4.3 REACTOR RECIRCULATION SYSTEM

4.3.1 Power Generation Objective

The objective of the Reactor Recirculation System is to provide forced cooling of the core and a variable moderator (coolant) flow to the reactor core for adjusting reactor power level.

4.3.2 Power Generation Design Basis

a. The Reactor Recirculation System shall provide sufficient subcooled water to the core during normal power operation to maintain normal operating temperatures.

b. The Reactor Recirculation System shall operate over a flow control range of 20 percent to 105 percent flow to allow power variation.

c. The Reactor Recirculation System shall be designed to minimize maintenance situations that would require core disassembly and fuel removal.

4.3.3 Safety Design Basis

a. The Reactor Recirculation System, including the recirculation pump trip (RPT) feature, shall be designed so that adequate fuel barrier thermal margin is assured following recirculation pump system malfunctions and postulated transients (such as turbine-generator trip or load rejection).

b. The Reactor Recirculation System shall be designed so that failure of piping integrity does not compromise the ability of the reactor vessel internals to provide a refloodable volume.

4.3.4 Description

The Reactor Recirculation System consists of the two recirculation pump loops external to the reactor vessel which provide the driving flow of water to the reactor vessel jet pumps (see Figures 4.3-1 and 4.3-2a sheets 1, 2, and 3). Each external loop contains one high-capacity motor-driven recirculation pump and two motor-operated gate valves for pump maintenance. Each pump discharge line contains a venturi-type flowmeter nozzle. The recirculation loops are a part of the nuclear system process barrier and are located inside the drywell containment structure. The jet pumps are reactor vessel internals and their location and mechanical design are discussed in Subsection 3.3, "Reactor Vessel Internals Mechanical Design." However, certain operational characteristics of the jet pumps are discussed in this subsection. A summary of the characteristics of the Reactor Recirculation System is presented in Table 4.3-1.

The recirculated coolant consists of saturated water from the steam separators and dryers which has been subcooled by incoming feedwater. This water passes down the annulus between the reactor vessel wall and the core shroud. A portion of the coolant exits from the vessel and passes through the two external recirculation loops to become the driving flow for the jet pumps. The two external recirculation loops each discharge high pressure flow into an external manifold from which individual recirculation inlet lines are routed to the jet pump risers within the reactor vessel. The remaining portion of the coolant mixture in the annulus becomes the driven flow for the jet pumps. This flow enters the jet pumps at the suction inlet and is accelerated by the driving flow. The driving and driven flows are mixed in the jet pump throat section resulting in partial pressure recovery. The balance of recovery is obtained in the jet pump diffusing section (see Figure 4.3-3). The adequacy of the total flow to the core is discussed in Subsection 3.7, "Thermal and Hydraulic Design." Tests have been conducted and documented[1] to show that the jet pump design is sound and that jet pump operation is stable and predictable.

The pump is started at slow speed with the discharge valve closed. Pump speed is not increased until after the discharge valve has been opened utilizing the jogging circuit that opens the valve in steps. There is actually a very low probability that a recirculation loop that has been allowed to cool would need to be placed in service again with the nuclear system hot. A valid reason for closing both the pump discharge valve and the suction valve is to prevent leakage out of that portion of the recirculation loop between the valves, e.g., excessive leakage through the pump mechanical seal. A leak of this nature cannot be repaired without shutting the plant down to permit access to the drywell; the nuclear system would in all probability have been cooled prior to repairing the leak.

Since the removal of Reactor Recirculation System valve internals requires unloading of the nuclear fuel, the valves are provided with high-quality back seats and trim to facilitate stem packing renewal without draining the vessel and to provide adequate leak tightness during normal operation.

The Reactor Recirculation System valves are designed and constructed to meet the requirements of USAS B31.1.0, 1967 edition, with added GE requirements which were implemented in lieu of the outdated B31 Nuclear Code Cases-N2, N7, N9, and N10. The valves are designed to operate under maximum prevailing operating conditions and postulated accident conditions in the drywell.

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1 "Design and Performance of G.E. BWR Jet Pumps," General Electric Company, Atomic Power Equipment Department, Sept. 1968 (APED-5460).

The Units 1 and 3 Reactor Recirculation Header equalizer valves were removed during the respective unit recirculation piping replacements in order to reduce the number of welds and, therefore, minimize susceptibility to Intergranular Stress Corrosion Cracking (IGSCC).

Under all operating conditions (Unit 2 only), one equalizer valve in the line between the two pump discharge lines shall be open and the other valve shall be closed (both valves having motive power removed). This is to prevent pressure buildup due to ambient and conduction heating of the water between the equalizer line valves.

The idle pump loop is not completely valved off if it is desired to return the idle loop to service prior to the next reactor cooldown (such as VFD repair for Units 1, 2, and 3). The recirculation pump casing allowable heatup rate is 100°F per hour, the same as the reactor vessel. It is possible to keep the idle loop hot with the equalizer line valved off (Unit 2 only) and the idle loop valves left open, permitting the pressure head created by reverse flow through the idle jet pumps to cause reverse flow through the idle loop. However, it is first necessary to stop the pump rotation by closing either the pump suction or discharge valve until pump rotation stops. Once the oil film is squeezed out of the pump thrust bearing, the pump will not rotate even with both the suction and discharge valves open.

Following one recirculation pump operation, an operational restriction is applied such that the discharge valve of the low speed pump may not be opened unless the speed of the faster pump is less than 50 percent of its rated speed. This limitation provides assurance when going from one-to-two pump operation that excessive vibration of the jet pump risers will not occur.

The feedwater flowing into the reactor vessel annulus during operation provides subcooling for the fluid passing to the recirculation pumps, thus determining the additional net positive suction head (NPSH) available beyond that provided by the pump location below the reactor vessel water level. If feedwater flow is below 17 percent, the recirculation pump speed is automatically limited.

The recirculation pumps can be operated during nuclear system heatup for hydrostatic tests. At this time, they act in conjunction with any contribution from reactor core decay heat to raise nuclear system temperature above the limit imposed on the reactor vessel by nil-ductility transition temperature (NDTT) considerations so that the hydrostatic test can be conducted.

A decontamination connection is provided in the piping on the suction side of the pump to permit flushing and decontamination of the pump and adjacent piping. This connection is arranged for convenient and rapid connection of temporary piping.

The piping low point drain is used during flushing or decontamination to conduct crud away from the piping low point and is also designed for connection of temporary piping.

Each recirculation pump is a single-stage, variable-speed, vertical, centrifugal pump equipped with mechanical shaft seal assemblies. The pump is capable of stable and satisfactory performance while operating continuously at any speed corresponding to a power supply frequency range of 11.5 to 57.5 Hz. For loop startup, each pump operates at a speed corresponding to a power supply frequency of 11.5 Hz with the discharge gate valve closed.

The recirculation pump shaft seal assembly consists of two seals built into a cartridge which can be readily replaced without removing the motor from the pump. The seal assembly is designed to require minimum maintenance over a long period of time, regardless of whether the pump is stopped or operating, and seal over a wide range of pressures and temperatures. The original seal design for Units 1, 2, and 3 has been changed to a seal assembly with an extended design life. Each individual seal in the cartridge is capable of sealing against pump design pressure so that any one seal can adequately limit leakage in the event that the other seal should fail. A breakdown annulus is provided along the pump shaft to reduce leakage in the event of a gross failure of both shaft seals. Provision is made for monitoring the pressure drop across each individual seal as well as the cavity temperature of each seal. Provision is also made for piping the seal leakage to a flow measuring device. Various control room alarms indicate improper seal performance.

The Reactor Building Closed Cooling Water System and the Control Rod Drive Hydraulic System provide cooling to the recirculation pump seals. If either one of these systems is operating, recirculation pump operation without the second cooling system may continue with no harm to the seals. If both seal cooling systems are inoperable (e.g., due to a loss of AC power), the pump seals will overheat approximately 7 minutes after the total loss of cooling and seal deterioration may begin.

Based on fluid loss analysis of extremely degraded seals, the leakage is less than 70 gpm. This amount of leakage will not lead to a safety concern but may degrade the seals such that they would have to be repaired prior to resuming operation.

Each recirculation pump motor is a variable-speed AC, electric motor which can drive the pump over a controlled range of 20 percent to 102 percent of rated pump speed. The motor is designed to operate continuously at any speed within the power supply frequency range of 11.5 Hz to 57.5 Hz. Recirculation pump motors are designed, constructed, and tested in accordance with the applicable sections of the NEMA Standards.

For Units 1, 2, and 3, a variable frequency drive unit located outside the drywell supplies power to each recirculation pump motor. Minimum speed corresponds to a frequency of 11.5 Hz.

For Units 1, 2, and 3, the combined rotating inertia of the recirculation pump and motor are modeled consistent with a coastdown of flow following loss of power to the drive motors, so that the core is adequately cooled during the loss-of-power transient. The effective inertia of these devices are specified in the following form, which takes into account the torque and speed conditions on each rotating shaft.

$$\frac{J\omega}{gTo} = \text{Time}$$

where

J = inertia ($lb\text{-}ft^2$)
ω = rated speed (rad/sec)
g = gravitational constant (32.3 ft/sec^2)
To = torque at rated speed (ft-lb).

From this equation, the required inertia (J) is calculated.

The recirculation pumps are Classified as machinery, and, as such, are specifically exempt from the jurisdiction of any section of the ASME Boiler and Pressure Vessel Code or of the USA Standard Code for Pressure Piping. The standards of the Hydraulic Institute are the only standards which are applicable; however, they are more pertinent to the testing and performance of the pump and consequently provide little or no guidance in the areas of casing quality and structural integrity.

To assure that the pump casing can withstand a pressure equivalent to that inside the reactor vessel, the pump casing is designed in accordance with the ASME Boiler and Pressure Vessel Code, Section III, Class C, as far as this code can be applied. The requirements of Section III of the ASME Boiler and Pressure Vessel Code for Class C vessels (1965 edition) are used as a guide in calculating the thickness of pressure-retaining parts of the recirculation pumps. The casings and forgings are fabricated from austenitic stainless steel. Class C is used because the pump casing does not experience temperature transients as severe as those that portions of the reactor vessel and certain piping connections experience; therefore, it is not necessary to make the cyclic analysis required for Class A equipment.

The design objective for the recirculation pump casing is a useful life of 40 years, accounting for corrosion, erosion, and material fatigue. For the 60 year operating life, the recirculation pump aging effects will be managed using the ASME Section XI Subsections IWB, IWC, and IWD Inservice Inspection Program, Chemistry Control Program, and BWR Stress Corrosion Cracking Program described in Appendix O, Section O.1.4. O.1.5, and O.1.10. Material fatigue for the 60 year operating life has been evaluated as a Time Limited Aging Analysis (TLAA). The summary of this evaluation is provided in Appendix O, Sections O.3.2.3 and O.3.2.4. The pump-drive motor, impeller, and wear rings are designed for as long a life as is practical. The design objective is to provide a unit which will not require removal from the system for rework or overhaul at intervals of less than 5 years.

The recirculation system piping is of stainless steel construction and is designed and constructed to meet the requirements of the USA Standard Code for Pressure Piping, Power Piping, USAS B31.1.0, 1967 edition, and the additional requirements of GE design and procurement specifications which were implemented in lieu of the outdated B31 Nuclear Code Cases-N2, N7, N9, and N10. The suction and discharge pipes are welded to the pump casing.

The coolant in the nuclear process system is at high pressure and contains a large amount of energy. Substantial failure of the nuclear process system could result in a rapid loss of coolant. Although loss of the moderator (coolant) would render the reactor core subcritical, lack of cooling could cause overheating of the reactor core from residual and decay heat, leading to fuel damage and fission product release. The Core Standby Cooling Systems (which adequately cool the reactor core following a design basis loss-of-coolant accident) and the primary containment and containment cooling systems (which control the release of fission products and absorb the energy released by the accident) are not intended to diminish the overall design objective of the entire nuclear system (to design and construct a nuclear system which will not fail). The intent of using Section III of the ASME Boiler and Pressure Vessel Code and USAS B31.1.0, with added GE requirements for the recirculation system, is to design piping systems of high quality.

The Reactor Recirculation System, except for the VFDs on Units 1, 2, and 3, is designed as Class I equipment (see Appendix C) to resist sufficiently the response motion at the installed location within the supporting structure for the Design Basis Earthquake, with the pump assumed filled with water for the analysis. Vibration snubbers located at the top of the motor and at the bottom of the pump casing are designed to resist the horizontal reactions.

The recirculation piping, valves, and pumps are supported by constant support hangers and by sway braces to avoid the use of piping expansion loops which would be required if the pumps were anchored. In addition, the recirculation loops are provided with a system of restraints designed to limit pipe motion so that reaction

forces associated with any split or circumferential break do not jeopardize containment integrity. This restraint system provides adequate clearance for normal thermal expansion movement of the loop. The spacing between limit stops is set on the basis that a split pipe retains its structural load-resisting characteristics. Impact loading is negligible on limit stops, since possible pipe movement is limited to slightly more than the clearance required for thermal expansion movement.

The recirculation system piping, valves, and pump casings are covered with all-metal, reflective, thermal insulation having an average maximum heat transfer rate of 80 Btu/hr-ft^2 with the system at rated operating conditions. The insulation is prefabricated into components for field installation. Removable insulation is provided at various locations to allow for periodic inspection of the insulated equipment.

4.3.5 Safety Evaluation

Reactor Recirculation System pump malfunctions that pose threats of damage to the fuel barrier are described and evaluated in Chapter 14.0, "Plant Safety Analysis." There it is shown that none of the malfunctions results in fuel damage; thus, the recirculation system has sufficient flow coastdown characteristics to maintain fuel thermal margins during abnormal operational transients. In addition, in order to achieve a more rapid core reactivity reduction in the event of a turbine or generator trip (thereby limiting the magnitude of the fuel thermal transient), a recirculation pump trip (RPT) feature has been added. By utilizing the recirculation pump trip in response to a turbine-generator trip or load rejection, the MCPR margin is reduced, allowing normal operation at higher power than without the RPT feature. This satisfies safety design basis a. The RPT feature is described in Subsection 7.9.

The core-flooding capability which is provided by a jet pump design is pictured in Figure 4.3-4. There is no postulated recirculation line break which can prevent reflooding of the core to the level of the jet pump suction inlet. The core-flooding capability of a jet pump design is discussed in detail in the Core Standby Cooling Systems document filed with the AEC as a GE Topical Report.[2] This satisfies safety design basis b.

The Reactor Recirculation System piping and pump design pressures (see Table 4.3-1) are based on peak steam pressure in the reactor dome, plus the static head above the lowest point in the recirculation loop, plus dynamic head due to system operation. Piping and related equipment pressure parts are chosen and analyzed in accordance with applicable codes. Use of the listed code design

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2 Ianni, P.W., "Core Standby Cooling Systems for Boiling Water Reactors," General Electric Company, Atomic Power Equipment

criteria provides assurance that a system designed, built, and operated within design limits has an extremely low probability of failure due to any known failure mechanism.

4.3.6 Inspection and Testing

Quality control methods were used during the fabrication and assembly of the Reactor Recirculation System to assure that the design specifications were met. Inspection and testing were carried out in accordance with USAS B31.1.0. The reactor coolant system was thoroughly cleaned and flushed before fuel was loaded initially.

During the preoperational test program, the Reactor Recirculation System was given a hydrostatic test at 125 percent of reactor vessel design pressure. A hydrostatic test at a pressure not to exceed system operational pressure is made following each removal and replacement of the reactor vessel head. Other preoperational tests on the Reactor Recirculation System included operating valves and verifying that seal leakage was small enough to permit pump maintenance work, operating pumps and variable frequency drive (Units 1, 2, and 3), and checking flow control transient operation.

During heatup in the startup test program, the horizontal and vertical motions of the Reactor Recirculation System piping and equipment were observed and adjustments of supports were made, as necessary, to assure that components were free to move as designed. Nuclear system responses to recirculation pump trips at rated temperatures and pressure were evaluated during the startup tests, and the plant power response to recirculation flow control was determined.

Inservice inspection is considered in the design of the Reactor Recirculation System to assure adequate working space and access for inspection of selected components. The criteria for selecting the components and locations to be inspected are based on the probability of a defect occurring or enlarging at a given location, including areas of known stress concentrations and locations where cyclic strain or thermal stress might occur. The recirculation pump casing and valve bodies can be examined when the pump or valve is disassembled for normal maintenance. The piping connection welds can be examined to the extent practical within the limitations of design, geometry, and materials of construction of the components. The inservice inspection and testing program for the recirculation system is detailed in Subsection 4.12.