compatibility with control rod drive structural materials.

7. Section 12.1: review of the plant design, including selection of materials to minimize activation products, for whether occupational radiation exposures will be as low as is reasonably achievable.

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. GDC 1, as it relates to SSCs important to safety being designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions to be performed.

2. GDC 14, as it relates to the RCPB being designed, fabricated, erected, and tested to have an extremely low probability of abnormal leakage, rapidly propagating failure, or gross rupture.

3. GDC 26, as it relates to control rods being capable of reliable control of reactivity changes to assure that under conditions of normal operation, including anticipated operational occurrences, and with appropriate margin of malfunctions, specified acceptable fuel design limits are not exceeded.

4. 10 CFR 50.55a, as it relates to SSCs being designed, fabricated, erected, constructed, tested, and inspected to quality standards commensurate with the importance of the safety function to be performed.

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.

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.

With respect to compliance with GDCs 1, 14, and 26 and 10 CFR 50.55a:

1. Materials Specifications. The properties of the materials selected for the CRDM should be equivalent to those of Section III, Appendix I, Division 1 of the ASME Code or Section II, Parts A, B, C, and D of the ASME Code. Cold-worked austenitic stainless steels should have a 0.2 percent offset yield strength no greater than 620 MPa (90,000 psi), to reduce the probability of stress corrosion cracking in these systems. Regulatory Guide (RG) 1.85 describes the acceptable code cases that may be used with these specifications.

2. Austenitic Stainless Steel Components. Acceptance criteria include criteria described in SRP Section 5.2.3, Subsections II.4.D and E, and the criteria described below.

RG 1.44 describes accepted methods for preventing intergranular corrosion of stainless steel components. Furnace-sensitized material should not be allowed, and methods described in this guide should be followed for cleaning and protecting austenitic stainless steels from contamination during handling, storage, testing, and fabrication and for determining the degree of sensitization during welding.

The controls for abrasive work on austenitic stainless steel surfaces should be adequate for preventing contamination that promotes stress corrosion cracking. The final surfaces should meet the acceptance standards specified in ASME NQA-1-1994 Edition, "Quality Assurance Requirements for Nuclear Facilities." Tools that contain materials that could contribute to stress-corrosion cracking or that, from previous usage, may be contaminated with such materials should not be used on austenitic stainless steel surfaces.

3. Other Materials. All materials for use in this system should be selected for their compatibility with the reactor coolant as described in Articles NB-2160 and NB-3120 of the ASME Code. The tempering temperature of martensitic stainless steels and the aging temperature of precipitation-hardening stainless steels should be specified for assurance that these materials will not deteriorate from stress corrosion cracking in service. Acceptable heat treatment temperatures include aging at 565° - 595°C (1050° - 1100°F) for Type 17-4 PH and 565°C (1050°F) for Type 410 stainless steel.

4. Cleaning and Cleanliness Control. Onsite cleaning and cleanliness control should be in accordance with ASME NQA-1-1994 edition. The oxygen content of the water in vented tanks need not be controlled. Vented tanks with deionized or demineralized water are normal sources of water for final cleaning or flushing of finished surfaces. Halogenated hydrocarbon cleaning agents should not be used.

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 quality standards commensurate with the importance of the safety functions performed. 10 CFR 50.55a also incorporates by reference applicable editions and addenda of the ASME Boiler and Pressure Vessel Code. The control rod drive system positions control rods for reactivity control and comprises a part of the RCPB. Application of 10 CFR 50.55a and GDC 1 to the control rod drive structural materials provides assurance that the control rod drive structure materials will perform as designed.

2. GDC 14 requires that the RCPB 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. The RCPB provides a fission product barrier and a confined volume for the inventory of reactor coolant. The RCPB includes portions of the control rod drive system. Application of GDC 14 assures that control rod drive materials are selected, fabricated, installed, and tested for an extremely low probability of significant degradation and, in the extreme, gross RCPB failure that could substantially reduce capability to contain reactor coolant inventory or capability to confine fission products.

3. GDC 26 establishes requirements for reactivity control system redundancy and capability. GDC 26 requires a control rod system, preferably including a positive means for inserting the rods, capable of reliably controlling reactivity changes to assure that under conditions of normal operation, including anticipated operational occurrences, the specified acceptable fuel design limits are not exceeded. The control rod drive system provides for rod positioning including insertion for reactivity control. Application of GDC 26 to the control rod drive system materials ensures that material selection and fabrication support reliable rod movement for reactivity control; it also preserves fuel and cladding integrity, the primary barriers to the release of fission products.

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. Material Specifications. The reviewer compares the properties of the material proposed for the control rod system to the criteria of Section III, Appendix I, Division 1 of the Code, Section II, Parts A, B, C and D of the ASME Code, or acceptable material code cases described in RG 1.85. The reviewer verifies whether cold-worked austenitic stainless steels used in fabrication of the reactivity control mechanisms comply with Subsection II.1 of the ASME Code.

2. Austenitic Stainless Steel Components. Review procedures include those described in SRP Section 5.2.3, Subsections III.4.D and E. The reviewer examines the applicant's 1) methods of controlling sensitized stainless steel and compares them to the positions of RG 1.44, especially as to cleaning and protection from contamination during handling and storage, 2) verification of non-sensitization of the material, and 3) qualification of the welding process for production. The qualification of the welding process uses the American Society for Testing and Materials (ASTM), A-262-1970, "Detecting Susceptibility to Intergranular Attack in Stainless Steels"; Practice A "Oxalic Acid Etch Test for Classification of Etch Structures of Stainless Steels"; Practice E, "Copper-Copper Sulfate-Sulfuric Acid Test for Detecting Susceptibility to Intergranular Attack in Stainless Steels"; and the Annual Book of ASTM Standards. If the applicant proposes alternative methods of testing the qualification welds for degree of sensitization, the reviewer determines whether these are satisfactory, taking into account branch positions taken on previous applications and their degrees of equivalence. The reviewer may ask the applicant to justify the technical basis for any departures from the cited positions. Alternative tests that have been accepted include the use of ASTM A-708-1974, "Detection of Susceptibility to Intergranular Corrosion in Severely Sensitized Austenitic Stainless Steel," Annual Book of ASTM Standards.

   The reviewer examines the methods of controlling and measuring the amount of delta ferrite in stainless steel weld deposits and compares them to the criteria of the ASME Code, Section III, especially as to the filler metal acceptance procedures for the determination of delta ferrite content. If the applicant proposes alternative positions,

the reviewer determines whether these are satisfactory, taking into account branch positions on previous applications. The reviewer may ask the applicant to justify the technical basis for any departures from the acceptance criteria stated in subsection II.2 of this SRP section.

The reviewer verifies the applicant's description of abrasive work controls for austenitic stainless steel surfaces is adequate to minimize the cold-working of surfaces and the introduction of contaminants that may promote stress corrosion cracking.

3. Other Materials. The reviewer examines the information in the applicant's safety analysis report on the compatibility of the materials (other than austenitic stainless steels) in contact with the reactor coolant to determine whether the materials are compatible with the service environment so that unacceptable degradation due to corrosion or stress corrosion of the component will not occur during its lifetime. Metallic and nonmetallic materials identified in subsection I.3 of this SRP section are reviewed for compatibility so loss of integrity will not occur during the life of the component.

   Operating experience indicates that certain nickel-chromium-iron alloys (e.g., Inconel) are susceptible to cracking due to corrosion. Inconel 690 alloy has improved corrosion resistance compared to Inconel alloy 600 previously used in reactor applications. Where nickel-chromium-iron alloys are proposed, the reviewer verifies whether an acceptable technical basis is either identified (by demonstrated satisfactory use in similar applications) or presented by the applicant for use of the material. The reviewer particularly emphasizes the corrosion-resistant and stress corrosion cracking-resistant properties of the proposed nickel-chromium-iron alloy(s).

   The reviewer determines whether the tempering temperatures of all martensitic stainless steels and the aging temperatures of precipitation-hardening stainless steels have been specified and are in accordance with the acceptance criteria of subsection II.3 of this SRP section.

4. Cleaning and Cleanliness Control. The reviewer verifies whether onsite cleaning and cleanliness control procedures are satisfactory and in accordance with the acceptance criteria stated in subsection II.4 of this SRP section.

5. 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).

6. 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.

1. The staff concludes that the CRDM structural materials are acceptable and meet the requirements of GDCs 1,14, and 26 and of 10 CFR 50.55a. This conclusion is based on the applicant's demonstration that the properties of materials selected for the CRDM components exposed to the reactor coolant satisfy Section III, Appendix I, Division 1 of the ASME Code, and Section II, Parts A, B, C, and D of the ASME Code, and the applicant's compliance with the staff position that the yield strength of cold-worked austenitic stainless steel should not exceed 620 MPa (90,000 psi). As to materials not selected in accordance with ASME Code provisions, the applicant has used materials of construction that are in accordance with the acceptable ASME code cases described in RG 1.85 or that are otherwise acceptable for the application.

2. In addition, the controls imposed upon the austenitic stainless steel of the mechanisms comply with the criteria of ASME Code, Section III, ASME NQA-1-1994 Edition, RG 1.44, "Control of the Use of Sensitized Stainless Steel," and the related criteria described in SRP Section 5.2.3, "Reactor Coolant Pressure Boundary Materials." Fabrication and heat treatment practices in accordance with these recommendations add assurance that stress corrosion cracking will not occur during the design life of the component. The compatibility of all materials in the control rod system in contact with the reactor coolant satisfies the criteria of Section III, Articles NB-2160 and NB-3120, Division 1 of the ASME Code. Both martensitic and precipitation-hardening stainless steels have been given tempering or aging treatments in accordance with staff positions. Cleanliness control is in accordance with ASME NQA-1-1994 Edition.

3. 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.

4. 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.

VI. REFERENCES

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

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

3. 10 CFR Part 50, Appendix A, GDC 14, "Reactor Coolant Pressure Boundary."

4. 10 CFR Part 50, Appendix A, GDC 26, "Reactivity Control System Redundancy and Capability."

5. Regulatory Guide 1.44, "Control of the Use of Sensitized Stainless Steel."

6. Regulatory Guide 1.85, "Materials Code Case Acceptability ASME Section III Division 1."

7. ASME Boiler and Pressure Vessel Code, Section II, "Materials," Parts A, B, C, and D; and Section III, "Rules for Construction of Nuclear Plant Components," Division 1, including Appendix I; American Society of Mechanical Engineers.

8. ASTM, A-262-1970, "Detecting Susceptibility to Intergranular Attack in Stainless Steels;" Practice A "Oxalic Acid Etch Test for Classification of Etch Structures of Stainless Steels"; Practice E, "Copper-Copper Sulfate-Sulfuric Acid Test for Detecting Susceptibility to Intergranular Attack in Stainless Steels"; Annual Book of ASTM Standards, American Society for Testing and Materials.

9. ASTM A-708-1974, "Detection of Susceptibility to Intergranular Corrosion in Severely Sensitized Austenitic Stainless Steel," Annual Book of ASTM Standards, American Society for Testing and Materials.

10. ASME NQA-1-1994 Edition, "Quality Assurance Requirements for Nuclear Facility Applications," Revision and Consolidation of ASME NQA-1-1989 and ASME NQA-2-1989 Editions, American Society of Mechanical Engineers.