U.S. NUCLEAR REGULATORY COMMISSION

STANDARD REVIEW PLAN

6.2.2 CONTAINMENT HEAT REMOVAL SYSTEMS

REVIEW RESPONSIBILITIES

Primary - Organization responsible for the review of containment integrity

Secondary - None

I. AREAS OF REVIEW

The review includes the information in the application concerning containment heat removal under postaccident conditions to ensure conformance with the requirements of General Design Criteria (GDC) 38, 39, and 40 of Appendix A to 10 CFR Part 50 and 10 CFR 50.46(b)(5). The types of systems provided to remove heat from the containment include fan cooler systems, spray systems, and residual heat removal (RHR) systems. These systems remove heat from the containment atmosphere and the containment sump water for pressurized-water reactors (PWRs) or the water in the containment wetwell for boiling-water reactors (BWRs).

The specific areas of review are as follows:

1. Analyses of the consequences of single component malfunctions.

2. Analyses of the available net positive suction head (NPSH) to the emergency core cooling system (ECCS) and containment heat removal system pumps.

3. Analyses of the heat removal capability of the spray water system.

4. Analyses of the heat removal capability of RHR and fan cooler heat exchangers.

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5. The potential for surface fouling and flow blockage of fan cooler, recirculation, and RHR heat exchangers and the effect on heat exchanger performance.

6. The design provisions and proposed program for periodic inservice inspection and operability testing of each system or component.

7. The design of sumps and water sources for emergency core cooling and containment spray systems (CSSs).

8. The effects of accident-generated debris, including an assessment for potential loss of long-term cooling capability resulting from loss-of-coolant accident (LOCA)-generated and latent debris. Potential effects include debris screen blockage, failure of pump seals and other downstream components, and debris fouling of nuclear fuel.

   As of the publication date of this SRP section, the staff is working to close out Generic Safety Issue-191, which relates to debris-induced PWR sump clogging. Additional guidance for review of information in applications regarding performance of ECCS strainers and downstream components, such as pumps, valves, and nuclear fuel, may be developed in the future. Until such time and in the absence of a separate SRP section on effects of debris, this SRP section addresses these subjects based on information currently available.

9. 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. Review of the secondary cooling systems that provide cooling water to the heat exchangers in the containment heat removal systems is performed under SRP Sections 9.2.2 and 9.2.3.

2. Review of the sensing and actuation instrumentation provided for the containment heat removal systems is performed under SRP Section 7.3.

3. Review of the qualification test program for the active components of the fan cooler system and the sensing and actuation instrumentation for the containment heat removal system is performed under SRP Section 3.11.

4. Evaluation of the quantity of unqualified paint that can potentially reach the emergency sump(s) under a design-basis pipe break accident is performed under SRP Section 6.1.2.

5. Review of fission product control features of containment heat removal systems is performed under SRP Section 6.5.2.

6. Review of the system seismic design and quality group classification of the containment heat removal systems is performed under SRP Sections 3.2.1 and 3.2.2.

7. Review of the proposed technical specifications for each system at the operating license stage of review is performed under SRP Section 16.0.

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 38 as it relates to the following:

   A. The ability of the containment heat removal system to rapidly reduce the containment pressure and temperature following a LOCA and to maintain these indicators at acceptably low levels.

   B. The ability of the containment heat removal system to perform in a manner consistent with the function of other systems.

   C. The safety-grade design of the containment heat removal system (i.e., suitable redundancy in components and features and suitable interconnections, leak detection, isolation, and containment capabilities shall be provided to ensure that for onsite electric power system operation (assuming offsite power is not available) and for offsite electric power system operation (assuming onsite power is not available) the system safety function can be accomplished in the event of a single failure).

2. GDC 39, as it relates to the design of the containment heat removal system to permit periodic inspection of components.

3. GDC 40, as it relates to the design of the containment heat removal system to allow periodic testing to ensure system integrity and the operability of the system and active components.

4. 10 CFR 50.46(b)(5), as it relates to requirements for long-term cooling, including adequate NPSH margin in the presence of LOCA-generated and latent debris.

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 containment heat removal systems should meet the redundancy and power source requirements for an engineered safety feature (i.e., the results of failure modes and effects analyses of each system should ensure that the system is capable of withstanding a single failure without loss of function). This conforms to the requirements of GDC 38.

2. With regard to GDC 38 as it relates to the capability of the containment system to accomplish its safety function, the spray system should be designed to accomplish this without pump damage caused by cavitation. A supporting analysis should be presented in sufficient detail to permit the staff to determine the adequacy of the analysis. This analysis should also demonstrate that the available NPSH is greater than or equal to the required NPSH. Regulatory Guide 1.82, Revision 3 (Ref. 1), describes methods acceptable to the staff for evaluating the NPSH margin. If containment accident pressure is credited in determining available NPSH, an evaluation of the contribution to plant risk from inadequate containment pressure should be made. One acceptable way of making this evaluation is to address the five key principles of risk-informed decisionmaking stated in Section 2 of Regulatory Guide 1.174 (Ref. 2).

3. In evaluating the performance capability of the CSS to satisfy GDC 38, the analyses of its heat removal capability should be based on the following considerations:

   A. The locations of the spray headers relative to the internal structures.

   B. The arrangement of the spray nozzles on the spray headers and the expected spray pattern. The spray systems should be designed to ensure that the spray header and nozzle arrangements produce spray patterns which maximize the containment volume covered and minimize the overlapping of the sprays.

   C. The spray drop size spectrum and mean drop size emitted from each type of nozzle as a function of differential pressure across the nozzle.

   D. The effect of drop residence time and drop size on the heat removal effectiveness of the spray droplets.

4. In evaluating the performance capability of the fan cooler system to satisfy GDC 38, the design heat removal capability (i.e., heat removal rate versus containment temperature) of the fan coolers should be established on the basis of qualification tests on production units or acceptable analyses that take into account the expected postaccident environmental conditions and variations in major operating parameters, such as the containment atmosphere steam-air ratio, condensation on finned surfaces, and cooling water temperature and flow rate. The equipment housing and ducting associated with the fan cooler system should be analyzed to determine that the design is adequate to withstand the effects of containment pressure following a LOCA. Fan cooler system designs that contain components that do not have a postaccident safety function should be designed so that failure of nonsafety-related equipment will not prevent the fan cooler system from accomplishing its safety function.

5. In evaluating the heat removal capability of the containment heat removal system to satisfy GDC 38, the potential for surface fouling of the secondary sides of fan cooler, recirculation, and RHR heat exchangers by the cooling water over the life of the plant and the effect of surface fouling on the heat removal capacity of the heat exchangers. The application should discuss the results of the analysis. The results will be acceptable if they demonstrate that provisions such as closed cooling water systems are provided

to prevent surface fouling or that surface fouling has been taken into account in the establishment of the heat removal capability of the heat exchangers.

6. To satisfy the requirements of GDC 38 and 10 CFR 50.46(b)(5) regarding the long-term spray system(s) and ECCS(s), the containment emergency sump(s) in PWRs and suppression pools in BWRs should be designed to provide a reliable, long-term water source for ECCS and CSS pumps. The containment design should allow for the drainage of spray and emergency core cooling water to the emergency sump(s) or suppression pool and for recirculation of this water through the containment sprays and ECCSs. The design of the sumps or suppression pools and the protective strainer assemblies is a critical element in ensuring long-term recirculation cooling capability. Therefore, adequate design consideration of (1) sump and suppression pool hydraulic performance, (2) evaluation of potential debris generation and associated effects including debris screen blockage, (3) RHR and CSS pump performance under postulated post-LOCA conditions, and (4) impacts of debris penetrating strainers on long-term coolability of the core is necessary. Regulatory Guide 1.82, Revision 3, as modified and supplemented for PWRs by the Nuclear Energy Institute (NEI) Guidance Report (GR) (Ref. 3) and the NRC safety evaluation (SE) (Ref. 4), provide guidance for PWR debris evaluations. Regulatory Guide 1.82, Revision 3, as supplemented by the NRC-approved Boiling Water Reactor Owners' Group (BWROG) Utility Resolution Guidance (URG) (Ref. 5), provide guidance for BWR debris evaluations.

7. In meeting the requirements of GDC 39 and 40 regarding inspection and testing, the design of the containment heat removal systems should provide for periodic inspection and operability testing of the systems and system components such as pumps, valves, duct pressure-relieving devices, and spray nozzles.

8. To satisfy the system design requirements of GDC 38, instrumentation should be provided to monitor the performance of the containment heat removal system and its components under normal and accident conditions. The instrumentation should determine whether a system is performing its intended function or whether a system train or component is malfunctioning and should be isolated.

This SRP section references separate guidance for PWR and BWR plants based on the design features of currently operating reactors. Advanced PWR or BWR designs may employ design features that existing NRC guidance associates with the opposite reactor design (e.g., an advanced PWR design that employs an in-containment refueling water storage tank that is similar to the suppression pool of a current BWR design or an advanced BWR design that employs a large dry containment that is similar to a current PWR design). Therefore, for advanced PWR and BWR designs, the guidance provided for both PWRs and BWRs that is appropriate and consistent with the plant's design features should be considered.

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. Compliance with GDC 38 requires that systems be provided to remove heat from the reactor containment. The system safety function is to rapidly reduce containment pressure and temperature after any LOCA and to maintain these indicators at acceptably low levels.

   This SRP section describes staff positions related to the design of containment heat removal systems. Requirements related to spray systems, heat removal systems,

cooling water sources, and cooling water recirculation are discussed. Regulatory Guide 1.82, Revision 3, provides guidance concerning sources of water that can be used for long-term recirculation cooling following a LOCA.

Meeting the requirements of GDC 38 regarding the characteristics and designs of containment heat removal systems provides assurance that containment pressure and temperature will be reduced to and maintained at acceptably low levels after any LOCA, thereby protecting the safety function of the containment as an engineered safety feature.

2. Compliance with GDC 39 requires that the designs of containment heat removal systems allow for appropriate periodic inspection of important components, such as the torus, sumps, spray nozzles, and piping, to ensure the integrity and capability of these systems.

   This SRP section describes staff positions related to the inspection of containment heat removal systems, indicating that provisions should be made for periodic inspection of system components.

   Meeting the requirements of GDC 39 with regard to periodic inspection of containment heat removal systems provides assurance that containment pressure and temperature will be reduced to and maintained at acceptably low levels after any LOCA, thereby protecting the safety function of the containment as an engineered safety feature.

3. Compliance with GDC 40 requires that the design of containment heat removal systems permits periodic pressure and functional testing to ensure leaktight integrity, operability, and performance of active components, as well as overall system operability.

   This SRP section describes staff positions related to the testing of containment heat removal systems, indicating that provisions should be made for startup and periodic operability testing of these systems and their components.

   Meeting the requirements of GDC 40 with regard to testing of containment heat removal systems provides assurance that containment pressure and temperature are reduced to and maintained at acceptably low levels after any LOCA, thereby protecting the safety function of the containment as an engineered safety feature.

4. Compliance with 10 CFR 50.46(b)(5) requires that systems be provided to ensure long-term cooling after any initial operation of the ECCS. The system safety function is to maintain the core temperature at acceptably low levels after any LOCA.

   This SRP section describes staff positions and is intended to ensure that systems are provided to maintain adequate core cooling.

   Meeting the requirements of 10 CFR 50.46(b)(5) with regard to long-term cooling provides assurance that core temperature will be maintained at acceptably low levels after any LOCA.

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.

The procedures described below provide guidance for the review of containment heat removal systems. The reviewer selects and emphasizes material from the review procedures as may be appropriate for a particular case. Portions of the review may be done on a generic basis for aspects of heat removal systems common to a class of containments or by adopting the results of previous reviews of plants with essentially the same system.

1. Upon request from the primary review organization, the review organizations with review interface responsibilities, as noted in Subsection I, will provide input for the areas of review, as stated in Subsection I of this SRP section. The input obtained will ensure that the review is complete. The primary review organization ensures that the design and functional capability of the containment heat removal system conforms to the requirements of 10 CFR 50.46(b)(5) and GDC 38, 39, and 40.

2. The acceptability of the containment heat removal system design is determined by reviewing the system to ensure the following:

   A. All potential single failures have been identified in accordance with GDC 38, and no single failure could incapacitate the entire system.

   B. Engineered safety feature design standards have been applied.

   C. The system design provisions for periodic inservice inspection and operability testing ensure that the system and components are accessible for inspection and all active components can be tested.

   D. The capability exists to monitor system performance and control active components from the control room so that the operator can exercise control over system functions or isolate a malfunctioning system component.

3. The primary review organization analyzes the containment spray system and ECCS pump NPSH margin and ensures that the analyses for the recirculation phase are done in accordance with the guidelines of Regulatory Guide 1.82, Revision 3.

4. The primary review organization also reviews the evaluation of the volume of the containment covered by the sprays and the extent of overlap with respect to heat removal capabilities. A judgment will be made regarding the acceptability of the spray coverage and extent of overlap; the volume of the containment covered by the sprays should be maximized and the extent of overlap kept to a minimum. Elevation and plan drawings of the containment depicting the spray patterns are used to determine coverage and overlap.

5. In general, the design requirements for the spray systems with respect to spray drop size spectrum and mean drop size, spray drop residence time in the containment atmosphere, containment coverage by the sprays, and extent of overlap of the sprays are more stringent when the acceptability of the system is being considered from an iodine removal capability standpoint rather than from a heat removal capability standpoint. Consequently, when the iodine removal capability of the system is satisfied, the heat removal capability is found acceptable.

A. The primary review organization for SRP Section 6.5.2 will determine the acceptability of the iodine removal effectiveness of the sprays.

B. Since all plants do not use the containment sprays as a fission product removal system, the primary review organization reviews the system for cases in which the system is used only as a heat removal system.

6. The primary review organization analyzes the heat removal capability of the spray system. This capability is a function of the degree of thermal equilibrium attained by the spray water and the volume of the containment covered by the spray water. The spray drop size and residence time in the containment atmosphere determine the degree of thermal equilibrium attained by the spray water. The reviewer confirms the validity of the degree of thermal equilibrium attained using the following information:

   A. An elevation drawing of the containment showing the locations of the spray headers relative to the internal structures, including fall heights.

   B. The results of the spray nozzle test program to determine the spectrum of drop sizes and mean drop size emitted from the nozzles as a function of pressure drop across the nozzles.

   C. Reference 6 contains information regarding the heating of spray drops in air-steam atmospheres which can be used to determine the validity of the degree of thermal equilibrium of the spray water used in the analyses.

7. The primary review organization reviews the adequacy of provisions made to prevent overpressurization of fan cooler ducting following a LOCA. The reviewer will ensure:

   A. The primary review organization reviews the heat removal capability of the fan coolers.

   B. The test programs and calculation models used to determine the performance capability of fan coolers are reviewed for acceptability.

   C. If the secondary side of a fan cooler heat exchanger is not a closed system, the primary review organization reviews the potential for surface fouling and blockage and determines whether surface fouling and blockage impair the heat removal capability of a fan cooler.

8. The primary review organization reviews the system to determine whether it allows drainage of containment spray water and emergency core cooling water to the recirculation suction points (sump or suppression pool).

   A. The primary review organization reviews the design of the protective strainer assemblies around the suction points.

      i. The primary review organization reviews plan and elevation drawings of the protective strainer assemblies which depict the relative positions and orientations of any trash racks or grating and the stages of screening to determine that the potential for debris clogging the screening is minimized.

      ii. The primary review organization also reviews the drawings to determine that redundant suction points do not share the same screened enclosure.

The effectiveness of the protective strainer assembly will be determined by comparing the smallest mesh size of screening provided to the clogging potential of pumps, heat exchangers, valves, and spray nozzles.

iii. The application should discuss, and the drawings should identify, the methods of attachment of any trash racks or grating and the screening to the protective strainer assembly structure.

iv. The application should discuss the adequacy of the surface area of screening with respect to ensuring a low velocity of approach of the water to minimize the potential for debris in the water being sucked against the screening.

v. For plants that do not have both trash racks and strainers, the staff review is intended to ensure that the strainer is functionally equivalent to trash racks and screens.

B. Regulatory Guide 1.82 Revision 3, provides guidelines for the acceptability of the design of PWR sump screens and BWR ECCS suction strainers. Additional guidance is found the BWROG URG (Ref. 5), the NEI GR (Ref. 3) and the NRC SE of the NEI GR (Ref. 4).

9. The primary review organization reviews performance evaluations for equipment (other than pumps) downstream of the strainers with regard to debris ingestion. Evaluations of core cooling in the presence of predicted debris loading are also reviewed.

10. 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).

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. Containment Heat Removal Systems

The containment heat removal systems include (identify the systems; these may include systems such as the RHR system in specified modes, ECCS, fan cooler systems, spray systems, containment sumps, and wetwells).

The scope of review of the containment heat removal systems for the (plant name) included system drawings and descriptive information. The review included the applicant's proposed design bases for the containment heat removal systems and analyses of the functional capability of the systems.

The staff concludes that the design of the containment heat removal system is acceptable and meets the requirements of 10 CFR 50.46(b)(5) and GDC 38, 39, and 40.

The conclusion is based on the following:

A. The staff's review indicates that the applicant complied with GDC 38 by providing containment heat removal systems consisting of (list systems). The applicant designed the containment heat removal systems according to the guidance provided in Regulatory Guide 1.82, Revision 3, as well as the additional guidance in (list appropriate). The staff's review indicates that the systems will be capable of performing their intended safety function, which is to rapidly reduce containment pressure and temperature and to maintain these indicators at acceptably low levels after any LOCA. Suitable redundancy in components and features and suitable interconnections, leak detection, isolation, and containment capabilities shall be provided to ensure that for onsite electric power system operation (assuming offsite power is not available) and for offsite electric power system operation (assuming onsite power is not available) the system safety function can be accomplished in the event of a single failure.

B. The staff's review indicates that the applicant complied with GDC 39 by designing the containment heat removal systems to permit appropriate periodic inspection of important components of the systems such as the torus, sumps, spray nozzles, and piping. (Other or additional examples may be appropriate.)

C. The staff's review indicates that the applicant complied with GDC 40 by designing the containment heat removal systems to permit appropriate periodic pressure and functional testing to ensure the structural and leaktight integrity of their components; the operability and performance of the active components of the systems such as fans, filters, dampers, pumps, and valves; and the operability of the systems as a whole. Testing will be conducted to ensure the performance of the full operational sequence that brings the systems into operation under conditions as close to design as practical, including operation of applicable portions of the protection system, the transfer between normal and emergency power sources, and the operation of associated systems.

D. The staff's review indicates that the applicant has demonstrated adequate long-term core cooling in accordance with 10 CFR 50.46(b)(5) in the presence of post-LOCA debris.

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.

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.

Implementation schedules for conformance to parts of the method discussed herein are contained in the referenced regulatory guides.

VI. REFERENCES

1. Regulatory Guide 1.82, Rev. 3, "Water Sources for Long Term Recirculation Cooling Following a Loss of Coolant Accident," November 30, 2003.

2. Regulatory Guide 1.174, Rev. 1, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant Specific Changes to the Licensing Basis," U.S. Nuclear Regulatory Commission, November 2002.

3. Guidance Report by the Nuclear Energy Institute, "Pressurized Water Reactor Sump Performance Evaluation Methodology," including Appendices A and B, NEI 04-07, May 28, 2004.

4. NRC Safety Evaluation of NEI GR, "Pressurized Water Reactor Containment Sump Evaluation Methodology, "December 6, 2004.

5. Safety Evaluation by the Office of Nuclear Reactor Regulation Related to NRC Bulletin 96-03, Boiling Water Reactor Owners Group Topical Report NEDO-32686-A, "Utility Resolution Guidance for ECCS Suction Strainer Blockage," August 20, 1998.

6. L.F. Parsly, "Design Considerations of Reactor Containment Spray Systems—Part VI, The Heating of Spray Drops in Air-Steam Atmospheres," ORNL-TM-2412, Oak Ridge National Laboratory, January 1970.