NUREG-0800
(Formerly NUREG-75/087)

U.S. NUCLEAR REGULATORY COMMISSION

STANDARD REVIEW PLAN

OFFICE OF NUCLEAR REACTOR REGULATION

6.2.2 CONTAINMENT HEAT REMOVAL SYSTEMS

REVIEW RESPONSIBILITIES

Primary - Containment Systems Branch (CSB)

Secondary - None

I. AREAS OF REVIEW

The CSB reviews the information in the applicant's safety analysis report (SAR) concerning containment heat removal under post-accident conditions to assure conformance with the requirements of General Design Criteria 38, 39, and 40 (Ref. 1, 2 and 3). 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 CSB 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.

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 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.

The CSB will coordinate other branch evaluations that interface with the overall review of the containment heat removal systems as follows: the Auxiliary Systems Branch (ASB) wll 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 SRP Section 9.2.2. The Instrumentation and Control Systems Branch (ICSB) 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. The Equipment Qualification Branch (EQB) 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. The Chemical Engineering Branch (CMEB) 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. The Accident Evaluation Branch (AEB) will review fission product control features of containment heat removal systems as part of its primary review responsibility for SRP Section 6.5.2. The Mechanical Engineering Branch (MEB) 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. The Licensing Guidance Branch (LGB) 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 being reviewed as part of the primary review responsibility of other branches, the acceptance criteria necessary for the review and their methods of application are contained in the referenced SRP section of the corresponding primary branch.

II. <u>ACCEPTANCE CRITERIA</u>

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

1. General Design Criterion 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., have suitable redundancy of components and features, and interconnections, to assure that for either a loss of onsite as a loss of offsite power, the system function can be accomplished assuming a single failure.

d. Leak detection, isolation and containment capabilities being incorporated in the design of the containment heat removal system.

2. General Design Criterion 39, as it relates to the containment heat removal system being designed to permit periodic inspecton of components.

3. General Design Criterion 40, as it relates to the containment heat removal system being designed to permit periodic testing to assure system integrity, and the operability of the system, and active components.

Specific acceptance criteria necessary to meet the relevant requirement of GDC 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 assure that the system is capable of withstanding a single failure without loss of function. This is conformance with the requirements of General Design Criterion 38.

2. With regard to General Design Criterion 38 as it relates to the capability of 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, Rev. 1 (Ref. 5) describes methods acceptable to the staff for evaluating the NPSH margin.

   In the recirculation phase; i.e., in the long term (after about one hour) following a LOCA, the containment spray system is required to circulate the water in the containment. The NPSH analysis will be acceptable if (1) it is done in accordance to the guidance in Regulatory Guide 1.82, Rev. 1 (Ref. 5) and (2) it is done in accordance with the guidelines of Regulatory Guide 1.1 (Ref. 4), i.e., is based on maximum expected temperature of the pumped fluid and with atmospheric pressure in the containment. For clarification, the analysis should be based on the assumption that the containment pressure equals the vapor pressure of the sump water. This ensures that credit is not taken for containment pressurization during the transient.

   The recirculation spray system for a subatmospheric containment is designed to start about five minutes after a loss-of-coolant accident, i.e., during the injection phase of spray system operation. For subatmospheric containments, the guidelines of Regulatory Guide 1.1 as defined above will apply after the injection phase has terminated, which occurs about one hour after the accident. Prior to termination of the injection phase the NPSH analyses should include conservative predictions of the containment atmosphere pressure and sump water temperature transients.

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 assure 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 ECCS and 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 assuring 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, c) RHR and CSS pump performance under postulated post-LOCA conditions is necessary. These design considerations are addressed in Regulatory Guide 1.82, Rev. 1 (Ref. 5) and NUREG-0897, Rev. 1 (Ref. 7).

7. In meeting the requirements of GDC 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.

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.

Upon request from CSB, the secondary review branches will provide input for the areas of review stated in subsection I of this SRP section. CSB obtains and uses such input as required to assure that this review procedure is complete. CSB assures that the design and functional capability of the containment heat removal system conform to the requirements of General Design Criteria 38, 39 and 40.

CSB determines the acceptability of a containment heat removal system design by reviewing failure modes and effects analyses of the system to be sure that all potential single failures have been identified and no single failure could incapacitate the entire system; verifying that engineered safety feature design standards have been applied; reviewing the system design provisions for periodic inservice inspection and operability testing to ensure that the system and components are accessible for inspection and all active components can be tested; and reviewing the capability 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.

CSB reviews analyses of the net positive suction head available to the spray system pumps. CSB assures that the analyses for the recirculation phase are done in accordance with the guidelines of Regulatory Guide 1.1, i.e., are based on maximum expected temperature of the pumped fluid and with atmospheric pressure in the containment. For clarification, the analyses should be based on the assumption that the containment pressure equals the vapor pressure of the sump water. This ensures that credit is not taken for containment pressurization during the transient. CSB assures that calculations of the available NPSH are based on transient values of the suction head and the friction head. The CSB reviews information provided by the applicant to identify and justify the conservatisms applied in determining the water level in the containment and the friction losses in the recirculation system suction piping. For example, the uncertainty in determining the free volume in the lower part of the containment that may be occupied by water, and the quantity of water that may be trapped by the reactor cavity and the refueling canal, should be factored into the calculation of the suction head.

The CSB reviews analyses of the available NPSH for subatmospheric containments for the period prior to termination of the injection phase of containment spray to determine that containment pressure and sump water temperature transients have been conservatively used in the NPSH calculations. The CSB reviews information provided by the applicant to identify and justify the conservatisms in the analysis of the containment atmosphere pressure and sump water temperature transients. The CSB also reviews the conservatisms used in determining the water level in the containment and the friction losses in the recirculation system piping.

The CSB compares the NPSH requirements for the containment heat removal system pumps to the minimum calculated NPSH available to the pumps to assure that a positive margin is maintained. The CSB also reviews the preoperational test programs, and periodic inservice inspection and test programs, to verify that adequate NPSH is available to the pumps and the continuing operability of the pumps during the lifetime of the plant.

If in the judgment of the CSB, the NPSH analyses were not done in a sufficiently conservative manner, confirmatory analyses are performed using the CONTEMPT-LT computer code.

The CSB 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.

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. The Accident Evaluation Branch is responsible for determining the acceptability of the iodine removal effectiveness of the sprays

(See Standard Review Plan Section 6.5.2). Since all plants do not use the containment sprays as a fission product removal system, the CSB reviews the system for cases where the system is used only as a heat removal system.

CSB 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. The CSB confirms the validity of the degree of thermal equilibrium attained using the following information: an elevation drawing of the containment showing the locations of the spray headers relative to the internal structures, including fall heights, and 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.

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.

CSB reviews the adequacy of provisions made to prevent overpressurization of fan cooler ducting following a loss-of-coolant accident (Standard Review Plan Section 6.2.5). CSB reviews the heat removal capability of the fan coolers. The test programs and calculation models used to determine the performance capability of fan coolers are reviewed for acceptability. If the secondary side of a fan cooler heat exchanger is not a closed system, the CSB reviews the potential for surface fouling. The CSB determines whether or not surface fouling impairs the heat removal capability of a fan cooler.

CSB reviews the system provided to allow drainage of containment spray water and emergency core cooling water to the recirculation suction points (sumps). CSB reviews the design of the protective screen assemblies around the suction points. CSB 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. CSB 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. 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. A discussion of the adequacy of the surface area of screening with respect to assuring 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. Regulatory Guide 1.82, Rev. 1 (Ref. 5) provides guidelines for the acceptability of the design of PWR sumps and BWR RHR suction inlets. NUREG-0897, Rev. 1 (Ref. 7) details technical considerations pertinent to these matters.

IV. EVALUATION FINDINGS

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

6.2.2 Containment Heat Removal Systems

The containment heat removal systems include (identify the systems).

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

The conclusion is based on the following: [The reviewer should discuss each item of the regulations or related set of regulations as indicated.]

1. The applicant has met the requirements of (cite regulation) with respect to (state limits of review in relation to regulation) by (for each item that is applicable to the review state how it was met and why acceptable with respect to the regulation being discussed):

   a. meeting the regulatory positions in Regulatory Guide _____ or Guides;

   b. providing and meeting an alternative method to regulatory positions in Regulatory Guide ____, that the staff has reviewed and found to be acceptable;

   c. meeting the regulatory position in BTP _____;

   d. using calculational methods for (state what was evaluated) that has been previously reviewed by the staff and found acceptable; the staff has reviewed the impact parameters in this case and found them to be suitably conservative or performed independent calculations to verify acceptability of their analysis; and/or

   e. meeting the provisions of (industry standard number and title) that has been reviewed by the staff and determined to be appropriate for this application.

2. Repeat discussion for each regulation cited above.

V. IMPLEMENTATION

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

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.

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

The PWR sump and BWR RHR suction inlet design and evaluation guidance provided in Subsection II.6 of this SRP section, RG 1.82, Rev. 1, and as further detailed in NUREG-0897, Rev. 1B, is applicable to:

1) construction permit applications and preliminary design approvals (PDAs) that are docketed after [2];
2) applications for Final Design Approval (FDA), for standardized designs which are intended for referencing in future construction permit applications that have not received approval at[2].
3) applications for licenses to manufacture that are docketed after [2].

The other portions of SRP Section 6.2.2 remain unchanged and are applicable to all CP and OL plants.

VI. <u>REFERENCES</u>

1. 10 CFR Part 50, Appendix A, General Design Criterion 38, "Containment Heat Removal."

2. 10 CFR Part 50, Appendix A, General Design Criterion 39, "Inspection of Containment Heat Removal System."

3. 10 CFR Part 50, Appendix A, General Design Criterion 40, "Testing of Containment Heat Removal System."

4. Regulatory Guide 1.1, "Net Positive Suction Head for Emergency Core Cooling and Containment Heat Removal System Pumps."

5. Regulatory Guide 1.82, Rev. 1, "Water Sources for Long Term Reicrculation Cooling Following a Loss of Coolant Accident," October 15, 1985.

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.

7. NUREG-0897, Rev. 1, "Containment Emergency Sump Performance - Technical Findings Related to USI A-43," October 1985.

[2] Six (6) months after issuance of this SRP Section (Ref. 4, October 1985) and Regulatory Guide 1.82, Rev. 1.