4.8 RESIDUAL HEAT REMOVAL SYSTEM (RHRS)

4.8.1 Safety Objective

The safety objectives of the Residual Heat Removal System (RHRS) are as follows:

a. To restore and maintain the coolant inventory in the reactor vessel so that the core is adequately cooled after a loss-of-coolant accident. The Residual Heat Removal System also provides cooling for the pressure suppression pool so that condensation of the steam resulting from the blowdown due to the design basis loss-of-coolant accident is ensured.

b. The Residual Heat Removal System further extends the redundancy of the Core Standby Cooling Systems by providing for containment cooling.

4.8.2 Power Generation Objective

The Residual Heat Removal System provides the means to meet the following power generation objectives:

a. Remove decay heat and residual heat from the nuclear system so that refueling and nuclear system servicing can be performed.

b. Supplement the Fuel Pool Cooling and Cleanup System capacity when necessary to provide additional pool cooling capacity.

4.8.3 Safety Design Basis

1. The RHRS shall act automatically (except when in the shutdown cooling mode), in combination with other Core Standby Cooling Systems, to restore and maintain the coolant inventory in the reactor vessel such that the core is adequately cooled to preclude fuel clad temperatures in excess of 2200°F following a design basis loss-of-coolant accident.

2. The RHRS, in conjunction with other Core Standby Cooling Systems, shall have such diversity and redundancy that only a highly improbable combination of events could result in their failure to provide adequate core cooling.

3. The source of water for restoration of reactor vessel coolant inventory shall be located within the primary containment in such a manner that a closed cooling water path is established.

4. To provide a high degree of assurance that the RHRS operates satisfactorily during a loss-of-coolant accident, each active component shall be capable of

being tested during operation of the nuclear system. The inboard isolation check valve can only be tested during cold shutdown (MODE 4 or MODE 5).

5. To provide an additional source of water for post-accident containment flooding a crosstie shall be provided between the RHR Service Water System and RHRS. (This long term capability is not credited in the mitigation of design basis accidents and does not perform an active safety related function.)

4.8.4 Power Generation Design Basis

1. The RHRS shall be designed with enough capacity that the service water outlet temperature can be limited during shutdown conditions to minimize fouling.

4.8.5 Summary Description

The RHRS is designed for five modes of operation to satisfy all the objectives and bases:

1. Shutdown cooling (Units 1, 2, and 3),

2. Containment spray and pool cooling,

3. Low pressure coolant injection, and

4. Standby cooling.

5. Supplemental fuel pool cooling.

To provide clarity to the information presented herein, each mode of operation is defined as a subsystem of the RHRS and is discussed separately. It is shown how each subsystem contributes toward satisfying all the objectives and bases of the RHRS.

The major equipment of the RHRS consists of four heat exchangers and four pumps for each unit. There are twelve RHR service water pumps for the plant (see Section 10.9, "RHR Service Water System"), eight of which can be used for RHRSW purposes. The equipment is connected by associated valves and piping, and the controls and instrumentation are provided for proper system operation. A process diagram of the RHRS is shown in Figures 7.4-6a sheets 1, 2, and 3 of Section 7.4. A description of the controls and instrumentation is presented in Section 7.4, "Core Standby Cooling Control and Instrumentation." A description of how operation of the equipment in the RHRS in conjunction with other Core Standby Cooling Systems protects the core in case of a loss-of-coolant accident is presented in Chapter 6.0, "Core Standby Cooling Systems."

The RHRS pumps are sized on the basis of the flow required during the low pressure coolant injection (LPCI) mode of operation, which is the mode requiring the maximum flow rate. In addition, the system pumps are equipped with discharge flow limiting orifice plates to prevent pump operation in "runout" conditions and to prevent any damage that might occur in the case of a recirculation line break. The heat exchangers are sized on the basis of their required duty for the pressure suppression pool cooling function. It is concluded that the power generation design objective is met. A summary of the design requirements of the RHRS pumps and the heat exchangers is presented in Table 4.8-1. See Section 6.5 for system requirements utilized in the Emergency Core Cooling System analysis.

Permanent connections with normally closed valves are provided on the shutdown cooling piping circuit for supplying cooling water to the Fuel Pool Cooling and Cleanup System (see Figures 7.4-6a sheets 1, 2, and 3). This permits the RHRS heat exchangers to be used to assist fuel pool cooling when required (see Section 10.5, "Fuel Pool Cooling and Cleanup System").

One of the RHRS loops, consisting of two heat exchangers, two pumps in parallel, and associated piping, is located in one area of the Reactor Building. The other heat exchangers, pumps, and piping, forming a second loop, are located in another area of the Reactor Building to minimize the possibility of a single physical event causing the loss of the entire system. This arrangement satisfies the safety design basis 2. In addition, the pump suction and heat exchanger discharge lines of one loop in Unit 1 (Loop II) are cross-connected to the pump suction and heat exchanger discharge lines of one loop in Unit 2. Unit 2 and Unit 3 systems are cross-connected in a similar manner. Two normally closed isolation valves are provided in each heat exchanger discharge cross-connection, and four normally closed isolation valves are provided in each suction cross-connection (one at each pump suction), as shown in Figure 4.8-1.

RHRS equipment is designed in accordance with Class I seismic criteria (see Appendix C) to resist sufficiently the response motion at the installed location within the supporting building from the Design Basis Earthquake.

The system piping and pumps are designed in accordance with the requirements of USAS B31.1.0, 1967 edition, as augmented by GE specifications which were implemented in lieu of the outdated B31 Nuclear Code Cases-N2, N7, N9, and N10. The system is constructed and tested in accordance with TVA construction specifications. The pumps are also designed and constructed in accordance with the standards of the Hydraulic Institute. The shell side of the heat exchangers is designed in accordance with the ASME Boiler and Pressure Vessel Code, 1965 edition, Section III, Class C vessels, and TEMA Class C; and the tube side is designed in accordance with Section VIII and TEMA Class C. The provisions of the

ASME Boiler and Pressure Vessel Code, Section III, Winter Addenda of 1966, paragraph N2113, apply.

4.8.6 Description

4.8.6.1 Shutdown Cooling

The shutdown cooling subsystem is an integral part of the RHRS and is placed in operation during a normal shutdown and cooldown. The initial phase of nuclear system cooldown is accomplished by dumping steam from the reactor vessel to the main condenser with the main condenser acting as the heat sink. The RHRS is typically placed in the shutdown cooling mode of operation when reactor vessel pressure has decreased sufficiently to clear the interlocks associated with the shutdown cooling suction valves. The shutdown cooling subsystem alone is capable of completing cooldown to 125°F in less than 20 (pre-uprated) or 24 (uprated) hours and maintaining the nuclear system at 125°F so that the reactor can be refueled and serviced.

Reactor coolant is pumped by the RHRS pumps from one of the recirculation loops through the RHRS heat exchangers, where cooling takes place by transferring heat to the RHR service water system. Reactor coolant is returned to the reactor vessel via either recirculation loop.

During a nuclear system shutdown and cooldown, any one of the four RHR shutdown cooling subsystems can provide the required decay heat removal function and maintain or reduce the reactor coolant temperature as required.

The RHRS is normally flushed with water of condensate quality or better in preparation for shutdown cooling operation during the steam dumping phase of plant cooldown. This flush is not required if 1) there is an immediate need for RHR shutdown cooling to control reactor vessel level, temperature, or pressure, or 2) RHR shutdown cooling is removed from and returned to service during an outage and no activities have occurred which could result in water quality degradation below acceptable limits for reactor vessel injection.

4.8.6.2 Containment Cooling

The containment cooling subsystem is an integral part of the RHRS and is placed in operation to limit the temperature of the water in the pressure suppression pool so that immediately after the design basis loss-of-coolant accident has occurred, the maximum bulk pool temperature does not exceed 177°F (Units 2 and 3) and 187.3°F (Unit 1 only). The maximum permissible bulk pool temperature is limited by the potential for stable and complete condensation of steam discharged from the main steam relief valves as well as the design analyses of the torus attached piping (see Sections 5.2.3.3.2 and 5.2.4.3).

With the RHRS in the suppression pool cooling mode of operation, the RHRS pumps are aligned to pump water from the pressure suppression pool through the RHRS heat exchangers where cooling takes place by transferring heat to the RHR service water. For adequate containment cooling, a minimum of two RHR pumps and associated heat exchangers must remain available for several hours after a design basis loss-of-coolant accident. The flow returns to the pressure suppression pool via the flow test line (see Figures 7.4-6a sheets 1, 2, and 3). Pressure suppression pool temperature operational limits are provided in Technical Specification, Section 3.6.2.1.

The pressure suppression pool cooling mode of RHRS is initiated to restore pressure suppression pool temperature to within allowable limits during plant operation. IN 87-10 Supplement 1 identifies the potential for the RHRS to be damaged and unable to perform its Low Pressure Coolant Injection function should a LOCA and LOOP occur while RHRS is in the SPC mode of operation. The safety design basis for RHRS requires that only a highly improbable combination of events can result in RHRS being rendered unable to perform its core cooling function (see Section 4.8.3). To meet this requirements, PRA analyses have established a time limit for RHRS operation in the SPC mode and the time RHRS is in SPC mode is tracked to ensure this time limit is not exceeded.

The containment spray cooling mode of operation provides additional redundancy to the Core Standby Cooling Systems for post-accident conditions. The water pumped through the RHRS heat exchangers may be diverted to spray headers in the drywell and above the pressure suppression pool. The spray headers in the drywell condense any steam that may exist in the drywell, thereby lowering containment pressure. The spray collects in the bottom of the drywell until the water level rises to the level of the pressure suppression vent lines, where it overflows and drains back to the pressure suppression pool. Approximately 5 percent of this flow may be directed to the pressure suppression chamber spray ring to cool any noncondensable gases collected in the free volume above the pressure suppression pool.

The spray headers of the RHRS cannot be placed in operation unless the core cooling requirements of the low pressure coolant injection subsystem have been satisfied. These requirements may be bypassed by the operator using a keylock switch in the control room (see Section 7.4, "Core Standby Cooling Control and Instrumentation").

4.8.6.3 Low Pressure Coolant Injection

The low pressure coolant injection (LPCI) subsystem is an integral part of the RHRS. It operates to restore and, if necessary, maintain the coolant inventory in the reactor vessel after a loss-of-coolant accident so that the core is sufficiently cooled to preclude fuel clad temperatures in excess of 2200°F and subsequent energy release due to a metal-water reaction. A detailed discussion of the requirements and response of the equipment which operates during LPCI for a loss-of-coolant accident may be found in Chapter 6.0, "Core Standby Cooling Systems." A detailed discussion of the requirements and response of the controls and instrumentation of LPCI during a loss-of-coolant accident may be found in Section 7.4, "Core Standby Cooling Control and Instrumentation."

In general, LPCI operation involves restoring the water level in the reactor vessel to a sufficient height for adequate cooling after a loss-of-coolant accident. The LPCI subsystem operates in conjunction with the High Pressure Coolant Injection System (HPCIS), the Auto Depressurization System and the Core Spray System to achieve this goal (see Chapter 6.0, "Core Standby Cooling Systems"). This capability satisfies safety design basis 1.

The HPCIS is a high-head, low-flow system and pumps water into the reactor vessel when the nuclear system is at high pressure. If the HPCIS fails to maintain the required level of water in the reactor vessel, the automatic depressurization feature of the Nuclear System Pressure Relief System functions to reduce nuclear system pressure so that LPCI operates to inject water into the pressure vessel. LPCI is a low-head, high-flow subsystem and delivers rated flow of ≥ 9000 gpm for each pump to the reactor vessel against an indicated pressure of ≥ 125 psig. All these operations are carried out automatically. LPCI is designed to reflood the reactor vessel to at least two-thirds core height and to maintain this level. After the core has been flooded to this height, the capacity of one RHR pump is more than sufficient to maintain the level.

During LPCI operation, the RHRS pumps take suction from the pressure suppression pool and discharge to the reactor vessel into the core region through both of the recirculation loops. Two pumps discharge to each injection header, assuring flooding of the vessel through at least one loop. Any spillage through a break in the lines within the primary containment returns to the pressure suppression pool through the pressure suppression vent lines. A bypass line to the pressure suppression pool is provided so that the pumps are not damaged if operating with the discharge valves shut.

Added resistance in the pump discharge lines prevents insufficient NPSH in the LPCI mode of operation. It is concluded that safety design basis 3 is satisfied.

Service water flow to the RHRS heat exchangers is not required immediately after a loss-of-coolant accident because heat rejection from the containment is not necessary during the time it takes to flood the reactor.

Power for the RHRS pumps and the RHR service water pumps comes from the 4-kV AC power shutdown boards. Power for these boards normally comes from the auxiliary supply, but if this source is not available, power is available from the standby (diesel) AC power source.

4.8.6.4 Standby Cooling

Standby coolant supply connection and RHR crossties are provided to maintain a long-term reactor core and primary containment cooling capability irrespective of primary containment integrity or operability of the Residual Heat Removal System associated with a given unit. The standby coolant supply connection and RHR crossties provide added long-term redundancy to the other emergency core and containment cooling systems and are designed to accommodate certain situations which, although unlikely to occur, could jeopardize the functioning of these systems.

By proper valve alignment (see Figure 4.8-1), the network created by the RHR crossties permits the B (or D) RHR pumps on Unit 1 to circulate Unit 2 pressure suppression pool or reactor vessel water through the B (or D) heat exchangers on Unit 1 in the unlikely event that the Unit 2 RHR pumps are unavailable. The crosstie network is sized for a minimum flow of 5,000 gpm, which will achieve about 91 percent of full flow heat transfer capability of the RHR heat exchangers.

In a like fashion, the A (or C) RHR pumps on Unit 2 can be used to circulate Unit 1 pressure suppression pool or reactor vessel water through the A (or C) heat exchangers on Unit 2. The B (or D) RHR pumps on Unit 2 and the A (or C) RHR pumps on Unit 3 can be similarly utilized.

Pressure suppression pool water which has been circulated through the RHR heat exchangers on one unit can be used to flood the reactor core, spray the drywell and pressure suppression chamber, or returned to the pressure suppression chamber of the adjacent unit. In this way, decay heat and residual heat can be removed from the reactor core and primary containment of the adjacent unit on a long-term basis. By proper valve alignment (see Figure 4.8-1), the network created by the standby coolant supply connection and RHR crossties permits the D2 (or D1) RHR service water pump and header to supply raw water directly to the reactor core of Units 1 or 2 as the reactor pressure approaches 50 psig. The service water pump and header can also be valved to supply raw water to the drywell or pressure suppression chamber spray headers or directly to the pressure suppression chamber of either unit. In a similar fashion, the B2 (or B1) RHR service water pump and header can supply raw water to the reactor core of Units 2 or 3 or into the respective drywell/pressure suppression chamber spray headers or directly to the pressure suppression chambers.

The Standby Coolant Supply System is sized to supply a minimum raw water flow of 3,250 gpm, against a reactor pressure of 65 psig with a drywell pressure of 15 psig. It is concluded that safety design basis 5 is satisfied.

4.8.6.5 Supplemental Fuel Pool Cooling

A description of how the RHRS heat exchangers can be used to assist fuel pool cooling when required is contained in Section 10.5, “Fuel Pool Cooling and Cleanup System.”

4.8.7 Safety Evaluation

Since the LPCI and containment cooling subsystems act with other Core Standby Cooling Systems to satisfy the safety objective, they are properly evaluated in conjunction with the other Core Standby Cooling Systems. This safety evaluation is in Chapter 6.0, "Core Standby Cooling Systems." The safety evaluation of the controls and instrumentation of the LPCI subsystem is in Section 7.4, "Core Standby Cooling Control and Instrumentation."

4.8.8 Inspection and Testing

A design flow functional test of the RHRS pumps is performed during normal plant operation by taking suction from the pressure suppression pool and discharging through the test lines back to the pressure suppression pool. The discharge valves to the reactor recirculation loops remain closed during this test and reactor operation is undisturbed.

An operational test of these discharge valves is performed by shutting the downstream valve after it has been satisfactorily tested and then operating the upstream valve. The discharge valves to the containment spray headers are checked in a similar manner by operating the upstream and downstream valves individually. All these valves can be actuated from the control room using remote manual switches. Control system design provides automatic return from test to operating mode if LPCI initiation is required during testing. It is concluded that safety design basis 4 is satisfied.

Periodic inspection and maintenance of the RHRS pumps, pump motors, valves and valve motors, and heat exchangers are based on manufacturer's recommendations and sound maintenance practices.

A discussion of the availability of engineered safeguards and frequency of testing of equipment is presented in Chapter 6.0, "Core Standby Cooling Systems."