U.S. NUCLEAR REGULATORY COMMISSION

STANDARD REVIEW PLAN

5.4.7 RESIDUAL HEAT REMOVAL (RHR) SYSTEM

REVIEW RESPONSIBILITIES

Primary - Organization responsible for review of reactor thermal hydraulic systems in PWRs and BWRs

Secondary - None

I. AREAS OF REVIEW

The residual heat removal (RHR) system is used to cool the reactor coolant system (RCS) during and following shutdown. For RCS cooldown, it is used in conjunction with (1) the feedwater systems by steaming to the main condenser, (2) the reactor core isolation cooling (RCIC) system in conjunction with the safety/relief valves in a boiling-water reactor (BWR), or (3) the auxiliary feedwater system in conjunction with the atmospheric dump valves or steaming to the main condenser in a pressurized-water reactor (PWR). Parts of the RHR system also act to provide low-pressure emergency core cooling and are reviewed as described in Standard Review Plan (SRP) Section 6.3. In addition, some parts of the RHR system provide containment heat removal capability and are reviewed as described in SRP Section 6.2.2. The reviews of SRP Section 6.2.2 also address PWR sump and BWR RHR suction screen inlet design and evaluation guidance to ensure that the containment sumps provide a reliable, long-term recirculation cooling capability and that conditions impacting the sumps after a loss-of-coolant accident (LOCA) will not adversely affect RHR pump performance. The reviewer of this SRP section will ensure that the design of the RHR system conforms with General Design Criteria (GDCs) 2, 4, 5, 19, and 34 in Appendix A to Title 10 of the *Code of Federal Regulations*, Part 50

(10 CFR Part 50) or similar requirements in the principle design criteria incorporated into the plant licensing basis.

Both PWRs and BWRs have RHR systems that provide long-term cooling once the main condenser, RCIC, or auxiliary feedwater systems have decreased the RCS temperature. In both existing plant types, the RHR is typically a low-pressure system that provides shutdown cooling when the RCS temperature is reduced to about 150 °C (300 °F). Although the RHR system function is similar for the two plant types, the system designs are different.

The RHR system in PWRs takes water from one or two RCS hot legs, cools it, and pumps it back to the cold legs or core flooding tank nozzles. The suction and discharge lines for the RHR pumps have valving to provide reasonable assurance that the low-pressure RHR system is isolated from the RCS when the RCS pressure is greater than the RHR system design pressure. Relief valves are provided to protect the RHR system from an overpressure condition, although the relief capability is not sufficient to protect the RHR system from an overpressure condition if isolation valves are open when the RCS pressure is significantly greater than the RHR design pressure.

To accomplish RHR heat removal, RHR heat exchangers transfer heat to the component cooling water or service water system, which then transports heat to the ultimate heat sink (UHS). In PWRs, the RHR system is also used to fill, drain, and remove heat from the refueling water cavity during refueling operations, to circulate coolant through the core during plant startup before RCS pump operation, and in some to provide an auxiliary pressurizer spray.

The RHR system in BWRs is typically composed of four subsystems. SRP Sections 6.2.2 and 6.3 discuss the containment heat removal and low-pressure emergency core cooling subsystems. This SRP section covers the shutdown cooling and steam condensing (via RCIC) subsystems, which use 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.

The steam condensing mode of RCIC operation in BWRs (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, and the RCIC pump returns the condensate to the reactor vessel. The service water system transports the heat removed in the heat exchangers to the UHS.

Other means of removing decay heat in the event that the RHR system is inoperable have been proposed for some BWRs. These approaches use some of the piping that is used for the steam condensing mode of RCIC. This SRP section also covers these approaches.

The RHR system in PWRs is used to cool the core during shutdown operations, including reduced inventory and midloop operations. High RHR system availability and reliability during shutdown conditions are important to mitigating risk and maintaining an appropriate level of safety. This SRP section covers the review of the methods used to ensure high reliability of the RHR system under these conditions.

The RCS temperatures and pressure must be decreased from power operating conditions 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 RCS power operating pressure and temperature to the cold depressurized condition. Further, as necessary to supplement the review under SRP Section 5.4.13, the reviewer must verify that actions have been taken to ensure the continued availability and high reliability of the decay heat removal system during shutdown operations.

The reviewer will also evaluate the requirements for leakage detection and control identified in NUREG-0737, item III.D.1.1. The organization responsible for the instrumentation and control systems reviews the hardware and procedures to provide reasonable assurance the leakage requirements are met.

Inspections, Tests, Analyses, and Acceptance Criteria (ITAAC). For design certification (DC) and combined license (COL) reviews, the staff reviews the applicant's proposed ITAAC associated with the structures, systems, and components (SSCs) related to this SRP section in accordance with SRP Section 14.3, "Inspections, Tests, Analyses, and Acceptance Criteria." The staff recognizes that the review of ITAAC cannot be completed until after the rest of this portion of the application has been reviewed against acceptance criteria contained in this SRP section. Furthermore, the staff reviews the ITAAC to ensure that all SSCs in this area of review are identified and addressed as appropriate in accordance with SRP Section 14.3.

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. As part of its primary review responsibility for SRP Section 3.12, the organization responsible for the review of materials engineering issues related to flaw evaluation and welding reviews the design of the RHR systems for new light-water reactor designs to verify, to the extent practical, that low-pressure portions of the RHR that interface with the RCS will withstand full RCS pressure. If designing the RHR with an ultimate rupture strength capable of withstanding full RCS pressure is not possible, the reviewer verifies that appropriate compensating measures have been taken in accordance with the review provided in SRP Section 3.12.

2. With respect to the staff review for compliance with Branch Technical Position (BTP) 5-4, the organizations responsible for the review of the steam and feedwater system, RCS, and reactor thermal hydraulic systems divide the evaluation as follows:

    A. For BWRs, the organization responsible for the review of reactor thermal hydraulic systems in BWRs reviews the processes and systems used in the cooldown of the reactor for the entire spectrum of potential RCS pressures and temperatures during decay heat removal.

B. For PWRs, the organization responsible for the review of reactor thermal hydraulic systems in PWRs reviews the approach used to meet the functional requirements of BTP 5-4 with respect to cooling down to the conditions permitting operation of the RHR system. Since an alternate approach to that normally used for cooldown may be specified, the reviewer identifies all components and systems used. The organization responsible for review of the RCS has primary review responsibility for the review of the pertinent portions of the chemical and volume control system (CVCS) (SRP Section 9.3.4). The organization responsible for the review of steam and feedwater system, as part of its primary review responsibility for SRP Sections 10.3 and 10.4.9, reviews the atmospheric dump valves and the source for auxiliary feedwater, respectively, for conformance to BTP 5-4. The organization responsible for the review of reactor thermal-hydraulic systems in pressurized-water reactors reviews the pressurizer relief valves and emergency core cooling system (ECCS), if used. As part of its primary review responsibility for SRP Section 6.8, the organization responsible for the review of reactor thermal hydraulic systems reviews the PWR depressurization systems used for cooldown. In addition, the organization responsible for the review of reactor thermal hydraulic systems reviews the tests and supporting analysis concerning the mixing of borated water and cooldown under natural circulation as required in BTP 5-4.

C. For both PWRs and BWRs, the organization responsible for the review of cooling water systems associated with balance of plant reviews the component cooling or service water systems that transfer decay heat from the RHR system to the UHS as part of its primary review responsibility for SRP Sections 9.2.1 and 9.2.2.

D. The organization responsible for the review of reactor thermal hydraulic systems 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 responsible organization reviews the effect of these systems on the RHR system. The responsible organization also reviews overpressure protection provided by the valving between the RCS and RHR system.

In addition, the organization responsible for the review of reactor thermal hydraulic systems will coordinate evaluations of other reviewers that interface with the overall review of the RHR system as follows:

1. The organization responsible for the review of containment integrity performs the following reviews:

   A. Evaluates the containment heat removal capability and the containment sump designs as part of its review responsibility for SRP Section 6.2.2

   B. Verifies that portions of the RHR system penetrating the containment barrier are designed with acceptable isolation features to maintain containment integrity for all operating conditions, including accidents, as part of its primary review responsibility for SRP Section 6.2.4

2. The organizations responsible for the structural analysis reviews and review of seismic/geotechnical issues determine the acceptability of the design analysis, procedures, and criteria used to establish the ability of seismic Category I structures housing the system and supporting systems to withstand the effects of natural phenomena such as a safe-shutdown earthquake (SSE), the probable maximum flood, and tornado missiles as part of their primary review responsibility for SRP Sections 3.3.1, 3.3.2, 3.5.3, 3.7.1 through 3.7.4, 3.8.4, and 3.8.5. The organization responsible for the review of the inspection, testing, evaluation, and repair of mechanical equipment and components also verifies that inservice inspection requirements are met for system components as part of its primary review responsibility for SRP Section 6.6.

3. Upon request, the organization responsible for the review of component integrity issues related to engineered safety features verifies the compatibility of the materials of construction with service conditions as part of its primary review responsibility for SRP Section 6.1.1.

4. The organization responsible for mechanical engineering reviews performs the following reviews:

   A. Determines the acceptability of the seismic and quality group classifications for system components as part of its primary review responsibility for SRP Sections 3.2.1 and 3.2.2. In addition, as part of its primary review responsibility for SRP Section 3.2.2, if the PWR pressurizer power-operated relief valves (PORVs) and block valves are relied upon to perform a safety-related function, such as plant cooldown in accordance with BTP 5-4, this organization will confirm the classification of the PORVs and block valves.

   B. Reviews the effects of pipe breaks inside and outside of containment, such as pipe whip and jet impingement, as part of its primary review responsibilities for SRP Section 3.6.2.

   C. Determines that the components, piping, and structures are designed and tested in accordance with applicable codes and standards as part of its primary review responsibility for SRP Sections 3.9.1 through 3.9.3.

   D. Reviews adequacy of the inservice testing program of pumps and valves as part of its primary review responsibility for SRP Section 3.9.6. For new plant designs, the reviewer responsible for the review of reactor thermal hydraulic systems in PWRs should coordinate with the organization responsible for the mechanical engineering reviews to ensure that the RHR system configuration allows for full-flow testing of safety-related pumps and check valves and that provisions are made to allow for the use of advanced techniques to detect degradation and monitor system performance.

5. The organization responsible for quality assurance reviews performs the following reviews:

   A. Evaluates the pre-operational and startup test programs to confirm that they are in conformance with the intent of Regulatory Guide (RG) 1.68 as part of its primary review responsibility for SRP Section 14.2

B. Has primary review responsibility for Task Action Plan items I.C.2 and I.C.6 of NUREG-0737 regarding procedures to ensure that system operability status is known, as part of its review responsibility for SRP Section 13.5.1.1

C. Evaluates quality assurance as part of its primary review responsibility for SRP Chapter 17.

6. The organization responsible for the review of mechanical effects of missiles on SSCs performs the following reviews:

A. Evaluates flood protection as part of its primary review responsibility for SRP Section 3.4.1.

B. Identifies the SSCs to be protected against externally generated missiles and reviews the adequacy of protection against such missiles as part of its primary review responsibility for SRP Sections 3.5.1.4 and 3.5.2.

C. Reviews protection against internally generated missiles both inside and outside of containment as part of its primary review responsibility for SRP Sections 3.5.1.1 and 3.5.1.2.

7. The organization responsible for the review of cooling water systems associated with balance of plant reviews the plant design for protection against postulated piping failures outside containment, as part of its primary review responsibility for SRP Section 3.6.1.

8. The organization responsible for the review of environmental qualification of electrical equipment reviews the acceptability of, and environmental qualification test program for, RHR equipment exposed to a postaccident environment, including consideration of the postaccident environmental design and source term considerations described in NUREG-0737 Task Action Plan item II.B.2 and NUREG-0718, as part of its review responsibility for SRP Section 3.11.

9. The organization responsible for the review of fire protection performs a review of fire protection as part of its primary review responsibility for SRP Section 9.5.1.

10. The organization responsible for the electrical engineering and power systems reviews identifies the safety-related electrical loads and determines that power systems supplying motive or control power for the RHR system meet acceptable criteria and will perform these intended functions during all plant operating and accident conditions, as part of its primary review responsibility for SRP Sections 8.1, 8.2, 8.3.1, and 8.3.2. In addition, this organization reviews the capability to withstand or cope with, and recovers from, a station blackout and coordinates with the review of the RHR system if the system is required to ensure adequate core cooling and/or decay heat removal, as part of its review under SRP Section 8.4.

11. The organization responsible for the review of instrumentation and control systems reviews those systems for the RHR system to determine that it will perform its design function as required and conform to all applicable acceptance criteria, as part of its primary review responsibility for SRP Sections 7.1 and 7.4. This organization also

reviews the provisions taken to meet GDC 19 with respect to equipment outside of the control room for hot and cold shutdown.

12. The organization responsible for the review of health physics has primary review responsibility for SRP Sections 12.1 through 12.5, including conformance with NUREG-0737 Task Action Plan item II.B.2 and NUREG-0718, which involve a radiation and shielding design review and corrective actions to ensure adequate access to vital areas and protection of safety equipment.

13. The organization responsible for the review of technical specifications evaluates the technical specifications as part of its primary review responsibility for 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 2, as it relates to the seismic design of SSCs whose failure could cause an unacceptable reduction in the capability of the RHR system, specifically based on meeting Regulatory Position C-2 of RG 1.29 or its equivalent

2. GDC 4, as it relates to dynamic effects associated with flow instabilities and loads (e.g., water hammer)

3. GDC 5, as it relates to the requirement that any sharing among nuclear power units of SSCs important to safety will not significantly impair their safety function

4. GDC 19, as it relates to control room requirements for normal operations and shutdown

5. GDC 34, as it relates to requirements for an RHR system

6. NUREG-0737 Task Action Plan item III.D.1.1, equivalent to 10 CFR 50.34(f)(2)(xxvi) for applicants subject to 10 CFR 50.34(f), as it relates to the provisions for a leakage detection and control program to minimize the leakage from those portions of the RHR system outside of the containment that contain or may contain radioactive material following an accident

7. 10 CFR 52.47(b)(1), which requires that a DC application contain the proposed ITAACs that are necessary and sufficient to provide reasonable assurance that, if the inspections, tests, and analyses are performed and the acceptance criteria met, a plant that incorporates the DC is built and will operate in accordance with the DC, the provisions of the Atomic Energy Act (AEA), and the U.S. Nuclear Regulatory Commission’s (NRC's) regulations;

8. 10 CFR 52.80(a), which requires that a COL application contain the proposed inspections, tests, and analyses, including those applicable to emergency planning, that

the licensee shall perform, and the acceptance criteria that are necessary and sufficient to provide reasonable assurance that, if the inspections, tests, and analyses are performed and the acceptance criteria met, the facility has been constructed and will operate in conformity with the COL, the provisions of the AEA, and the NRC's regulations.

SRP Acceptance Criteria

Specific SRP acceptance criteria acceptable to meet the relevant requirements of the NRC's regulations identified above are as follows for the review described in this SRP section. The SRP is not a substitute for the NRC's regulations, and compliance with it is not required. However, an applicant is required to identify differences between the design features, analytical techniques, and procedural measures proposed for its facility and the SRP acceptance criteria and evaluate how the proposed alternatives to the SRP acceptance criteria provide acceptable methods of compliance with the NRC regulations.

1. The system or systems must satisfy the functional, isolation, pressure relief, pump protection, and test requirements specified in BTP 5-4.

2. To meet the requirements of GDC 4, design features and operating procedures should be provided to prevent damaging water hammer caused by such mechanisms as voided lines.

3. Interfaces between the RHR system and the 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.

4. When the RHR system is used to control or mitigate the consequences of an accident, it must meet the design requirements of an engineered safety feature system. This includes meeting the guidelines of RG 1.82 regarding water sources for long term recirculation cooling following a loss-of-coolant accident.

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. GDC 2 requires that SSCs important to safety be designed to withstand the effects of natural phenomena, such as earthquakes, without the loss of capability to perform their safety functions. The RHR system is relied upon to provide removal of residual heat from the reactor core to maintain the reactor in a safe-shutdown condition. In addition, the RHR system may be capable of cooling the spent fuel pool. RG 1.29 provides guidance for determining which systems should be designated seismic Category I; Regulatory Position C.1 provides guidance for safety-related portions and Regulatory Position C.2 addresses nonsafety-related systems and components. Meeting the requirements of GDC 2 will enhance plant safety by ensuring that the RHR system will be available to cool the core and/or the spent fuel pool during and following a seismic event.

2. GDC 4 requires that SSCs important to safety be designed to accommodate the effects of and be compatible with the environmental conditions associated with normal operation, maintenance, testing, and postulated accident conditions, including such effects as pipe whip and jet impingement. The safety function of the RHR system is to transfer heat from the reactor to the environment during and after plant shutdown. To ensure the availability of the decay heat removal function, the RHR system must be capable of performing heat transfer under the expected operational and postulated accident conditions for the plant. These conditions include consideration of the dynamic effects of flow instabilities and the loadings caused by water hammer events. Compliance with GDC 4 enhances plant safety by providing assurance that the dynamic effects of events such as flow instabilities and water hammer will not affect the capability of the RHR system to remove decay heat.

3. GDC 5 prohibits the sharing of SSCs among nuclear power units unless it can be shown that such sharing will not significantly impair the ability of the SSCs to perform their safety functions, including, in the event of an accident in one unit, and orderly shutdown and cooldown of the remaining units. The RHR systems are relied upon to transfer decay heat from the reactor to the environment after a reactor shutdown. The RHR system must be designed such that the ability to perform this and other designated safety-related functions is not compromised for each unit regardless of equipment failures or other events that may occur in another unit. Meeting the requirements of GDC 5 enhances plant safety by providing assurance that the unacceptable effects of equipment failures or other events occurring in one unit of a multiunit site will not prevent an orderly shutdown and cooldown of the unaffected unit(s).

4. GDC 19 requires that a control room be provided from which actions can be taken to operate the nuclear power unit during both normal operating and accident conditions, including the LOCA. BTP 5-4 provides guidance for compliance with GDC 19 with regard to achieving cold shutdown from the control room using only safety-grade equipment. The RHR system is required for safe shutdown and cooldown of the reactor during normal and accident conditions. Compliance with GDC 19 enhances plant safety by ensuring the availability of adequate instrumentation and controls in the control room to perform the required safety functions of the RHR system under all anticipated conditions.

5. GDC 34 requires the capability to transfer decay heat and other residual heat from the reactor such that fuel and pressure boundary design limits are not exceeded. In addition, the system must be designed with sufficient redundancy and isolation capability to ensure that the safety function can be accomplished assuming a single failure of an active component with or without a coincident loss of offsite power. The RHR system transfers the fission product decay and other residual heat from the reactor core. Removal of decay and residual heat is necessary to prevent core damage under both normal and accident shutdown conditions. BTP 5-4 provides an acceptable approach to ensure compliance with GDC 34 with regard to accomplishing the RHR system safety functions assuming a single failure. Compliance with GDC 34 enhances plant safety by providing assurance that decay and RHR will be accomplished and the RCS pressure boundary and fuel cladding integrity will be maintained, thereby minimizing the potential for the release of fission products to the environment.

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.

For operating license (OL) reviews, the reviewer uses the procedures to verify that the final design appropriately implements the initial design criteria and bases as set forth in the final safety analysis report (SAR). The OL review also covers the proposed technical specifications to ensure that they are adequate with regard to limiting conditions of operation and periodic surveillance testing.

As noted in Subsections I and II, the organization responsible for the review of reactor thermal hydraulic systems for PWRs considers only the low pressure—low temperature RHR system. For BWRs, the review includes all of the systems used to transfer residual heat from the reactor over the entire range of potential reactor coolant temperatures and pressures. The reviewer should apply the following steps for the appropriate systems, depending on whether the plant is a PWR or BWR. The reviewer should adapt these steps to construction permit or OL reviews as appropriate.

1. Using the description given in the applicant's SAR, including component lists and performance specifications, the reviewer determines that the system piping and instrumentation provide reasonable assurance that the system(s) will operate as intended, with or without offsite power and given any single active component failure. To do this, the reviewer evaluates the piping and instrumentation diagrams (P&IDs) to confirm that piping arrangements permit the achievement of the required flowpaths and that sufficient process sensors are available to measure and transmit required information. The reviewer uses a failure modes and effects analysis (or similar system safety analysis) provided in the SAR to determine conformance to the single failure criterion.

2. Using the comparison tables of SAR Section 1.3, the reviewer compares the RHR system to the designs and capacities of such systems in similar plants to confirm 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 BTP 5-4 are satisfied.

4. The reviewer determines that the RHR system design has provisions to prevent damage to the RHR pumps in accordance with BTP 5-4. The reviewer checks the isolation valves in the suction line for potential closure, net positive suction head requirements, pump runout, and potential loss of miniflow line during pump testing. If operator action is required to protect the pumps, the reviewer evaluates the instrumentation that will alert the operator and the adequacy of the timeframe for operator action.

The reviewer verifies that the applicant has considered the following guidance regarding the design of the RHR miniflow systems necessary to ensure safety-related RHR pump protection (see NRC Generic Letter 89-04 and Bulletins 86-01 and 88-04):

A. Ensure that the minimum cooling flow provided for the RHR pumps is adequate under all conditions, including verification that the system configuration precludes pump-to-pump interaction during miniflow operation that could result in dead-heading one or more of the pumps. The miniflow must be sufficient to prevent damage to the pump(s) under all conditions.

B. The miniflow system should be designed such that the miniflow function can be performed assuming a single failure. A single failure should not result in conditions causing no flow through the RHR pumps.

C. In cases where only the miniflow return line is available for pump testing, flow instrumentation must be installed on the miniflow return line. This instrumentation is necessary to provide flow rate measurements during pump testing so these data can be evaluated with the measured pump differential pressure to monitor for pump hydraulic degradation.

5. The staff reviews the RHR system to evaluate the adequacy of design features and procedures that have been provided to prevent damaging water hammer and degradation or loss of RHR pumps because of such mechanisms as voided lines. NUREG-0927 provides guidance for water hammer prevention and mitigation and Generic Letter 88-17 provides guidance for shutdown operation.

6. 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 conditions permitting operation of the RHR system in a reasonable period of time, assuming a single failure of an active component with only either onsite or offsite electric power available. For the purposes of this review, the NRC considers 36 hours a reasonable time period. The organization responsible for the review of steam and feedwater systems evaluates the initial cooldown phase for PWRs, so this review effort should be coordinated with that reviewer. For the purposes of the cooldown review of both PWRs and BWRs, the reviewer should only assume the operation of safety-grade equipment. For PWRs, if the PORVs are relied upon in the performance of a safety-related function such as plant cooldown for compliance with BTP 5-4, the PORVs must meet the guidance contained in Generic Letter 90-06 (see also NUREG-1316), as reviewed under SRP Section 6.8. For new PWRs that use PORVs, the valves should be safety related.

7. The staff reviews the cooldown function to determine whether 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. The applicant must justify any operation required outside of the control room. As with item 6 above, the organization responsible for the review of steam and feedwater systems will evaluate the initial cooldown for PWRs.

8. By reviewing the system description and the P&IDs, the reviewer confirms that the RHR system satisfies the pressure relief requirements of BTP 5-4.

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 concerning shared systems.

10. The reviewer of reactor thermal hydraulic systems contacts the reviewer of steam and feedwater systems in conjunction with the review of the RHR system heat sink and refueling system interaction to exchange information and ensure that the reviews consider the interfacing parameters consistently. For example, the organization responsible for the review of cooling water systems associated with balance of plant review determines the maximum service or component cooling water temperature. The reviewer of reactor thermal hydraulic systems then evaluates the RHR system description to determine that the RHR system design allows for this maximum temperature.

11. The reviewer of reactor thermal hydraulic systems contacts the reviewer of instrumentation and control systems to obtain any needed information from that review. Specifically, the reviewer of instrumentation and control systems 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 must have sufficient redundancy to satisfy the single failure criterion.

12. The reviewer of reactor thermal hydraulic systems contacts the reviewer of containment integrity to exchange information related to their reviews.

13. The reviewer of reactor thermal hydraulic systems contacts the reviewer of the quality assurance and maintenance to discuss any special test requirements and to confirm that the proposed preoperational test program for the RHR system is in conformance with the intent of RG 1.68.

14. The reviewer evaluates the proposed plant technical specifications as follows:

    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 because of repairs and maintenance.

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

15. The reviewer contacts the reviewers of structural analysis and seismic/geotechnical issues to confirm that the systems employed to remove residual heat are housed in a structure whose design and design criteria provide adequate protection against wind, tornadoes, floods, and missiles, as appropriate.

16. For PWRs, the reviewer confirms that the auxiliary feedwater supply satisfies the requirements of BTP 5-4.

17. The reviewer provides information to other reviewers in those areas where the organization responsible for the review of reactor thermal hydraulic systems has a review responsibility that is not explicitly covered in steps 1–15 above. These additional areas of review responsibility include:

A. Identification of engineered safety features and safe-shutdown electrical loads, and verification that the minimum time intervals for the connection of the engineered safety features 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

18. The reviewer considers compliance with acceptance criteria requirements II.6 by verifying that a leakage control program includes those portions of the RHR systems located outside of containment that contain or may contain radioactive material following an accident. The leakage control program should include periodic leak testing and measures to minimize leakage from the RHR systems.

19. As necessary, the reviewer verifies that actions have been taken to ensure the continued availability and high reliability of the decay heat removal systems during shutdown operations.

For PWRs, design features should be incorporated to prevent a loss of RHR functions under reduced inventory and mid-Loop operations. The reviewer should verify that the RHR-specific guidance and measures contained in Generic Letter 88-17 and summarized as follows are satisfied:

A. The reviewer verifies that the applicant/licensee will have measures in place to ensure that the RCS will remain stable and controlled while in a reduced inventory condition. These measures include both prevention of a loss of RHR and enhanced monitoring requirements to ensure timely response to a loss of RHR, should such a loss occur.

B. The reviewer verifies that the applicant/licensee has the capability of continuously monitoring RHR system performance and RCS characteristics important for core cooling whenever a RHR system is being used for cooling the RCS.

C. The reviewer verifies that the RHR system has visible and audible indications of abnormal conditions in temperature, level, and RHR system performance parameters.

20. The reviewer verifies that new light-water reactor applicants have ensured high reliability of the shutdown decay heat removal system as follows (see SECY-90-016 and the associated staff requirements memorandum (SRM) dated June 26, 1990, SECY-93-087 and the associated SRM dated July 21, 1993, and NUREG-1449):

A. The reviewer verifies that design provisions exist to reasonably ensure the continuity of flow through the core and RHR system with low-liquid levels at the junction of the RHR system suction lines and the RCS (new PWR applicants only).

B. The reviewer verifies that provisions exist to ensure the availability of reliable systems for decay heat removal.

C. The reviewer verifies that the applicant has provided reliable measurements of liquid levels at the junction of the RHR system suction lines and the RCS (new PWR applicants only).

D. The reviewer verifies that automatic closure interlocks for the RHR suction isolation valves, if provided, are designed in such a manner as to minimize inadvertent valve closure during system operation (new PWR applicants only).

21. The reviewer verifies that the applicant has reviewed its RHR system design configurations to identify any piping connected to the RCS that could be subjected to temperature distributions that could result in unacceptable thermal stresses. This review should consider the potential for thermal stratification, thermal cycling, and thermal fatigue, given the RHR system configuration. The reviewer verifies that appropriate action has been taken, where such piping is identified, to ensure that the piping will not be subjected to unacceptable thermal stresses (see NRC Bulletin 88-08). This review should focus on RHR system configurations; the organization responsible for mechanical engineering reviews under SRP Section 3.9.3 reviews the stress analysis and ensures that it conforms to the American Society of Mechanical Engineers Boiler and Pressure Vessel Code.

22. The NRC states its regulatory position with respect to minimizing the potential for an intersystem LOCA in advanced or evolutionary light-water reactors in SECY-90-016 and SECY-93-087 and their associated SRM. In keeping with that position, the reviewer will verify that, to the extent practical, the RHR system for advanced or evolutionary light-water reactors is designed to an ultimate rupture strength at least equal to the normal RCS operating pressure. All elements of the RHR system are to be considered (e.g., instrument lines, pump seals, heat exchanger tubes, valve bonnets) The licensee should provide justification for elements not designed to an ultimate rupture strength at least equal to the normal RCS operating pressure.

23. Some advanced light-water reactor (ALWR) designs make extensive use of passive systems to meet regulatory requirements. Often, they include a nonsafety-related active system for use during normal plant operation and to provide defense in depth to the safety-related passive system. The nonsafety-related active systems are the first line of defense to reduce challenges to the passive systems in the event of transients or plant upsets. The extensive use of safety-related passive systems and the nonsafety-related active system design philosophy presents a departure from previous licensing practices. Therefore, in SECY-94-084, the staff developed new regulatory and review guidance for a reliability assurance program to establish the regulatory treatment of nonsafety systems. Among other functions, ALWR designs have used the design philosophy of safety-related passive systems and nonsafety-related active systems for RHR. When reviewing such a design, the reviewer should use SECY-94-084 to determine the amount of regulatory oversight necessary.

24. 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. 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 or other NRC approvals (e.g., manufacturing license, site suitability report or topical report).

For review of both DC and COL applications, SRP Section 14.3 should be followed for the review of ITAAC. The review of ITAAC cannot be completed until after the completion of this section.

IV. EVALUATION FINDINGS

The reviewer verifies that the applicant has provided sufficient information and that the review and calculations (if applicable) support conclusions of the following type to be included in the staff's safety evaluation report (SER). The reviewer also states the bases for those conclusions.

1. For PWRs

The RHR function is accomplished in two phases—the initial cooldown phase and the RHR system operation phase. In the event of a loss of offsite power, the initial phase of cooldown is accomplished through 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. Section ___ of the SER discusses the review of the initial cooldown phase. The review of the RHR system operational phase is discussed below. The RHR system removes core decay heat and provides 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 included the applicant's proposed design criteria and design bases for the RHR system, analysis of the adequacy of those criteria and bases, and conformance of the design to those criteria and bases.

Based on the following, the staff concludes that the design of the RHR system is acceptable and meets the requirements of GDCs 2, 4, 5, 19, and 34 and 10 CFR 50.34(f)(2)(xxvi):

A. The applicant has met GDC 2 with respect to Regulatory Position C-2 of RG 1.29 concerning the seismic design of SSCs whose failure could cause an unacceptable reduction in the capability of the RHR system.

B. The applicant has met GDC 4 with respect to dynamic effects associated with flow instabilities and loads (e.g., water hammer).

C. The applicant has met the requirements of GDC 5 with respect to the sharing of SSCs by demonstrating that such sharing does not significantly impair the ability of the RHR system to perform its safety function, including, in the event of an accident to one unit, an orderly shutdown and cooldown of the remaining units.

D. The applicant has met GDC 19, with respect to the main control room requirements for normal operations and shutdown, and GDC 34, which specifies requirements for the RHR by meeting the regulatory positions in BTP 5-4.

E. The applicant has met the parameters in Item III.D.1.1 of NUREG-0737, equivalent to 10 CFR 50.34(f)(2)(xxvi) for applicants subject to 10 CFR 50.34(f), with respect to leakage detection and control in the design of RHR systems outside containment that contain (or may contain) radioactive material following an accident.

2. For BWRs

The RHR function is accomplished in two phases—the initial cooldown phase and a low pressure-temperature operation phase. In the event of a loss of offsite electrical power, the initial cooldown phase is accomplished through the RCIC system and the safety/relief valves. The RHR system usually supports the low pressure-temperature mode of operation. 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 scope of review of these systems 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 these systems, analysis of the adequacy of those criteria and bases, and conformance of the design to those criteria and bases.

Based on the following, the staff concludes that the design of the RHR system is acceptable and meets the requirements of GDCs 2, 4, 5, 19, and 34 and 10 CFR 50.34(f)(2)(xxvi):

A. The applicant has met GDC 2 with respect to Regulatory Position C-2 of RG 1.29 concerning the seismic design of SSCs whose failure could cause an unacceptable reduction in the capability of the RHR system.

B. The applicant has met GDC 4 with respect to dynamic effects associated with flow instabilities and loads (e.g., water hammer).

C. The applicant has met the requirements of GDC 5 with respect to the sharing of SSCs by demonstrating that such sharing does not significantly impair the ability of the RHR system to perform its safety function, including, in the event of an accident to one unit, an orderly shutdown and cooldown of the remaining units.

D. The applicant has met GDC 19, with respect to the main control room requirements for normal operations and shutdown, and GDC 34, which specifies requirements for the RHR system by meeting the regulatory positions in BTP 5-4.

E. The applicant has met the parameters of Item III.D.1.1 of NUREG-0737, equivalent to 10 CFR 50.34(f)(2)(xxvi) for applicants subject to 10 CFR 50.34(f), with respect to leakage detection and control in the design of RHR systems outside containment that contain (or may contain) radioactive material following an accident.

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 for other types of RHR systems (e.g., systems that are designed to withstand RCS operating pressure or systems located entirely inside containment) will be considered on an individual basis.

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

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

V. IMPLEMENTATION

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

The provisions of this SRP section apply to reviews of applications submitted 6 months or more after the date of issuance of this SRP section, unless superseded by a later revision.

The referenced BTP 5-4, RGs, NUREGs, and implementation of the acceptance criteria in Subsection II above provide the implementation schedules, summarized as follows, for conformance to parts of the method discussed in this SRP section:

1. Plants with an OL issued before April 1984 and OL applications docketed before April 1984 need not comply with the provisions of this item but may do so voluntarily.

2. Applicants for a construction permit must comply with the provisions of this item.

3. The staff will review applications for OLs, DCs, and COLs docketed during or after April 1984 according to the provisions of this item.

VI. REFERENCES

1. 10 CFR 50.34(f), "Additional TMI-Related Requirements."

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

3. 10 CFR Part 50, Appendix A, GDC 4, "Environmental and Dynamic Effects Design Bases."

4. 10 CFR Part 50, Appendix A, GDC 5, "Sharing of Structures, Systems and Components."

5. 10 CFR Part 50, Appendix A, GDC 19, "Control Room."

6. 10 CFR Part 50, Appendix A, GDC 34, "Residual Heat Removal."

7. BTP 5-4, "Design Requirements of the Residual Heat Removal System."

8. RG 1.82, "Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident."

9. RG 1.29, "Seismic Design Classification."

10. SECY-90-016, "Evolutionary Light Water Reactor (LWR) Certification Issues and Their Relationship to Current Regulatory Requirements," January 12, 1990.

11. SRM, "SECY 90-016 - Evolutionary Light Water Reactor (LWR) Certification Issues and Their Relationships to Current Regulatory Requirements," June 26, 1990.

12. SECY-93-087, "Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advanced Light-Water Reactor (ALWR) Designs," April 2, 1993.

13. SRM, "SECY 93-087—Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advanced Light- Water Reactor (ALWR) Designs," July 21, 1993.

14. Generic Letter 88-17, "Loss of Decay Heat Removal" October 17, 1988.

15. Generic Letter 89-04, "Guidance on Developing Acceptable Inservice Testing Programs," April 3, 1989.

16. Generic Letter 90-06, "Resolution of Generic Issue 70, 'Power-Operated Relief-Valve and Block Valve Reliability,' and Generic Issue 94, 'Additional Low-Temperature Overpressure Protection for Light-Water Reactors," June 25, 1990.

17. Generic Letter 92-02, "Resolution of Generic Issue 79, 'Unanalyzed Reactor Vessel (PWR) Thermal Stress During Natural Convection Cooldown,'" March 6, 1992.

18. NRC Bulletin 86-01, “Minimum Flow Logic Problems That Could Disable RHR Pumps,” May 23, 1986.

19. NRC Bulletin 88-04, “Potential Safety- Related Pump Loss,” May 5, 1988.

20. NRC Bulletin 88-08, “Thermal Stresses in Piping Connected to Reactor Coolant Systems,” June 22, 1988, and Supplements 1 through 3.

21. NUREG-0660, “NRC Action Plan Developed as a Result of the TMI-2 Accident.”

22. NUREG-0718, “Licensing Requirements for Pending Applications for Construction Permits and Manufacturing License.”

23. NUREG-0737, “Clarification of TMI Action Plan Requirements.”

24. NUREG-1316, “Technical Findings and Regulatory Analysis Related to Generic Issue 70—Evaluation of Power- Operated Relief Valve and Block Valve Reliability in PWR Nuclear Power Plants.”

25. NUREG-1449, “Shutdown and Low-Power Operation at Nuclear Power Plants in the United States.”

26. NUREG-0927, Revision 1, “Evaluation of Water Hammer Occurrences in Nuclear Power Plants,” March 1984.

27. SECY-94-084, “Policy and Technical Issues Associated with the Regulatory Treatment of Non-Safety Systems in Passive Plant Designs,” March 28, 1994.

28. SECY-95-132, “Policy and Technical Issues Associated with the Regulatory Treatment of Non-Safety Systems (RTNSS) in Passive Plant Designs,” May 22, 1995.

PAPERWORK REDUCTION ACT STATEMENT

The information collections contained in the Standard Review Plan are covered by the requirements of 10 CFR Part 50 and 10 CFR Part 52, and were approved by the Office of Management and Budget, approval number 3150-0011 and 3150-0151.

PUBLIC PROTECTION NOTIFICATION

The NRC may not conduct or sponsor, and a person is not required to respond to, a request for information or an information collection requirement unless the requesting document displays a currently valid OMB control number.

SRP Section 5.4.7
"Residual Heat Removal (RHR) System"
Description of Changes

Revision 5 to SRP Section 5.4.7 updates Revision 3 of this section, dated March 2007, to reflect the following changes:

1. This SRP section is administratively updated by the Office of New Reactors, per request from Juan D. Peralta, Branch Chief, Quality and Vendor Branch 1, Division of Construction, Inspection, and Operational Programs, memorandum dated February 17, 2010 (ADAMS Accession No. ML10090148).