5.0 Reactor Coolant System and Connected Systems

5.1 Summary Description

The reactor coolant system (RCS) is a closed, four-loop system designed to transfer heat generated by the reactor core, located in the reactor pressure vessel (RPV), to the secondary side of the steam generators for plant power generation. The RCS consists of one RPV, four steam generators, four reactor coolant pumps (RCP), one pressurizer, one pressurizer relief tank (PRT), and the piping that connects the components. The RCS is located in the Reactor Building.

5.1.1 Design Bases

- The RCS provides a pressure boundary so that the reactor coolant and radioactive particles are confined within the RCS. The RCS serves as the second barrier against the release of radioactivity from the fission products of the fuel.

- The RCS circulates reactor coolant between the steam generators and the reactor fuel during power operation to remove heat from the reactor fuel, so that core thermal design limits are not exceeded.

- The RCS circulates reactor coolant between the steam generators and the reactor fuel during hot standby and hot shutdown operating modes to remove decay heat from the reactor fuel, so that core thermal design limits are not exceeded. Sufficient decay heat is removed:

  - For onsite electric power system operation (assuming offsite power is not available).

  - For offsite electric power system operation (assuming onsite power is not available).

- The RCS performs within the limits assumed in the design basis accident analyses.

- The RCS provides a means of rapidly inserting negative reactivity into the core via control rods filled with neutron absorbing material, so that core thermal design limits are not exceeded. The water of the RCS is used as a neutron moderator, neutron reflector, and solvent of concentrated boric acid, which is used to compensate for reactivity changes due to fuel burn-up.

- The RCS provides the capability to vent non-condensable gases from the RCS to support natural circulation core cooling during beyond design basis accidents. Generation of non-condensable gases is not postulated under design basis accidents.

- The RCS provides a redundant means to discharge reactor coolant and to depressurize the RCS during beyond design basis accidents to allow for safety injection (feed and bleed core cooling) and to avoid high pressure core melt ejection.

- In the event of a station blackout, the integrity of the RCP pressure boundary is maintained to prevent unacceptable reactor coolant pressure boundary (RCPB) leakage.

The RCS component design bases are specified in the corresponding sections identified in Section 5.1.3.

5.1.2 System Description

The RCS, shown in Figure 5.1-1—RCS Schematic Flow Diagram, consists of four heat transfer loops connected to the RPV. Each loop contains an RCP and a steam generator. In addition, the system includes a pressurizer connected to a single hot leg, pressurizer safety relief valves (PSRV), interconnecting piping and valves, and instrumentation necessary for operational control.

The RCS transfers the heat generated in the core during power operation to the secondary side of the steam generators, where steam is produced to drive the turbine generator. Borated, demineralized water is circulated in the RCS at a flow and temperature consistent with achieving reactor core thermal-hydraulic performance. The water also acts as a neutron moderator, a neutron reflector, and a solvent for the boron used as a chemical shim.

During operation, a saturated water-steam mixture within the PZR is maintained in equilibrium by electrical heaters and water sprays and is adjusted as necessary to control RCS pressure. Steam can be formed by the heaters or condensed by the PZR spray to minimize pressure variations due to contraction and expansion of the reactor coolant. PSRVs allow for steam discharge from the RCS if necessary. Discharged steam is piped to the PRT, where the steam is condensed and cooled by mixing with water.

The RCS includes the following major components:

- RPV and reactor vessel internals.
- Control rod drive mechanisms (CRDM).
- RCP, drive motor, and auxiliaries.
- Steam generators.
- Reactor coolant piping.
- Pressurizer.
- Pressurizer relief tank.
- Post-accident high point vents.

- Pressurizer safety relief valves.
- Primary depressurization valves.
- Component and pipe supports and restraints.

The RCS also includes piping and valves connected to the major components, component insulation, and the RPV closure head equipment.

Figure 5.1-2—RCS Layout and Figure 5.1-3—RCS Elevation, provide plan and elevation views of the RCS, indicating principal dimensions of RCS components in relation to supporting and surrounding steel and concrete structures.

The arrangement of the RCS, including the extent of the RCPB and the points of separation between the RCS and connected systems, is shown in Figure 5.1-4—RCS Piping and Instrumentation Diagram. A tabulation of design pressures and temperatures is included on Figure 5.1-4 and additional design parameters are included in Table 5.1-1—RCS Design and Operating Parameters.

5.1.3 System Components

The major components of the RCS are as follows:

- Reactor pressure vessel—The RPV contains the reactor fuel and the vessel internals which direct the flow of reactor coolant. The RPV has four inlet and four outlet nozzles located in a horizontal plane just below the reactor vessel flange, but above the top of the fuel. The reactor coolant enters the RPV through the inlet nozzles and is guided downward into the annulus of the vessel shell and then directed upward through the core, acquiring thermal energy. The reactor coolant leaves the RPV through the outlet nozzles.

  The RPV closure head contains penetrations for control rod drive mechanism adapters, in-core instrumentation adapters, and a high point vent. There are no penetrations in the RPV lower head. The RPV is described in Section 5.3.

- Control rod drive mechanisms—Eighty-nine CRDMs, of electromagnetic jack design, are mounted to the RPV closure head and are used to raise, lower, and maintain position of the rod cluster control assemblies (RCCAs) to control core power level and distribution. The CRDMs are described in Section 3.9.4.

- Reactor coolant pumps—The RCPs are vertical, single stage, centrifugal units driven by air-cooled, three-phase induction motors. The RCP motor is mounted above the pump on the top of the vertical shaft. A flywheel on the shaft above the motor provides inertia to extend pump coast-down. Water suction is axial and discharge is radial. The RCP shaft seal system consists of a multi-stage seal and a standstill seal. The RCPs are described in Section 5.4.1.

- Steam generators—The steam generators are vertical shell and U-tube evaporators with integral moisture separating equipment. The reactor coolant supply and return for the inverted U-tubes is through nozzles located in the hemispherical bottom head of the steam generator. Steam is generated on the shell side and flows upward through the moisture separators to exit through the nozzle in the top of the steam generator shell. An axial economizer enhances heat transfer between the primary and secondary coolant. The steam generators are described in Section 5.4.2.

- Reactor coolant piping—The RCS hot legs extend from the RPV outlet nozzles to the steam generators. The cold legs extend from the RCP outlets to the inlet nozzles of the RPV. The crossover legs connect the steam generator outlets to the RCP inlets. The pressurizer surge line and two spray lines connect the pressurizer to one hot leg and two cold legs, respectively. The reactor coolant piping is described in Section 5.4.3.

- Pressurizer—The pressurizer is a vertical, cylindrical vessel with hemispherical top and bottom heads. Heaters are installed vertically through the bottom head, and spray nozzles are mounted in the steam space in the upper head. The PZR connects to the RCS through the surge line, mounted between the surge line nozzle in the bottom PZR head and the hot leg of reactor coolant loop 3. During steady-state operating conditions, a controlled volume of saturated liquid with a saturated steam cover (bubble) is maintained in the PZR. The RCS pressure is maintained by varying the properties of this vapor covered liquid volume through use of the heaters and sprays. The configuration also allows the pressurizer to serve as an expansion tank for the RCS; minimizing RCS pressure fluctuations that result from variations in RCS water volume due to changes in RCS temperature and reactor power level. The pressurizer is described in Section 5.4.10.

- Pressurizer relief tank—The PRT collects and condenses steam discharged from the pressurizer. The pressurizer discharge passes through a submerged sparger in the tank to condense the steam. Rupture disks on the PRT provide overpressure protection for the tank. The PRT is described in Section 5.4.11.

- Post-accident high point vents—The RCS is equipped with post-accident high point vents to remove non-condensable gases from the RPV for beyond design basis accident mitigation. The post-accident high point vents are described in Section 5.4.12.

- Pressurizer safety relief valves—For RCS overpressure protection, the pressurizer is equipped with three safety relief valves that discharge into the PRT. Each PSRV is equipped with two solenoid-operated pilot valves mounted in series and a spring-operated pilot valve. The spring-operated pilot valve operates the PSRV in hot conditions. The solenoid-operated pilot valves operate the PSRV during low temperature operations. The PSRVs are described in Section 5.4.13.

- Component supports and restraints—The RCS component supports and restraints control relative displacement due to thermal and pressure expansion that occurs during normal operation. They also restrict displacement during accidents and seismic events. The component supports and restraints are described in Section 5.4.14.

5.1.4 System Evaluation

Design and operating parameters of the RCS are provided in Table 5.1-1—RCS Design and Operating Parameters.

Three reactor coolant flow rates are identified for specific plant design considerations: thermal hydraulic, best estimate, and mechanical.

- Thermal hydraulic design flow (minimum flow)—The thermal hydraulic design flow is a conservatively low flow used in the core cooling analysis of the RCS. The thermal hydraulic flow is determined from the best estimate flow, decreased by an allowance for the uncertainties on pressure loss coefficients, reactor coolant pump head, and flow measurement accuracy.
- Best estimate flow—The best estimate flow is the most likely value for the actual plant operating condition. This flow is based on the best estimate of the flow resistances in the reactor vessel, steam generator, and piping, and on the best estimate of the reactor coolant pump head-flow capacity, with no uncertainties assigned to either the system flow resistance or the pump head. Best estimate flow is that at which the RCP head and the gravitational driving head (natural circulation effect), both calculated considering effective temperature and pressure conditions, balance the pressure losses due to friction and singularities.
- Mechanical design flow (maximum flow)—Mechanical design flow is a conservatively high flow used in the mechanical design of the RCS. The mechanical design flow is determined from the best estimate flow, increased by an allowance for uncertainties in the pressure loss coefficients, the reactor coolant pump head, and the flow measurement accuracy.

Table 5.1-1—RCS Design and Operating Parameters

Parameter	Value
Core Thermal Power	4590 MW_t
Core Thermal Power Heat Balance Uncertainty	±22 MW_t
Pump Heat (4 RCPs)	24 MW_t
RCS Operating Pressure	2250 psia
RCS Cold Leg / Cross-over Leg Temperature (Best Estimate)	563.4°F
RCS Hot Leg Temperature (Best Estimate)	624.6°F
RCS Average Temperature (Best Estimate)	594.0°F
RCS Loop Volumetric Flow (Thermal Hydraulic)	119,692 gpm/loop
RCS Loop Volumetric Flow (Best Estimate)	124,741 gpm/loop
RCS Loop Volumetric Flow (Mechanical)	134,662 gpm/loop
RCS Loop Mass Flow (Thermal Hydraulic)	12,253 lb_m/s/loop
RCS Loop Mass Flow (Best Estimate)	12,769 lb_m/s/loop
RCS Loop Mass Flow (Mechanical)	13,750 lb_m/s/loop
RCS Nominal Volume (not including the PZR)	13,596 ft^3
PZR Nominal Volume	2649 ft^3
Nominal RCS Letdown Flow for Purification	79,366 lb_m/hr
Nominal RCS Letdown Flow for Boron Control	500 lb_m/hr
RCS Temperature at Hot Standby	577.9°F

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