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U.S. NUCLEAR REGULATORY COMMISSION

# STANDARD REVIEW PLAN

OFFICE OF NUCLEAR REACTOR REGULATION

## 6.2.2 CONTAINMENT HEAT REMOVAL SYSTEMS

REVIEW RESPONSIBILITIES

Primary - Probabilistic Safety Assessment Branch (SPSB)

Secondary - None

## I. AREAS OF REVIEW

SPSB reviews the information in the applicant's safety analysis report (SAR) concerning containment heat removal under post-accident conditions to ensure conformance with the requirements of General Design Criteria 38, 39, and 40. The types of systems provided to remove heat from the containment include fan cooler systems, spray systems, and residual heat removal systems. These systems remove heat from the containment atmosphere and the containment sump water, or the water in the containment wetwell. The SPSB review includes the following analyses and aspects of containment heat removal system designs:

1. Analyses of the consequences of single component malfunctions.
2. Analyses of the available net positive suction head (NPSH) to the 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 fan cooler heat exchangers.
5. The potential for surface fouling of fan cooler, recirculation, and residual heat removal heat exchangers, and the effect on heat exchanger performance.





ATTACHMENT 3

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, including an assessment for potential loss of long-term cooling capability due to loss-of-coolant accident (LOCA) generated debris effects such as debris screen blockage and pump seal failure.

8. The effects of debris such as thermal insulation on recirculating fluid systems.

Review Interfaces

SPSB will coordinate other branch evaluations that interface with the overall review of the containment heat removal systems as follows:

A. The primary review organization for Standard Review Plan (SRP) 9.2.2 will review the secondary cooling systems, which provide cooling water to the heat exchangers in the containment heat removal systems, as part of its primary review responsibility for Standard Review Plan (SRP) Section 9.2.2.

B. The primary review organization for SRP 7.3 will review the sensing and actuation instrumentation provided for the containment heat removal systems as part of its primary review responsibility for SRP Section 7.3.

C. The primary review organization for SRP 3.11 will review 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 as part of its primary review responsibility for SRP Section 3.11.

D. The primary review organization for SRP 6.1.2 will evaluate the quantity of unqualified paint that can potentially reach the emergency sump(s) under design basis pipe break accident review responsibility for SRP Section 6.1.2.

E. The primary review organization for SRP 6.5.2 will review fission product control features of containment heat removal systems as part of its primary review responsibility for SRP Section 6.5.2.

F. The primary review organization for SRP Sections 3.2.1 and 3.2.2 will review the system seismic design and quality group classification as part of its primary review responsibility for SRP Section 3.2.1 and SRP Section 3.2.2, respectively.

G. The primary review organization for SRP 16.10 will review the proposed technical specifications for each system at the operating license stage of review as part of the primary review responsibility for SRP Section 16.0.

For those areas of review identified above as part of the primary review responsibility of other branches, the acceptance criteria and methods of application are contained in the referenced SRP section.

## II. ACCEPTANCE CRITERIA

The SPSB acceptance criteria for the design of the containment heat removal system are based on meeting the relevant requirements of General Design Criteria 38, 39, and 40. The relevant requirements and guidelines are as indicated below.

A. General Design Criterion 38 (GDC 38) as it relates to:

   a. Containment heat removal system being capable of reducing rapidly the containment pressure and temperature following a LOCA, and maintaining them at acceptably low levels.

   b. The containment heat removal system performance being consistent with the function of other systems.

   c. The containment heat removal system being safety-grade design; 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, assuming a single failure.

B. General Design Criterion 39 (GDC 39), as it relates to the containment heat removal system being designed to permit periodic inspection of components.

C. General Design Criterion 40 (GDC 40), as it relates to the containment heat removal system being designed to permit periodic testing to ensure system integrity, and the operability of the system, and active components.

Specific acceptance criteria necessary to meet the relevant requirements of General Design Criteria 38, 39, and 40 are as follows:

1. The containment heat removal systems should meet the redundancy and power source requirements for an engineered safety feature; i.e., the systems should be designed to accommodate a single active failure. 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 is in conformance with 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 cavitation occurring. Therefore, the net positive suction head available to the pumps in both the injection and recirculation phases of operation should be greater than the required NPSH. A supporting analysis should be presented in sufficient detail to permit the staff to determine the adequacy of the analysis and should show that the available NPSH is greater than the required NPSH. Regulatory Guide 1.82 (Reference 1) describes methods acceptable to the staff for evaluating the NPSH margin.

3. In evaluating the performance capability of the containment spray system, to satisfy GDC 38, 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.

c. The type of spray nozzles used and the nozzle atomizing capability, i.e., 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.

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.

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 vs. containment temperature) of fan coolers should be established on the basis of qualification tests on production units or acceptable analyses that take into account the expected post-accident 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 loss-of-coolant accident (see SRP Section 6.2.5). Fan cooler system designs that contain components which do not have a post-accident safety function should be designed such that a 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 residual heat removal 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 should be analyzed and the results discussed in the SAR. The analysis will be acceptable if it is shown that provisions such as closed cooling water systems are provided to prevent surface fouling or surface fouling has been accounted for in establishing the heat removal capability of the heat exchangers.

6. To satisfy the requirement of GDC 38 regarding the long-term spray system(s) and emergency core cooling system(s), the containment emergency sump(s) should be designed to provide a reliable, long-term water source for the emergency core cooling system (ECCS) and containment spray system (CSS) recirculation pumps. Provision should be made in the containment design to allow drainage of spray and emergency core cooling water to the emergency sump(s), and for recirculation of this water through the containment sprays and emergency core cooling systems. The design of the sumps, and the protective screen assemblies is a critical element in ensuring long-term recirculation cooling capability. Therefore, adequate design consideration of (a) sump hydraulic performance, (b) evaluation of potential debris generation and associated effects including debris screen blockage, and (c) residual heat removal (RHR) and CSS pump performance under postulated post-LOCA conditions, is necessary. These design considerations are addressed in Regulatory Guide 1.82 Revision 4 (Reference 1).

7. In meeting the requirements of General Design Criteria 39 and 40 regarding inspection and testing, provisions should be made in the design of containment heat removal systems 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 containment heat removal system and system component performance under normal and accident conditions. The instrumentation should be

capable of determining whether a system is performing its intended function, or a system train or component is malfunctioning and should be isolated.

Technical Rationale

The technical rationale for application of these acceptance criteria to reviewing the containment heat removal systems is discussed in the following paragraphs:

(a) Compliance with GDC 38 requires that systems be provided to remove heat from the reactor containment. The system safety function is to reduce containment pressure and temperature rapidly after any LOCA and to maintain them 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 4 provides guidance for "Water Sources For Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident."

Meeting the requirements of GDC 38 regarding the characteristics of containment heat removal systems and their design ensures 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.

(b) Compliance with GDC 39 requires that containment heat removal systems be designed to permit appropriate periodic inspection of important components such as the torus, sumps, spray nozzles, and piping to ensure the integrity and capability of these systems.

Meeting the requirements of GDC 39 with regard to periodic inspection of containment heat removal systems ensures 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.

(c) Compliance with GDC 40 requires that containment heat removal systems be designed to permit periodic pressure and functional testing to ensure leaktight integrity, operability, and performance of active components, as well as overall system operability.

Meeting the requirements of GDC 40 with regard to testing of containment heat removal systems ensures 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.

## III. REVIEW PROCEDURES

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 SPSB, the review branches with review interface responsibilities, as noted in subsection I, will provide input for the areas of review stated in subsection I of this SRP section. SPSB obtains and uses such input as required to ensure that this review procedure is complete. SPSB ensures that the design and functional capability of the containment heat removal system conform to the requirements of General Design Criteria 38, 39, and 40.

2. SPSB determines the acceptability of a containment heat removal system design by reviewing failure modes and effects analyses of the system to ensure that:

   a. All potential single failures have been identified 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; and

   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. SPSB reviews analyses of the net positive suction head available to the spray system pumps. SPSB ensures that the analyses for the recirculation phase are done in accordance with the guidelines of Regulatory Guide 1.82 Revision 4.

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

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 overlapping 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 will be found acceptable.

   a. The primary review organization responsible for SRP Section 6.5.2 is responsible for determining 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, SPSB reviews the system for cases where the system is used only as a heat removal system.

6. SPSB reviews analyses of 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. SPSB 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; and

c. Reference 2, "Design Considerations of Reactor Containment Spray Systems - Part VI, The Heating of Spray Drops In Air-Steam Atmospheres," 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. SPSB reviews the adequacy of provisions made to prevent over-pressurization of fan cooler ducting following a loss-of-coolant accident (Standard Review Plan Section 6.2.5).

    a. SPSB 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, SPSB reviews the potential for surface fouling. SPSB determines whether or not surface fouling impairs the heat removal capability of a fan cooler.

8. SPSB reviews the system provided to allow drainage of containment spray water and emergency core cooling water to the recirculation suction points (sumps).

    a. SPSB reviews the design of the protective screen assemblies around the suction points.

        i. SPSB reviews plan and elevation drawings of the protective screen assemblies, showing the relative positions and orientations of the trash bars or grating and the stages of screening, to determine that the potential for debris clogging the screening is minimized.

        ii. SPSB also reviews the drawings to determine that suction points do not share the same screened enclosure. The effectiveness of the protective screen 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 methods of attachment of the trash bars or grating and the screening to the protective screen assembly structure should be discussed in the SAR and shown on drawings.

        iv. A discussion of 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 should be presented.

        v. For new applicants, the size of the suction inlet screen area (PWR) and suction strainers (BWR) should be determined to be consistent with Regulatory Guide 1.82 Revision 4.

    b. Regulatory Guide 1.82 Revision 4 provides guidelines for the acceptability PWR sump designs and BWR RHR suction inlet designs.

For standard design certification reviews under 10 CFR Part 52, the procedures above should be followed, as modified by the procedures in SRP Section 14.3

(draft), to verify that the design set forth in the standard safety analysis report, including inspections, tests, analysis, and acceptance criteria (ITAAC), site interface requirements and combined license action items, meet the acceptance criteria given in subsection II. SRP Section 14.3 (draft) contains procedures for the review of certified design material (CDM) for the standard design, including the site parameters, interface criteria, and ITAAC.

## IV. EVALUATION FINDINGS

The reviewer verifies that sufficient information has been provided and that the evaluation supports conclusions of the following type, to be included in the staff's safety evaluation report (SER):

6.2.2 Containment Heat Removal Systems

The containment heat removal systems include (identify the systems; these may include systems such as the residual heat removal system in specified modes, emergency core cooling system, fan cooler systems, spray systems, containment sumps, wetwells, etc.).

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 systems is acceptable and meets the requirements of General Design Criteria 38, 39 and 40 and the guidelines of SRP 19.0 if credit is taken for containment accident pressure in determining the available NPSH of the ECCS and containment heat removal pumps.

The conclusion is based on the following:

1. The staff's review indicates that the applicant complied with General Design Criterion 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 4. The staff's review indicates that the systems will be capable of performing their intended safety function, which is to reduce containment pressure and temperature rapidly and to maintain them at acceptably low levels after any loss-of-coolant accident (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, assuming a single failure.

2. The staff's review indicates that the applicant complied with General Design Criterion 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.)

3. The staff's review indicates that the applicant complied with General Design Criterion 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.

For design certification reviews, the findings will also summarize, to the extent that the review is not discussed in other safety evaluation report sections, the staff's evaluation of inspections, tests, analyses, and acceptance criteria (ITAAC), including design acceptance criteria (DAC), site interface requirements, and combined license action items that are relevant to this SRP section.

## V. IMPLEMENTATION

The following is intended to provide guidance to applicants and licensees regarding the NRC staff's plan for using this SRP section.

This SRP section will be used by the staff when performing safety evaluations of license applications submitted by applicants pursuant to 10 CFR 50 or 10 CFR 52. Except in those cases in which the applicant proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the method described herein will be used by the staff in its evaluation of conformance with Commission regulations.

The provisions of this SRP section apply to reviews of applications docketed six months or more after the date of issuance of this SRP section.

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. 4, "Water Sources for Long Term Recirculation Cooling Following a Loss-of-Coolant Accident." To be issued for public comment.

2. 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.