U.S. NUCLEAR REGULATORY COMMISSION

STANDARD REVIEW PLAN

3.9.4 CONTROL ROD DRIVE SYSTEMS

REVIEW RESPONSIBILITIES

Primary - Organization responsible for the review of component performance and testing

Secondary - None

I. AREAS OF REVIEW

The control rod drive system (CRDS) consists of the control rods and the related mechanical components which provide the means for mechanical movement. 10 CFR Part 50, Appendix A, General Design Criteria (GDC) 26 and 27 require that the CRDS provide one of the independent reactivity control systems. The rods and the drive mechanism shall be capable of reliably controlling reactivity changes under conditions of normal operation, including anticipated operational occurrences, and under postulated accident conditions. A positive means for inserting the rods shall always be maintained to ensure appropriate margin for malfunction, such as stuck rods. Since the CRDS is important to safety and portions of the CRDS are a part of the reactor coolant pressure boundary (RCPB), GDC 1, 2, 14, and 29 and 10 CFR 50.55a require that the system be designed, fabricated, and tested to quality standards commensurate with the safety functions to be performed so as to assure an extremely high probability of accomplishing the safety functions in the event of anticipated operational occurrences, postulated accidents and natural phenomena such as earthquakes.

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Information in the areas noted below is provided in the applicant's safety analysis report and is reviewed by the primary review branch in accordance with this standard review plan (SRP) section. This information pertains to the CRDS, which is considered to extend to the coupling interface with the reactivity control elements in the reactor pressure vessel. For electromagnetic systems, the review under this SRP section is limited to just the control rod drive mechanism (CRDM) portion of the CRDS. For hydraulic systems, the review covers the CRDM and also the hydraulic control unit, the condensate supply system, and the scram discharge volume. For both types of systems, the CRDM housing should be treated as part of the RCPB; the relevant mechanical engineering information is presented either in this SRP section or by reference to the sections on the RCPB.

If other types of CRDS are proposed or if new features that are not specifically mentioned here are incorporated in CRDS of current types, the information supplied for the new systems or new features should be similar to the information described below.

The specific areas of review are as follows:

1. The descriptive information, including design criteria, testing programs, drawings, and a summary of the method of operation of the control rod drives, is reviewed to permit an evaluation of the adequacy of the system to perform its mechanical function properly.

2. A review is performed of design codes, standards, specifications, and standard practices, as well as GDC, regulatory guides, and branch positions that apply to the design, fabrication, construction, and operation of the CRDS.

   The various criteria, described in general terms above, should be supplied along with the names of the apparatus to which the criteria apply. Pressurized portions of the system that are a part of RCPB are reviewed to determine the extent to which the applicant complies with the Class 1 requirements of Section III of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (Code). Those portions that are not part of the RCPB are reviewed for compliance with other specified parts of Section III, or other sections of the ASME Code. The non-pressurized portions of the CRDS are reviewed to determine the acceptability of design margins for allowable values of stress, deformation, and fatigue used in the analyses. If an experimental testing program is used in lieu of analysis, the program is reviewed to determine whether it adequately covers stress, deformation, and fatigue.

3. A review of applicable design loads and their appropriate combinations, the corresponding design stress limits, and the corresponding allowable deformations is performed. The deformations are of interest in the present context only in those instances where a failure of movement due to excessive deformation could be postulated and such movement would be necessary for a safety-related function.

   If the applicant selects an experimental testing option in lieu of establishing a set of stress and deformation allowables, a detailed description of the testing program must be provided for review. The load combinations, design stress limits and allowable deformations criteria should be provided for review in the preliminary safety analysis report (PSAR). In the final safety analysis report (FSAR) for an operating license, or the final safety evaluation report (FSER) for design certification (DC) applications, the actual design should be compared with the design criteria and limits to demonstrate that the criteria and limits have not been exceeded.

Loadings imposed during normal plant operation and startup and shutdown transients include but are not limited to pressure, deadweight, temperature effects, and anticipated operational occurrences. Loadings associated with specific seismic and other dynamic events are then combined with the above plant-type loads. For boiling water reactors (BWRs) only, the CRDS is reviewed to verify that the system is capable of withstanding adverse dynamic loads such as water hammer. The response to each set of combined loads has a selected stress or deformation limit. The selection of a specific limit is influenced by the probability of the postulated event and the need to assure operation during and after the event.

4. A review of the portion of the SAR that describes plans for the conduct of an operability assurance program or that references previous test programs or standard industry procedures for similar apparatus is performed. For example, the life cycle test program for the CRDS is reviewed. The operability assurance program is reviewed to ascertain coverage of the following:

   A. Life cycle test program

   B. Proper service environment imposed during test, including appropriate conditions for normal operation, anticipated operational occurrences, seismic events, and postulated accident conditions

   C. Mechanism functional tests

   D. Program results

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. Verification that CRDS pressure-retaining components are acceptably classified and that corresponding appropriate quality standards are applied is performed under SRP Sections 3.2.2 and/or 5.2.1.1.

2. Evaluation of BWR CRDS piping with respect to locations and effects of postulated piping failures is performed under SRP Section 3.6.2.

3. The adequacy of the fuel system design, including effects of the CRDS on fuel behavior in meeting the requirements of the reactor core design under various normal operating and accident conditions, is reviewed under SRP Section 4.2.

4. The functional design of reactivity control systems, including the CRDS and its design for protection against the effects of postulated piping and equipment failures, is reviewed under SRP Section 4.6.

5. The adequacy of programs for assuring the integrity of bolting and threaded fasteners is reviewed under SRP Section 3.13.

6. The material aspects of CRDS are reviewed under SRP Section 4.5.1.

7. The adequacy of specified environments and service conditions for equipment qualification and of the overall demonstration that components of the CRDS are qualified to perform their functions is reviewed under SRP Section 3.11.

8. The adequacy of BWR CRDS piping with respect to locations and effects of postulated piping failures is reviewed under SRP Section 3.6.2.

9. The structural integrity of Code Class 1, 2, and 3 components, component supports, and core support structures is reviewed under SRP Section 3.9.3.

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 and 10 CFR 50.55a, as they relate to the CRDS, require that the CRDS be designed to quality standards commensurate with the importance of the safety functions to be performed.

2. GDC 2, as it relates to CRDS, requires that the CRDS be designed to withstand the effects of an earthquake without loss of capability to perform its safety functions.

3. GDC 14, as it relates to CRDS, requires that the RCPB portion of the CRDS be designed, constructed, and tested for the extremely low probability of leakage or gross rupture.

4. GDC 26, as it relates to CRDS, requires that the CRDS be one of the independent reactivity control systems that is designed with appropriate margin to assure its reactivity control function under conditions of normal operation, including anticipated operational occurrences.

5. GDC 27, as it relates to CRDS, requires that the CRDS be designed with appropriate margin, and in conjunction with the emergency core cooling system, be capable of controlling reactivity and cooling the core under postulated accident conditions.

6. GDC 29, as its relates to CRDS, requires that the CRDS, in conjunction with reactor protection systems, be designed to assure an extremely high probability of accomplishing its safety functions in the event of anticipated operational occurrences.

7. 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;

8. 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.

1. The descriptive information is determined to be sufficient provided the minimum requirements for such information meet Section 3.9.4 of Regulatory Guide (RG) 1.29.

2. Construction (as defined in NCA-1110 of Section III of the ASME Code) should meet the following codes and standards utilized by the nuclear industry which have been reviewed and found acceptable:

A. For pressurized portions of equipment classified as Quality Group A, B, C (RG 1.26):

Section III of the ASME Code, Class 1, 2, or 3 as appropriate.

B. For pressurized portions of equipment classified as Quality Group D (RG 1.26):

i. Section VIII, Division 1, of the ASME Code for vessels and pump casings.

ii. For piping systems (American National Standards Institute, ANSI):(1)

B16.5	Steel Pipe Flanges and Flanged Fittings
B16.9	Steel Butt Welding Fittings
B16.11	Steel Socket Welding Fittings
B16.25	Butt Welding Ends
B16.34	Steel Valves with Flanged and Butt Welding Ends
B31.1	Power Piping
MSS-SP-25	Marking for Valves, Fittings, Flanges, and Unions

C. For nonpressurized equipment (Non-ASME Code):

Design margins presented for allowable stress, deformation, and fatigue should be equal to or greater than margins for other plants of similar design with successful operating experience. A justification of any decreases in design margins should be provided.

3. For the various design and service conditions defined in NB-3113 of Section III of the ASME Code, load combination sets are as given in SRP Section 3.9.3.

The stress limits applicable to pressurized and nonpressurized portions of the control rod drive systems should be as given in SRP Section 3.9.3 for the response to each loading set. For BWRs, the CRDS design should adequately consider water hammer loads to assure that system safety functions can be achieved.

4. The operability assurance program will be acceptable provided the observed performance as to wear, functioning times, latching, and ability to overcome a stuck rod meet system design requirements.

<u>Technical Rationale</u>

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 establish requirements regarding the quality standards to be applied to the CRDS. Specifically, 10 CFR 50.55a identifies the ASME Code

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(1)This list can be extended by a staff review and acceptance of other ANSI and Manufacturers Standardization Society (MSS) standards in the piping system area.

requirements, Code editions, and addenda that must be applied to pressure-retaining portions of the CRDS that are of the highest importance to safety. RG 1.26 identifies acceptable standards to be applied for pressure-retaining portions of the CRDS that are less important to safety but which may contain radioactive material. The CRDS is an independent reactivity control system designed to ensure the capability to control reactivity changes in the reactor under normal operating and accident conditions. The fuel cladding and RCPB are protected by CRDS safety functions, including insertion of adequate negative reactivity to preserve these fission product barriers under specified conditions. In addition, the CRDS comprises a portion of the RCPB and provides a barrier to the release of fission products. The application of GDC 1 and 10 CFR 50.55a requirements to the design, fabrication, installation and testing ensures the CRDS meets quality standards that are adequate to provide assurance that these safety functions will be performed.

2. GDC 2 establishes requirements regarding the ability of the CRDS to withstand the effects of an earthquake. The CRDS must satisfy Seismic Category I requirements and be capable of controlling reactivity when subjected to a seismic disturbance thereby ensuring that the fission process can be rapidly terminated. Consequently, plant protection and safety is augmented by the capability of the CRDS to perform its safety function under earthquake conditions.

3. GDC 14 establishes requirements regarding the RCPB portion of the CRDS. The CRDM is relied on, in part, to provide a barrier to the release of fission products to the containment through proper design of the control rod drive housing and components that are part of the RCPB. Application of the GDC 14 criteria to the CRDM components functioning as a RCPB enhances safety by ensuring that the RCPB will have an extremely low probability of failure.

4. GDC 26 establishes requirements regarding the reactivity control systems' redundancy and capability. The CRDS is one of the reactivity control systems relied on during normal operating and anticipated operational occurrences to control reactivity changes and ensure that the fuel design limits are not exceeded. Application of GDC 26 criteria to the CRDS improves safety by providing protection for the fuel rods and cladding, which is the primary barrier to the release of fission products.

5. GDC 27 establishes requirements regarding the combined reactivity control system capability. The CRDS is one of the reactivity control systems relied on to control reactivity changes and ensure that the capability to cool the core is maintained during postulated accident conditions. Requiring compliance with GDC 27 for the CRDS augments the protection provided for the primary fission product barrier by providing one means to ensure that the core will be maintained in a coolable geometry under postulated accident conditions.

6. GDC 29 establishes requirements regarding the capability of the CRDS to accomplish its safety functions in the event of anticipated operational occurrences. In order to provide protection for the fuel rods and cladding, which is the primary barrier to the release of fission products, the CRDS must have a high probability of accomplishing its safety function during anticipated operational occurrences. Application of this requirement augments plant protection and safety by requiring a highly reliable fast-acting control rod drive mechanism capable of operation during anticipated operational occurrences.

7. The specified codes and standards establish requirements for construction of the applicable portions of the CRDS. The individual components of the CRDS must be designed, fabricated, installed, and tested to quality standards commensurate with the importance of the safety function to be performed by that component. The individual codes and standards each provide a set of applicable limits that the design must meet in order to ensure that the applicable component can carry out its designated safety function.

III. <u>REVIEW PROCEDURES</u>

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. The objectives of the review are to determine that design, fabrication, and construction of the CRDM provide structural adequacy and that suitable life cycle testing programs have been utilized to prove operability under service conditions.

   In the construction permit (CP) review, it should be determined that the design criteria utilize proper load combinations, stress and deformation limits, and that operability assurance is provided by reference to a previously accepted testing program, or a commitment is made to perform a testing program that includes the essential elements listed below. In the operating license (OL) review, the results of any testing program not previously reviewed should be evaluated.

2. The design criteria presented should be evaluated for the internal pressure-containing portions and other portions of the CRDS, including the CRDM housing, the hydraulic control unit, the condensate supply system and scram discharge volume, and portions such as the cylinder, tube, piston, and collet assembly.

   Of particular interest are any new and unique features that have not been used in the past. Pressure-containing components are checked to ensure that they meet the design requirements of the codes and criteria that have been accepted and are identified in SRP Section 3.2.2. The review of the functional design of reactivity control systems, including CRDS, is performed as part of the review of SRP Section 4.6. The loading combinations for the various plant operating conditions are reviewed as part of the review of SRP Section 3.9.3; given these loading combinations, the stress limits of the appropriate code should not be exceeded, or the limits in SRP Section 3.9.3 should not be exceeded if limits are not specified in the listed design code.

   For BWR CRDS that include a scram discharge volume system, the reviewer verifies that the system piping design meets or exceeds the acceptable owner's group classifications and criteria discussed in the enclosure to Generic Letter 86-01 to ensure that breaks and through wall cracks in the piping need not be postulated. The reviewer also verifies that acceptable commitments are made regarding associated inspections, periodic visual verification of the scram system piping integrity, and actions in response to detected leakage to adequately address prevention and mitigation of the effects of leakage associated with potential failures of this piping.

For BWR CRDS that include a control rod drive return line, the reviewer verifies acceptable commitments for the return line design and its implementation in accordance with Generic Letter 80-95 and Part II, Section 8 of NUREG-0619.

The choice of structural materials of construction for the CRDS is reviewed in SRP Section 4.5.1.

3. Loading combinations are defined as those loadings associated with plant operations that are expected to occur one or more times during the lifetime of the plant and include, but are not limited to, loss of power to all recirculation pumps, tripping of the turbine generator set, isolation of the main condenser, and loss of all offsite power, combined with loadings caused by natural or accident events including water hammer loads for BWRs. The load combinations that are postulated to occur are specified for each of the design and service conditions as defined in Paragraph NB-3113 of the ASME Code. These load combinations are defined in SRP Section 3.9.3 and are part of the review.

   The design stress limits, including fatigue limits and deformation limits appropriate to the components of the CRDM, are compared to the limits of specified codes, previously designed and successfully operating systems, or the results of scale model and prototype testing programs.

4. The CRDM of a new design or configuration should be subjected to a life cycle test program to determine the ability of the drive components to function during and after normal operation, anticipated operational occurrences, seismic events, and postulated accident conditions over the full range of temperatures, pressures, loadings, and misalignment expected in service. The tests should include functional tests to determine insertion and withdrawal times, latching operation, scram operation and time, system valve operation and scram accumulator leakage for hydraulic CRDS, ability to overcome a stuck rod condition, and wear. Rod travel and number of operational trips and test trips expected during the mechanism operational life should be duplicated in the tests.

   The reviewer checks the elements of the test program to be sure all required parameters have been included, and finally reviews the test results to determine acceptability. Excessive wear, malfunction of components, operating times beyond determined limits, scram accumulator leakage, etc.; all would be cause for retesting.

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).

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 applicant has met the requirement of GDC 1 and 10 CFR 50.55a, with respect to designing components important to safety to quality standards commensurate with the importance of the safety functions to be performed. The design procedures and criteria used for the control rod drive system are in conformance with the requirements of appropriate ANSI and ASME Codes.

2. The applicant has met the requirements of GDC 2, 14, and 26 with respect to designing the control rod drive system to withstand effects of earthquakes and conditions of normal operation, including anticipated operational occurrences, with adequate margins to assure the system’s reactivity control function and with extremely low probability of leakage or gross rupture of the reactor coolant pressure boundary. The specified design transients, design and service loadings, combination of loads, and resulting stresses and deformations under such loading combinations are reviewed within SRP Section 3.9.3.

3. The applicant has met the requirements of GDC 27 and 29 with respect to designing the CRDS to assure its capability of controlling reactivity and cooling the reactor core with appropriate margin in conjunction with either the emergency core cooling system or the reactor protection system. The operability assurance program is acceptable with respect to meeting system design requirements in observed performance as to wear, functioning times, latching, and overcoming a stuck rod.

Accordingly, the staff concludes that the design of the CRDS is acceptable and meets the requirements of General Design Criteria 1, 2, 14, 26, 27, and 29, and 10 CFR 50.55a.

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

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

V. IMPLEMENTATION

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

The provisions of this SRP section apply to reviews of applications submitted six months or more after the date of issuance of this SRP section, unless superseded by a later revision

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 2, "Design Bases for Protection Against Natural Phenomena."

4. 10 CFR Part 50, Appendix A, General Design Criterion 14, "Reactor Coolant Pressure Boundary."

5. 10 CFR Part 50, Appendix A, General Design Criterion 26, "Reactivity Control System Redundancy and Capability."

6. 10 CFR Part 50, Appendix A, General Design Criterion 27, "Combined Reactivity Control Systems Capability."

7. 10 CFR Part 50, Appendix A, General Design Criterion 29, "Protection Against Anticipated Operational Occurrences."

8. Regulatory Guide 1.26, "Quality Group Classifications and Standards for Water-, Steam-, and Radioactive-Waste-Containing Components of Nuclear Power Plants."

9. Regulatory Guide 1.29, "Seismic Design Classification."

10 NUREG-0619, "BWR Feedwater Nozzle and Control Rod Drive Return Line Nozzle Cracking," November 1980.

11. NRC Letter to BWR Applicants and Licensees, "Final Edition of NUREG-0619, 'BWR Feedwater Nozzle and Control Rod Drive Return Line Nozzle Cracking' (Generic Letter No. 80-95)," November 13, 1980.

12. NRC Letter to BWR Applicants and Licensees, "Safety Concerns Associated with Pipe Breaks in the BWR Scram System (Generic Letter No. 86-01)," January 3, 1986.

13. ASME Boiler and Pressure Vessel Code, Section III, “Nuclear Power Plant Components,” and Section VIII, Division 1, “Pressure Vessels,” American Society of Mechanical Engineers.

14. ANSI B 16.5, “Steel Pipe Flanges and Flanged Fittings,” American National Standard Institute.

15. ANSI B 16.9, “Wrought Steel Butt Welding Fittings,” American National Standard Institute.

16. ANSI B 16.11, “Forged Steel Fittings, Socket-Welding and Threaded ,” American National Standard Institute.

17. ANSI B 16.25, “Butt Welding Ends - Pipe, Valves, Flanges, and Fittings,” American National Standard Institute.

18. ANSI B 16.34, ”Steel Valves with Flanged and Butt Welding Ends,” American Society of Mechanical Engineers.

19. ANSI B 31.1, “Power Piping,” American National Standard Institute.

20. MSS-SP-25, “Marking for Valves, Fittings, Flanges, and Unions,” Manufacturers Standardization Society.