U.S. NUCLEAR REGULATORY COMMISSION

# DESIGN-SPECIFIC REVIEW STANDARD FOR mPOWER™ iPWR DESIGN

## 4.5.1 CONTROL ROD DRIVE STRUCTURAL MATERIALS

**RESPONSIBILITIES**

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

**Secondary -** None

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 design specific review standard (DSRS) Section 5.2.3, "Reactor Coolant Pressure Boundary Materials".

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 in the fabrication of control rod drives 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 Alloy 625, Alloy 718, Alloy X-750 and cobalt-base alloys.

2. Austenitic Stainless Steel Components. Areas of review for austenitic stainless steel components are similar to the applicable subsections of DSRS 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

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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 control rod drive mechanism (CRDM) that are not included in 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(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 DSRS 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 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.

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 and DSRS 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. Section 9.3.6, "Reactor Coolant Inventory and Purification system (RCIPS)": 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 DSRS 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. Title 10 of the *Code of Federal Regulations* (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 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 (AEA), and the U.S. Nuclear Regulatory Commission's (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 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 as follows for review described in this DSRS section. The DSRS is not a substitute for the NRC's regulations, and compliance with it is not required. Identifying the differences between this DSRS section and the design features, analytical techniques, and procedural measures proposed for the facility, and discussing how the proposed alternative provides an acceptable method of complying with the regulations that underlie the DSRS acceptance criteria, is sufficient to meet the intent of 10 CFR 52.47(a)(9), "Contents of applications; technical information."

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 permitted by Section III, 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) 1.84 describes the acceptable code cases that may be used with these specifications.

2. Austenitic Stainless Steel Components. Acceptance criteria include criteria described inDSRS Section 5.2.3, Subsections II.4., 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 Facility Applications." 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. Stress-Corrosion Cracking. All materials for use in this system should be selected for their compatibility with the reactor coolant as described in Sub 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°F - 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.

5. 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 CRDM 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:

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 the CRDM dump valves and CRDM block valves which are part 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 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. In accordance with 10 CFR 52.47(a)(8),(21), and (22), and 10 CFR 52.79(a)(17) and (20), for new reactor 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 six 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). 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.

2. Material Specifications. The reviewer compares the properties of the material proposed for the control rod system to the criteria of Section III, 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 1.84. The reviewer verifies whether cold-worked austenitic stainless steels used in fabrication of the reactivity control mechanisms comply with Subsection II.1.

3. Austenitic Stainless Steel Components. The reviewer examines procedures include those described in DSRS Section 5.2.3, Subsections III.4. 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, "Standard Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels"; Practice A "Oxalic Acid Etch Test for Classification of Etch Structures of Austenitic Stainless Steels"; Practice E, "Copper-Copper Sulfate-Sulfuric Acid Test for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels". 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.

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 DSRS 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.

4. 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 DSRS section are reviewed for compatibility so loss of integrity will not occur during the life of the component.

   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 DSRS section.

5. 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 DSRS section.

6. 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 technical submittal meets the acceptance criteria. DCs have referred to the technical submittal 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 technical submittal.

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 or other NRC approvals (e.g., manufacturing license, site suitability report or topical report).

7. 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, 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 1.84 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 DSRS 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 DSRS 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 DSRS section in performing safety evaluations of mPower$^{TM}$-specific DC, or COL, applications submitted by applicants pursuant to 10 CFR Part 52. The staff will use the method described herein to evaluate conformance with Commission regulations.

Because of the numerous design differences between the mPower™ and large light-water nuclear reactor power plants, and in accordance with the direction given by the Commission in 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), to develop risk-informed licensing review plans for each of the small modular reactor reviews including the associated pre-application activities, the staff has developed the content of this DSRS section as an alternative method for mPower™ -specific DC, or COL submitted pursuant to 10 CFR Part 52 to comply with 10 CFR 52.47(a)(9), “Contents of applications; technical information.”

This regulation states, in part, that the application must contain “an evaluation of the standard plant design against the Standard Review Plan (SRP) revision in effect sixmonths before the docket date of the application.” The content of this DSRS section has been accepted as an alternative method for complying with 10 CFR 52.47(a)(9) as long as the mPower™ DCD final safety analysis report does not deviate significantly from the design assumptions made by the NRC staff while preparing this DSRS section. The application must identify and describe all differences between the standard plant design and this DSRS section, and discuss how the proposed alternative provides an acceptable method of complying with the regulations that underlie the DSRS acceptance criteria. If the design assumptions in the DC application deviate significantly from the DSRS, the staff will use the SRP as specified in 10 CFR 52.47(a)(9). Alternatively, the staff may supplement the DSRS section by adding appropriate criteria in order to address new design assumptions. The same approach may be used to meet the requirements of 10 CFR 52.79(a)(41) for COL applications.

## 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 10 CFR Part 52, Subpart B “Standard Design Certifications” Section 52.47 “Contents of Applications; Technical Information” and Subpart C “Combined Licenses” Section 52.80 “Contents of Applications; Additional Technical Information.”

6. RG 1.44, "Control of the Use of Sensitized Stainless Steel."

7. RG 1.84, "Design, Fabrication, and Materials Code Case Acceptability, ASME Section III".

8. 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,; American Society of Mechanical Engineers.

9. ASTM, A-262-, "Standard Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels;"" American Society for Testing and Materials, West Conshohocken, PA.

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.