SECTION 5.4.7 RESIDUAL HEAT REMOVAL (RHR) SYSTEM

REVIEW RESPONSIBILITIES

Primary - Reactor System Branch (RSB)

Secondary - Auxiliary and Power Conversion Systems Branch (APCSB)
Containment Systems Branch (CSB)
Core Performance Branch (CPB)
Electrical, Instrumentation and Control Systems Branch (EICSB)
Materials Engineering Branch (MTEB)
Mechanical Engineering Branch (MEB)

I. AREAS OF REVIEW

The residual heat removal (RHR) system is used in conjunction with the main steam and feedwater systems (main condenser), or the reactor core isolation cooling (RCIC) system in conjuction with the safety/relief valves in a boiling water reactor (BWR), or auxiliary feedwater system in conjuction with the atmospheric dump valves in a pressurized water reactor (PWR) to cool down the reactor coolant system following shutdown. Parts of the RHR system also act to provide low pressure emergency core cooling and are reviewed as described in Standard Review Plan (SRP) 6.3. Some parts of the RHR system also provide containment heat removal capability and are reviewed as described in SRP 6.2.2.

Both PWR's and BWR's have RHR systems which provide long term cooling once the reactor coolant temperature has been decreased by the main condenser, RCIC, or auxiliary feedwater systems. In both types of plants, the RHR is typically a low pressure system which takes over the shutdown cooling function when the reactor coolant system (RCS) temperature is reduced to about 300°F. Although the RHR system function is similar for the two types of plants, the system designs are different.

The RHR system in PWR's is composed of piping, pumps, valves, heat exchangers, monitors, and controls which take water from the RCS hot legs, cool it, and pump it back to the cold legs or core flooding tank nozzles. The suction and discharge lines for the RHR pumps have appropriate valving to assure that the low pressure RHR system is always isolated from the RCS when the reactor coolant pressure is greater than the RHR design pressure. The heat removed in the heat exchangers is transported to the ultimate heat sink by the component cooling water or service water system. In PWR's, the RHR system is also used to fill, drain, and remove heat from the refueling canal during refueling operations; to provide an auxiliary pressurizer spray; and to circulate coolant through the core during plant startup prior to RCS pump operation.

The RHR system in BWR's is typically composed of four subsystems. The containment heat removal and low pressure emergency core cooling subsystems are discussed in SRP 6.2.2 and 6.3. The shutdown cooling and steam condensing (via RCIC) subsystems are covered by this plan. These subsystems make use of the same hardware, consisting of pumps, piping, heat exchangers, valves, monitors, and controls. In the shutdown cooling mode, the BWR RHR system can also be used to supplement spent fuel pool cooling. As in the PWR, the low pressure RHR piping is protected from high RCS pressure by isolation valves.

The steam condensing mode of RCIC operation in BWR's (when included in the plant design) provides an alternative to the main condenser or normal RCIC mode of operation during the initial cooldown. Steam from the reactor is transferred to the RHR heat exchangers where it is condensed. The condensate is piped to the suction side of the RCIC pump. The RCIC pump returns the condensate to the reactor vessel via the feedwater line. The heat removed in the heat exchangers is transported to the ultimate heat sink by the service water system.

Other means of removing decay heat in the event that the RHR system is inoperable have been proposed for some BWR's. These approaches use some of the piping that is used for the steam condensing mode of RCIC. These approaches are also covered by this plan.

The reactor coolant temperatures and pressure must be decreased before the low pressure RHR system can be placed in operation, therefore the review of the decay heat removal function must consider all conditions from shutdown at normal reactor operating pressure and temperature to the cold depressurized condition required for refueling. This effort is divided between the RSB and the APCSB as follows:

1. For BWR's the RSB reviews the transfer of decay heat from the reactor for the entire spectrum of potential reactor coolant system pressures and temperatures during decay heat removal. 2

2. For PWR's the APCSB reviews the transfer of decay heat from the reactor over the range of conditions from normal reactor operating temperature and pressure to the values of these parameters that permit operation of the RHR system. The RSB reviews the decay heat removal function for all lower temperatures and pressures.

3. For both PWR's & BWR's, the APCSB reviews the component cooling or service water systems that transfer decay heat from the RHR system to the ultimate heat sink as described in SRP 9.2.1 and 9.2.2.

4. The RSB reviews the design and operating characteristics of the RHR system with respect to its shutdown and long term cooling function. Where the RHR system interfaces with other systems (e.g., RCIC system, component cooling water system) the effect of these systems on the RHR system is reviewed. Overpressure protection provided by the valving between the RCS and RHR system is also reviewed.

The proposed RHR system preoperational and initial startup test programs are reviewed and the proposed technical specifications are evaluated in regard to limiting conditions of operation and periodic surveillance testing.

The RHR system is reviewed to assure that it has the proper seismic and quality group classifications. This aspect of the review is performed as a portion of the effort described in SRP 3.2.1 and 3.2.2. The RHR system is to be enclosed in a structure having the proper seismic classification. The review is done as a part of the effort described in SRP 3.2.2.

The RHR system is to be housed in a structure that provides adequate protection against wind, tornadoes, floods, and missiles (as appropriate). The review of the adequacy of this enclosure is performed as described in other standard review plans.

The CSB, as described in SRP 6.2.4, reviews the design of the RHR system to see that it is compatible with the function of the containment and that adequate isolation capabilities are provided.

The EICSB, as described in SRP 7.4, reviews motor-operated valve controls, interlocks, sensors for interlocks, position indicators, and power sources. EICSB determines that the interlocks on motor-operated valves used as barriers between the high and low pressure RHR piping are suitable independent and diverse and that trip signals close the valves when the pressure is too high.

The MEB, as described in SRP 3.9.3, reviews the design and installation of the RHR system to see that applicable code requirements are met.

The MTEB reviews the materials and inservice inspection program for the RHR system, as described in SRP 6.1.1 and 6.6.

The CPB reviews the core decay energy output on which the design is based to see that it is applicable and suitably conservative.

The MEB and APCSB review the effects of pipe breaks both in and outside containment on reactor shutdown systems. This review includes the effects of pipe whip, jet impingement forces, and any environmental conditions created. The effect of missiles on the RHR system is also reviewed by these branches.

II. <u>ACCEPTANCE CRITERIA</u>

The general objective of the review is to determine that the system or systems employed to remove residual heat meets the requirements of General Design Criteria (GDC) 34 (Ref. 4) regarding residual heat removal, and GDC 19 (Ref. 16) regarding operability from the control room. As noted in Section I, the overall heat removal function must consider a wide range of potential reactor coolant temperatures and pressures. A portion of this range is reviewed by the APCSB for PWR's. This plan deals specifically with the areas of review performed by the RSB. The acceptance criteria are discussed in the following paragraphs.

The system or systems must be capable of performing the function of transferring heat from the reactor to the environment using only safety grade systems. The system(s) and the system(s) enclosure must be in accordance with GDC 2 (Ref. 1) and GDC 4 (Ref. 2), and should conform to the recommendations of Regulatory Guide 1.29 (Ref. 12), Regulatory Guide 1.46

(Ref. 13), and the staff positions on protection against piping failures outside containment (Ref. 15).

The system(s) are to satisfy the functional, isolation, pressure relief, pump protection, and test requirements specified in Branch Technical Position RSB 5-1 (Ref. 11). 4

Interfaces between the RHR system and RCIC and component or service water systems should be designed so that operation of one does not interfere with, and provides proper support (where required) for the other. In relation to these and other shared systems (e.g., emergency core cooling and containment heat removal systems), the RHR system must conform to GDC 5 (Ref. 3). Component cooling and service water systems removing heat from the RHR heat exchangers must conform to GDC 44, 45, and 46 (Refs. 5, 6, and 7). Containment isolation provisions for the RHR system must conform to GDC 55, 56, and 57 (Refs. 8, 9, and 10).

In addition to the above criteria, the acceptability of the RHR system may be based on the degree of design similarity with previously approved plants. Deviations from these criteria from other types of RHR systems (e.g., systems that are designed to withstand reactor coolant system operating pressure or systems located entirely inside containment) will be considered on an individual basis. 1

III. REVIEW PROCEDURES

The procedures below are used during the construction permit (CP) review to assure that the design criteria and bases and the preliminary design as set forth in the preliminary safety analysis report meet the acceptance criteria given in Section II of this plan.

For operating license (OL) reviews, the procedures are utilized to verify that the initial design criteria and bases have been appropriately implemented in the final design as set forth in the final safety analysis report. The OL review also includes the proposed technical specifications, to assure that they are adequate in regard to limiting conditions of operation and periodic surveillance testing.

As noted in Sections I & II, the RSB review for PWR's is limited to the low pressure - low temperature RHR system. For BWR's, the review is to include all of the systems used to transfer residual heat from the reactor over the entire range of potential reactor coolant temperatures and pressures. The following steps are to be applied by the reviewer for the appropriate systems, depending on whether a PWR or BWR is being reviewed. These steps should be adapted to CP or OL reviews as appropriate. 1 2

1. Using the description given in the applicant's safety analysis report (SAR), including component lists and performance specifications, the reviewer determines that the system(s) piping and instrumentation are such as to allow the system(s) to operate as intended, with or without offsite power and given any single active component failure. This is accomplished by reviewing the piping and instrumentation diagrams (P&IDs) to confirm that piping arrangements permit the required flow paths to be achieved and that sufficient process sensors are available to measure and transmit required information.

A failure modes and effects analysis (or similar system safety analysis) provided in the SAR is used to determine conformance to the single failure criterion.

2. Using the comparison tables of SAR Section 1.3, the RHR system is compared to designs and capacities of such systems in similar plants to see that there are no unexplained departures from previously reviewed plants. Where possible, comparisons should be made with actual performance data from similar systems in operating plants.

3. From the system description and P&IDs, the reviewer determines that the isolation requirements of Branch Technical Position RSB 5-1 (Ref. 11) are satisfied.

4. The reviewer determines that the RHR system design has provisions to prevent damage to 4
the RHR pumps due to the closure of the isolation valves in accordance with Branch Technical Position RSB 5-1 (Ref. 11).

5. Using the system process diagrams, P&IDs, failure modes and effects analysis, and component performance specifications, the reviewer determines that the system(s) has the capacity to bring the reactor to cold shutdown conditions in a reasonable period of
time, assuming a single failure of an active component with only either onsite or 1
offsite electric power available. For the purposes of the review, 36 hours is considered
a reasonable time period. The reviewer consults with the CPB to confirm that the 2
proper core decay energy output was assumed for the analysis. The APCSB is responsible for the review of the initial cooldown phase for PWR's. Therefore, this review effort
is to be coordinated with that branch. For the purposes of the review of both PWR's 3
and BWR's, only the operation of safety grade equipment is to be assumed.

6. The cooldown function is to be reviewed to determine if it can be performed from the control room assuming a single failure of an active component, with only either onsite
or offsite electric power available. Any operations required outside of the control 3
room is to be justified by the applicant. Like Item 5, the initial cooldown for PWR's is to be reviewed by APCSB.

7. By reviewing the system description and the P&IDs, the reviewer confirms the RHR system 4
satisfies the pressure relief requirements of Branch Technical Position RSB 5-1 (Ref. 11).

8. The reviewer checks the P&IDs to see that essential components of the systems employed to remove residual heat are designated seismic Category I and Safety Class II (the cooling water side of heat exchangers can be Safety Class III). Based on statements made in SAR Section 5.4.7 or on the reviews made by other branches the RSB reviewer confirms that the RHR system meets the requirements of GDC 2 (Ref. 1) and 4 (Ref. 2), and conforms to the recommendations of Guides 1.29 (Ref. 12) and 1.46 (Ref. 13) and the staff positions on piping failures outside containment.

9. By reviewing the piping arrangement and system description of the RHR system, the reviewer confirms that the RHR system meets the requirements of GDC 5 (Ref. 3) concerning shared systems.

10. The RSB reviewer contacts the APCSB reviewer in conjunction with his review of the RHR system heat sink and refueling system interaction to interchange information and assure that the reviews are consistent in regard to the interfacing parameters. For example, the APCSB review determines the maximum service or component cooling water temperature. The RSB reviewer then reviews the RHR system description to determine that this maximum temperature has been allowed for in the RHR system design.

11. The RSB reviewer contacts his counterpart in the EICSB to obtain any needed information from their review. Specifically, EICSB confirms that automatic actuation and remote-manual valve controls are capable of performing the functions required, and that sensor and monitoring provisions are adequate. The instrumentation and controls of the RHR system are to have sufficient redundancy to satisfy the single failure criterion.

12. The RSB engineer contacts his counterpart in CSB so that the information needed concerning their reviews will be interchanged.

13. The applicant's proposed preoperational and initial startup test programs are reviewed to determine that they are consistent with the intent of Regulatory Guide 1.68 (Ref. 14). At the OL stage, the reviewer assures that sufficient information is provided by the applicant to identify the test objectives, methods of testing, and test acceptance criteria (see par. C.2.b of Regulatory Guide 1.68).

    The reviewer evaluates the proposed test programs to determine if they provide reasonable assurance that the RHR system will perform its safety function. As an alternative to this detailed evaluation, the reviewer may compare the RHR system design to that of previously reviewed plants. If the design is essentially identical and if the proposed test programs are essentially the same, the reviewer may conclude that the proposed test programs are adequate for the RHR system. If the RHR system differs significantly from that of previously reviewed designs, the impact of the proposed changes on the required preoperational and initial startup testing programs are reviewed at the CP stage. This effort should particularly evaluate the need for any special design features required to perform acceptable test programs.

14. The proposed plant technical specifications are reviewed to:

    a. Confirm the suitability of the limiting conditions of operation, including the proposed time limits and reactor operating restrictions for periods when system equipment is inoperable due to repairs and maintenance.

    b. Verify that the frequency and scope of periodic surveillance testing is adequate.

15. The reviewer confirms that the systems employed to remove residual heat are housed in a structure whose design and design criteria have been reviewed by other branches to assure that it provides adequate protection against wind, tornadoes, floods, and missiles, as appropriate.

16. The RSB reviewer provides information to other branches in those areas where the RSB has a secondary review responsibility that is not explicitly covered in steps 1-11 above. These additional areas of secondary review responsibility include:

a. Identification of engineered safety features (ESF) and safe shutdown electrical loads, and verification that the minimum time intervals for the connection of the ESF to the standby power systems are satisfactory.

b. Identification of vital auxiliary systems associated with the RHR system and determination of cooling load functional requirements and minimum time intervals.

c. Identification of essential components associated with the main steam supply and the auxiliary feedwater system that are required to operate during and following shutdown.

IV. EVALUATION FINDINGS

The reviewer verifies that the SAR contains sufficient information and his review supports the following kinds of statements and conclusions, which should be included in the staff's safety evaluation report for CP applications. For OL reviews, the requirements regarding single failure and operation from the control room are less stringent. The sample evaluation findings provided below should, therefore, be appropriately modified for OL reviews. 1

For PWR's

"The residual heat removal function is accomplished in two phases, the initial cooldown phase and the residual heat removal (RHR) system operation phase. In the event of loss of offsite power, the initial phase of cooldown is accomplished by use of the auxiliary feedwater system and the atmospheric dump valves. This equipment is used to reduce the reactor coolant system temperature and pressure to values that permit operation of the RHR system. The review of the initial cooldown phase is discussed in Section ______ of the SER. The review of the RHR operational phase is discussed below. The residual heat removal (RHR) system includes the piping, valves, pumps, heat exchangers, instrumentation, and controls used to remove core decay heat and provide long term core cooling following the initial phase of reactor cooldown. The scope of review of the RHR system for the _____ plant included piping and instrumentation diagrams, equipment layout drawings, failure modes and effects analysis, and design performance specifications for essential components. The review has included the applicant's proposed design criteria and design bases for the RHR system and his analysis of the adequacy of those criteria and bases and the conformance of the design to these criteria and bases.

"The drawings, component descriptions, design criteria, and supporting analyses associated with the RHR system have been reviewed and have been found to conform to Commission regulations, regulatory guides, and staff technical positions. The RHR system has been found to conform to General Design Criteria 2, 4, 5, 19, 34, 55, 56, 57 and to Regulatory Guides 1.29, 1.46, and 1.68. The system was found capable of performing its shutdown cooling functions from the control room with only onsite electrical power or offsite power available, assuming the most restrictive single active component failure. 1

It was also found that two independent and redundant barriers are always in place between the reactor coolant systems (RCS) and RHR system whenever the RCS pressure is higher than the RHR design pressure.

"The staff concludes that the design of the residual heat removal system conforms to the Commission's regulations, and to applicable regulations, guides and staff positions, and is acceptable."

For BWR's

"The residual heat removal function is accomplished in two phases, the initial cooldown phase and a low pressure-temperature operation phase. In the event of loss of offsite electrical power, the initial cooldown phase is accomplished using the reactor core isolation cooling (RCIC) system and the safety/relief valves. The low pressure-temperature mode of operation is usually accomplished by the residual heat removal (RHR) system. However, certain single failures can render the RHR system inoperative. In that event, two alternate systems that use components of the RCIC and RHR system are available to bring the reactor to cold shutdown conditions.

"The systems employed to transfer residual heat from the reactor include the piping, valves, pumps, heat exchangers, instrumentation, and controls. The scope of review of these systems for the _____ plant included piping and instrumentation diagrams, equipment layout drawings, failure mode and effects analysis, and design performance specifications for essential components. The review has included the applicant's proposed design criteria and design bases for these systems and his analysis of the adequacy of those criteria and bases and of the conformance of the design to these criteria and bases.

"The drawings, component descriptions, design criteria, and supporting analyses associated with the systems employed to remove residual heat from the reactor have been reviewed and have been found to conform to Commission regulations, regulatory guides, and staff technical positions. These systems have been found to conform to General Design Criteria 2, 4, 5, 19, 34, 55, 56, 57 and to Regulatory Guides 1.29, 1.46 and 1.68. The system was found capable of performing its shutdown cooling functions from the control room with only onsite electrical power or offsite power available, assuming the most restrictive single active component failure. It was also found that two independent and redundant barriers are always in place between the RCS and RHR system whenever the RCS pressure is higher than the RHR design pressure.

"The staff concludes that the design of the systems employed to remove residual heat from the reactor conform to the Commission's regulations and to applicable regulatory guides and staff technical positions, and is acceptable."

V. REFERENCES

1. 10 CFR Part 50, Appendix A, General Design Criterion 2, "Design Bases for Protection Against Natural Phenomena."

2. 10 CFR Part 50, Appendix A, General Design Criterion 4, "Environmental and Missile Design Bases."

3. 10 CFR Part 50, Appendix A, General Design Criterion 5, "Sharing of Structures, Systems, and Components."

4. 10 CFR Part 50, Appendix A, General Design Criterion 34, "Residual Heat Removal."

5. 10 CFR Part 50, Appendix A, General Design Criterion 44, "Cooling Water."

6. 10 CFR Part 50, Appendix A, General Design Criterion 45, "Inspection of Cooling Water System."

7. 10 CFR Part 50, Appendix A, General Design Criterion 46, "Testing of Cooling Water System."

8. 10 CFR Part 50, Appendix A, General Design Criterion 55, "Reactor Coolant Pressure Boundary Penetrating Containment."

9. 10 CFR Part 50, Appendix A, General Design Criterion 56, "Primary Containment Isolation."

10. 10 CFR Part 50, Appendix A, General Design Criterion 57, "Closed System Isolation Valves."

11. Branch Technical Position RSB 5-1, "Design Requirements of the Residual Heat Removal System," attached to SRP 5.4.7. 4

12. Regulatory Guide 1.29, "Seismic Design Classification," Revision 1.

13. Regulatory Guide 1.46, "Protection Against Pipe Whip Inside Containment."

14. Regulatory Guide No. 1.68, "Preoperational and Initial Startup Test Programs for Water-Cooled Power Reactors."

15. Branch Technical Positions APCSB 3-1, "Protection Against Postulated Piping Failures in Fluid Systems Outside Containment," attached to SRP 3.6.1, and MEB 3-1, "Postulated Break and Leakage Locations in Fluid System Piping Outside Containment," attached to SRP 3.6.2.

16. 10 CFR Part 50, Appendix A, General Design Criterion 19, "Control Room."